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2019/01/25
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CIPO OPIC J000053188

Application Number: 2949039
Title of invention: ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS
Applicant(s) or Inventor(s) Name(s): PILOT ENERGY SOLUTIONS, LLC
Reference Number: K8001075CADIV6

#464609

Instructions: In response to the Notice of Allowance dated July 27, 2018, we are submitting herewith the prescribed Final Fee in the amount of $300.00.

We look forward to receiving the official Letters Patent document in due course.

Should the fees submitted with this letter be insufficient to cover all of the fees for which payment is explicitly or implicitly requested by this letter, CIPO is authorized to charge the amount of the insufficiency to Deposit Account No. 600000109 or Deposit Account No. 600000107 in the name of Gowling WLG (Canada) LLP.

Attached are the following documents:
1. K8001075CADIV Corr to CIPO Final Fee payment.pdf

Other

Description of Fee (standard fee)
1. Final fee ss.30(1) or (5) - filed on or after Oct. 1/89 - standard fee (1 x $300): $300.00
Total Fee Payment: $300.00

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(3)

IN THE CANADIAN INTELLECTUAL PROPERTY OFFICE

In The Matter of Canadian Patent Application:

Category	:	**Regular**
Current Owner	:	**Pilot Energy Solutions, LLC**
Original Applicant	:	**Pilot Energy Solutions, LLC**
Serial No.	:	**2,949,039**
Filing Date	:	**May 6, 2011**
Title	:	**ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS**
Our File	:	**K8001075CADIV6**
Date	:	**January 25, 2019**

The Commissioner of Patents
Place du Portage I
50 Victoria Street, Room C-114
Gatineau, Quebec K1A 0C9

Payment of Final Fee

The Commissioner of Patents:

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Respectfully submitted,

Gowling WLG (Canada) LLP

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CERTIFICAT DE DÉPÔT
FILING CERTIFICATE

N° de demande/Application No. : 2,949,039 **Date de dépôt /Filing date :** 2011/05/06

Votre référence/ Your reference : K8001075CADIV6

Date prévue de mise à la disponibilité du public/ : 2012/10/28
Expected Open to public Inspection Date

Date de priorité/ Priority Date : United States of America, 13/096,788, 2011/04/28

Titre de l'invention/ Title of Invention : ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS

Demandeur(s)/Applicant(s) : PILOT ENERGY SOLUTIONS, LLC

Inventeur(s)/Inventor(s) : PRIM, ERIC; BAKER, NAOMI; GARIKIPATI, JHANSI

Cette demande est un complément de 2,739,366, déposée le 6 mai 2011 (05-05-2011).

This application is a division of 2,739,366, filed on 6 May 2011 (05-05-2011).

La requête d'examen et la taxe prescrite ont été inscrites au dossier.

The Request for Examination and prescribed fee for examination has been made of record.

Avis spécial

Veuillez noter que la taxe annuelle qui permet de maintenir votre demande en état est applicable tous les ans à compter du 2e anniversaire jusqu'au 20e et vous devez la payer au plus tard à la date d'anniversaire. L'omission de payer cette taxe avant l'expiration du délai fixé résultera en l'abandon de votre demande.

Special Notice

You are reminded that annual fees to maintain your application are needed for each one year period between the 2nd and 20th anniversaries and must be paid on or before each anniversary. Failure to pay within the time limit will lead to abandonment of your application.

Commissaire aux brevets/Commissioner of Patents

Innovation, Sciences et Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

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(12) BREVET CANADIEN RÉEXAMINE
CANADIAN RE-EXAMINED PATENT

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(22) Date de dépôt/Filing Date: 2011/05/06

(41) Mise à la disp. pub./Open to Public Insp.: 2012/10/28

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(30) Priorité/Priority: 2011/04/28 (US13/096,788)

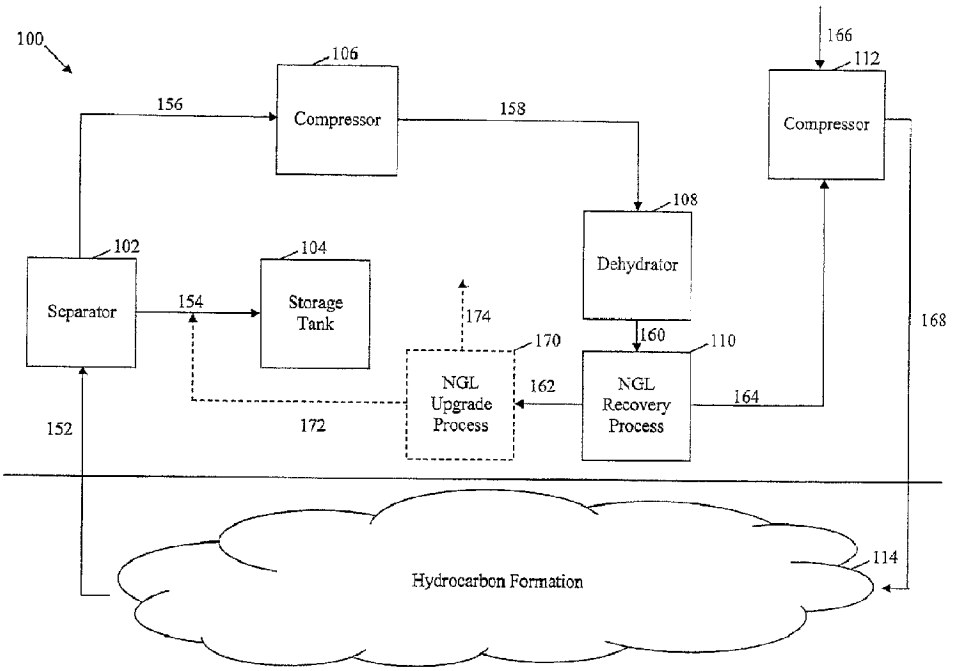
(51) Cl.Int./Int.Cl. *E21B 43/40* (2006.01),
E21B 43/16 (2006.01)

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PILOT ENERGY SOLUTIONS, LLC, US

(74) Agent: GOWLING WLG (CANADA) LLP

(54) Titre : PROCESSUS DE RECUPERATION AMELIORE DU GAZ NATUREL SOUS FORME LIQUIDE
(54) Title: ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS



(57) Abrégé/Abstract:
A method comprises receiving a hydrocarbon feed stream; separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a recycle stream, wherein the recycle stream comprises a gas selected from the group consisting of carbon dioxide, nitrogen, air, and water; and separating the recycle stream into a natural gas liquids (NGL) rich stream and a purified recycle stream. A plurality of process equipment configured to receive a hydrocarbon feed stream, separate the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a recycle stream comprising at least one C3+ hydrocarbon and a gas selected from the group consisting of carbon dioxide, nitrogen, air, and water, and separate the recycle stream into a NGL rich stream and a purified recycle stream.

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September 10, 2021

Our file no.: **RX-137/20**

GOWLING WLG (CANADA) LLP
50 Queen Street North, Suite 1020
KITCHENER Ontario
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Dear Sir/Madam:

Re: Request for Re-examination of Patent no. 2,949,039

Title:	**ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS**
Patentee:	PILOT ENERGY SOLUTIONS, LLC
Your file no.:	**K8001075CADIV6**
Requester:	MARKS & CLERK CANADA

In accordance with subsection 48.3(3) of the *Patent Act*, the Re-examination Board ("the Board") has completed a re-examination of issued claims 1-28 of Canadian Patent number 2,949,039 (hereinafter "the '039 patent").

Procedural History

The Board received a compliant request for Re-examination of all of issued claims 1-28 of the '039 Patent on February 26th, 2020 ("the Request"). In a notice dated June 12th, 2020 ("the Notice"), the Board gave notice under subsection 48.2(4) of the *Patent Act* that the Request raised a substantial new question of patentability with respect to issued claims 1-3, 6, 7, 8, 10-13, 15-16, 18-22, 25, 26 and 27. In particular, the Board indicated that a substantial new question of novelty was raised with respect to issued claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27 and the Board indicated that a substantial new question of obviousness was raised with respect to issued claims 1, 6, 7, 15, 19, 20, 25 and 26.

Pursuant to subsection 48.2(5) of the *Patent Act*, the Patentee submitted a reply to the Notice on September 11, 2020 ("the First Reply"). The Patentee submitted proposed claims 29-51 with the First Reply. The Patentee also made submissions with respect to the patentability of proposed claims 29-51.

On March 12, 2021, the Board sent a letter ("the Second Stage Letter") to the Patentee in response to the

First Reply. In the Second Letter the Board considered the Patentee's submissions and maintained that, in its preliminary view, claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27 would have lacked novelty and do not comply with paragraph 28.2(1)(b) of the *Patent Act* and claims 1, 6, 7, 15, 19, 20, 25 and 26 would have been obvious and therefore do not comply with paragraph 28.3(b) of the *Patent Act*. The Board further set out its preliminary view that proposed claims 29-51 would have been novel at the claim date and therefore comply with paragraph 28.2(1)(b) of the *Patent Act* and that proposed claims 29-51 would have been non-obvious and comply with paragraph 28.3(b) of the *Patent Act*.

The Board also indicated that proposed claims 30 and 45 submitted with the First Reply are indefinite and do not comply with subsection 27(4) of the *Patent Act*.

The Patentee submitted a subsequent reply to the Second Stage Letter on June 8, 2021 ("the Second Reply"). The Patentee amended the proposed claims by canceling claims 30 and 45, and submitted new proposed claims 50-60.

As discussed below, the Board has considered the Patentee's submissions and concludes that claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27 would have lacked novelty at the claim date and do not comply with paragraph 28.2(1)(b) of the *Patent Act* and claims 1, 6, 7, 15, 19, 20, 25 and 26 would have been obvious and therefore do not comply with paragraph 28.3(b) of the *Patent Act.* Additionally, the Board concludes that the proposed claims 29-60 are patentable in view of the prior art of record and shall be incorporated into the '039 Patent as per paragraph 48.4(1)(c) of the *Patent Act*.

Prior Art

In the request for re-examination, the Requester has brought to the attention of the Board the following prior art consisting of:

(1) US 4,753,666 (Pastor et al., hereinafter "Pastor");
(2) "Practical Aspects of CO_2 Flooding", Society of Petroleum Engineers (SPE) Monograph Series, vol. 22, (published in 2002) 214 pp. ch. 5;(Jarrell et al., hereinafter "Jarrell");
(3) US 4,428,759 (Ryan et al., hereinafter "Ryan");
(4) US 4,595,404 (Ozero et al., hereinafter "Ozero")

Description Of References Applied

Pastor discloses a process of separating a carbon dioxide recycle stream into a purified carbon dioxide (overhead gas) stream and a natural gas stream (bottoms product) In order to overcome the problems associated with methane/CO2 distillation, Pastor's process leaves the methane in the overhead gas. To offset the effect of methane in the overhead gas, H2S, ethane, propane and a portion of butane remain in the overhead gas. The separation process of Pastor does not teach utilizing cryogenics or membranes.

Jarrell discloses processing steps used at each stage of a CO2 flooding process, beginning with generating a production stream at the "production well", separating the production stream into an oil (i.e. heavy hydrocarbon) -containing stream and a gas stream, separating the gas stream into a recovered carbon dioxide stream and a natural gas liquids stream, and reinjecting the recovered carbon dioxide stream into

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the "injection well". An oil stream and a natural gas liquids stream are sold as "oil sales" and "NGL sales", respectively.

Ryan discloses a process of separating a carbon dioxide recycle stream into a purified carbon dioxide (overhead gas) stream and a natural gas stream (bottoms product). Ryan's process teaches a distillative technique involving recycling a small portion of a bottom product stream of a second distillation column, typically a C3 to C6 stream, to a first distillation column, wherein the overhead stream is not significantly contaminated by the recycled bottom product stream, to adjust column operating conditions and effect energy savings.

Ozero pertains to a process for regeneration of a carbon dioxide gaseous stream such used in a carbon dioxide miscibility flood process. Ozero's process dehydrates the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

Claim Construction

Claims construction is antecedent to considerations of both validity and infringement issues. (*Whirlpool Corp v Camco Inc,* 2000 SCC 67 at para 43 [*Whirlpool*]).

Person Skilled in the Art

As set out in the Notice, the Board considers the person skilled in the art to be a person or team skilled and knowledgeable in the field of oil and gas production and carbon dioxide recovery and reinjection. The Patentee did not dispute this view in the First Reply or the Second Reply.

Common General Knowledge

The skilled person is considered to be equipped with the common general knowledge; that is, the subset of the prior art that is generally known by persons skilled in the relevant art at the relevant time (*Sanofi-Synthelabo Canada Inc v Apotex Inc*, 2008 SCC 61 [*Sanofi*] at para 37.

As set out in the Board notice of June 12, 2020, the Board considers that the relevant common general knowledge of the notional person skilled in the art includes:

- the knowledge of injecting carbon dioxide to enhance recovery of heavy hydrocarbons;
- the knowledge of separation methods and equipment used for isolating carbon dioxide, Natural Gas Liquids (NGL), and heavy hydrocarbons from a hydrocarbon feed stream;
- the knowledge of the varying composition of the hydrocarbon feed stream.

The Patentee did not dispute this view in the First Reply or the Second Reply.

Scope of certain claim terms

In the Board's notice of June 12, 2020 we set out a preliminary analysis of the scope of certain terms used in the issued claims that, in our view, required some clarification. The Board wrote:

> In *Whirlpool* at paragraph 44, the Supreme Court of Canada stated that claims should be given a purposive construction:

> ... A patent specification should be given a purposive construction rather than a purely literal one derived from applying to it the kind of meticulous verbal analysis in which lawyers are too often tempted by their training to indulge. The question in each case is: whether persons with practical knowledge and experience of the kind of work in which the invention was intended to be used, would understand that strict compliance with a particular descriptive word or phrase appearing in a claim was intended by the patentee to be an essential requirement of the invention so that any variant would fall outside the monopoly claimed, even though it could have no material effect upon the way the invention worked.

Claim no. 1 of the '039 Patent states at line 14:

> separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream, wherein the sweet NGL rich stream includes the substantially all of the C_3-C_8 hydrocarbons in the source NGL rich stream. [Emphasis added]

In the Board's preliminary view, the scope of the phrase "source NGL rich stream" is not evident from the claim language itself. It is not clear if the stream is a new stream or if an error has occurred and the stream is the sour NGL rich stream. However, we take the reference to "source NGL rich stream" to be an error. It is our preliminary view that this should have referred to "sour NGL rich stream."

Claim no. 2 of the '039 Patent states:

> 2. A method comprising:
> receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and
> separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,
> wherein the purified carbon dioxide recycle stream includes the carbon dioxide,
> wherein the natural gas liquids stream includes the natural gas liquids, and
> wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream. [Emphasis added]

In the Board's preliminary view, the scope of the phrase "natural gas liquids stream" is not evident from the claim language itself.

The specification of the '039 Patent teaches:
Pg. 4, lines 2-7

> The term "natural gas liquids" or NGLs may refer to natural gases that may be liquefied without refrigeration, and may include C_3 -C_8 hydrocarbons. Both natural gas and NGL are terms known in the art and are used herein as such. In contrast, the term "heavy hydrocarbons" may refer to any hydrocarbon that may exist in a liquid phase under atmospheric or downhole conditions, and

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> generally includes liquid crude oil, which may comprise C_9+ hydrocarbons, branched hydrocarbons, aromatic hydrocarbons, and combinations thereof.

It is the preliminary view of the Board that the abovementioned phrase can be understood as teaching the person skilled in the art that any of the C_3-C_8 hydrocarbons ***may*** be considered an NGL.

In the Board's preliminary view, the scope of the phrase "cryogenic conditions" is not evident from the claim language itself or the specification.

The dictionary definition of Cryogenic is defined as from −150 °C (−238 °F) to absolute zero (−273 °C or −460 °F), the temperature at which molecular motion comes as close as theoretically possible to ceasing completely.

It is the preliminary view of the Board that the abovementioned phrase can be understood as teaching the person skilled in the art that a cryogenic process occurs at temperatures from −150 °C (−238 °F) to absolute zero (−273 °C or −460 °F).

The above claim construction was not disputed by the Applicant in the First Reply or the Second Reply. We therefore apply it in our analyses below.

Further, we have applied the same claim construction to the proposed new claims 29-60.

In our assessments of novelty and obviousness below, all the elements of the claims have been considered to be essential and taken into account.

Issued claims 1-28 of the '039 patent

Novelty

Principles of Law

The admissibility of prior art in assessing novelty is set out in subsection 28.2(1) of the *Patent Act*.

In *Sanofi* at paragraphs 24-27 and 33-37, the Supreme Court stated that in order to be anticipatory, a single piece of prior art must both:

> disclose the invention of the patent in question; and
>
> enable a skilled reader to make the invention using the prior art reference and common knowledge, allowing for some (uninventive and not unduly burdensome) trial and error experimentation to make it work.

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Analysis

Novelty in view of Pastor

In the Notice and the Second Stage Letter, we indicated that, in our preliminary view, claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27 would have lacked novelty in view of Pastor; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

It is the opinion of the Board, for the reasons set out in the Notice, that **claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27** encompass subject-matter disclosed in the prior art before the claim date and do not comply with **paragraph 28.2(1)(b) of the *Patent Act***.

Obviousness

Principles of Law

Section 28.3 of the *Patent Act* sets out the conditions under which a claim may be found to be obvious:

> 28.3 The subject-matter defined by a claim in an application for a patent in Canada must be subject-matter that would not have been obvious on the claim date to a person skilled in the art or science to which it pertains, having regard to
>
> (*a*) information disclosed more than one year before the filing date by the applicant, or by a person who obtained knowledge, directly or indirectly, from the applicant in such a manner that the information became available to the public in Canada or elsewhere; and
>
> (*b*) information disclosed before the claim date by a person not mentioned in paragraph (a) in such a manner that the information became available to the public in Canada or elsewhere.

Pursuant to paragraph 28.3(*b*), a patent claim will be invalid if, based on information that was available to the public before the claim date, its subject-matter would have been obvious to a person skilled in the art or science to which it pertains. In *Sanofi* at paragraph 67, the Supreme Court of Canada outlines a four-step approach to be followed when assessing obviousness:

> (1) Identify (a) the notional "person skilled in the art"; and (b) the relevant common general knowledge of that person;
>
> (2) Identify the inventive concept of the claim in question or if that cannot readily be done, construe it;
>
> (3) Identify what, if any, differences exist between the matter cited as forming part of the "state of the art" and the inventive concept of the claim or the claim as construed; and
>
> (4) Viewed without any knowledge of the alleged invention as claimed, do those differences constitute steps which would have been obvious to the person skilled

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in the art or do they require any degree of invention?

This approach has been applied in the following analysis.

Analysis

In the Notice and the Second Stage Letter, we indicated that, in our preliminary view, claim 1 would have been obvious having regard to Jarrell, in view of Ryan; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

In the Notice and the Second Stage Letter, we indicated that, in our preliminary view, claims 6, 7, 25 and 26 would have been obvious having regard to Pastor, in view of Ozero; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

In the Notice and the Second Stage Letter, we indicated that, in our preliminary view, claims 15 and 19 would have been obvious having regard to Pastor, in view of Jarrell; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

In the Notice and the Second Stage Letter, we indicated that, in our preliminary view, claim 20 would have been obvious having regard to Ryan, in view of Jarrell and the relevant common general knowledge of the person skilled in the art; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

In the Notice and the Second Stage Letter, we indicated that in our preliminary view, contrary to the Requester's assertion, claims 4, 5, 14, 23 and 24 would have been non-obvious, as the subject-matter would not have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to Pastor in view of Ryan; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view.

In the Notice and the Second Stage Letter, we indicated that in our preliminary view, contrary to the Requester's assertion, claims 9, 17 and 28 would have been non-obvious, as the subject-matter would not have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to Pastor in view of the common general knowledge; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

It is therefore the opinion of the Board that **claims 1, 6, 7, 15, 19, 20, 25 and 26** would have been obvious and do not comply with **paragraph 28.3(b) of the *Patent Act***.

Proposed Claims 29-60

The Principles of Law followed for the proposed claims submitted with the Second Reply are identical to those presented above in relation to the issued claims.

Further, we take the person skilled in the art and the relevant common general knowledge to be the same for the assessment below of the proposed claims submitted with the Second Reply.

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Novelty and Obviousness

Analysis

Pastor is considered the closest prior art and discloses a process of separating a carbon dioxide recycle stream into a purified carbon dioxide (overhead gas) stream and a natural gas stream (bottoms product). In order to overcome the problems associated with methane/CO2 distillation, Pastor's process leaves the methane in the overhead gas. To offset the effect of methane in the overhead gas, H2S, ethane, propane and a portion of butane remain in the overhead gas. The separation process of Pastor does not teach utilizing cryogenics or membranes.

Proposed Independent claim 29

Proposed independent claim 29 is based on issued independent claim 2; in our preliminary view, Pastor is the closest prior art in relation to proposed claim 29.

The Patentee has built on independent claim 2 by adding that the carbon dioxide recycle stream includes methane, ethane, and C3 hydrocarbons, and further adding that the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes a second portion of the C3 hydrocarbons from the carbon dioxide recycle stream, and wherein the second portion of the C3 hydrocarbons contains a molar percentage of the C3 hydrocarbons that is greater than a molar percentage of the C3 hydrocarbons of the first portion of the C3 hydrocarbons.

Regarding Pastor with respect to issued claim 2, the Notice and the Second Stage Letter read in part:

> With regard to claim 2, Pastor teaches a method comprising: receiving a carbon dioxide recycle stream(CO2 gas stream 25), wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids(column 3, line 51 - the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons"); and separating the carbon dioxide recycle stream(distillation column 3 separates the CO2 gas stream 25) into a purified carbon dioxide recycle stream(overhead product stream 21) and a natural gas liquids stream(bottoms product 26), wherein the purified carbon dioxide recycle stream includes the carbon dioxide, wherein the natural gas liquids stream includes the natural gas liquids(column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons'; see above Claim Construction issue, an NGL **may** be any of C3-C8), and wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions (Pastor does not subject any stream to cryogenic conditions(see above Claim Construction issue); furthermore Pastor does not describe isolating either methane or ethane, for which cryogenic conditions are conventionally used; additionally, Pastor utilizes propane as a refrigerant for condenser 7 (see column 4 line 29), and propane refrigerant is not considered to provide cryogenic conditions), membranes(Pastor does not mention using membranes), and carbon dioxide recovery solvents(Pastor does not use solvents in the process; the background section of Pastor discusses solvent use as being problematic, see column 1, lines 47 to 55) between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream. [Emphasis in original]

Thus the arrangement of proposed claim 29 differs from Pastor in that it specifies that a mole percentage of C3 hydrocarbons in the natural gas liquids stream is greater than that in the purified carbon dioxide recycle stream. This is the opposite of what Pastor teaches; TABLE I in Pastor shows a mole percentage of C3 hydrocarbons in the natural gas liquids stream ('Bottoms Product') as being much less than that in

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the purified carbon dioxide stream ('Overhead Product').

None of Jarrell, Ryan, or Ozero suggest a separation providing a purified CO2 stream comprising all of the CO2 from the recycle stream, as well as methane and ethane. Ozero does provide a stream comprising CO2, methane, ethane, and propane (28, Fig. 1); however, it is not the primary purified CO2 stream. One skilled in the art would not be led from any combination of these documents to the characterizing feature of proposed claim 29. In view of the above, the opinion of the Board is that proposed independent claim 29 would have been novel and non-obvious at the claim date.

Proposed independent claim 30

Proposed independent claim 30 is based on issued dependent claim 4; in relation to issued dependent claim 4, the Notice and the Second Stage Letter read in part:

> In our preliminary review, with regard to claims 4-5 and 23-24, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with Ryan. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with methane/CO2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping H2S in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13). The removal of the H2S gas from the purified carbon dioxide recycle stream would result in a decrease in the miscibility of the recycle stream and limit the recycle gases injection effectiveness. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of Ryan.

Thus it was the preliminary opinion of the Board that issued claim 4 is non-obvious in view of Pastor, having regard of Ryan.

Proposed independent claim 30 is based on issued dependent claim 4; the Patentee has built on issued dependent claim 4 by adding that carbon dioxide recycle stream and the purified carbon dioxide recycle stream each include methane and ethane; and also by clarifying that the acid gas is H2S. Proposed independent claim 30 therefore represents a narrowing of issued dependent claim 4.

In the opinion of the Board, Pastor is the closest prior art document to the subject-matter of proposed independent claim 30. As Pastor does not disclose all the features of proposed independent claim 30, it would have been, in our view, novel at the claim date.

Further, it is the opinion of the Board that proposed independent claim 30 would have been non-obvious, for the same reasons set out above as to why issued claim 4 would have been non-obvious and in light of the added features.

In view of the differences in respect of issued claim 4, discussed above, proposed independent claim 30 is not redundant in view of issued dependent claim 4.

Proposed independent claim 36

Proposed independent claim 36 is based on issued independent claim 10; the Notice and the Second Stage Letter gave the preliminary opinion that issued independent claim 10 was not novel in view of Pastor. In our view, Pastor is the closest prior art in relation to proposed claim 36.

To arrive at proposed independent claim 36, the Patentee has built on issued independent claim 10 by adding that the recycle stream further includes methane and ethane; and that the purified recycle stream includes the injection gas, the methane, the ethane, and a first portion of the C3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar

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percentage of the methane in the purified recycle stream, wherein the natural gas liquids stream includes a second portion of the C3 hydrocarbons from the recycle stream, and wherein the second portion of the C3 hydrocarbons contains a molar percentage of the C3 hydrocarbons that is greater than a molar percentage of the C3 hydrocarbons of the first portion of the C3 hydrocarbons.

As discussed above in relation to proposed independent claim 29, the subject matter of proposed claim 36 differs from that of Pastor in that it specifies that a mole percentage of C3 hydrocarbons in the natural gas liquids stream is greater than that in the purified carbon dioxide recycle stream. This is the opposite of what Pastor teaches; TABLE I in Pastor shows a mole percentage of C3 hydrocarbons in the natural gas liquids stream ('Bottoms Product') as being much less than that in the purified carbon dioxide stream ('Overhead Product').

In view of the above, and the reasoning given in the discussion relating to proposed claim 29, the opinion of the Board is that proposed independent claim 36 would have been novel and non-obvious at the claim date.

Proposed independent claim 39

Proposed independent claim 39 is based on issued dependent claim 14; in relation to issued dependent claim 14, the Notice and the Second Stage Letter read in part:

> In our preliminary review, with regard to claims 14, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with Ryan. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with methane/CO2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping H2S in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13; Table 1 does not teach any H2S in the Bottoms Product (NGL)). Since there is no acid in the NGL steam, there is no need to add an acid removal step. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of Ryan.

Thus it was the preliminary opinion of the Board that issued claim 14 is non-obvious in view of Pastor, having regard of Ryan, and common general knowledge.

Proposed independent claim 39 is based on issued dependent claim 14; the Patentee has built on issued dependent claim 14 by adding that carbon dioxide recycle stream and the purified carbon dioxide recycle stream each include methane and ethane; and also by clarifying that the acid gas is H2S. Therefore, proposed independent claim 39 represents a narrowing of issued dependent claim 14.

In the opinion of the Board, Pastor is the closest prior art document to the subject-matter of proposed independent claim 39. As Pastor does not disclose all the features of proposed independent claim 39, it would have been, in our view, novel at the claim date.

Further, in the opinion of the Board, proposed independent claim 39 would have been non-obvious for the reasons set out above as to why issued claim 14 would not have been obvious, and in light of the added features.

In light of the added features, proposed independent claim 39 differs from issued dependent claim 14, and thus there is no redundant claiming.

Proposed independent claim 43

Proposed independent claim 43 is based on issued dependent claim 21; the Notice and the Second Stage

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Letter gave the preliminary opinion that issued dependent claim 21 was not novel in view of Pastor. In our view, Pastor is the closest prior art in relation to proposed claim 43.

To arrive at proposed independent claim 43, the Patentee has built on issued independent claim 21 by adding that the carbon dioxide recycle stream further includes methane and ethane and C3 hydrocarbons; and that the purified recycle stream includes the injection gas, the methane, the ethane, and a first portion of the C3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream, wherein the natural gas liquids stream includes a second portion of the C3 hydrocarbons from the recycle stream, and wherein the second portion of the C3 hydrocarbons contains a molar percentage of the C3 hydrocarbons that is greater than a molar percentage of the C3 hydrocarbons of the first portion of the C3 hydrocarbons.

As discussed above in relation to proposed independent claim 29, the subject matter of the proposed claim differs from that of Pastor in that it specifies that a mole percentage of C3 hydrocarbons in the natural gas liquids stream is greater than that in the purified carbon dioxide recycle stream. This is the opposite of what Pastor teaches; TABLE I in Pastor shows a mole percentage of C3 hydrocarbons in the natural gas liquids stream ('Bottoms Product') as being much less than that in the purified carbon dioxide stream ('Overhead Product').

In light of the above, and the reasoning given in the discussion relating to proposed claim 29, the opinion of the Board is that proposed independent claim 43 would have been novel and non-obvious at the claim date.

Proposed independent claim 44

Proposed independent claim 44 is based on issued dependent claim 23; in relation to issued dependent claim 23, the Notice and the Second Stage Letter read in part:

> In our preliminary review, with regard to claims 4-5 and 23-24, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with Ryan. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with methane/CO2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping H2S in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13). The removal of the H2S gas from the purified carbon dioxide recycle stream would result in a decrease in the miscibility of the recycle stream and limit the recycle gases injection effectiveness. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of Ryan.

Thus it was the preliminary opinion of the Board that issued claim 23 is non-obvious in view of Pastor, having regard of Ryan, and common general knowledge.

Proposed independent claim 44 is based on issued dependent claim 23; the Patentee has built on issued dependent claim 23 by adding that carbon dioxide recycle stream and the purified carbon dioxide recycle stream each include methane and ethane; and also by clarifying that the acid gas is H2S. Therefore, proposed independent claim 44 represents a narrowing of issued dependent claim 23.

In the opinion of the Board, Pastor is the closest prior art document to the subject-matter of proposed independent claim 44. As Pastor does not disclose all the features of proposed independent claim 44, it would have been, in our view, novel at the claim date.

Further, the opinion of the Board is that proposed independent claim 44 would have been non-obvious for the reasons set out above in relation to issued claim 23 and in light of the added features.

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In light of the added features, proposed independent claim 44 differs from issued dependent claim 23, and thus there is no redundant claiming.

Proposed dependent claims 31-35, 37-38, 40-42, and 45-60

As it is the opinion of the Board that all proposed independent claims would have been novel and non-obvious, so too it is the Board's opinion that all proposed dependent claims would have been novel and non-obvious.

Summary of Proposed Claims Analysis

It is the opinion of the Board that proposed **claims 29-60** would have been novel at the claim date and comply with **paragraph 28.2(1)(b) of the *Patent Act***.

It is the opinion of the Board that proposed **claims 29-60** would have been non-obvious and comply with **paragraph 28.3(b) of the *Patent Act***.

Conclusions for the issued claims 1-28

It is the opinion of the Board that issued **claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27** encompass subject-matter disclosed in the prior art before the claim date and do not comply with **paragraph 28.2(1)(b) of the *Patent Act***.

It is the opinion of the Board that issued **claims 1, 6, 7, 15, 19, 20, 25 and 26** would have been obvious and do not comply with **paragraph 28.3(b) of the *Patent Act***.

It is the opinion of the Board that issued **claims 4, 5, 9, 14, 17, 23, 24, and 28** would have been non-obvious and do comply with **paragraph 28.3(b) of the *Patent Act***.

Conclusions for the proposed claims 29-60

It is the opinion of the Board that the subject-matter of proposed **claims 29-60** would have been novel at the claim date and does comply with **paragraph 28.2(1)(b) of the *Patent Act***.

It is the opinion of the Board that proposed **claims 29-60** would have been non-obvious and comply with **paragraph 28.3(b) of the *Patent Act***.

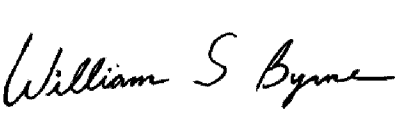
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Completion of the Re-Examination

Please find enclosed a Certificate of Re-examination issued under subsection 48.4(1) of the *Patent Act*, cancelling claims 1-3, 6-8, 10-13, 15-16, 18-22, and 25-27 of CA Patent number 2,949,039, and incorporating proposed claims 29-60 submitted by the Patentee in the Second Reply.

Please also find enclosed a Registration Certificate indicating that the enclosed Certificate of Re-examination has been registered as an "Other Document" against CA Patent number 2,949,039.

Under section 48.5 of the *Patent Act*, no appeal may be taken from the decision of the Re-examination Board after three (3) months from the date a copy of the Certificate of Re-examination is sent by registered mail to the Patentee.


Chairperson	**Member**	**Member**
Stephen MacNeil	William Byrne	Sean Wilkinson

c.c. **Marks & Clerk Canada**
100 Simcoe Street, Suite 200
Toronto, Ontario
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Canadian Intellectual Property Office

BUREAU DES BREVETS
CONSTAT DE RÉEXAMEN

PATENT OFFICE
CERTIFICATE OF RE-EXAMINATION

N° de brevet - Patent No: **2,949,039**

Par la présente, les soussignés certifient que le brevet susmentionné a été réexaminé selon les paragraphes 48.1 à 48.3 de la *Loi sur les brevets* et que le Conseil de réexamen convient de ce qui suit:

The undersigned hereby certify that the above-noted patent has been re-examined pursuant to section 48.1 to 48.3 of the *Patent Act* and that the Re-examination Board has determined the following:

(i)	Les revendications/ Claims	1-3, 6-8, 10-13, 15-16, 18-22 and 25-27	du brevet susmentionné sont non brevetables et sont rejetées / are unpatentable and are cancelled from the above noted patent.
(ii)	Les revendications / Claims	4, 5, 9, 14, 17, 23, 24 and 28	du brevet susmentionné sont brevetables / of the above noted patent are hereby confirmed to be patentable.
(iii)	Les nouvelles revendications / New claims	29-60	(soumises le 8 juin 2021 / submitted June 8, 2021) sont brevetables et font partie du brevet susmentionné à compter de ce jour / are patentable and have been incorporated into the above noted patent as of this date.

Stephen MacNeil Président Chairperson	William Byrne Membre Member	Sean Wilkinson Membre Member

Daté à Gatineau (Québec), ce 10e jour de septembre, 2021
Dated at Gatineau, Quebec, this 10th day of September, 2021

Canada

Courtoisie - Certificat d'enregistrement (document(s) connexe(s))
Courtesy - Certificate of Registration (Related Document(s))

GOWLING WLG (CANADA) LLP
CIPO@gowlingwlg.com

Détails du certificat / Certificate Details	
Date du certificat: / Certificate Date:	2021/09/10
N° d'enregistrement: / Registration N°:	05830058
Votre n° de référence: / Your Reference N°:	K8001075CADIV6

Document enregistré:	AUTRE DOCUMENT
Document Registered:	OTHER DOCUMENT

Les dossiers du Bureau des brevets indiquent qu'un document a été enregistré relativement à la (aux) demande(s) et/ou au(x) brevet(s) suivants:

Patent Office records indicate that a document has been registered for the following application(s) and/or patent(s):

Brevets/Patents:

2,949,039

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CLAIMS

1. A method comprising:

receiving a hydrocarbon feed stream, wherein the hydrocarbon feed stream includes carbon dioxide, natural gas liquid (NGL), and heavy hydrocarbons, wherein the NGL includes C_3-C_8 hydrocarbons, and wherein the heavy hydrocarbons include C_{9+} hydrocarbons;

separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon rich stream includes most of the C_{9+} hydrocarbons in the hydrocarbon feed stream, and wherein the carbon dioxide recycle stream includes most of the carbon dioxide and most of the C_3-C_8 hydrocarbons in the hydrocarbon feed stream;

separating the carbon dioxide recycle stream into a sour NGL rich stream and a purified carbon dioxide recycle stream, wherein the sour NGL rich stream includes some of the C_3-C_8 hydrocarbons in the carbon dioxide recycle stream, and wherein the purified carbon dioxide recycle stream includes most of the carbon dioxide in the carbon dioxide recycle stream;

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separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream, wherein the sweet NGL rich stream includes the substantially all of the C_3-C_8 hydrocarbons in the source NGL rich stream, and wherein the carbon dioxide rich stream includes substantially all of the carbon dioxide in the sour NGL rich stream;

combining a carbon dioxide makeup stream from a source external to the method with the purified carbon dioxide recycle stream; and

subsequently injecting the combined carbon dioxide makeup stream and the purified carbon dioxide recycle stream into a subterranean formation,

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wherein the carbon dioxide is not removed from the hydrocarbon feed stream and is not removed from the carbon dioxide recycle stream prior to separating the carbon dioxide recycle stream into the sour NGL rich stream and the purified carbon dioxide recycle stream, and

wherein the hydrocarbon feed stream, the carbon dioxide recycle stream, and the sour NGL rich stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the heavy hydrocarbon rich stream, the purified carbon dioxide recycle stream, the sweet NGL rich stream, and the carbon dioxide rich stream.

2. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

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wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

3. The method according to claim 2, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon

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dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

4. The method according to claim 2, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

5. The method according to claim 4, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

6. The method according to claim 2, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

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7. The method according to claim 2, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

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adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

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8. The method according to claim 2, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

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9. The method according to claim 2, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

10. A system comprising:

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piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream;

wherein the purified recycle stream includes the injection gas,

wherein the natural gas liquids stream includes the C_3-C_8 hydrocarbons, and

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream.

11. The system according to claim 10, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

12. The system according to claim 10, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

13. The system according to claim 10, wherein the recycle stream comprises C_1 to C_2 hydrocarbons, and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream.

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14. The system according to claim 10, wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream, wherein the sweet natural gas liquids stream includes the C_3-C_8 hydrocarbons, and wherein the acid gas stream includes H_2S and/or CO_2.

15. The system according to claim 10, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

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16. The system according to claim 10, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

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17. The system according to claim 10, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified recycle stream includes substantially all of the injection gas, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the

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purified recycle stream, wherein the natural gas liquids stream includes substantially none of the injection gas and a second portion of the C_3 hydrocarbons from the recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

18. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

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wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas,

wherein the natural gas liquids stream comprises the natural gas liquids,

wherein the natural gas comprises C_1 to C_2 hydrocarbons, and

wherein the natural gas liquids comprise C_3-C_8 hydrocarbons.

19. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;

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separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids; and

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separating a feed stream into the carbon dioxide recycle stream and a heavy hydrocarbon stream, wherein the heavy hydrocarbon stream includes C_{9+} hydrocarbons.

20. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids;

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receiving a feed stream, wherein the feed stream includes carbon dioxide, C_1 to C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_{9+} hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons; and

separating the feed stream into a heavy hydrocarbon stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon stream includes substantially all of the C_{9+} hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream, wherein the heavy hydrocarbon stream includes substantially none of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream, and wherein the carbon dioxide

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recycle stream includes substantially all of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream,

wherein the purified carbon dioxide recycle stream includes substantially all of the C_2 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially none of the C_2 hydrocarbons from the carbon dioxide recycle stream, and

wherein the purified carbon dioxide recycle stream includes substantially none of the C_3 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially all of the C_3 hydrocarbons from the carbon dioxide recycle stream.

21. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

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wherein the natural gas liquids stream includes the natural gas liquids, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

22. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the

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purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

23. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

24. The set of process equipment according to claim 23, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

25. The set of process equipment according to claim 21, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

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26. The set of process equipment according to claim 21, further configured to:

compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

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add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

27. The set of process equipment according to claim 21, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

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28. The set of process equipment according to claim 21, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

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29. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C_3 hydrocarbons, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,

wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

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30. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, and the ethane,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the carbon dioxide recycle stream comprises H_2S, and

wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the H_2S into the natural gas liquids stream.

31. The method according to claim 30, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream.

32. The method according to claim 29, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

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33. The method according to claim 29, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

34. The method according to claim 29, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

35. The method according to claim 29, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

36. A system comprising:

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piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas, methane, ethane, and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas,

wherein the natural gas liquids stream includes the C_3 to C_8 ~~C_3-C_8~~-hydrocarbons,

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream,

wherein the purified recycle stream includes the injection gas, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the recycle stream,

wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

37. The system according to claim 36, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

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38. The system according to claim 36, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

39. A system comprising:

piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas, methane, ethane, and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas, the methane, and the ethane,

wherein the natural gas liquids stream includes the C_3 to C_8 hydrocarbons,

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream,

wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream, and

wherein the sweet natural gas liquids stream includes the C_3 to C_8 hydrocarbons.

40. The system according to claim 36, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

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dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

41. The system according to claim 36, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

42. The system according to claim 36, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

43. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C_3 hydrocarbons, and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids,

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wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,

wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

44. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

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wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, and the ethane,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the carbon dioxide recycle stream comprises H_2S, and

wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the H_2S into the natural gas liquids stream.

45. The set of process equipment according to claim 44, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream.

46. The set of process equipment according to claim 44, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

47. The set of process equipment according to claim 43, further configured to:

compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

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add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

48. The set of process equipment according to claim 43, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

49. The set of process equipment according to claim 43, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

50. The method according to claim 4, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

51. The method according to claim 4, further comprising:

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compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

52. The method according to claim 4, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

53. The system according to claim 14, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

54. The system according to claim 14, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

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55. The system according to claim 14, wherein the recycle stream comprises C_1 to C_2 hydrocarbons, and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream.

56. The system according to claim 14, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

57. The system according to claim 14, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

58. The set of process equipment according to claim 23, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

59. The set of process equipment according to claim 23, further configured to:

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compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

60. The set of process equipment according to claim 23, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

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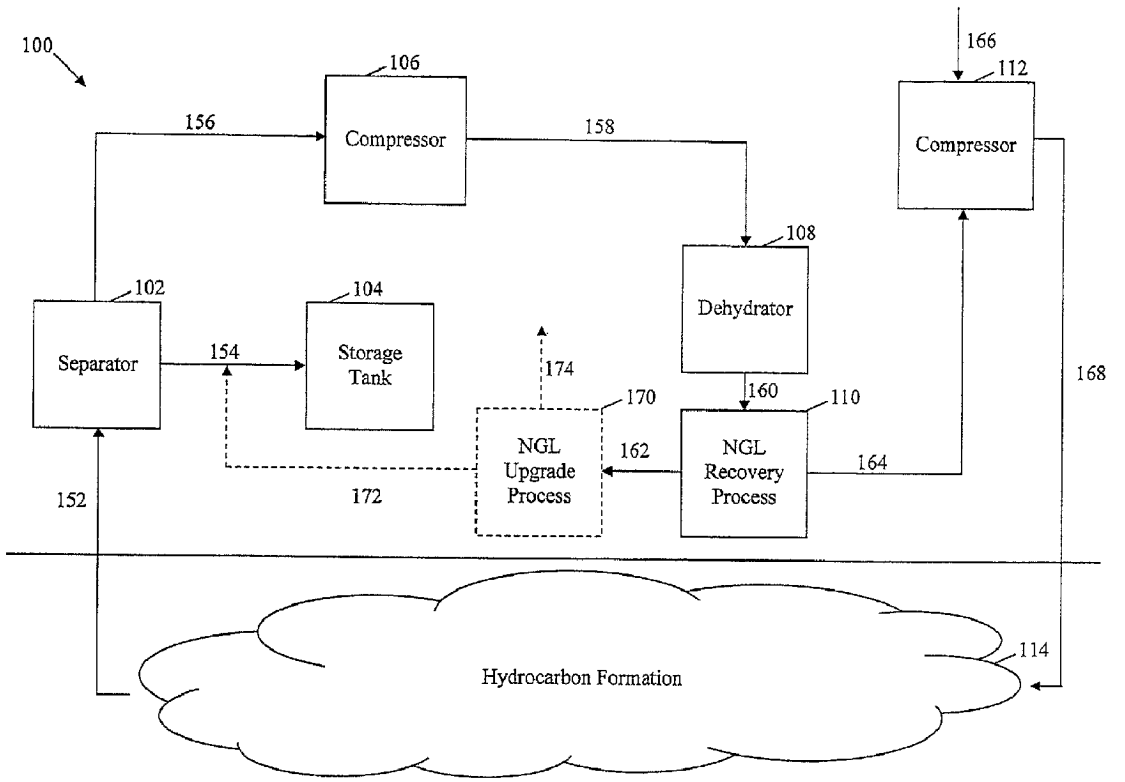
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(54) Titre : PROCESSUS DE RECUPERATION AMELIORE DU GAZ NATUREL SOUS FORME LIQUIDE
(54) Title: ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS



(57) Abrégé/Abstract:
A method comprises receiving a hydrocarbon feed stream; separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a recycle stream, wherein the recycle stream comprises a gas selected from the group consisting of carbon dioxide,

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(57) **Abrégé(suite)/Abstract(continued):**
nitrogen, air, and water; and separating the recycle stream into a natural gas liquids (NGL) rich stream and a purified recycle stream. A plurality of process equipment configured to receive a hydrocarbon feed stream, separate the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a recycle stream comprising at least one C3+ hydrocarbon and gas selected from the group consisting of carbon dioxide, nitrogen, air, and water, and separate the recycle stream into a NGL rich stream and a purified recycle stream.

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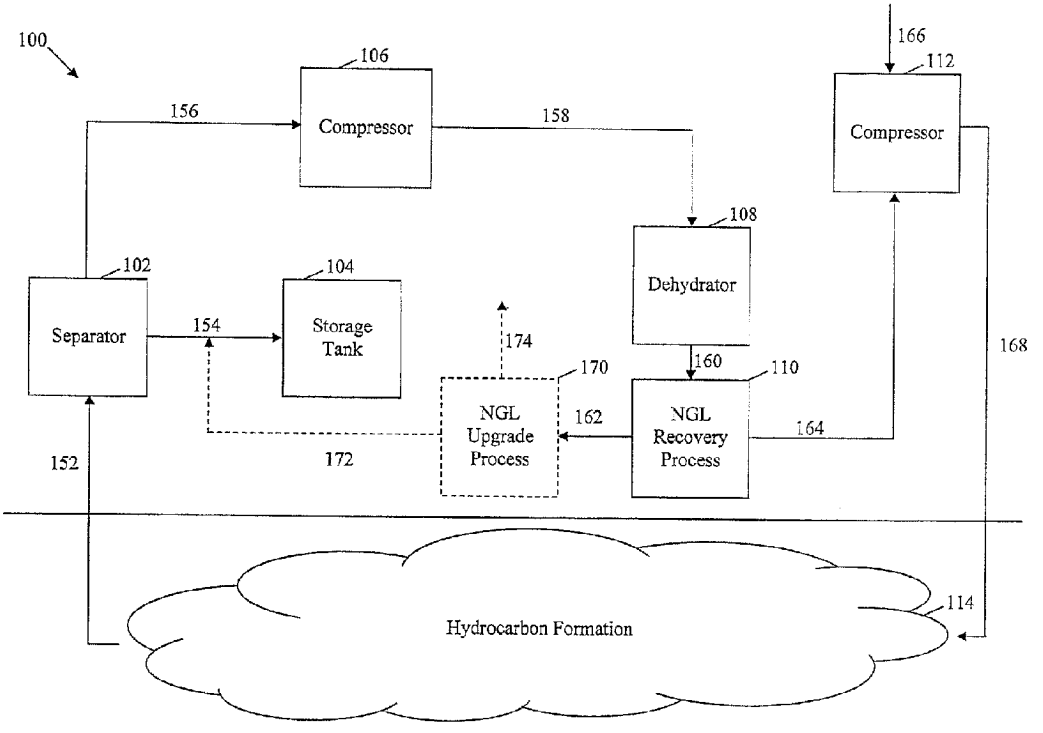
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(57) **Abrégé/Abstract:**
A method comprises receiving a hydrocarbon feed stream; separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a recycle stream, wherein the recycle stream comprises a gas selected from the group consisting of carbon dioxide, nitrogen, air, and water; and separating the recycle stream into a natural gas liquids (NGL) rich stream and a purified recycle stream. A plurality of process equipment configured to receive a hydrocarbon feed stream, separate the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a recycle stream comprising at least one C3+ hydrocarbon and a gas selected from the group consisting of carbon dioxide, nitrogen, air, and water, and separate the recycle stream into a NGL rich stream and a purified recycle stream.

ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS

BACKGROUND

Carbon dioxide (CO_2) is a naturally occurring substance in most hydrocarbon subterranean formations. Carbon dioxide also may be used for recovering or extracting oil and hydrocarbons from subterranean formations. One carbon dioxide based recovery process involves injecting carbon dioxide into an injection well, and recovering heavy hydrocarbons and perhaps some of the carbon dioxide from at least one recovery well. Carbon dioxide reinjection process also may produce natural gas liquids (NGLs).

SUMMARY

In one aspect, the disclosure includes a method comprising receiving a hydrocarbon feed stream, separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a carbon dioxide recycle stream, separating the carbon dioxide recycle stream into a NGL rich stream and a purified carbon dioxide recycle stream, and injecting the purified carbon dioxide recycle stream into a subterranean formation.

In another aspect, the disclosure includes a plurality of process equipment configured to implement a method comprising receiving a recycle stream comprising at least one C_{3+} hydrocarbon and a gas selected from the group consisting of carbon dioxide, nitrogen, air, and water, and separating the recycle stream into a NGL rich stream and a purified recycle stream, wherein the NGL rich stream comprises less than about 70 percent of the C_{3+} hydrocarbons from the recycle stream.

In a third aspect, the disclosure includes a method comprising selecting a first recovery rate for a NGL recovery process, estimating the economics of the NGL recovery process based on the first recovery rate, selecting a second recovery rate that is different from the first recovery rate, estimating the economics of the NGL recovery process based on the second recovery rate, and selecting the first recovery rate for the NGL recovery process when the estimate based on the first recovery rate is more desirable than the estimate based on the second recovery rate.

In a fourth aspect, the disclosure includes a method comprising receiving a hydrocarbon feed stream; separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a

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recycle stream, wherein the recycle stream comprises a gas selected from the group consisting of carbon dioxide, nitrogen, air, and water; and separating the recycle stream into a NGL rich stream and a purified recycle stream.

In a fifth aspect, the disclosure includes a plurality of process equipment configured to receive a hydrocarbon feed stream; separate the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a recycle stream comprising at least one C_{3+} hydrocarbon and a gas selected from the group consisting of carbon dioxide, nitrogen, air, and water; and separate the recycle stream into a NGL rich stream and a purified recycle stream.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a process flow diagram for an embodiment of a carbon dioxide reinjection process.

FIG. 2 is a schematic diagram of an embodiment of a NGL recovery process.

FIG. 3 is a chart depicting an embodiment of the relationship between the NGL recovery rate and the energy requirement.

FIG. 4 is a schematic diagram of an embodiment of a NGL upgrade process.

FIG. 5 is a process flow diagram for another embodiment of a reinjection process.

FIG. 6 is a schematic diagram of another embodiment of a NGL recovery process.

FIG. 7 is a flowchart of an embodiment of a NGL recovery optimization method.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

It should be understood at the outset that although an illustrative implementation of one or more embodiments are provided below, the disclosed systems and/or methods may be implemented using any number of techniques, whether currently known or in existence. The disclosure should in no way be limited to the illustrative implementations, drawings, and techniques illustrated below, including the exemplary designs and implementations illustrated and described herein, but may be modified within the scope of the appended claims along with their full scope of equivalents.

Disclosed herein is a NGL recovery process that may be implemented as part of a carbon dioxide reinjection process to recover NGLs from a carbon dioxide recycle stream. When

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implementing a carbon dioxide reinjection process, the carbon dioxide is typically injected downhole into an injection well and a stream comprising hydrocarbons and carbon dioxide is generally recovered from a recovery well. The carbon dioxide may be separated from the heavy hydrocarbons and then recycled downhole, e.g., in the reinjection well. In some cases, the carbon dioxide recycle stream may comprise some NGLs, which may be recovered prior to injecting the carbon dioxide recycle stream downhole. The NGL recovery process may be optimized by weighing the NGL recovery rate against the amount of energy expended on NGL recovery.

FIG. 1 illustrates an embodiment of a carbon dioxide reinjection process 100. The carbon dioxide reinjection process 100 may receive hydrocarbons and carbon dioxide from a subterranean hydrocarbon formation 114, separate heavy hydrocarbons and some of the NGLs from the carbon dioxide, and inject the carbon dioxide downhole. As shown in FIG. 1, additional process steps may be included in the carbon dioxide reinjection process, such as compressing the carbon dioxide, dehydrating the carbon dioxide, and/or adding additional carbon dioxide to the carbon dioxide recycle stream. The specific steps in the carbon dioxide reinjection process 100 are explained in further detail below.

The carbon dioxide reinjection process 100 may receive a hydrocarbon feed stream 152 from a subterranean hydrocarbon formation 114. The hydrocarbon feed stream 152 may be obtained from at least one recovery well as indicated by the upward arrow in FIG. 1, but also may be obtained from other types of wells. In addition, the hydrocarbon feed stream 152 may be obtained from the subterranean hydrocarbon formation 114 using any suitable method. For example, if a suitable pressure differential exists between the subterranean hydrocarbon formation 114 and the surface, the hydrocarbon feed stream 152 may flow to the surface via the pressure differential. Alternatively, surface and/or downhole pumps may be used to draw the hydrocarbon feed stream 152 from the subterranean hydrocarbon formation 114 to the surface.

Although the composition of the hydrocarbon feed stream 152 will vary from one location to another, the hydrocarbon feed stream 152 may comprise carbon dioxide, methane, ethane, NGLs, heavy hydrocarbons, hydrogen sulfide (H_2S), helium, nitrogen, water, or combinations thereof. The term "hydrocarbon" may refer to any compound comprising, consisting essentially of, or consisting of carbon and hydrogen atoms. The term "natural gas" may refer to any hydrocarbon that may exist in a gas phase under atmospheric or downhole conditions, and

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includes methane and ethane, but also may include diminishing amounts of $C_3 - C_8$ hydrocarbons. The term "natural gas liquids" or NGLs may refer to natural gases that may be liquefied without refrigeration, and may include $C_3 - C_8$ hydrocarbons. Both natural gas and NGL are terms known in the art and are used herein as such. In contrast, the term "heavy hydrocarbons" may refer to any hydrocarbon that may exist in a liquid phase under atmospheric or downhole conditions, and generally includes liquid crude oil, which may comprise C_{9+} hydrocarbons, branched hydrocarbons, aromatic hydrocarbons, and combinations thereof.

The hydrocarbon feed stream 152 may enter a separator 102. The separator 102 may be any process equipment suitable for separating at least one inlet stream into a plurality of effluent streams having different compositions, states, temperatures, and/or pressures. For example, the separator 102 may be a column having trays, packing, or some other type of complex internal structure. Examples of such columns include scrubbers, strippers, absorbers, adsorbers, packed columns, and distillation columns having valve, sieve, or other types of trays. Such columns may employ weirs, downspouts, internal baffles, temperature control elements, and/or pressure control elements. Such columns also may employ some combination of reflux condensers and/or reboilers, including intermediate stage condensers and reboilers. Alternatively, the separator 102 may be a phase separator, which is a vessel that separates an inlet stream into a substantially vapor stream and a substantially liquid stream, such as a knock-out drum, flash drum, reboiler, condenser, or other heat exchanger. Such vessels also may have some internal baffles, temperature control elements, and/or pressure control elements, but generally lack any trays or other type of complex internal structure commonly found in columns. The separator 102 also may be any other type of separator, such as a membrane separator. In a specific embodiment, the separator 102 is a knockout drum. Finally, the separator 102 may be any combination of the aforementioned separators arranged in series, in parallel, or combinations thereof.

The separator 102 may produce a heavy hydrocarbon stream 154 and a carbon dioxide recycle stream 156. The heavy hydrocarbon stream 154 may comprise most of the heavy hydrocarbons from the hydrocarbon feed stream 152. In embodiments, the heavy hydrocarbon stream 154 may comprise at least about 90 percent, at least about 95 percent, at least about 99 percent, or substantially all of the heavy hydrocarbons from the hydrocarbon feed stream 152. The heavy hydrocarbon stream 154 may be sent to a pipeline for transportation or a storage tank

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104, where it is stored until being transported to another location or being further processed. In contrast, the carbon dioxide recycle stream 156 may comprise most of the carbon dioxide from the hydrocarbon feed stream 152. In embodiments, the carbon dioxide recycle stream 156 may comprise at least about 90 percent, at least about 95 percent, at least about 99 percent, or substantially all of the carbon dioxide from the hydrocarbon feed stream 152. Similarly, the carbon dioxide recycle stream 156 may comprise at least about 80 percent, at least about 90 percent, at least about 95 percent, or substantially all of the natural gas from the hydrocarbon feed stream 152. All of the percentages referred to herein are molar percentages until otherwise specified.

The carbon dioxide recycle stream 156 may enter a compressor 106. The compressor 106 may be any process equipment suitable for increasing the pressure, temperature, and/or density of an inlet stream. The compressor 106 may be configured to compress a substantially vapor phase inlet stream, a substantially liquid phase inlet stream, or combinations thereof. As such, the term "compressor" may include both compressors and pumps, which may be driven by electrical, mechanical, hydraulic, or pneumatic means. Specific examples of suitable compressors 106 include centrifugal, axial, positive displacement, turbine, rotary, and reciprocating compressors and pumps. In a specific embodiment, the compressor 106 is a turbine compressor. Finally, the compressor 106 may be any combination of the aforementioned compressors arranged in series, in parallel, or combinations thereof.

The compressor 106 may produce a compressed carbon dioxide recycle stream 158. The compressed carbon dioxide recycle stream 158 may contain the same composition as the carbon dioxide recycle stream 156, but at a higher energy level. The additional energy in the compressed carbon dioxide recycle stream 158 may be obtained from energy added to the compressor 106, e.g., the electrical, mechanical, hydraulic, or pneumatic energy. In embodiments, difference in energy levels between the compressed carbon dioxide recycle stream 158 and the carbon dioxide recycle stream 156 is at least about 50 percent, at least about 65 percent, or at least about 80 percent of the energy added to the compressor 106.

The compressed carbon dioxide recycle stream 158 may enter a dehydrator 108. The dehydrator 108 may remove some or substantially all of the water from the compressed carbon dioxide recycle stream 158. The dehydrator 108 may be any suitable dehydrator, such as a

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condenser, an absorber, or an adsorber. Specific examples of suitable dehydrators 108 include refrigerators, molecular sieves, liquid desiccants such as glycol, solid desiccants such as silica gel or calcium chloride, and combinations thereof. The dehydrator 108 also may be any combination of the aforementioned dehydrators arranged in series, in parallel, or combinations thereof. In a specific embodiment, the dehydrator 108 is a glycol unit. Any water accumulated within or exiting from the dehydrator 108 may be stored, used for other processes, or discarded.

The dehydrator 108 may produce a dehydrated carbon dioxide recycle stream 160. The dehydrated carbon dioxide recycle stream 160 may contain little water, e.g., liquid water or water vapor. In embodiments, the dehydrated carbon dioxide recycle stream 160 may comprise no more than about 5 percent, no more than about 3 percent, no more than about 1 percent, or be substantially free of water.

The dehydrated carbon dioxide recycle stream 160 may enter a NGL recovery process 110. The NGL recovery process 110 may separate the dehydrated carbon dioxide recycle stream 160 into a NGL rich stream 162 and a purified carbon dioxide recycle stream 164. The NGL rich stream 162 may only comprise a portion of the total NGLs from the dehydrated carbon dioxide recycle stream 160. For example, the NGL rich stream 162 may comprise less than about 70 percent, from about 10 percent to about 50 percent, or from about 20 percent to about 35 percent of the NGLs from the dehydrated carbon dioxide recycle stream 160. By taking a less aggressive cut of the NGLs and/or disregarding the recovery of methane, ethane, and optionally propane from the dehydrated carbon dioxide recycle stream 160, the NGL recovery process 110 may produce a relatively high quality NGL rich stream 162 with relatively little process equipment or energy. A specific example of a suitable NGL recovery process 110 is shown in FIG. 2 and described in further detail below.

As mentioned above, the NGL recovery process 110 may produce a relatively high-quality NGL rich stream 162. Specifically, while the NGL recovery process 110 recovers only a portion, e.g., about 20 to about 35 percent, of the NGLs in the dehydrated carbon dioxide recycle stream 160, the resulting NGL rich stream 162 is relatively lean with respect to methane and the acid gases. For example, the NGL rich stream 162 may comprise most of the butane and heavier components from the dehydrated carbon dioxide recycle stream 160. For example, the NGL rich stream 162 may comprise at least about 90 percent, at least about 95 percent, at least about 99

percent, or substantially all of the C_{4+} from the dehydrated carbon dioxide recycle stream 160. In an embodiment, the NGL rich stream 162 may comprise at least about 20 percent, at least about 40 percent, at least about 60 percent, or at least about 70 percent of the C_{3+} from the dehydrated carbon dioxide recycle stream 160. In embodiments, the NGL rich stream 162 may comprise no more than about 10 percent, no more than about 5 percent, no more than about 1 percent, or be substantially free of ethane. Similarly, the NGL rich stream 162 may comprise no more than about 5 percent, no more than about 3 percent, no more than about 1 percent, or be substantially free of methane. Moreover, the NGL rich stream 162 may comprise no more than about 5 percent, no more than about 3 percent, no more than about 1 percent, or be substantially free of acid gases, such as carbon dioxide or hydrogen sulfide. It will be realized that the composition of the NGL rich stream 162 may be dependent on the dehydrated carbon dioxide recycle stream 160 composition. The examples provided below show the composition of the NGL rich stream 162 for three different dehydrated carbon dioxide recycle stream 160 compositions. The NGL rich stream 162 may be sent to a pipeline for transportation or a storage tank, where it is stored until being transported to another location or being further processed.

In an embodiment, the NGL rich stream 162 optionally may be processed in an NGL upgrade process 170. The NGL upgrade process 170 may produce a relatively heavy NGL stream 172 that may be combined with the heavy hydrocarbon stream 154. When combined, the heavy NGL stream 172 and the heavy hydrocarbon stream 154 may meet or exceed the pipeline and/or transportation thresholds or standards for a heavy hydrocarbon stream, as described in more detail with respect to Figure 4. A relatively light NGL stream 174 may be sent to a pipeline for transportation or a storage tank, where it may be stored until transported to another location or further processed, as described in more detail with respect to Figure 4. A specific example of a suitable NGL upgrade process 170 is shown in FIG. 5 and described in further detail below.

As mentioned above, the NGL recovery process 110 may produce a purified carbon dioxide recycle stream 164. The purified carbon dioxide recycle stream 164 may comprise most of the carbon dioxide from the dehydrated carbon dioxide recycle stream 160, as well as some other components such as methane, ethane, propane, butane, nitrogen, and hydrogen sulfide. In embodiments, the purified carbon dioxide recycle stream 164 may comprise at least about 90 percent, at least about 95 percent, at least about 99 percent, or substantially all of the carbon

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dioxide from the dehydrated carbon dioxide recycle stream 160. In addition, the purified carbon dioxide recycle stream 164 may comprise at least about 90 percent, at least about 95 percent, at least about 99 percent, or substantially all of the methane from the dehydrated carbon dioxide recycle stream 160. As such, the purified carbon dioxide recycle stream 164 may comprise at least about 65 percent, at least about 80 percent, at least about 90 percent, or at least about 95 percent carbon dioxide. In embodiments, the purified carbon dioxide recycle stream 164 may comprise no more than about 10 percent, no more than about 5 percent, no more than about 1 percent, or be substantially free of C_{3+}. Similarly, the purified carbon dioxide recycle stream 164 may comprise no more than about 20 percent, no more than about 10 percent, no more than about 5 percent, or be substantially free of C_{2+}.

The purified carbon dioxide recycle stream 164 may enter a compressor 112. The compressor 112 may comprise one or more compressors, such as the compressor 106 described above. In a specific embodiment, the compressor 112 is a turbine compressor. The compressor 112 may compress the purified carbon dioxide recycle stream 164, thereby producing a carbon dioxide injection stream 168. The carbon dioxide injection stream 168 may contain the same composition as the purified carbon dioxide recycle stream 164, but at a higher energy level. The additional energy in the carbon dioxide injection stream 168 may be obtained from energy added to the compressor 112, e.g., the electrical, mechanical, hydraulic, or pneumatic energy. In some embodiments, the difference in energy levels between the carbon dioxide injection stream 168 and the purified carbon dioxide recycle stream 164 is at least about 50 percent, at least about 65 percent, or at least about 80 percent of the energy added to the compressor 112.

In some embodiments, a makeup stream 166 may be combined with either the purified carbon dioxide recycle stream 164 or the carbon dioxide injection stream 168. Specifically, as the carbon dioxide reinjection process 100 is operated, carbon dioxide and other compounds will be lost, e.g., by replacing the hydrocarbons in the subterranean hydrocarbon formation 114, by leakage into inaccessible parts of the subterranean hydrocarbon formation 114, and/or to other causes. Alternatively, it may be desirable to increase the amount of carbon dioxide and other compounds injected downhole. As such, the makeup stream 166 may be combined with either the purified carbon dioxide recycle stream 164 and/or the carbon dioxide injection stream 168, for example in the compressor 112. Alternatively or additionally, the makeup stream 166 may

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be combined with the carbon dioxide recycle stream 156, the compressed carbon dioxide recycle stream 158, the dehydrated carbon dioxide recycle stream 160, or combinations thereof. The makeup stream 166 may comprise carbon dioxide, nitrogen, methane, ethane, air, water, or any other suitable compound. In an embodiment, the makeup stream 166 comprises at least 75 percent, at least 85 percent, or at least 95 percent carbon dioxide, nitrogen, methane, air, water, or combinations thereof. Finally, the carbon dioxide injection stream 168 may be sent to a carbon dioxide pipeline rather than being immediately injected downhole. In such a case, the carbon dioxide injection stream 168 may meet the carbon dioxide pipeline specifications. One example of a carbon dioxide pipeline specification is: at least about 95 percent carbon dioxide, substantially free of free water, no more than about 30 pounds of vapor-phase water per million cubic feet (mmcf) of product, no more than about 20 parts per million (ppm) by weight of hydrogen sulfide, no more than about 35 ppm by weight of total sulfur, a temperature of no more than about 120 °F, no more than about four percent nitrogen, no more than about five percent hydrocarbons (wherein the hydrocarbons do not have a dew point exceeding about -20 °F), no more than about 10 ppm by weight of oxygen, and more than about 0.3 gallons of glycol per mmcf of product (wherein the glycol is not in the liquid state at the pressure and temperature conditions of the pipeline).

FIG. 2 illustrates an embodiment of a NGL recovery process 200. The NGL recovery process 200 may recover some of the NGLs from a carbon dioxide recycle stream described above. For example, the NGL recovery process 200 may be implemented as part of the carbon dioxide reinjection process 100, e.g., by separating the dehydrated carbon dioxide recycle stream 160 into a NGL rich stream 162 and a purified carbon dioxide recycle stream 164. Alternatively, the NGL recovery process 200 may be implemented as a stand-alone process for recovering NGLs from a hydrocarbon containing stream.

The NGL recovery process 200 may begin by cooling the dehydrated carbon dioxide recycle stream 160 in a heat exchanger 202. The heat exchanger 202 may be any equipment suitable for heating or cooling one stream using another stream. Generally, the heat exchanger 202 is a relatively simple device that allows heat to be exchanged between two fluids without the fluids directly contacting each other. Examples of suitable heat exchangers 202 include shell and tube heat exchangers, double pipe heat exchangers, plate fin heat exchangers, bayonet heat

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exchangers, reboilers, condensers, evaporators, and air coolers. In the case of air coolers, one of the fluids comprises atmospheric air, which may be forced over tubes or coils using one or more fans. In a specific embodiment, the heat exchanger 202 is a shell and tube heat exchanger.

As shown in FIG. 2, the dehydrated carbon dioxide recycle stream 160 may be cooled using the cooled, purified carbon dioxide recycle stream 258. Specifically, the dehydrated carbon dioxide recycle stream 160 is cooled to produce the cooled carbon dioxide recycle stream 252, and the cooled, purified carbon dioxide recycle stream 258 is heated to produce the purified carbon dioxide recycle stream 164. The efficiency of the heat exchange process depends on several factors, including the heat exchanger design, the temperature, composition, and flowrate of the hot and cold streams, and/or the amount of thermal energy lost in the heat exchange process. In embodiments, the difference in energy levels between the dehydrated carbon dioxide recycle stream 160 and the cooled carbon dioxide recycle stream 252 is at least about 60 percent, at least about 70 percent, at least about 80, or at least about 90 percent of the difference in energy levels between the cooled, purified carbon dioxide recycle stream 258 and the purified carbon dioxide recycle stream 164.

The cooled carbon dioxide recycle stream 252 then enters a NGL stabilizer 204. The NGL stabilizer 204 may comprise a separator 206, a condenser 208, and a reboiler 210. The separator 206 may be similar to any of the separators described herein, such as separator 102. In a specific embodiment, the separator 206 is a distillation column. The condenser 208 may receive an overhead 254 from the separator 206 and produce the cooled, purified carbon dioxide recycle stream 258 and a reflux stream 256, which is returned to the separator 206. The condenser 208 may be similar to any of the heat exchangers described herein, such as heat exchanger 202. In a specific embodiment, the condenser 208 is a shell and tube, kettle type condenser coupled to a refrigeration process, and contains a reflux accumulator. As such, the condenser 208 may remove some energy 282 from the reflux stream 256 and cooled, purified carbon dioxide recycle stream 258, typically by refrigeration. The cooled, purified carbon dioxide recycle stream 258 is substantially similar in composition to the purified carbon dioxide recycle stream 164 described above. Similarly, the reboiler 210 may receive a bottoms stream 260 from the separator 206 and produce a sour NGL rich stream 264 and a boil-up stream 262, which is returned to the separator 206. The reboiler 210 may be like any of the heat exchangers described herein, such as heat

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exchanger 202. In a specific embodiment, the reboiler 210 is a shell and tube heat exchanger coupled to a hot oil heater. As such, the reboiler 210 adds some energy 284 to the boil-up stream 262 and the sour NGL rich stream 264, typically by heating. The sour NGL rich stream 264 may be substantially similar in composition to the NGL rich stream 162, with the exception that the sour NGL rich stream 264 has some additional acid gases, e.g., acid gases 270 described below.

The sour NGL rich stream 264 then may be cooled in another heat exchanger 212. The heat exchanger 212 may be like any of the heat exchangers described herein, such as heat exchanger 202. For example, the heat exchanger 212 may be an air cooler as described above. A cooled, sour NGL rich stream 266 may exit the heat exchanger 212 and enter a throttling valve 214. The throttling valve 214 may be an actual valve such as a gate valve, globe valve, angle valve, ball valve, butterfly valve, needle valve, or any other suitable valve, or may be a restriction in the piping such as an orifice or a pipe coil, bend, or size reduction. The throttling valve 214 may reduce the pressure, temperature, or both of the cooled, sour NGL rich stream 266 and produce a low-pressure sour NGL rich stream 268. The cooled, sour NGL rich stream 266 and the low-pressure sour NGL rich stream 268 have substantially the same composition as the sour NGL rich stream 264, albeit with lower energy levels.

The low-pressure sour NGL rich stream 268 then may be sweetened in a separator 216. The separator 216 may be similar to any of the separators described herein, such as separators 102 or 206. In an embodiment, the separator 216 may be one or more packed columns that use a sweetening process to remove acid gases from the low-pressure sour NGL rich stream 268. Suitable sweetening processes include amine solutions, physical solvents such as SELEXOL or RECTISOL, mixed amine solution and physical solvents, potassium carbonate solutions, direct oxidation, absorption, adsorption using, e.g., molecular sieves, or membrane filtration. The separator 216 may produce the NGL rich stream 162 described above. In addition, any acid gases 270 accumulated within or exiting from the separator 216 may be stored, used for other processes, or suitably disposed of. Finally, while FIGS. 1 and 2 are described in the context of carbon dioxide reinjection, it will be appreciated that the concepts described herein can be applied to other reinjection processes, for example those using nitrogen, air, or water.

FIG. 3 illustrates an embodiment of a chart 300 depicting the relationship between the NGL recovery rate and the energy expended to recover NGLs in the NGL recovery process. The

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NGL recovery rate may be a percentage recovery, and may represent the amount of C_{3+} in the carbon dioxide recycle stream that is recovered in the NGL rich stream. The energy requirement may be measured in joules (J) or in horsepower (hp), and may represent the energy required to generate the condenser energy and reboiler energy described above. If additional compressors are needed at any point in the carbon dioxide reinjection process than would be required in an otherwise similar carbon dioxide reinjection process that lacks the NGL recovery process, then the energy required to operate such compressors may be included in the energy requirement shown in FIG. 3.

As shown by curve 302, the energy requirements may increase about exponentially as the NGLs are recovered at higher rates. In other words, substantially higher energy may be required to recover the NGLs at incrementally higher rates. For example, recovering a first amount 304 of from about 20 percent to about 35 percent of C_{3+} may require substantially less energy than recovering a second amount 306 of from about 40 percent to about 65 percent of C_{3+}. Moreover, recovering the second amount 306 of from about 40 percent to about 65 percent of C_{3+} may require substantially less energy than recovering a third amount 308 of from about 70 percent to about 90 percent of C_{3+}. Such significant reduction in energy requirements may be advantageous in terms of process feasibility and cost, where relatively small decreases in NGL recovery rates may require significantly less energy and process equipment, yielding significantly better process economics. Although the exact relationship of the curve 302 may depend on numerous factors especially the price of C_{3+}, in an embodiment the economics of the NGL recovery process when the NGL recovery rate is in the second amount 306 may be better than the economics of the NGL recovery process when the NGL recovery rate is in the third amount 308. Similarly, the economics of the NGL recovery process when the NGL recovery rate is in the first amount 304 may be significantly better than the economics of the NGL recovery process when the NGL recovery rate is in the second amount 306. Such a relationship is counterintuitive considering that in many other processes, the process economics generally improve with increased recovery rates.

FIG. 4 illustrates an embodiment of a NGL upgrade process 500. The NGL upgrade process 500 may separate a portion of the heavier components of the NGL rich stream 162 for blending with the heavy hydrocarbon stream 154. For example, the NGL upgrade process 500

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may be used to produce a relatively heavy NGL stream 172 for combining with the heavy hydrocarbon stream 154 and a relatively light NGL stream 174 that may be sold and/or used as a NGL product. In general, the heavy hydrocarbon stream 154 may sell for a higher price than the NGL rich stream 162. By mixing at least a portion of the NGL rich stream 162 with the heavy hydrocarbon stream 154, the NGL upgrade process 500 may be used to improve the economics and/or revenue from the NGL recovery process. As a result, the NGL upgrade process 500 may be considered in the NGL recovery optimization method 400 described in more detail below.

The NGL upgrade process 500 may begin by passing the NGL rich stream 162 into an NGL upgrade unit 502. The NGL rich stream 162 may be in the liquid phase after passing through separator 216. The NGL upgrade unit 502 may comprise a separator 506, and a reboiler 510. While not illustrated in FIG. 4, some embodiments of the NGL upgrade unit 502 also may comprise a condenser. The separator 506 may be similar to any of the separators described herein, such as separator 102. In a specific embodiment, the separator 506 is a stripping column with a partial reboiler 510, and the separator 506 may not comprise a condenser. The downcoming liquid phase may be provided by the liquid NGL rich stream 162, which may be introduced at or near the top of the separator 506. In an embodiment, a condenser may be used to at least partially condense overhead stream 524 to produce at least a portion of the downcoming liquid in separator 506. For example, the condenser may be similar to any of the heat exchangers described herein, such as heat exchanger 202. The reboiler 510 may receive a bottoms stream 508 from the separator 506 and produce a heavy NGL stream 514 and a boil-up stream 512, which is returned to the separator 506 to provide the rising vapor phase within the separator 506. The reboiler 510 may be like any of the heat exchangers described herein, such as heat exchanger 202. In a specific embodiment, the reboiler 510 is a shell and tube heat exchanger coupled to a hot oil heater. As such, the reboiler 510 adds some energy 516 to the boil-up stream 512 and the heavy NGL stream 514, typically by heating. The heavy NGL stream 514 may be substantially similar in composition to the heavy NGL stream 172.

The heavy NGL stream 514 then may be cooled in a heat exchanger 518. The heat exchanger 518 may be any equipment suitable for heating or cooling one stream using another stream. Generally, the heat exchanger 518 is a relatively simple device that allows heat to be exchanged between two fluids without the fluids directly contacting each other (i.e., indirect heat

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exchange). In an embodiment, heat integration that comprises using one or more streams in the overall process to cool the heavy NGL stream 514, and thereby heating the one or more streams, may be used with heat exchanger 518. Examples of suitable heat exchangers 518 include shell and tube heat exchangers, double pipe heat exchangers, plate fin heat exchangers, bayonet heat exchangers, reboilers, condensers, evaporators, and air coolers. In the case of air coolers, one of the fluids comprise atmospheric air, which may be forced over tubes or coils using one or more fans. In a specific embodiment, the heat exchanger 518 is a shell and tube heat exchanger with the heavy NGL stream 514 passing on one side of the exchanger and a cooling fluid stream 522 passing on the other. The cooled, heavy NGL stream 172 may have substantially the same composition as the heavy NGL stream 514, albeit with lower energy levels.

The overhead stream 524 from separator 506 may comprise at least a portion of the lighter NGL components and may be cooled in another heat exchanger 526. The heat exchanger 526 may be like any of the heat exchangers described herein, such as heat exchanger 202. For example, the heat exchanger 526 may be an air cooler as described above. The cooled, light NGL stream 174 may have substantially the same composition as the overhead stream 524, albeit with lower energy levels.

As shown in FIG. 4, one or more additional NGL input streams 530, 532 may be introduced into the NGL upgrade process 500 upstream of the NGL upgrade unit 502. The additional NGL input streams 530, 532 may comprise NGL streams from any suitable source, such as one or more additional recovery plants. The NGL input streams 530, 532 may be transported to the NGL upgrade unit 502 by any suitable means. For example, the NGL input streams 530, 532 may be transported to the NGL upgrade unit 502 through a pipeline or by truck. The additional NGL input streams 530, 532 may contain one or more acid gases and/or other contaminants. Depending on their compositions, the additional NGL input streams 530, 532 may be introduced at various input locations in the NGL recovery process. For example, an input location may comprise a point upstream of the separator 216 for an NGL input stream 530 comprising acid gas components at or above a threshold level (e.g., a pipeline or storage threshold), thereby allowing for sweetening prior to being introduced to the downstream processes. As another example, an input location for an NGL input stream 532 that comprises acid gas components below the threshold level may comprise a point downstream of the separator

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216, thereby reducing the energy use of the overall recovery process. The use of one or more additional input streams may allow an NGL upgrade process 500 to upgrade the NGL streams from a plurality of NGL recovery processes. For example, multiple NGL recovery processes and/or additional sources of NGL rich streams may feed the NGL product to a NGL upgrade process, thereby reducing the need to install an NGL upgrade process at each source of an NGL stream.

In general, the NGL upgrade process may be used to separate a relatively heavy NGL stream 172 for blending with the heavy hydrocarbon stream 154. The composition and flowrate of the heavy NGL stream 172 may vary depending on the composition and flowrate of the heavy hydrocarbon stream 154. As discussed above, the heavy hydrocarbon stream 154 may be sent to a pipeline for transportation or a storage tank, where it is stored until being transported to another location or being further processed. Each of the downstream uses for the heavy hydrocarbon stream 154 may have one or more thresholds and/or standards that the heavy hydrocarbon stream 154 must meet in order to be transported or further processed. For example, pipelines may generally have standards setting thresholds for fluids passing through the pipeline, such as thresholds on vapor pressure (e.g., expressed as a Reid vapor pressure standard), carbon dioxide content, acid gas content (e.g., hydrogen sulfide content), and water content (e.g., a dew point standard). In an embodiment, the fluid transported in the pipeline may have a Reid vapor pressure of no more than about 20, no more than about 15, or no more than about 10. Accordingly, the composition and the flowrate of the heavy NGL stream 172 may be controlled so that the heavy hydrocarbon stream 154 may meet the transportation and/or further processing standards and/or threshold downstream of the mixing point between the heavy hydrocarbon stream 154 and the heavy NGL stream 172.

In an embodiment, the composition and/or flowrate of the heavy NGL stream 172 and the light NGL stream 174 may be controlled, at least in part, to allow the light NGL stream 174 to satisfy one or more transportation thresholds. The light NGL stream 174 may be transported using a variety of transportation means and/or methods including, but not limited to, a pipeline and a tanker truck. Each transportation method may have one or more thresholds that the light NGL stream 174 may need to satisfy prior to being accepted for transportation. For example, a pipeline may have a heating value standard of between about 1,000 British thermal units per cubic

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foot (Btu/ft^3) and about 1,200 Btu/ft^3, or alternatively between about 1,050 Btu/ft^3 and about 1,100 Btu/ft^3. In an embodiment, the light NGL stream 174 also may be subject to a dew point standard. As another example, tanker truck transportation may have a vapor pressure requirement that the light NGL stream 174 not exceed a vapor pressure of about 250 pounds per square inch gauge (psig) at a temperature of 100° F. Based on the applicable thresholds, the composition and the flowrate of the heavy NGL stream 172 and the light NGL stream 174 may be controlled so that the light NGL stream 174 may meet the transportation thresholds, allowing the light NGL stream 174 to be transported for further use.

FIG. 5 illustrates another embodiment of a carbon dioxide reinjection process 600. The process shown in FIG. 5 and the process of FIG. 1 are similar, and those portions with similar numbering are described in more detail with respect to FIG. 1 above. In the interest of brevity, only those portions that differ from FIG. 1 will be discussed with respect to FIG. 5.

As can be seen in FIG. 5, the dehydration of the compressed carbon dioxide recycle stream 158 may be integrated with the NGL recovery/dehydration process 610. The compressed carbon dioxide recycle stream 158 may enter a NGL recovery/dehydration process 610. In an embodiment, the NGL recovery/dehydration process 610 may comprise a separator 102 that produces multiple streams and allow one or more phases of the compressed carbon dioxide recycle stream 158 to be dehydrated without dehydrating the entirety of the compressed carbon dioxide recycle stream 158. This may allow for a reduction in the size of the dehydration unit and a reduction in the operating expense associated with the dehydrator. Further, the separate processing of the phases may allow the downstream processing units to receive each phase at a different location, which may further improve the process economics as described in more detail below with respect to FIG. 7.

The compressed carbon dioxide recycle stream 158 may enter the NGL recovery/dehydration process 610. The NGL recovery/dehydration process 610 may dehydrate, process, and separate the compressed carbon dioxide recycle stream 158 into a NGL rich stream 162 and a purified carbon dioxide recycle stream 164. The NGL rich stream 162 may only comprise a portion of the total NGLs from the dehydrated carbon dioxide recycle stream 160. A specific example of a suitable NGL recovery/dehydration process 610 is shown in FIG. 6 and described in further detail below.

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As mentioned above, the NGL recovery/dehydration process 610 may produce a relatively high-quality NGL rich stream 162. The NGL rich stream 162 may have about the same composition as the NGL rich stream 162 in FIG. 1. The NGL rich stream 162 may be sent to a pipeline for transportation or a storage tank, where it is stored until transported to another location or further processed. In an embodiment, the NGL rich stream optionally may be processed in an NGL upgrade process 170, as described in more detail above. The NGL upgrade process 170 may produce a relatively heavy NGL stream 172 that may be combined with the heavy hydrocarbon stream 154. When combined, the heavy NGL stream 172 and the heavy hydrocarbon stream 154 may meet or exceed the pipeline and/or transportation properties for a heavy hydrocarbon stream. A relatively light NGL stream 174 may be sent to a pipeline for transportation or a storage tank 104, where it may be stored until being transported to another location or being further processed. A specific example of a suitable NGL upgrade process 170 is shown in FIG. 4 and described in further detail above.

As mentioned above, the NGL recovery/dehydration process 610 may produce a purified carbon dioxide recycle stream 164. The purified carbon dioxide recycle stream 164 may have about the same composition as the purified carbon dioxide recycle stream 164 in FIG. 1. The purified carbon dioxide recycle stream 164 may enter a compressor 112. The compressor 112 may comprise one or more compressors, such as the compressor 106 described above. In some embodiments, a makeup stream 166 may be combined with either the purified carbon dioxide recycle stream 164 or the carbon dioxide injection stream 168. The resulting carbon dioxide injection stream 168 then may be injected into the subterranean hydrocarbon formation 114 or sent to a carbon dioxide pipeline.

FIG. 6 illustrates an embodiment of a NGL recovery/dehydration process 700. The NGL recovery/dehydration process 700 may dehydrate and recover some of the NGLs from a carbon dioxide recycle stream. For example, the NGL recovery/dehydration process 700 may be implemented as part of the carbon dioxide reinjection process 600, e.g., by separating the dehydrated carbon dioxide recycle stream 160 into a NGL rich stream 162 and a purified carbon dioxide recycle stream 164.

The NGL recovery process 700 may begin by cooling the compressed carbon dioxide recycle stream 158 in a heat exchanger 702. The heat exchanger 702 may be any equipment

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suitable for heating or cooling one stream using another stream. Generally, the heat exchanger 702 is a relatively simple device that allows heat to be exchanged between two fluids without the fluids directly contacting each other. Examples of suitable heat exchangers 702 include shell and tube heat exchangers, double pipe heat exchangers, plate fin heat exchangers, bayonet heat exchangers, reboilers, condensers, evaporators, and air coolers. In the case of air coolers, one of the fluids comprises atmospheric air, which may be forced over tubes or coils using one or more fans. In a specific embodiment, the heat exchanger 702 is a shell and tube heat exchanger.

As shown in FIG. 6, the compressed carbon dioxide recycle stream 158 may be cooled using the cooled, purified carbon dioxide recycle stream 758. Specifically, the compressed carbon dioxide recycle stream 158 is cooled to produce the cooled carbon dioxide recycle stream 752, and the cooled, purified carbon dioxide recycle stream 758 is heated to produce the purified carbon dioxide recycle stream 164. The efficiency of the heat exchange process depends on several factors, including the heat exchanger design, the temperature, composition, and flowrate of the hot and cold streams, and/or the amount of thermal energy lost in the heat exchange process. In embodiments, the difference in energy levels between the compressed carbon dioxide recycle stream 158 and the cooled carbon dioxide recycle stream 752 is at least about 60 percent, at least about 70 percent, at least about 80, or at least about 90 percent of the difference in energy levels between the cooled, purified carbon dioxide recycle stream 758 and the purified carbon dioxide recycle stream 164.

The cooled carbon dioxide recycle stream 752 then enters a separator 718. The separator 718 may be similar to any of the separators described herein, such as separator 102. In a specific embodiment, the separator 718 is a three phase separator, which is a vessel that separates an inlet stream into three distinct phases such as a substantially vapor stream, a substantially first liquid stream (e.g., an organic liquid phase), and a substantially second liquid stream (e.g., an aqueous liquid phase). The first liquid stream may primarily comprise hydrocarbons and the second liquid stream may primarily comprise an aqueous fluid so that the first and second liquid streams are at least partially insoluble in each other and form two separable liquid phases. A three-phase separator may have some internal baffles and/or weirs, temperature control elements, and/or pressure control elements, but generally lacks any trays or other type of complex internal structure commonly found in columns. In an embodiment, the separator 718 may separate the cooled

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carbon dioxide recycle stream 752 into a vapor recycle stream 724, a liquid recycle stream 728, and an aqueous fluid stream 732. The aqueous fluid stream 732 exiting from the dehydrator 722 may be stored, used for other processes, or discarded. The aqueous fluid stream 732 may first be treated to remove a portion of any hydrocarbons in the stream prior to storage, further use or process, or being discarded.

The vapor recycle stream 724 optionally may enter a dehydrator 720. The dehydrator 720 may remove some or substantially all of the water from the vapor recycle stream 724. The dehydrator 720 may be any suitable dehydrator, such as a condenser, an absorber, or an adsorber. Specific examples of suitable dehydrators 720 include refrigerators, molecular sieves, liquid desiccants such as glycol, solid desiccants such as silica gel or calcium chloride, and combinations thereof. The dehydrator 720 also may be any combination of the aforementioned dehydrators 720 and 722 arranged in series, in parallel, or combinations thereof. In a specific embodiment, the dehydrator 720 is a glycol unit. Any water accumulated within or exiting from the dehydrator 720 may be stored, used for other processes, or discarded.

The dehydrator 720 may produce a dehydrated vapor recycle stream 726. The dehydrated vapor recycle stream 726 may contain little water, e.g., liquid water or water vapor. In embodiments, the dehydrated vapor recycle stream 726 may comprise no more than about 5 percent, no more than about 3 percent, no more than about 1 percent, or be substantially free of water.

The liquid recycle stream 728 from the separator 718 optionally may enter a dehydrator 722. The dehydrator 722 may remove some or substantially all of the water from the liquid recycle stream 728. The dehydrator 722 may be any suitable dehydrator, such as a condenser, an absorber, or an adsorber. Suitable liquid-liquid separators such as hydro-cyclones and heater treaters also may be used. In an embodiment, the water in the liquid recycle stream 728 may be in the form of hydrates (e.g., clathrate hydrates) and/or an emulsion. Suitable separators utilizing physical solvents, chemical solvents, and or heat may be used to break the hydrates and/or emulsion and separate the water from the remaining liquid recycle stream 728 components. Specific examples of suitable dehydrators 722 include hydro-cyclones, heater treaters, molecular sieves, liquid desiccants such as glycol, solid desiccants such as silica gel or calcium chloride, and combinations thereof. The dehydrator 722 also may be any combination of the

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aforementioned dehydrators 722 arranged in series, in parallel, or combinations thereof. Any water accumulated within or exiting from the dehydrator 722 may be stored, used for other processes, or discarded.

The dehydrator 722 may produce a dehydrated liquid recycle stream 730. The dehydrated liquid recycle stream 730 may contain little water, e.g., liquid water or water vapor. In embodiments, the dehydrated liquid recycle stream 730 may comprise no more than about 5 percent, no more than about 3 percent, no more than about 1 percent, or be substantially free of water.

In an embodiment, only one of the dehydrators 720, 722 may be used. For example, any water contained in the cooled carbon dioxide recycle stream 752 may preferentially distribute to the vapor recycle stream 724 or the liquid recycle stream 728. By only using one separator 720, 722 on the stream containing the majority of the water, the dehydration requirements may be reduced, thereby reducing both the installation and operating costs associated with operating the dehydration system. In an embodiment in which only one dehydrator is used, the remaining stream may pass directly from the separator 718 to the separator 706. In an embodiment, both dehydrators 720, 722 may be used, and dehydrators 720, 722 may comprise different types of dehydrators. For example, dehydrator 720 may comprise a gas dehydration system while dehydrator 722 may comprise a unit designed to primarily perform a liquid-liquid phase separation. In an embodiment, both dehydrators 720, 722 may be used and the separator 718 may be used to perform a first stage separation of any free water, thereby reducing the dehydration requirements. In still another embodiment, neither dehydrator 720, 722 may be used and rather separator 718 may be sufficient for removing any free water and thereby dehydrating the cooled carbon dioxide recycle stream 752 along with performing a first stage flash of the cooled carbon dioxide recycle stream 752 to allow the stream to be introduced to the NGL fractionator 704 as separate streams. In yet another embodiment, the vapor recycle stream 724 and the liquid recycle stream 728 may be combined and passed to a single dehydrator.

The dehydrated vapor recycle stream 726 and the dehydrated liquid recycle stream 730 then may enter a NGL fractionator 704 as separate streams. In an embodiment, the dehydrated vapor recycle stream 726 and the dehydrated liquid recycle stream 730 may be fed to a separator 706 in the NGL fractionator 704 at separate input locations. The ability to feed the dehydrated

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vapor recycle stream 726 and the dehydrated liquid recycle stream 730 at separate locations in the separator 706 may aid in the separation of the various components into the overhead stream 754 and the bottoms stream 760. While the dehydrated vapor recycle stream 726 is illustrated as entering the separator 706 above the dehydrated liquid recycle stream 730, the dehydrated vapor recycle stream 726 may entering the separator 706 below the dehydrated liquid recycle stream 730, or enter at or near the same tray and/or location. In an embodiment, the dehydrated vapor recycle stream 726 and the dehydrated liquid recycle stream 730 may be combined prior to entering the NGL fractionator 704.

The NGL fractionator 704 may comprise a separator 706, a condenser 708, and a reboiler 710. The separator 706 may be similar to any of the separators described herein, such as separator 102. In a specific embodiment, the separator 706 is a distillation column. In an embodiment, dehydrated vapor recycle stream 726 may be introduced onto the tray and/or inlet location (e.g., when structured packing is used) with the closest matching vapor composition in the distillation column. Similarly, the dehydrated liquid recycle stream 730 may be introduced onto the tray and/or inlet location with the closest matching liquid composition. Actual compositional measurements and/or process models may be used to match the dehydrated vapor recycle stream 726 and the dehydrated liquid recycle stream 730 to the appropriate trays and/or inlet location in the distillation column.

The condenser 708 may receive an overhead stream 754 from the separator 706 and produce the cooled, purified carbon dioxide recycle stream 758 and a reflux stream 756, which is returned to the separator 706. The condenser 708 may be similar to any of the heat exchangers described herein, such as heat exchanger 702. In a specific embodiment, the condenser 708 is a shell and tube, kettle type condenser coupled to a refrigeration process, and contains a reflux accumulator. As such, the condenser 708 may remove some energy 782 from the reflux stream 756 and cooled, purified carbon dioxide recycle stream 758, typically by refrigeration. The cooled, purified carbon dioxide recycle stream 758 is substantially similar in composition to the purified carbon dioxide recycle stream 164 described above. Similarly, the reboiler 710 may receive a bottoms stream 760 from the separator 706 and produce a sour NGL rich stream 764 and a boil-up stream 762, which is returned to the separator 706. The reboiler 710 may be like any of the heat exchangers described herein, such as heat exchanger 702. In a specific

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embodiment, the reboiler 710 is a shell and tube heat exchanger coupled to a hot oil heater. As such, the reboiler 710 adds some energy 784 to the boil-up stream 762 and the sour NGL rich stream 764, typically by heating. The sour NGL rich stream 764 may be substantially similar in composition to the NGL rich stream 162, with the exception that the sour NGL rich stream 764 has some additional acid gases, e.g., acid gases 770 described below.

The sour NGL rich stream 764 then may be cooled in another heat exchanger 712. The heat exchanger 712 may be like any of the heat exchangers described herein, such as heat exchanger 702. For example, the heat exchanger 712 may be an air cooler as described above. A cooled, sour NGL rich stream 766 exits the heat exchanger 712 and enters a throttling valve 714. The throttling valve 714 may be an actual valve such as a gate valve, globe valve, angle valve, ball valve, butterfly valve, needle valve, or any other suitable valve, or may be a restriction in the piping such as an orifice or a pipe coil, bend, or size reduction. The throttling valve 714 may reduce the pressure, temperature, or both of the cooled, sour NGL rich stream 766 and produce a low-pressure sour NGL rich stream 768. The cooled, sour NGL rich stream 766 and the low-pressure sour NGL rich stream 768 have substantially the same composition as the sour NGL rich stream 764, albeit with lower energy levels.

The low-pressure sour NGL rich stream 768 then may be sweetened in a separator 716. The separator 716 may be similar to any of the separators described herein, such as separator 102. In an embodiment, the separator 716 may be one or more packed columns that use a sweetening process to remove acid gases 770 from the low-pressure sour NGL rich stream 768. Suitable sweetening processes include amine solutions, physical solvents such as SELEXOL or RECTISOL, mixed amine solution and physical solvents, potassium carbonate solutions, direct oxidation, absorption, adsorption using, e.g., molecular sieves, or membrane filtration. The separator 716 may produce the NGL rich stream 162 described above. In addition, any acid gases 770 accumulated within or exiting from the separator 716 may be stored, used for other processes, or suitably disposed of. Finally, while FIGS. 5 and 6 are described in the context of carbon dioxide recovery and/or reinjection, it will be appreciated that the concepts described herein can be applied to other recovery and/or reinjection processes, for example those using nitrogen, air, or water.

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As referenced above, FIG. 7 illustrates an embodiment of a NGL recovery optimization method 400. The NGL recovery optimization method 400 may be used to determine an improved or optimal project estimate for implementing the NGL recovery process and recovering NGLs at a suitable rate. As such, the NGL recovery process may be configured using appropriate equipment design based on the NGL recovery rate. Specifically, the NGL recovery optimization method 400 may design or configure the equipment size, quantity, or both based on an initial NGL recovery rate and required energy, and hence estimate the project feasibility and cost. The method 400 may upgrade or improve the project estimate by iteratively incrementing the initial NGL recovery rate, re-estimating the project, and comparing the two estimates.

At block 402, the method 400 may select an initial NGL recovery rate. The initial NGL recovery rate may be relatively small, such as no more than about 20 percent recovery, no more than about 10 percent recovery, no more than about 5 percent recovery, or no more than about 1 percent recovery. Choosing the initial NGL recovery rate at a small percentage of the total NGL amount may result in a relatively low project estimate that may be increased gradually to reach improved estimates.

The method 400 then may proceed to block 404, where the project equipment size may be determined based on the initial NGL recovery rate. Specifically, the size of the equipment described in the NGL recovery process and any additional compressors as described above may be determined. In addition, the pressure and temperature ratings and material compositions of such equipment may be determined at block 404, if desired.

The method 400 then may proceed to block 406, where the project may be estimated. Project estimation may comprise an economic evaluation of the NGL recovery process, and may include the cost of obtaining, fabricating, and/or field constructing the equipment sized in block 404. In addition, project estimation may include the cost of operating and maintaining the NGL process, as well as the revenue generated by the sale or use of the products obtained by implementing the NGL process. As such, the project estimate may comprise the total project benefits (including production, sales, etc.) minus the total project capital and operating costs (including cost, equipment, etc.). In some embodiments, the project estimate may be based on an existing carbon dioxide reinjection plant that lacks the NGL recovery process.

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The method 400 then may proceed to block 408, where the recovery rate is incremented. The NGL recovery rate may be incremented by a relatively small percentage, for example no more than about 10 percent, not more than about 5 percent, or no more than about 1 percent. The method 400 then may proceed to block 410, which is substantially similar to block 404. The method 400 then may proceed to block 412, which is substantially similar to block 406.

The method 400 then may proceed to block 414, where the method 400 may determine whether the project estimate has improved. For instance, the method 400 may compare the project estimate from block 412 with the previous project estimate (either block 406 or the previous iteration of block 412) and determine whether the revised estimate is more economically desirable. The method 400 may return to block 408 when the condition at block 414 is met. Otherwise, the method 400 may proceed to block 416.

At block 416, the method 400 may choose the previous project estimate as the final estimate. For example, the method 400 may select the previous NGL recovery rate (either block 406 or the previous iteration of block 412) instead of the estimate obtained at block 412. In some embodiments, the desired or optimum recovery rate selected at block 416 may represent a range of desirable or optimum points, as opposed to a single point. Accordingly, the method 400 may select the equipment sizing corresponding to the selected NGL recovery rate. The selected project estimate and sizing then may be used for the NGL recovery process. Of course, it will be appreciated that the method 400 may be revised to include a decremented, top-down estimation approach as opposed to an incremented, bottom-up estimation approach.

The method 400 may have several advantages over other project estimation methods. For example, process equipment of a specific size may be selected, and the corresponding recovery rate determined. Alternatively, a required recovery rate may be selected, and the equipment sized to achieve the recovery rate. However, it has been discovered that such approaches are inflexible and often yields suboptimal process economics. For example, relatively high NGL recovery rates will not lead to an improvement in process economics, e.g., because of the exponential increase in energy consumption. In contrast, the method 400 provides a flexible approach to determining a desirable or optimal project estimate.

In an embodiment, the equipment size may be configured to allow for variations in recovery rates to accommodate changes in economic conditions, such as C_{3+} or energy pricing.

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Specifically, the equipment described herein can be sized above or below the desired or optimum amount to allow the processes described herein to operate at recovery rates slightly greater than or slightly less than the desirable or optimum point obtained in method 400. As the process parameters and the energy requirements may be closely related, the ability of the process to continue to successfully operate under differing conditions may be reflected by constrained changes in the energy requirements of the process. When operating in the first amount 304 or the second amount 306 on the curve 302 in FIG. 3, significant increases or decreases in NGL recovery rate may be obtained with little change in the energy requirements. Such is not the case when operating in the third amount 308 on the curve 302 in FIG. 3, where significant increases or decreases in energy requirements yield only incremental changes in NGL recovery rate.

EXAMPLE 1

In one example, a process simulation was performed using the NGL recovery process 200 shown in FIG. 2. The simulation was performed using the Hyprotech Ltd. HYSYS Process v2.1.1 (Build 3198) software package. The NGL recovery process 200 separated the dehydrated carbon dioxide recycle stream 160 into the purified carbon dioxide recycle stream 164, the NGL rich stream 162, and the acid gas stream 270. The specified values are indicated by an asterisk (*). The physical properties are provided in degrees Fahrenheit (F), psig, million standard cubic feet per day (MMSCFD), pounds per hour (lb/hr), U.S. gallons per minute (USGPM), and British thermal units per hour (Btu/hr). The material streams, their compositions, and the associated energy streams produced by the simulation are provided in tables 1, 2, and 3 below, respectively.

Name	**Dehydrated CO_2 Recycle Stream 160**	**Cooled CO_2 Recycle Stream 252**	**Cooled, Purified CO_2 Recycle Stream 258**
Vapor Fraction	0.9838	0.9392	1.0000
Temperature (F)	104.0*	45.00*	4.011
Pressure (psig)	340.0*	335.0	330.0
Molar Flow (MMSCFD)	17.00*	17.00	15.88
Mass Flow (lb/hr)	8.049e+04	8.049e+04	7.254e+04

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Name	Dehydrated CO_2 Recycle Stream 160	Cooled CO_2 Recycle Stream 252	Cooled, Purified CO_2 Recycle Stream 258
Liquid Volume Flow (USGPM)	218.1	218.1	192.3
Heat Flow (Btu/hr)	-2.639e+08	-2.658e+08	-2.577e+08

Table 1A: Material Streams

Name	Purified CO_2 Recycle Stream 164	Sour NGL Rich Stream 264	Cooled Sour NGL Rich Stream 266
Vapor Fraction	1.0000	0.00000	0.0000
Temperature (F)	97.39	202.6	120.0*
Pressure (psig)	325.0	340.0	635.3*
Molar Flow (MMSCFD)	15.88	1.119	1.119
Mass Flow (lb/hr)	7.254e+04	7947	7947
Liquid Volume Flow (USGPM)	192.3	25.84	25.84
Heat Flow (Btu/hr)	-2.558e+08	-8.443e+06	-8.862e+06

Table 1B: Material Streams

Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162
Vapor Fraction	0.0000	1.0000	0.0000
Temperature (F)	120.9	100.0*	111.8

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Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162
Pressure (psig)	200.3*	5.304*	185.3*
Molar Flow (MMSCFD)	1.119	0.1030	1.016
Mass Flow (lb/hr)	7947	446.4	7501
Liquid Volume Flow (USGPM)	25.84	1.100	24.74
Heat Flow (Btu/hr)	-8.862e+06	-1.083e+06	-7.779e+06

Table 1C: Material Streams

Name	Dehydrated CO_2 Recycle Stream 160	Cooled CO_2 Recycle Stream 252	Cooled, Purified CO_2 Recycle Stream 258
Comp Mole Frac (H_2S)	0.0333*	0.0333	0.0327
Comp Mole Frac (Nitrogen)	0.0054*	0.0054	0.0058
Comp Mole Frac (CO_2)	0.7842*	0.7842	0.8359
Comp Mole Frac (Methane)	0.0521*	0.0521	0.0558
Comp Mole Frac (Ethane)	0.0343*	0.0343	0.0348
Comp Mole Frac (Propane)	0.0406*	0.0406	0.0313
Comp Mole Frac (i-Butane)	0.0072*	0.0072	0.0022
Comp Mole Frac (n-Butane)	0.0171*	0.0171	0.0015
Comp Mole Frac (i-Pentane)	0.0058*	0.0058	0.0000
Comp Mole Frac (n-Pentane)	0.0057*	0.0057	0.0000
Comp Mole Frac (n-Hexane)	0.0070*	0.0070	0.0000
Comp Mole Frac (n-Octane)	0.0071*	0.0071	0.0000
Comp Mole Frac (H_2O)	0.0000*	0.0000	0.0000

Table 2A: Stream Compositions

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Name	Purified CO_2 Recycle Stream 164	Sour NGL Rich Stream 264	Cooled Sour NGL Rich Stream 266
Comp Mole Frac (H_2S)	0.0327	0.0421	0.0421
Comp Mole Frac (Nitrogen)	0.0058	0.0000	0.0000
Comp Mole Frac (CO_2)	0.8359	0.0500	0.0500
Comp Mole Frac (Methane)	0.0558	0.0000	0.0000
Comp Mole Frac (Ethane)	0.0348	0.0281	0.0281
Comp Mole Frac (Propane)	0.0313	0.1728	0.1728
Comp Mole Frac (i-Butane)	0.0022	0.0789	0.0789
Comp Mole Frac (n-Butane)	0.0015	0.2388	0.2388
Comp Mole Frac (i-Pentane)	0.0000	0.0887	0.0887
Comp Mole Frac (n-Pentane)	0.0000	0.0866	0.0866
Comp Mole Frac (n-Hexane)	0.0000	0.1063	0.1063
Comp Mole Frac (n-Octane)	0.0000	0.1077	0.1077
Comp Mole Frac (H_2O)	0.0000	0.0000	0.0000

Table 2B: Stream Compositions

Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162
Comp Mole Frac (H_2S)	0.0421	0.4568	0.0000
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000
Comp Mole Frac (CO_2)	0.0500	0.5432	0.0000
Comp Mole Frac (Methane)	0.0000	0.0000	0.0000
Comp Mole Frac (Ethane)	0.0281	0.0000	0.0309

Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162
Comp Mole Frac (Propane)	0.1728	0.0000	0.1903
Comp Mole Frac (i-Butane)	0.0789	0.0000	0.0869
Comp Mole Frac (n-Butane)	0.2388	0.0000	0.2630
Comp Mole Frac (i-Pentane)	0.0887	0.0000	0.0977
Comp Mole Frac (n-Pentane)	0.0866	0.0000	0.0954
Comp Mole Frac (n-Hexane)	0.1063	0.0000	0.1171
Comp Mole Frac (n-Octane)	0.1077	0.0000	0.1186
Comp Mole Frac (H_2O)	0.0000	0.0000	0.0000

Table 2C: Stream Compositions

Name	Heat Flow (Btu/hr)
Condenser Q Energy Stream 282	1.469e+06
Reboiler Q Energy Stream 284	1.152e+06

Table 3: Energy Streams

EXAMPLE 2

In another example, the process simulation was repeated using a different dehydrated carbon dioxide recycle stream 160. The material streams, their compositions, and the associated energy streams produced by the simulation are provided in tables 4, 5, and 6 below, respectively.

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Name	Dehydrated CO_2 Recycle Stream 160	Cooled CO_2 Recycle Stream 252	Cooled, Purified CO_2 Recycle Stream 258
Vapor Fraction	0.9874	0.9286	1.0000
Temperature (F)	104.0*	60.00*	22.77
Pressure (psig)	685.3*	680.3	590.0
Molar Flow (MMSCFD)	20.00*	20.00	18.86
Mass Flow (lb/hr)	8.535e+04	8.535e+04	7.780e+04
Liquid Volume Flow (USGPM)	258.0	258.0	232.2
Heat Flow (Btu/hr)	-2.741e+08	-2.760e+08	-2.683e+08

Table 4A: Material Streams

Name	Purified CO_2 Recycle Stream 164	Sour NGL Rich Stream 264	Cooled Sour NGL Rich Stream 266
Vapor Fraction	1.0000	0.00000	0.0000
Temperature (F)	87.48	290.7	120.0*
Pressure (psig)	585.0	600.0	635.3*
Molar Flow (MMSCFD)	18.86	1.139	1.139
Mass Flow (lb/hr)	7.780e+04	7552	7552
Liquid Volume Flow (USGPM)	232.2	25.83	25.83
Heat Flow (Btu/hr)	-2.663e+08	-7.411e+06	-8.371e+06

Table 4B: Material Streams

Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162

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Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162
Vapor Fraction	0.0000	1.0000	0.0000
Temperature (F)	120.5	100.0*	118.6
Pressure (psig)	200.3*	5.304*	185.3*
Molar Flow (MMSCFD)	1.139	0.02943	1.110
Mass Flow (lb/hr)	7552	141.2	7411
Liquid Volume Flow (USGPM)	25.83	0.3421	25.49
Heat Flow (Btu/hr)	-8.371e+06	-5.301e+05	-7.841e+06

Table 4C: Material Streams

Name	Dehydrated CO_2 Recycle Stream 160	Cooled CO_2 Recycle Stream 252	Cooled, Purified CO_2 Recycle Stream 258
Comp Mole Frac (H_2S)	0.0004*	0.0004	0.0004
Comp Mole Frac (Nitrogen)	0.0153*	0.0153	0.0162
Comp Mole Frac (CO_2)	0.6592*	0.6592	0.6975
Comp Mole Frac (Methane)	0.1813*	0.1813	0.1922
Comp Mole Frac (Ethane)	0.0620*	0.0620	0.0620
Comp Mole Frac (Propane)	0.0411*	0.0411	0.0275
Comp Mole Frac (i-Butane)	0.0064*	0.0064	0.0017
Comp Mole Frac (n-Butane)	0.0179*	0.0179	0.0024
Comp Mole Frac (i-Pentane)	0.0040*	0.0040	0.0000
Comp Mole Frac (n-Pentane)	0.0049*	0.0049	0.0000
Comp Mole Frac (n-Hexane)	0.0030*	0.0030	0.0000
Comp Mole Frac (n-Octane)	0.0045*	0.0045	0.0000

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Name	Dehydrated CO_2 Recycle Stream 160	Cooled CO_2 Recycle Stream 252	Cooled, Purified CO_2 Recycle Stream 258
Comp Mole Frac (H_2O)	0.0000*	0.0000	0.0000

Table 5A: Stream Compositions

Name	Purified CO_2 Recycle Stream 164	Sour NGL Rich Stream 264	Cooled Sour NGL Rich Stream 266
Comp Mole Frac (H_2S)	0.0004	0.0008	0.0008
Comp Mole Frac (Nitrogen)	0.0162	0.0000	0.0000
Comp Mole Frac (CO_2)	0.6975	0.0250	0.0250
Comp Mole Frac (Methane)	0.1922	0.0000	0.0000
Comp Mole Frac (Ethane)	0.0620	0.0613	0.0613
Comp Mole Frac (Propane)	0.0275	0.2670	0.2670
Comp Mole Frac (i-Butane)	0.0017	0.0836	0.0836
Comp Mole Frac (n-Butane)	0.0024	0.2751	0.2751
Comp Mole Frac (i-Pentane)	0.0000	0.0697	0.0697
Comp Mole Frac (n-Pentane)	0.0000	0.0858	0.0858
Comp Mole Frac (n-Hexane)	0.0000	0.0527	0.0527
Comp Mole Frac (n-Octane)	0.0000	0.0790	0.0790
Comp Mole Frac (H_2O)	0.0000	0.0000	0.0000

Table 5B: Stream Compositions

Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162
Comp Mole Frac (H_2S)	0.0008	0.0315	0.0000
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000
Comp Mole Frac (CO_2)	0.0250	0.9685	0.0000
Comp Mole Frac (Methane)	0.0000	0.0000	0.0000
Comp Mole Frac (Ethane)	0.0613	0.0000	0.0629
Comp Mole Frac (Propane)	0.2670	0.0000	0.2740
Comp Mole Frac (i-Butane)	0.0836	0.0000	0.0858
Comp Mole Frac (n-Butane)	0.2751	0.0000	0.2824
Comp Mole Frac (i-Pentane)	0.0697	0.0000	0.0716
Comp Mole Frac (n-Pentane)	0.0858	0.0000	0.0881
Comp Mole Frac (n-Hexane)	0.0527	0.0000	0.0541
Comp Mole Frac (n-Octane)	0.0790	0.0000	0.0811
Comp Mole Frac (H_2O)	0.0000	0.0000	0.0000

Table 5C: Stream Compositions

Name	Heat Flow (Btu/hr)
Condenser Q Energy Stream 282	1.884e+06
Reboiler Q Energy Stream 284	2.211e+06

Table 6: Energy Streams

EXAMPLE 3

In a third example, the process simulation was repeated using a different dehydrated carbon dioxide recycle stream 160. The material streams, their compositions, and the associated energy streams produced by the simulation are provided in tables 7, 8, and 9 below, respectively.

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Name	Dehydrated CO_2 Recycle Stream 160	Cooled CO_2 Recycle Stream 252	Cooled, Purified CO_2 Recycle Stream 258
Vapor Fraction	1.0000	0.9988	1.0000
Temperature (F)	104.0*	30.00*	4.617
Pressure (psig)	340.0*	335.0	330.0
Molar Flow (MMSCFD)	17.00*	17.00	16.82
Mass Flow (lb/hr)	8.083e+04	8.083e+04	7.968e+04
Liquid Volume Flow (USGPM)	203.4	203.4	199.5
Heat Flow (Btu/hr)	-3.016e+08	-3.032e+08	-3.025e+08

Table 7A: Material Streams

Name	Purified CO_2 Recycle Stream 164	Sour NGL Rich Stream 264	Cooled Sour NGL Rich Stream 266
Vapor Fraction	1.0000	0.00000	0.0000
Temperature (F)	76.45	199.4	120.0*
Pressure (psig)	325.0	340.0	635.3*
Molar Flow (MMSCFD)	16.82	0.1763	0.1763
Mass Flow (lb/hr)	7.968e+04	1153	1153
Liquid Volume Flow (USGPM)	199.5	3.894	3.894
Heat Flow (Btu/hr)	-3.009e+08	-1.278e+06	-1.340e+06

Table 7B: Material Streams

Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162

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Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162
Vapor Fraction	0.0000	1.0000	0.0000
Temperature (F)	120.4	100.0*	115.4
Pressure (psig)	200.3*	5.304*	185.3*
Molar Flow (MMSCFD)	0.1763	0.01048	0.1659
Mass Flow (lb/hr)	1153	48.82	1105
Liquid Volume Flow (USGPM)	3.894	0.1188	3.776
Heat Flow (Btu/hr)	-1.340e+06	-1.653e+05	-1.175e+06

Table 7C: Material Streams

Name	Dehydrated CO_2 Recycle Stream 160	Cooled CO_2 Recycle Stream 252	Cooled, Purified CO_2 Recycle Stream 258
Comp Mole Frac (H_2S)	0.0031*	0.0031	0.0030
Comp Mole Frac (Nitrogen)	0.0008*	0.0008	0.0008
Comp Mole Frac (CO_2)	0.9400*	0.9400	0.9493
Comp Mole Frac (Methane)	0.0219*	0.0219	0.0222
Comp Mole Frac (Ethane)	0.0156*	0.0156	0.0157
Comp Mole Frac (Propane)	0.0116*	0.0116	0.0088
Comp Mole Frac (i-Butane)	0.0015*	0.0015	0.0002
Comp Mole Frac (n-Butane)	0.0031*	0.0031	0.0001
Comp Mole Frac (i-Pentane)	0.0007*	0.0007	0.0000
Comp Mole Frac (n-Pentane)	0.0006*	0.0006	0.0000
Comp Mole Frac (n-Hexane)	0.0005*	0.0005	0.0000
Comp Mole Frac (n-Octane)	0.0006*	0.0006	0.0000

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Name	Dehydrated CO_2 Recycle Stream 160	Cooled CO_2 Recycle Stream 252	Cooled, Purified CO_2 Recycle Stream 258
Comp Mole Frac (H_2O)	0.0000*	0.0000	0.0000

Table 8A: Stream Compositions

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Name	Purified CO_2 Recycle Stream 164	Sour NGL Rich Stream 264	Cooled Sour NGL Rich Stream 266
Comp Mole Frac (H_2S)	0.0030	0.0094	0.0094
Comp Mole Frac (Nitrogen)	0.0008	0.0000	0.0000
Comp Mole Frac (CO_2)	0.9493	0.0500	0.0500
Comp Mole Frac (Methane)	0.0222	0.0000	0.0000
Comp Mole Frac (Ethane)	0.0157	0.0000	0.0000
Comp Mole Frac (Propane)	0.0088	0.2794	0.2794
Comp Mole Frac (i-Butane)	0.0002	0.1265	0.1265
Comp Mole Frac (n-Butane)	0.0001	0.2985	0.2985
Comp Mole Frac (i-Pentane)	0.0000	0.0713	0.0713
Comp Mole Frac (n-Pentane)	0.0000	0.0617	0.0617
Comp Mole Frac (n-Hexane)	0.0000	0.0482	0.0482
Comp Mole Frac (n-Octane)	0.0000	0.0550	0.0550
Comp Mole Frac (H_2O)	0.0000	0.0000	0.0000

Table 8B: Stream Compositions

Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162
Comp Mole Frac (H_2S)	0.0094	0.1584	0.0000
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000
Comp Mole Frac (CO_2)	0.0500	0.8416	0.0000
Comp Mole Frac (Methane)	0.0000	0.0000	0.0000
Comp Mole Frac (Ethane)	0.0000	0.0000	0.0000
Comp Mole Frac (Propane)	0.2794	0.0000	0.2970
Comp Mole Frac (i-Butane)	0.1265	0.0000	0.1345

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Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162
Comp Mole Frac (n-Butane)	0.2985	0.0000	0.3174
Comp Mole Frac (i-Pentane)	0.0713	0.0000	0.0758
Comp Mole Frac (n-Pentane)	0.0617	0.0000	0.0656
Comp Mole Frac (n-Hexane)	0.0482	0.0000	0.0512
Comp Mole Frac (n-Octane)	0.0550	0.0000	0.0584
Comp Mole Frac (H_2O)	0.0000	0.0000	0.0000

Table 8C: Stream Compositions

Name	Heat Flow (Btu/hr)
Condenser Q Energy Stream 282	6.236e+06
Reboiler Q Energy Stream 284	5.666e+06

Table 9: Energy Streams

EXAMPLE 4

In a fourth example, a process simulation was performed using the NGL recovery/dehydration process 700 shown in FIG. 6. The simulation was performed using the Bryan Research and Engineering ProMax software package. The NGL recovery/dehydration process 700 separated the compressed carbon dioxide recycle stream 158 into the purified carbon dioxide recycle stream 164, the NGL rich stream 162, and the acid gas stream 770. The specified values are indicated by an asterisk (*). The material streams, their compositions, and the associated energy streams produced by the simulation are provided in tables 10, 11, and 12 below, respectively.

Name	Compressed Carbon Dioxide Recycle Stream 158	Cooled Carbon Dioxide Recycle Stream 752	Purified Carbon Dioxide Recycle Stream 164
Temperature (°F)	110	55	72.0898
Pressure (psig)	535	532	526.909
Mole Fraction Vapor (%)	100	97.1149	100
Mole Fraction Light Liquid (%)	0	2.63789	0
Mole Fraction Heavy Liquid (%)	0	0.247192	0
Molecular Weight (lb/lbmol)	34.5734	34.5734	33.2372
Molar Flow (lbmol/hr)	143.165	143.165	136.153
Vapor Volumetric Flow (ft^3/hr)	1369.35	1144.29	1217.29
Liquid Volumetric Flow (gpm)	170.725	142.665	151.766
Std Vapor Volumetric Flow (MMSCFD)	1.30389	1.30389	1.24003
Std Liquid Volumetric Flow (sgpm)	16.1721	16.1721	14.7954
Enthalpy (Btu/hr)	-1.54233E+07	-1.55479E+07	-1.49692E+07
Net Ideal Gas Heating Value (Btu/ft^3)	512.476	512.476	391.24

Table 10A: Material Streams

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Name	Cooled, Purified Carbon Dioxide Recycle Stream 758	Dehydrated Vapor Recycle Stream 726	NGL Rich Stream 162
Temperature (°F)	-4.70484	54.9077	121.117
Pressure (psig)	529.909	531	438.3
Mole Fraction Vapor (%)	100	99.9993	0
Mole Fraction Light Liquid (%)	0	0.000671338	100
Mole Fraction Heavy Liquid (%)	0	0	0
Molecular Weight (lb/lbmol)	33.2372	33.941	65.1996
Molar Flow (lbmol/hr)	136.153	138.957	5.97957
Vapor Volumetric Flow (ft^3/hr)	880.68	1140.73	10.8305
Liquid Volumetric Flow (gpm)	109.799	142.221	1.35029
Std Vapor Volumetric Flow (MMSCFD)	1.24003	1.26557	0.0544597
Std Liquid Volumetric Flow (sgpm)	14.7954	15.4591	1.2954
Enthalpy (Btu/hr)	-1.50938E+07	-1.51048E+07	-405001
Net Ideal Gas Heating Value (Btu/ft^3)	391.24	463.982	3359.57

Table 10B: Material Streams

Name	Aqueous Fluid Stream 732	Sour NGL Rich Stream 764	Cooled, Sour NGL Rich Stream 766
Temperature (°F)	54.9077	262.193	120

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Name	Aqueous Fluid Stream 732	Sour NGL Rich Stream 764	Cooled, Sour NGL Rich Stream 766
Pressure (psig)	531	531.909	521.909
Mole Fraction Vapor (%)	0	0	0
Mole Fraction Light Liquid (%)	100	100	100
Mole Fraction Heavy Liquid (%)	0	0	0
Molecular Weight (lb/lbmol)	18.2988	63.2785	63.2785
Molar Flow (lbmol/hr)	0.354052	6.58207	6.58207
Vapor Volumetric Flow (ft^3/hr)	0.103218	14.3659	11.2331
Liquid Volumetric Flow (gpm)	0.0128688	1.79107	1.40049
Std Vapor Volumetric Flow (MMSCFD)	0.00322458	0.0599471	0.0599471
Std Liquid Volumetric Flow (sgpm)	0.013039	1.36091	1.36091
Enthalpy (Btu/hr)	-43829.7	-468892	-508612
Net Ideal Gas Heating Value (Btu/ft^3)	0.450311	3053.71	3053.71

Table 10C: Material Streams

Name	Low-Pressure Sour NGL Rich Stream 768	Acid Gases 770
Temperature (°F)	120.145	120
Pressure (psig)	441.3	12.3041
Mole Fraction Vapor (%)	0	100
Mole Fraction Light Liquid (%)	100	0
Mole Fraction Heavy Liquid (%)	0	0
Molecular Weight (lb/lbmol)	63.2785	42.366

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Name	Low-Pressure Sour NGL Rich Stream 768	Acid Gases 770
Molar Flow (lbmol/hr)	6.58207	0.645859
Vapor Volumetric Flow (ft^3/hr)	11.2586	147.542
Liquid Volumetric Flow (gpm)	1.40367	18.3949
Std Vapor Volumetric Flow (MMSCFD)	0.0599471	0.00588224
Std Liquid Volumetric Flow (sgpm)	1.36091	0.0667719
Enthalpy (Btu/hr)	-508612	-106053
Net Ideal Gas Heating Value (Btu/ft^3)	3053.71	9.39946

Table 10D: Material Streams

Name	Compressed Carbon Dioxide Recycle Stream 158	Cooled Carbon Dioxide Recycle Stream 752	Purified Carbon Dioxide Recycle Stream 164
Comp Molar Flow H_2S (lb_{mol}/hr)	0	0	0
Comp Molar Flow Nitrogen (lb_{mol}/hr)	5.42488	5.42488	5.42487
Comp Molar Flow CO_2 (lb_{mol}/hr)	78.374	78.374	77.7679
Comp Molar Flow Methane (lb_{mol}/hr)	46.8833	46.8833	46.8831
Comp Molar Flow Ethane (lb_{mol}/hr)	5.04264	5.04264	4.97376
Comp Molar Flow Propane (lb_{mol}/hr)	2.60218	2.60218	1.06689
Comp Molar Flow i-Butane	0.632167	0.632167	0.0262049

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Name	Compressed Carbon Dioxide Recycle Stream 158	Cooled Carbon Dioxide Recycle Stream 752	Purified Carbon Dioxide Recycle Stream 164
(lb_{mol}/hr)			
Comp Molar Flow n-Butane (lb_{mol}/hr)	1.01441	1.01441	0.0106494
Comp Molar Flow i-Pentane (lb_{mol}/hr)	0.543958	0.543958	2.47836E-05
Comp Molar Flow n-Pentane (lb_{mol}/hr)	0.27933	0.27933	6.5645E-06
Comp Molar Flow n-Hexane (lb_{mol}/hr)	1.94061	1.94061	6.8325E-08
Comp Molar Flow n-Heptane (lb_{mol}/hr)	0	0	0
Comp Molar Flow H_2O (lb_{mol}/hr)	0.427428	0.427428	1.88221E-05
Comp Molar Flow Diethyle Amine (lb_{mol}/hr)	0	0	0

Table 11A: Stream Compositions

Name	Cooled, Purified Carbon Dioxide Recycle Stream 758	Dehydrated Vapor Recycle Stream 726	NGL Rich Stream 162
Comp Molar Flow H_2S (lb_{mol}/hr)	0	0	0
Comp Molar Flow Nitrogen	5.42487	5.41324	5.81573E-09

Name	Cooled, Purified Carbon Dioxide Recycle Stream 758	Dehydrated Vapor Recycle Stream 726	NGL Rich Stream 162
(lb_{mol}/hr)			
Comp Molar Flow CO_2 (lb_{mol}/hr)	77.7679	77.1797	1.75658E-06
Comp Molar Flow Methane (lb_{mol}/hr)	46.8831	46.6143	2.21379E-05
Comp Molar Flow Ethane (lb_{mol}/hr)	4.97376	4.89657	0.068452
Comp Molar Flow Propane (lb_{mol}/hr)	1.06689	2.39516	1.53245
Comp Molar Flow i-Butane (lb_{mol}/hr)	0.0262049	0.529946	0.605608
Comp Molar Flow n-Butane (lb_{mol}/hr)	0.0106494	0.799268	1.00312
Comp Molar Flow i-Pentane (lb_{mol}/hr)	2.47836E-05	0.345064	0.543843
Comp Molar Flow n-Pentane (lb_{mol}/hr)	6.5645E-06	0.161123	0.279274
Comp Molar Flow n-Hexane (lb_{mol}/hr)	6.8325E-08	0.622204	1.9405
Comp Molar Flow n-Heptane (lb_{mol}/hr)	0	0	0
Comp Molar Flow H_2O (lb_{mol}/hr)	1.88221E-05	0.000761257	0.0062375
Comp Molar Flow Diethyle Amine (lb_{mol}/hr)	0	0	7.30571E-05

Table 11B: Stream Compositions

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Name	Aqueous Fluid Stream 732	Sour NGL Rich Stream 764	Cooled, Sour NGL Rich Stream 766
Comp Molar Flow H_2S (lb_{mol}/hr)	0	0	0
Comp Molar Flow Nitrogen (lb_{mol}/hr)	7.93825E-06	5.94147E-09	5.94147E-09
Comp Molar Flow CO_2 (lb_{mol}/hr)	0.00385078	0.602328	0.602328
Comp Molar Flow Methane (lb_{mol}/hr)	0.000125243	2.25954E-05	2.25954E-05
Comp Molar Flow Ethane (lb_{mol}/hr)	1.31496E-05	0.0688655	0.0688655
Comp Molar Flow Propane (lb_{mol}/hr)	6.92895E-06	1.53528	1.53528
Comp Molar Flow i-Butane (lb_{mol}/hr)	4.43906E-07	0.605962	0.605962
Comp Molar Flow n-Butane (lb_{mol}/hr)	1.35201E-06	1.00376	1.00376
Comp Molar Flow i-Pentane (lb_{mol}/hr)	3.68843E-07	0.543932	0.543932
Comp Molar Flow n-Pentane (lb_{mol}/hr)	1.57397E-07	0.279323	0.279323
Comp Molar Flow n-Hexane (lb_{mol}/hr)	1.94686E-07	1.9406	1.9406
Comp Molar Flow n-Heptane (lb_{mol}/hr)	0	0	0
Comp Molar Flow H_2O (lb_{mol}/hr)	0.350046	0.00199881	0.00199881
Comp Molar Flow Diethyle Amine (lb_{mol}/hr)	0	0	0

Table 11C: Stream Compositions

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Name	Low-Pressure Sour NGL Rich Stream 768	Acid Gases 770
Comp Molar Flow H_2S (lb_{mol}/hr)	0	0
Comp Molar Flow Nitrogen (lb_{mol}/hr)	5.94147E-09	0
Comp Molar Flow CO_2 (lb_{mol}/hr)	0.602328	0.602272
Comp Molar Flow Methane (lb_{mol}/hr)	2.25954E-05	2.56258E-07
Comp Molar Flow Ethane (lb_{mol}/hr)	0.0688655	0.000254578
Comp Molar Flow Propane (lb_{mol}/hr)	1.53528	0.00159919
Comp Molar Flow i-Butane (lb_{mol}/hr)	0.605962	0.00016306
Comp Molar Flow n-Butane (lb_{mol}/hr)	1.00376	0.000353691
Comp Molar Flow i-Pentane (lb_{mol}/hr)	0.543932	3.41627E-05
Comp Molar Flow n-Pentane (lb_{mol}/hr)	0.279323	2.16905E-05
Comp Molar Flow n-Hexane (lb_{mol}/hr)	1.9406	4.4341E-05
Comp Molar Flow n-Heptane (lb_{mol}/hr)	0	0
Comp Molar Flow H_2O (lb_{mol}/hr)	0.00199881	0.0411157
Comp Molar Flow Diethyle Amine (lb_{mol}/hr)	0	4.17895E-20

Table 11D: Stream Compositions

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Name	Heat Flow (Btu/hr)
Condenser Energy Stream 782	320524
Reboiler Energy Stream 784	253961

Table 12: Energy Streams

EXAMPLE 5

In a fifth example, the process simulation was continued for the NGL upgrade process 500 shown in FIG. 4. The simulation was performed using the Aspen Tech. HYSYS Version 7.2 (previously Hyprotech Ltd. HYSYS) software package. The NGL upgrade process 500 separates the NGL rich stream 162 into the heavy NGL stream 172 and the light NGL stream 174. In the following tables and results, the low-pressure sour NGL rich stream 268 has the composition as determined by the simulation model of the low-pressure sour NGL rich stream 768 from Example 4. Similarly, the acid gas stream 270 has the composition as determined by the simulation model of the acid gas stream 770 from Example 4. In addition, the NGL rich stream 162 has the composition as determined by the simulation model of the NGL rich stream 162 from Example 4. The material streams, their compositions, and the associated energy streams produced by the simulation are provided in tables 13, 14, and 15 below, respectively.

Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162
Vapor Fraction	0.0000	1.0000	0.0000
Temperature (F)	120.145	120.0	94.16
Pressure (psig)	441.3	12.3041	250.0
Molar Flow (MMSCFD)	0.321888	5.8822e-002	1.019
Mass Flow (lb/hr)	416.5033	27.362473	7567
Standard Liquid Volume Flow (barrel/day)	46.6598	2.2893	840.0
Heat Flow (Btu/hr)	-508612	-106053	-7.920e+006

Table 13A: Material Streams

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Name	Overhead Stream 524	Heavy NGL Stream 514	Light NGL Stream 174
Vapor Fraction	1.0000	0.0000	0.0000
Temperature (F)	185.7	270.6	134.0
Pressure (psig)	160.0	165.0	155.0
Molar Flow (MMSCFD)	0.3687	0.6507	0.3687
Mass Flow (lb/hr)	2186	5381	2186
Standard Liquid Volume Flow (barrel/day)	266.4	576.5	266.4
Heat Flow (Btu/hr)	-2.029e+006	-4.885e+006	-2.367e+006

Table 13B: Material Streams

Name	Cooled, Heavy NGL Stream 172
Vapor Fraction	0.0000
Temperature (F)	100.0
Pressure (psig)	160.0
Molar Flow (MMSCFD)	0.6507
Mass Flow (lb/hr)	5381
Standard Liquid Volume Flow (barrel/day)	576.5
Heat Flow (Btu/hr)	-5.478e+006

Table 13C: Material Streams

Name	Low-Pressure Sour NGL Rich Stream 268	Acid Gas Stream 270	NGL Rich Stream 162
Comp Mole Frac (H_2S)			0.0000
Comp Mole Frac (Nitrogen)			0.0000
Comp Mole Frac (CO_2)	0.09151	0.93251	0.0000
Comp Mole Frac (Methane)	0.00000	0.00000	0.0000
Comp Mole Frac (Ethane)	0.01046	0.00039	0.0027
Comp Mole Frac (Propane)	0.23325	0.00248	0.1653
Comp Mole Frac (i-Butane)	0.09206	0.00025	0.0756
Comp Mole Frac (n-Butane)	0.15250	0.00055	0.2423
Comp Mole Frac (i-Pentane)	0.08264	0.00005	0.1092
Comp Mole Frac (n-Pentane)	0.04244	0.00003	0.0915
Comp Mole Frac (n-Hexane)	0.29483	0.00007	0.2943
Comp Mole Frac (n-Heptane)	0.00000	0.00000	0.0191
Comp Mole Frac (n-Octane)	--	--	0.0000
Comp Mole Frac (H_2O)	0.00030	0.06366	0.0000

Table 14A: Stream Compositions

Name	Overhead Stream 524	Heavy NGL Stream 514	Light NGL Stream 174
Comp Mole Frac (H_2S)	0.0000	0.0000	0.0000
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000
Comp Mole Frac (CO_2)	0.0000	0.0000	0.0000
Comp Mole Frac (Methane)	0.0000	0.0000	0.0000
Comp Mole Frac (Ethane)	0.0075	0.0000	0.0075
Comp Mole Frac (Propane)	0.4547	0.0013	0.4547

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Name	Overhead Stream 524	Heavy NGL Stream 514	Light NGL Stream 174
Comp Mole Frac (i-Butane)	0.1330	0.0431	0.1330
Comp Mole Frac (n-Butane)	0.2751	0.2236	0.2751
Comp Mole Frac (i-Pentane)	0.0486	0.1435	0.0486
Comp Mole Frac (n-Pentane)	0.0359	0.1230	0.0359
Comp Mole Frac (n-Hexane)	0.0437	0.4363	0.0437
Comp Mole Frac (n-Heptane)	0.0013	0.0292	0.0013
Comp Mole Frac (n-Octane)	0.0000	0.0000	0.0000
Comp Mole Frac (H_2O)	0.0000	0.0000	0.0000

Table 14B: Stream Compositions

Name	Cooled, Heavy NGL Stream 172
Comp Mole Frac (H_2S)	0.0000
Comp Mole Frac (Nitrogen)	0.0000
Comp Mole Frac (CO_2)	0.0000
Comp Mole Frac (Methane)	0.0000
Comp Mole Frac (Ethane)	0.0000
Comp Mole Frac (Propane)	0.0013
Comp Mole Frac (i-Butane)	0.0431
Comp Mole Frac (n-Butane)	0.2236
Comp Mole Frac (i-Pentane)	0.1435
Comp Mole Frac (n-Pentane)	0.1230
Comp Mole Frac (n-Hexane)	0.4363
Comp Mole Frac (n-Heptane)	0.0292
Comp Mole Frac (n-Octane)	0.0000
Comp Mole Frac (H_2O)	0.0000

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Table 14C: Stream Compositions

Name	Heat Flow (Btu/hr)
Reboiler Energy Stream 516	25.4×10^3
Cooling Fluid Stream 522	39.72×10^3

Table 15: Energy Streams

At least one embodiment is disclosed and variations, combinations, and/or modifications of the embodiment(s) and/or features of the embodiment(s) made by a person having ordinary skill in the art are within the scope of the disclosure. Alternative embodiments that result from combining, integrating, and/or omitting features of the embodiment(s) are also within the scope of the disclosure. Where numerical ranges or limitations are expressly stated, such express ranges or limitations should be understood to include iterative ranges or limitations of like magnitude falling within the expressly stated ranges or limitations (e.g., from about 1 to about 10 includes, 2, 3, 4, etc.; greater than 0.10 includes 0.11, 0.12, 0.13, etc.). For example, whenever a numerical range with a lower limit, R_l, and an upper limit, R_u, is disclosed, any number falling within the range is specifically disclosed. In particular, the following numbers within the range are specifically disclosed: $R = R_l + k * (R_u - R_l)$, wherein k is a variable ranging from 1 percent to 100 percent with a 1 percent increment, e.g., k is 1 percent, 2 percent, 3 percent, 4 percent, 5 percent, ..., 50 percent, 51 percent, 52 percent, ..., 95 percent, 96 percent, 97 percent, 98 percent, 99 percent, or 100 percent. Moreover, any numerical range defined by two R numbers as defined in the above is also specifically disclosed. Use of the term "optionally" with respect to any element of a claim means that the element is required, or alternatively, the element is not required, both alternatives being within the scope of the claim. Use of broader terms such as comprises, includes, and having should be understood to provide support for narrower terms such as consisting of, consisting essentially of, and comprised substantially of. Accordingly, the scope of protection is not limited by the description set out above but is defined by the claims that follow, that scope including all equivalents of the subject matter of the claims. Each and every claim is incorporated as further disclosure into the specification and the claims are embodiment(s) of the present disclosure. The discussion of a reference in the disclosure is not an admission that

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it is prior art, especially any reference that has a publication date after the priority date of this application. The disclosure of all patents, patent applications, and publications cited in the disclosure are hereby incorporated by reference, to the extent that they provide exemplary, procedural, or other details supplementary to the disclosure.

While several embodiments have been provided in the present disclosure, it should be understood that the disclosed systems and methods might be embodied in many other specific forms without departing from the spirit or scope of the present disclosure. The present examples are to be considered as illustrative and not restrictive, and the intention is not to be limited to the details given herein. For example, the various elements or components may be combined or integrated in another system or certain features may be omitted, or not implemented.

In addition, techniques, systems, subsystems, and methods described and illustrated in the various embodiments as discrete or separate may be combined or integrated with other systems, modules, techniques, or methods without departing from the scope of the present disclosure. Other items shown or discussed as coupled or directly coupled or communicating with each other may be indirectly coupled or communicating through some interface, device, or intermediate component whether electrically, mechanically, or otherwise. Other examples of changes, substitutions, and alterations are ascertainable by one skilled in the art.

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CLAIMS:

1. A method comprising:

receiving a hydrocarbon feed stream, wherein the hydrocarbon feed stream includes carbon dioxide, natural gas liquid (NGL), and heavy hydrocarbons, wherein the NGL includes C_3-C_8 hydrocarbons, and wherein the heavy hydrocarbons include C_{9+} hydrocarbons;

separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon rich stream includes most of the C_{9+} hydrocarbons in the hydrocarbon feed stream, and wherein the carbon dioxide recycle stream includes most of the carbon dioxide and most of the C_3-C_8 hydrocarbons in the hydrocarbon feed stream;

separating the carbon dioxide recycle stream into a sour NGL rich stream and a purified carbon dioxide recycle stream, wherein the sour NGL rich stream includes some of the C_3-C_8 hydrocarbons in the carbon dioxide recycle stream, and wherein the purified carbon dioxide recycle stream includes most of the carbon dioxide in the carbon dioxide recycle stream;

separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream, wherein the sweet NGL rich stream includes the substantially all of the C_3-C_8 hydrocarbons in the source NGL rich stream, and wherein the carbon dioxide rich stream includes substantially all of the carbon dioxide in the sour NGL rich stream;

combining a carbon dioxide makeup stream from a source external to the method with the purified carbon dioxide recycle stream; and

subsequently injecting the combined carbon dioxide makeup stream and the purified carbon dioxide recycle stream into a subterranean formation,

wherein the carbon dioxide is not removed from the hydrocarbon feed stream and is not removed from the carbon dioxide recycle stream prior to separating the carbon dioxide recycle stream into the sour NGL rich stream and the purified carbon dioxide recycle stream, and

wherein the hydrocarbon feed stream, the carbon dioxide recycle stream, and the sour NGL rich stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the heavy hydrocarbon rich

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stream, the purified carbon dioxide recycle stream, the sweet NGL rich stream, and the carbon dioxide rich stream.

2. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids;

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide, and wherein the natural gas liquids stream includes the natural gas liquids, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

3. The method according to claim 2, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

4. The method according to claim 2, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

5. The method according to claim 4, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

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6. The method according to claim 2, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

7. The method according to claim 2, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

8. The method according to claim 2, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

9. The method according to claim 2, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes

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approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

10. A system comprising:

piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas and C3 to C8 hydrocarbons;

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream, wherein the purified recycle stream includes the injection gas, and wherein the natural gas liquids stream includes the C_3-C_8 hydrocarbons, and

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream.

11. The system according to claim 10, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

12. The system according to claim 10, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

13. The system according to claim 10, wherein the recycle stream comprises C_1 to C_2 hydrocarbons, and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream.

14. The system according to claim 10, wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream,

wherein the sweet natural gas liquids stream includes the C_3-C_8 hydrocarbons, and wherein the acid gas stream includes H_2S and/or CO_2.

15. The system according to claim 10, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

16. The system according to claim 10, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

17. The system according to claim 10, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified recycle stream includes substantially all of the injection gas, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream, wherein the natural gas liquids stream includes substantially none of the injection gas and a second portion of the C_3 hydrocarbons from the recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C~~3~~ hydrocarbons from the recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C~~3~~ hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C~~3~~ hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

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18. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids.

19. The method according to claim 18, wherein the natural gas comprises C_1 to C_2 hydrocarbons, and wherein the natural gas liquids comprise C_3-C_8 hydrocarbons.

20. The method according to claim 18, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

21. The method according to claim 20, further comprising separating the natural gas liquids stream into an acid gas stream and a sweet natural gas liquids stream.

22. The method according to claim 18, further comprising separating a feed stream into the carbon dioxide recycle stream and a heavy hydrocarbon stream, wherein the heavy hydrocarbon stream includes C_{9+} hydrocarbons.

23. The method according to claim 18, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

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24. The method according to claim 18, further comprising:

receiving a feed stream, wherein the feed stream includes carbon dioxide, C_1 to C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_{9+} hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons; and

separating the feed stream into a heavy hydrocarbon stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon stream includes substantially all of the C_{9+} hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream, wherein the heavy hydrocarbon stream includes substantially none of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream, and wherein the carbon dioxide recycle stream includes substantially all of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream,

wherein the purified carbon dioxide recycle stream includes substantially all of the C_2 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially none of the C_2 hydrocarbons from the carbon dioxide recycle stream, and wherein the purified carbon dioxide recycle stream includes substantially none of the C_3 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially all of the C_3 hydrocarbons from the carbon dioxide recycle stream.

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CLAIMS

1. A method comprising:

receiving a hydrocarbon feed stream, wherein the hydrocarbon feed stream includes carbon dioxide, natural gas liquid (NGL), and heavy hydrocarbons, wherein the NGL includes C_3-C_8 hydrocarbons, and wherein the heavy hydrocarbons include C_{9+} hydrocarbons;

separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon rich stream includes most of the C_{9+} hydrocarbons in the hydrocarbon feed stream, and wherein the carbon dioxide recycle stream includes most of the carbon dioxide and most of the C_3-C_8 hydrocarbons in the hydrocarbon feed stream;

separating the carbon dioxide recycle stream into a sour NGL rich stream and a purified carbon dioxide recycle stream, wherein the sour NGL rich stream includes some of the C_3-C_8 hydrocarbons in the carbon dioxide recycle stream, and wherein the purified carbon dioxide recycle stream includes most of the carbon dioxide in the carbon dioxide recycle stream;

separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream, wherein the sweet NGL rich stream includes the substantially all of the C_3-C_8 hydrocarbons in the source NGL rich stream, and wherein the carbon dioxide rich stream includes substantially all of the carbon dioxide in the sour NGL rich stream;

combining a carbon dioxide makeup stream from a source external to the method with the purified carbon dioxide recycle stream; and

subsequently injecting the combined carbon dioxide makeup stream and the purified carbon dioxide recycle stream into a subterranean formation,

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wherein the carbon dioxide is not removed from the hydrocarbon feed stream and is not removed from the carbon dioxide recycle stream prior to separating the carbon dioxide recycle stream into the sour NGL rich stream and the purified carbon dioxide recycle stream, and

wherein the hydrocarbon feed stream, the carbon dioxide recycle stream, and the sour NGL rich stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the heavy hydrocarbon rich stream, the purified carbon dioxide recycle stream, the sweet NGL rich stream, and the carbon dioxide rich stream.

2. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

3. The method according to claim 2, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon

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dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

4. The method according to claim 2, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

5. The method according to claim 4, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

6. The method according to claim 2, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

7. The method according to claim 2, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

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8. The method according to claim 2, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

9. The method according to claim 2, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

10. A system comprising:

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piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas,

wherein the natural gas liquids stream includes the C_3-C_8 hydrocarbons, and

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream.

11. The system according to claim 10, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

12. The system according to claim 10, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

13. The system according to claim 10, wherein the recycle stream comprises C_1 to C_2 hydrocarbons, and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream.

14. The system according to claim 10, wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream, wherein the sweet natural gas liquids stream includes the C_3-C_8 hydrocarbons, and wherein the acid gas stream includes H_2S and/or CO_2.

15. The system according to claim 10, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

16. The system according to claim 10, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

17. The system according to claim 10, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified recycle stream includes substantially all of the injection gas, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the

purified recycle stream, wherein the natural gas liquids stream includes substantially none of the injection gas and a second portion of the C_3 hydrocarbons from the recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

18. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas,

wherein the natural gas liquids stream comprises the natural gas liquids,

wherein the natural gas comprises C_1 to C_2 hydrocarbons, and

wherein the natural gas liquids comprise C_3-C_8 hydrocarbons.

19. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;

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separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids; and

separating a feed stream into the carbon dioxide recycle stream and a heavy hydrocarbon stream, wherein the heavy hydrocarbon stream includes C_{9+} hydrocarbons.

20. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids;

receiving a feed stream, wherein the feed stream includes carbon dioxide, C_1 to C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_{9+} hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons; and

separating the feed stream into a heavy hydrocarbon stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon stream includes substantially all of the C_{9+} hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream, wherein the heavy hydrocarbon stream includes substantially none of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream, and wherein the carbon dioxide

recycle stream includes substantially all of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream,

wherein the purified carbon dioxide recycle stream includes substantially all of the C_2 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially none of the C_2 hydrocarbons from the carbon dioxide recycle stream, and

wherein the purified carbon dioxide recycle stream includes substantially none of the C_3 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially all of the C_3 hydrocarbons from the carbon dioxide recycle stream.

21. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

22. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the

purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

23. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

24. The set of process equipment according to claim 23, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

25. The set of process equipment according to claim 21, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

26. The set of process equipment according to claim 21, further configured to:

compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

27. The set of process equipment according to claim 21, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

28. The set of process equipment according to claim 21, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

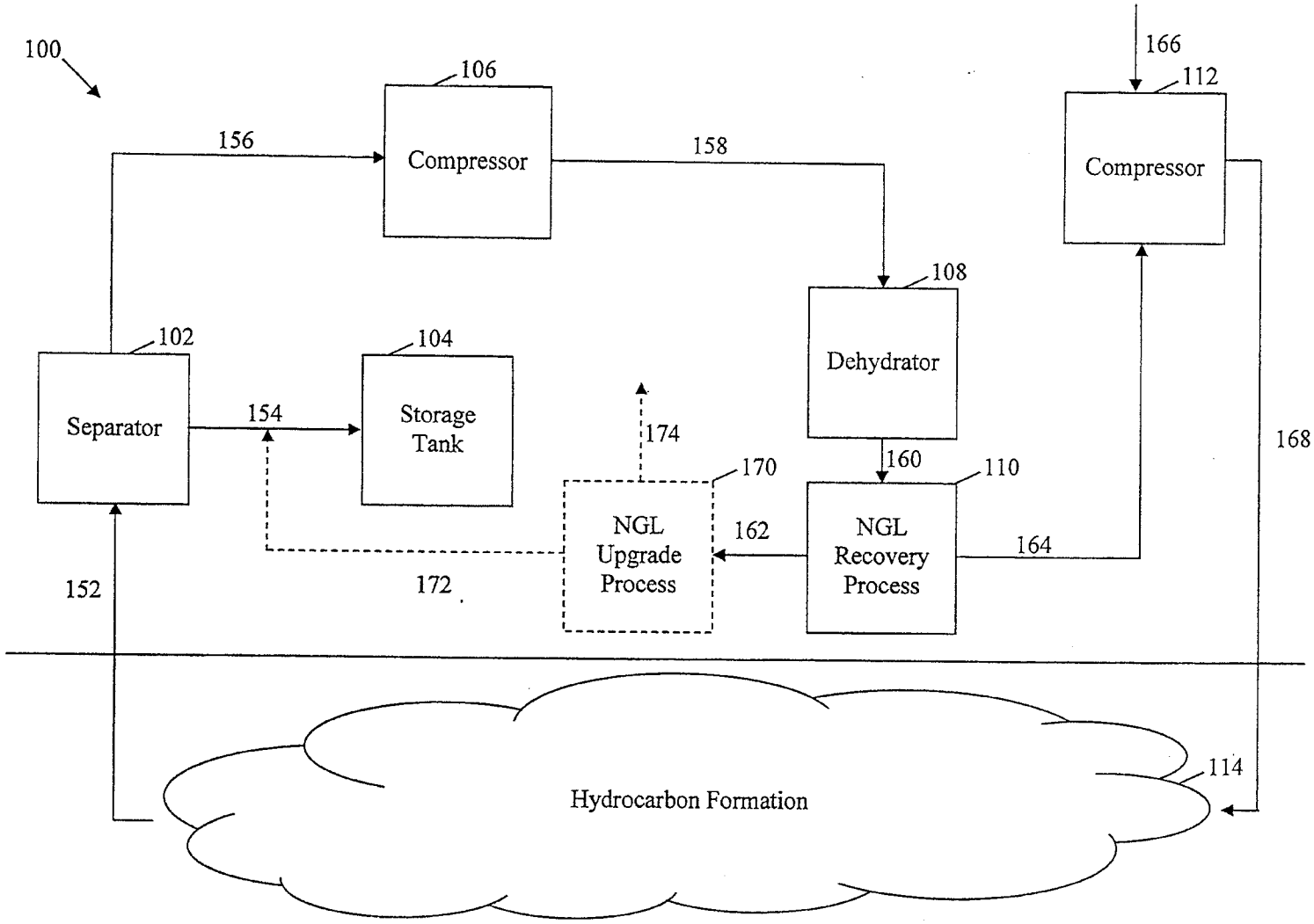


FIG. 1

CA 02949039 2016-11-17

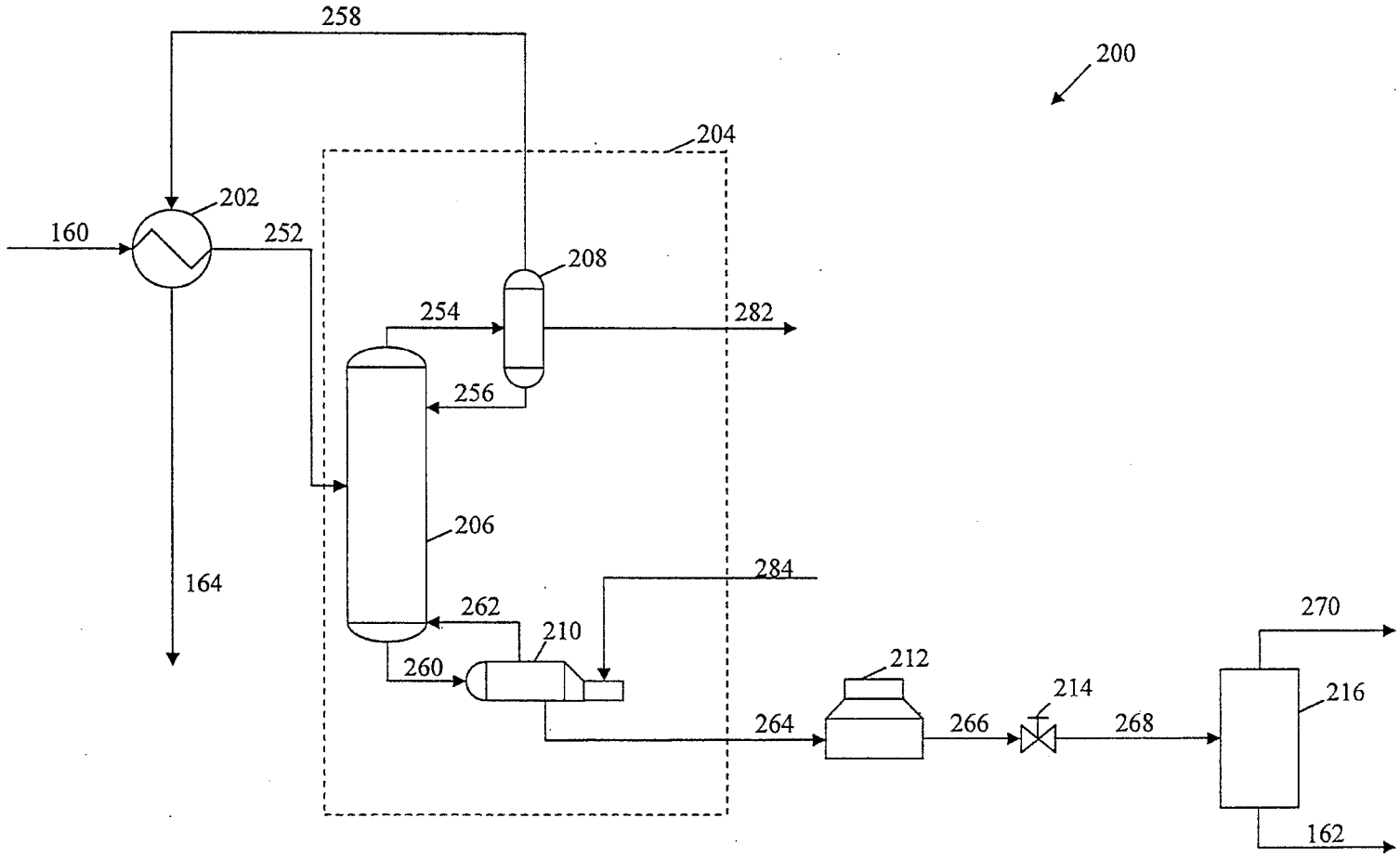


FIG. 2

CA 02949039 2016-11-17

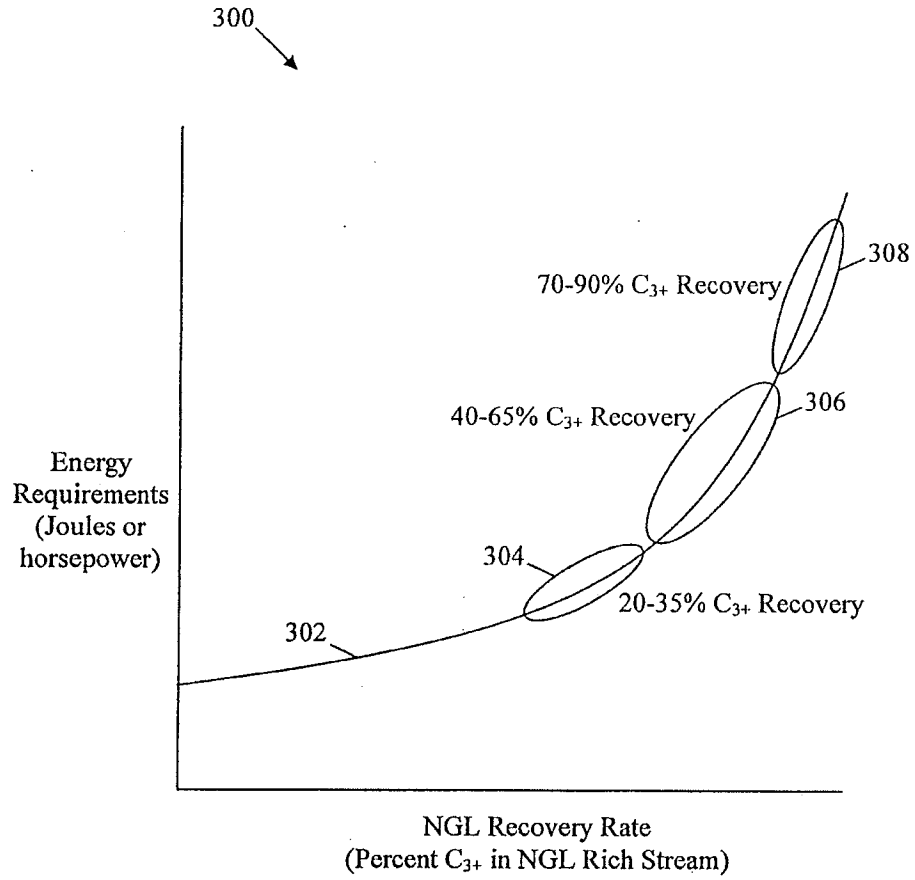

300
70-90% C_{3+} Recovery
308
40-65% C_{3+} Recovery
306
304
20-35% C_{3+} Recovery
302
Energy Requirements (Joules or horsepower)
NGL Recovery Rate
(Percent C_{3+} in NGL Rich Stream)

FIG. 3

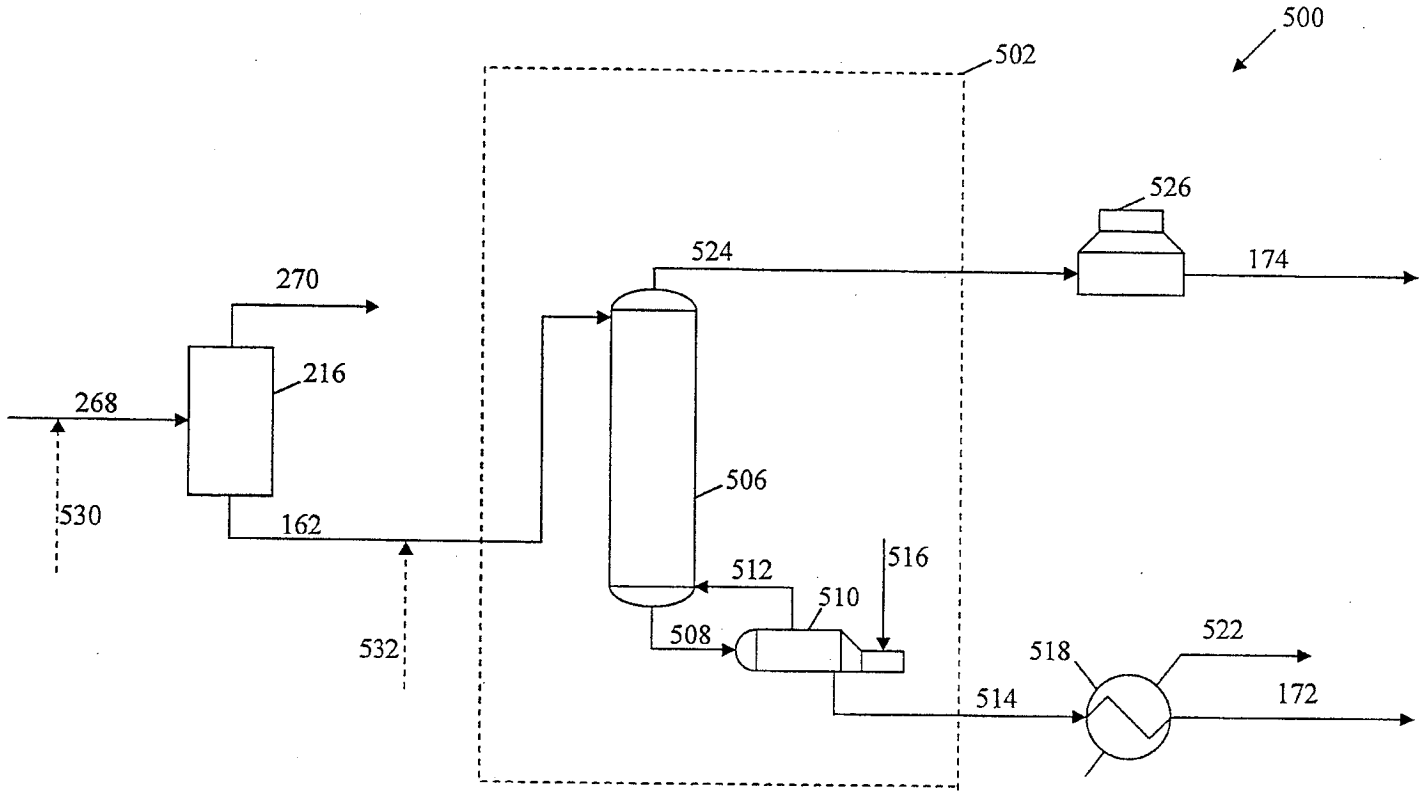


FIG. 4

CA 02949039 2016-11-17

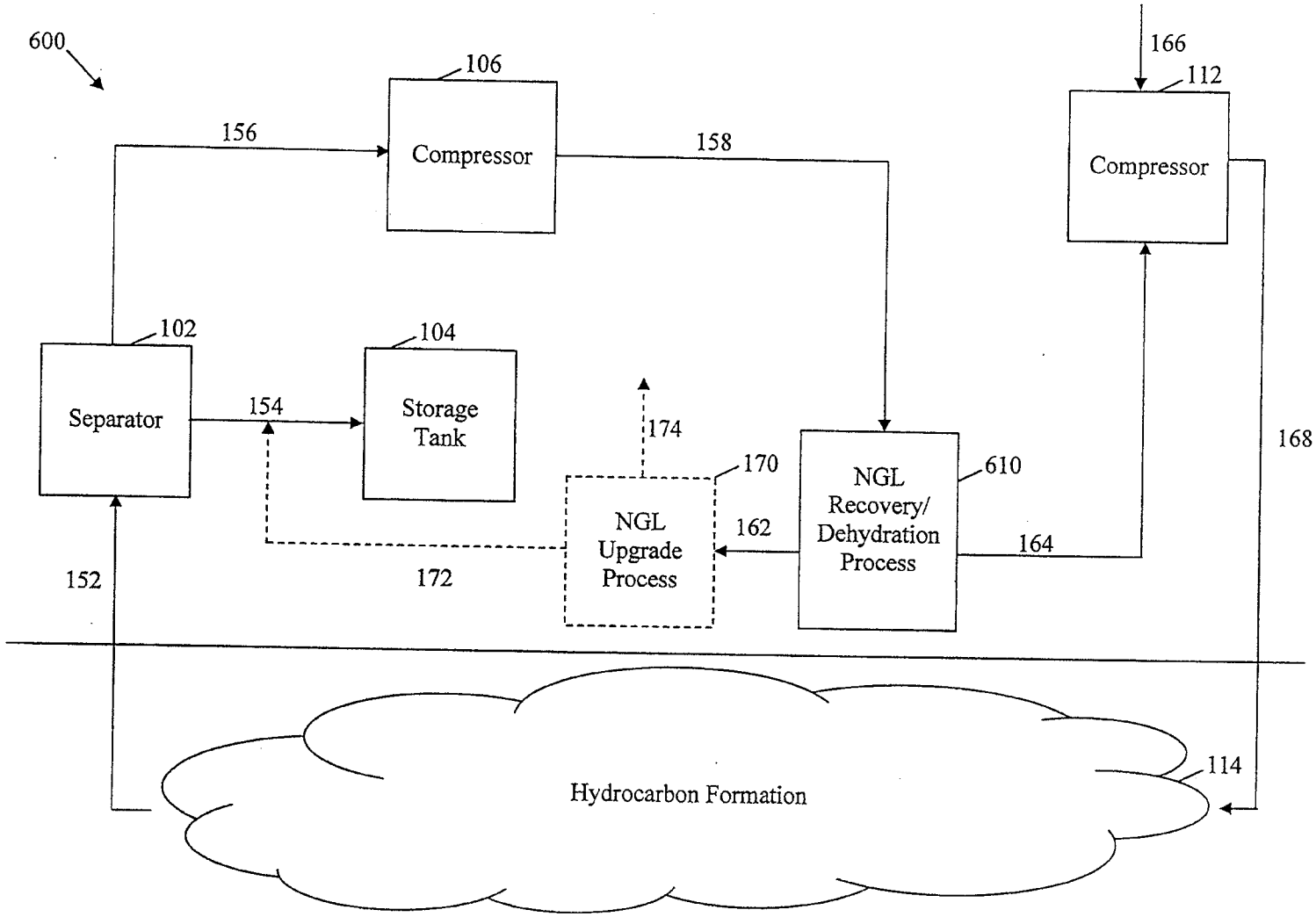


FIG. 5

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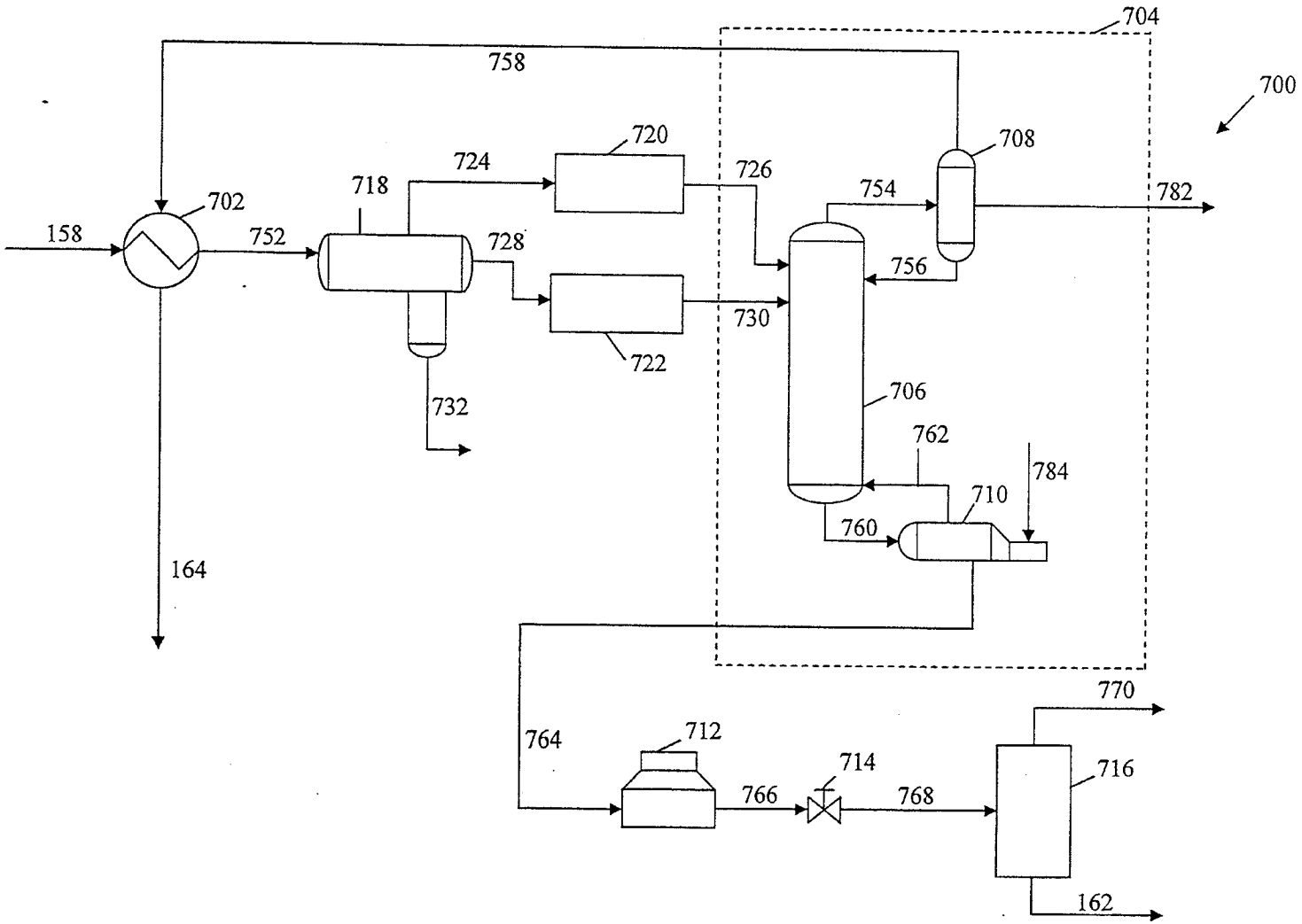


FIG. 6

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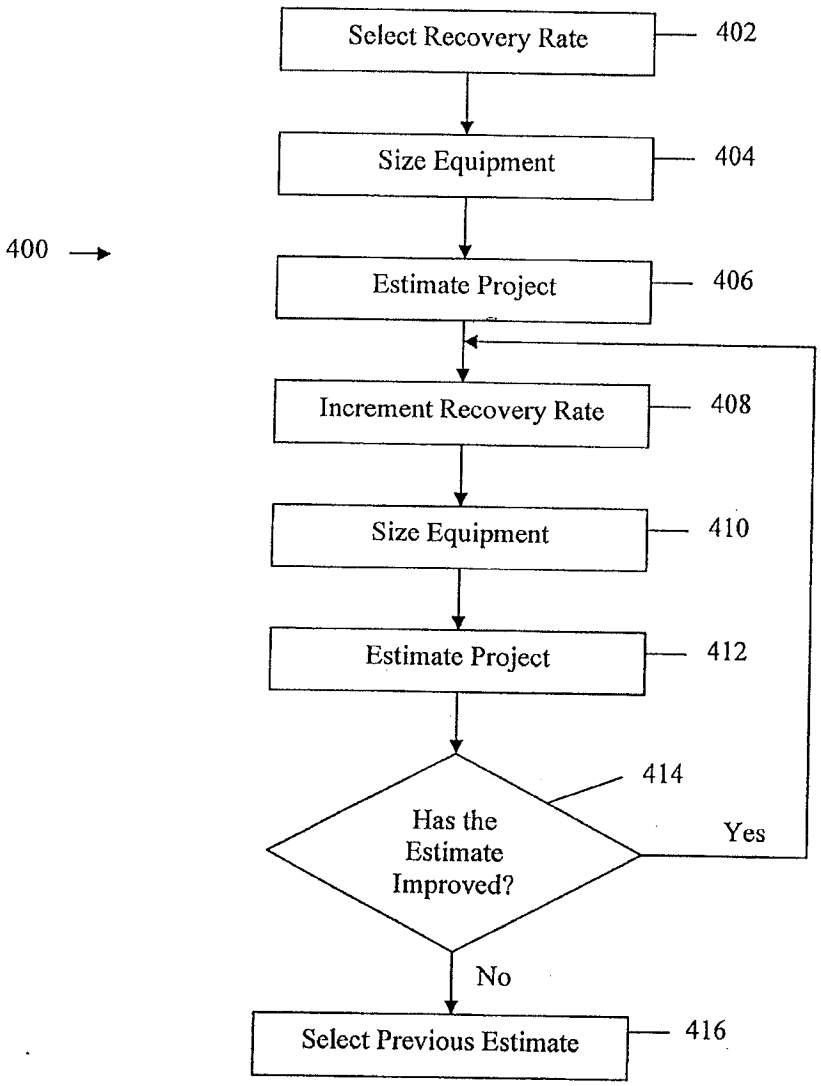

400
Select Recovery Rate
402
Size Equipment
404
Estimate Project
406
Increment Recovery Rate
408
Size Equipment
410
Estimate Project
412
414
Has the Estimate Improved?
Yes
No
Select Previous Estimate
416

FIG. 7

ABSTRACT

A method comprises receiving a hydrocarbon feed stream; separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a recycle stream, wherein the recycle stream comprises a gas selected from the group consisting of carbon dioxide, nitrogen, air, and water; and separating the recycle stream into a natural gas liquids (NGL) rich stream and a purified recycle stream. A plurality of process equipment configured to receive a hydrocarbon feed stream, separate the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a recycle stream comprising at least one C3+ hydrocarbon and a gas selected from the group consisting of carbon dioxide, nitrogen, air, and water, and separate the recycle stream into a NGL rich stream and a purified recycle stream.

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Instruction Letter

Industry Canada Industrie Canada
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Date : November 17, 2016 12:18:20.

Commissioner of Patents
50 Victoria Street
Place du Portage
Phase I
Gatineau, Quebec
Canada
K1A 0C9

Application Number: New application

Applicant: Pilot Energy Solutions, LLC

Title: ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS

Reference Number: K8001075CADIV6

I(we) would like to obtain a patent. Attached with this electronic message (is a copy/are copies) of the following document(s):
FILE NAME: Declaration.pdf
FILE TYPE: DECLARATION

FILE NAME: K8001075CADIV-Abstract.pdf
FILE TYPE: ABSTRACT

FILE NAME: K8001075CADIV-Assignment.pdf
Assignment
FILE NAME: K8001075CADIV-Description.pdf
FILE TYPE: DESCRIPTION

FILE NAME: K8001075CADIV-Drawings.pdf
FILE TYPE: DRAWING

FILE NAME: Petition.pdf
FILE TYPE: PETITION

FILE NAME: Claims.pdf
FILE TYPE: CLAIM

I am also requesting examination of this application.

I am including the following fee(s): Filing Fee: $400.00Examination Fee: $800.00Assignment Fee: $100.00Maintenance Fees: $500.00Should the fees submitted with this letter be insufficient to cover all of the fees for which payment is explicitly or implicitly requested by this letter, the Commissioner is authorized to charge the amount of the insufficiency to account number 600000107 or 600000109.. The total fees should amount to: $1800

Please credit my Deposit Account for my payment.

I wish to correspond via regular mail.

Supplemental Instructions are following:
We submit the following documents herewith in connection with a new divisional application for patent:1. Petition for Grant of a Patent2. Legal Representative Declaration3. Assignment for Registration, including Notice of Recordation from the United States Patent and Trademark Office4. Abstract5. Disclosure pages 1 to 526. Claims pages 53 to 59, containing claims 1 to 247. 7 sheets of DrawingsExamination is hereby requested.Payment of the 2nd, 3rd, 4th and 5th anniversary maintenance fees is submitted herewith.

Gowling WLG (Canada) LLP
50 Queen Street North, Suite 1020
KitchenerOntario
CANADA
N2H 6M2
Tel:519-576-6910Fax:519-576-0141

Transmission identification: IPWaterloo1711115635_885135343

The applicant requested that no petition be generated.

File No. K8001075CADIV6

Canada – Petition by Assignees

Petition for Grant of a Patent

1. The applicant,

   Pilot Energy Solutions, LLC

   whose complete address is:

   333 North Sam Houston Pkwy E., Houston, Texas, 77060, USA

   request the grant of a patent for an invention, entitled:

   ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS

   which is described and claimed in the accompanying specification.

2. **This application is a division of application number 2,739,366 filed in Canada on May 6, 2011.**

3. The applicants request priority in respect of the application on the basis of the following previously regularly filed application(s):

   Country of filing: **U.S.A.**
   Application no.: **13/096,788**
   Filing date: **April 28, 2011**

4. The applicants appoint the firm of **Gowling WLG (Canada) LLP**, whose complete address in Canada is Suite 1020, 50 Queen Street North, Kitchener, Ontario, Canada N2H 6M2 as the applicants' representative, in Canada, pursuant to section 29 of the *Patent Act.*

5. The applicants appoint the said **Gowling WLG (Canada) LLP** as the applicants' patent agent.

6. The applicants request that Figure No. 1 of the drawings accompany the abstract when it is open to public inspection under section 10 of the *Patent Act* or published.

SIGNED at Kitchener, Ontario, Canada this 17th day of November, 2016.

Pilot Energy Solutions, LLC

Gowling WLG (Canada) LLP
Agents for Applicant

Jeffrey W. Wong/cgk
Gowling WLG (Canada) LLP
Suite 1020
50 Queen Street North
P.O. Box 2248
Kitchener ON N2H 6M2

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PATENT ASSIGNMENT

Electronic Version v1.1
Stylesheet Version v1.1

SUBMISSION TYPE:	NEW ASSIGNMENT
NATURE OF CONVEYANCE:	ASSIGNMENT

CONVEYING PARTY DATA

Name	Execution Date
Eric` Pim	10/31/2011
Naomi Baker	10/31/2011
Jhansi Garikipati	10/28/2011

RECEIVING PARTY DATA

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Street Address:	333 North Sam Houston Parkway East
Internal Address:	Suite 600
City:	Houston
State/Country:	TEXAS
Postal Code:	77060

PROPERTY NUMBERS Total: 1

Property Type	Number
Application Number:	13096788

CH $40.00 13096788

CORRESPONDENCE DATA

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ATTORNEY DOCKET NUMBER:	2103-00903
NAME OF SUBMITTER:	Grant Rodolph

Atty Dkt. No. 2103-00903

ASSIGNMENT

WHEREAS, the Undersigned has invented certain new and useful improvements as below entitled, for which application for United States Letters Patent is made, said application having been executed on the date set forth below; and

WHEREAS, Pilot Energy Solutions, LLC (hereinafter referred to as "Assignee"), a limited liability company organized and existing under the laws of the State of Texas, United States of America, Assignee, having its principal office and place of business at 333 North Sam Houston Parkway East, Suite 600, Houston, Texas 77060, desires to acquire the Undersigned's entire right, title and interest in and to the invention, and in and to said application and any Letters Patent that may issue thereon;

NOW, THEREFORE, for and in consideration of One Dollar ($1.00), and other good and valuable consideration, the receipt of which is hereby acknowledged, the Undersigned:

Hereby sells, assigns and transfers to Assignee, its successors, assigns and legal representatives, the entire right, title and interest for the United States and all foreign countries, in and to any and all improvements which are disclosed in the application for United States Letters Patent, Application No. 13/096,788, filed April 28, 2011, if not identified here by filing date and application number, executed by me on even date, entitled:

ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS

and in and to said application and all applications that claim priority to said Application No. 13/096,788 and all provisional, divisional, continuing, substitute, renewal, reissue and all other applications for Letters Patent which have been or shall be filed in the United States and all foreign countries on any of said improvements; and in and to all original and reissued patents which have been or shall be issued in the United States and all foreign countries on said improvements; and in and to all utility models, industrial models, certificates of invention, and designs on said improvements;

Agrees that said Assignee may apply for and receive Letters Patent for said improvements in its own name; and that, when requested, without charge to but at the expense of said Assignee, its successors, assigns and legal representatives, to carry out in good faith the intent and purpose of this assignment, the Undersigned will execute all divisional, continuing, substitute, renewal, reissue and all other patent applications, and all other like rights of exclusion in any country on any and all said improvements; execute all rightful oaths, declarations, assignments, powers of attorney and other papers; communicate to said Assignee, its successors, assigns and representatives, all facts known to the Undersigned relating to said improvements and the history thereof; and generally do everything possible which said Assignee, its successors, assigns and representatives shall consider desirable for aiding in securing and maintaining proper patent protection for said improvements and vesting title to said improvements and all applications for patents and all patents on said improvements, in said Assignee, its successors, assigns and legal representatives; and

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Agrees that the Undersigned will upon request of Assignee, render prompt assistance and cooperation in the prosecution of legal proceedings involving said improvements, said applications and patents granted thereon, including reexaminations, reissues, interferences, priority contests, public use proceedings and court proceedings, and testify in such proceedings if requested, provided, however, that the expense which may be incurred by the Undersigned in lending such assistance and cooperation be paid by Assignee; and

Covenants with said Assignee, its successors, assigns and legal representatives that no assignment, grant, mortgage, license or other agreement affecting the rights and property herein conveyed has been made to others by the Undersigned, except as set forth below, and that full right to convey the same as herein expressed is possessed by the Undersigned.

This assignment shall be binding on the heirs and legal representatives of the Undersigned.

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Citizenship:	US

E Prim
Eric Prim

10/31/11
(Date)

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Residence Address:	13801 Napoli Drive, Ap. #9210 Houston, Texas 77070
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Jhansi

Jhansi Garikipati

10/28/2011

(Date)

Witness Signature

Witness Name (Print)

Multiple 075

IN THE CANADIAN INTELLECTUAL PROPERTY OFFICE

In The Matter of Canadian Patent Application:

Applicant	:	**Pilot Energy Solutions, LLC**
Serial No.	:	**2,949,015; 2,949,058; 2,949,016; 2,949,087; 2,949,042; 2,949,039; 2,949,051; 2,949,044; 2,949,055; 2,949,014**
Filing Date	:	**May 6, 2011**
Title	:	**ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS**
Our File	:	**K8001075CADIV1; K8001075CADIV2; K8001075CADIV3 K8001075CADIV4; K8001075CADIV5; K8001075CADIV6; K8001075CADIV7; K8001075CADIV8; K8001075CADIV9; K8001075CADIV10**
Date	:	**December 13, 2016**

Industry Canada Industrie Canada

A/M/J Y/M/D

2016/12/13

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CIPO OPIC

E002399398

BY FACSIMILE 1-819-953-2476 (1 page)

The Commissioner of Patents
Place du Portage I
50 Victoria Street, Room C-114
Gatineau, Quebec K1A 0C9

INVENTOR ADDRESS UPDATE

This is to request that you please note in your records a change of mailing address for the first inventor, **PRIM, Eric**, for all the above captioned applications.

From: 9318 Walnut Brook Court, Houston, Texas, 77040-7649, US

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PAGE 1/1 * RCVD AT 12/13/2016 11:59:55 AM [Eastern Standard Time] * SVR:FOO003/21 * DNIS:3905 * CSID:Gowling WLG RightFax * DURATION (mm-ss):00-43

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RS

Date: February 26, 2020 11:17:06 AM

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2020/02/26
057 - 20
OPIC-CIPO M000704979

#4182210

Application Number: 2949039
Title of invention: ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS
Applicant(s) or Inventor(s) Name(s): PILOT ENERGY SOLUTIONS, LLC, US
PILOT ENERGY SOLUTIONS, LLC, US
Reference Number: LT202967CA

Instructions: This is a request for re-examination pursuant to Section 48.1 of the Patent Act of claims 1 to 28 of Canadian Patent No. 2,949,039 in the name of PILOT ENERGY SOLUTIONS, LLC, US issued on March 12, 2019 and entitled ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS.

Attached are the following documents:
1. 2020-02-26 - Request for re-examination.pdf
Request for Re-examination of CA 2949039
Other
2. Re-examination FeePaymentForm - LT202967CA.PDF
Fee Payment Form
Other
3. D1.pdf
Prior art reference D1
Other
4. D2.pdf
Prior art reference D2
Other
5. D3.pdf
Prior art reference D3
Other
6. D4.pdf
Prior art reference D4
Other

Description of Fee (standard fee)
1. Re-examination of one or more claims of a patent (1 x $2,000.00): $2,000.00
Total Fee Payment: $2,000.00

120

Reception, Toronto

Marks & Clerk Canada
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Transmission Identifier: pgc_SIMAdmin_20200226111706145_8183680

General Correspondence (Patent)

Date: February 26, 2020 11:17:06 AM

Application Number

2949039

Title of invention

ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS

Applicant(s) or Inventor Name(s)

Applicant or Inventor Name

Sender

Family Name: Reception
First Name: Toronto
Initial:
Name of Corporation or Firm:
Address Line 1: Marks & Clerk Canada
Address Line 2: 100 Simcoe Street, Suite 200
Address Line 3:
City/Town: Toronto
Province/State: Ontario
Country: Canada
Postal/Zip Code: M5H 3G2
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Communicate by: Electronic Mail (Non secure)

Correspondence Instructions

This is a request for re-examination pursuant to Section 48.1 of the Patent Act of claims 1 to 28 of Canadian Patent No. 2,949,039 in the name of PILOT ENERGY SOLUTIONS, LLC, US issued on March 12, 2019 and entitled ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS.

Description of Fee (standard fee)

1. Re-examination of one or more claims of a patent (1 x $2,000.00): $2,000.00

Total Fee Payment: $2,000.00

Payment method

Common Payment Component

Attachments

1. 2020-02-26 - Request for re-examination.pdf
Other
Request for Re-examination of CA 2949039

2. Re-examination FeePaymentForm - LT202967CA.PDF
Other
Fee Payment Form

3. D1.pdf
Other
Prior art reference D1

4. D2.pdf
Other
Prior art reference D2

5. D3.pdf
Other
Prior art reference D3

6. D4.pdf
Other
Prior art reference D4

Transmission Identifier: pgc_SIMAdmin_20200226111706145_8183680

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The Commissioner of Patents
Canadian Intellectual Property Office
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Gatineau QC K1A 0C9

Our Ref: LT202967CA

Date: **February 26, 2020**

Re: Canadian Patent No: 2949039
Issued: March 12, 2019
Title: ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS
Owner: PILOT ENERGY SOLUTIONS, LLC, US

Dear Commissioner,

REQUEST FOR RE-EXAMINATION

This is a request for re-examination pursuant to Section 48.1 of the *Patent Act* of claims 1 to 28 of Canadian Patent No. 2,949,039 in the name of PILOT ENERGY SOLUTIONS, LLC, US issued on March 12, 2019 and entitled ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS.

Canadian Patent No. 2,949,039

Canadian Patent No. 2,949,039 is a divisional application of Canadian Patent No. 2,739,366, which has a filing date of May 6, 2011. Section 36(4) of the *Patent Act* provides that a divisional application "shall have the same filing date as the original application". The filing date of Canadian Patent No. 2,949,039 is therefore **May 6, 2011**.

At the time of filing Canadian Patent No. 2,739,366, a request for priority from U.S. Patent Application No. 13/096,788 was made. The filing date of U.S. Patent Application No. 13/096,788 is April 28, 2011. Section 28.1 of the *Patent Act* provides that the date of a claim is the filing date of a previously regularly filed application that is (a) "filed by a person who is entitled to protection under the terms of any treaty or convention relating to patents to which Canada is a party and who has, or whose agent, legal representative or predecessor in title has,

This letter is sent on behalf of Marks & Clerk Canada, a general partnership registered in Ontario with registered number 240659516. Marks & Clerk is a trading name of Marks & Clerk Canada and other entities within the Marks & Clerk network of associated operating firms, each of which is a separately constituted entity.
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previously regularly filed in or for any other country that by treaty, convention or law affords similar protection to citizens of Canada an application for a patent disclosing the subject-matter defined by the claim"; where (b) "the filing date of the pending application is within twelve months after the filing date of the previously regularly filed application". Assuming the subject matter claimed in Canadian Patent No. 2,949,039 is disclosed in U.S. Patent Application No. 13/096,788, the claim date of Canadian Patent No. 2,949,039 is **April 28, 2011**.

Canadian Patent No. 2,949,039 generally pertains to the field of processing of gas streams obtained from a carbon dioxide miscibility flood process. More particularly, Canadian Patent No. 2,949,039 relates to separating a carbon dioxide recycle stream obtained from a carbon dioxide miscibility flood process, and containing carbon dioxide and natural gas liquids, into a purified carbon dioxide recycle stream and a natural gas liquids stream. The natural gas liquids stream may optionally be separated into a sweet natural gas liquids stream and an acid gas stream.

Canadian Patent No. 2,949,039 has 28 claims, of which claims 1, 2, 10, 18, 19, 20 and 21 are independent.

Requirements of Sections 28.2(1) and 28.3 of the *Patent Act*

Section 28.2(1) of the *Patent Act* requires that "the subject-matter defined by a claim in an application for a patent in Canada must not have been disclosed:

(a) before the one-year period immediately preceding the filing date or, if the claim date is before that period, before the claim date by the applicant, or by a person who obtained knowledge, directly or indirectly, from the applicant, in such a manner that the subject-matter became available to the public in Canada or elsewhere; or

(b) before the claim date by a person not mentioned in paragraph (a) in such a manner that the subject-matter became available to the public in Canada or elsewhere".

Section 28.3 of the *Patent Act* requires that the subject-matter defined by a claim in an application for a patent in Canada must be subject-matter that would not have been obvious on the claim date to a person skilled in the art or science to which it pertains, having regard to

(a) information disclosed before the one-year period immediately preceding the filing date or, if the claim date is before that period, before the claim date by the applicant, or by a person who obtained knowledge, directly or indirectly, from the applicant in such a manner that the information became available to the public in Canada or elsewhere; and

(b) information disclosed before the claim date by a person not mentioned in paragraph (a) in such a manner that the information became available to the public in Canada or elsewhere".

Section 48.1(1) of the *Patent Act* – Request for Re-examination

In accordance with Section 48.1(1) of the *Patent Act*, the following prior art, consisting of three (3) patents and one (1) printed publication, is being filed herewith in support of this request:

D1 U.S. Patent No. 4,753,666 to Pastor (published June 28, 1988);

D2 "Practical Aspects of CO_2 Flooding", Society of Petroleum Engineers (SPE) Monograph Series, vol. 22, (published in 2002) 214 pp. ch. 5;

D3 U.S. Patent No. 4,428,759 to Ryan et al. (published January 31, 1984); and

D4 U.S. Patent No. 4,595,404 to Ozero et al. (published June 17, 1986).

Each of D1, D2, D3 and D4 has a publication date that predates the claim date of Canadian Patent No. 2,949,039 (namely, April 28, 2011). Therefore, each of D1, D2, D3 and D4 is citable under Sections 28.2(1)(*a*), 28.2(1)(*b*), 28.3(*a*) and 28.3(*b*) of the *Patent Act* against the claims of Canadian Patent No. 2,949,039.

Section 48.1(2) of the *Patent Act* – Pertinency of Request

In accordance with Section 48.1(2) of the *Patent Act*, the pertinency of the prior art and the manner of applying the prior art to claims 1 to 28 for which re-examination is being requested, is set forth below:

1) **It is submitted that claims 2, 3, 8, 10 to 13, 16, 18, 21, 22, 27 do not comply with Section 28.2(1)b of the *Patent Act*. These claims are directed to subject matter that was disclosed before the claim date in a manner that the subject-matter became available to the public.**

Independent **claim 2** recites a method comprising: receiving a carbon dioxide recycle

stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide, wherein the natural gas liquids stream includes the natural gas liquids, and wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

D1 anticipates the subject matter recited in independent claim 2 as each and every feature recited in independent claim 2 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A.

In particular, D1 discloses a method comprising: receiving a carbon dioxide recycle stream *[CO_2 gas stream 25]*, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids *[column 3, line 51 – the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons"]*; and

separating the carbon dioxide recycle stream *[distillation column 3 separates the CO_2 gas stream 25]* into a purified carbon dioxide recycle stream *[overhead product stream 21]* and a natural gas liquids stream *[bottoms product 26]*,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, wherein the natural gas liquids stream includes the natural gas liquids *{column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons"]*, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions *[D1 does not subject any stream to cryogenic conditions; furthermore D1 does not describe isolating either methane or ethane, for which cryogenic conditions are conventionally used; additionally, D1 utilizes propane as a refrigerant for condenser 7 (see column 4 line 29), and propane refrigerant is not considered to provide cryogenic conditions]*, membranes *[D1 does not mention using membranes]*, and carbon dioxide recovery solvents *[D1 does not use solvents in the process; the background section of D1 discusses solvent use as being problematic, see column 1, lines 47 to 55]* between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

Clearly, at least based on the above, independent claim 2 is unpatentable over D1 and

should be cancelled.

Dependent **claim 3** recites: the method according to claim 2, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

D1 anticipates the subject matter recited in dependent claim 3 as each and every feature recited in dependent claim 3 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A. In particular, D1 discloses that the carbon dioxide recycle stream comprises natural gas *[column 3, line 51 – the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons", and TABLE I, "feed", which contains C_1 and C_2]*, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream *[column 3, line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons"]*.

Clearly at least based on the above, dependent claim 3 is unpatentable over D1 and should be cancelled.

Dependent **claim 8** recites the method according to claim 2, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises: receiving the carbon dioxide recycle stream at a separation column; reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

D1 anticipates the subject matter recited in dependent claim 8 as each and every feature recited in dependent claim 8 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A. In particular, D1 discloses receiving the carbon dioxide recycle stream *[CO_2 gas stream 25]* at a separation column *[CO_2 gas stream 25 is received at distillation column 3]*; reboiling a portion of the carbon dioxide recycle stream received from the separation column *[distillation column 3]* with a reboiler *[reboiler 5]* to generate the natural gas liquids stream *[column 4, line 14 "The bottom portion of the column is equipped with a reboiler 5... the*

bottoms product 26 flows from the bottom of the column]; and condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream *[column 4 line 27 to 29 – "the overhead vapors 10 flow to an overhead condenser 7 which cools and partially condenses the overhead vapors", condenser 7 operates in tandem with reflux drum 19 to yield the overhead product stream 21]*.

Clearly at least based on the above, dependent claim 8 is unpatentable over D1 and should be cancelled.

Independent **claim 10** recites a system comprising: piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas and C_3 to C_8 hydrocarbons; and a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream, wherein the purified recycle stream includes the injection gas, wherein the natural gas liquids stream includes the C_3-C_8 hydrocarbons, and wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream.

D1 anticipates the subject matter recited in independent claim 10 as each and every feature recited in independent claim 10 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A.

In particular, D1 discloses a system comprising: piping configured to receive a recycle stream *[CO_2 gas stream 25]*, wherein the recycle stream includes an injection gas *[column 3, lines 47 to 49 –system is for treatment of a "hydrocarbon rich CO_2 gas for injection into an oil-bearing formation"]* and C_3 to C_8 hydrocarbons *[column 3, line 51 – the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons; and TABLE I, which shows the "feed" containing CO_2 and C_3 to "C_{7+}"]*; and

a separator coupled to the piping and configured to separate the recycle stream *[distillation column 3 separates the CO_2 gas stream 25]* into a purified recycle stream *[overhead product stream 21]* and a natural gas liquids stream *[bottoms product 26, and column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons"]*, wherein the purified recycle stream *[overhead product stream 21]* includes the injection gas

[TABLE I, which shows "overhead product" containing the CO_2], wherein the natural gas liquids stream *[bottoms product 26]* includes the C_3 -C_8 hydrocarbons *[TABLE I, showing "bottoms product" containing C_3 to C_{7+}]*, and

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions *[D1 does not subject any stream to cryogenic conditions; furthermore D1 does not describe isolating either methane or ethane, for which cryogenic conditions are conventionally used; additionally, D1 utilizes propane as a refrigerant for condenser 7 (see column 4 line 29), and propane refrigerant is not considered to provide cryogenic conditions]*, membranes *[D1 does not mention using membranes]*, and carbon dioxide recovery solvents *[D1 does not use solvents in the process; the background section of D1 discusses solvent use as being problematic, see column 1, lines 47 to 55]* between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

Clearly at least based on the above, independent claim 10 is unpatentable over D1 and should be cancelled.

Dependent **claim 11** recites the system according to claim 10, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

D1 anticipates the subject matter recited in dependent claim 11 as each and every feature recited in dependent claim 11 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A. In particular, D1 discloses that the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water *[column 3, lines 47 to 49 – "...a hydrocarbon rich CO_2 gas for injection into an oil-bearing formation"]*.

Clearly at least based on the above, dependent claim 11 is unpatentable over D1 and should be cancelled.

Dependent **claim 12** recites the system according to claim 10, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

D1 anticipates the subject matter recited in dependent claim 12 as each and every feature recited in dependent claim 12 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A. In particular, D1 discloses that the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas

liquids stream using a phase separator and/or a column *[distillation column 3 is a separation column]*.

Clearly at least based on the above, dependent claim 12 is unpatentable over D1 and should be cancelled.

Dependent **claim 13** recites the system according to claim 10, wherein the recycle stream comprises C_1 to C_2 hydrocarbons, and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream.

D1 anticipates the subject matter recited in dependent claim 13 as each and every feature recited in dependent claim 13 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A. In particular, D1 discloses that the recycle stream *[CO_2 gas stream 25]* comprises C_1 to C_2 hydrocarbons *[column 3 lines 51 to 53 – "the feed stream may contain a mixture of carbon dioxide, methane, ethane..."]*, and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream *[TABLE I, showing "overhead product" containing C_1 to C_2]*.

Clearly at least based on the above, dependent claim 13 is unpatentable over D1 and should be cancelled.

Dependent **claim 16** recites the system according to claim 10, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

D1 anticipates the subject matter recited in dependent claim 16 as each and every feature recited in dependent claim 16 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A. In particular, D1 discloses that the separator *[distillation column 3]* comprises a separation column *[distillation column 3 is a separation column]*, a reboiler *[reboiler 5]*, and a condenser *[condenser 7]*,

wherein the separation column receives the recycle stream *[distillation column 3 receives CO_2 gas stream 25]*,

wherein the reboiler *[reboiler 5]* receives a first portion of the recycle stream from the separation column *[distillation column 3]* and generates the natural gas liquids stream *[column 4,*

line 14 "The bottom portion of the column is equipped with a reboiler 5… the bottoms product 26 flows from the bottom of the column], and

wherein the condenser *[condenser 7]* receives a second portion of the recycle stream from the separation column and generates the purified recycle stream *[condenser 7 operates in tandem with reflux drum 19 to yield the overhead product stream 21].*

Clearly at least based on the above, dependent claim 16 is unpatentable over D1 and should be cancelled.

Independent **claim 18** recites a method comprising: receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids; and separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, wherein the natural gas liquids stream comprises the natural gas liquids, wherein the natural gas comprises C_1 to C_2 hydrocarbons, and wherein the natural gas liquids comprise C_3-C_8 hydrocarbons.

D1 anticipates the subject matter recited in independent claim 18 as each and every feature recited in independent claim 18 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A.

In particular, D1 discloses a method comprising: receiving a carbon dioxide recycle stream *[CO_2 gas stream 25]*, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids *[column 3, line 51 – the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons…"]*; and

separating the carbon dioxide recycle stream *[distillation column 3 separates the CO_2 gas stream 25]* into a purified carbon dioxide recycle stream *[overhead product stream 21]* and a natural gas liquids stream *[bottoms product 26]*,

wherein the purified carbon dioxide recycle stream *[overhead product stream 21]* includes the carbon dioxide and the natural gas *[TABLE I, showing "overhead product" containing CO_2, C_1 and C_2]*, wherein the natural gas liquids stream *[bottoms product 26]* comprises the natural gas liquids *[TABLE I, showing "bottoms product" containing C_3 to C_{7+}]*, wherein the natural gas comprises C_1 to C_2 hydrocarbons *[TABLE I, showing overhead product containing C_1 to C_2]*, and wherein the natural gas liquids comprise C_3-C_8 hydrocarbons *[TABLE I, showing "bottoms product" containing C_3 to C_{7+}]*.

Clearly at least based on the above, independent claim 18 is unpatentable over D1 and

should be cancelled.

Independent **claim 21** recites a set of process equipment configured to: receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide, wherein the natural gas liquids stream includes the natural gas liquids, and wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

D1 anticipates the subject matter recited in independent claim 21 as each and every feature recited in independent claim 21 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A.

In particular, D1 discloses a set of process equipment configured to: receive a carbon dioxide recycle stream *[CO_2 gas stream 25]*, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids *[column 3, line 51 – the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons…"]*; and

separate *[distillation column 3]* the carbon dioxide recycle stream *[CO_2 gas stream 25]* into a purified carbon dioxide recycle stream *[overhead product stream 21]* and a natural gas liquids stream *[bottoms product 26]*,

wherein the purified carbon dioxide recycle stream *[overhead product stream 21]* includes the carbon dioxide *[column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide…"; and TABLE I, showing "overhead product" containing the CO_2]*,

wherein the natural gas liquids stream *[bottoms product 26]* includes the natural gas liquids *[column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons"]*,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions *[D1 does not use cryogenic conditions]*, membranes *[D1 does not use membranes]*, and carbon dioxide recovery solvents *[D1 does not use solvents]* between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

Clearly at least based on the above, independent claim 21 is unpatentable over D1 and should be cancelled.

Dependent **claim 22** recites the set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

D1 anticipates the subject matter recited in dependent claim 22 as each and every feature recited in dependent claim 22 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A. In particular, D1 discloses that the carbon dioxide recycle stream *[CO_2 gas stream 25]* comprises natural gas *[see column 3, line 51, and TABLE I, "feed", which contains C_1 and C_2]*, and

wherein separating the carbon dioxide recycle stream *[CO_2 gas stream 25]* into the purified carbon dioxide recycle stream *[overhead product stream 21]* and the natural gas liquids stream *[bottoms product 26]* includes separating the natural gas into the purified carbon dioxide recycle stream *[column 3, line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane..."]*.

Clearly at least based on the above, dependent claim 22 is unpatentable over D1 and should be cancelled.

Dependent **claim 27** recites the set of process equipment according to claim 21, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises: receiving the carbon dioxide recycle stream at a separation column; reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

D1 anticipates the subject matter recited in dependent claim 27 as each and every feature recited in dependent claim 27 is explicitly shown in D1 as set out below and as highlighted in the claim chart of Appendix A. In particular, D1 discloses receiving the carbon dioxide recycle stream *[CO_2 gas stream 25]* at a separation column *[CO_2 gas stream 25 is received at distillation column 3]*;

reboiling a portion of the carbon dioxide recycle stream received from the separation

column *[distillation column 3]* with a reboiler *[reboiler 5]* to generate the natural gas liquids stream *[column 4, line 14 "The bottom portion of the column is equipped with a reboiler 5... the bottoms product 26 flows from the bottom of the column]*; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser *[condenser 7]* to generate the purified carbon dioxide recycle stream *[condenser 7 operates in tandem with reflux drum 19 to yield the overhead product stream 21]*.

Clearly at least based on the above, dependent claim 21 is unpatentable over D1 and should be cancelled.

2) **It is submitted that claim 1 does not comply with Section 28.3 of the *Patent Act*. This claim is directed to subject matter that would have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to D2 in view of D3.**

Independent **claim 1** recites a method comprising: receiving a hydrocarbon feed stream, wherein the hydrocarbon feed stream includes carbon dioxide, natural gas liquid (NGL), and heavy hydrocarbons, wherein the NGL includes C_3-C_8 hydrocarbons, and wherein the heavy hydrocarbons include C_{9+} hydrocarbons; separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon rich stream includes most of the C_{9+} hydrocarbons in the hydrocarbon feed stream, and wherein the carbon dioxide recycle stream includes most of the carbon dioxide and most of the C_3-C_8 hydrocarbons in the hydrocarbon feed stream; separating the carbon dioxide recycle stream into a sour NGL rich stream and a purified carbon dioxide recycle stream, wherein the sour NGL rich stream includes some of the C_3-C_8 hydrocarbons in the carbon dioxide recycle stream, and wherein the purified carbon dioxide recycle stream includes most of the carbon dioxide in the carbon dioxide recycle stream; separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream, wherein the sweet NGL rich stream includes the substantially all of the C_3-C_8 hydrocarbons in the [sour] NGL rich stream, and wherein the carbon dioxide rich stream includes substantially all of the carbon dioxide in the sour NGL rich stream; combining a carbon dioxide makeup stream from a source external to the method with the purified carbon dioxide recycle stream; and subsequently injecting the combined carbon dioxide

makeup stream and the purified carbon dioxide recycle stream into a subterranean formation, wherein the carbon dioxide is not removed from the hydrocarbon feed stream and is not removed from the carbon dioxide recycle stream prior to separating the carbon dioxide recycle stream into the sour NGL rich stream and the purified carbon dioxide recycle stream, and wherein the hydrocarbon feed stream, the carbon dioxide recycle stream, and the sour NGL rich stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the heavy hydrocarbon rich stream, the purified carbon dioxide recycle stream, the sweet NGL rich stream, and the carbon dioxide rich stream.

D2 and D3 render obvious the subject matter recited in independent claim 1 as set out below and as highlighted in the claim chart of Appendix B. D2 provides a general overview of the carbon dioxide miscibility flood process. In particular, D2 describes processing steps used at each stage of the process, beginning with generating a production stream at the "production well", separating the production stream into an oil (i.e. heavy hydrocarbon) -containing stream and a gas stream, separating the gas stream into a recovered carbon dioxide stream and a natural gas liquids stream, and reinjecting the recovered carbon dioxide stream into the "injection well". An oil stream and a natural gas liquids stream are sold as "oil sales" and "NGL sales", respectively. D2 is therefore in the same general field as Canadian Patent No. 2,949,039.

Turning again to independent claim 1, D2 teaches receiving a hydrocarbon feed stream *[Figure 5.1, stream output by "producer"],* wherein the hydrocarbon feed stream includes carbon dioxide, natural gas liquid (NGL), and heavy hydrocarbons, wherein the NGL includes C_3-C_8 hydrocarbons, and wherein the heavy hydrocarbons include C_{9+} hydrocarbons *[Figure 5.1, stream output by "producer" would contain carbon dioxide and a wide range of hydrocarbons, including C_3 to C_{9+}]*; and

separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream *[Figure 5.1, stream at "oil sales", and Figure 5.4, stream at "oil sales"]* and a carbon dioxide recycle stream *[Figure 5.1, stream entering "CO_2 extraction plant"]*, wherein the heavy hydrocarbon rich stream includes most of the C_{9+} hydrocarbons in the hydrocarbon feed stream, and wherein the carbon dioxide recycle stream includes most of the carbon dioxide and most of the C_3-C_8 hydrocarbons in the hydrocarbon feed stream *[Figure 5.1, stream at "oil sales" would include most of C_{9+} hydrocarbons, and stream at "CO_2 extraction plant" would include most of the carbon dioxide and most of the C_3-C_8 hydrocarbons].*

D2 does not explicitly show in Figures 5.1 and 5.4, separating the carbon dioxide recycle stream into a sour NGL rich stream and a purified carbon dioxide recycle stream, or separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream.

D3 generally describes separation of a feed stream containing hydrocarbon components by distillation, resulting in the production of a bottom product stream and an overhead product stream, both with desired specifications. In particular, D3 describes a distillative technique involving recycling a small portion of a bottom product stream of a second distillation column, typically a C_3 to C_6 stream, to a first distillation column, wherein the overhead stream is not significantly contaminated by the recycled bottom product stream, to adjust column operating conditions and effect energy savings. D3 is therefore in the same general field as Canadian Patent No. 2,949,039.

D3 teaches distilling a carbon dioxide recycle stream that "is derived from one or more prior separation processes" *[see column 5, lines 53 to 57]*. In particular, D3 teaches separating a carbon dioxide recycle stream *[distillative column 14 separates line 12]* into a sour NGL rich stream *[line 32]* and a purified carbon dioxide recycle stream *[line 20]*, wherein the sour NGL rich stream includes some of the C_3-C_8 hydrocarbons in the carbon dioxide recycle stream *[column 6, lines 7 to 9 "the bottom product stream, containing C_{2+} and the C_3-C_6 additive and hydrogen sulfide, is withdrawn through line 32"]*, and wherein the purified carbon dioxide recycle stream includes most of the carbon dioxide in the carbon dioxide recycle stream *[column 5 lines 65 to 66 "an enriched carbon-dioxide overhead product stream is removed overhead through line 20"]*; and

separating the sour NGL rich stream *[distillative column 38 separates line 32]* into a sweet NGL rich stream *[line 60, TABLE I, bottoms stream 60 contains no H_2S and is therefore sweet]* and a carbon dioxide rich stream *[line 44]*, wherein the sweet NGL rich stream includes the substantially all of the C_3-C_8 hydrocarbons in the source NGL rich stream *[column 6 lines 19 to 24 "bottom product stream containing the C_3 -C_6 additive agent is removed through line 48 into a reboiler 50, where a portion is recycled through line 52 to the bottom of the column, while another portion is removed by line 60"]*, and wherein the carbon dioxide rich stream includes substantially all of the carbon dioxide in the sour NGL rich stream *[TABLE I, "overhead stream 44" contains all CO_2 of feed stream 36]*, and

wherein the hydrocarbon feed stream, the carbon dioxide recycle stream, and the sour NGL rich stream are not subjected to cryogenic conditions *[D3 does not mention using cryogenic conditions in Figure 1; also, column 6 lines 57 to 60 "the higher temperature of the overhead*

reflux condenser permits employing a less expensive cooling source, such as cooling water, air or a more moderate refrigerant source"], membranes *[D3 does not mention using membranes]* and carbon dioxide recovery solvents *[D3 does not mention using solvents]* between being received and being separated into the heavy hydrocarbon rich stream, the purified carbon dioxide recycle stream, the sweet NGL rich stream, and the carbon dioxide rich stream.

Turning again to D2, D2 teaches combining a carbon dioxide makeup stream from a source external to the method with the purified carbon dioxide recycle stream *[Figure 5.1, "CO_2 plant delivery"];* subsequently injecting the combined carbon dioxide makeup stream and the purified carbon dioxide recycle stream into a subterranean formation *[Figure 5.1, "CO_2 injection"];* and wherein the carbon dioxide is not removed from the hydrocarbon feed stream and is not removed from the carbon dioxide recycle stream prior to separating the carbon dioxide recycle stream into the sour NGL rich stream and the purified carbon dioxide recycle stream *[Figure 5.1 does not show net removal of CO_2 between "Production Well" and "CO_2 Extraction plant"].*

It would have been obvious to a person skilled in the art to combine the teachings of D2 and D3 to provide a carbon dioxide miscibility flood process in which sour gas is separated from NGL by a distillative technique, and without the use of cryogenic conditions, membranes or carbon dioxide recovery solvents, to effect energy savings for the carbon dioxide miscibility flood process.

Clearly at least based on the above, independent claim 1 is unpatentable over D2 in view of D3 and should be cancelled.

3) **It is submitted that claims 4, 5, 14, 23 and 24 do not comply with Section 28.3 of the *Patent Act*. These claims are directed to subject matter that would have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to D1 in view of D3 and common general knowledge.**

Dependent **claim 4** recites the method according to claim 2, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

D1 and D3 render obvious the subject matter recited in dependent claim 4 as set out

below and as highlighted in the claim chart of Appendix C. D1 generally pertains to a method of treating carbon dioxide rich gas for injection into a petroleum reservoir in a carbon dioxide miscibility flood process. The carbon dioxide rich gas contains methane, nitrogen, ethane, propane, butanes, and heavier components, and is distilled such that substantially all of the carbon dioxide, ethane, and propane are produced as an overhead vapor, and substantially all of the heavier components are produced as a commercially marketable bottoms product. D1 is therefore in the same general field as Canadian Patent No. 2,949,039.

D1 teaches that the carbon dioxide recycle stream comprises acid gas, but D1 does not teach that the acid gas is separated into the natural gas liquids stream. Although D1 correctly teaches that H_2S improves the miscibility of the injection gas *[column 3, line 12]*, it is common general knowledge that H_2S is a corrosive material and imposes strict materials and handling requirements on downstream equipment, such as valves and pipe joints *[for example, see D2, page 111, first paragraph]*. Additionally, it is common general knowledge that H_2S poses a safety hazard. Carbon dioxide miscibility flood processes carried out in more populated areas often need to comply with local bylaws, which prohibit H_2S to remain in the carbon dioxide reinjection stream due to safety issues associated with H_2S transport through pipelines. In such cases, the H_2S cannot be reinjected and must be removed.

D3 teaches that the carbon dioxide recycle stream *[Figure 1, line 12]* comprises acid gas *[column 5, lines 57 and 58 "the feed stream comprises hydrogen sulfide"]*, and wherein separating the carbon dioxide recycle stream *[distillative column 14 separates line 12]* into the purified carbon dioxide recycle stream *[line 20]* and the natural gas liquids stream *[line 32]* includes separating the acid gas into the natural gas liquids stream *[column 6, lines 7 to 9 "the bottom product stream, containing C_{2+} and the C_3 -C_6 additive and hydrogen sulfide is withdrawn through line 32"]*.

It would have been obvious to a person skilled in the art to combine the teachings of D1 and D3 in view of common general knowledge to separate acid gas from the purified carbon dioxide recycle stream prior to reinjection, as the acid gas serves as a contaminant during subsequent CO_2–NGL separation cycles *[see D3, column 6 lines 18 and 19 "contaminants, such as hydrogen sulfide, is removed"]* and poses a safety hazard.

Clearly at least based on the above, dependent claim 4 is unpatentable over D1 in view of D3 and should be cancelled.

Dependent **claim 5** recites the method according to claim 4, further comprising

separating the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

D1 and D3 render obvious the subject matter recited in dependent claim 5 as set out below and as highlighted in the claim chart of Appendix C. D3 teaches separating the natural gas liquids stream *[distillative column 38 separates line 32]* into a sweet natural gas liquids stream *[TABLE I, "bottoms stream 60" contains no H_2S and is therefore sweet]* and an acid gas stream *[TABLE I, "overhead stream 44" contains all H_2S of feed stream 36]*.

It would have been obvious to a person skilled in the art to combine the teachings of D1 and D3 to provide a purified bottoms product with acid gas removed, in order to increase the sale value of the bottoms product and render it more commercially marketable.

Clearly at least based on the above, dependent claim 5 is unpatentable over D1 in view of D3 and should be cancelled.

Dependent **claim 14** recites the system according to claim 10, wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream, wherein the sweet natural gas liquids stream includes the C_3-C_8 hydrocarbons, and wherein the acid gas stream includes H_2S and/or CO_2.

D1 and D3 render obvious the subject matter recited in dependent claim 14 as set out below and as highlighted in the claim chart of Appendix C. D3 teaches separating the natural gas liquids stream *[distillative column 38 separates line 32]* into a sweet natural gas liquids stream *[TABLE I, "bottoms stream 60" contains no H_2S and is therefore sweet]* and an acid gas stream *[TABLE I, "overhead stream 44" contains all H_2S of feed stream 36]*.

It would have been obvious to a person skilled in the art to combine the teachings of D1 and D3 to provide a purified bottoms product with acid gas removed, in order to increase the sale value of the bottoms product and render it more commercially marketable.

Clearly at least based on the above, dependent claim 14 is unpatentable over D1 in view of D3 and should be cancelled.

Dependent **claim 23** recites the set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

D1 and D3 render obvious the subject matter recited in dependent claim 23 as set out

below and as highlighted in the claim chart of Appendix C.

D1 teaches that the carbon dioxide recycle stream comprises acid gas, but D1 does not teach that the acid gas is separated into the natural gas liquids stream. Although D1 correctly teaches that H_2S improves the miscibility of the injection gas *[column 3, line 12]*, it is common general knowledge that H_2S is a corrosive material and imposes strict materials and handling requirements on downstream equipment, such as valves and pipe joints *[for example, see D2, page 111, first paragraph]*. Additionally, it is common general knowledge that H_2S poses a safety hazard. Carbon dioxide miscibility flood processes carried out in more populated areas often need to comply with local bylaws, which prohibit H_2S to remain in the carbon dioxide reinjection stream due to safety issues associated with H_2S transport through pipelines. In such cases, the H_2S cannot be reinjected and must be removed.

D3 teaches separating the natural gas liquids stream *[line 32]* into a sweet natural gas liquids stream *[TABLE I, "bottom stream 60" contains no H_2S and is therefore sweet]* and an acid gas stream *[TABLE I, "overhead stream 44" contains all H_2S of feed stream 36]*.

It would have been obvious to a person skilled in the art to combine the teachings of D1 and D3 in view of common general knowledge to separate acid gas from the purified carbon dioxide recycle stream prior to reinjection, as the acid gas serves as a contaminant during subsequent CO_2–NGL separation cycles *[see D3, column 6 lines 18 and 19 "contaminants, such as hydrogen sulfide, is removed"]* and poses a safety hazard.

Clearly at least based on the above, dependent claim 23 is unpatentable over D1 in view of D3 and should be cancelled.

Dependent **claim 24** recites the set of process equipment according to claim 23, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

D1 and D3 render obvious the subject matter recited in dependent claim 24 as set out below and as highlighted in the claim chart of Appendix C. D3 teaches separating the natural gas liquids stream *[line 32]* into a sweet natural gas liquids stream *[TABLE I, "bottom stream 60" contains no H_2S and is therefore sweet]* and an acid gas stream *[TABLE I, "overhead stream 44" contains all H_2S of feed stream 36]*.

It would have been obvious to a person skilled in the art to combine the teachings of D1 and D3 to provide a purified bottoms product with acid gas removed, in order to increase the sale value of the bottoms product and render it more commercially marketable.

Clearly at least based on the above, dependent claim 24 is unpatentable over D1 in view of D3 and should be cancelled.

4) **It is submitted that claims 6, 7, 25 and 26 do not comply with Section 28.3 of the *Patent Act*. These claims are directed to subject matter that would have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to D1 in view of D4.**

Dependent **claim 6** recites the method according to claim 2, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

D1 and D4 render obvious the subject matter recited in dependent claim 6 as set out below and as highlighted in the claim chart of Appendix D. D1 does not teach dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream. D4 pertains to a process for regeneration of a carbon dioxide gaseous stream such used in a carbon dioxide miscibility flood process. The process utilizes an economic, low energy intensive cycle with at least one distillation column to regenerate a carbon dioxide recovery stream, which is recycled for further use. D4 is therefore in the same general field as Canadian Patent No. 2,949,039.

D4 teaches dehydrating the carbon dioxide recycle stream *[stream 10]* before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream *[Figure 1, feed gas stream 10 is dehydrated in dryer unit 22 before being separated into a purified carbon dioxide recycle stream and a natural gas liquids stream].*

It would have been obvious to a person skilled in the art to combine the teachings of D1 and D4 to remove water from the feed stream prior to separation, to increase the efficiency of the CO_2–NGL separation and thereby render the separation more economical.

Clearly at least based on the above, dependent claim 6 is unpatentable over D1 in view of D4 and should be cancelled.

Dependent **claim 7** recites the method according to claim 2, further comprising: compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

D1 and D4 render obvious the subject matter recited in dependent claim 7 as set out below and as highlighted in the claim chart of Appendix D. D1 does not teach compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

D4 teaches compressing the carbon dioxide recycle stream *[stream 10]* before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream *[Figure 1, feed gas stream 10 is compressed by feed gas compressor unit 12 prior to being separated into CO_2 product stream 20 and NGL-containing bottoms stream 64];* and

adding additional carbon dioxide to the purified carbon dioxide recycle stream *[CO_2 product stream 20]* to form a carbon dioxide injection stream *[column 5 lines 10 to 18 - CO_2 product stream 20 "is preferably mixed with fresh CO_2 before being reinjected into the petroleum-bearing subsurface"]*.

It would have been obvious to a person skilled in the art to combine the teachings of D1 and D4 to compress the carbon dioxide recycle stream before entering the distillation column in order to achieve a desired operating pressure *[D1, column 4 line 1, "the feed 1 enters the column at approximately 350 psia"]*, and to add additional carbon dioxide to the purified carbon dioxide stream in order to compensate for carbon dioxide sequestration that inevitably occurs in the carbon dioxide miscibility flood process.

Clearly at least based on the above, dependent claim 7 is unpatentable over D1 in view of D4 and should be cancelled.

Dependent **claim 25** recites the set of process equipment according to claim 21, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

D1 and D4 render obvious the subject matter recited in dependent claim 25 as set out below and as highlighted in the claim chart of Appendix D. D4 teaches dehydrating the carbon dioxide recycle stream *[stream 10]* before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream *[Figure 1, feed gas*

stream 10 is dehydrated in dryer unit 22 before being separated into a purified carbon dioxide recycle stream and a natural gas liquids stream].

It would have been obvious to a person skilled in the art to combine the teachings of D1 and D4 to remove water from the feed stream prior to separation, to increase the efficiency of the CO_2–NGL separation and thereby render the operation more economical.

Clearly at least based on the above, dependent claim 25 is unpatentable over D1 in view of D4 and should be cancelled.

Dependent **claim 26** recites the set of process equipment according to claim 21, further configured to: compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

D1 and D4 render obvious the subject matter recited in dependent claim 26 as set out below and as highlighted in the claim chart of Appendix D. D4 teaches compressing the carbon dioxide recycle stream *[feed gas stream 10]* before separating the carbon dioxide recycle stream *[feed gas stream 10]* into the purified carbon dioxide recycle stream and the natural gas liquids stream *[Figure 1 - feed gas stream 10 is compressed by feed gas compressor unit 12 prior to being separated into CO_2 product stream 20 and NGL-containing bottoms stream 64];* and

adding additional carbon dioxide to the purified carbon dioxide recycle stream *[CO_2 product stream 20]* to form a carbon dioxide injection stream *[column 5 line 10, CO_2 product stream 20 "is preferably mixed with fresh CO_2 before being reinjected into the petroleum-bearing subsurface"*].

petroleum-bearing subsurface"].

It would have been obvious to a person skilled in the art to combine the teachings of D1 and D4 to compress the carbon dioxide recycle stream before entering the distillation column in order to achieve a desired operating pressure *[D1, column 4 line 1, "the feed 1 enters the column at approximately 350 psia"]*, and to add additional carbon dioxide to the purified carbon dioxide stream in order to compensate for carbon dioxide sequestration that inevitably occurs in the carbon dioxide miscibility flood process.

Clearly at least based on the above, dependent claim 26 is unpatentable over D1 in view of D4 and should be cancelled.

5) **It is submitted that claims 9, 17 and 28 do not comply with Section 28.3 of the *Patent Act*. These claims are directed to subject matter that would have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to D1.**

Dependent **claim 9** recites the method according to claim 2, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole% to 28 mole % of the natural gas liquids stream.

D1 renders obvious the subject matter recited in dependent claim 9 as set out below and as highlighted in the claim chart of Appendix E. D1 teaches the purified carbon dioxide recycle stream *[overhead product stream 21]* is suitable for reinjection into a subterranean formation in an enhanced oil recovery process *[Column 4 line 59 "overhead product stream is further compressed in a compressor (not shown) and sent to injection wells 24"]*, wherein the purified carbon dioxide recycle stream *[overhead product stream 21]* includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream *[Table I, "overhead product" contains all CO_2, all C_1 and a portion of the C_3 from the "feed"]*, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream *[overhead product stream 21]* is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream *[Table I, "overhead product" contains a greater molar percentage of CO_2 than methane]*, wherein the natural gas

liquids stream *[bottoms product 26]* includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream *[Table I, "bottoms product" contains no CO_2 and some C_3 hydrocarbons]*.

D1 does not teach that the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole% to 28 mole % of the natural gas liquids stream. However, D1 does teach that the amount of C_3 in the overhead and bottoms streams is adjustable *[see D1, column 3 line 8, "the recovery of C_3/C_4 can be monitored to...optimize the economical operation of the plant"; and TABLE II, which defines the available operating range of reboiler 5 as "225 to 400 °F "]*. Also, the amount of C_3 in the incoming carbon dioxide recycle stream is greater in Canadian Patent No. 2,949,039 *[see Table 8A, "Dehydrated Recycle Stream 160", which contains a C_3 percentage of 4.0 %]* as compared to D1 *[Table I, "feed" contains a C_3 percentage of only 1.1 %]*.

It would have been within the ambit of a person skilled in the art to adjust the operating conditions of D1, such as lowering the operating temperature of reboiler 5, to increase the amount of C_3 in the bottoms product 26 to increase its sale value and thereby render the operation more economical.

Clearly at least based on the above, dependent claim 9 is unpatentable over D1 in view of common general knowledge and should be cancelled.

Dependent **claim 17** recites the system according to claim 10, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified recycle stream includes substantially all of the injection gas, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream, wherein the natural gas liquids stream includes substantially none of the injection gas and a second portion of the C_3 hydrocarbons from the recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second

portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

D1 renders obvious the subject matter recited in dependent claim 17 as set out below and as highlighted in the claim chart of Appendix E. D1 teaches the purified recycle stream *[overhead product stream 21]* is suitable for reinjection into a subterranean formation in an enhanced oil recovery process *[Column 4 line 59 "overhead product stream is further compressed in a compressor (not shown) and sent to injection wells 24"]*,

wherein the purified recycle stream *[overhead product stream 21]* includes substantially all of the injection gas, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the recycle stream *[Table I, "overhead product" contains all CO_2, all C_1 and a portion of the C_3 from the "feed"]*,

wherein a molar percentage of the injection gas in the purified recycle stream *[overhead product stream 21]* is greater than a molar percentage of the methane in the purified recycle stream *[Table I, "overhead product" contains a greater molar percentage of CO_2 than methane]*,

wherein the natural gas liquids stream *[bottoms product 26]* includes substantially none of the injection gas and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream *[Table I, "bottoms product" contains no CO_2 and some C_3 hydrocarbons]*.

D1 does not teach that the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole% to 28 mole % of the natural gas liquids stream. However, D1 does teach that the amount of C_3 in the overhead and bottoms streams is adjustable *[see D1, column 3 line 8, "the recovery of C_3/C_4 can be monitored to…optimize the economical operation of the plant"; and TABLE II, which defines the available operating range of reboiler 5 as "225 to 400 °F "]*. Also, the amount of C_3 in the incoming carbon dioxide recycle stream is greater in Canadian Patent No. 2,949,039 *[see Table 8A, "Dehydrated Recycle Stream 160", which contains a C_3 percentage of 4.0 %]* as compared to D1 *[Table I, "feed" contains a C_3 percentage of only 1.1 %]*.

It would have been within the ambit of a person skilled in the art to adjust the operating conditions of D1, such as lowering the operating temperature of reboiler 5, to increase the amount of C_3 in the bottoms product 26 to increase its sale value and thereby render the operation more economical.

Clearly at least based on the above, dependent claim 17 is unpatentable over D1 in view of common general knowledge and should be cancelled.

Dependent **claim 28** recites the set of process equipment according to claim 21, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole% to 28 mole % of the natural gas liquids stream.

D1 renders obvious the subject matter recited in dependent claim 28 as set out below and as highlighted in the claim chart of Appendix E. D1 teaches that the purified carbon dioxide recycle stream *[overhead product stream 21]* is suitable for reinjection into a subterranean formation in an enhanced oil recovery process *[Column 4 line 59 "overhead product stream is further compressed in a compressor (not shown) and sent to injection wells 24"]*,

wherein the purified carbon dioxide recycle stream *[overhead product stream 21]* includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream *[Table I, "overhead product" contains all CO_2, all C_1 and a portion of the C_3 from the "feed"]*,

wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream *[overhead product stream 21]* is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream *[Table I, "overhead product" contains a greater molar percentage of CO_2 than methane]*, and

wherein the natural gas liquids stream *[bottoms product 26]* includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream *[Table I, "bottoms product" contains no CO_2 and some C_3 hydrocarbons]*.

D1 does not teach that the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole% to 28 mole % of the natural gas liquids stream. However, D1 does teach that the amount of C_3 in the overhead and bottoms streams is adjustable *[see D1, column 3 line 8, "the recovery of C_3/C_4 can be monitored to...optimize the economical operation of the plant"; and TABLE II, which defines the available operating range of reboiler 5 as "225 to 400 °F "]*. Also, the amount of C_3 in the incoming carbon dioxide recycle stream is greater in Canadian Patent No. 2,949,039 *[see Table 8A, "Dehydrated Recycle Stream 160", which contains a C_3 percentage of 4.0 %]* as compared to D1 *[Table I, "feed" contains a C_3 percentage of only 1.1 %]*.

It would have been within the ambit of a person skilled in the art to adjust the operating conditions of D1, such as lowering the operating temperature of reboiler 5, to increase the amount of C_3 in the bottoms product 26 to increase its sale value and thereby render the operation more economical.

Clearly at least based on the above, dependent claim 28 is unpatentable over D1 in view of common general knowledge and should be cancelled.

6) **It is submitted that claims 15 and 19 do not comply with Section 28.3 of the *Patent Act*. These claims are directed to subject matter that would have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to D1 in view of D2.**

Dependent **claim 15** recites the system according to claim 10, wherein the system is further configured to: receive a feed stream; separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

D1 and D2 render obvious the subject matter recited in dependent claim 15 as set out below and as highlighted in the claim chart of Appendix F. D2 teaches receiving a feed stream *[Figure 5.1, stream output by "producer"]*;

separating the feed stream into the recycle stream and a heavy hydrocarbons stream *[Figure 5.1, stream at "oil sales", and Figure 5.4, stream at "oil sales"]*, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons *[Figures 5.1 and 5.4, streams at "oil sales" would include C_{9+} hydrocarbons]*; and

dehydrating the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream *[Figure 5.1, "production separators", which separate out "water and oil", and see Section 5.5.1, "four basic chemical products are used to dehydrate gas: glycol, calcium chloride, glycerol and solid dessicants"; glycol is considered in the art to be the predominant dehydration solvent; see also Figure 5.8, showing "dehydrator" positioned directly upstream from "NGL column" separator]*.

It would have been obvious to a person skilled in the art to combine the teachings of D1 and D2 to provide a carbon dioxide miscibility flood process in which CO_2 is separated from NGL liquids in a cost-effective manner by using a single distillation tower, and in which water is removed prior to CO_2–NGL separation to improve the efficiency of the CO_2–NGL separation.

Clearly at least based on the above, dependent claim 15 is unpatentable over D1 in view of D2 and should be cancelled.

Independent **claim 19** recites a method comprising: receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids; separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids; and separating a feed stream into the carbon dioxide recycle stream and a heavy hydrocarbon stream, wherein the heavy hydrocarbon stream includes C_{9+} hydrocarbons.

D1 and D2 render obvious the subject matter recited in independent claim 19 as set out below and as highlighted in the claim chart of Appendix F. D1 teaches receiving a carbon dioxide recycle stream *[CO_2 gas stream 25]*, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids *[column 3, line 51 – the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons"]*; and

separating the carbon dioxide recycle stream *[distillation column 3 separates the CO_2 gas stream 25]* into a purified carbon dioxide recycle stream *[overhead product stream 21]* and a natural gas liquids stream *[bottoms product 26]*, wherein the purified carbon dioxide recycle

stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids *[column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons"]*.

D1 does not explicitly teach separating a feed stream into the carbon dioxide recycle stream and a heavy hydrocarbon stream, wherein the heavy hydrocarbon stream includes C_{9+} hydrocarbons. D2 teaches separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a carbon dioxide recycle stream [*Figure 5.1, stream at "oil sales"]*, wherein the heavy hydrocarbon stream includes C_{9+} hydrocarbons *[Figure 5.1, the heavy hydrocarbon stream at "oil sales" would include C_{9+} hydrocarbons]*.

It would have been obvious to a person skilled in the art to combine the teachings of D1 and D2 to provide a carbon dioxide miscibility flood process in which CO_2 is separated from NGL liquids in a cost-effective manner by using a single distillation tower.

Clearly at least based on the above, in dependent claim 19 is unpatentable over D1 in view of D2 and should be cancelled.

7) **It is submitted that claim 20 does not comply with Section 28.3 of the *Patent Act*. This claim is directed to subject matter that would have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to D3 in view of D2.**

Independent **claim 20** recites a method comprising: receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids; separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids; receiving a feed stream, wherein the feed stream includes carbon dioxide, C_1 to C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_{9+} hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons; and separating the feed stream into a heavy hydrocarbon stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon stream includes substantially all of the C_{9+} hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream, wherein the heavy hydrocarbon stream includes

substantially none of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream, and wherein the carbon dioxide recycle stream includes substantially all of the carbon dioxide, the C, to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream, wherein the purified carbon dioxide recycle stream includes substantially all of the C_2 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially none of the C_2 hydrocarbons from the carbon dioxide recycle stream, and wherein the purified carbon dioxide recycle stream includes substantially none of the C_3 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially all of the C_3 hydrocarbons from the carbon dioxide recycle stream.

D3 and D2 render obvious the subject matter recited in independent claim 20 as set out below and as highlighted in the claim chart of Appendix G. D3 teaches receiving a carbon dioxide recycle stream *[line 152]*, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids *[column 10 line 59, "a feed stream, consisting essentially of CO_2, ethane and C_{3+}, is introduced by line 152"];* separating the carbon dioxide recycle stream *[distillative column 150 separates line 152]* into a purified carbon dioxide recycle stream *[line 160]* and a natural gas liquids stream *[line 168]*, wherein the purified carbon dioxide recycle stream *[line 160]* includes the carbon dioxide and the natural gas *[column 10 line 66, "a mixture, composed essentially of CO_2 and ethane, is removed as an overhead product stream by line 160"]*, and wherein the natural gas liquids stream *[line 168]* comprises the natural gas liquids *[column 11 line 2, "a bottom product stream, comprising primarily propane, together with any recycled liquid additive agent introduced into the condenser or upper part of the column 150, is withdrawn by line 168"],*

wherein the purified carbon dioxide recycle stream *[line 160]* includes substantially all of the C_2 hydrocarbons from the carbon dioxide recycle stream *[TABLE VII, showing "overhead stream 160" containing all of C_2 in "feed stream 152"]* and the natural gas liquids stream *[line 168]* includes substantially none of the C_2 hydrocarbons from the carbon dioxide recycle stream *[TABLE VII, showing "bottom stream 168" containing no C_2]*, and wherein the purified carbon dioxide recycle stream *[line 160]* includes substantially none of the C_3 hydrocarbons from the carbon dioxide recycle stream *[TABLE VII, showing "overhead stream 160" containing only about 10% of C_3 in "feed stream 152"]* and the natural gas liquids stream includes substantially all of the C_3 hydrocarbons from the carbon dioxide recycle stream *[TABLE VII, showing "bottom stream 168" containing about 90% of C_3 in "feed stream 152". It would have been obvious to modify the operating conditions of D3, such as lowering the operating temperature of reboiler*

164 or condenser 156, to increase the amount of C_3 in the bottom stream 168 to near 100% to increase the yield of C_3 in propane output line 182].

D3 does not explicitly teach receiving a feed stream, wherein the feed stream includes carbon dioxide, C_1 to C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_{9+} hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons; or separating the feed stream into a heavy hydrocarbon stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon stream includes substantially all of the C_{9+} hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream. However, D3 does teach that "the feed stream is derived from one or more prior separation processes" *[see column 5, lines 53 to 57].* D2 teaches receiving a feed stream *[Figure 5.1, stream output by "producer"],* wherein the feed stream includes carbon dioxide, C_1 to C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_{9+} hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons *[Figure 5.1, these hydrocarbons would all be present in stream output by "producer"].* D2 also teaches separating the feed stream into a heavy hydrocarbon stream *[Figure 5.1, stream at "oil sales", and Figure 5.4, stream at "oil sales"]* and a carbon dioxide recycle stream *[Figure 5.1, stream at "CO_2 extraction plant"]*, wherein the heavy hydrocarbon stream includes substantially all of the C_{9+} hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream *[Figure 5.1, heavy hydrocarbon stream at "oil sales" would include substantially all of the C_{9+} hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons]*, wherein the heavy hydrocarbon stream includes substantially none of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream *[Figures 5.1 and 5.4, streams at "oil sales" would have this composition]*, and wherein the carbon dioxide recycle stream includes substantially all of the carbon dioxide, the C, to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream, *[Figure 5.1, stream at "CO_2 extraction plant" would have this composition].*

It would have been obvious to a person skilled in the art to combine the teachings of D3 and D2 to provide a carbon dioxide miscibility flood process in which heavy hydrocarbons are separated prior to CO_2–NGL separation.

Clearly at least based on the above, independent claim 20 is unpatentable over D3 in view of D2 and should be cancelled.

At least for the reasons set forth above, it is believed that the prior art submitted herewith raises substantial new questions affecting the patentability of each of claims 1 to 28 of Canadian

Patent No. 2,949,039. Re-examination of these claims is earnestly solicited.

In accordance with Section 48.1(1) of the *Patent Act*, please charge the fee prescribed in Schedule 2, item 30(b) of the *Patent Rules* to the credit card identified in our Fee Payment Form. Should the fee submitted with this letter be insufficient to cover all of the fees for which payment is explicitly or implicitly requested by this letter, CIPO is requested to charge the amount of the insufficiency to the Marks & Clerk Deposit Account No. 600000249. In this eventuality, we would appreciate being advised by telephone or correspondence of the amount so deducted and our file reference as set out on this letter. In the event that there are insufficient funds in the Marks & Clerk deposit account to cover the indicated amount or any deficiency therein, it is requested that CIPO telephone Accounting at 1 416 595 1155, as soon as possible to notify of the same so that additional funds can be remitted promptly

Respectfully submitted,

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APPENDIX A

Claim chart comparison of claims 2, 3, 8, 10 to 13, 16, 18, 21, 22, 27 of Canadian Patent No. 2,949,039 to subject matter disclosed by D1.

Claim of Canadian Patent No. 2,949,039	Prior Art
2. A method comprising: receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and	D1 discloses receiving a carbon dioxide recycle stream *[CO_2 gas stream 25]*, which includes carbon dioxide and natural gas liquids *[column 3, line 51 – the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons..."]*; and
separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,	separating the carbon dioxide recycle stream *[distillation column 3 separates the CO_2 gas stream 25]* into a purified carbon dioxide recycle stream *[overhead product stream 21]* and a natural gas liquids stream *[bottoms product 26],*
wherein the purified carbon dioxide recycle stream includes the carbon dioxide, wherein the natural gas liquids stream includes the natural gas liquids, and	wherein the purified carbon dioxide recycle stream *[overhead product stream 21]* includes the carbon dioxide, wherein the natural gas liquids stream *[bottoms product 26]* includes the natural gas liquids *{column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of*

	said heavier hydrocarbons"], and wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions *[D1 does not subject any stream to cryogenic conditions]*, membranes *[D1 does not use membranes]*, and carbon dioxide recovery solvents *[D1 does not use solvents in the process]* between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.
3. The method according to claim 2, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.	D1 discloses: the carbon dioxide recycle stream *[CO_2 gas stream 25]* comprises natural gas *[see column 3, line 51, and TABLE I, "feed", which contains C_1 and C_2]*, and wherein separating the carbon dioxide recycle stream *[CO_2 gas stream 25]* into the purified carbon dioxide recycle stream *[overhead product stream 21]* and the natural gas liquids stream *[bottoms product 26]* includes separating the natural gas into the purified carbon dioxide recycle stream *[column 3, line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane..."]*.
8. The method according to claim 2,	D1 discloses:

wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises: receiving the carbon dioxide recycle stream at a separation column; reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.	receiving the carbon dioxide recycle stream *[CO_2 gas stream 25]* at a separation column *[CO_2 gas stream 25 is received at distillation column 3]*; reboiling a portion of the carbon dioxide recycle stream received from the separation column *[distillation column 3]* with a reboiler *[reboiler 5]* to generate the natural gas liquids stream *[column 4, line 14 "The bottom portion of the column is equipped with a reboiler 5… the bottoms product 26 flows from the bottom of the column]*; and condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser *[condenser 7]* to generate the purified carbon dioxide recycle stream *[condenser 7 operates in tandem with reflux drum 19 to yield the overhead product stream 21; alternatively, D3 teaches a condenser 18 that generates a purified carbon dioxide stream 20]*.
10. A system comprising: piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas and C_3 to C_8 hydrocarbons; and	D1 discloses piping configured to receive a recycle stream *[CO_2 gas stream 25]*, wherein the recycle stream includes an injection gas *[column 3, line 47 – system is for treatment of*

	a "hydrocarbon rich CO_2 gas for injection into an oil-bearing formation"] and C_3 to C_8 hydrocarbons *[see column 3, line 51; and TABLE I, which shows the "feed" containing CO_2 and C_3 to "C_{7+}"]* and
a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,	a separator *[distillation column 3]* coupled to the piping and configured to separate the recycle stream *[CO_2 gas stream 25]* into a purified recycle stream *[overhead product stream 21]* and a natural gas liquids stream *[bottoms product 26]*
wherein the purified recycle stream includes the injection gas,	wherein the purified recycle stream *[overhead product stream 21]* includes the injection gas *[TABLE I, which shows "overhead product" containing the CO_2]*
wherein the natural gas liquids stream includes the C_3-C_8 hydrocarbons, and	wherein the natural gas liquids stream *[bottoms product 26]* includes the C_3-C_8 hydrocarbons *[TABLE I, which shows "bottoms product" containing C_3 to C_{7+}]*, and
wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream.	wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions *[D1 does not use cryogenic conditions]*, membranes *[D1 does not use membranes]*, and carbon dioxide recovery solvents *[D1 does not use solvents]* between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

11. The system according to claim 10, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.	D1 discloses wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water *[column 3, lines 47 to 49 – "...a hydrocarbon rich CO_2 gas for injection into an oil-bearing formation"]*.
12. The system according to claim 10, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.	D1 discloses wherein the separator *[distillation column 3]* is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column *[distillation column 3 is a column]*.
13. The system according to claim 10, wherein the recycle stream comprises C_1 to C_2 hydrocarbons, and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream.	D1 discloses wherein the recycle stream *[CO_2 gas stream 25]* comprises C_1 to C_2 hydrocarbons *[column 3 lines 51 to 53 – "the feed stream may contain a mixture of carbon dioxide, methane, ethane..."]*, and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream *[TABLE I, showing "overhead product" containing C_1 to C_2]*.
16. The system according to claim 10, wherein the separator comprises a separation column, a reboiler, and a condenser,	D1 discloses wherein the separator *[distillation column 3]* comprises a separation column *[distillation column 3 is a separation column]*, a reboiler *[reboiler 5]*, and a condenser

	[condenser 7],
wherein the separation column receives the recycle stream,	wherein the separation column receives the recycle stream *[distillation column 3 receives CO_2 gas stream 25]*,
wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and	wherein the reboiler *[reboiler 5]* receives a first portion of the recycle stream from the separation column *[distillation column 3]* and generates the natural gas liquids stream *[column 4, line 14 "The bottom portion of the column is equipped with a reboiler 5... the bottoms product 26 flows from the bottom of the column]*, and
wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.	wherein the condenser *[condenser 7]* receives a second portion of the recycle stream from the separation column and generates the purified recycle stream *[condenser 7 operates in tandem with reflux drum 19 to yield the overhead product stream 21; alternatively, D3 teaches a condenser 18 that generates a purified carbon dioxide stream 20].*
18. A method comprising: receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids; and	D1 discloses: receiving a carbon dioxide recycle stream *[CO_2 gas stream 25]*, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids *[column 3, line 51 – the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and*

	heavier hydrocarbons..."]
separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,	separating the carbon dioxide recycle stream *[distillation column 3 separates the CO_2 gas stream 25]* into a purified carbon dioxide recycle stream *[overhead product stream 21]* and a natural gas liquids stream *[bottoms product 26]*,
wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas,	wherein the purified carbon dioxide recycle stream *[overhead product stream 21]* includes the carbon dioxide and the natural gas *[TABLE I, showing "overhead product" containing CO_2, C_1 and C_2]*,
wherein the natural gas liquids stream comprises the natural gas liquids,	wherein the natural gas liquids stream *[bottoms product 26]* comprises the natural gas liquids *[TABLE I, showing "bottoms product" containing C_3 to C_{7+}]*,
wherein the natural gas comprises C_1 to C_2 hydrocarbons, and	wherein the natural gas comprises C_1 to C_2 hydrocarbons *[TABLE I, showing overhead product containing C_1 to C_2]*, and
wherein the natural gas liquids comprise C_3-C_8 hydrocarbons.	wherein the natural gas liquids comprise C_3-C_8 hydrocarbons *[TABLE I, showing "bottoms product" containing C_3 to C_{7+}]*.
21. A set of process equipment configured to:	D1 discloses
receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle	receiving a carbon dioxide recycle stream *[CO_2 gas stream 25]*, wherein the

stream includes carbon dioxide and natural gas liquids; and	carbon dioxide recycle stream includes carbon dioxide and natural gas liquids *[column 3, line 51 – the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons…"]*; and
separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,	separate *[distillation column 3]* the carbon dioxide recycle stream *[CO_2 gas stream 25]* into a purified carbon dioxide recycle stream *[overhead product stream 21]* and a natural gas liquids stream *[bottoms product 26]*,
wherein the purified carbon dioxide recycle stream includes the carbon dioxide,	wherein the purified carbon dioxide recycle stream *[overhead product stream 21]* includes the carbon dioxide *[column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide…"; and TABLE I, showing "overhead product" containing the CO_2]*,
wherein the natural gas liquids stream includes the natural gas liquids, and	wherein the natural gas liquids stream *[bottoms product 26]* includes the natural gas liquids *[column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons"]*
wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are	wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are

not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.	not subjected to cryogenic conditions *[D1 does not use cryogenic conditions]*, membranes *[D1 does not use membranes]*, and carbon dioxide recovery solvents *[D1 does not use solvents]* between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.
22. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.	D1 discloses the carbon dioxide recycle stream *[CO_2 gas stream 25]* comprises natural gas *[see column 3, line 51, and TABLE I, "feed", which contains C_1 and C_2]*, and wherein separating the carbon dioxide recycle stream *[CO_2 gas stream 25]* into the purified carbon dioxide recycle stream *[overhead product stream 21]* and the natural gas liquids stream *[bottoms product 26]* includes separating the natural gas into the purified carbon dioxide recycle stream *[column 3, line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane..."]*
27. The set of process equipment according to claim 21, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:	D1 discloses:

receiving the carbon dioxide recycle stream at a separation column;	receiving the carbon dioxide recycle stream *[CO_2 gas stream 25]* at a separation column *[CO_2 gas stream 25 is received at distillation column 3]*;
reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and	reboiling a portion of the carbon dioxide recycle stream received from the separation column *[distillation column 3]* with a reboiler *[reboiler 5]* to generate the natural gas liquids stream *[column 4, line 14 "The bottom portion of the column is equipped with a reboiler 5... the bottoms product 26 flows from the bottom of the column]*; and
condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.	condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser *[condenser 7]* to generate the purified carbon dioxide recycle stream *[condenser 7 operates in tandem with reflux drum 19 to yield the overhead product stream 21; alternatively, D3 teaches a condenser 18 that generates a purified carbon dioxide stream 20].*

APPENDIX B

Claim chart comparison of claim 1 of Canadian Patent No. 2,949,039 to subject matter taught by D2 and D3.

Claim of Canadian Patent No. 2,949,039	Prior Art
1. A method comprising: receiving a hydrocarbon feed stream, wherein the hydrocarbon feed stream includes carbon dioxide, natural gas liquid (NGL), and heavy hydrocarbons, wherein the NGL includes C_3-C_8 hydrocarbons, and wherein the heavy hydrocarbons include C_{9+} hydrocarbons;	D2 teaches: receiving a hydrocarbon feed stream *[Figure 5.1, stream output by "producer"]*, wherein the hydrocarbon feed stream includes carbon dioxide, natural gas liquid (NGL), and heavy hydrocarbons, wherein the NGL includes C_3-C_8 hydrocarbons, and wherein the heavy hydrocarbons include C_{9+} hydrocarbons *[Figure 5.1, stream output by "producer" would contain carbon dioxide and C_3 to C_{9+} hydrocarbons]*; and
separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon rich stream includes most of the C_{9+} hydrocarbons in the hydrocarbon feed stream, and wherein the carbon dioxide recycle stream includes most of the carbon dioxide and most of the C_3-C_8 hydrocarbons in the hydrocarbon feed stream;	separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream *[Figure 5.1, stream at "oil sales", and Figure 5.4, stream at "oil sales"]* and a carbon dioxide recycle stream *[Figure 5.1, stream entering "CO_2 extraction plant"]*, wherein the heavy hydrocarbon rich stream includes most of the C_{9+} hydrocarbons in the hydrocarbon feed stream, and wherein the carbon dioxide recycle stream includes most of the carbon dioxide and most of the C_3-C_8 hydrocarbons in the hydrocarbon feed stream *[Figure 5.1, stream at "oil sales" would include most of C_{9+} hydrocarbons, and stream at "CO_2 extraction*

	plant" would include most of the carbon dioxide and most of the C_3-C_8 hydrocarbons]; D3 teaches:
separating the carbon dioxide recycle stream into a sour NGL rich stream and a purified carbon dioxide recycle stream,	separating the carbon dioxide recycle stream *[distillative column 14 separates line 12]* into a sour NGL rich stream *[line 32]* and a purified carbon dioxide recycle stream *[line 20]*,
wherein the sour NGL rich stream includes some of the C_3-C_8 hydrocarbons in the carbon dioxide recycle stream, and	wherein the sour NGL rich stream *[line 32]* includes some of the C_3-C_8 hydrocarbons in the carbon dioxide recycle stream *[column 6, line 7 "the bottom product stream, containing C_{2+} and the C_3-C_6 additive and hydrogen sulfide, is withdrawn through line 32"]*, and
wherein the purified carbon dioxide recycle stream includes most of the carbon dioxide in the carbon dioxide recycle stream;	wherein the purified carbon dioxide recycle stream *[line 20]* includes most of the carbon dioxide in the carbon dioxide recycle stream *[column 5 line 65, "an enriched carbon-dioxide overhead product stream is removed overhead through line 20"]*;
separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream,	separating the sour NGL rich stream *[distillative column 38 separates line 32]* into a sweet NGL rich stream *[line 60, and TABLE I, bottoms stream 60 contains no H_2S and is therefore sweet]* and a carbon dioxide rich stream *[line 44]*,
wherein the sweet NGL rich stream	wherein the sweet NGL rich stream

includes the substantially all of the C_3-C_8 hydrocarbons in the [sour] NGL rich stream, and	*[line 60]* includes the substantially all of the C_3-C_8 hydrocarbons in the sour NGL rich stream *[column 6 line 19, "bottom product stream containing the C_3-C_6 is removed by line 60"]*, and
wherein the carbon dioxide rich stream includes substantially all of the carbon dioxide in the sour NGL rich stream;	wherein the carbon dioxide rich stream *[line 44]* includes substantially all of the carbon dioxide in the sour NGL rich stream *[TABLE I, "overhead stream 44" contains all CO_2 of feed stream 36]*, and
	D2 teaches:
combining a carbon dioxide makeup stream from a source external to the method with the purified carbon dioxide recycle stream; and	combining a carbon dioxide makeup stream from a source external to the method with the purified carbon dioxide recycle stream *[Figure 5.1, "CO_2 plant delivery"]*
subsequently injecting the combined carbon dioxide makeup stream and the purified carbon dioxide recycle stream into a subterranean formation,	subsequently injecting the combined carbon dioxide makeup stream and the purified carbon dioxide recycle stream into a subterranean formation *[Figure 5.1, "CO_2 injection"]*
wherein the carbon dioxide is not removed from the hydrocarbon feed stream and is not removed from the carbon dioxide recycle stream prior to separating the carbon dioxide recycle stream into the sour NGL rich stream and the purified carbon dioxide recycle stream, and	wherein the carbon dioxide is not removed from the hydrocarbon feed stream and is not removed from the carbon dioxide recycle stream prior to separating the carbon dioxide recycle stream into the sour NGL rich stream and the purified carbon dioxide recycle stream *[Figure 5.1 does not show net removal of CO_2 between "Production Well" and "CO_2 Extraction plant"]*.

wherein the hydrocarbon feed stream, the carbon dioxide recycle stream, and the sour NGL rich stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the heavy hydrocarbon rich stream, the purified carbon dioxide recycle stream, the sweet NGL rich stream, and the carbon dioxide rich stream.	D3 teaches wherein the hydrocarbon feed stream, the carbon dioxide recycle stream, and the sour NGL rich stream are not subjected to cryogenic conditions *[D3 does not use cryogenic conditions in Figure 1; also, column 6, line 57: "the higher temperature of the overhead reflux condenser permits employing a less expensive cooling source, such as cooling water, air or a more moderate refrigerant source"]*, membranes *[D3 does not use membranes]* and carbon dioxide recovery solvents *[D3 does not use solvents]* between being received and being separated into the heavy hydrocarbon rich stream, the purified carbon dioxide recycle stream, the sweet NGL rich stream, and the carbon dioxide rich stream.

APPENDIX C

Claim chart comparison of claims 4, 5, 14, 23 and 24 of Canadian Patent No. 2,949,039 to subject matter taught by D1 and D3.

Claim of Canadian Patent No. 2,949,039	Prior Art
4. The method according to claim 2, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.	D3 teaches wherein the carbon dioxide recycle stream *[line 12]* comprises acid gas *[column 5, line 57 "the feed stream comprises hydrogen sulfide"]*, and wherein separating the carbon dioxide recycle stream *[distillative column 14 separates line 12]* into the purified carbon dioxide recycle stream *[line 20]* and the natural gas liquids stream *[line 32]* includes separating the acid gas into the natural gas liquids stream *[column 6, line 7 "the bottom product stream, containing ...hydrogen sulfide is withdrawn through line 32"]*.
5. The method according to claim 4, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.	D3 teaches separating the natural gas liquids stream *[distillative column 38 separates line 32]* into a sweet natural gas liquids stream *[TABLE I, "bottom stream 60" contains no H_2S and is therefore sweet]* and an acid gas stream *[TABLE I, "overhead stream 44" contains all H_2S of feed stream 36]*.

14. The system according to claim 10, wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream, wherein the sweet natural gas liquids stream includes the C_3-C_8 hydrocarbons, and wherein the acid gas stream includes H_2S and/or CO_2.	D3 teaches separating the natural gas liquids stream *[line 32]* into a sweet natural gas liquids stream *[TABLE I, "bottom stream 60" contains no H_2S and is therefore sweet]* and an acid gas stream *[TABLE I, "overhead stream 44" contains all H_2S of feed stream 36]*. wherein the sweet natural gas liquids stream *[line 60]* includes the C_3-C_8 hydrocarbons *[TABLE I, "bottom stream 60" contains C_3 to C_{6+} hydrocarbons]* and wherein the acid gas stream *[line 44]* includes H_2S and/or CO_2 *[TABLE I, "overhead stream 44" contains all H_2S of feed stream 36]*.
23. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.	D3 teaches: wherein the carbon dioxide recycle stream *[line 12]* comprises acid gas *[column 5, line 57 "the feed stream comprises hydrogen sulfide"]*, and wherein separating the carbon dioxide recycle stream *[distillative column 14 separates line 12]* into the purified carbon dioxide recycle stream *[line 20]* and the natural gas liquids stream *[line 32]* includes separating the acid gas into the natural gas

	liquids stream *[column 6, line 7 "the bottom product stream, containing ...hydrogen sulfide is withdrawn through line 32"]*.
24. The set of process equipment according to claim 23, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.	D3 teaches separating the natural gas liquids stream *[line 32]* into a sweet natural gas liquids stream *[TABLE I, "bottom stream 60" contains no H_2S and is therefore sweet]* and an acid gas stream *[TABLE I, "overhead stream 44" contains all H_2S of feed stream 36]*.

APPENDIX D

Claim chart comparison of claims 6, 7, 25 and 26 of Canadian Patent No. 2,949,039 to subject matter taught by D1 and D4.

Claim of Canadian Patent No. 2,949,039	Prior Art
6. The method according to claim 2, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.	D4 teaches dehydrating the carbon dioxide recycle stream *[stream 10]* before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream *[Figure 1, feed gas stream 10 is dehydrated in dryer unit 22 before being separated into a purified carbon dioxide recycle stream and a natural gas liquids stream].*
7. The method according to claim 2, further comprising: compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and adding additional carbon dioxide to	D4 teaches compressing the carbon dioxide recycle stream *[stream 10]* before separating the carbon dioxide recycle stream *[feed gas stream 10]* into the purified carbon dioxide recycle stream and the natural gas liquids stream *[Figure 1 - feed gas stream 10 is compressed by feed gas compressor unit 12 prior to being separated into CO_2 product stream 20 and NGL-containing bottoms stream 64];* and adding additional carbon dioxide to

the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.	the purified carbon dioxide recycle stream *[CO_2 product stream 20]* to form a carbon dioxide injection stream *[column 5 line 10, CO_2 product stream 20 "is preferably mixed with fresh CO_2 before being reinjected into the petroleum-bearing subsurface"]*.
25. The set of process equipment according to claim 21, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.	D4 teaches dehydrating the carbon dioxide recycle stream *[stream 10]* before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream *[Figure 1, feed gas stream 10 is dehydrated in dryer unit 22 before being separated into a purified carbon dioxide recycle stream and a natural gas liquids stream]*.
26. The set of process equipment according to claim 21, further configured to: compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and add additional carbon dioxide to the	D4 teaches compressing the carbon dioxide recycle stream *[feed gas stream 10]* before separating the carbon dioxide recycle stream *[feed gas stream 10]* into the purified carbon dioxide recycle stream and the natural gas liquids stream *[Figure 1 - feed gas stream 10 is compressed by feed gas compressor unit 12 prior to being separated into CO_2 product stream 20 and NGL-containing bottoms stream 64];* and adding additional carbon dioxide to

purified carbon dioxide recycle stream to form a carbon dioxide injection stream.	the purified carbon dioxide recycle stream *[CO_2 product stream 20]* to form a carbon dioxide injection stream *[column 5 line 10, CO_2 product stream 20 "is preferably mixed with fresh CO_2 before being reinjected into the petroleum-bearing subsurface"]*.

APPENDIX E

Claim chart comparison of claims 9, 17 and 28 of Canadian Patent No. 2,949,039 to subject matter taught by D1.

Claim of Canadian Patent No. 2,949,039	Prior Art
9. The method according to claim 2, wherein	D1 teaches
the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process,	the purified carbon dioxide recycle stream *[overhead product stream 21]* is suitable for reinjection into a subterranean formation in an enhanced oil recovery process *[Column 4 line 59 "overhead product stream is further compressed in a compressor (not shown) and sent to injection wells 24"]*,
wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,	wherein the purified carbon dioxide recycle stream *[overhead product stream 21]* includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream *[Table I, "overhead product" contains all CO_2, all C_1 and a portion of the C_3 from the "feed"]*,
wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,	wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream *[overhead product stream 21]* is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream *[Table I, "overhead product" contains a greater molar percentage of CO_2*

	than methane],
wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,	wherein the natural gas liquids stream *[bottoms product 26]* includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream *[Table I, "bottoms product" contains no CO_2 and some C_3 hydrocarbons].*
wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole% to 28 mole % of the natural gas liquids stream.	wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole% to 28 mole % of the natural gas liquids stream *[D1 teaches that the amount of C3 in the overhead and bottoms streams is adjustable, see D1, column 3 line 8, "the recovery of C_3/C_4 can be monitored to…optimize the economical operation of the plant"; and TABLE II, which defines the available operating range of reboiler 5 as "225 to 400 °F"]. It would have been obvious to modify the operating conditions of D1, such as lowering the operating temperature of reboiler 5, to increase the amount of C_3 in the bottoms product 26 to increase its sale value and*

	thereby render the operation more economical].
17. The system according to claim 10, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process,	D1 teaches the purified recycle stream *[overhead product stream 21]* is suitable for reinjection into a subterranean formation in an enhanced oil recovery process *[Column 4 line 59 "overhead product stream is further compressed in a compressor (not shown) and sent to injection wells 24"],*
wherein the purified recycle stream includes substantially all of the injection gas, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the recycle stream,	wherein the purified recycle stream *[overhead product stream 21]* includes substantially all of the injection gas, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the recycle stream *[Table I, "overhead product" contains all CO_2, all C_1 and a portion of the C_3 from the "feed"],*
wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream,	wherein a molar percentage of the injection gas in the purified recycle stream *[overhead product stream 21]* is greater than a molar percentage of the methane in the purified recycle stream *[Table I, "overhead product" contains a greater molar percentage of CO_2 than methane],*
wherein the natural gas liquids stream includes substantially none of the injection gas and a second portion of the C_3	wherein the natural gas liquids stream *[bottoms product 26]* includes substantially none of the injection gas and a second

hydrocarbons from the recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.	portion of the C_3 hydrocarbons from the carbon dioxide recycle stream *[Table I, "bottoms product" contains no CO_2 and some C_3 hydrocarbons].* wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole% to 28 mole % of the natural gas liquids stream *[D1 teaches that the amount of C3 in the overhead and bottoms streams is adjustable, see D1, column 3 line 8, "the recovery of C_3/C_4 can be monitored to…optimize the economical operation of the plant"; and TABLE II, which defines the available operating range of reboiler 5 as "225 to 400 °F". It would have been obvious to modify the operating conditions of D1, such as lowering the operating temperature of reboiler 5, to increase the amount of C_3 in the bottoms product 26 to increase its sale value and thereby render the operation more economical].*
28. The set of process equipment according to claim 21, wherein the purified carbon dioxide recycle	D1 teaches the purified carbon dioxide recycle

stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process,	stream *[overhead product stream 21]* is suitable for reinjection into a subterranean formation in an enhanced oil recovery process *[Column 4 line 59 "overhead product stream is further compressed in a compressor (not shown) and sent to injection wells 24"]*,
wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,	wherein the purified carbon dioxide recycle stream *[overhead product stream 21]* includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream *[Table I, "overhead product" contains all CO_2, all C_1 and a portion of the C_3 from the "feed"]*,
wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,	wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream *[overhead product stream 21]* is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream *[Table I, "overhead product" contains a greater molar percentage of CO_2 than methane]*,
wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,	wherein the natural gas liquids stream *[bottoms product 26]* includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream *[Table I, "bottoms product" contains no CO_2 and some C_3 hydrocarbons]*.

wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole% to 28 mole % of the natural gas liquids stream.	wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole% to 28 mole % of the natural gas liquids stream *[D1 teaches that the amount of C3 in the overhead and bottoms streams is adjustable, see D1, column 3 line 8, "the recovery of C_3/C_4 can be monitored to...optimize the economical operation of the plant"; and TABLE II, which defines the available operating range of reboiler 5 as "225 to 400 °F"]. It would have been obvious to modify the operating conditions of D1, such as lowering the operating temperature of reboiler 5, to increase the amount of C_3 in the bottoms product 26 to increase its sale value and thereby render the operation more economical].*

APPENDIX F

Claim chart comparison of claims 15 and 19 of Canadian Patent No. 2,949,039 to subject matter taught by D1 and D2.

Claim of Canadian Patent No. 2,949,039	Prior Art
15. The system according to claim 10, wherein the system is further configured to:	D2 teaches
receive a feed stream;	receiving a feed stream *[Figure 5.1, stream output by "producer"]*;
separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and	separating the feed stream into the recycle stream and a heavy hydrocarbons stream *[Figure 5.1, stream at "oil sales", and Figure 5.4, stream at "oil sales"]*, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons *[Figures 5.1 and 5.4, streams at "oil sales" would include C_{9+} hydrocarbons]*; and
dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.	dehydrating the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream *[Figure 5.1, "production separators", which separate out "water and oil", and see Section 5.5.1, "four basic chemical products are used to dehydrate gas: glycol, calcium chloride, glycerol and solid dessicants"; glycol is considered in the art to be the predominant dehydration solvent; see also Figure 5.8, showing "dehydrator" positioned directly upstream from "NGL column" separator]*.

19. A method comprising: receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;	D1 teaches receiving a carbon dioxide recycle stream *[CO_2 gas stream 25]*, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids *[column 3, line 51 – the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons"]*; and
separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,	separating the carbon dioxide recycle stream *[distillation column 3 separates the CO_2 gas stream 25]* into a purified carbon dioxide recycle stream *[overhead product stream 21]* and a natural gas liquids stream *[bottoms product 26]*,
wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids; and	wherein the purified carbon dioxide recycle stream *[overhead product stream 21]* includes the carbon dioxide and the natural gas, and wherein the natural gas liquids *[bottoms product 26]* stream comprises the natural gas liquids *[column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons"]*,
separating a feed stream into the carbon dioxide recycle stream and a heavy	D2 teaches separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream

hydrocarbon stream, wherein the heavy hydrocarbon stream includes C_{9+} hydrocarbons.	and a carbon dioxide recycle stream *[Figure 5.1, stream at "oil sales"]*, wherein the heavy hydrocarbon stream includes C_{9+} hydrocarbons *[Figure 5.1, heavy hydrocarbon stream at "oil sales" would include C_{9+} hydrocarbons]*.

APPENDIX G

Claim chart comparison of claim 20 of Canadian Patent No. 2,949,039 to subject matter taught by D3 and D2.

Claim of Canadian Patent No. 2,949,039	Prior Art
20. A method comprising:	D3 teaches:
receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;	receiving a carbon dioxide recycle stream *[line 152]*, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids *[column 10 line 59, "a feed stream, consisting essentially of CO_2, ethane and C_{3+}, is introduced by line 152"];*
separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,	separating the carbon dioxide recycle stream *[distillative column 150 separates line 152]* into a purified carbon dioxide recycle stream *[line 160]* and a natural gas liquids stream *[line 168]*,
wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and	wherein the purified carbon dioxide recycle stream *[line 160]* includes the carbon dioxide and the natural gas *[column 10 line 66, "a mixture, composed essentially of CO_2 and ethane, is removed as an overhead product stream by line 160"]*, and
wherein the natural gas liquids stream comprises the natural gas liquids;	wherein the natural gas liquids stream *[line 168]* comprises the natural gas liquids *[column 11 line 2, "a bottom product stream, comprising primarily propane, together with*

	any recycled liquid additive agent introduced into the condenser or upper part of the column 150, is withdrawn by line 168"]
receiving a feed stream, wherein the feed stream includes carbon dioxide, C_1 to C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_{9+} hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons; and	D2 teaches receiving a feed stream *[Figure 5.1, stream output by "producer"],* wherein the feed stream includes carbon dioxide, C_1 to C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_{9+} hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons *[Figure 5.1, carbon dioxide and these hydrocarbons would all be present in stream output by "producer"]*; and
separating the feed stream into a heavy hydrocarbon stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon stream includes substantially all of the C_{9+} hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream, wherein the heavy hydrocarbon stream includes substantially none of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream, and wherein the carbon dioxide recycle stream includes substantially all of the carbon dioxide, the C, to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream,	separating the feed stream into a heavy hydrocarbon stream *[Figure 5.1, stream at "oil sales", and Figure 5.4, stream at "oil sales"]* and a carbon dioxide recycle stream *[Figure 5.1, stream at "CO_2 extraction plant"]*, wherein the heavy hydrocarbon stream includes substantially all of the C_{9+} hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream *[Figure 5.1, heavy hydrocarbon stream at "oil sales" would include substantially all of the C_{9+} hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons]*, wherein the heavy hydrocarbon stream includes substantially none of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream *[Figures 5.1 and 5.4, streams at "oil sales" would have this*

	composition], and wherein the carbon dioxide recycle stream includes substantially all of the carbon dioxide, the C, to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream, *[Figure 5.1, stream at "CO_2 extraction plant" would have this composition],* D3 teaches
wherein the purified carbon dioxide recycle stream includes substantially all of the C_2 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially none of the C_2 hydrocarbons from the carbon dioxide recycle stream, and	wherein the purified carbon dioxide recycle stream *[line 160]* includes substantially all of the C_2 hydrocarbons from the carbon dioxide recycle stream *[TABLE VII, showing "overhead stream 160" containing all of C_2 in "feed stream 152"]* and the natural gas liquids stream *[line 168]* includes substantially none of the C_2 hydrocarbons from the carbon dioxide recycle stream *[TABLE VII, showing "bottom stream 168" containing no C_2]*, and
wherein the purified carbon dioxide recycle stream includes substantially none of the C_3 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially all of the C_3 hydrocarbons from the carbon dioxide recycle stream.	wherein the purified carbon dioxide recycle stream *[line 160]* includes substantially none of the C_3 hydrocarbons from the carbon dioxide recycle stream *[TABLE VII, showing "overhead stream 160" containing only about 10% of C_3 in "feed stream 152"]* and the natural gas liquids stream includes substantially all of the C_3 hydrocarbons from the carbon dioxide recycle stream *[TABLE VII, showing "bottom stream 168" containing about 90% of C_3 in "feed stream 152". It would have been obvious to modify the operating conditions of D3, such*

	as lowering the operating temperature of reboiler 164 or condenser 156, to increase the amount of C_3 in the bottom stream 168 to near 100% to raise the yield of C_3 in propane output line 182].

United States Patent [19]

Pastor et al.

[11] **Patent Number: 4,753,666**

[45] **Date of Patent: Jun. 28, 1988**

[54] **DISTILLATIVE PROCESSING OF CO_2 AND HYDROCARBONS FOR ENHANCED OIL RECOVERY**

[75] Inventors: **Gerald R. Pastor**, Englewood; **Janet F. Peters**, Littleton; **Wayne K. Larsen**, Aurora; **Al C. Iakovakis**, Englewood, all of Colo.

[73] Assignee: **Chevron Research Company**, San Francisco, Calif.

[21] Appl. No.: **889,975**

[22] Filed: **Jul. 24, 1986**

[51] **Int. Cl.**[4] **F25J 3/02**

[52] **U.S. Cl.** **62/24**; 62/37; 62/54

[58] **Field of Search** 62/9, 11, 23, 24, 27, 62/28, 54, 37

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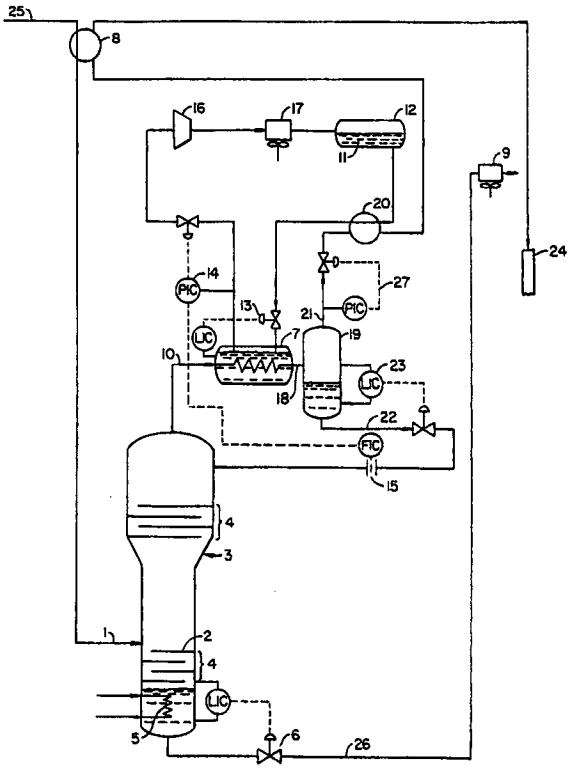
Primary Examiner—Ronald C. Capossela

Attorney, Agent, or Firm—S. R. LaPaglia; E. J. Keeling; V. A. Norviel

[57] **ABSTRACT**

A method of treating CO_2 rich gas for injection into a petroleum reservoir is described. CO_2 rich gas containing methane, nitrogen, ethane, propane, butanes, and heavier components is distilled such that substantially all of the heavier components are produced as a bottoms product and substantially all of the CO_2, ethane, and propane are produced as an overhead vapor. The presence of ethane and propane in the overhead vapors overcomes the effect of nitrogen and methane on minimum miscibility pressure in the reservoir, and the problems created by CO_2 freezing and the CO_2/ethane azeotrope are avoided, furthermore, a readily marketable liquid product is produced.

15 Claims, 2 Drawing Sheets



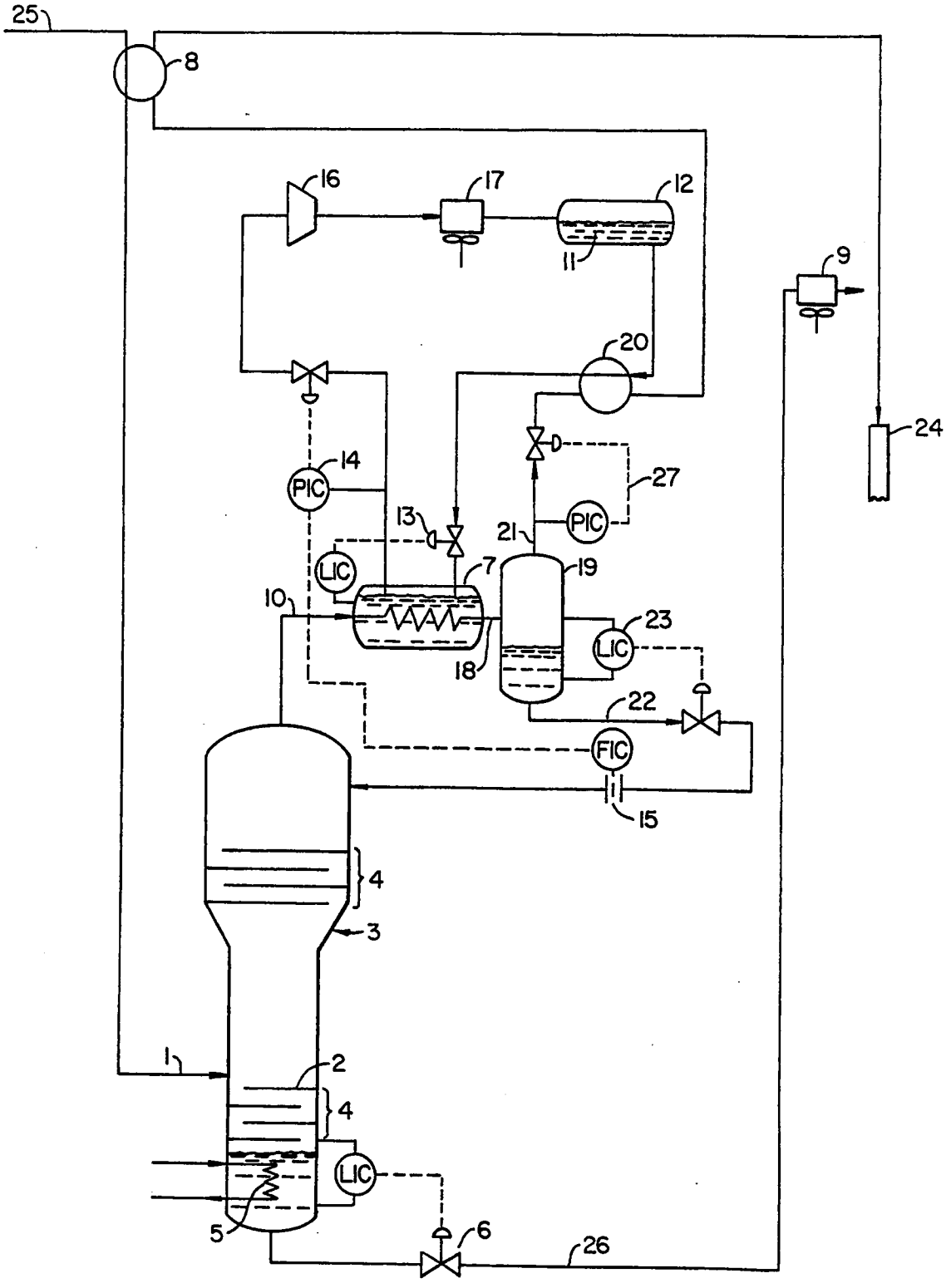

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FIG.__1.

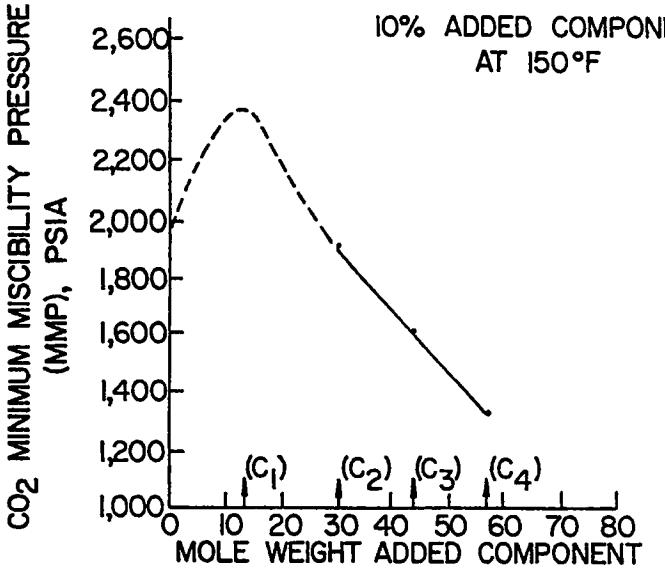


FIG._2.

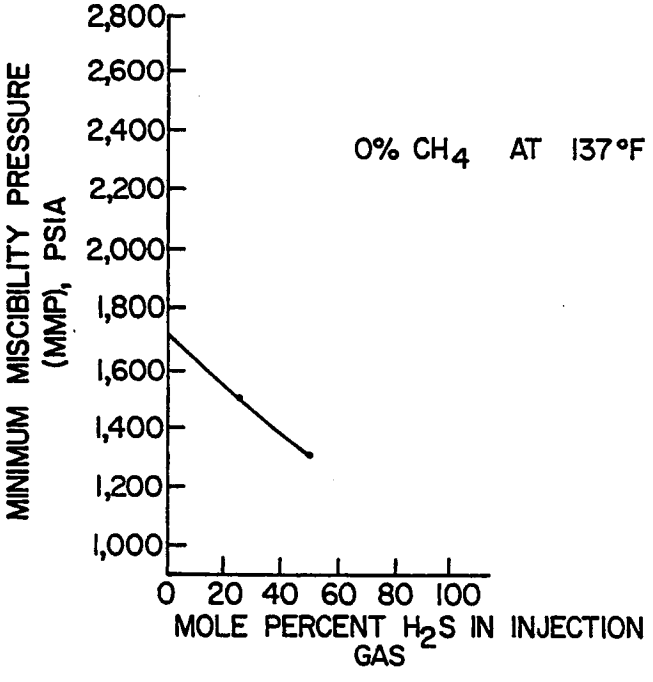


FIG._3.

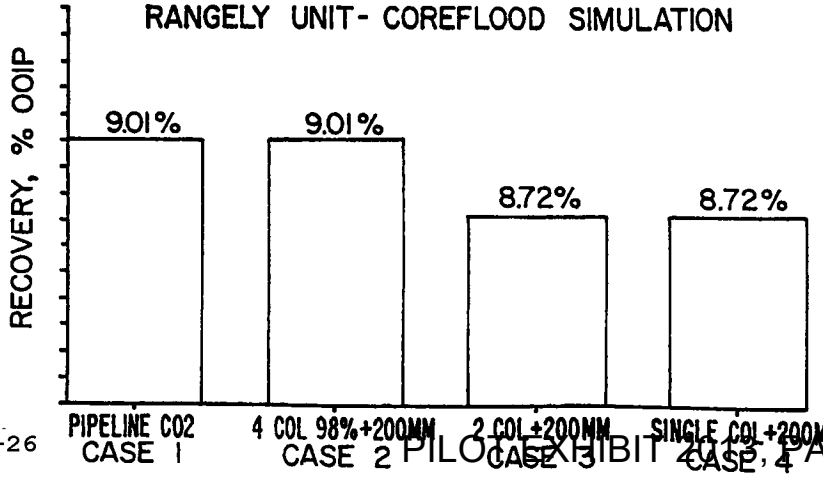


FIG._4.

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DISTILLATIVE PROCESSING OF CO_2 AND HYDROCARBONS FOR ENHANCED OIL RECOVERY

FIELD OF THE INVENTION

This invention relates generally to an improved method for enhanced oil recovery. More specifically the invention provides an improved method for treating CO_2 rich gas streams for injection into oil-bearing formations.

BACKGROUND OF THE INVENTION

It is well known that only a small fraction of the original oil in place in a petroleum reservoir can be recovered with so called "primary" and "secondary" production methods. Various "tertiary" methods of increasing the recovery of oil contained in oil-bearing rocks have been devised. Among these tertiary recovery techniques is the method of injecting a miscible compound into the reservoir. The most common miscible compound used is carbon dioxide (CO_2).

In the initial stages of a CO_2 flood, CO_2 gas is commonly purchased from a large CO_2 distribution pipeline. The price of gas purchased from these pipelines is presently in the range of $1.00 to $1.50 per thousand standard cubic feet (MSCF).

After injecting CO_2 into the reservoir for a period of time, associated gas production will contain increasingly high percentages of CO_2 due to breakthrough of the injected CO_2 gas. It is often economical to recycle this gas into the petroleum reservoir. However, this recycled gas commonly has several undesirable components contained in it and it must be processed before reinjection. The primary constituents that must be considered in processing of this gas are methane (CH_4) and nitrogen (N_2) because these gases will dramatically reduce the miscibility of the injected gas. Other components that should be considered are heavier hydrocarbons (because of both their economic value as separate products and because of their ability to offset the miscibility problems created by CH_4 and N_2), H_2S (because of safety concerns and sales specifications), and water (because of hydrate problems).

Extensive efforts have been devoted to developing an economical method for treating these gas streams and a large number of process schemes have been devised.

Chemical solvents (such as amines) have been considered for removal of CO_2 from the hydrocarbon components. Use of these solvents becomes impractical in gas streams containing high concentrations of CO_2 because of the large energy demand of amine reboilers and other equipment. Further, the CO_2 is saturated with water in amine plants and this can create hydrate and corrosion problems downstream.

Distillation of CO_2 from methane has also been considered. The relative volatility of methane and CO_2 is very high and this distillation is in theory quite easy. However, the process must operate at relatively high pressure and low temperature and, therefore, the possibility of a solid carbon dioxide phase coexisting with vapor/liquid CO_2/CH_4 mixture is high. Solutions to this problem have been proposed in U.S. Pat. Nos. 4,318,723, 4,293,322 et al. in which an additive (generally natural gasoline recycled from elsewhere in the plant) is introduced into the feed. This prevents CO_2 freezing and also aids in breaking an ethane/CO_2 azeotrope. These processes have several inherent disadvantages, however. Initially, these processes are extremely expensive from both a capital and operating perspective since it is necessary to provide multiple distillation columns and massive refrigeration capacity to cool the entire inlet gas stream to −40° F. or colder. For example, in the example labeled "Table II" in U.S. Pat. No. 4,318,723, the feed temperature is reduced to −65° F. This also results in the need to use exotic materials of construction for the process equipment.

Further, the process produces sour, high vapor pressure liquid streams that must be subjected to additional processing before sale. Further, the ultimate value of the liquid products is offset by the need to purchase additional CO_2 as a result of the lost gas volume, i.e., there is significant shrinkage associated with the process.

Simpler techniques for treating hydrocarbon rich CO_2 streams have also been proposed in broad conceptual terms. For example, in "Looking at CO_2 Recovery in Enhanced-Oil-Recovery Projects," *Oil and Gas Journal*, Dec. 24, 1984, the authors show a "Straight Refrigeration" process for separating hydrocarbons from CO_2. However, this process also has several inherent disadvantages. Initially, as with the processes described in the above-mentioned patents, the inlet gas stream must be cooled to −40° F. or colder for recovery of C_3+, requiring extremely high refrigeration capacity. Further, the liquid stream produced by this process would require further treatment before sale since it will have a high vapor pressure (approximately 40 psia RVP) as well as unacceptable CO_2 and H_2S concentrations. Finally, a large portion of the C_4+ would go overhead and be unnecessarily wasted since no rectification section is provided on the column.

In summary, it is desirable to create a process that recognizes the ability of ethane, propane and butane to overcome the negative effects of nitrogen and methane on the miscibility of CO_2 injection gas. It is further desirable to create a process that produces both acceptable CO_2 injection gas and saleable liquid products. It is further desirable to create a process that treats CO_2 injection gas is an economical manner from both a capital investment and operating expense perspective. It is further desirable to create a process that does not require elaborate processing to overcome the CO_2/C_2H_6 azeotrope or to avoid CO_2 solid formation. It is further desirable to create a process which minimizes the shrinkage of the CO_2 injection gas.

BRIEF SUMMARY OF THE INVENTION

Accordingly, the present invention provides a method and apparatus for treating hydrocarbon rich CO_2 gas streams for injection into oil-bearing formations in an effective and economical manner. A hydrocarbon rich CO_2 gas stream is compressed to approximately 350 psia. The gas enters a multi-tray distillation column at an intermediate tray. Overhead vapor from the column is cooled in an overhead condenser to approximately −20° to 0° F. with propane refrigerant to produce a two-phase stream. The two-phase stream is separated into a liquid and a vapor (product) stream in a reflux drum. Vapor from the reflux drum is further compressed for injection into an oil-bearing formation. Liquid from the reflux drum is returned to the top tray of the column as reflux.

A reboiler on the bottom of the column maintains the bottom temperature at approximately 360° F. An NGL

bottoms product consisting of a large fraction of the C_4+ in the inlet stream is removed from the column, cooled, and sold.

Most of the C_2 and C_3 and a significant fraction of the C_4 go overhead with the CO_2 injection gas. By leaving the C_2, C_3, and a portion of the C_4 (mostly isobutane) in the CO_2, the negative effects of C_1 on the miscibility of the CO_2 injection gas are overcome. The recovery of C_3/C_4 can be monitored to control the miscibility of the CO_2 injection gas and optimize the economical operation of the plant.

H_2S is concentrated in the overhead gas. H_2S is known to enhance the miscibility of injection gas. Furthermore, H_2S would have to be removed from a liquid product requiring expensive processing equipment.

The process produces a CO_2 gas stream with a relatively low minimum miscibility pressure with a minimum capital investment since only one distillation column, and only a fraction of the refrigeration capacity needed in other processes is necessary. The use of exotic materials of construction is also minimized because of the higher plant operating temperature and lower operating pressures. Further, since the distillation split takes place at the temperatures and pressures necessary to make a split at the C_4 level, the CO_2/C_2 azeotrope and CO_2 solid formation are not problems. Shrinkage is also minimized because most of the C_1 to C_3 remains in the CO_2 gas product.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic flow diagram showing the distillative apparatus for carrying out the invention described herein. (PIC=Pressure Indicating Controller, FIC=Flow Indicating Controller, and LIC=Level Indicating Controller.)

FIG. 2 is a graph showing minimum miscibility pressure versus the molecular weight of an added component for a selected crude oil.

FIG. 3 is a graph showing the minimum miscibility pressure versus mole percent H_2S for injection gas.

FIG. 4 is a bar graph showing the percentage of original oil in place recovered using the present invention and various prior art devices.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides a method for economically treating hydrocarbon rich CO_2 gas for injection into an oil-bearing formation utilizing the steps of introducing a feed stream into distillation equipment. The feed stream may contain a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons. The feed stream is distilled in the distillation equipment to produce an overhead stream and a bottoms stream. The overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons. The overhead stream is then injected into a hydrocarbon bearing formation.

Referring to FIG. 1, in the preferred embodiment of the invention, a CO_2 gas stream **25** containing a substantial percentage of hydrocarbons and potentially containing hydrogen sulfide, nitrogen, mercaptans and other trace components is cross-exchanged in heat exchanger **8** with the column overhead product **21** and flows onto the feed tray **2** of a distillation column **3** containing a plurality of vapor/liquid contacting devices **4** such as bubble cap trays, sieve trays or packing.

In the preferred embodiment of the invention, the feed **1** enters the column at approximately 350 psia and 90° F. Other temperatures and pressures may be chosen. For example, lower feed temperatures may be desirable in some cases. 90° F. is chosen as being easy to achieve with an air cooler that may be located upstream of the process and feed/product heat exchanger **8**.

In the preferred embodiment, the rectification portion of the column **3** is a larger diameter than the stripping section, as shown in FIG. **1**. This feature is desirable because large vapor loadings will be present in the upper portion of the column.

The bottom portion of the column is equipped with a reboiler **5** that supplies heat to the column via hot oil or steam. The reboiler is equipped with temperature control equipment that maintains the temperature of the bottoms at approximately 360° F. in the preferred embodiment. The bottom of the column is also equipped with level control equipment **6** which maintains the liquid level at a point above the reboiler but sufficiently below the first tray. The bottoms product **26** flows from the bottom of the column to a bottoms air cooler **9** to be cooled to approximately ambient temperature for sale or blending with crude oil.

The overhead vapors **10** flow to an overhead condenser **7** which cools and partially condenses the overhead vapors. In the preferred embodiment, propane is used as a refrigerant. Other refrigerants could be used, as would be readily obvious to one skilled in the art (for example, ammonia). Liquid propane **11** is supplied from a propane surge drum **12**. A level control system **13** maintains the level of propane above tubes in the overhead condenser. The pressure in the overhead condenser is maintained with a pressure control system **14** which, in the preferred embodiment, has its pressure set-point determined by a reflux flow measuring device **15**. This control system enables the operator to maintain a fixed quantity of reflux to the column.

Propane vapors from the overhead condenser are compressed in a compressor **16**, condensed in a propane condenser **17**, and returned to the propane surge drum **12**. A propane subcooler **20** may also be desirable to increase the energy efficiency of the process.

The two-phase mixture **18** flowing from the overhead condenser is separated in a reflux drum **19**. The two-phase mixture is separated into an overhead product stream **21** and a reflux stream **22**. A level control system **23** maintains a constant amount of liquid in the reflux drum, and is opened to allow liquid to flow into the column.

The pressure at which the distillation equipment operates is controlled by pressure control equipment **27**. The product vapor stream flows from the reflux drum to the propane/overhead subcooler **20** and then to the overhead/feed heat exchanger **8**. The overhead product stream is further compressed in a compressor (not shown) and sent to injection wells **24**.

To illustrate the operation of the above described process, the program PROCESS™ (*Simulation Sciences Inc.*, Version 1.01, 1985) was used to simulate the operation of the process on a typical CO_2/hydrocarbon gas stream. The results of the simulation are illustrated in Table I:

TABLE I

Summary of PROCESS TM Simulation of the Present Invention on a Typical CO_2/Hydrocarbon Stream

No. of Ideal Trays in Column	20
Feed Point Tray	7
Gas Feed Rate	110 MMSCF
Reflux Drum Pressure	350 psia
Column Differential Pressure	5 psia
Condenser Duty	17 MM BTU/Hour
Reboiler Duty	8 MM BTU/Hour
Reflux Temperature	1.2° F.
Bottoms Temperature	360° F.

	Stream Name		
	Feed	Overhead Product	Bottoms Product
Rate	110 MMSCF	107 MMSCF	2620 BPD
H_2S (ppmv)	500	514	—
	Mole Percent		
N_2	3.4	3.5	—
CO_2	83.9	86.3	—
C_1	6.6	6.9	—
C_2	1.4	1.4	—
C_3	1.1	1.1	0.02
iC_4	0.5	0.4	3.1
nC_4	0.7	0.3	16.7
iC_5	0.4	0.001	16.0
nC_5	0.6	—	23.3
C_6	0.6	—	24.4
C_7+	0.4	—	16.4

As can be seen, operation of the process in the above-described manner results in a separation in which essentially all of the propane and ethane go into the overhead stream while most of the butane and essentially all of the pentane and heavier components are present in the bottoms stream.

Although the invention has been illustrated with regard to the above example, a range of operating pressures and temperatures might be selected to make the above described separation. The optimum range of the major process variables are described in Table II:

TABLE II

Optimum Process Variables	
Column Pressure	150 to 400 psia
Overhead Condenser Temperature	−40 to 20° F.
Reboiler Temperature	225 to 400° F.
Reflux Ratio	0.21 to 0.30
Number of Trays	22 to 40
Number of Trays above Feed Point	10 to 20
Number of Trays Below Feed Point	15 to 25

An important advantage of the above described process is that the negative effects of methane and nitrogen on the miscibility of the injection gas are largely overcome with the presence of ethane, propane and butane, and the process does not require elaborate process steps to avoid CO_2 freezing and/or to overcome the CO_2/Ethane azeotrope.

FIGS. 2 and 3 (adapted from "Miscible Displacement", F. I. Stalkup, Society of Petroleum Engineers of AIME, 1983, pages 141 and 140, respectively), and 4 generally illustrate the effect of distilling the CO_2 injection gas in the described method. FIG. 2 shows the effect of various alkyl hydrocarbons on CO_2 miscibility at 150° F. when 10% of the alkyl hydrocarbon is added to CO_2. As shown in FIG. 2, methane has a negative effect, i.e. the miscibility pressure is increased. By contrast, the presence of ethane, propane and butane is a positive one, i.e. the minimum miscibility pressure is decreased below that of pure CO_2. Similarly, the presence of H_2S is positive, as illustrated in FIG. 3. As the percentage of H_2S in the gas increases, the minimum miscibility pressure decreases, regardless of the concentration of methane present.

The present invention takes full advantage of these effects. Unlike prior art processes, methane is left in the overhead gas, thereby overcoming the many problems associated with methane/CO_2 distillation discussed above. To offset the effect of methane or minimum miscibility pressure, H_2S, ethane, propane, and a portion of the butane remain in the overhead gas. Further, an easily saleable liquid product is produced.

To further illustrate this advantage, various reservoir simulations were performed to determine the effect of various process schemes on the ultimate recovery of oil in a petroleum reservoir in Rangely, Colo., using a miscible flood reservoir simulation program of the type familiar to one skilled in the art. The program was run assuming the following:

Case 1 It was assumed that "pipeline quality" (99.3%) CO_2 was purchased and used exclusively for injection. Produced gas would be flared or otherwise disposed of in this case.

Case 2 It was assumed that a "Four Column Ryan-Holmes Plant" similar to that described in FIG. 13 of "Looking at CO_2 Recovery in Enhanced Oil Recovery Projects" was used to treat produced gas and that the CO_2 product from this plant was injected along with 200 MMSCF of pipeline quality gas.

Case 3 It was assumed that a "Two Column Ryan-Holmes Plant" similar to that described in FIG. 12 of "Looking at CO_2 Recovery in Enhanced Oil Recovery Projects" was used to treat produced gas and that the CO_2 product from this plant was injected along with 200 MMSCF of pipeline quality gas.

Case 4 It was assumed that a 1 column plant as described in the present invention was used to treat produced gas and that the CO_2 product from this plant was injected along with 200 MMSCF of pipeline quality gas.

The results of those reservoir simulations are shown in FIG. 4. As would be expected in Case 1, the pure pipeline quality gas recovers the greatest percentage of the original oil in place. The elaborate 4 column Ryan-Holmes plant in Case 2 achieves essentially the same results as Case 1 since the gas is processed to almost pipeline quality.

It is seen in Case 4 that the simpler 1 column plant described in the present invention achieves essentially the same results as the more complex 2 column Ryan-Holmes plant used in Case 3. However, the present invention has the advantages of having a lower capital cost lower refrigeration requirements, and lower overall operating costs. Similarly, the plant described in Case 4, while achieving a lower percentage recovery of original oil in place than Case 2, would have dramatically lower capital and operating costs than the 4-Column Ryan-Holmes plant used in Case 2. These lower costs could (in many situations) result in better overall economics.

It is intended that the above description be illustrative and not restrictive. Variations on the above process will be readily apparent to those skilled in the art. The scope of the invention should, therefore be limited not to the above description but by the appended claims.

What is claimed is:

1. A method for treating hydrocarbon rich CO_2 gas for injection into an oil-bearing formation comprising the steps of:

(a) introducing a feed stream into distillation equipment, said feed stream comprising a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons;

(b) distilling said feed stream with said distillation equipment to produce an overhead stream and a bottoms stream, said overhead stream containing substantially all of said carbon dioxide, methane, ethane and propane, and said bottoms stream containing substantially all of said heavier hydrocarbons; and

(c) injecting said overhead stream into a hydrocarbon bearing formation.

2. A method for treating a gas stream, containing carbon dioxide, methane, ethane, propane, butane, and heavier hydrocarbons for reinjection into an oil-bearing formation comprising the steps of:

(a) introducing the gas stream into a distillation column at a feed tray, said distillation column containing a plurality of vapor/liquid contacting devices, said feed tray below a rectification section and above a stripping section;

(b) operating said distillation column to produce an overhead stream containing substantially all of said carbon dioxide, methane, ethane and propane, and a bottoms stream containing substantially all of said heavier hydrocarbons, and;

(c) injecting said overhead stream into an oil-bearing formation.

3. A method for treating hydrocarbon-rich CO_2 gas containing carbon dioxide, methane, ethane, propane, butane, and heavier hydrocarbons for injection into an oil-bearing formation in an economical manner comprising the steps of:

(a) introducing said hydrocarbon-rich gas stream into a multi-tray distillation column at an intermediate tray;

(b) cooling an overhead vapor from said distillation column in a partial condenser to produce a two-phase stream;

(c) separating said two-phase stream in a reflux drum to produce a reflux stream and a product stream;

(d) introducing said reflux stream onto a top tray of said distillation column;

(e) reboiling said distillation column with a reboiler;

(f) injecting said product stream into a hydrocarbon-bearing formation; and

(g) said steps of introducing said gas stream into a distillation column, chilling, separating, introducing said reflux stream onto a top tray of said distillation column, and reboiling carried out under conditions which most of said methane, ethane, and propane are contained in said product stream.

4. The method of claim 2 wherein said step of operating said distillation column further comprises the step of cooling an overhead stream in a partial condenser.

5. The method of claim 2 wherein said step of operating said distillation column further comprises the step of reboiling a bottoms stream in a reboiler.

6. The method of claim 1 wherein said distillation equipment further comprises a distillation column, a condenser, and a reboiler.

7. The method of claim 2, 3 or 6 wherein said distillation column operates in a range of pressures from 150 to 400 psia.

8. The method of claim 3, 4 or 6 wherein said condenser operates in the temperature range from −40° F. to 20° F.

9. The method of claim 3, 4 or 6 wherein said reboiler operates in the temperature range from 225° F. to 400° F.

10. The method of claim 3, 4 or 6 wherein said condenser is cooled with a propane refrigerant.

11. The method of claim 3, 4 or 6 wherein said condenser is cooled with an ammonia refrigerant.

12. The method of claim 10 further comprising the step of setting a pressure of said propane refrigerant based on a reflux flow rate.

13. The method of claim 12 further comprising the step of warming said overhead gas with said propane.

14. The method of claim 13 further comprising the step of cooling said feed stream with said overhead stream.

15. A method for treating hydrocarbon-rich CO_2 gas for injection into an oil-bearing formation consisting essentially of the steps of:

(a) introducing a feed stream into distillation equipment, said feed stream comprising a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons;

(b) distilling said feed stream with said distillation equipment to produce an overhead stream and a bottoms stream, said overhead stream containing substantially all of said carbon dioxide, methane, ethane and propane, and said bottoms stream containing substantially all of said heavier hydrocarbons; and

(c) injecting said overhead stream into a hydrocarbon-bearing formation.

* * * * *

Practical Aspects of CO_2 Flooding

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Chapter 5
Surface Facilities Design

This chapter discusses the design of the various surface facilities that make up a CO_2 flood, including material selection and specification. Topics include:

- Introduction—This includes data requirements and initial design steps.
- Specification methods—While field tests are the most accurate means of determining the usefulness of a particular approach, other sources of information also are available.
- Production systems—This section covers design issues for separation, gas gathering, production satellite, liquid gathering, central battery, field compression, and emergency shutdown systems.
- Injection systems—This section covers design issues related to gas repressurization, water injection, and CO_2 distribution systems.
- Gas processing systems-Here we cover basic process selection, H_2S removal issues, and sulfur recovery and disposal systems.

5.1 Introduction

In this chapter we explore surface facility design considerations for CO_2 flooding. We do not intend it to be a comprehensive design manual with a step-by-step method; instead, our purpose is to identify the important (and often unique) issues that must be addressed for a CO_2 flood. There is no single, correct answer, and there are many designs that offer effective solutions.

An important aspect of CO_2 facility design is that many elements must be designed concurrently, involving the simultaneous consideration of many factors, e.g., number and location of separation facilities, amount of compression required, gathering system pressure levels, and type of separation process. Carbon dioxide facility design is a process of evaluating trade-offs and economics. Is it more economically attractive to use a single large facility (with the higher cost of long flowlines but lower cost for pressure) or would it be better to build multiple, smaller, remote facilities for which pressure vessels would cost more but flowlines less? Exhaustive evaluation of alternatives is the only way to arrive at the most cost effective, process-efficient solution.

Several aspects of CO_2 facilities design are similar to those used in design of conventional facilities such as for waterfloods. Key differences include the effects of multiphase flow, the material selection criteria to be used, and the higher pressures that must be handled. **Fig. 5.1** shows a facility overview as a reference for the discussion that follows.

5.1.1 Data Requirements. Designing field facilities for a CO_2 flood requires a large amount of data, which may come from sources such as other design teams (e.g., reservoir, production, and plant teams), operating personnel, design manuals, laboratory testing, company facility files, standard industry practices, and vendor literature. **Table 5.1** shows some of the critical data requirements and sources. This table is not all-inclusive, and each design will have unique requirements.

5.1.2 Initial Design Steps. The first step in designing field facilities for a CO_2 flood is to determine which existing facilities, if any, can be used as-is or with slight modification. The use of existing facilities can reduce capital outlay dramatically, although physical restrictions—such as maximum allowable pressure, capacity limits, and locations available for new facilities—are commonplace. Several questions must be answered to determine whether an existing facility can be used or modified for use in the CO_2 flood:

- Does the facility meet the design requirements for the CO_2 flood? Can it handle the rates, corrosivity, pressures, and temperatures that will be required?
- Does the facility meet safety and reliability requirements for continued operation? Have there been multiple failures of any key components, indicating reliability or safety concerns?
- Is the facility located where it can be used economically?
- Does the location of the facility jeopardize public safety?
- Would there be significant improvements in efficiency, productivity, reliability, and/or safety if the facility were replaced or upgraded?
- Could modifications make otherwise unusable components usable? Would the cost of modification be justified or would replacement be a better alternative?

These questions really are of two types: "Can it be used?" and "Should it be used?" A positive response to the first does not necessarily imply a positive response to the second. Some existing facilities may not offer the desired reliability or performance, and replacement might be more effective in the long run.

5.2 Specification Methods for Material Selection

Suitable materials for CO_2 flooding commonly are selected based on company specifications, manufacturer recommendations, empirical data (field tests), and experience.

5.2.1 Field Tests. ***Overview.*** The purpose of most CO_2-flood field testing is not to test surface facilities, but to collect important data about the reservoir. However, field testing does offer an opportunity to test materials and gain valuable operating experience, which can lead to substantial savings.

A field test can encompass a single well, a pattern, or a small area of the potential flood. Product performance can be gauged by durability, reliability, corrosion resistance, erosion resistance, and

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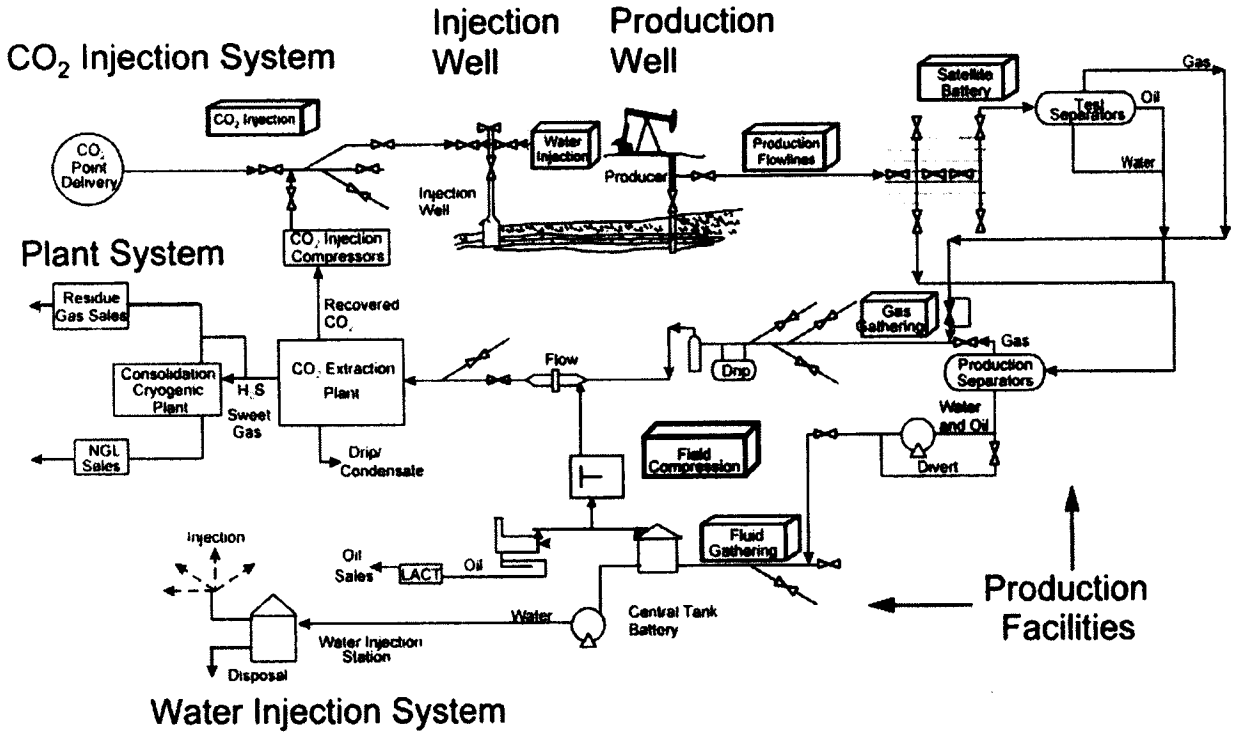


Fig. 5.1—Schematic of a west Texas CO_2 flood. This figure is modified from Fig. 3.16, adding the gas compression leg.

perhaps repair and maintenance costs. A properly designed, installed, and evaluated field test saves money by reducing initial capital requirements, improving system reliability, and lowering future repair and replacement costs. The test also can help establish inventory levels for replacement equipment and repair parts, and it may point out opportunities for standardizing equipment. Standardization not only helps lower purchase costs through larger orders, it also helps prevent confusion about which materials should be used for specific applications.

Field tests should measure material performance in each application—CO_2 injection, water injection, and production—where the material may be used. One might think that only the CO_2 injection system would need evaluation, but nothing could be less true. Many flood design elements are affected by CO_2. Here are a few examples: (1) the presence of CO_2 makes produced water much more corrosive; (2) makeup water from new sources may interact with formation water to create new problems with scale or corrosion; (3) a CO_2 flood may cause paraffins and asphaltenes to precipitate out of the oil, which can cause plugging and emulsion problems; and (4) the potentially dramatic increase in production caused by the flood could cause more formation fines to be entrained in the oil, potentially causing plugging, erosion, and processing problems. Indeed, CO_2 can affect nearly every area of the oil field in one way or another.

The evaluation of material performance depends mostly on visual examination. Material samples should be removed from service and inspected after one, three, and six months. A six-month test should suffice for clear evaluation of most materials.

A visual examination may not tell the entire story, however, and laboratory testing also should be considered. For example, hardness tests and dye-penetrant tests on carbon-steel welds can identify sulfide stress cracking, a dye-penetrant test on stainless steel can find chloride stress cracking, and tensile tests on fiberglass can quantify any loss in strength. How much testing to perform will depend on the cost savings at stake, the time available for testing, and accessibility of resources needed to perform the tests.

The sections below briefly cover piping, valve application, and elastomers, three design choices for which field tests can prove especially valuable.

Piping. Selecting appropriate piping is crucial in a CO_2 flood, and field testing can be an invaluable tool for making the most cost-effective choice.

Materials sometimes are selected for CO_2 applications based on manufacturers' published corrosion resistance, and high-alloy and/or highly specified materials work extremely well in mitigating corrosion-related failures. These products often are more expensive than traditional materials, however, and they can be susceptible to failure mechanisms other than corrosion. For example, austenitic stainless steels such as Grade 316 are susceptible to chloride stress cracking. The best way of evaluating the trade-offs between service capabilities and cost is to field-test each material under operating conditions.

Common piping materials for CO_2 service include fiberglass, stainless steel, cement-lined carbon steel, and internally coated carbon steel, all of which tend to cost more to purchase and install than bare carbon—and which may not always be necessary. We are aware of many fields (Bairoil, Budafa, Crossett, and North Farnsworth) where carbon steel has performed well in three-phase production service (oil, water, gas).

The best way to test pipe materials is to install spool pieces in the service and withdraw them after one, three, and six months for visual inspection and measurements that might indicate changes such as weight loss. When installing different materials in a single pipeline, be aware that galvanic corrosion can adversely affect the test.

Valve Applications. The field test is an ideal opportunity to test valve bodies, seats and trims (internals). How well do the valves perform mechanically? Do they shut off as they are supposed to? Are they easy to open and close? Does the material selected give the corrosion and erosion resistance needed?

While there are some common materials for valve bodies—carbon steel for dry CO_2 injection service and Grade 316 stainless steel in water injection—there can be tremendous variation in the material used, both within the field and between fields. The choice will depend on the corrosivity and erosion potential of the fluids handled.

Materials for valve bodies include standard carbon steel, internally coated carbon steel, Alloy 20, and Grade 316 stainless steel. These and other materials also are used for valve trim. Alloy 20 and nickel aluminum bronze (NiAlBr) are commonly selected materials for corrosion resistance in CO_2 service, although experience has shown that these materials are subject to higher failure rates from erosion and general wear.

The valve seat material can greatly affect valve and system performance, reliability, and total cost. Testing can help with assessing reliability vs. cost for each field's specific operating conditions.

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TABLE 5.1—DATA REQUIRED AND DATA SOURCES FOR CO_2 FLOOD FIELD FACILITY DESIGN

Facility	Data Required	Source
CO_2 plant	Location, inlet pressure, maximum capacity, discharge pressure, discharge temperature, discharge composition	Plant design team
Production forecasts	Oil, water, and gas forecasts for individual wells and the total field	Reservoir and production design team
Maps	Topography, well locations, existing facilities locations, lease and unit boundaries, roads	USGS, company sources
Existing facilities	Detailed design criteria, operation and maintenance histories, construction materials, construction and design codes	Operation personnel, facility records, equipment manufacturers
Compositions	Oil, water, and gas (produced and injected) expected through the life of the flood	Reservoir simulation and analog data
Injection pressures	Desired and maximum, surface and bottomhole	Reservoir and production team
Target injection rates	CO_2 and water for each well	Reservoir and production team
Design and construction codes	ASME, API, ASTM, company specifications	Online or library
Environmental and regulatory restrictions	BLM, OSHA, EPA, plus state regulations	Online, library, or agency offices
Environmental conditions	Elevations, pressure and temperature ranges, wind speeds, earthquake or tornado activity, flooding, proximity to populated areas or public facilities	Specifics may be derived from CO_2 release dispersion modeling; U.S. Weather Bureau
Power supplies available	Electricity, fuel gas	Company sources
Sales contract specifications	Oil, gas, NGL, CO_2	Company sources

Elastomers. The performance of elastomers also should be evaluated because failures in these seemingly small components can wreak havoc with operations and cause costly downtime and repairs. Critical locations of elastomers within CO_2 flood surface facilities include spectacle blinds, orifice fittings, and downhole packers.

Elastomers can fail because of swelling, hardening, or cracking, all of which are the direct result of exposure to CO_2. Carbon dioxide diffuses into elastomeric compounds under pressure and temperature. Repeated pressurizing and depressurizing of an elastomer can cause a phenomenon called explosive decompression, which shows up as blistering, fracturing, or cracking. There is no single solution to this problem, which is affected by three factors: the rate of decompression, the permeability of the elastomer to CO_2, and the strength of the elastomer. Because of the difficulty of controlling the rate of decompression, and because most commonly used elastomers have some permeability to CO_2, the most common way of reducing susceptibility to explosive decompression is to increase the hardness (strength) of the elastomer.

The most common elastomers in CO_2 service are peroxide- or sulfur-cured Buna-N (nitrile) and various grades of Viton. Nitrile is a copolymer of butadiene and acrylonitrile monomers and may be compounded for a wide range of service temperatures, from −55 to 125°C. It is the most widely used elastomer in the seal industry and has excellent resistance to petroleum products. For CO_2 service, a durameter rating of 90 or greater usually is specified.

Viton is a trade name for a fluorinated monomer. Fluorocarbon compounds become hard below −20°C but can provide high temperature (225°C) capability. While these compounds have excellent chemical and heat resistance and good mechanical and compression properties, they normally are more expensive than other elastomers. The use of both nitrile and Viton products must be considered carefully if they will be exposed to H_2S because some nitrile and Viton elastomers will degrade in the presence of H_2S.

In addition to the three elastomers discussed above, epichlorohydrine, EPDM (a terpolymer of ethylene and propylene), and Kalrez have been used successfully in CO_2 floods.

To date, there is no industry consensus on which elastomer is best for CO_2 service, but we offer the following guidelines: (1) keep the rate of decompression as low as possible; (2) choose the least permeable elastomer; and (3) select harder (higher strength) compounds because these elastomers tend to resist explosive decompression.

5.2.2 Other Sources of Information. If field testing materials is not possible, the design engineer must turn to other data sources, including analogous CO_2 floods, laboratory testing, and industry publications.

Analogous CO_2 Flood Field Data. Nearby CO_2 floods can be an excellent source of design, operating, and maintenance information. In selecting analogous floods, choose those with process conditions that closely match the conditions anticipated. There are

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a multitude of process conditions that potentially could be matched. The more that actually *do* match, the better, but the "short list" of matching conditions for surface facility design includes initial crude oil composition (e.g., API gravity and asphaltene content), reservoir pressure and temperature, and H_2S content. In general, any field that provides a good basis for the scaleup process used in screening (see Chap. 3) is a potential source for facility design information.

Laboratory Test Data. Laboratory testing can provide excellent design information and criteria. Typically, one simulates the anticipated fluid composition and then synthesizes these fluids in the laboratory. Tests are run at different conditions, either to match anticipated operating conditions or to provide an accelerated environment (e.g., twice the anticipated temperature) to shorten test duration.

5.3 Production

Before moving on to rigorous technical design of production systems, three complex issues must be analyzed and resolved: how many stages of separation, whether each stage is two-or three-phase separation, and what the operating pressure will be for each stage of separation. The normal design approach is to address gas processing first, then work backward through the remaining systems.

The design of gas processing facilities normally takes precedence in planning a CO_2 flood for four reasons. First, gas processing facilities require substantial capital outlay—they are by far the single most expensive component of a CO_2 flood except for the purchased CO_2 volume (see Sec. 3.3.2 and Fig. 3.20). Second, compression facilities are expensive to operate, primarily because of power requirements and maintenance. Third, compression is a relatively inefficient process because gas absorbs so much energy as force is applied. Thus the best design is one that minimizes overall compression (the gas processing facility plus the field), taking into account the impact of higher backpressure on oil production rates. Fourth, the inlet and outlet pressures fixed by the design of the gas processing plant determine the operating pressure ranges and limits of field equipment.

5.3.1 Separation Issues. Separation is the process of separating the produced gas (hydrocarbons and CO_2), oil, and water. Issues here include the number of stages of separation to be used, the location for each stage of separation, whether each stage will be two-phase or three-phase separation, and the operating pressure for each stage.

Design of the separation facility begins only after the gas processing facility design is fixed, especially for location, inlet pressure, capacity, and outlet pressure, four parameters that are of primary concern in separation facility design.

Separation Locations, Capacities, and Technologies. Separation facilities typically include a few strategically located central facilities (central batteries), as well as several smaller separation facilities (satellites) located throughout the field. The central batteries provide the primary oil and water separation services, and their number is decided based on distance, location relative to the gas processing facility, lease or unit requirements, operating and capital costs, and forecasts of fluid handling requirements. Satellites generally provide a location for well testing and also may provide a stage of gas separation.

The number and location of separation facilities and what separation technology (two-stage or three-stage) is to be used are key concerns because they deal with the need to monitor production rates during a CO_2 flood. This is more important for a CO_2 flood than for a waterflood because in the reservoir, CO_2 is both more costly and more difficult to control than water. Obtaining good areal and vertical sweep depends on fine-tuning the injection of CO_2 and water, and doing this effectively requires accurate information about what is happening in each area of the flood.

Unfortunately, there is no clear-cut answer as to the appropriate number and location of satellites and central batteries—neither is there a simple procedure to find an answer. Once again, one must develop alternatives and analyze trade-offs. In doing so, these data are needed:

- Gas processing facility inlet pressure.
- Crude oil composition.
- Produced gas composition.
- Crude oil sales specifications [e.g., maximum allowabl basic sediment and water (BS&W), gravity penalties, and the Rei vapor pressure].
- Regulatory requirements governing the discharge of pro duced gases.
- Desired injection water quality (e.g., allowable oil and greas and total suspended solids).
- Required water disposal and/or reinjection specification (e.g., total dissolved solids, ion limits, oil and grease limits).
- Map of well locations.

Number of Satellites. A common monitoring practice is tc measure production rates for individual wells for 12 to 24 hours. Assuming that a production engineer must be able to obtain two tc four well tests per well per month, then the size of a test site must be limited to 15 to 20 wells. This criterion can be used to arrive at the fewest number of test sites (satellites).

Having more satellites provides the opportunity to test wells more frequently, which can help fine-tune the CO_2 flood to improve oil production and better manage gas production and injection. However, an increase in the number of satellites also means an increase in the number of vessels and support equipment that must be purchased, installed, operated, and maintained. Three-phase meter technology offers one alternative to the use of pressure vessels for well testing, but the effectiveness of this technology depends upon how well the fluids and the process fit the metering specifications. Only a cost/benefit comparison can determine which approach will be more cost-efficient.

Several options are available for the components at CO_2 flood satellites: They can be the same as those used during waterflood operations, they may be upgraded for CO_2 conditions, or they may be newly designed and constructed to handle the increase in pressure, fluid rates (especially gas), and fluid corrosivity associated with CO_2.

Satellite Separation or Not? A satellite can be designed simply to direct all accumulated fluid to a central facility, or it can include a stage of separation. If all produced fluids are routed to a central facility, operation and maintenance requirements are consolidated within a small geographic area, but this also creates the opportunity for slug flow and requires larger diameter lines. Separating the gas at a satellite eliminates slug flow into the central facility and saves money through the use of smaller diameter liquid collection lines—but it requires separators at each satellite, as well as the installation of more gas-gathering lines. A cost/benefit comparison of several alternatives is the only method of finding the cost-effective solution.

Natural Flow or Compression? If the decision is made to install two- or three-phase separation at the satellites, there are two more alternatives. First, each separator can operate at a pressure higher than the sum of the gas processing facility inlet pressure plus pressure losses in the gas-gathering system. This allows the separated gas to flow naturally to the gas processing facility, without the capital and operating cost of field compression. The downside of this approach is that it increases backpressure on the producing wells, thus reducing total production rates.

The second alternative is to operate the satellite at a low pressure and use field compression to move the gas to the gas processing facility. The downside here is the cost to install and operate field compression.

How Many Stages? The more stages of separation there are (sum of the stages in the satellites plus those in the central facility), the more light-end hydrocarbons that stay in the liquid that is to be sold as oil. Thus, more stages of separation increases both the volume and the value of the oil, but it also increases the amount of vessels and support equipment that must be purchased, installed, operated, and maintained.

As these examples show, there are pros and cons for every alternative, and only by performing cost/benefit analyses can one arrive at a solution that takes into consideration all components: capital investment, revenue generated, operating costs, maintenance costs, reliability, and safety.

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5.3.2 Gas-Gathering System. The gas-gathering system consists of the piping that delivers produced gas from the separation and field compression facilities to the gas processing facility inlet. Design of the system requires several sets of data: the maximum anticipated rates from each of the gas sources (separation facilities and compression), gas composition, field topography, regulatory requirements, and industry design specifications.

Multiple design issues are involved, including material selection, sizing for flow rates, design for pressure rating, selection of the route, and the location and design of drip vessels. The final design will depend on the material, installation, and maintenance costs for each alternative investigated.

Materials. A number of materials can be used as piping in the gas-gathering system, including stainless steel, fiberglass, aluminum, internally coated carbon steel, and other corrosion resistant alloys. Polyethylene piping has been used in a few cases because it is inexpensive to install, but its use is rare because it absorbs hydrocarbons and can be used only at low pressures.

Of the above materials, the most common are fiberglass, stainless steel, and internally coated carbon steel, each of which has advantages and disadvantages. The final decision on materials usually is made on the basis of corrosion resistance and cost (initial purchase, installation, and maintenance).

Corrosion resistance is very important because the drop in pressure and temperature that occurs as produced gas flows to the gas processing facility causes water and hydrocarbon condensation. Water in the presence of CO_2 forms carbonic acid, which readily attacks a number of materials.

The design engineer also must be aware of external corrosion resulting from electrolytic attack. Typically, selecting corrosion resistant materials, applying external coatings, and/or using cathodic protection mitigates this problem.

In the sections that follow, we discuss various piping materials. From the standpoint of corrosion resistance and cost, we have found fiberglass to be the most satisfactory material for wet CO_2-rich gas applications.

Aluminum. Aluminum has superb resistance to CO_2 and H_2S corrosion mechanisms—it can provide adequate pressure ratings at high temperatures and it has exceptional cold temperature ($<-20°F$) properties.

On the downside, aluminum requires external corrosion protection, such as an external coating or impressed-current cathodic protection. It also can be susceptible to attack from heavy metal ions, the most common of which is iron, which can originate in carbonic acid attack of any bare carbon steel in the system (e.g., casing, tubing, valves, flowlines, etc.). Trace amounts of other heavy metals, such as mercury, also have been observed in some production streams and could prove troublesome. The produced fluid must be tested for iron and other heavy metals before using aluminum.

For the line diameters usually used in gas-gathering systems, the aluminum joining technique is tungsten-inert-gas (TIG) welding, which is a relatively slow and expensive technique that drives up the total cost. Large-diameter aluminum lines (greater than four inches) cannot be plowed into the ground and require excavation in addition to specialized welding, all of which usually makes them more costly than internally coated carbon steel.

In contrast, small-diameter aluminum lines (less than four inches) can be installed from a coil and may be plowed into place, factors which may reduce costs enough to make small-diameter aluminum lines more attractive than internally coated carbon steel.

Carbon Steel. Carbon steel's primary advantages are cost and high-pressure ratings—and every operator in the oil field is familiar with carbon steel and the welding process. The use of bare carbon steel is not common in wet (water saturated) CO_2 service because as temperature and pressure drop, water condenses and reacts with CO_2 to form carbonic acid.

Carbonic acid is a strong corrosive agent in carbon steel, but using corrosion inhibitors or internal coatings, both of which increase the total cost, can mitigate its attack. The use of internal coatings mandates different joining methods—threaded connections, flange connections, or press-together crimp-type connections—because conventional welding techniques are no longer suitable. Threaded connections are not common in line-pipe applications because of the potential for thread leaks.

Carbon steel also is susceptible to electrolytic attack, but using impressed-current cathodic protection and/or the application of an external coating can reduce this susceptibility. Again, both of these increase the total cost. Although carbon steel is not common in gathering systems, internally coated carbon steel is a common material in above-ground separation facilities.

Stainless Steel. Stainless steel provides exceptional corrosion resistance to carbonic acid and H_2S attack, but is susceptible to chloride stress cracking and electrolytic attack. Because water condensation in the gas-gathering system is almost a given, chloride stress cracking is a serious concern. It can occur internally or externally and depends on chloride concentration and operating temperature. NACE *Stand. MR0175-91*[1] provides guidelines for the application of stainless steel when there is potential for chloride stress cracking.

Like other metals, stainless steels can use impressed-current cathodic protection or external coatings to combat electrolytic attack. Stainless steel can be cost-competitive with internally coated carbon steel and, therefore, is a common material in above-ground separation facilities.

Alloys. Numerous corrosion-resistant alloys are available for use in wet CO_2 service, although these alloys generally are not cost effective for piping applications. Such alloys often are used in specialty applications such as downhole products, wellheads, valves, and vessel internals. Three popular alloys for use in wet CO_2 service are NiAlBr, chrome/molybdenum combinations (9Cr/1Mo or 13Cr/1Mo), and Alloy 20.

Fiberglass. Fiberglass (fiber-reinforced plastic, or FRP) is a popular material for wet gas service. It has excellent corrosion resistance; is relatively inexpensive; and when used by experienced personnel, its installation costs can approach those for carbon steel.

Fiberglass works under a wide range of pressures. The maximum operating pressure decreases as temperature increases, however, so operating temperature is an important design parameter. Most gas-gathering applications operate at temperatures well within fiberglass capabilities, although temperature issues may be encountered in production flowlines and compressor piping applications.

Because fiberglass nearly always is buried to prevent ultraviolet degradation of the resins, installation quality is a major concern. Extreme care must be taken during the joining process (whether each connection is glued, threaded, or flanged) to ensure effective, long-lasting connections.

There also are other installation concerns: The bedding material must be compacted around the fiberglass and, along with the backfill material, must be free of large rocks. Manufacturer specifications must be followed to ensure that allowable bends are not exceeded. Some type of marker (e.g., metallic tape, surface markers) must be installed to locate the line once it is buried. Finally, the maximum allowable burial depth may impose limits and must be checked using the procedure outlined in ASTM *Stand. D 3839-89*.[2]

Gas-Gathering Lines. While materials are being selected for the gas-gathering system, the pipeline route or right-of-way (ROW) must be determined, and it should avoid large elevation changes, if possible. Other factors influencing ROW selection can include waterway and highway crossings, special permitting requirements (historical or archeological sites), distance, accessibility, county line crossings, presence of housing or public roads, and lease or unit boundaries. The length and topography of each line influences other design aspects.

Line Diameter. Once the ROW is established, a computer model generally is used to develop the optimum line diameters based on frictional pressure drop, cost, and the degree of confidence in the gas-rate forecast. A common design approach is to use the American Gas Association (AGA) gas equation3 that follows, in conjunction with pipeline efficiencies.

$$q=C_1 E\left[(p_2^2-p_1^2)\, d^5 / \gamma_g L T f \bar{z}\right]^{0.5}, \quad \ldots\ldots\ldots\ldots\ldots\ldots (5.1a)$$

where: q=flow rate, scf/D; C_1=units constant; E=pipeline efficiency, fraction; p_1=upstream pressure, psia; p_2=downstream

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pressure, psia; d=pipe diameter, ft; γ_g=gas gravity (air=1.0); T=gas temperature, °R; L=pipe length, ft; f=friction factor; and $\overline{z}$=gas compressibility factor at average pressure ($\overline{p}$); and where $\overline{p}$, in psia, is determined by

$$\overline{p}=0.67\,[p_1+p_2-(p_1\,p_2)/(p_1+p_2)] \quad \ldots\ldots\ldots\ldots\ldots\ldots (5.1b)$$

In Eq. 5.1a, the friction factor, f, is determined using either of the following relationships, which are for partially turbulent flow and fully turbulent flow, respectively:

$$(1/f)^{0.5}=4\log\,[N_{Re}/(1/f)^{0.5}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.1c)$$

$$(1/f)^{0.5}=4\log\,(3.7\,d/k)\,, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.1d)$$

where N_{Re}=Reynolds number; and k=roughness, in.

The design begins with a trial-and-error approach. The plant inlet pressure becomes fixed during the gas processing facility design. Diameters for each line are selected and input along with the appropriate flow rates, and the model is executed to calculate the upstream pressure for each gathering line. The final sizing selection is made after analyzing the cost for lines and vessels for several different pipe diameters.

Once again, the process involves analyzing alternatives and selecting the best one. The trade-offs are straightforward: Larger diameter piping costs more but provides lower operating pressures that enable the use of vessels that are less expensive because they have lower operating pressures.

The inlet pressures to the gas-gathering system provide the basis for vessel, compressor, and piping design at the separation facilities, as described below.

Design Pressure and the Pressure Relief System. The inlet side of the gas-gathering system is connected to pressure vessels (e.g., separators) or compressors, both of which have some type of pressure relief system to provide protection from overpressurizing. The pressure relief system may comprise pressure relief valves (also known as pressure safety valves or PSV's), rupture disks (also called burst plates), or a combination of these.

The highest pressure in a gas-gathering system generally occurs at the system inlet, as dictated by the pressure relief valve there. Most gas-gathering applications use the pressure relief valve setting as the design basis for piping, adding a safety factor of 10%. This safety factor also should be adjusted to accommodate other conditions, such as piping that runs through a populated area.

The pressure-drop model selected for piping design should provide a summary of pressures throughout the pipe system. This pressure summary gives the maximum pressure that each component of the system must be capable of withstanding.

Once the design pressure is established, the remaining design steps follow conventional techniques that determine the required minimum wall thickness for the specific material. As is done in conventional facilities design, choose the next largest commercially available wall thickness.

Metering. Meter Type and Metering Points. There are two notable differences between metering of CO_2 and metering of natural gas. One difference is that the materials used for CO_2 metering usually are constructed out of Grade 316 stainless steel to resist corrosion. The other is that CO_2 requires density adjustments for custody transfer applications.

Turbine meters commonly are used for data collection applications, although vortex meters also are emerging as a cost effective method. Orifice meters—the same used for natural gas production—typically are used for custody transfer measurement.

The selection of metering locations is governed by several factors, including the layout of the CO_2 flood. Metering may be required if the gathering system crosses lease or unit boundaries or if gas production from multiple leases will be commingled. If the CO_2 flood encompasses only one lease, a single total flow meter would suffice.

Allocation metering requires additional meter locations. The purpose of allocation metering is to gather data needed to make resource decisions. Because allocation meters assign production to a lease, formation, or individual we accurate allocation metering is important in effective management of a CO_2 flood. The number and locations of allocation meters may be governed by regulatory agencies, with final decisions influenced by the size of the CO_2 flood.

Allocation meters for gas can be either turbine or orifice meters whereas for liquids they nearly always are turbine meters. There no standard in place for allocation meters, such as there is for custody transfer meters.

Orifice Meters. API *Stand. MPMS 14.3*[4] provides extensive specifications for the design of an orifice meter run.

The general orifice meter equation developed by the AGA[5] is

$$q_b=C'\,(p_{dw}\,p_{su})^{0.5}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.2$$

where q_b=rate of flow at base conditions, ft³/hr; C'=orifice flow constant; p_{dw}=differential pressure, in. of water at 60°F; p_{su}=absolute static pressure, psia; and $(p_{dw}\,p_{su})^{0.5}$=the pressure extension.

In Eq. 5.2a, C' is calculated as

$$C'=F_b\,F_{Re}\,F_e\,F_{pb}\,F_{tb}\,F_{tf}\,F_g\,F_{pv}\,F_m\,F_l\,F_a, \quad \ldots\ldots\ldots\ldots (5.2$$

where F_b=basic orifice factor; F_{Re}=Reynolds number factor; F_e=expansion factor; F_{pb}=pressure base factor; F_{tb}=temperature base factor; F_{tf}=flowing temperature factor; F_g=specific gravity factor; F_{pv}=supercompressibility factor; F_m=manometer factor; F_l=gauge location factor; and F_a=orifice thermal expansion factor. Ikoku[6] provides an excellent reference for the calculation procedure.

Gas Density. The density of CO_2 is the single largest obstacle to accurate gas measurement. Carbon dioxide does not behave like an ideal gas; it undergoes phase changes and its density impacts the basic orifice factor, the Reynolds number, specific gravity factor, and the supercompressibility factor used in orifice meter flow calculations.

The CO_2 density generally is determined using an in-line densitometer or by using an algorithm that incorporates pressure, temperature, and gas composition. Custody transfer applications generally require densitometers if composition is variable; for allocation measurements or situations in which composition is fairly constant, a correlation typically is used. Densitometers require frequent calibration and are relatively expensive to purchase.

Drip Vessels. Definition and Function. The final step in the design of the gas-gathering system is to design and select the locations for drip vessels (drips) that collect liquids that either condense out of the gas stream along the pipeline or are carried over from the upstream process. Drips are crucial to the effective operation of a gas-gathering system because the presence of liquids in the system creates a second phase that causes an unnecessary pressure drop. Under the worst case scenario, liquids can build up in low spots until upstream pressure drives them forward in large volumes, referred to as slugs. Liquid buildup also increases susceptibility to freezing in cold temperatures. It is far better to install too many drips than too few.

A drip vessel is classified as a code pressure vessel if it operates at pressures over 15 psig, and most gas-gathering system pressures exceed this limit. Even if a drip vessel's maximum pressure is under 15 psig, it still may qualify as a code pressure vessel if it exceeds the minimum size specified in ASME *Sec. VIII ASME Boiler and Pressure Vessel Code*.[7] Code vessels must be manufactured and maintained under a specific set of requirements spelled out in Sec. VIII.

Drip Design. In designing a drip, the primary need is to determine the optimum size. Some companies have standardized sizes; however, it is much better to size drips technically to arrive at the right drip size (and cost) for each use. An EOS software package can predict liquid condensation rates reasonably accurately, and the drips can be sized accordingly. The design engineer also should consider the size of potential liquid slugs that could originate from liquid carryover or upsets in upstream vessels. In addition, if a drip must be emptied manually, drip size should be based on the desired service interval. This factor is less important if the drip can be emptied automatically to a lower-pressure facility. Always, one must strike a compromise between ease of operation

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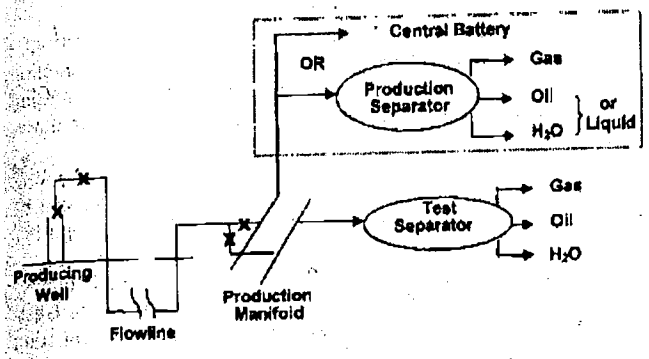


Fig. 5.2—Production satellite schematic.

(larger drips mean less frequent emptying) and initial cost (larger drips cost more to purchase).

Drips should be located at the low spots in the topography of the gas-gathering system route. If the route is relatively flat, EOS software can be used to forecast liquid condensation for drip placement.

Drip vessels usually are constructed of internally coated material because of the potential corrosivity of the condensed liquids. If the drip is classified as a pressure vessel (code vessel), its design must conform to ASME Section VIII as noted above. Drips often are buried beneath or to the side of the gas-gathering system to facilitate the accumulation of liquids. If they are buried, drip vessels also must be externally coated to mitigate electrolytic corrosion. Controls, monitors, and access areas for buried drip vessels should be located above ground.

5.3.3 Production Satellite Design. ***Satellite Batteries.*** The gas-gathering system design completion fixes the maximum design pressure for vessels at the production satellites. **Fig. 5.2** shows a schematic layout for a typical satellite battery, and **Table 5.2** compares alternatives and relative costs (L=low, M=medium, H=high).

Production satellites generally contain a production manifold, a two- or three-phase separator (referred to as a production separator), and a smaller three-phase test separator to provide well test data. Auxiliary equipment at a production satellite may include an instrument air compressor, chemical injection equipment, and automation systems.

The three-phase test separator cycles from one individual well to the next, periodically measuring production rates for each. Production from all the other wells served by the satellite may go directly to a central battery for phase separation, or it may be separated at the satellite by a two- or three-phase production separator. Three-phase separators (gas, oil, and water) are useful for acquiring data on the performance of that specific group of wells, data that are important in effective flood management.

If the satellite is used for three-phase separation, the water and oil phases can either be kept separate or be recombined before being sent on to a central tank battery. Fluids separated at satellites may be recombined, which would reduce capital costs by eliminating the need for two pipelines.

The central battery provides the final cleanup. Oil is separated and processed to meet pipeline sales specifications; water is separated and cleaned to meet injection-water quality guidelines; and CO_2 gas is processed to remove any liquids present, then compressed and sent to the gas processing facility.

If a satellite is used for a stage of separation, the gas dump valves provide the inlet gas feed either to a field compressor or to the gas-gathering system.

Production Flowlines. Production flowlines connect individual producing wells to a production satellite. In most cases, new production flowlines will be needed to handle the higher rates and pressures that CO_2 floods generate, as well as to mitigate corrosion, improve safety, and achieve acceptable reliability. The main design considerations for production flowlines are capacity, pressure rating, and corrosion resistance.

Multiphase Flow. The size for CO_2 flood production flowlines is dictated by multiphase flow considerations. The addition of any gas to a predominately liquid system complicates the flow and the pressure drop calculations. Multiphase flow causes frictional pressure drops that significantly exceed those found in single-phase flow.

Multiphase flow calculations introduce a modification to the basic flow equation to account for fluids and fluid-flow properties in terms of two phases rather than one. The various flow correlations in use differ from each other in how they define two-phase properties and in the range of properties over which they are valid. Most define a flow regime and efficiency loss (sometimes referred to as a holdup).

The general form of the multiphase flow equation[3] is:

$$(dp/dL)=[(f_{tp}\,\rho_{tp}\,v_{tp}^2)/(2\,g_c\,d)]+[(g\,\rho_{tp}\sin\theta)/g_c]$$
$$+\{[(\rho_{tp}\,v_{tp})/g_c]\,(d\,v_{tp}/d\,L)\}, \quad \ldots\ldots\ldots\ldots\ldots\ldots (5.3)$$

where (dp/dL)=pressure drop per unit length; p=pressure; d=pipe diameter, ft; L=length; f_{tp}=friction factor, two-phase; ρ_{tp}=density, two-phase; v_{tp}=velocity, two-phase; g=gravitational acceleration,; g_c=gravitational constant; θ=angle of inclination,; $[(f_{tp}\,\rho_{tp}\,v_{tp}^2)/(2\,g_c\,d)]$=frictional component;

TABLE 5.2—ALTERNATIVES AND RELATIVE COSTS FOR SEPARATOR DESIGN

Production Separator	Test Separator Fluids	Capital Cost	Operator Cost	Downstream Piping	Issues
None	Recombine and send to central battery	L	H	Three-phase collection system	Slugging, higher frictional pressure drop
Two-phase	Gas to gas processing facility; combined liquid to central battery	M	M	Gas collection and liquid collection	
Three-phase	Gas to gas processing facility; water to central battery or water injection station; oil to central battery	H	L	Gas collection, oil collection, and water collection	High capital requirements

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$[(g\ \rho_{tp}\ \sin\theta)/g_c]$=elevation component; and $\{[(\rho_{tp}\ v_{tp})/g_c]\ (d\ v_{tp}/d\ L)\}$=acceleration component.

Computer software packages for multiphase flow designs offer a number of equations and correlations to calculate pressure drops. One common design technique uses the Beggs and Brill correlation[8] modified to use Colebrook[9] (Moody diagram) friction factors.

As was the case with the gas-gathering system design, the optimum flowline diameter is determined by trial-and-error.

Pressure Considerations. The pressure rating for production flowlines is an important issue. While normal operating pressures may be relatively low, flowlines easily can be exposed to significantly higher pressures when unexpected conditions occur. In fact, producing wells in a CO_2 flood may be able to flow after gas breakthrough, when gas flow increases significantly.

The possibility of flowing conditions means, of course, that high pressures can be transmitted to surface facilities. If flowlines are not designed adequately, serious mechanical failures can result. Production flowlines must be able to handle the maximum anticipated shut-in surface pressure.

At first glance, this might not seem like a significant issue, but producing wells may be capable of flowing at hundreds of psia, and if flow is blocked in (e.g., valve closed or line plugged), the pressure can build quickly to even higher levels. The maximum possible pressure is the pressure of the reservoir minus the hydrostatic pressure created by a full column of produced gas. Production flowlines must be designed to handle this maximum pressure, or there must be a built-in capability to automatically isolate the flowline from the well.

Another safeguard is to have in place is a method of leak detection. A common technique is to monitor the temperature and/or pressure, to detect changes from normal conditions.

Corrosion Resistance. A final design issue is corrosion mitigation. Oil, water, and carbon dioxide are produced fluids, and water and CO_2 together create the potential for carbonic acid attack. Bare carbon steel has been used effectively in some fields; however, its use can be risky, and field-testing is the only means of determining how it will perform. Most production flowlines in CO_2 floods use fiberglass.

Production Manifold. The production manifold is an arrangement of valves and piping that directs fluid flow from individual wells to a specific process (test or separation). Production manifolds usually are constructed in a modular fashion that uses flange connections to facilitate expansion or contraction as the CO_2 flood matures.

Valves. Valving in the manifold can range from a series of manually operated valves to a single automated valve with an actuator that, depending upon its position, directs produced fluid either into a line feeding the production separator or into another line feeding the test separator. Usually only one well is tested at a time, so the remaining wells coming into the production satellite are directed to the satellite production separator or downstream to the central battery.

Valving must have excellent corrosion and erosion resistance, and must not induce an unnecessary pressure drop. Typical materials used in these valves include Alloy 20, Grade 316 stainless steel (depending on chloride stress cracking potential), Monels, chrome/molybdenum combinations, and other less-common corrosion-resistant alloys, such as Inconels. Valve selection depends on variables such as temperature, pressure, and the composition of the produced fluids.

Piping. The piping used in production manifolds usually is internally coated carbon steel or Grade 316 stainless steel. Fiberglass has been used, but it does not provide adequate safety during unplanned occurrences, such as large liquid slugs that could cause pipe-burst conditions. Safety is paramount in a CO_2 flood, so material selection processes should take into account all risks associated with potential failures.

Pressure Design. The manifold must be designed to accommodate the highest probable pressure. Because producing wells in a CO_2 flood may be able to flow instead of having to be pumped, the manifold must be rated to handle the maximum shut-in surface [...] to use a method of pressure relief.

Separators/Vessels. Vessel design in a CO_2 flood operation is extremely important. Design issues include high gas production rates, adequate pressure rating, sufficient relief systems, separation quality, corrosion resistance, and whether to use two- or three-phase separation.

Cost-effective vessel design depends on the accuracy of the forecasts for oil, water, and gas production rates. Inaccuracies can be accommodated using a conservative design approach, although this is an expensive method of dealing with low-quality information.

Separation Quality—Retention Time. Achieving high quality separation depends on there being adequate retention time (residence time) in the separation vessel. Residence time is a function of the fluid flow rate and the size of the vessel.

The best way to determine retention time (also called residence time) is to conduct a static emulsion breakout test at the anticipated operating temperature and pressure, measuring the relative quality of each fluid over time. The test also can be conducted in the presence of separation aids such as demulsifiers, or at an increased temperature. Though demulsifiers may enable you to reduce capital costs by installing smaller vessels, the demulsifier cost will be an ongoing expense.

Another effective method for determining retention time is by analogy to other CO_2 floods. It is best to run the comparison with a flood whose operating conditions closely match the one you are designing.

Once the retention time has been determined, the size of the vessel components (e.g., oil and water buckets, nozzles) is calculated exactly, just as it is for conventional operations.

Retention time can be used in the following equation to determine the vessel size:

$$t=(V_l\,/\,q_l)\ 1{,}440, \quad \text{(5.4)}$$

where t=design retention time, min; V_l=required separator liquid section volume, bbl; and q_l=liquid throughput, B/D.

Table 5.3 shows the API *Spec 12J*[10] retention time recommendations for gas/oil separation. These guidelines do not account for production problems such as emulsions, foaming, solids, or the presence of water.

Retention times in a CO_2 flood are adversely affected by high gas rates, dissolved CO_2 in the produced liquids, low operating temperatures, emulsions, surging flow rates, and the presence of paraffins and asphaltenes in the produced fluid.

Vessel Corrosion. Of the other pressure-vessel modifications that must be considered in a CO_2 flood; the foremost is the potential for corrosion. The vessel shell, heads, and internals will be in contact with carbonic acid, and possibly with H_2S and sulfate-reducing bacteria, as well.

Two methods commonly are used to prevent corrosion attack: The typical method is to coat the vessel shell, head, and nozzles internally with a coating appropriate for all of the fluids and temperatures to which the vessel will be exposed. Manufacturer data often are used to determine material suitability, and laboratory testing helps, as well. NACE *Standard RP-01-78*[11] and NACE *Standard RP-01-81*[12] provide excellent guidelines for surface preparation and internal coating selection, respectively.

In the second method, sacrificial anodes are used inside the vessel along with internal coatings. Sacrificial anodes have been used in conventional vessel applications, but their use in CO_2 flooding

TABLE 5.3—RETENTION TIME RECOMMENDATION FOR GAS/OIL SEPARATION

Oil Relative Density	Minutes
Below 0.85	1
0.85 to 0.93	1 to 2
0.93 to 1.00	2 to 4

After Ref. 10.

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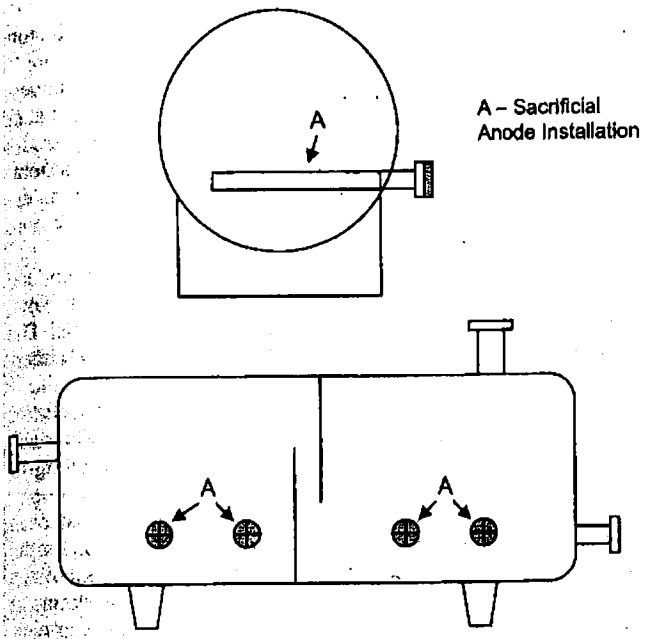


Fig. 5.3—Sacrificial anode installation in a pressure vessel. The top drawing shows the view from the end of the vessel; the bottom shows a side view. The anode is connected at the nozzle.

is even more important, considering the potential corrosivity of the fluids. The decision to use sacrificial anodes must be made early in the design process so that appropriate nozzles can be included during vessel manufacturing.

Sacrificial anodes are designed using the same procedure used for conventional applications. **Fig. 5.3** shows a common sacrificial anode installation.

Vessel internals (mist extractors, weirs, baffles, and vortex breakers) also must be able to resist potential corrosion. Most are made of corrosion-resistant materials such as fiberglass, stainless steel, Monels, and coated carbon steel. Because internal components can be subjected to high stress levels, the metal products are the most common.

Design for Redundancy. One valuable design consideration in a CO_2 flood is redundancy, or spare equipment. No vessel, regardless of application, can be expected be 100% available during its life. This design approach is especially important in a CO_2 flood because of the potential loss of revenue associated with the high oil production rates created by the flood.

If the satellite has both separation and well-test functions, redundancy can be created by designing the test separator to handle most, if not all, of the production separator's capacity. In addition to selecting the appropriate vessel size for this, the piping system connecting the production manifold and the test separator must have adequate capacity. Also, it must be possible to isolate the two vessels through valving. The use of spectacle blinds is one technique to ensure that the vessel being worked on is isolated from both pressure and produced fluid.

Auxiliary Systems. The auxiliary systems in a production satellite—actuators, chemical injection systems, and automation systems—are critical to efficient operation. Actuators require energy to operate. Typically, this will be compressed air, fuel gas, electricity, or other compressed gases, but which one of these will depend on what process is being maintained and, therefore, what hazards might result from an actuator failure caused by an interruption in the energy supply.

Actuators for Dump Valves. Dump valve operation generally is considered to be hazardous service because if a dump valve actuator fails, the vessel either will relieve to atmosphere or will become overpressurized and possibly burst. For this reason, dump valve actuators must have a reliable energy source. Typically, compressed air is used.

Most air compressors contain surge bottles that store energy for use in the event of an electrical interruption, the potential for which is high over the life of the flood. (Electrical actuation rarely is used for this reason.) Bottles of compressed gas, such as air or nitrogen, can be used as emergency backup for highly critical service, although they are not a cost effective primary energy source.

In some cases, dump valve actuators use another high-pressure gas, such as CO_2 or fuel gas. One important consideration in using CO_2 is that the CO_2 must be dehydrated before use to eliminate carbonic acid and its potential corrosivity. Another is that actuator control gas is vented off at the actuator, and in a confined area such as a building, venting CO_2 would be unsafe.

There are similar issues with using fuel gas as an actuator energy source: fuel gas is relatively expensive and also can create a potentially explosive atmosphere. One way to handle this would be to install piping and vent the CO_2 or fuel gas outside the building.

Typically, the cost to dehydrate and vent CO_2 or to purchase fuel gas dictates the use of compressed air.

Chemical Injection Systems. Chemical injection systems are an integral part of production satellites. Chemicals can include demulsifiers, solid control agents, scale inhibitors, and water clarifiers. Demulsifiers and solid control agents (also called interface control chemicals) typically are used to improve separation in the production separator, test separator, and downstream vessels. Because pressure drop and gas breaking out of solution tend to create an ideal environment for scale, scale inhibitors may be injected to prevent downstream scale deposition. Water clarifiers may be added to help achieve water quality targets for reinjection or disposal. Typically, all these chemicals are injected at the production manifold to allow adequate mixing time.

Automation. Automated systems commonly are used to monitor vessel operation and to warn of the existence of adverse conditions. Automation also can be used to control well testing and to control and monitor chemical injection. The degree of automation can range from data acquisition, to monitoring, to on-site control (automatic shutdown or divert), to remote control.

Within the industry, opinions differ about how much and what to automate. Larger operators tend to be proautomation, while small operators do not.

We support the use of automation in CO_2 floods for several reasons. First, CO_2 is so expensive that we believe automation will easily pay for itself through better CO_2 control. Second, conditions in a CO_2 flood (high pressures and flow rates, corrosive fluids, dangerous gas) are such that the risk of catastrophic failure is much higher than in primary or waterflood operations. Because automation makes possible a much safer operation through automatic shut-in capabilities, in an overall risk-management approach to a CO_2 flood, one should have little trouble justifying automation. Third, automation makes sense for well testing because individual well production rates are so much higher than they are in a waterflood. When wells perform at high levels, they should be monitored closely. One of the best ways of doing that is to test them frequently, which is only practical through automation. In summary, while CO_2 automation adds capital and operating costs, we believe it pays for itself many times over.

5.3.4 Liquid Gathering: Satellites to Central Battery. The piping system used to deliver produced liquids from the production satellite to downstream processes at the central battery commonly is referred to as the liquid-gathering or liquid-collection system. The design of this piping system is quite similar to that of the gas-gathering system: The pressure rating, material selection, capacity, and route must be established.

The pressure rating of the line should at least match the maximum allowable working pressure of the upstream vessel or the pump discharge pressure. If the topography of the system creates higher pressures because of hydrostatic effects, this must be taken into account, as well. The density associated with liquids is significant, and hydrostatic pressures can be high.

Fluid Phases and Number of Lines. If a production satellite performs only test separation, then the liquid-gathering system will be designed to accommodate three-phase flow. However, if the upstream satellite also provides a stage of separation, then the design of the liquid-gathering system will be driven by the previous decisions regarding two-phase vs. three-phase separation. For two-phase separation, the mixture of oil and water is piped through

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a single line to downstream processes. For three-phase separation, the liquids can be recombined and transported through a single line (to reduce capital costs) or kept segregated by using separate lines.

Multiphase Considerations. It is important to remember that the liquids dumped into the gathering lines from the satellite vessels are in equilibrium at the vessel's operating conditions. Additional pressure drop (such as that experienced across the dump valve) will cause the evolution of gas from the liquid. Thus, two- or three-phase flow may result, rather than the single- or two-phase flow expected. See Sec. 5.3.3 for multiphase flow calculations.

The selection of materials and the determination of ROW's for the line follow the same process outlined for the gas-gathering system (see Sec. 5.3.2). Again, fiberglass is the most commonly used material for liquid-gathering systems because gas evolution creates the potential for carbonic acid attack.

5.3.5 Central Battery Design. The central production battery typically consists of separators, tanks, compressors, a LACT unit, a flare or vent stack, piping, valves, and numerous auxiliary systems, as shown in **Fig. 5.4.**

The central production battery is the heart of CO_2 field facilities, providing the final separation and cleanup, of individual fluids before sale or shipment to another process. All liquids are transported to this destination, and processes here are important to sales and other downstream operations. For this reason, redundant systems are common.

Separators. The separators in production batteries typically are designed for two distinct goals: bulk separation and final cleanup.

At the knockout (the first stage of separation in this facility), the bulk of the gas is taken off the produced fluids. The nearly all the water is removed here, as well, leaving a relatively water-free volume of oil.

Additional separation steps clean each stream further. The treater (heater/treater) removes gas and breaks any remaining emulsion so that virtually all water can be removed. Other vessels may clarify the water, capturing some additional oil. The fluids then are sent downstream for accumulation. Water is collected in tanks, and oil, which now should be sale quality, is sent to a storage or surge vessel before custody transfer.

Separator Design Process. The design process for pressure vessels, or separators, for the battery application is the same as that of the production satellites (see Sec. 5.3.3); however, the pressure requirements for central battery vessels are lower, as are the temperatures of the produced fluids. Because of lower pressures, less energy is available to move fluids, which makes frictional pressure analysis particularly important here.

The lower operating temperature of the central battery can lead to separation quality problems. With additional retention time, chemicals and/or applied heat can mitigate these problems. The lower temperature also may affect the decision about which internal coating to use.

As we discussed earlier, a common design practice for facilities that are critical to the bottom line is vessel redundancy. The presence of redundant systems also implies that adequate valving or other isolation equipment is in place.

Two- or Three-Phase Separation. The type of separators chosen at the production battery depends on what type was selected for the satellites. If two-phase separation was chosen for the satellites, then a single line delivers fluids to the battery and the separators at the battery must be three-phase. If three-phase separation was chosen for the satellites, then two separate lines typically will deliver the water and oil phases, and the separators at the battery need to be two-phase.

Water cleanup can be accomplished with two-phase separation if the downstream water tanks are designed with oil recovery capabilities (oil skimming). The oil stream requires three-phase separation. Three-phase separation at the battery also is required if the satellites provide only a well-testing function.

Three-phase separation at the satellites usually leads to better oil quality at the battery because of reduced volumes of fluid transported, lower gas breakout rates, and reduced surges. Two-phase satellite separation offers the advantage of lower cost vessels because fewer nozzles and vessel internals are required.

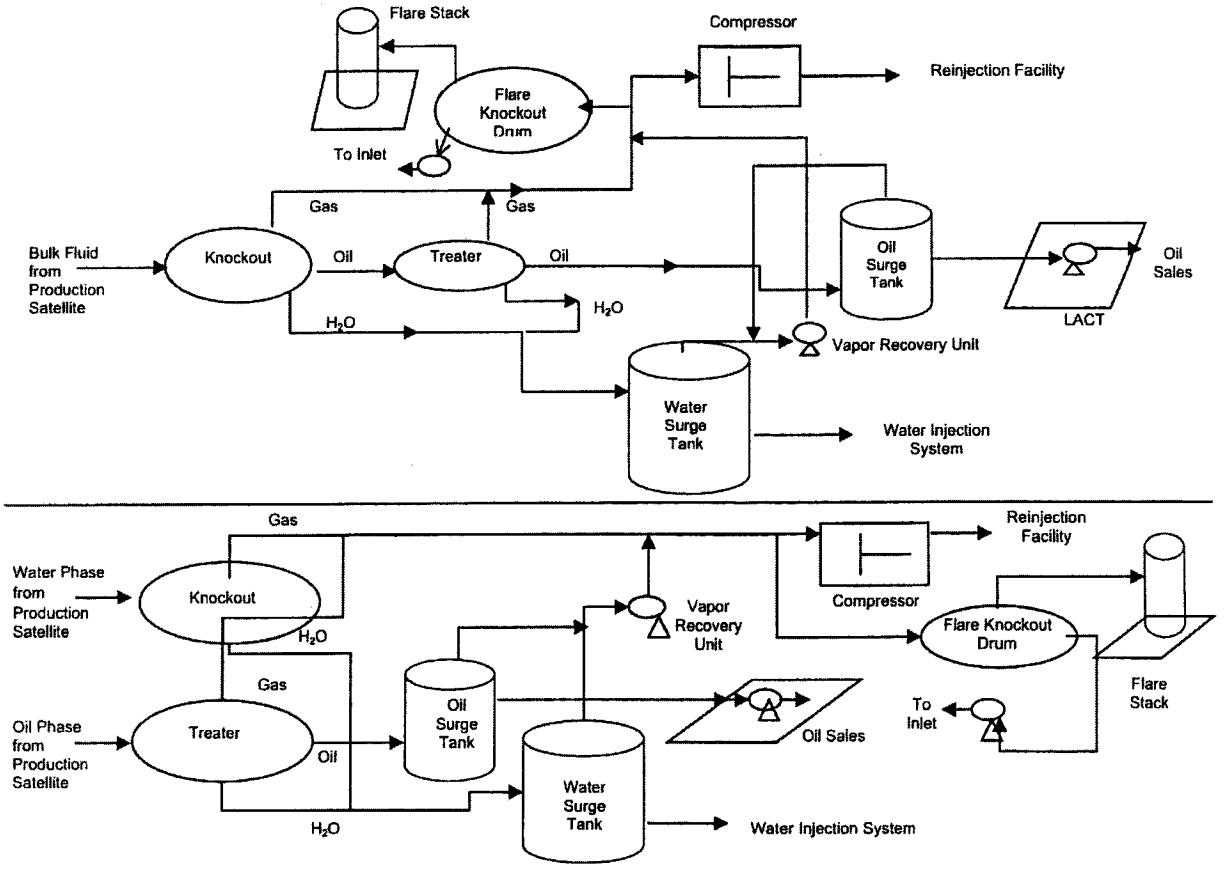


Fig. 5.4—Central battery configuration. The central battery provides final separation and cleanup to get fluids ready for sale or shipment to another process.

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Piping. Most production battery piping is metal; nonmetal piping has greater potential for burst failure. Internally coated carbon steel commonly is used for liquid lines, and Grade 316 stainless steel for gas lines.

Internally coated carbon steel usually is joined through flanges, a technique that requires that the system be designed and prefabricated before installation. Stainless steel can be joined by welding or through flanged connections.

Valving used within the production battery must be corrosion and erosion resistant, as outlined in the production satellite section (see Sec.5.3.3).

Tanks. *Tank Uses.* Tanks perform a number of roles at production batteries. "Bad oil" or "slop" tanks collect "non-spec" oil and other fluids from the field. These fluids usually are pumped back to the inlet of the battery and reprocessed. In CO_2 flooding, the volume of non-spec oil can increase because asphaltenes and paraffins tend to precipitate out and remain suspended in the oil, forcing it outside the range of sale specifications.

Another common tank use is to provide surge capacity and suction pressure for waterflood injection pumps. The location of these tanks depends on the location of the injection pump station.

Water cleanup also may use tanks. While this separation process takes place naturally under gravity, the quality and speed of separation can be improved with the use of vortex nozzles and/or the addition of clarifying chemicals. Depending on the volume of separated oil and the amount of solids dropping out, it might not be feasible to carry out the water cleanup function in a surge tank, and special tanks may be required upstream from the surge capacity.

Other tank applications include sump collection, drip liquids collection, and product storage.

Internal Tank Corrosion. To provide a reliable tank system, the design engineer must counteract corrosion. Internal corrosion, in particular, can be severe. Most tanks operate at or near atmospheric pressure, which facilitates gas breakout as liquids enter the tank, and leads to the development of a blanket of corrosive gas above the liquid. Corrosion attack can be mitigated by the use of an internal coating or by using a noncorrosive blanket of nitrogen gas or fuel gas.

Liquid entering a tank still contains small amounts of CO_2 that can create small carbonic acid corrosion cells. This type of corrosion attack usually is stopped by the use of an internal coating.

The accumulation of solids (sludge) in the bottom of a tank also presents challenges. Sludge is a prime environment for the growth of bacteria that can attack the tank bottom and cause severe corrosion problems. This situation can be prevented by using an internal coating, a fiberglass bottom, and/or sacrificial anodes.

Vapor Recovery Unit (VRU). *VRU Compression Options.* The gas vapor liberated as pressure decreases during the separation process must be handled in one of three ways: compressing the gas to a sufficient pressure to allow it to enter the gas-gathering system; flaring; or venting to the atmosphere. Although regulatory permits can be obtained for flaring and venting, most operators install a VRU because of the value of the gas (CO_2, NGL's, and hydrocarbon gas) and because of regulatory considerations.

Recovering all gas vapors may require multiple compressors operating at different pressures, including a compressor that will recover tank vapors at a pressure slightly above atmospheric pressure. Compressor design is discussed in Sec. 5.3.6.

Compression Piping. Gas vapors coming from the separators and tanks will be saturated with water at each vessel's operating temperature and pressure. As pressure drops and the gas cools en route to the compressor, additional liquids will condense out of the gas stream. The presence of these liquids affects material selection and compression design.

As might be expected, corrosion is a key concern in compression piping. The corrosion resistance of internally coated carbon steel and Grade 316 stainless steel make them the two most popular materials for the application. If either material is to be buried, external coatings also should be used, along with insulating flanges to mitigate electrolytic corrosion.

Flare System. The flare system directs gas from the separation facility to a location where it can be safely and efficiently burned. A typical flare system consists of piping, valves, a flare knockout drum, and a flare stack. **Fig. 5.5** illustrates a typical configuration.

Why Flare? Gas vapors must be handled safely during periods when there are downstream problems or when field compression is not fully operational. The alternatives to flaring are venting and shutting in production. The value loss associated with shutting in production makes it highly undesirable, and venting typically is not permitted because of high concentrations of H_2S in the gas. Permits usually are required to flare gas. The most common permit is an "emergency use only" one that allows flaring in the event of a process upset or interruption.

Flare System Inlet. Typically, the flare system ties into the piping before the first-stage compressor suction(s). A control valve that senses pressure in the compressor inlet piping usually controls this tie-in: If the pressure climbs past a pre-established setpoint, the valve opens and allows gas to flow to the flare. The control valve usually uses compressed air actuation because of the critical service requirement. Selection of the pressure setpoint for the flare control valve is crucial. It must be high enough to allow high-rate gas flow through the entire flare system, yet low enough to prevent the operation of relief valves and rupture disks on upstream vessels.

System Capacity and Flare Stack Sizing. The first, and perhaps most important, step in the design of a flare system is to determine the design gas rate. API *RP 521*[13] provides a list of potential gas sources that a flare system should be sized to handle. Some operators have installed emergency shutdown (ESD) systems to mechanically restrict the amount of gas flow that the flare system must handle. We will discuss this later in this chapter.

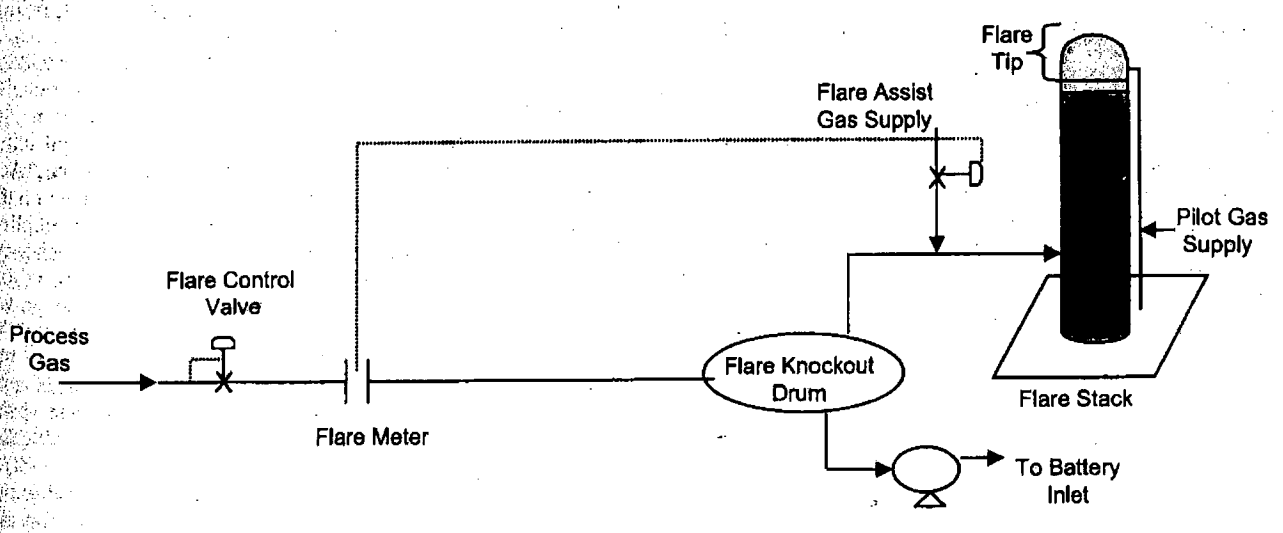


Fig. 5.5—Flare system configuration.

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Even though a flare is intended for emergency use only, it may have to be quite large. If a liquid dump valve in a production separator fails in the open position, all gas handled by the satellite flows to the production battery and ultimately to the flare system to provide vessel relief. The gas rate can be quite high.

One common cause of flaring is compressor downtime. If field compression at a battery becomes unavailable, the flare system must be able to handle the rate normally being processed through the compression equipment.

Flare stack sizing is very important. A flare stack whose diameter is too small can create noise pollution problems or might not be sufficient to handle the upstream pressure. A flare stack that is too large can make it difficult to keep the flare burning on a windy day if gas velocities are low.

Liquid Handling. Flare systems are designed primarily for gas; however, flare system design must also account for the presence of liquids. Liquids originate from condensation, carryover, and vessel upsets, and they can cause severe problems that range from the system's reduced ability to relieve pressure to the potential for releasing burning fluids out the top of the stack. It is virtually impossible to keep liquids out of the flare system. A knockout drum must be installed to collect and remove liquids safely.

A flare knockout drum essentially functions as drip (see Sec. 5.3.2) and is installed upstream of the flare stack. The knockout system collects liquids and pumps them back into the upstream process.

The design of the knockout drum must prevent liquid carryover or re-entrainment in the gas stream. Liquid levels should be kept to an absolute minimum in the knockout drum, and level indicators must be highly reliable to ensure that excess liquids do not build up. If the drum is located above ground, the design must include a means to prevent liquids from freezing in cold weather.

Flare Control Valve and Piping Design. The pressure setpoint for the flare control valve should be established concurrent with the flare system piping design. The piping design and material selection process is very close to that for gas-gathering systems (see Sec. 5.3.2), though there are a few differences. One difference is that the operating pressure of the flare system piping usually is much lower, which means both that it does not take as much wall thickness to withstand operating pressures and that little frictional pressure drop can be tolerated. Another difference is that the flare system piping must be sloped toward the flare knockout drum so that liquids in the piping will drain naturally into the drum for removal. A third difference is that, because the flare system is open to the atmosphere, oxygen can accelerate corrosion. Once again, internally coated carbon steel and fiberglass are generally the materials of choice.

Flare Stack Design. The flare itself is comprised of the foundation, guying, stack, tip, and igniter. The presence of H_2S in many CO_2 floods requires the use of a vertical flare system to minimize the potential for hazardous accumulation of H_2S or sulfur dioxide (SO_2) at ground level. Flare systems that handle H_2S also must have a continuous pilot flame to reduce the possibility that the gas will not be burned.

The design of the flare stack is similar to that of conventional operations. When CO_2 is present in high concentrations, it will have an extremely low heating value or heat of combustion, as referenced in API *RP 521*.[13] Heating values less than 200 Btu/scf are common in existing CO_2 floods. Because a gas normally must have a heating value of at least 300 Btu/scf to burn, another energy source—fuel gas, propane, or butane—must be added.

The equipment used to add this external energy is the flare assist system, which is designed to add higher-Btu gas automatically whenever the flare system becomes active. The flare assist system often is controlled off flow rate through the flare system.

The low heating value of CO_2 also affects calculations of stack height and diameter. Normally, stack design is derived from API *RP 521*[13] specifications; however, the low heating value of CO_2 often yields a short flare stack using these calculations, and short stacks are not recommended if there is a possibility of H_2S presence (which is likely to occur if the CO_2 flood follows waterflooding). Common industry practice is to use a tall flare stack to minimize the potential for hazardous concentrations of H_2S or SO_2 at ground level.

Flare Tip and Igniter. Numerous flare tip designs are available commercially. Options include flame retention rings, windshields, mixing chambers, connections for pilot lines, and smokeless designs.

Smokeless designs commonly use steam to dampen emissions and are used for flare gases that contain significant amounts of heavier hydrocarbons (above C_3).

Pilot connections and mixing chambers are used in flare systems where flame dependability is critical. If the flare gas has a low heating value and if it contains H_2S, a continuously burning pilot is required. Flame retention rings help protect the flare and pilot from the wind. All flare-tip materials must be resistant to high temperatures.

There are two common styles of flare igniter: flame front and electrical sparking systems. In the flame-front design, a thermocouple monitors temperature at the flare tip; if the temperature drops, gas is ignited in the piping at ground level and transported through a line to ignite the pilot or the flare gas. The sparking design relies on an electric charge that bridges a gap between electrodes suspended above the pilot or flare gas. The sparking igniter can be set up using a timer, so that it sparks every few seconds, which ensures that the pilot or flare remains ignited.

5.3.6 Field Compression. As mentioned in our discussion on the separation process (see Sec. 5.3.1), compression facilities must be installed (or existing facilities modified) to recover gas and boost it from low-pressure sources to the gas processing facility.

The compression facility includes compressors, interstage coolers, scrubbers, piping, valves, and auxiliary support systems such as lube oil, instrument air, and automation. The design of field compression for a CO_2 flood is similar to the design for conventional gas compression; however, the properties of CO_2 have a significant impact on compressor design and operation, as well as on the design and performance of the interstage coolers.

Compressors—Number and Location. Compressor downtime is the most common cause of flaring. A thorough reliability and redundancy analysis must be undertaken to address downtime.

One of the first decisions in the design phase is the number and location of compressor stations. If a single central battery is used, the logical solution is one compression station at that battery. Multiple batteries require analysis of economic alternatives, which include having a single, centrally located compression facility connected to the batteries by piping; locating compression facilities at each battery; or some combination of these two. A single compression facility costs less to build and operate, but the cost of piping increases. Perhaps the most important component of the compressor design calculation is the normal operating gas rate. The best way to determine this is to use process simulation software that models flash separation of produced gas from liquids. Accurate liquid rate forecasts are required to develop accurate gas rate forecasts.

Prime Movers. The required input for compressor design includes the available suction pressure and temperature, the required discharge pressure and temperature, and the composition and properties of the gas stream to be compressed.

Most CO_2 compressors are reciprocating, although centrifugal units can be effective. Reciprocating units tend to be the first choice because they are more available, operators are more familiar with them, and they generally are more efficient than centrifugal units. Reciprocating compressors can be driven by alternating current (AC) motors, direct current (DC) motors, or gas engines, depending on the details of the compression process and the available power supplies. Natural gas can be a cost-effective source if it is available onsite.

Compressor driver decisions should be made only after a thorough analysis of purchase, installation, maintenance, and power costs. Gas engines are maintenance-intensive. Direct current motors require more maintenance than their AC counterparts but have natural variable-speed characteristics. Alternating current motors operate at a fixed speeds but can provide variable-speed capability if they are equipped with variable-speed drives (VSD's). Note, however, that VSD's are quite expensive.

The most efficient way to handle gas-rate variation is through variable-speed capability (natural or drive); another common but inefficient way is to use a gas bypass or recycle line. This approach

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increases flexibility and is much less expensive than a VSD, but adds incremental operating cost because of its inefficiency: Any gas that gets recycled has been compressed, then depressurized in the recycle line, then recompressed.

Finally, gas-rate fluctuation can be handled using variable clearance pockets, which simply increase or decrease the volume of a cylinder to change the capacity of the compressor. Clearances can be adjusted automatically or manually.

The most common approach is reciprocating compression with variable clearance pockets and a gas recycle line. Alternating current motors and gas engines are the most common compression drivers.

Compressor Design and Horsepower Determination. The first step in compressor design is to determine the number of stages of compression, using the following compression ratio equation:[6]

$$F_c=(p_{df}/p_s)^{(1/n)}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.5)$$

where F_c=compression ratio; p_{df}=final discharge pressure, psia; p_s=suction pressure, psia; and n=number of stages of compression.

The calculation is iterative. Increasing values (integers) for n are substituted into Eq. 5.5 until the desired compression ratio is achieved. Design compression ratios usually range from three to six per stage.

In determining compressor horsepower and discharge temperature for CO_2, the conventional compressor equations apply. For multiple-stage compressors, calculations are made for each stage; horsepower requirements for each stage are totaled to determine the required driver size.

Cylinder discharge temperatures are important in terms of cylinder temperature limitations and also in the design of interstage cooling.

Ideal Isentropic Horsepower Calculation. For reciprocating compressors, the ideal isentropic horsepower can be calculated as follows:

$$-w=\{C_{pv}/(C_{pv}-1)\}\,(3.027\,p_b/T_b)$$

$$T_s\,\{[(p_d/p_s)^{zs}]^{(C_{pv}-1)/C_{pv}}-1\}, \quad \ldots\ldots\ldots\ldots\ldots\ldots (5.6a)$$

where w=adiabatic work of compression, hp/MMscf/D ($-w$ denotes work output); C_{pv}=ratio of specific heats (C_p/C_v) at suction conditions; p_b=base pressure, psia; T_b=base temperature, °R; T_s=suction temperature, °R; p_s=suction pressure, psia; p_d=discharge pressure, psia; z_s=compressibility factor at suction conditions; C_p=specific heat at constant pressure, Btu/lbm-°R; and C_v=specific heat at constant volume, Btu/lbm-°R. Base conditions refers to the temperature and pressure required to specify 1.0 scf.

In Eq. 5.6a, the variable C_{pv} can be determined with Kay's mixing rule,[6]

$$C_{pv}=\sum(y_i\,M_i\,C_{pi})/[\sum(y_i\,M_i\,C_{pi})-1.986], \quad \ldots\ldots\ldots\ldots (5.6b)$$

where y_i=mole fraction for each component; M_i=molecular weight for each component, C_{pi} is specific heat at constant pressure for each component, Btu/lbm-°R; and C_p for pure CO_2 at 60°F and 14.696 psia=0.199 Btu/lbm-°F.

Discharge Temperature Calculation. The discharge temperature can be calculated as

$$T_d/T_s=(p_d/p_s)^{[z_s(C_{pv}-1)/C_{pv}]}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.7)$$

where T_d=discharge temperature, °R.

Required Duty of Interstage Coolers Calculation. The required duty of interstage coolers can be calculated as follows:

$$-dH_g=n_m\,C_{pa}\,dT, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.8)$$

where dH_g=required duty (change in enthalpy), Btu; n_m=number of moles, lbm mol; C_{pa}=constant pressure molal specific heat at cooler operating pressure and average cooler temperature, Btu/(lbm mol-°F); and dT=temperature drop across cooler, °F.

Brake Horsepower. Brake horsepower, or the actual horsepower required at the prime mover, is determined by dividing the ideal horsepower by the compression efficiency. Compression efficiency accounts for losses of energy stemming from thermodynamic and mechanical causes, and the in modern compressors it typically ranges from 75 to 85% of isentropic compression. Compression efficiency also is a function of compression ratio; it peaks at compression ratios of 3.5 to 4.5, after which it begins to decrease.[6]

Coolers. When multiple-stage compressors are used, the gas must be cooled between stages, which is done by heat exchangers commonly referred to as interstage coolers. Shell-and-tube heat exchangers and aerial (also called fin fan) coolers are the most common.

Shell-and-tube exchangers work by transferring heat from a hot fluid through a conductive material (multiple-tube walls) to a low-temperature fluid. These exchangers usually are more efficient, but they require a sustainable source of low-temperature fluid. Fin fan coolers work by circulating air across a set of tubes. They are less efficient and depend on ambient temperatures.

Interstage coolers usually are included by the vendor as part of a compression package. Cooler design is relatively easy; it requires knowledge of gas composition, operating pressure and temperature for each stage; maximum allowable temperatures for the compressor cylinder; and environmental conditions such as elevation and ambient temperature ranges. Most process simulation software can design these heat exchangers.

The choice of tube material for interstage coolers is critical: Any condensed liquids present will contain water and create the potential for carbonic acid attack. All the austenitic stainless steels (e.g., Grade 316 stainless) are susceptible to chloride stress cracking, and chlorides commonly are present in water. The potential for chloride stress cracking is a function of chloride concentration and temperature; the metal is more susceptible at the high temperatures present in interstage cooling applications. Before selecting an austenitic stainless, it is wise to analyze the chloride content of the condensed liquids in the laboratory, using a synthetic gas to match process conditions. Although condensation yields liquids with low total dissolved solids, at high temperatures it only takes chloride concentrations of a few parts per million to cause chloride stress cracking.

If austenitic stainless steel is not acceptable, alternatives include carbon steel and corrosion resistant metals such as Monel and titanium alloys. Carbon steel can provide adequate service life if the design includes sufficient corrosion allowance (additional metal thickness of 1/16 to 1/8 in.) and if a corrosion inhibitor is added to the gas stream. Corrosion resistant alloys such as Monels and titaniums offer exceptional performance but are extremely expensive.

Scrubbers. Gas leaving an upstream vessel is saturated with liquids at the upstream vessel's operating pressure and temperature. These liquids (water and hydrocarbons) condense out of the gas stream as it cools en route to the field compression facility. A two-phase separator, often called a scrubber, must be installed upstream from the compressor suction to catch both condensed liquids and those from process upsets.

Because gas velocity and volume dominates the smaller liquid volumes, scrubbers typically are vertical separators. Most scrubbers are internally coated and use corrosion resistant materials for internal components. Depending on operating pressure, scrubber liquids either are dumped directly to a low-pressure tank or pumped back into the process.

Scrubbers also must be used between stages of compression to capture and remove liquids that condense during interstage cooling. Accurate prediction of liquid condensation rates requires calculation of mass flow rate, which entails the use of phase envelopes (from a simulator or the GPSA Gas Processors Suppliers Association Engineering Data Book) and process data, including pressure, temperature, gas composition, and gas flow rate.

5.3.7 Emergency Shutdown (ESD) System. No matter how well the planning and design phases are carried out, emergency situations will arise during a CO_2 flood. Good design practice anticipates such events and strives to prevent their occurrence and/or mitigate their effects by including an ESD system. An ESD system should be designed to handle process upsets, to accommodate electrical and process shutdowns, and to manage unexpected failures or

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releases safely. Though they are not mandatory, we strongly recommend that ESD systems be included in all CO_2 floods.

The scope and complexity of the ESD system installed is dictated by such factors as the complexity of the process, environmental conditions (e.g., offshore, near a river, probable tornadoes) facility staffing, and remoteness and anticipated response time.

Fail-Close Valves. The fail-close valve (ESD valve) is common in ESD systems and is designed to stop flow at its locations should a failure occur. This valve commonly is used on vessel inlets (to stop process flow into the vessel), gathering and distribution systems (to stop flow in the event of a line failure), and wellheads (to shut off produced fluids in the event of a downstream failure). Some operators have considered the use of a downhole ESD valve (subsurface safety valve) to prevent releases to atmosphere in the event of a wellhead failure.

The ESD valve can be designed to close on virtually any parameter, including pressure, temperature, liquid level, and flow rate. It normally remains open and only activates when the monitored operating condition falls outside the allowable range. Valve actuation usually is pneumatic, although electrical actuation with high-pressure nitrogen bottles as a backup also has been used. Either way, the actuator must be designed so that the valve fails closed if actuation energy is lost.

The operation of an ESD valve can cause a release of produced fluids in the upstream process—e.g., when an activated ESD valve causes pressure in an upstream vessel to increase until the vessel's relief valve opens. Because of this, it is important to consider where and how releases should take place when installing ESD valves.

It also is wise to design the release location in a way that prevents damage or large cleanup costs. It should be constructed so that liquids can be contained in a tank or overflow storage pit.

Remote ESD Devices. Remote shutdown capabilities may be desirable to prevent sustained discharges, to manage major upsets, or to manage events that impact a large area of the system or field facilities. In these cases, valve actuators either are hard-wired to a central location or they are equipped with telemetry capabilities to receive a signal initiating the shutdown process. The primary advantage of remote capability is that a large area can be shut down quickly and safely.

One common remote ESD application is the ability to shut down an entire process, such as a field-compression or water injection facility. Typically these systemwide shutdowns are accomplished by interfacing with equipment controllers or the main power supply. Shutdown generally is an automatic process based on operating conditions, although most installations include provisions for manual initiation.

Critical ESD systems (those that protect the public), generally are monitored by a host computer using a direct or telemetry communication link. Telemetry is the most common link because of the large distances involved. The host computer checks to make sure that actuation energy is available and that ESD devices are operating properly. If the host senses a problem at an ESD site, it can initiate an automatic shutdown or activate a visual and/or audible alarm to call for human intervention. The host computer also provides an audit trail, 24-hour monitoring and quick response for emergencies.

Gas-Release Dispersion Models. Computer simulators using gas dispersion models predict the travel (velocity, direction, and height) and concentration of compounds resulting from a gas release to the atmosphere, and they commonly are used in designing critical ESD systems. Input parameters for a dispersion model include pressure, temperature, gas composition, direction of the release (vertical or horizontal), and environmental conditions such as elevation, wind velocity, and ambient temperature. The model predicts the direction and speed of the vapor cloud and, more importantly, it predicts the dispersion of gases and provides concentrations along the path. The results from the dispersion model can be used to locate ESD devices (e.g., valves) to minimize the chance that hazardous gas concentrations will reach a public location.

5.4 Injection

Because most current CO_2 floods use the WAG process, there are two injection systems: water and CO_2. We will begin with the

Most CO_2 floods are implemented after some period of waterflooding, so a system of water injection facilities already is in place. Plans for the water side of the CO_2 flood should begin with an analysis of these facilities to see if any can or should be used. The analysis also should investigate modifications to existing facilities that can enable their use, which can have a favorable impact on capital investment. Critical factors in determining whether they can be used or modified include the maximum pump discharge pressure, desired injection rates, pressure rating of the flowlines, and maintenance and operating history of the facilities.

5.4.1 Repressurization. Sometimes the reservoir pressure is below the thermodynamic MMP for CO_2, and if miscible CO_2 displacement is desired, the reservoir pressure must be raised above the thermodynamic MMP before injecting CO_2.

The three general methods for repressurizing are to increase the injection rate until it is above the total fluid production rate, to restrict production, and to both increase injection rate and reduce the production rate. Repressurization must proceed relatively slowly to prevent fracture development in the reservoir. The reservoir team should provide a repressurization plan that will underlie the design of the facility. Jarrell and Stein outlined a method for accelerating reservoir pressure growth using Hearn and Hall plots, a technique used successfully in a Slaughter field CO_2 flood.[14]

Water Supply: Compatibility and Corrosion. Because the goal is to inject more fluid than is produced, repressurization may require an additional supply of water. The facility engineer must analyze the required capacity and delivery pressure of the water supply to ensure that it will be adequate. The makeup water also must be analyzed for compatibility with the produced fluid and for corrosion potential.

Compatibility with produced water is an important factor in selecting the makeup water supply. For instance, mixing a water high in calcium with a water high in sulfates can cause precipitation of calcium sulfate scale. An easy test for potential scale precipitation is to mix the desired waters in various ratios and visually inspect the mixture for color change or solids precipitation. Note, however, that this test does not guarantee water compatibility because scale precipitation also depends on pressure and temperature. In addition to physical testing, we advise calculating the scaling tendencies across the range of pressures and temperatures likely to be encountered in the flood operation.

Transporting additional water to the field requires piping that is designed for the appropriate pressure and capacity. The corrosion and scaling tendency of the makeup water can affect the selection of piping materials. Shallow aquifers often have high oxygen concentrations that can render the water extremely corrosive, and it may be more economical to combat this with corrosion resistant materials (e.g., HDPE or fiberglass) than with chemicals.

Regardless of how you manage oxygen in the makeup water piping, oxygen-accelerated corrosion must be addressed before mixing the makeup water with produced water for reinjection. The most common technique is to use an oxygen scavenger, although these chemicals tend to be both toxic (an important factor when surface discharge is a possibility) and expensive. Alternatives are to use corrosion inhibitors, to relocate the oxygen-scavenger treatment point further downstream so that any emergency situation discharges untreated water, to find another source of makeup water, or to live with higher corrosion rates.

Balancing Makeup and Injection Rates. Once the makeup water supply is identified and its means of delivery to the field determined, the facility engineer must add the appropriate amount of makeup water to the produced water to achieve injection target volumes. One method for doing this is to use the level of produced water in a surge tank to control the feed of makeup water. There also must be a way of adjusting upstream water supply, which can be done using variable-speed controllers on pumps, using a large surge tank, by turning multiple wells on or off on demand, or by continuously discharging excess fresh water.

Although the primary need for makeup water occurs during repressurization, makeup water may also be needed at certain times during the CO_2 flood, e.g., when reservoir pressure increases are

necessary. Water may also be continuously needed if there are off-structure fluid losses.

In addition to the routine flood uses, the makeup water supply also can be useful for fresh water dilution, fire systems, cooling systems, and perhaps even as a potable water supply.

5.4.2 Water Injection Facilities. Two critical design parameters must be analyzed to determine whether existing water-injection facilities can be used for a WAG CO_2 flood. The first is injection pressure: The injection pressure required for a CO_2 flood usually is greater than the pressure required during waterflooding, and this new pressure may affect the usability of existing flowlines and waterflood pumps. While it may be possible to use existing equipment in its entirety, some modifications may be required.

The second design parameter is the required injection rate, which varies during the course of the flood. During repressurization, the injection rate may be greater than the capacity of the existing waterflood system. When CO_2 injection begins, the rate should decline; and as the flood matures, the rate will increase. Because the need for increased injection rate is relatively short-term, it often can be met by installing temporary additional pump capacity and by eliminating large pressure drops in the system.

Water injection facilities include surge tanks (discussed above), waterflood pumps, piping, measurement and control devices, and a water disposal system. As with production facilities, the size, number, and location of new injection equipment depends on the existing facilities that can be used.

Injection Pumps. The water level in surge tanks usually provides the hydrostatic head (suction pressure) for the injection pumps. Suction pressure requirements are unique to each type of pump, and adequate suction pressure must be provided to prevent cavitation. If the surge tank water level is insufficient, a booster pump will be necessary.

Centralized vs. Decentralized Pump Locations. It would be unusual to install a new water injection pump station solely for starting a CO_2 flood because, in most cases, existing pumps can be modified to meet injection requirements.

If injection capacity is to be increased through the installation of additional pumps, the design engineer must determine the optimal facility site. There are two types of pumping facilities, centralized and decentralized, each with advantages and disadvantages. Ultimately, the choice between them is made by weighing the economics of each. Installation costs for a centralized location may be lower, but the pumps may have to operate at higher pressures to overcome higher frictional pressure drop, thereby increasing operating costs. In addition, a central facility requires that all produced water be transported to one location, and piping costs for this will drive up the total cost. A decentralized system has an advantage in that it can allow a portion of total water injection to continue in the event of a system failure that impacts one pump station.

Pump Types. The two pump types commonly used for water injection are centrifugal and reciprocating, and each has advantages and disadvantages. Reciprocating pumps maintain a fixed discharge rate at all pressures up to the maximum capacity of the pump, while the rate and pressure produced by a centrifugal pump vary inversely: As discharge pressure increases, the discharge rate decreases. In some cases, booster pumps provide an economic means of boosting rates and pressures from existing equipment.

Piping and Valves. Waterflood pumps discharge water into an injection trunk line, a large-diameter line designed for long-distance transport with minimal frictional pressure losses. Design concerns here are selection of piping material, arrangement of water injection piping, and materials used for waterflood valves.

Piping Material. Piping design for a waterflood is identical to design for conventional facilities: The route, material, pressure rating, and capacity must be determined. Most piping design equations handle single-phase water flow extremely well.

Because of pressure requirements, waterflood piping usually is externally coated carbon steel. Internally coated and cement-lined carbon steel have been used where the water is extremely corrosive. Fiberglass also has been used effectively in water injection service.

Water Injection Piping Arrangement. The piping that takes water from the trunkline to the injection facilities can be arranged in one of two ways. The first is a tree configuration that uses a trunkline with lateral lines branching off to each injection well. Well control, automation, and measurement devices are located at each well. In the second configuration, a trunkline delivers injection water to a central manifold (referred to as an injection header), from which individual flowlines run to each injection well. In this configuration, all the well control, automation, and measurement equipment is located at the injection header.

Using injection headers facilitates automation of the water injection process because this arrangement requires only a single remote telemetry unit (RTU) at the header rather than one at each injection well. Note, however, that if each well has its own RTU, waterflood automation can be combined with CO_2 automation. Once again, you must weigh alternatives.

Valves. Valves are used throughout the water injection system to isolate flow and control flow rate. The materials selected for waterflood valves should be based on the corrosivity of water, solids content (erosion problems), dissolved CO_2 content, water composition (specifically the chloride content), and the potential for a sour operating environment (sulfide stress cracking). Serious consideration should be given to using isolation valves at selected points in the distribution system trunklines; these valves can allow downstream maintenance and inspection to take place without a costly, complete system shutdown.

Measurement and Control. *Control Parameters—Rate vs. Pressure.* Two variables—injection rate and pressure—are used to control water injection. Normally, control is based on whichever criteria, pressure or rate, is reached first, although there may be specific operations in which there is only one control parameter. For example., wells injecting on a vacuum would be rate controlled.

Rate control would be advantageous when accuracy is critical in injecting a certain volume of water for each volume of CO_2 injected (maintaining an exact WAG ratio), when the water injection system pressure fluctuates frequently, or when the water supply is limited.

Pressure control would be the first choice when formation parting pressures are substantially lower than the pressure capabilities of the system and you want to preclude the possibility of initiating a fracture.

Measurement and Control Devices. Water injection measurement and control can be accomplished manually or with automated equipment. Injection rate usually is measured with a turbine meter, and in some CO_2 floods, the same turbine meter is used for both water and CO_2 injection. Turbine meters can be automated to collect data at regular intervals.

Pressure can be measured with a simple pressure gauge or, if automated control is desired, a pressure transducer can be used. The transducer converts pressure to an electric signal, which is sent to a local microprocessor (or host computer) as a control variable. A filter screen should be installed upstream of each meter to protect it from plugging or damage by foreign materials in the piping or injection fluid.

Rate and pressure are controlled by adjusting a choke or ball valve. A choke is commonly used because it is specifically designed to handle large pressure drops with minimal erosion. Ball valves have been used effectively when the required pressure drops are not large.

The valve either is opened or closed, manually or automatically, as the control parameter dictates. Automation offers the distinct advantage of frequent and rapid control—a computer can monitor and adjust a valve every few seconds. On the downside, automated controls require additional upfront capital investment, as well as operators with specialized skills.

Water Disposal System. During the life of a CO_2 flood, produced water rates may exceed the water injection requirement, which means that it will become necessary to dispose of excess water. Disposal also will be required if the water injection system goes down for any reason. Water can be disposed of several ways: disposal wells, injection in a nearby waterflood, hauling to a water disposal site, storage, or surface discharge. The choice depends on environmental regulations and total cost.

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If the disposal system involves the use of disposal wells within the field, it is feasible to tie the disposal system into the injection control function. This allows disposal wells to be opened up when pressure limits or water surge-tank levels rise above a threshold value.

5.4.3 CO_2 Distribution System. The CO_2 distribution system delivers CO_2 to individual injection wells from the pipeline supply and the gas processing facility. This system is separate and independent of the water injection system and includes its own piping, valves, measurement, and control facilities.

Piping and Valves. *Piping Arrangement and Materials.* Components of a CO_2 distribution system include trunklines, laterals, and individual well injection flowlines. Trunklines transport CO_2 from the source (e.g., pipeline or gas processing facility) to and through the field. Laterals branch off to deliver CO_2 to several injection wells. Injection flowlines branch off the laterals to deliver CO_2 to each well.

A common material for CO_2 piping is carbon steel, which is excellent as long as free water is not present; that is, as long as the CO_2 has been dehydrated to prevent free water from condensing out of the injection stream when pressure and temperature drop en route to injection wells. Other materials used for the CO_2 distribution piping are stainless steel and fiberglass.

Carbon steel piping has one significant disadvantage: Most carbon steel is rated only to −20°F, which can be insufficient for aboveground installations in cold climates. Note that the temperature of pipe does not depend solely on weather—its temperature can drop significantly below ambient temperature when CO_2 is throttled through a valve or if a line leaks. Carbon steel may have to be ordered to a cold-temperature specification if operation below −20°F is anticipated.

The governing specification for carbon steel in cold temperature service is ASTM *Spec. A333/A333M-88a*,[15] which uses a Charpy V-notch test to establish cold-temperature suitability. The test measures the ability of a material to absorb energy, which reveals how susceptible the material will be to potentially catastrophic brittle failure.

Standard stainless steel produced by normal manufacturing processes all is rated for service at low temperatures.

Fiberglass pipe poses a different set of potential problems: It might not withstand high pressures, it might have limited applicability in cold-temperature service, and its pipe length may change significantly as temperature changes. Given these caveats, one must obtain manufacturer recommendations before using fiberglass for this application.

Handling H_2S. Hydrogen sulfide often is present in the CO_2 reinjection stream but is only problematic if free water is present because the combination of free water and H_2S can cause sulfide stress cracking. The design engineer must design the system to prevent the presence of free water or to operate in sour conditions.

Free water can originate from insufficient dehydration, excess pressure or temperature drop, or plant upsets. The WAG process itself creates another source of free water in the CO_2 distribution system: If the supply pressure drops while the injection well is on a CO_2 cycle (injecting CO_2), the injection well has the potential to backflow water from the formation if the check valve fails to hold.

The CO_2 distribution and gas processing systems should be designed to prevent free water from occurring. However, design provisions for a sour environment should also be considered, including ones for H_2S removal, dehydration, and/or mechanisms to prevent backflow conditions. If downstream components are not designed to handle sour conditions, the design engineer must further enhance system integrity by including automated controls, alarms, and even backup systems that can prevent sour conditions from occurring.

Another alternative is to design downstream components to handle the combination of H_2S and water, which may necessitate the use of different materials and welding procedures. Carbon steel still can be used, as long as sulfide stress cracking and corrosion are adequately addressed.

Blowdown Capability. To perform maintenance on the CO_2 distribution system safely (e.g., in an emergency), one must be able to depressurize the system safely and effectively. This is accomplished through a blowdown station, which simply is a vertical vent pipe that has an isolation (blowdown) valve and is welded to the main distribution line. To depressurize the system, the blowdown valve is opened, and CO_2 vents to the atmosphere.

Blowdown pipe and valve sizing is important, as is the location of blowdown stations. The extreme noise, large temperature drop, and presence of CO_2 during blowdown operations all can cause safety and health problems for both operating personnel and the public (see Chap. 9 for recommended measures for avoiding damage to hearing). Pipes and valves must be sized to minimize these problems and to prevent the formation of pipe-blocking hydrates that can be generated by a large pressure drop. Hydrates can be prevented by large, nonrestrictive valves or by adding heat.

Importance of CO_2 Phases. Piping in CO_2 distribution systems must be designed taking CO_2 phase changes into account because the frictional pressure drop of dense-phase CO_2 (which behaves more like a liquid) exceeds that of supercritical CO_2, which behaves more like a gas. Dense-phase CO_2 can generate much larger hydrostatic pressures than supercritical CO_2.

Phase changes within the distribution system are even more troublesome. A two-phase mixture of liquid-like and gas-like CO_2 generates a larger frictional pressure drop than either phase alone.

Because of the complexities of phase behavior and the number of alternative arrangements for piping, a pipeline simulator model generally is used to design the CO_2 distribution system. Because heat transfer and pressure changes can cause CO_2 to change phase, the simulator model should include a thermodynamic package to account for heat losses through the piping.

Incremental pressure drop caused by multiphase flow must be accommodated by using larger-diameter piping or adding horsepower to the compression system. The alternative to this expense is to prevent multiphase mixtures in the distribution system, which can be done by installing cooling capabilities at the compressor discharge, using insulation on piping to prevent heat gain, increasing discharge pressure to overcome density changes, and/or selecting pipe diameters and a layout that will minimize pressure drop.

Valves. Valves in CO_2 distribution systems usually are carbon steel and may need to be specified for cold temperature service. If the valve is rated for cold temperatures, the bolts holding it in place also must be cold-temperature rated as outlined in ASTM *Spec. A320/A320M-00a*.[16]

The most common uses of valves in the CO_2 distribution system are for isolation and control at laterals and well sites. Measurement and control devices usually have isolation valves to facilitate maintenance. Other valve functions include emergency shutdown service, bleeders, blowdown service, and check valves to prevent backflow.

Metering and Control. The relatively high cost of CO_2 makes metering and control an important issue. The level of automation can range from none, to monitoring, to data collection and storage, to full control. The use of automation commonly reflects the operator's overall philosophy on benefits.

The costs for metering and control depend on the design of the distribution and injection system. A trunkline/flowline arrangement (see Sec. 5.4.2) may result in lower capital requirements because the piping costs less; however, the cost of instrumentation at every well will increase capital and operating expenses higher than they would be in a configuration with all control at a central manifold.

Metering and Control Skids. It is beneficial to place all metering and control equipment on skids, and, if environmental conditions warrant, enclose the skids in small utility buildings.

A skid arrangement, while not required, offers two distinct advantages. The first is that it confines metering and control to a single location, which improves maintenance and repair efficiency. Second, a skid is mobile so that the equipment is easy to move during a phased CO_2 flood implementation.

A CO_2 metering and control skid **(see Fig. 5.6)** consists of a choke, metering device, a pressure gauge or transducer, a temperature gauge or transducer, a screen to protect the metering device, isolation valves, and an enclosure, if warranted. The skid is set away from the wellhead to minimize interference with downhole operations. A flexible line connects the wellhead to the skid.

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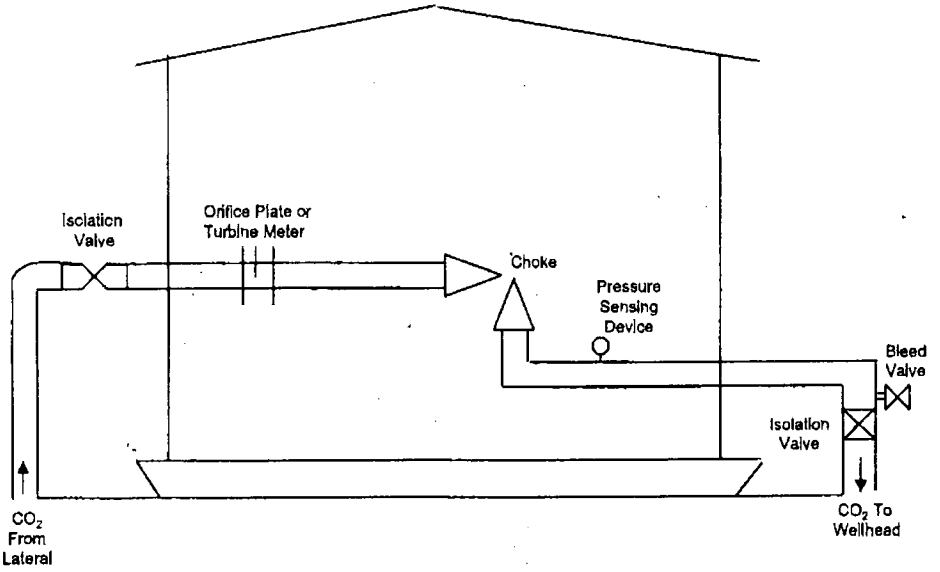


Fig. 5.6—Carbon dioxide injection skid. The use of skids simplifies the task of relocating metering and control equipment as the CO_2 flood is implemented in different parts of the field.

Pressure Control. CO_2 injection can be controlled on rate or pressure or both. Pressure control, using a pressure gauge or transducer and a choke, probably is the most common. A manual system requires a pressure gauge downstream of the choke; the operator simply adjusts the choke to meet the desired injection pressure. An automated system uses a pressure transducer, a pressure setpoint, and an actuator that adjusts the choke valve automatically to keep pressure at the desired level. Automated systems require an on-site or centrally located microprocessor.

Rate Control. Rate control requires some type of measurement device and a choke, and it also can be manual or automatic. The two most common measurement devices are turbine meters and orifice meters.

Most CO_2 floods inject dense-phase CO_2, which means that some form of density compensation must be included for accurate rate measurement. Density compensation can be accomplished using an algorithm or an in-line densitometer. Densitometers are more accurate but quite expensive to purchase and maintain.

Density algorithms are based on an EOS, and can be expressed either as an equation or a table. These algorithms require measures of pressure and temperature, plus a measured or assumed gas composition. Because of their complexity, they are used best in conjunction with an automated system.

Because orifice meters tend to be more accurate than turbine meters, and for that reason they commonly are used for custody transfer. They are more expensive to purchase, but once installed need less maintenance. Orifice meter calculations require measurements of gas composition, differential pressure across the orifice plate, and flowing temperature, as well as knowledge of the meter run configuration. If orifice meters are used for CO_2 injection metering, the orifice plates should be sized to operate as close to the middle of the differential pressure range as possible.

Amoco tested turbine meters for supercritical CO_2 measurement and found excessive bearing wear and failures in the meters. The CO_2 apparently was stripping the bearing lubrication, which accelerated frictional wear and led to gradually reduced accuracy of measurement.* Forced lubrication was tried unsuccessfully. However, at least two operators, Exxon and Chevron, used turbine meters for supercritical CO_2 measurement and experienced adequate measurement accuracy with lower operating costs than with orifice meters. Turbine meters have been used at the Rangely Weber Sand Unit, Wickett Unit, Cordona Lake Unit, and Means Units.

In general, orifice meters are more expensive to install but easier and less expensive to maintain than turbine meters. Orifice meters require only periodic inspections of the orifice plate (and replacement of the elastomer O-rings), while turbine meters tend to wear out bearings and turbine blades more frequently. Once again the decision comes down to a trade-off between capital and operating costs.

Control Devices. In most cases, chokes or ball valves are used to adjust flow rate to meet the rate or pressure setpoint. A choke differs from most other valves in that it is designed to operate with large pressure drops and its construction materials are highly resistant to erosion and cavitation. In most cases, a 90°-angle choke is installed as the piping rises vertically out of the ground, and rate measurement takes place on the horizontal portion of the pipe. Typical chokes have a carbon-steel body with internals made mostly of carbon steel. The disks that restrict flow usually are ceramic.

Ball valves can be used when pressure drops are lower. Ball valves should be sized to operate within a 20 to 80% open range to provide smoother and more consistent control of the injection pressure and/or rate. Slotted-ball control valves with ring-joint flanged ends have been used successfully in CO_2 floods in the Slaughter and Wasson fields. This valve type can be ordered with several port sizes, and care should be taken to ensure the proper operating range.

5.5 Gas Processing

The gas processing facility receives produced gas at a relatively low pressure, processes the gas to remove various components and contaminants, and then discharges the gas at a pressure high enough to be injected into the formation. In its simplest form, this facility includes inlet liquid separation, gas compression, and gas dehydration. Additional equipment enables recovery of NGL's and removal of H_2S.

Gas processing facilities are virtually a necessity; the alternatives are to flare the gas (not only environmentally unacceptable, but also a major waste of money); to reinject the gas into a disposal horizon that will never be produced again; and to sell it to someone else. The last alternative can be an attractive option if a buyer can be found and the cost for transportation is not prohibitive. However, by far the most common approach for managing produced gas in a CO_2 flood is to reinject it into the CO_2-flooded horizon to reduce long-term purchase volumes and improve flood economics.

The design of the gas processing facility should be completed early in the overall CO_2 flood design process because the inlet pressure to this facility impacts many design aspects of other field facilities. For example, the gas processing facility inlet pressure is required in order to design the gas collection system, field compression facilities, and the vessels at the central battery and satellites.

*Personal com...

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The inlet pressure at the gas processing facility also affects the processing rate of the reservoir because it establishes the minimum backpressure that a producing well encounters. This affects the well's production rate, which, in turn, affects the injection rates at the offset injection wells.

Clearly, then, an integrated team approach is crucial to the successful design of a CO_2 flood. Selection of the inlet pressure at the gas processing facility is not a simple process and requires analysis of several alternatives. A low inlet pressure increases the processing rate of the CO_2 flood and lowers the cost of compression, piping, and vessels in the field, but it increases compression costs at the gas processing facility. A high inlet pressure has the opposite effect—it lowers the processing rate and raises the costs of compression, piping, and vessels, but lowers the compression costs. Obviously, the design of the gas processing facility affects both initial capital requirements and ongoing operating costs for the CO_2 flood, and it is important to have as much input as possible.

The desired purity of injected CO_2 also must be considered in the design of a gas processing facility. Purity definitely will have an impact on the density of the injectant and on the thermodynamic MMP in the reservoir (see Sec. 2.1.6). Density and the thermodynamic MMP, in turn, dictate the required discharge pressure of the gas processing facility, and that will affect the amount of compression required.

5.5.1 Basic Process Selection. Gas processing facilities have three basic functions: liquids separation (to prevent liquids from damaging the compressors); gas compression (to raise the pressure to a level suitable for injection); and gas dehydration (to prevent liquid condensation at any time during the process and to avoid the possibility of corrosion). In a CO_2 flood, the critical processes that should be considered are CO_2 dehydration, NGL recovery, and H_2S removal. The following subsections briefly describe typical systems used for these processes.

Dehydration. Four basic chemical products are used to dehydrate gas: glycol, calcium chloride, glycerol, and solid desiccants (e.g., mole sieve and silica gel). Triethylene glycol (TEG) systems **(see Fig. 5.7)** and mole sieve systems are the most common.

NGL Recovery. In some cases, it is economically attractive to recover hydrocarbons in the form of NGL's from the produced gas stream. The value of the NGL's must be weighed against the loss of value that results from the reduced density of the injectant and from the increase in thermodynamic MMP caused by the removal of hydrocarbons from the CO_2. Three methods enable recovery of NGL's: refrigeration, CO_2 fractionation, and membrane separation.

Refrigeration (using ammonia or propane as the refrigerant) is the simplest and least expensive process. The injection gas stream is cooled and hydrocarbon liquids condense out and fall to the bottom of the vessel for collection. The remaining vapor rises and is directed to the reinjection process. Although refrigeration is simple and low-cost, it has a distinct disadvantage—it cannot recover as much hydrocarbon product as other processes can, and attempts at deeper recovery only lead to substantial CO_2 contamination of the NGL product.

Carbon dioxide fractionation or membrane separation can be used to obtain deeper hydrocarbon recoveries, if economically justified. The recovery of uncontaminated hydrocarbons (especially lighter products) from a CO_2-rich gas stream is difficult because CO_2 and ethane form an azeotrope, a constant-boiling-point mixture. This property prevents ethane recovery without significant CO_2 contamination.

One means of separating CO_2, ethane, and other hydrocarbons is the Ryan-Holmes process shown in **Fig. 5.8.**

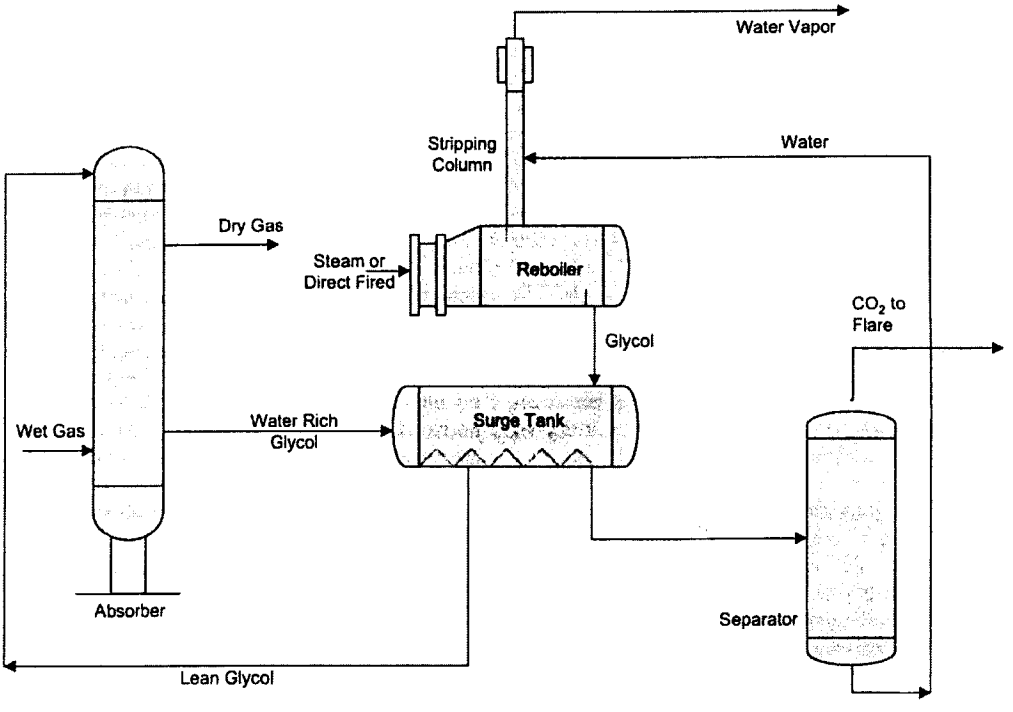
The Ryan-Holmes process separates CO_2 and ethane by introducing an additive into the production stream and performing an extractive distillation. The additive typically is generated by the Ryan-Holmes process and is comprised of hydrocarbons.

Membrane separation also can be used to remove hydrocarbons from a CO_2-rich gas stream **(Fig. 5.9).**

Membrane system design involves two key parameters—pore size and solubility of the membrane material. The membrane simply is a section of fibers through which the gas passes. Some molecules are too large to pass, and other molecules are absorbed by the fibers. NGL's and hydrocarbon gases are separated in the first membrane stage. A second stage can be added to obtain higher purity CO_2, if desired.

It is important to note that the physical and thermodynamic properties of the reinjection gas are changed when NGL's are removed, and these changes must be accounted for in designing the gas processing facility.

5.5.2 H_2S Removal. ***Sour Gas Reinjection.*** The produced gas stream often contains H_2S, which either can be removed or can be reinjected along with the CO_2. If H_2S is left in the CO_2, the injection gas stream becomes "sour," extremely corrosive and deadly. Sour gas reinjection can be used effectively and economically as long as the proper materials are used, dehydration is effective and reliable, and adequate safety systems are in place.



hydration system. This is the most common dehydration process in oil field operations.

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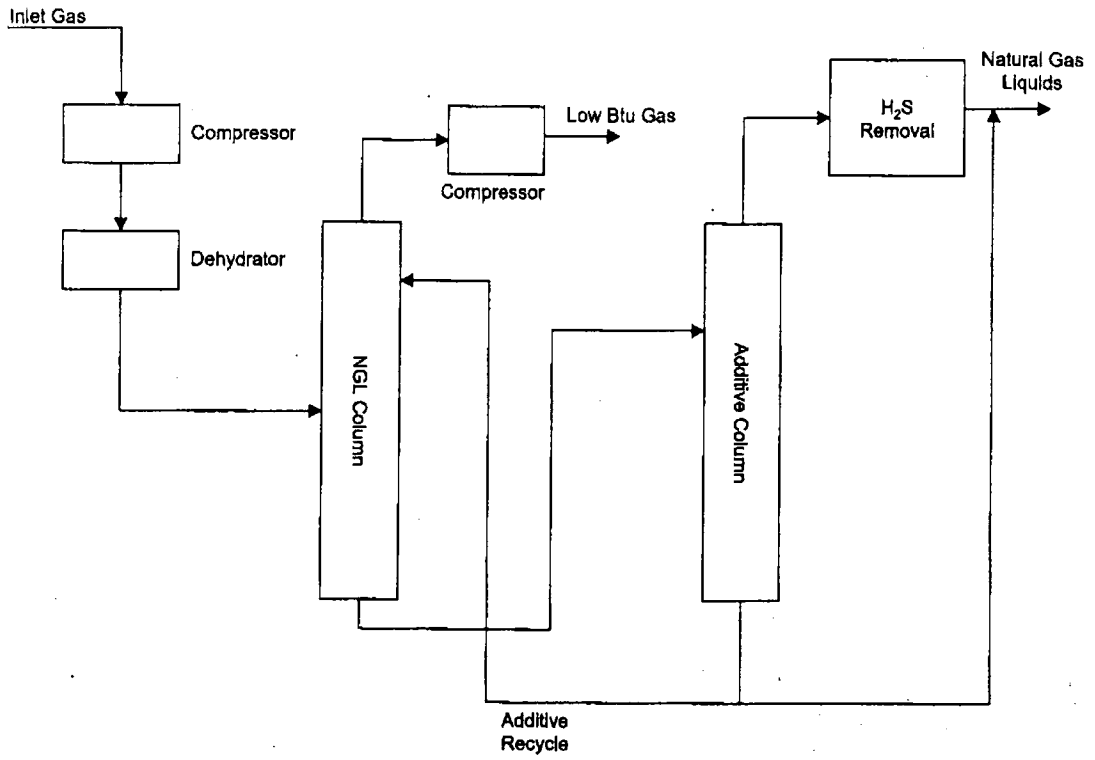


Fig. 5.8—Two-column Ryan-Holmes process. In this process, a hydrocarbon-based additive stream is added to a distillation column to break the azeotrope and allow deeper NGL recoveries.

Although the removal of H_2S adds to the initial capital requirement and to the ongoing operating costs of the gas processing facility, it has benefits: lower costs for downstream materials; lower costs for some safety systems; and lower risks associated with a gas release. In addition, H_2S removal may be necessary to meet product specifications for NGL or CO_2 sales.

There are four basic methods to remove H_2S: recirculating solvent systems, direct REDOX (reduction-oxidation) conversion systems, regenerative adsorption systems, and throw-away solid and liquid scavengers.[17] The REDOX and scavenger systems are direct conversion systems that create a sulfur product that can be disposed of directly; the other systems—recirculating solvent and regenerative adsorption—generate an acid gas that must be further treated, usually by a Claus sulfur-recovery process.

Recirculating Solvent Systems. Recirculating solvent systems can be used on the front end of the plant to treat the inlet gas stream, and they can be used to treat hydrocarbon product streams such as NGL's. The solvent contacts the gas stream and strips out the H_2S. The solvent is then cleaned up to remove the H_2S, and recycled back through the process. Amine systems (**see Fig. 5.10**) are the most commonly used recirculating solvent systems, and have the advantage of being relatively simple and having a high degree of operator familiarity.

REDOX System. The REDOX system uses a solvent (there are many choices of solvent) to convert H_2S directly to elemental sulfur, as shown in **Fig. 5.11.**

REDOX systems have the advantage of being highly selective in removing H_2S and of having a high conversion rate of H_2S to sul-

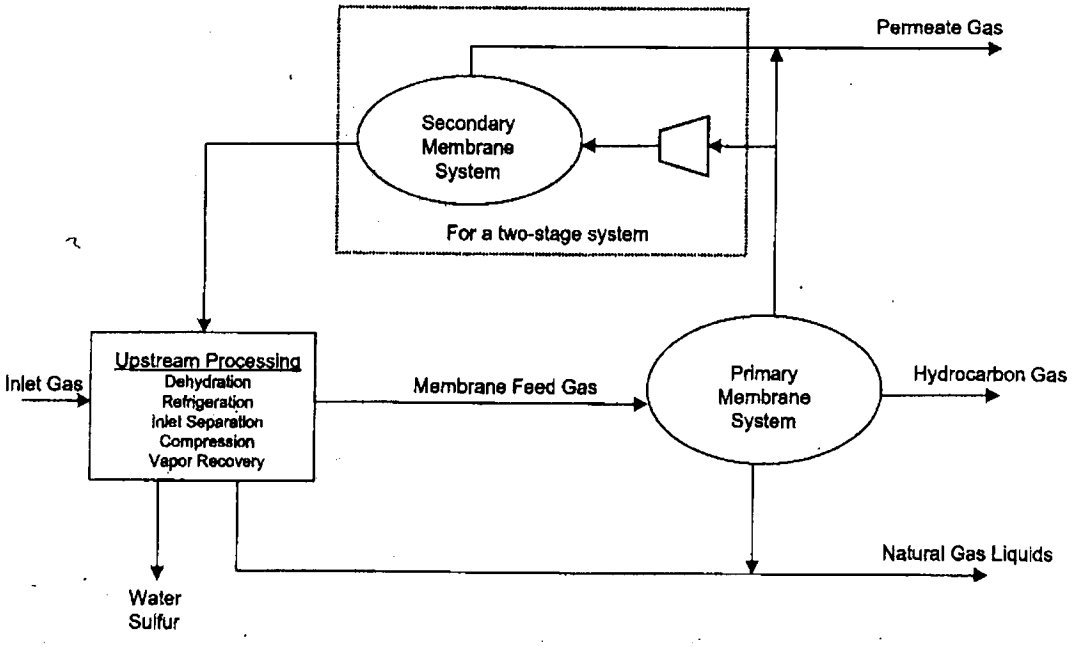


Fig. 5.9—Membrane system with recycle. Engineered fibers absorb or block certain molecules while allowing others to pass through, enabling separation of hydrocarbons and CO_2.

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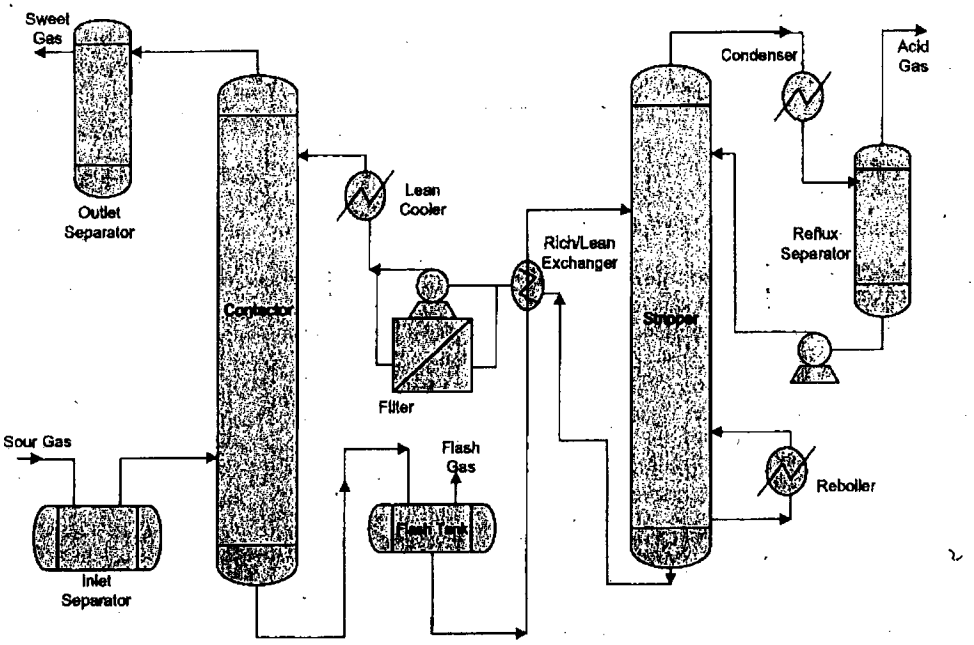


Fig. 5.10—Amine solvent system for H_2S removal. As gas flows upward in the contactor tower, amine solvent flows downward and removes H_2S from the gas. The contaminated amine then is sent to the stripper column, where the acid gas is removed. The lean amine is sent back to the contactor.

fur. The primary disadvantages include the complex chemistry and the high chemical costs that accrue because of solvent degradation.

Regenerative Adsorption Systems. Because regenerative adsorption systems can be expensive to install, they generally are used for smaller gas volumes and for treating final products. The mole-sieve system is one example of the regenerative adsorption process. The H_2S-contaminated gas passes through a vessel containing the mole sieve. The H_2S is adsorbed onto the mole sieve, which can be regenerated through a chemical, temperature, or mechanical process. A mole sieve can be regenerated a limited number of times before needing replacement.

Solid and Liquid Scavenger Systems. Like regenerative adsorption systems, the solid and liquid scavenger systems generally are limited to treating small volumes of gas or product when a continuous process cannot be justified. This is a convenient approach for batch treatment. **Fig. 5.12** shows a simple diagram for the most common H_2S scavenger processes.

5.5.3 Sulfur Recovery and Disposal. The recirculating solvent systems create an acid-gas stream that can be injected into a disposal well, flared, or processed into elemental sulfur. The most common process used to convert the acid gas to elemental sulfur is the Claus process, diagrammed in **Fig. 5.13.**

The sulfur created by direct conversion (REDOX) systems or by a sulfur recovery process such as the Claus process must be disposed of properly. Although it may be a saleable product in the agriculture industry, it is more commonly sent to a landfill, where it must meet the landfill regulatory requirements. In general, sulfur is not considered hazardous waste.

Nomenclature

C' = orifice flow constant, dimensionless
C_1 = units constant, dimensionless
C_p = specific heat at constant pressure, Btu/lbm-°R

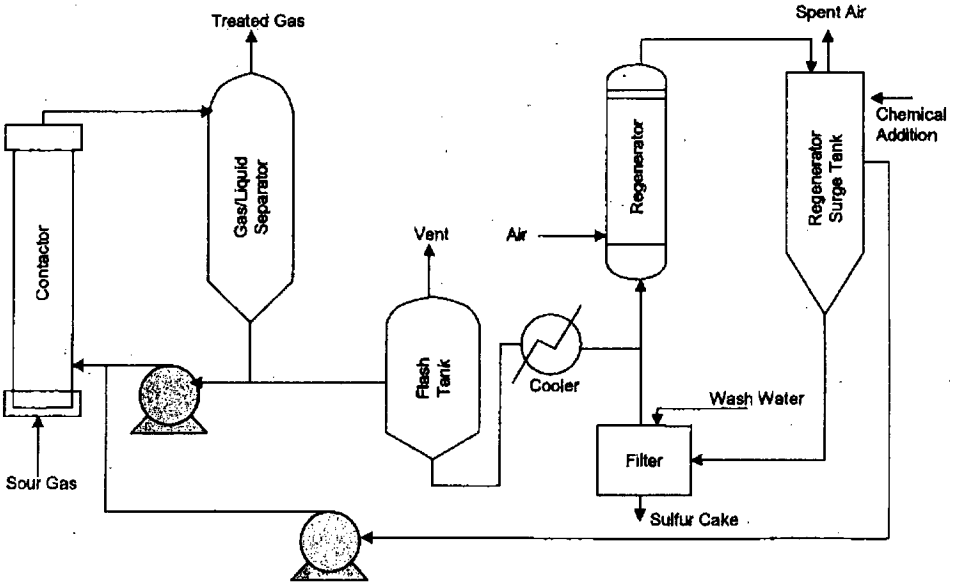


Fig. 5.11—Direct conversion (REDOX) system. The sour gas contacts the treatment chemical in the contactor and flows to the separator. Here, the purified CO_2 leaves the top of the tower, while the chemical and sulfur compounds collect at the bottom. The rest of the process completes the reduction/oxidation of H_2S to elemental sulfur and recirculates the chemical, sending it back to the contactor.

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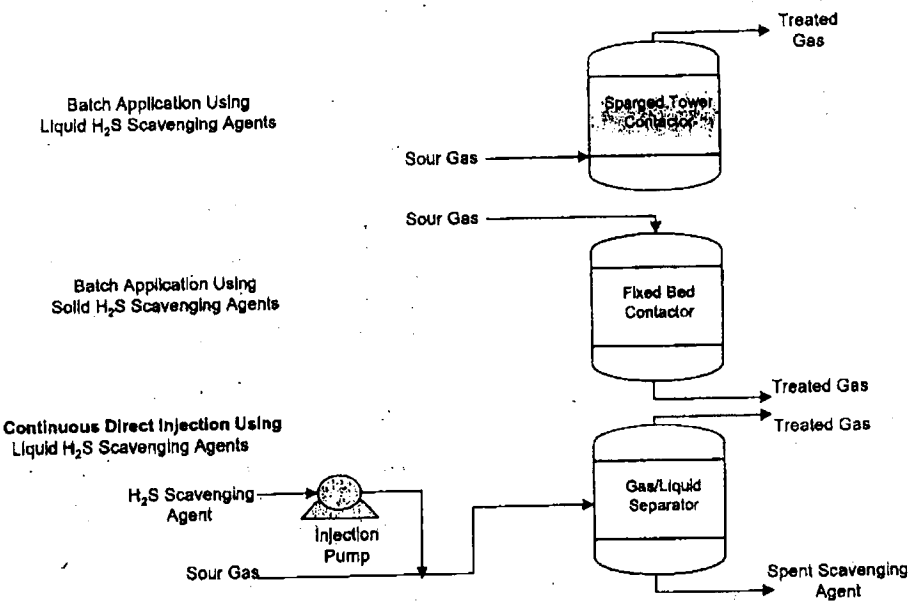


Fig. 5.12—Solid and liquid scavenger systems. There are three types: sparged towers, fixed bed contactors, and gas/liquid separators. The first two generally are used in batch operations, while the third can be used continuously.

C_{pm} = constant pressure molal specific heat at cooler operating pressure and average cooler temperature, Btu/(lbm mol-°F)
C_{pi} = specific heat at constant pressure for each component, using Kay's mixing rule, Btu/lbm-°R
C_{pv} = ratio of specific heats (Cp/Cv) at suction conditions
C_v = specific heat at constant volume, Btu/lbm-°R
d = pipe diameter, L, ft
dH_g = required duty (change in enthalpy), Btu
dT = temperature drop across a cooler, T, °F
E = pipeline efficiency, fraction
f = friction factor, dimensionless
f_{tp} = friction factor, two-phase, dimensionless
F_a = orifice thermal expansion factor, dimensionless
F_b = basic orifice factor, dimensionless
F_c = compression ratio, dimensionless
F_e = expansion factor, dimensionless
F_g = specific gravity factor, dimensionless
F_l = gauge location factor, dimensionless
F_m = manometer factor, dimensionless
F_{pb} = pressure base factor, dimensionless
F_{pv} = supercompressibility factor, dimensionless
F_{Re} = Reynolds number factor, dimensionless
F_{tb} = temperature base factor, dimensionless
F_{tf} = flowing temperature factor, dimensionless
g = gravitational acceleration, L/t^2
g_c = gravitational constant, dimensionless
k = roughness, L, in.
L = pipe length, L, ft
M_l = molecular weight of each component, using Kay's mixing rule, lbm/lbm-mol
n = number of stages of compression
n_m = number of moles, m, lbm mol
N_{Re} = Reynolds number, dimensionless
p = pressure, m/Lt^2

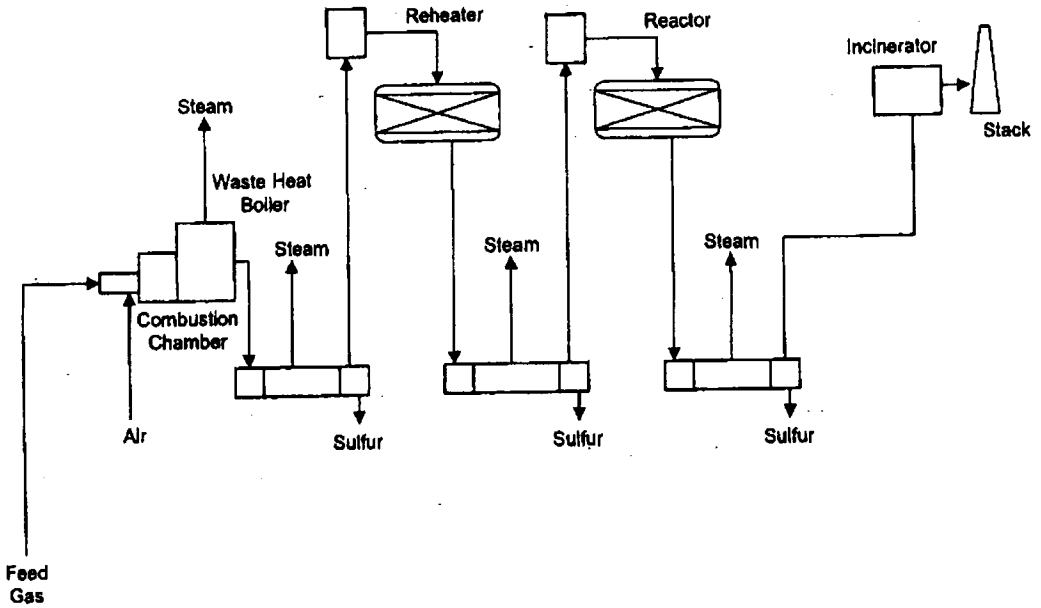


Fig. 5.13—The Claus process. This is the staple of sulfur recovery. The feed gas is the acid-gas stream from solvent recovery systems, which may contain up to 25 to 30% H_2S.

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$\bar{p}$ = average pressure, m/Lt^2, psia
p_b = base pressure, m/Lt^2, psia
p_d = discharge pressure, m/Lt^2, psia
p_{df} = final discharge pressure, m/Lt^2, psia
p_{dw} = differential pressure, m/Lt^2, in. of water at 60°F
p_{st} = absolute static pressure, m/Lt^2, psia
p_s = suction pressure, m/Lt^2, psia
p_1 = upstream pressure, m/Lt^2, psia
p_2 = downstream pressure, m/Lt^2, psia
q = flow rate, L^3/t, scf/D
q_b = rate of flow at base conditions, L^3/t, ft^3/hr
q_l = liquid throughput, L^3/t, B/D
t = design retention time, t, min
T = gas temperature, T, °R
T_b = base temperature, T, °R
T_d = discharge temperature, T, °R
T_s = suction temperature, T, °R
v_{tp} = velocity, two-phase, L/t, ft/sec
V_l = required separator liquid section volume, L^3, bbl
w = adiabatic work of compression, hp/MMscf/D
y_i = mole fraction for each component, using Kay's mixing rule, dimensionless
$\bar{z}$ = gas compressibility factor at average pressure, dimensionless
z_s = compressibility factor at suction conditions
ρ_{tp} = density, two-phase, m/L^3
θ = angle of inclination, degrees
γ_g = gas gravity (air = 1.0), dimensionless

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SI Metric Conversion Factors

bbl	× 1.589 873	E − 01 = m^3
Btu	× 1.055 056	E + 00 = kJ
Btu/lbm-°F	× 2.3885	E − 04 = J/Kg-K
°C	°C + 273.15	= K
°F	(°F − 32)/1.8	= °C
°F	°F + 459.67	= °R
ft	× 3.048*	E − 01 = m
ft^3	× 2.831 685	E − 02 = m^3
hp	× 1.341	E + 00 = kW
in.	× 2.54*	E + 00 = cm
lbf	× 4.448 222	E + 00 = N
lbm	× 4.535 924	E − 01 = kg
lbm mol	× 4.535 924	E − 01 = kmol
min	× 6.0*	E − 01 = s
psi	× 6.894 757*	E + 00 = kPa
°R	× °R/1.8	= K

*Conversion factor is exact.

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United States Patent [19]

Ryan et al.

[11] **4,428,759**

[45] **Jan. 31, 1984**

[54] **DISTILLATIVE SEPARATION EMPLOYING BOTTOM ADDITIVES**

[75] Inventors: **James M. Ryan**, Weston; **John V. O'Brien**, Shrewsbury, both of Mass.

[73] Assignee: **Koch Process Systems, Inc.**, Westboro, Mass.

[21] Appl. No.: **458,047**

[22] Filed: **Jan. 14, 1983**

[51] **Int. Cl.**[3] **F25J 3/04**

[52] **U.S. Cl.** **62/17**; 62/20; 62/28

[58] **Field of Search** 62/17, 20, 23-28; 55/68

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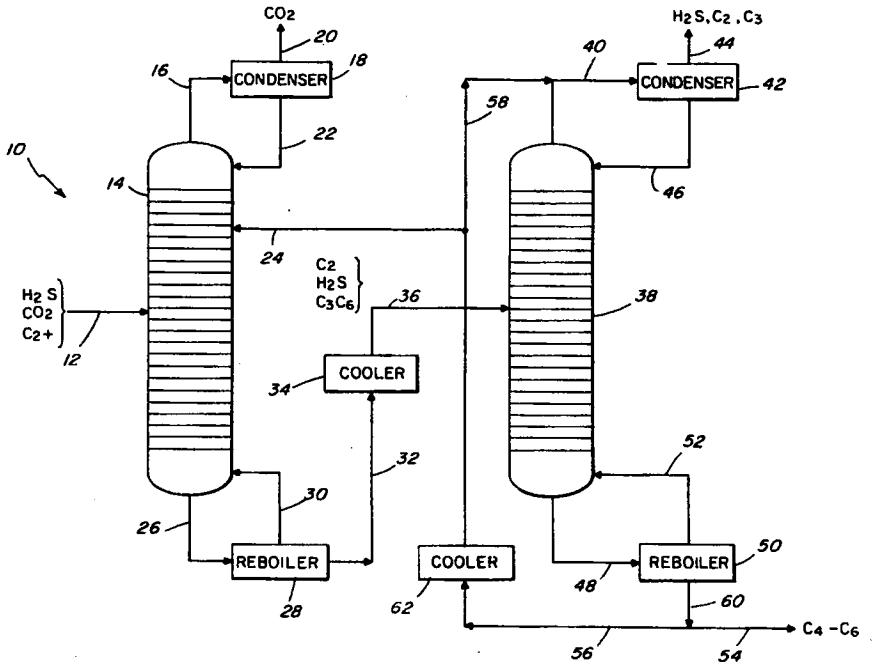
3,595,782	7/1971	Bucklin et al.	62/23
4,035,167	7/1977	Starks	62/17

Primary Examiner—Frank Sever
Attorney, Agent, or Firm—Richard P. Crowley

[57] **ABSTRACT**

An improved method for the distillation of a feed stream containing hydrocarbon components, which method is directed toward the production of a bottom product stream and an overhead product stream, both with desired specifications, which method comprises recycling a minor portion of the bottom product stream typically, but not necessarily, derived from said separation directly to a reflux condenser for the overhead product stream of said method, in order to effect a savings in energy in said distillative method, such as by adjusting the column operating conditions, such as the column operating pressure or the top or bottom operating temperatures of said column.

30 Claims, 3 Drawing Figures



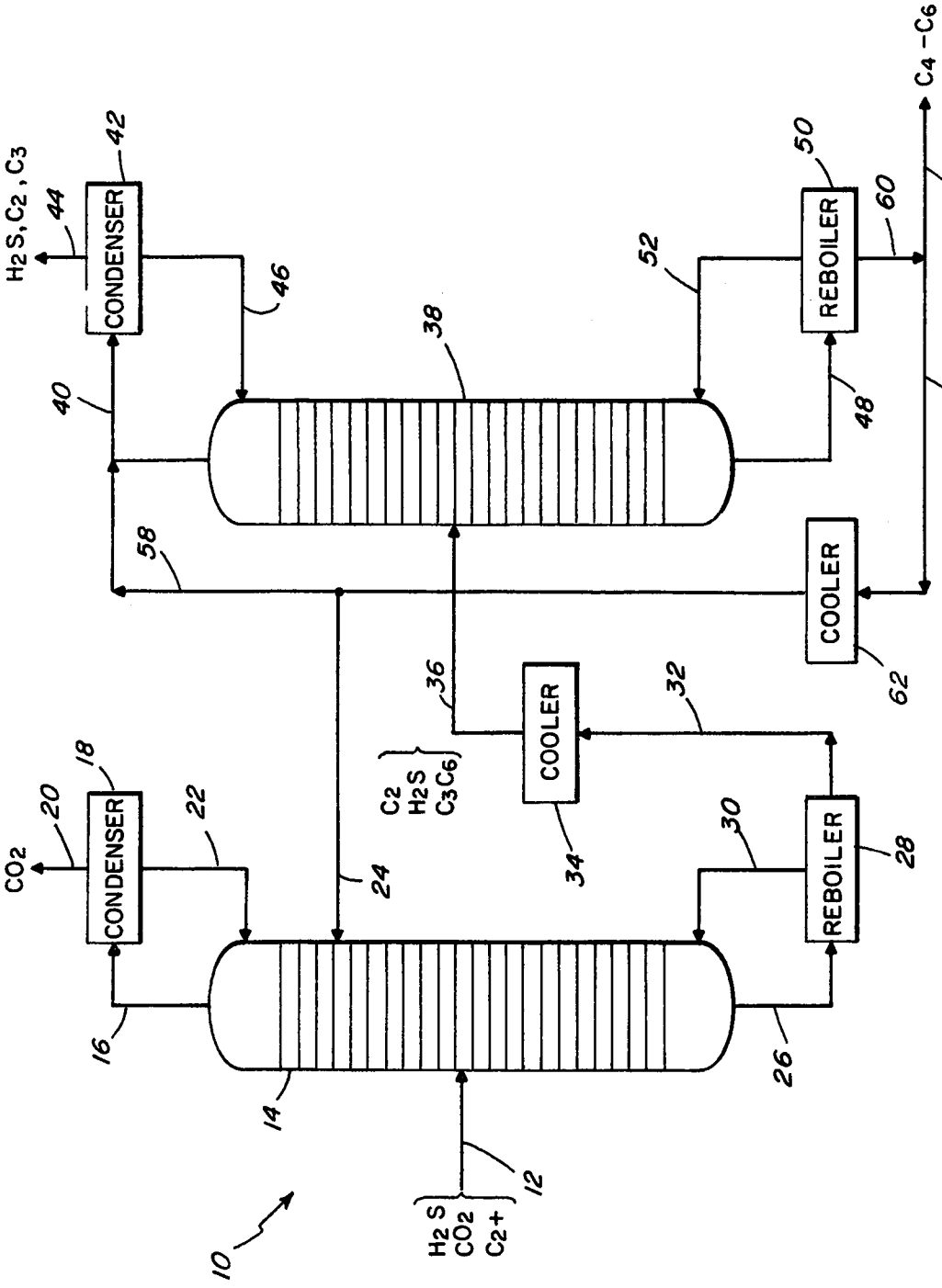
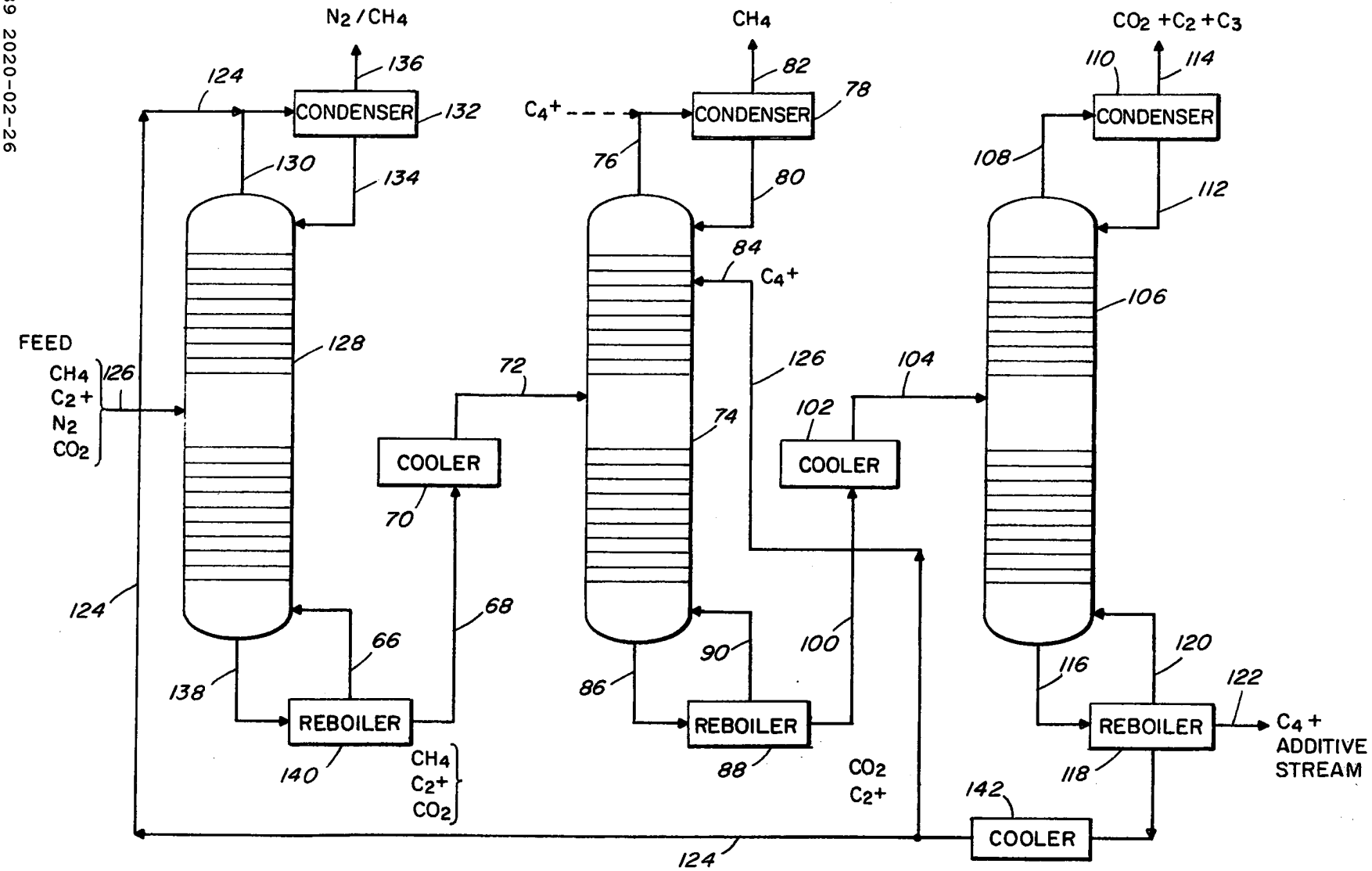


FIG. 1

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FIG. 2



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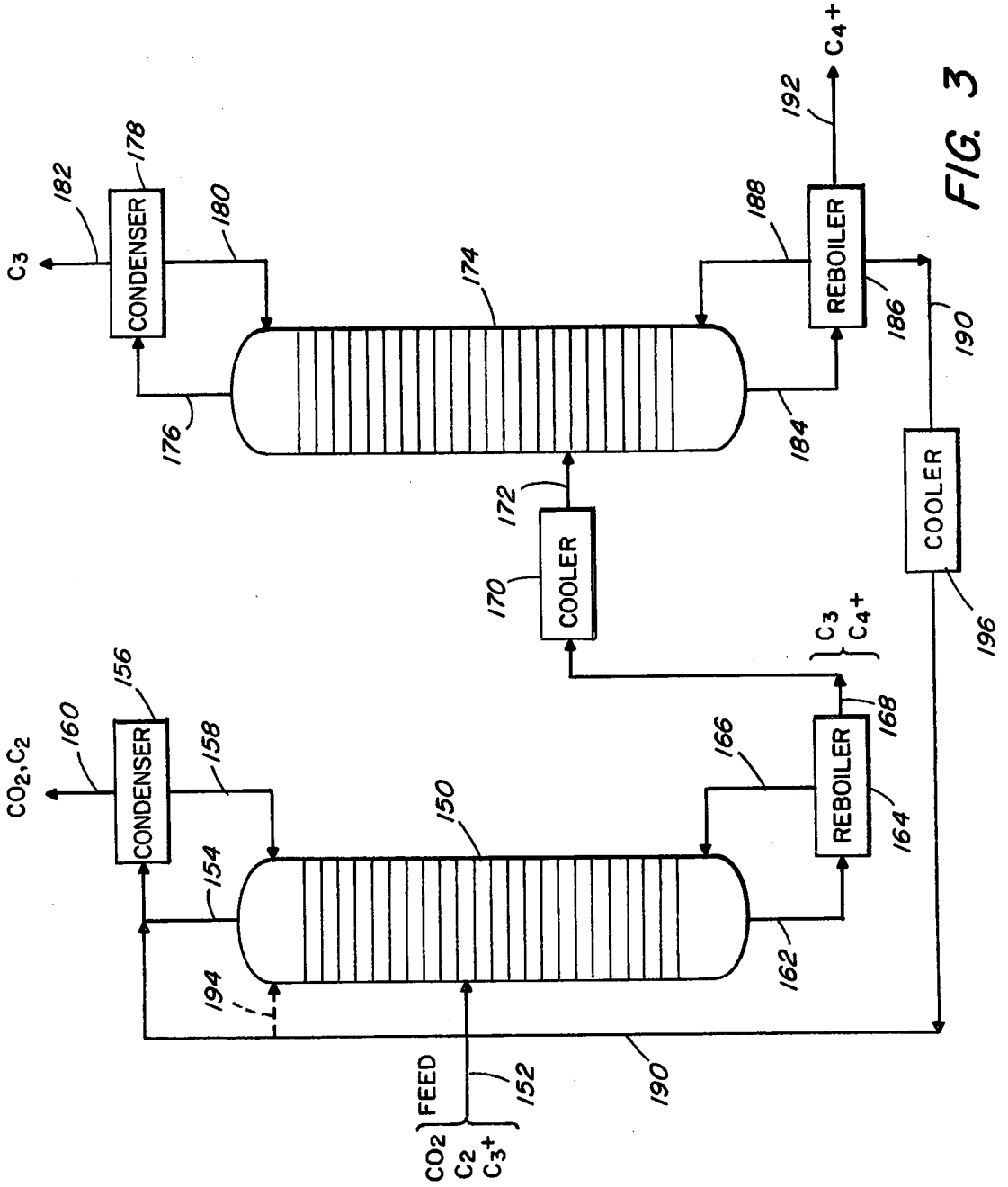


FIG. 3

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DISTILLATIVE SEPARATION EMPLOYING BOTTOM ADDITIVES

BACKGROUND OF THE INVENTION

It is desirable to operate distillative processes at minimum energy, to effect separation of the feed stream into a desired overhead product stream and a bottom product stream in a distillative column having vapor-liquid contacting devices, such as distillation trays, packing devices or a combination thereof. In typical distillative processes, the overhead product stream is at least partially condensed and a small portion recycled to the top of the distillative column, while the bottom product stream is withdrawn and reboiled and at least a portion recycled to the bottom of the column, to provide desirable column operating conditions. Some distillative columns operate under such conditions, so as to obtain the desired overhead product stream of defined specifications enriched in a desirable component, or conversely to obtain a bottom product stream of defined sepcifications enriched in a particular component, or both, so as to obtain purified streams for further separation or recovery or use in a chemical, refinery or petrochemical operation. In any event, such distillative techniques should be carried out at the most desirable column operating conditions, wherein optimum energy savings can be effected.

It is known that the separation of a feed stream in a distillative column, particularly a gaseous hydrocarbon feed stream comprising methane and an acid gas component, such as carbon dioxide, may be separated efficiently through the use of a nonpolar additive agent, such as a liquid additive agent; for example, a C_3–C_6 alkane, particularly butane-plus, introduced into the upper portion of said distillative column in an amount to prevent the formation of solids in the cryogenic distillation of methane from carbon dioxide, such as, for example, as more particularly set forth in U.S. Pat. No. 4,318,723, issued Mar. 9, 1982 (hereby incorporated by reference).

Also, it has been known that, in the prevention of azeotropic formation between ethane and carbon dioxide and ethylene and hydrogen sulfide and other components, the introduction of a nonpolar additive agent, such as a liquid hydrocarbon additive agent, such as a C_3–C_6 alkane, particularly butane-plus, prevents or inhibits the formation of azeotropes and enables the separation to provide an overhead product stream more enriched in a desirable component and a bottom product stream more enriched in a bottom product component, through the alteration of the azeotropic formation, such as, for example, as set forth and described more particularly in U.S. Pat. No. 4,350,511, issued Sept. 21, 1982 (hereby incorporated by reference).

Also, it is known to change the relative volatility of acid gas components, such as carbon dioxide to hydrogen sulfide, through the use of an additive agent, such as a nonpolar liquid additive agent, such as hydrocarbon; for example, a C_3–C_6 alkane, particularly butane-plus, in order to enhance the relative volatility of the carbon dioxide and hydrogen sulfide and, therefore, to increase the efficiency of separation, as set forth in U.S. Pat. No. 4,293,322, issued Oct. 6, 1981, now U.S. Pat. No. 4,383,842, issued May 17, 1983.

U.S. patent application Ser. No. 307,672, filed Oct. 1, 1981 (hereby incorporated by reference) relates to an improvement in the effective separation of methane from carbon dioxide in a distillative column, wherein the upper portion of the column is operated at temperatures above the triple point of carbon dioxide; that is, −70° F., by increasing the amount of nonpolar additive agent added to the reflux condenser, to maintain the reflux condenser and all portions of the column above the triplepoint temperature.

In all of the prior operations, the resulting bottom product stream contains, in addition to the usual bottom product stream components, a liquid nonpolar additive, particularly the liquid hydrocarbon additive added to change the operating conditions in the column. The liquid additive agent may be recycled with the bottom product stream or may be separated and recycled for use in any one or all of the aforementioned uses of an additive agent, particularly where such distillative processes are employed in one-, two-, three- or multiple-column operations for the separation of a natural gas stream or petro-chemical stream into the desired components. The feed streams employed in such distillation process include those streams which have major amounts of an acid gas component desired to be removed and those streams containing minor amounts of or even no acid gas components. It would be desirable, in such distillative separations or a combination of operations and other distillative operations where additives are not used, to reduce the energy requirements of such distillation techniques.

SUMMARY OF THE INVENTION

The invention relates to a distillative technique, wherein a product stream is employed to adjust distillative column operating conditions and to save energy. In particular, the invention concerns a distillative technique, wherein a small portion of a bottom product stream of defined specifications, typically a C_3–C_6 stream, is recycled to the condenser of a distillative column, wherein the overhead stream is not significantly contaminated by the recycled bottom product stream, to adjust column operating conditions and effect energy savings.

It has been discovered that the recycling of a portion of a column bottom product stream; for example, a minor amount, typically such as less than 30%; for example, 20%, and more typically about 1.0 to 10 mols of recycled product per 100 moles of feed stream, and introducing the recycled bottom product stream into the condenser employed for the column overhead stream of that or another column, or a plurality of distillative columns, permit the column operating conditions to be adjusted with a considerable savings of energy. It has been found that the recycling of the column bottom product stream to the reflux condenser of a distillation system permits the adjustment of column operating conditions, such as the raising of the top temperature of the column, the lowering of the bottom temperature of the column, or the lowering of the pressure of the column or lowering of the heating and cooling loads or a combination thereof, in order to permit the savings of energy.

In order to be effective in the practice of the invention, the introduction of the liquid additive agent into the condenser should be carried out, so as to provide that the additive agent is uniformly mixed with the overhead product stream from the distillative column entering the condenser, and typically to flow concurrently through the condenser with the overhead stream.

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It would be ineffectual to introduce the liquid additive agent to the condenser outlet and of considerably reduced efficiency to introduce the liquid additive poorly distributed into the inlet of the condenser. Therefore, the liquid additive should be introduced in and admixed with the incoming overhead product vapor stream and flow concurrently therewith, so that the liquid additive is generally uniformly distributed at least throughout the major portion of the heat-exchange surface or area of the condenser. One method of introducing and admixing is to employ a sparger adjacent the inlet of the condenser or adjacent or directly upstream of the heat-exchange surface of the condenser. Another suitable method of introducing and admixing comprises spraying the liquid additive concurrently into the incoming vapor overhead product stream.

One method of the invention is directed to those additive-recovery distillative techniques employing distillative columns, wherein the technique is directed toward mainly bottom-product-stream end specifications, and wherein the overhead product stream removes one or more contaminants or impurities from the feed stream. Thus, where the introduction of a bottom product stream; for example, a butane-plus stream, into a condenser, containing an overhead product stream, does not affect the operating specifications of the particular distillation technique, then the recycling of the bottom product stream into said condenser will permit the advantageous adjustment of the operating conditions of the column.

The invention is particularly useful wherein an additive agent is introduced into a column, to prevent the formation of a solids zone, to enhance the relative volatility of particular components, or to prevent azeotropic formation, such as those distillative techniques as described in the prior art in the Background of the Invention. The bottom product stream from the additive-recovery column of such operation can be recycled to the overhead condenser of the additive-recovery column or other column in the system to save energy.

The method of the invention is also of use wherein the feed stream comprises a hydrocarbon-containing stream, such as a petroleum or natural or synthetic gas stream high in hydrocarbons and which has a low amount of acid gas components or essentially few acid gas components. The invention is directed toward those bottom product streams, wherein the bottom product stream is typically enriched in higher alkanes and more particularly C_4–C_6 alkanes, such as iC_4, nC_4, iC_5, nC_5 and heavier hydrocarbon components. The recycling of the heavier hydrocarbon components of C_4+ directly from the bottom product stream into the overhead condenser of the distillation system provides for the overhead condenser to operate at a higher temperature, or alternatively the distillative column can be operated at a lower pressure, where the heavier components are present in the overhead product.

For example, in a feed stream which is low in acid gas components or contains essentially no acid gas components and wherein the bottom product stream is the desired stream of defined specifications and the overhead product stream is a stream containing undesired contaminants, the recycling of the bottom product stream directly from the bottom product stream, without separation into the overhead condenser employed for the overhead product stream, permits the temperature at the top of the column and of the condenser to increase, for example, from 10° F. to 60° F.; for example, 15° F. to 50° F., while providing for a reduction in temperature of the bottom of the column; for example, from 5° F. to 50° F. The column operating temperatures may be maintained and the overall column pressure reduced, all with the effective savings in energy, without affecting, or, in fact, in some cases increasing, the efficiency of separation of the bottom product stream. Also, the amount of the bottom product stream recycled may vary, to effect a reduction in column operating pressure of greater than 20 psi; for example, 30 psi, such as from 30 to 150 psi.

The method of the invention is advantageous where the feed stream comprises a butane-plus additive agent from a prior separation, and wherein the condenser of the distillative column is refrigerated by propane, ammonia or Freon (a trademark of du Pont Co.), and the bottom product additive is fed into the condenser, to raise the condenser temperature. The increase in temperature of the condenser permits the overhead product stream to be cooled or condensed employing a higher temperature; for example, the use of cooling water or any equivalent, cheap heat sink, providing increasing energy efficiency of the column operation.

For example, in one embodiment of the method of the invention, it is desirable to recover a bottom product stream containing C_4+ hydrocarbons; that is, the non-polar liquid additive agent from a prior operation, and not to separate such hydrocarbons, with the hydrocarbon bottoms having a hydrogen sulfide concentration kept below a given level; for example, 10 parts per million, and with C_3 removed to below a given level; for example, 0.5% by volume, and then to use the bottom product stream as at least a portion of a liquid additive stream in a cryogenic separation in another column. It has been found that the overhead stream is desirably cooled against water or an equivalent energy heat sink, by recycling a portion of the bottom product stream through the overhead condenser, so that the overhead condenser will operate at a higher temperature or, alternatively and preferably, the column can be operated at a lower pressure, if a sufficient amount of the heavier C_4+ hydrocarbons are in the overhead product stream.

In a further embodiment of the invention, such as in the separation of a substantially pure methane product stream from a natural gas feed stream containing nitrogen, such as from about 5% to 30% by volume or more nitrogen, the method provides for a residual gas stream of low carbon dioxide or hydrogen sulfide content, a fuel gas stream of low carbon dioxide, hydrogen sulfide and nitrogen content and a sour liquefied petroleum gas stream with a high ethane-plus recovery containing the bulk of the carbon dioxide and the hydrogen sulfide.

In this method, a natural gas feed stream containing nitrogen is introduced into a refrigerated distillative column, wherein a liquid additive is fed through the condenser to maintain ethylene-level refrigeration temperatures, and to wash the methane to the base of the column, with the overhead product stream being enriched in nitrogen. An additional refrigerated distillative column employing a liquid additive, such as in U.S. Pat. No. 4,318,723, issued Mar. 9, 1982, is employed to provide for the separation of a methane and carbon dioxide, with the carbon dioxide in the bottom product stream, together with the liquid additive of C_4+, and the methane removed from the overhead product stream, the formation of a solids zone prevented by the introduction of the liquid additive agent to the upper portion of the column. A third column for additive

recovery is then employed, wherein the bottom product stream, containing the liquid additive, is employed as a refrigerated feed stream into the first and second distillative columns.

In a further embodiment, the separation of carbon dioxide and C_2 from C_3+ in a distillative column has been found to be enhanced significantly and considerable heat energy saved by the recycling of a minor amount of the bottom stream, such as the C_4+ bottom stream, from an additive-recovery column to the condenser or to the upper section of the column separating CO_2 and C_3. In order to obtain improved recovery of propane or reduction in energy, it is necessary that the nonpolar liquid C_4+ additive bottom agent be introduced a sufficient number of trays above the feed tray. The C_4+ bottom recycled stream may be added to the overhead condenser; however, some C_4+ stream will be produced or be present in the CO_2–C_2 overhead stream. If desired, to reduce the content of C_4+ stream in the CO_2–C_2 overhead stream, some or all of the C_4+ recycled bottom stream may be introduced into the uppermost tray section of the distillative column, so that the trays above will reduce the C_4+ content in the overhead stream. Typically, if the C_4+ recycled bottom stream is introduced into the upper section of the column, such introduction occurs in the first top ten trays of the column or less, such as the first top five or less trays. The reduction in heat removal is due to the improved relative volatility of the CO_2 to C_3 with the increased concentration of the C_4+ recycled bottom stream in the liquid in the column. This savings in heat energy generally occurs without significant changes in the overhead temperature and column operating pressure, due to the improved volatility ratio of the components.

This invention will be described for the purpose of illustration only in connection with certain specific embodiments; however, it is recognized that those persons skilled in the art may make various changes or modifications to such illustrated embodiments, all without departing from the spirit and scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of an application of the invention to additive recovery;

FIG. 2 is a schematic illustration of an application to a nitrogen separation method employing the invention; and

FIG. 3 is a schematic illustration of an application of CO_2-propane separation employing the invention.

DESCRIPTION OF THE EMBODIMENTS

FIG. 1 is a schematic illustration of a distillative separation method employing the present invention of a nonpolar-liquid-agent additive-recovery application, wherein the feed stream is derived from one or more prior separation processes, and wherein the feed stream comprises hydrogen sulfide, carbon dioxide and C_2+ hydrocarbons introduced through line **12** into a distillative column **14** with vapor-liquid contact devices therein, such as distillation trays, and with a stream removed overhead through line **16** introduced into a reflux condenser **18** and a liquefied portion of the overhead stream recycled to the top of the column through line **22**, while an enriched carbon-dioxide overhead product stream is removed overhead through line **20**. In the operation of the column, a liquid additive, such as an alkane mixture; for example, C_3–C_6, comprising a major amount of butane-plus, is introduced into the upper section of the column **14** through line **24**, to prevent or to modify azeotropic formations within the column **14**. A column bottom stream is removed through line **26** and is introduced into a reboiler **28**, and a portion is recycled through line **30** to the bottom of the column, while the bottom product stream, containing C_2+ and the C_3–C_6 additive and hydrogen sulfide, is withdrawn through line **32**, is cooled in a heat exchanger **34** and is then introduced through line **36** as a feed stream into an additive-recovery distillative column **38** containing distillation trays.

An overhead product stream is removed through line **40** of column **38** and is introduced into a condenser **42**, and a portion of the liquefied overhead stream is recycled to the top of the column through line **46**, while an overhead product stream, containing C_2, C_3 and perhaps some very minor amounts of C_4+ and contaminants, such as hydrogen sulfide, is removed. A bottom product stream containing the C_3–C_6 additive agent is removed through line **48** into a reboiler **50**, where a portion is recycled through line **52** to the bottom of the column, while another portion is removed by line **60** to line **56** through cooler **62** and is recycled and introduced concurrently directly by line **58** and line **40** into the inlet of the overhead reflux condenser **42** of column **38**, to increase the operating temperature of the reflux condenser **42**. The remaining portion of the defined bottom product stream containing C_4+ is removed through line **54**. Optionally as illustrated, a further portion of the bottom stream is removed by line **24** from line **56** and is introduced as all or a portion of the additive agent introduced into column **14**. Compositionally, it is not desired to separate the C_3–C_6 bottom stream, such as the C_4+ bottom stream or heavier components, and this stream may be recycled for use as an additive stream in one or more columns or merely recovered. The bottom product-recovery stream in the defined method is a specified stream having a hydrogen sulfide concentration kept below a defined specification level; for example, about 10 ppm or less of H_2S, and with C_3 removed to below a given specification level; for example, about 0.5% by volume or less. If operation of the column is desired with the same overhead condenser temperature, then the operating pressure of the column could be lowered.

In the method described in FIG. 1, the overhead reflux condenser **42** of the additive-recovery column **38** will operate at a higher temperature, or, alternatively, the distillative column **38** may be operated at a lower pressure, while maintaining the same overhead reflux condenser temperature. In the operation of column **38**, the specifications are directed to the recovery of the additive agent as bottoms, so that the recycle of the additive bottom stream to the reflux condenser of the column does not contaminate the overhead product stream. The higher temperature of the overhead reflux condenser permits employing a less expensive cooling source, such as cooling water, air or a more moderate refrigerant source.

A number of computer simulations of the method were run, employing a plate-to-plate column calculator program, to simulate column condition and operation. The software computer-program simulation employed was the Process SM Simulation Program of Simulation Sciences, Inc. Of Fullerton, Calif., Version 0881. The composition of the feed, bottom, overhead and recycle additive agent streams in a representative computer

simulation of the operation of an additive-recovery column, with recycle to the condenser of the additive-recovery column, such as column **38** of FIG. **1**, is set forth in Table I for 100 psia operation.

The operation of the additive-recovery column at 100 psia, without any recycle of the additive agent to the reflux condenser **42** of the column **38**, is illustrated by the data of Table II.

TABLE I

Components	FLOW RATES - LB MOLS/HR Overhead Stream (44)	Bottom Stream (60)	Feed Stream (36)	Recycle Liquid Stream (58)
H_2S	8.80	0.01	8.81	0.00
N_2	0.00	0.00	0.00	0.00
CO_2	17.6	0.00	17.6	0.00
C_1	0.00	0.00	0.00	0.00
C_2	123.13	0.09	123.22	0.00
C_3	174.79	29.38	201.67	2.50
iC_4	28.76	54.12	78.28	4.60
nC_4	88.52	411.27	464.47	35.32
iC_5	16.70	1263.12	1172.26	107.56
nC_5	15.75	1868.65	1725.44	158.97
nC_6	3.73	1673.61	1535.24	142.10
nC_7	0.44	576.26	527.78	48.92
Totals	478.22	5876.53	5854.75	500.00
Temperature Deg. F.	109.00	232.80	210.00	232.70

TABLE II

Tray	Temp. Deg. F.	FLOW RATES - LB MOLS/HR Liquid	Vapor	Products, Feeds	Duties mm BTU/hr
1	93.3	1146		0 (recycle feed) 462 (overhead net product)	11.0 (condenser)
2	139.0	1143	1608		
3	161.1	1137	1605		
4	173.4	1130	1599		
5	181.1	1116	1592		
6	187.4	1087	1578		
7	195.2	1030	1549		
8	208.0	6810	1492	5855 (feed)	
9	213.0	6955	1417		
10	216.5	7054	1563		
11	219.3	7127	1661		
12	221.9	7190	1735		
13	224.7	7249	1797		
14	228.6	7293	1856		
15	236.9		1900	5392 (bottom net product)	19.0 (reboiler)

The trays shown in Table II are theoretical or equivalent, perfect equilibrium trays, with the reflux condenser **42** as tray **1**, the reboiler **50** as tray **15** and the feed stream introduced at tray **7**.

The operation of the additive-recovery column at the same pressure, but with the recycle of the liquid additive stream to the reflux condenser in accordance with the invention, is illustrated by the data of Table III.

TABLE III

Tray	Temp. Deg. F.	FLOW RATES - LB MOLS/HR Liquid	Vapor	Products, Feeds	Duties mm BTU/hr
1	109.0	1738		500 (recycle feed) 478 (overhead net product)	13.9 (condenser)
2	141.2	1818	1716		
3	156.8	1839	1797		
4	167.1	1839	1818		
5	175.6	1831	1818		
6	183.5	1814	1810		
7	192.3	1772	1792		
8	204.9	7490	1750	5854 (feed)	
9	209.4	7635	1614		
10	212.4	7729	1759		
11	214.9	7798	1853		
12	217.2	7856	1921		
13	219.8	7911	1980		
14	223.8	7953	2034		
15	232.8		2076	5876 (bottom net product)	21.7 (reboiler)

The effect of recycling 500-lb moles/hour of the C_4+ additive agent from the reboiler to the reflux condenser of the recovery column provides for an increase of the reflux condenser temperature from 93.3° F. without additive to 109.0° F. with the additive, and a decrease in the reboiler temperature from 236.9° F. to 232.8° F. This adjustment of the reflux condenser permits the overhead product stream to be cooled using cooling water or an equivalent, inexpensive heat sink, while the recycled additive agent does not contaminate the overhead stream, since the desired specification stream from the column is the C_4+ bottom product stream. If desired, the distillation could be operated at a lower pressure of 70 psia, if the reflux condenser is desired to be maintained at the same temperature as without additive. Thus, the data illustrate the significant advantage of saving energy by the recycling of the C_4+ liquid additive agent stream from the reboiler to the reflux condenser in the illustrated method of FIG. **1**.

FIG. **2** is a schematic illustration of another distillative separation employing the present invention, wherein a C_3–C_6 bottom product stream is recycled to the overhead of a column different from the column from which the bottom product stream is removed. In this embodiment, a feed stream, typically comprising a natural gas stream of a major amount of methane, some C_2+, nitrogen; for example, 9% to 25% nitrogen, and CO_2, is introduced by line **126** into a distillative column **128**, and an overhead product stream is removed through line **130** and introduced into a condenser **132**, and a portion of the liquefied, condensed stream is recycled through line **134** to the top of the column **128**, while a mixture of essentially all nitrogen and part of the methane is removed as an overhead stream through line **136**. A bottom product stream is removed through line **138** and is introduced into a reboiler **140**, and a portion is recycled through line **66** to the bottom of the column **128**. The bottom product stream, comprising part of the methane and practically all of the C_2+ and carbon dioxide, flows through line **68** into a heat exchanger **70**, to cool the stream, which cool stream is introduced through line **72** as the feed stream into the next distillative column **74**.

An overhead product stream is removed through line **76** and is introduced into a condenser **78**, and a condensed portion is recycled to the top of the column **74** through line **80**, while the overhead product stream of enriched, substantially pure methane is removed through line **82**. In the operation of the column, a liquid additive C_3–C_6 alkane agent is added to the top of the column through line **84**, to prevent the formation of a carbon-dioxide solids zone, as in U.S. Pat. No. 4,318,723. A bottom product stream is removed through line **86** and is introduced into a reboiler **88**, and

a portion is recycled through line **90** to the bottom of the column **74**, and the bottom product stream from the reboiler, comprising carbon dioxide and C_2+ (with the additive agent), is removed through line **100** and is passed through heat exchanger **102**, to cool the stream, and is introduced as a feed stream through line **104** into an additive-recovery distillative column **106**. This column is operated as in FIG. **1**, in order to provide a specified bottom product of essentially the liquid additive agent and to remove the carbon dioxide as an impurity in the overhead product stream.

An overhead product vapor stream, comprising carbon dioxide, C_2 and C_3, is removed from the top of the column through line **108** and is introduced into a reflux condenser **110**, and a condensed portion is recycled through line **112** into the top of the column, while carbon dioxide, C_2 and C_3 are removed as an overhead stream from line **114**. A bottom product stream, comprising primary C_4+, is removed from the bottom of the column through line **116** and is introduced into a reboiler **118**, and a portion is recycled through line **120** to the bottom of the column **106**. A specified bottom product stream, with defined specifications as in FIG. **1**, is removed through line **122**, while a portion thereof; for example, 0.5% to 20% or more; for example, 1.0% to 5% by moles relative to column feed, is continuously recycled through line **124** and cooler **142** and is introduced into condenser **132** of the distillative column **128**, and a portion optionally may be introduced, via line **124** or **126** as shown, into condenser **78** (as illustrated by dotted lines), to increase the operating temperature of the condensers **132** and **78**, thereby permitting a reduction in the operating pressure of columns **128** and **74** or a savings in heat energy. This operation permits the recovery of essentially all of the C_2, while CO_2 removal prior to the N_2/CH_4 separation is not required. In the process, the overhead temperature of the distillative column **128** can be raised independently of the overhead N_2/CH_4 content. The reflux condenser **132** temperature can be controlled and adjusted by the rate of the recycled additive addition to the condenser. In view of the very low boiling point of nitrogen removed in the overhead stream in column **128**, the recycled additive rate may be set to require only an ethylene refrigeration system operating at about −125° F.

In a computer simulated example of the operation of distillative column **128** at 572 psia for the separation of N_2 and CH_4, the compositions of the streams are set forth in Table IV, while the column operating conditions are set forth in Table V.

TABLE IV

	FLOW RATES - LB MOLS/HR			
Components	Feed Stream (126)	Recycle Bottom Stream (124)	Overhead Stream (136)	Bottom Stream (68)
N_2	336.38	0.00	334.8	1.52
CO_2	266.91	0.00	2.47	264.42
CO	6.21	0.00	6.08	.13
COS	.65	0.00	.00	.65
H_2S	131.63	0.00	.00	131.62
C_1	2427.04	0.00	1637.02	790.07
C_2	161.32	0.00	.00	161.31
C_3	126.87	27.38	.44	153.81
iC_4	50.01	130.37	.59	179.78
nC_4	75.39	196.65	.49	271.54
iC_5	40.25	105.17	.07	145.35
nC_5	7.60	19.72	.00	27.31
nC_6	15.21	39.98	.00	55.19
nC_7	10.85	28.48	.00	39.34
Totals	3656.40	547.78	1982.07	2222.11
Temperature Deg. F.	−80.	−120.	−125.	−48.

TABLE V

		FLOW RATES - LB MOLS/HR			
Tray	Temp. Deg. F.	Liquid	Vapor	Products, Feeds	Duties mm BTU/hr
1	−125	1854		548 (recycle feed) 1982 (overhead net product)	2.9 (condenser)
2	−119	1870	3288		
3	−116	1802	3305		
4	−112	1700	3236		
5	−106	1580	3135		
6	−97	1466	3015		
7	−86	1437	2901	2481 (vapor feed)	
8	−81	2659	390	1175 (liquid feed)	
9	−78	2701	437		
10	−76	2730	479		
11	−73	2723	508		
12	−48		501	2222	2.4 (reboiler)

The addition of 548-lb moles/hour of the liquid bottom product from reboiler **118** to reflux condenser **132** in the separation of N_2 and CH_4 from the feed stream provided the recovery of 790-lb moles/hour of CH_4 with the bottom stream from column **128**, which CH_4 is recovered as an essentially pure CH_4 overhead stream in column **74**. The overhead product stream of column **128** is essentially over 99% a mixture of N_2 and CH_4. Without the introduction of the recycled C_4+ bottom additive stream, the reflux condenser temperature would be well below the limit (about −150° F.) of an ethylene refrigeration system, while, with the recycle of the bottom stream, the overhead temperature is −125° F., effecting a savings in heat energy in the operation of the column.

FIG. **3** is a schematic illustration of a process of the invention, wherein the separation of CO_2 and ethane from propane by a distillative technique was discovered to be enhanced significantly by the introduction of small amounts of a liquid C_4+ additive recycled bottom stream to the condenser or to the uppermost tray section of the distillative separation column. The introduction of small amounts; for example, 1 to 8 mols, of a C_4+ bottom stream from the additive-recovery or other distillative column source per 100 mols of feed improves the relative volatility of the CO_2 to the propane with increased C_4+ fraction, and considerably reduces the heat duty on the reflux condenser and reboiler by over 60%.

In the embodiment shown in FIG. **3**, a feed stream, consisting essentially of CO_2, ethane and C_3+, is introduced by line **152** in a distillative column **150** containing a plurality of distillation trays, and an overhead vapor stream is removed by line **154** and is introduced in a reflux condenser **156**, and a portion of the liquid condensed stream is recycled through line **158** to the top of column **150**. A mixture, composed essentially of CO_2 and ethane, is removed as an overhead product stream by line **160**. A bottom product stream is removed by line

162 to a reboiler 164, and a portion is recycled through line 166 to the bottom of column 150. The bottom product stream, comprising primarily propane, together with any recycled liquid additive agent introduced into the condenser or upper part of the column 150, is withdrawn by line 168 as a bottom product stream and is introduced into a heat exchanger 170 to cool the bottom product stream.

The cool bottom product stream is introduced by line 172 into the C_4+ additive-recovery column 174. An overhead product stream is removed by line 176 and is introduced into a condenser 178, and a portion from the condenser is recycled by line 180 into the top of the column 174. The overhead product stream, comprising primarily propane, is removed by line 182. A bottom product stream, comprising C_4+ additive agent, is removed by line 184 into reboiler 186, where a portion is recycled to the bottom of column 174 by line 188, and the C_4+ additive fraction is recovered by line 192 for recycle, recovery or for other use. A small portion of the recovered additive bottom product stream from column 174; for example, 1% to 5% by mol of the feed stream to separation column 150, is removed from the reboiler 186 by line 190 and is recycled through cooler 196 to the condenser 156 of separation column 150, and optionally, if desired, the liquid C_4+ additive bottom product stream also may be introduced into the uppermost tray section of the column 150 by line 194 shown as a dotted line.

In the operation of the separation column 150, Table VI shows a computer simulated data of the composition of the column feed stream comprising a major amount of CO_2, ethane and propane. The recycled additive-recovery column bottom additive stream from column 174, comprising primarily C_4–C_6 alkane liquid additive, is introduced in small amounts (less than about 4%; for example, 3%, by moles relative to the feed stream) by line 190 to the condenser 156 (tray 1), while the feed stream is introduced by line 152 to tray 7 of column 150. The overhead stream removes essentially all of the CO_2, C_1 and C_2 of the feed stream, while the bottom product stream is rich in the C_3+ components; that is, the separated C_3 and the recycled C_4+ additive bottom stream.

Table VII is the same as Table VI, except illustrating the feed, overhead and bottom stream compositions, wherein a recycled additive bottom stream is not employed in separation column 150.

TABLE VI

	FLOW RATES - LB MOLS/HR			
Components	Feed (152)	Recycled Bottom Additive (190)	Overhead Stream (160)	Column Bottoms Stream (168)
N_2	0.59	0.0	0.59	0.00
O_2	0.06	0.0	0.06	0.00
C_1	60.70	0.0	60.70	0.00
CO_2	247.04	0.0	246.97	0.06
C_2	8.13	0.0	8.13	0.00
C_3	7.04	0.0	0.71	6.33
iC_4	0.75	1.30	0.20	1.85
nC_4	2.00	3.46	0.32	5.14
iC_5	0.39	0.68	0.02	1.05
nC_5	0.36	0.62	0.01	0.96
nC_6	2.27	3.92	0.05	6.14
Totals	329.39	10.00	317.81	21.57
Temperature Deg. F.	90	13	13	303

TABLE VII

	FLOW RATES - LB MOLS/HR		
Components	Feed Stream (152)	Overhead Stream (160)	Bottom Stream (168)
N_2	0.59	0.59	0.00
O_2	0.06	0.06	0.00
C_1	60.70	60.70	0.00
CO_2	247.04	246.97	0.06
C_2	8.13	8.13	0.00
C_3	7.04	0.70	6.34
iC_4	0.75	0.00	0.75
nC_4	2.00	0.00	2.00
iC_5	0.39	0.00	0.39
nC_5	0.36	0.00	0.36
nC_6	2.27	0.00	2.27
Totals	329.39	317.18	12.20
Temperature Deg. F.	90	12	255

Tables VIII and IX illustrate the operation of the CO_2+C_2/C_3 separation column 150 at 500 psia, both with and without the employment of and illustrating more particularly the change in the heat duty of the reboiler and condenser by the addition of the C_4+ recycled bottom additive stream to the condenser.

TABLE VIII

		FLOW RATES - LB MOLS/HR			
Tray	Temp. Deg. F.	Liquid	Vapor	Products, Feeds	Duties mm BTU/hr
1	12.0	2516		0 (recycle feed) 317 (overhead net product)	11.6 (condenser)
2	26.0	2612	2834		
3	29.0	2628	2929		
4	29.0	2631	2945		
5	29.0	2634	2948		
6	29.0	2639	2952		
7	30.0	2645	2956		
8	30.0	2588	2962	329 (feed)	
9	32.0	2609	2576		
10	33.0	2622	2597		
11	33.0	2641	2610		
12	34.0	2669	2629		
13	35.0	2704	2657		
14	40.0	2644	2693		
15	61.0	2288	2631		
16	116.0	2292	2276		
17	164.0	2643	2280		
18	193.0	2709	2631		
19	219.0	2406	2697		
20	255.0		2394	12.20 (bottom net product)	11.3 (reboiler)

TABLE IX

		FLOW RATES - LB MOLS/HR			
Tray	Temp. Deg. F.	Liquid	Vapor	Products, Feeds	Duties mm BTU/hr
1	13.0	1081		10 (recycle feed) 318 (overhead net product)	4.9 (condenser)
2	25.0	1116	1389		
3	27.0	1122	1424		
4	28.0	1123	1427		
5	28.0	1125	1431		
6	28.0	1127	1433		
7	28.0	1129	1435		
8	29.0	1066	1436	329 (feed)	
9	32.0	1080	1044		
10	33.0	1086	1053		
11	34.0	1093	1064		
12	35.0	1102	1071		
13	37.0	1102	1081		
14	47.0	998	1080		
15	89.0	860	976		
16	154.0	953	838		

TABLE IX-continued

		FLOW RATES - LB MOLS/HR			
Tray	Temp. Deg. F.	Liquid	Vapor	Products, Feeds	Duties mm BTU/hr
17	198.0	1045	931		
18	229.0	1016	1023		
19	263.0	943	995		
20	303.4		922	21.6 (bottom net product)	4.7 (reboiler)

As illustrated, a small amount of recycled C_4+ additive bottom stream markedly reduces the heat load on the condenser and reboiler, while significantly enhancing the separation of CO_2 from C_3, resulting not only in enhanced separation efficiency by a change in relative volatility, but accompanied by a savings in energy in the column operation.

The advantages of recycling the higher alkane bottom product stream of defined specifications and into an overhead condenser, wherein the bottom product stream does not constitute or serve as a contaminant for the overhead product stream, provide for energy savings.

What is claimed is:

1. In a method for the distillative separation, in a distillative column containing vapor-liquid contact devices, of a hydrocarbon-containing feed stream, which method comprises:

(a) introducing the feed stream into a distillative column operating under defined conditions of pressure, temperatue and feed composition;

(b) withdrawing an overhead product stream enriched in at least one component to be removed from the feed stream;

(c) condensing at least a portion of the overhead product stream in a condenser and recycling a portion of the condensed overhead stream to the top portion of the said distillative column;

(d) recovering a bottom product stream with defined specifications enriched with at least one defined component of the feed stream for which recovery is sought; and

(e) reboiling at least a portion of the withdrawn bottom product stream and recycling a portion of the bottom stream to the bottom portion of the column, the improvement which comprises

introducing from about 1 to 30 mols per 100 mols of feed stream of a recycled liquid bottom product stream comprising C_3–C_6 alkanes into an overhead condenser zone of the distillation column, the liquid bottom product stream introduced into the condenser zone concurrently and admixed with the overhead product stream in the condenser zone, the overhead product stream not being subject to substantial contamination by the recycled bottom product stream in the condenser zone, and the amount of the recycled bottom product stream sufficient, to provide adjusting of the operating condition of the distillation zone to effect a saving in the distillation column operating energy by:

(a) increasing the temperature of the condenser zone of the distillation column by about 10° F. or more; or

(b) decreasing the temperature of the bottom of the distillation column by about 5° F. or more; or

(c) reducing the distillation column operating pressure by about 20 psi or more.

2. The method of claim 1 wherein the amount of recycled liquid bottom product stream ranges from about 1 to 10 mols per 100 mols of feed stream.

3. The method of claim 1 which includes introducing sufficient, recycled, liquid bottom product stream into the overhead condenser zone, to increase the temperature of the overhead condenser zone from about 10° F. to 60° F. from the temperature of the overhead condenser zone, without the introduction of the bottom product stream.

4. The method of claim 1 which includes introducting sufficient, recycled, liquid bottom product stream into the overhead condenser zone, to permit the reduction in the distillative column operating pressure from the operating pressure employed, without the introduction of the bottom product stream.

5. The method of claim 4 which includes introducing sufficient bottom product stream, to reduce the operating pressure of the distillation column from about 30 to 150 psi.

6. The method of claim 1 wherein the recycled liquid bottom product stream comprises a majority of C_4+ alkanes.

7. The method of claim 1 which includes removing heat from the overhead condenser zone to which the bottom product stream has been added, by employing cooling water or a refrigerating system.

8. The method of claim 1 wherein the recycled liquid bottom product stream is recycled to the overhead condenser zone of the same distillative column from which the bottom product stream is recovered.

9. The method of claim 8 wherein the feed stream to the distillative column comprises a cool feed stream of H_2S and C_2+ alkanes and is essentially free of carbon dioxide, and the overhead stream is enriched in H_2S, C_2 and C_3 and the bottom product stream is enriched in C_4+ alkanes.

10. The method of claim 1 wherein the recycled bottom product stream has less than about 0.5% mols of C_3 and a maximum of about 10 ppm of H_2S.

11. The method of claim 1 wherein the feed stream comprises CO_2, H_2S and C_2–C_6 alkanes, and the bottom product stream comprises primarily C_4–C_6 alkanes.

12. The method of claim 1 wherein the feed stream is essentially free of acid gas components.

13. The method of claim 1 which includes introducing the liquid bottom product stream into the overhead condenser zone by sparging the liquid bottom stream into the vapor overhead product stream.

14. The method of claim 1 which includes spraying the liquid bottom stream concurrently into the vapor overhead product stream introduced into the overhead condensing zone.

15. The method of claim 1 for the distillative separation of carbon dioxide from a gaseous hydrocarbon feed stream containing carbon dioxide, which method comprises:

(a) introducing the feed stream into a first distillative column;

(b) introducing a nonpolar liquid C_3–C_6 alkane additive agent into the upper section of the column above the point of introduction of the feed stream;

(c) withdrawing a first overhead product stream from the top of the first column enriched in carbon dioxide;

(d) withdrawing a first bottom product stream from the bottom of the first column containing the liquid additive agent;

(e) introducing the first bottom product stream into a second distillative column as a feed stream for the second column;

(f) withdrawing from the top of the second column a second overhead product stream comprising primarily C_2 and C_3 alkanes;

(g) withdrawing from the bottom of the second column a second bottom product stream comprising primarily C_4+ alkanes;

(h) condensing at least a portion of the second overhead product stream in an overhead condenser and recycling a portion of the second overhead product stream to the top of the second column;

(i) reboiling at least a portion of the second bottom product stream in a reboiler and recycling a portion of the reboiled bottom product stream to the bottom of the second column;

(j) recovering a reboiled second bottom product stream comprising C_4+; and

(k) recycling a portion of from about 1 to 30 mols of the second bottom product C_4+ stream, based on 100 mols of the feed stream in the second column, into the second overhead condenser and introducing the recycled C_4+ bottom stream concurrently with the second overhead product stream into the second overhead condenser, to increase the temperature of the second overhead condenser or to reduce the operating pressure of the first column.

16. The method of claim **15** which includes recycling a portion of the reboiled bottom product stream as at least a portion of the liquid additive stream introduced into the first column.

17. The method of claim **1** for the distillative separation of carbon dioxide from a gaseous hydrocarbon feed stream containing the carbon dioxide and C_2, C_3 and C_4+, which method comprises:

(a) introducing the feed stream into a first distillative column;

(b) withdrawing a first overhead product stream enriched in carbon dioxide and C_2 from the top of the first column;

(c) withdrawing a first bottom product stream enriched in C_3 from the bottom of the first column;

(d) condensing at least a portion of the first overhead product stream in a first overhead condenser and recycling a portion of the first overhead product stream to the top of the first column;

(e) reboiling at least a portion of the first bottom product stream in a reboiler and recycling a portion of the reboiled bottom product stream to the bottom of the first column;

(f) introducing a first bottom product stream as the feed stream into a second distillative column containing a plurality of distillation trays;

(g) withdrawing from the top of the second column a second overhead product stream comprising primarily C_3;

(h) withdrawing from the bottom of the second column a second bottom product stream comprising primarily C_4+;

(i) recovering a reboiled second bottom product stream; and

(j) recycling a portion of from about 1 to 10 mols of the second bottom C_4+ product stream, based on 100 mols of the feed stream in the first column, into the inlet of the first overhead condenser concurrently with the first overhead product stream, to admix uniformly the bottom stream and overhead product stream in the condenser, or to the upper ten or less trays of the first column, to reduce the heat duty in the operation of the first column.

18. The method of claim **1** for the distillative separation of nitrogen and methane from a gaseous feed stream comprising nitrogen, methane, carbon dioxide and C_2+ alkanes, which method comprises:

(a) introducing the feed stream into a first distillative column;

(b) withdrawing from the top of the first column a first overhead product stream enriched in nitrogen;

(c) withdrawing from the bottom of the first column a first bottom product stream containing CH_4, CO_2 and C_2+;

(d) condensing at least a portion of the first overhead product stream in a first overhead condenser and recycling a portion of the condensed first overhead product stream to the top of the first column;

(e) introducing the first bottom product stream as a second feed stream into a second distillative column;

(f) withdrawing from the top of the second column a second overhead product stream enriched in methane;

(g) withdrawing from the bottom of the second column a second bottom product stream containing CO_2 and C_2+ products;

(h) introducing into the upper section of the second column, above the point of introduction of the second feed stream, a nonpolar, liquid, C_3-C_6 alkane additive agent;

(i) condensing at least a portion of the second overhead product stream in a second overhead condenser and recycling a portion of the condensed second overhead stream to the top of the second column;

(j) introducing the second bottom product stream as the third feed stream into a third distillative column;

(k) withdrawing from the top of the third column a third overhead product stream containing CO_2, C_2 and C_3;

(l) withdrawing and recovering a third bottom produce stream from the bottom of the third column composed primarily of C_4+ alkanes; and

(m) recycling at least a portion of the third bottom product stream to the first overhead condenser concurrently with the first overhead product stream, to admix uniformly the bottom stream and overhead product stream in the condenser, to provide for an increase in the temperature of the overhead condenser or a reduction in the operating pressure of the first column.

19. The method of claim **18** which includes recycling a portion of the third bottom product stream for introduction as at least a part of the liquid additive agent into the second column.

20. The method of claim **18** wherein the first overhead product stream comprises essentially nitrogen and methane, and the second overhead product stream comprises essentially pure methane.

21. The method of claim **1** which includes introducing recycled liquid bottom product stream into the overhead condenser zone in an amount sufficient to reduce the operating temperature of the bottom of the column from about 5° to 50° F. from the temperature without the introduction of the recycled liquid bottom product stream.

22. The method of claim 1 which comprises the distillative separation in the distillation column of a carbon dioxide and C_2 overhead stream and a C_3+ bottom stream which includes recycling a minor amount of a bottom product stream into the uppermost tray section of the distillative column separating carbon dioxide and C_2 overhead stream from the C_3+ and bottom stream.

23. The method of claim 22 wherein the bottom product stream comprises a C_4+ stream and is introduced into at least one of the top ten trays of the distillation column.

24. The method of claim 1 which comprises the distillative separation of nitrogen and methane from a feed stream in a CH_4-N_2 distillative separation column and which includes introducing a liquid bottom product stream from the distillative separation of CO_2, C_2 and C_3 as an overhead stream and the C_4+ additive bottom product stream into the overhead condenser zone of the CH_4-N_2 distillation column for the separation of CH_4 and N_2 to increase the column operating temperature of the CH_4-N_2 overhead condenser zone.

25. The method of claim 1 which comprises the separation of a hydrogen sulfide, C_2 and C_3 stream as an overhead stream from a C_4–C_6+ liquid bottom product stream in a distillation column which includes recycling the C_4–C_6+ liquid bottom product stream into the overhead condenser zone of the distillation column to increase the temperature of the overhead condenser zone.

26. The method of claim 25 wherein from about 1 to 8 mols of the bottom product stream is recycled per 100 mols of feed stream to the CO_2-C_2 distillation column.

27. The method of claim 1 which comprises the distillative separation of carbon dioxide and ethane stream from propane stream which includes distillatively separating CO_2 and C_2 as an overhead stream in a distillation column and recovering a C_3+ bottom stream as a feed stream for distillatively separating in another distillation column of C_3 as an overhead product stream and C_4+ as a liquid bottom additive stream and recycling a portion of the liquid bottom product stream to the overhead condenser of the distillative column for the CO_2-C_2 separation from C_3+ to increase the operating temperature of the overhead condenser zone of the CO_2-C_2 distillation column.

28. The method of claim 1 wherein the bottom product stream is admixed with the overhead product stream upstream of the heat exchange area in the condenser zone so that the admixed overhead and the bottom product stream are generally uniformly distributed through the vapor portion of the heat exchange area of the condenser zone.

29. The method of claim 1 wherein the overhead condensing zone is maintained by the recycling of the bottom product stream at a temperature of about −125° F. or more.

30. The method of claim 1 which includes recycling the liquid bottom product stream from a different distillation column into the condenser zone of the distillation overhead column.

* * * * *

United States Patent [19]

Ozero et al.

[11] **Patent Number: 4,595,404**

[45] **Date of Patent: Jun. 17, 1986**

[54] **CO_2 METHANE SEPARATION BY LOW TEMPERATURE DISTILLATION**

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[73] Assignee: **Brian J. Ozero**, New York, N.Y.

[21] Appl. No.: **691,298**

[22] Filed: **Jan. 14, 1985**

[51] **Int. Cl.**[4] **F25J 3/02**

[52] **U.S. Cl.** **62/18**; 62/24; 62/29; 62/31; 62/34

[58] **Field of Search** 62/23, 24, 31, 32, 34, 62/25-30, 18

[56] **References Cited**

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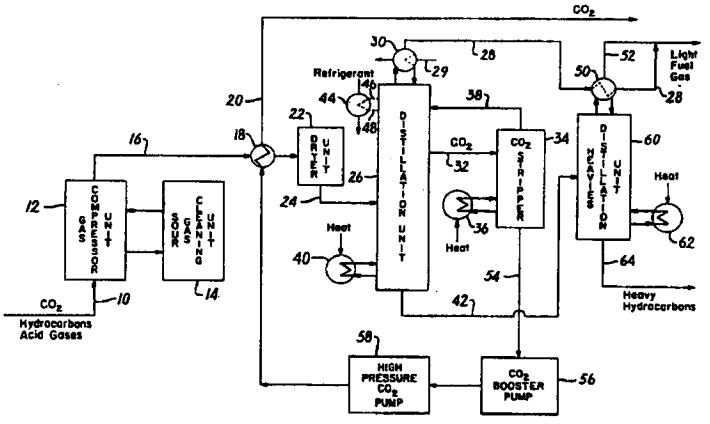
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Primary Examiner—Frank Sever
Attorney, Agent, or Firm—Daniel R. Zirker

[57] **ABSTRACT**

A process for the regeneration of a CO_2 gaseous stream such as are utilized in CO_2 miscible flooding for petroleum recovery, is disclosed. The process utilizes an economic, low energy intensive cycle to regenerate a wide range of CO_2 containing compositions, which are typically recycled for further use.

18 Claims, 2 Drawing Figures



CA 2949039 2020-02-26

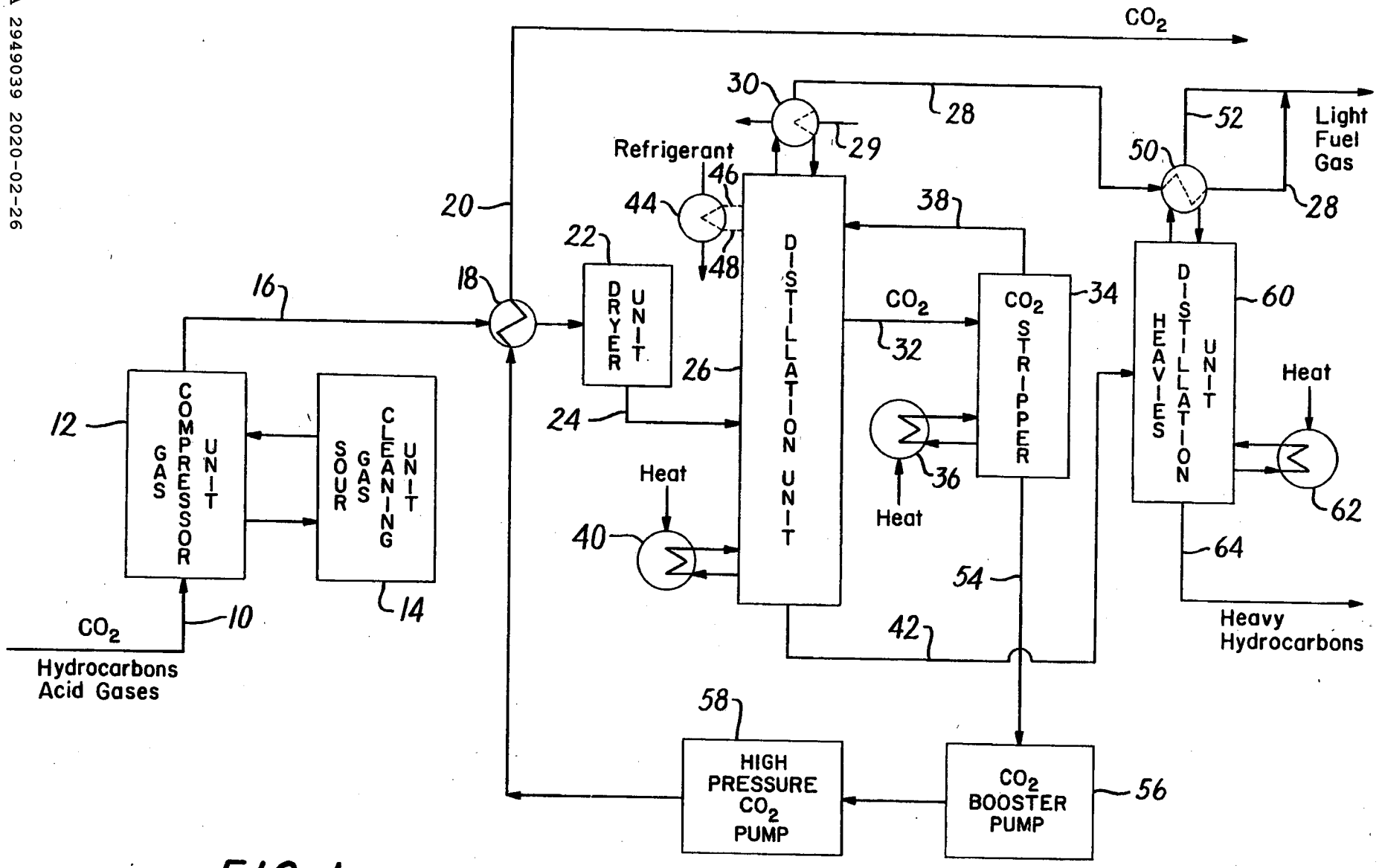


FIG. 1

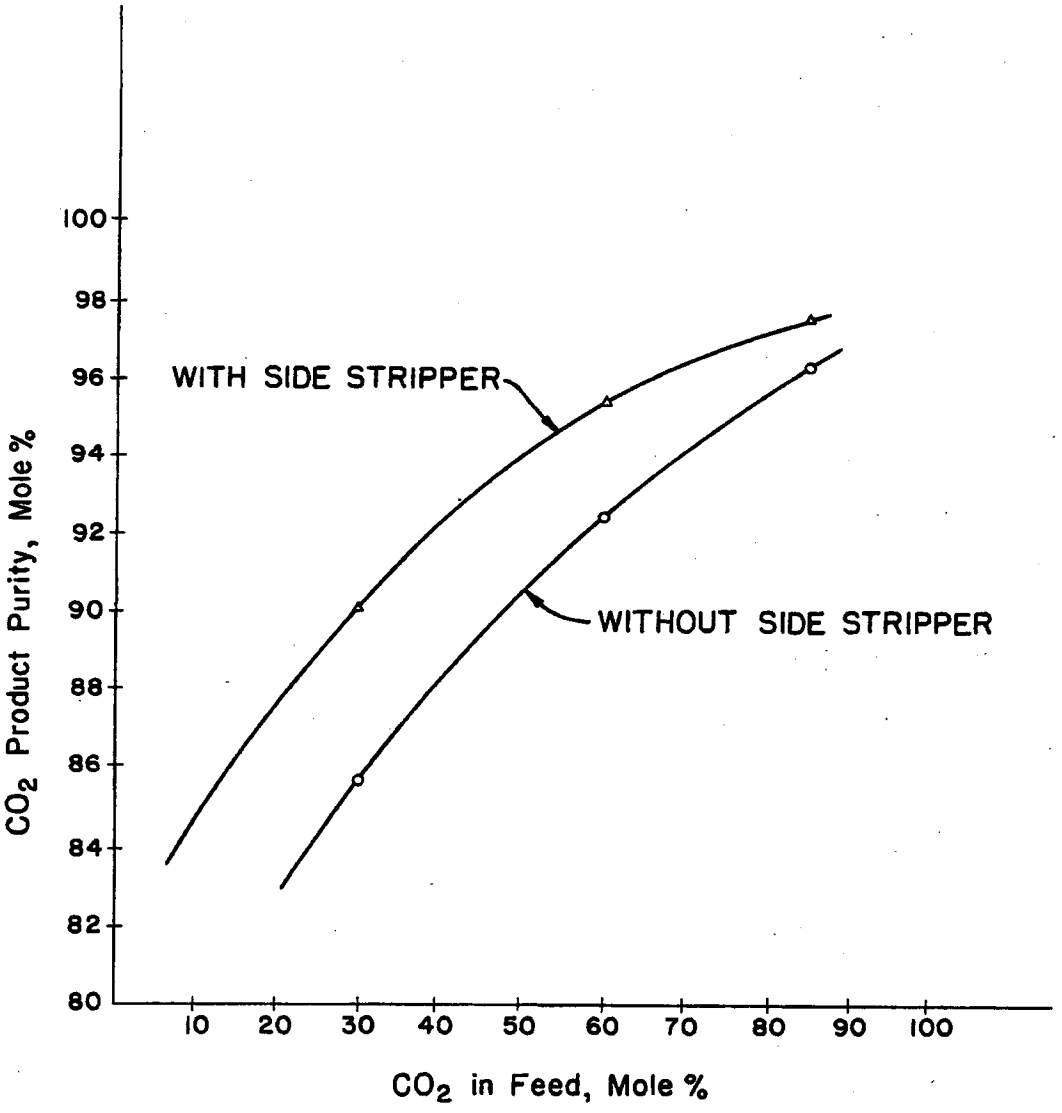

100
98
96
94
92
90
88
86
84
82
80
WITH SIDE STRIPPER
WITHOUT SIDE STRIPPER
CO_2 Product Purity, Mole %
10
20
30
40
50
60
70
80
90
100
CO_2 in Feed, Mole %

FIG. 2

CO_2 METHANE SEPARATION BY LOW TEMPERATURE DISTILLATION

BACKGROUND OF THE INVENTION

Many hydrocarbon gas streams in addition to containing a substantial methane component also possess significant amounts of heavier hydrocarbons such as ethane, propane, butane, etc., as well as substantial amounts of acid gases such as COS, H_2S and, particularly, CO_2. Frequently it is necessary to separate the acid gas, e.g., CO_2 component, from the hydrocarbon component as well as separate the heavier hydrocarbon fractions from the methane. For example, in order for natural gas to be commercially acceptable, it must first meet stringent specifications with regard to heating value, hydrogen sulfide and carbon dioxide content.

There are currently a number of established technologies for the removal or partial separation of acid gases from hydrocarbon streams. Thus, it is known to use physical solvents which are selective toward the acid gas component and chemical solvents which will react with such components. Suitable examples of physical solvents include propylene carbonate, dimethylether and polyethylene glycol. Examples of suitable chemical solvents are aqueous solutions of potassium carbonate as well as a variety of amines, such as monoethanolamine, diethanolamine and the like.

Carbon dioxide flooding is a process which can be particularly useful in enhanced oil recovery processes. Carbon dioxide flooding can proceed through a variety of mechanisms, including:

(1) immiscible CO_2 drive;
(2) miscible CO_2 drive;
(3) hydrocarbon-CO_2 miscible drive;
(4) solution gas drive;
(5) hydrocarbon vaporization; and
(6) multiple-contact dynamic miscible drive. In the L. M. Home et al, December 1974 publication in the Journal of Petroleum Technology, the CO_2 properties believed to be important in causing oil displacement were stated to be the following:
(1) CO_2 reduces oil viscosity;
(2) CO_2 increases oil density;
(3) CO_2 promotes swelling of oil;
(4) CO_2 is highly soluble in water;
(5) CO_2 in water has an acidic effect on limestone and carbonate rock and thus dissolves the rock;
(6) CO_2 vaporizes and extracts portions of crude oil; and
(7) CO_2 is transported chromatographically through porous rock.

Miscible flooding with CO_2 has recently become increasingly popular, due both to its ability to recover valuable hydrocarbons from naturally occurring gas formations which were previously uneconomical to recover and also to the increased suitability for the recovery of petroleum deposits. Thus, the use of carbon dioxide for miscible flooding is gaining momentum; consequently, growing amounts of associated gas utilized in wells stimulated by this method must be processed, both in order to recover the extracted hydrocarbon content and also to efficiently recover and recycle the carbon dioxide for reinjection into the well. However, the effectiveness of CO_2 is greatly reduced when contamined with impurities such as methane and nitrogen. Accordingly, an economical method for producing a rich CO_2 stream substantially either reduced or free from these impurities has been a goal of the art.

A number of distillation techniques can be useful for the separation of CO_2-hydrocarbon streams, particularly at higher CO_2 levels. One such attempt, the so-called Ryan-Holmes process, involves an initial separation of the methane component present from the CO_2 and the heavier hydrocarbons. Since CO_2 freezes at the temperatures usually encountered in a demethanizer, an alkane is fed in at the top of the column, thereby preventing freezing of the CO_2. Subsequent distillation can separate CO_2 from the hydrocarbon stream, and the various hydrocarbons themselves, but this leads to an expensive, involved process.

A combination distillation-membrane process has been set forth in U.S. Pat. No. 4,374,657 to Fluor, Inc.

In U.S. Pat. No. 4,417,449 a process for the separation of CO_2 and sulfide gases from oil shale retorting, coal gasification, oxygen fireflooding, and CO_2 miscible flood enhanced oil recovery of the off gases for various recycle processes, such as to a petroleum reservoir, is reported. The process separates the off gases into an essentially sulfur-free light BTU fuel gas, a heavy hydrocarbon stream, and a CO_2 acid gas stream, with the CO_2 stream being expanded in an auto-refrigeration step to provide the necessary process refrigeration.

SUMMARY OF THE INVENTION

Accordingly, the invention comprises a process for the regeneration of a carbon dioxide gaseous stream further containing a significant acid gas component, such as H_2S and COS, as well as a variety of carbonaceous, e.g., petroleum-based compounds. The process comprises: compressing and cooling the CO_2 feed stream, typically containing CO_2, acid gases, light fuel gases, and heavy hydrocarbons, e.g., petroleum products from a subsurface well, to a suitable elevated temperature e.g., 70° to 90° F., and superatmospheric, e.g., 450 to 550 psig, pressure; substantially removing any acid gases, i.e., sour gases, present, e.g., by liquid phase oxidation, from the CO_2 feed stream; preferably further cooling the feed stream by contacting with a suitable cool product stream, e.g., a pressurized, liquid CO_2 stream in a suitable heat exchange zone; drying the CO_2 feed stream, e.g., by conventional low temperature procedures to about 0–2 ppm water; separating the CO_2 feed stream in a single distillation zone which is primarily externally refrigerated into a (1) light fuel gas stream, (2) a liquid, substantially CO_2-containing stream, and (3) a heavy hydrocarbon stream; the external refrigeration, preferably comprising about 60–90%, most preferably about 75%, occurring by the utilization of a distillation intercooler unit positioned above the CO_2 containing sidedraw stream withdrawal; cooling the light fuel gas stream e.g., preparing it for use as a suitable product, e.g., by contacting in a suitably refrigerated overhead condenser unit and removing a desired light fuel gas fraction; pressurizing and transporting the substantially CO_2-containing liquid stream, e.g., a sidedraw stream, preferably substantially stripped of non CO_2 component in an adjacent stripping zone, into a suitable heat exchange zone, i.e., for heating by contacting the entering CO_2 feed stream before exiting as product, e.g., recycling the stream to underground petroleum formations; separating the heavy hydrocarbon stream into a lighter hydrocarbon gas stream which, preferably, is combined with the light fuel gas product

stream, and a heavier hydrocarbon stream, e.g., by a suitable distillation stage.

FIG. 1 discloses a simplified outline of the preferred embodiment of the invention.

FIG. 2 discloses a range of calculated CO_2 product purity streams depending upon whether or not a side stripping unit is utilized in the primary distillation zone.

DETAILED DESCRIPTION OF THE INVENTION

One major utilization of carbon dioxide miscible flooding is the recovery of liquid hydrocarbons such as petroleum in underground formations which are not naturally producing due to high viscosities, surface tensions, and/or a lack of adequate pressure present in the petroleum formations. Carbon dioxide miscible flooding enhanced oil recovery involves no deliberate combustion, but rather a high pressurization of the subsurface formation with CO_2 so as to dissolve the oil in the CO_2 and withdraw a single phase, CO_2-petroleum containing fluid toward a surface well.

In FIG. 1 a simplified outline of the preferred embodiment of the regeneration of the carbon dioxide utilized in a miscible flooding process or the like has been set forth. A feed gas stream **10**, typically passing from a crude separation unit or the like, comprises a CO_2-hydrocarbon stream having a CO_2 content ranging from about 10 to 95 mole %, preferably, from about 60 to 90 mole %, at about 100° F. and 5–10 psig. The stream is compressed in feed gas compressor unit **12**, preferably to an intermediate pressure level, e.g., 30 to 60 psig, with the hydrocarbon condensate being recovered in the decanters following the aftercoolers, flashed and returned to the crude oil separator for recovery (not shown). If, as usually is the case, the feed stream contains H_2S, COS, mercapatans, or the like, some or all of these components can be removed in gas cleaning unit **14** by suitable procedures, e.g., direct liquid phase oxidation of H_2S to sulfur, and the like. After one or, preferably two additional compression steps and suitable amounts of aftercooling, the feed stream **16** preferably next passes into a feed-product heat interchanger **18**, where the feed gas is cooled to 80° F., preferably by contacting with a cooled, substantially liquid CO_2 product stream **20** maintained at a temperature of about 50 to 60° F. Hydrocarbon and water condensates are again separated from the feed stream following cooling, with the hydrocarbons being decanted, flashed, and passed back to the crude oil separator. The feed gas stream is then dehydrated to about 0–2 ppm H_2O, preferably less than about 1 ppm H_2O, in dryer unit **22**, which is typically a solid desiccant dryer, or the like. After dehydration, the feed gas stream is then passed through line **24** to the primary distillation unit **26**, which is a low-temperature multi-product column in which a cold fuel gas overhead stream **28**, typically comprised of about 64 mole % CH_4, 18–22% CO_2, 5% propane, 6% butane, and the remaining various other hydrocarbons and inerts, is taken off and passes through condensor **30** at a pressure of about 400 to 600 psig and −60° to −70° F.; a liquid product stream **32**, typically comprised of at least 90 mole % CO_2 with minor fractions of methane, ethane and the like, at a pressure of about 400–600 psig and 20°–30° F., passes from the column as a sidedraw stream, in a manner similar to that described in U.S. Pat. No. 4,417,449. In the most preferred embodiment, a substantial improvement in CO_2 purity is obtained by further stripping the exiting sidedraw liquid product stream **32**, as is further indicated in FIG. 2 and accompanying Table I. Surprisingly, a 95 mole % CO_2 product stream can be obtained using the side stripper unit **34** with feeds as low as 57 mole % CO, whereas only about 75% is obtainable without using the side stripper unit. Sidedraw stream **32** is so processed by entering CO_2 stripping unit **34**, typically a small, suitably packed column known to those in the art, whereupon the incoming liquid stream **32** is stripped by the vapors generated in the stripper reboiler unit **36**, with the exiting vapors from the stripper in line **38** re-entering the primary distillation unit **26** at a suitable tray positioned above the sidedraw stream **32** location. The vapor for primary distillation unit **26** is provided by reboiler unit **40**.

TABLE I

	Feed Makeup: (Mole %)*				
Example	CO_2	C_2H_6	C_3H_8	CH_4	C_{4s}
1	30%	7.0%	6.8%	45.7%	9.5%
2	60%	4.0%	3.9%	26.1%	5.4%
3	85%	1.5%	1.5%	9.8%	2.0%

*The balance is comprised of N_2, O_2.

A smaller, heavier hydrocarbon bottoms stream **42**, typically comprising about 42 mole % hexane, 22% isopentane, 27% pentane, 8% butane, along with various minor products is removed by pressure let-down from the bottom of distillation column **26**. In sharp contrast to the expensive auto-refrigeration system required in the aforementioned U.S. Pat. No. 4,417,449, since in this system much of the condenser duty is required for the liquefaction of the CO_2 component, a surprising improvement has been realized through the utilization of a distillation intercooler unit **44**. The unit, when appropriately positioned near the top of the column above the CO_2 sidedraw tray, as would be apparent to one skilled in the art, substantially reduces the use of the expensive refrigerant in line **29** otherwise required in the primary distillation unit condenser **30** positioned at the top of the column treating the light fuel gas overhead stream **28**. The vapors from a suitable upper tray in the column **26** are withdrawn through line **46** and cooled in the intercooler **44** by a suitable, e.g., −10° F., refrigerant, with the vapor and liquid exchanger effluent returning to the column via line **48**. In such a manner the expensive refrigeration requirement is substantially shifted from the more expensive condenser unit **30** to the intercooler **44**, thereby providing a substantial economic benefit. That is, the distillation column now employs a dual overhead "knockback" condenser, as well as a side stream refrigerated condenser which is adapted to operate to shift a very substantial amount, e.g., about 60 to 90%, usually about 75%, of the condensing load to conventional refrigeration at about −10° F., with only the remaining, e.g., 25% being at a substantially lower, e.g., −75° F., and more expensive temperature level.

The fuel gas distillate stream **28**, which is typically 76–80 mole % hydrocarbon and at a temperature of −60° to −70° F., is preferably passed to a heavies column condenser unit **50** and utilized as a coolant in the condenser for the column overhead stream **52**. After heating, the gas stream is depressurized to a desired pressure, e.g., a suitable delivery pressure to customers, such as 200 psig, and mixed with the cooled overhead from the heavies column **52**, typically comprising mostly propane and butanes, thereby increasing the

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heating value of the resulting gas stream to a desired heating value, e.g., 800 BTU/SCF. Preferably, a substantial amount of the gas stream can be consumed within the process as fuel for the refrigeration and compressor gas engines.

The substantially liquid CO_2 sidedraw stream **32** after leaving the distillation unit and side stripper passes through line **54** to pump **56**, preferably a CO_2 booster pump, in order to obtain an adequate NPSH for the following high pressure CO_2 pump **58**. The pressurized CO_2 stream is then heated, preferably in feed product heat interchanger **18** by incoming feed stream **16**, and the exiting CO_2 product stream typically leaves the process at about 800 to 3500 psig and about 30°–60° F. through line **20**, where it is preferably mixed with fresh CO_2 before being reinjected into the petroleum-bearing subsurface, or utilized in another manner.

The bottoms stream **42** of the primary distillation unit **26** typically comprises a propane fraction along with lesser amounts of other heavier components present in the feed stream, together with a small amount of CO_2 and ethane. The stream is passed to a suitable separation unit, e.g., a small heavies distillation column **60**, which, typically, is a small packed tower with an overhead condenser unit **50** cooled by the primary distillation unit overhead stream **28**, and heated by a suitable reboiler unit **62**. The small bottoms stream **64** from the column, typically comprising about 42 mole % hexane, 27% pentane, 22% isopentane and 8% butane, is preferably cooled and pressured back to a crude oil separator (not shown), while the lighter components are preferably taken overhead as a vapor distillate **52** and combined with the fuel gas stream **28** (as noted above) so as to increase the heating value of the exit gas to a desired content.

In the preferred embodiment of the invention, the liquid CO_2 sidedraw stream **32** is substantially stripped of its remaining small methane content by passing the stream through a suitable stripping zone, e.g., CO_2 stripping unit **34**. The stripping enables the process to operate with a higher CO_2 purity, thereby greatly expanding the range of allowable CO_2 concentrations in feed gas streams. This is in contrast to prior art systems, particularly the one disclosed in U.S. Pat. No. 4,417,449, which are by necessity severely limited by their ability to process CO_2 streams containing a minimum of about 90% CO_2.

It is to be noted that, although the preferred embodiment of the invention has been set forth, various modifications can be made without deviating from the scope of the invention, such as the use of recycle streams and the like and, accordingly, the invention is not to be limited except as so defined in the appended claims.

We claim:

1. A process comprising, regenerating a CO_2 gaseous feed stream further containing a significant acid gas component having a CO_2 concentration of about 60–90 mole %, as well as a variety of carbonaceous compounds, including,

compressing and cooling the CO_2 feed stream to a suitable elevated temperature and superatmospheric pressure;

substantially removing any acid gases present from the CO_2 feed stream;

drying the CO_2 feed stream;

separating the CO_2 feed stream in a single distillation zone, which is primarily externally refrigerated, into:

(a) a light fuel gas stream having a CO_2 concentration sufficiently high to proclude freezing in said distillation zone,

(b) a liquid, substantially CO_2-containing stream of a purity sufficient for use in tertiary oil recovery, and

(c) a heavy hydrocarbon stream;

cooling the light fuel gas stream;

pressurizing and transporting the substantially CO_2-containing liquid stream into a suitable heat exchange zone;

heating the CO_2-containing liquid stream to a suitable temperature to form a suitable product stream;

separating the heavy hydrocarbon stream into a lighter fuel gas stream and a heavier substantially CO_2-free hydrocarbon stream.

2. A process as claimed in claim **1** wherein the acid gas component comprises H_2S, COS, mercapatans, and various mixtures thereof.

3. A process as claimed in claim **1** wherein the carbonaceous compounds present in the CO_2 stream comprise a variety of petroleum-based compounds.

4. A process as claimed in claim **1** wherein the CO_2 feed stream is compressed and cooled to about 450 to 550 psig and 70° to 90° F.

5. A process as claimed in claim **1** wherein the compressed, cooled and acid gas component removed CO_2 feed is further cooled by contacting with a pressurized CO_2-containing liquid product stream in a suitable heat exchange zone.

6. A process as claimed in claim **1** wherein the CO_2 feed stream is dried to about 0 to 2 ppm water by an effective low temperature drying stage.

7. A process as claimed in claim **1** wherein the light fuel gas stream is substantially comprised of butane and lower hydrocarbons maintained at a temperature of about −60° to −70° F. and a pressure of about 400 to 600 psig.

8. A process as claimed in claim **1** wherein the substantially CO_2-containing stream is a liquid sidedraw stream comprising at least about 90 mole % CO_2 maintained at about 20°–30° F. and a pressure of about 400 to 600 psig.

9. A process as claimed in claim **1** wherein the heavy hydrocarbon stream substantially comprises the butanes and heavier hydrocarbons.

10. A process as claimed in claim **1** wherein the distillation zone is externally refrigerated by the utilization of a distillation intercooler unit positioned above the CO_2-containing sidedraw stream withdrawal.

11. A process as claimed in claim **10** wherein the refrigerant for the intercooler unit enters the unit at a temperature of about −10° F.

12. A process as claimed in claim **1** wherein the substantially CO_2-containing liquid stream is substantially stripped of non CO_2 component in an adjacent stripping zone.

13. A process as claimed in claim **1** wherein the light fuel gas stream is prepared for use as a suitable product stream.

14. A process as claimed in claim **1** wherein the CO_2 product stream is maintained at about 800–3500 psig and 30°–60° F.

15. A process as claimed in claim **1** wherein the heavy hydrocarbon stream is separated into a light fuel gas product stream and a heavier hydrocarbon product stream by a suitable distillation stage.

16. A process as claimed in claim **15** wherein the lighter gas product stream is combined with the light

fuel gas stream from the primary distillation zone to form a fuel gas product stream.

17. A process as claimed in claim 1 wherein the CO_2-containing product stream is recycled to underground petroleum formations.

18. A process as claimed in claim 1 wherein the light fuel gas stream is cooled for use as a product by contacting in a suitably refrigerated overhead condenser unit and removing a desired light fuel gas fraction.

* * * * *

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Office de la propriété intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

MAR 3 1 2020

Our file no.: **RX-137/20**

GOWLING WLG (CANADA) LLP
CIPO@gowlingwlg.com

Dear Sir/Madam:

Re: Request for Re-examination of Patent no. **2,949,039**

Title:	**ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS**
Patentee:	PILOT ENERGY SOLUTIONS, LLC
Your file no.:	**K8001075CADIV6**
Requester:	MARKS & CLERK CANADA

A compliant request for the Re-examination of Canadian Patent No. 2,949,039, dated February 26, 2020, has been received.

This request fulfills the requirements of subsections 48.1(1) and (2) of the *Patent Act*.

In compliance with subsection 48.1(3) of the *Patent Act*, please find enclosed a copy of the request together with a copy of the prior art submitted by the requester.

As set forth by subsection 48.2(1) of the *Patent Act*, a Re-examination Board is established comprising:

Stephen MacNeil	William Byrne	Sean Wilkinson
Chairperson	Member	Member

Under subsections 48.2(2) to 48.4 of the *Patent Act*, the Re-examination Board is responsible for all Re-examination proceedings.

Canada

Within three months of the date hereof, the Re-examination Board will give notice of its determination as to whether a substantial new question of patentability is raised by the request.

Yours sincerely,

Johanne Bélisle
Commissioner of Patents, Registrar
of Trademarks and Chief Executive Officer

Enclosure

c.c. **MARKS & CLERK CANADA**
100 Simcoe Street, Suite 200
TORONTO, Ontario
M5H 3G2

June 12, 2020

Our File No: RX-137/20

GOWLING WLG (CANADA) LLP
CIPO@gowlingwlg.com

Dear Sir/Madam:

Re: Request for Re-examination of Patent no. 2,949,039

Title:	ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS
Patentee:	PILOT ENERGY SOLUTIONS, LLC
Your file no:	**K8001075CADIV6**
Requester:	MARKS & CLERK CANADA

In accordance with subsection 48.2(2) of the *Patent Act*, the Re-examination Board ("the Board") has reviewed the request for re-examination of all of issued claims 1-28 of Canadian Patent number 2,949,039 (the "'039 Patent") dated February 26th, 2020. The Board has determined that it raises a substantial new question of patentability with regard to claims 1-28.

Prior Art

In the request for re-examination, the Requester has brought to the attention of the Board the following prior art consisting of the following four (4) documents.

(1) US 4,753,666 (Pastor et al., hereinafter "Pastor");
(2) "Practical Aspects of CO_2 Flooding", Society of Petroleum Engineers (SPE) Monograph Series, vol. 22, (published in 2002) 214 pp. ch. 5;(Jarrell et al., hereinafter "Jarrell");
(3) US 4,428,759 (Ryan et al., hereinafter "Ryan");
(4) US 4,595,404 (Ozero et al., hereinafter "Ozero")

Pastor discloses a process of separating a carbon dioxide recycle stream into a purified carbon dioxide (overhead gas) stream and a natural gas stream (bottoms product) In order to overcome the problems associated with methane/CO_2 distillation, Pastor's process leaves the methane in the overhead gas. To offset the effect of methane in the overhead gas, H_2S, ethane, propane and a portion of butane remain in

the overhead gas. The separation process of Pastor does not teach utilizing cryogenics or membranes.

Jarrell discloses processing steps used at each stage of a CO_2 flooding process, beginning with generating a production stream at the "production well", separating the production stream into an oil (i.e. heavy hydrocarbon) -containing stream and a gas stream, separating the gas stream into a recovered carbon dioxide stream and a natural gas liquids stream, and reinjecting the recovered carbon dioxide stream into the "injection well". An oil stream and a natural gas liquids stream are sold as "oil sales" and "NGL sales", respectively.

Ryan discloses a process of separating a carbon dioxide recycle stream into a purified carbon dioxide (overhead gas) stream and a natural gas stream (bottoms product). Ryan's process teaches a distillative technique involving recycling a small portion of a bottom product stream of a second distillation column, typically a C_3 to C_6 stream, to a first distillation column, wherein the overhead stream is not significantly contaminated by the recycled bottom product stream, to adjust column operating conditions and effect energy savings.

Ozero pertains to a process for regeneration of a carbon dioxide gaseous stream such used in a carbon dioxide miscibility flood process. Ozero's process dehydrates the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

The prior prosecution of the granted '039 Patent

The *Manual of Patent Office Practice*, revised December 2015 (CIPO) at §30.01.02 states that:

> In order to raise a substantial new question of patentability the request must present an issue relating to the validity of one or more claims that was not previously considered during the prosecution of the application that resulted in the patent for which re-examination has been requested, and that was not considered during any other prior proceeding involving the patent. The issue must also not be so closely related to one previously considered such that it is not a substantial new question.
>
> A substantial new question of patentability is most often raised by prior art that was not on record during the original prosecution. However, if prior art is so similar to that which was considered during examination that it would be applied in the same manner, there would not be any material effect on the record and substantial new question of patentability would not be established. [Emphasis in original]

During the original prosecution of the '039 Patent, US Patent no. 4,563,202 was cited as showing a lack of novelty of then pending claims 18, 20-21 and 23 in an office action dated September 22, 2017. In

response, the then Applicant (now Patentee) amended the application to cancel claims 18, 20-21 and 23, after which the patent was granted.

The Board notes that US Patent no. 4,563,202 has not been submitted with the request for examination of the '039 Patent and in light of the amendments made during prosecution of the application, claims of the scope of cancelled claims 18, 20-21 and 23 are not part of the granted '039 Patent. Therefore, it is our view that the prior prosecution of the '039 Patent does not preclude the establishment of a substantial new question of patentability by the request for examination filed February 26, 2020.

Claim Construction

Claims construction is antecedent to considerations of both validity and infringement issues. (*Whirlpool Corp v Camco Inc,* 2000 SCC 67 at para 43 [*Whirlpool*]).

Person Skilled in the Art

A patent is not addressed to an ordinary member of the public, but to a worker skilled in the art described as:

> a hypothetical person possessing the ordinary skill and knowledge of the particular art to which the invention relates, and a mind willing to understand a specification that is addressed to him. This hypothetical person has sometimes been equated with the "reasonable man" used as a standard in negligence cases. He is assumed to be a man who is going to try to achieve success and not one who is looking for difficulties or seeking failure.

The skilled person to whom the patent is addressed is deemed to be unimaginative and uninventive, but at the same time is understood to have an ordinary level of competence and knowledge incidental to the field to which the patent relates and to be reasonably diligent in keeping up with advances (*AstraZeneca Canada Inc v Apotex Inc,* 2014 FC 638 at para 51). The person skilled in the art may also be a team of people (P*fizer Canada Inc v Pharmascience Inc*, 2013 FC 120 at para 28).

In the Board's preliminary view, the person skilled in the art is a person or team skilled and knowledgeable in the field of oil and gas production and carbon dioxide recovery and reinjection.

Common General Knowledge

The skilled person is considered to be equipped with the common general knowledge; that is, the subset of the prior art that is generally known by persons skilled in the relevant art at the relevant time (*Sanofi-Synthelabo Canada Inc v Apotex Inc*, 2008 SCC 61 [*Sanofi*] at para 37.

In the Board's preliminary view, it considers that the relevant common general knowledge of the notional person skilled in the art includes:

- the knowledge of injecting carbon dioxide to enhance recovery of heavy hydrocarbons;

- the knowledge of separation methods and equipment used for isolating carbon dioxide, NGL and heavy hydrocarbons from a hydrocarbon feed stream;
- the knowledge of the varying composition of the hydrocarbon feed stream.

Analysis of the Claims

In *Whirlpool* at paragraph 44, the Supreme Court of Canada stated that claims should be given a purposive construction:

> ... A patent specification should be given a purposive construction rather than a purely literal one derived from applying to it the kind of meticulous verbal analysis in which lawyers are too often tempted by their training to indulge. The question in each case is: whether persons with practical knowledge and experience of the kind of work in which the invention was intended to be used, would understand that strict compliance with a particular descriptive word or phrase appearing in a claim was intended by the patentee to be an essential requirement of the invention so that any variant would fall outside the monopoly claimed, even though it could have no material effect upon the way the invention worked.

Claim no. 1 of the '039 Patent states at line 14:

> separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream, wherein the sweet NGL rich stream includes the substantially all of the C_3-C_8 hydrocarbons in the source NGL rich stream. [Emphasis added]

In the Board's preliminary view, the scope of the phrase "source NGL rich stream" is not evident from the claim language itself. It is not clear if the stream is a new stream or if an error has occurred and the stream is the sour NGL rich stream. However, we take the reference to "source NGL rich stream" to be an error. It is our preliminary view that this should have referred to "sour NGL rich stream."

Claim no. 2 of the '039 Patent states:

> 2. A method comprising:
> receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and
> separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,
> wherein the purified carbon dioxide recycle stream includes the carbon dioxide,
> wherein the natural gas liquids stream includes the natural gas liquids, and
> wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream. [Emphasis added]

In the Board's preliminary view, the scope of the phrase "natural gas liquids stream" is not evident from the claim language itself.

The specification of the '039 Patent teaches:
Pg. 4, lines 2-7

> The term "natural gas liquids" or NGLs may refer to natural gases that may be liquefied without refrigeration, and may include C_3 -C_8 hydrocarbons. Both natural gas and NGL are terms known in the art and are used herein as such. In contrast, the term "heavy hydrocarbons" may refer to any hydrocarbon that may exist in a liquid phase under atmospheric or downhole conditions, and generally includes liquid crude oil, which may comprise C_9+ hydrocarbons, branched hydrocarbons, aromatic hydrocarbons, and combinations thereof.

It is the preliminary view of the Board that the abovementioned phrase can be understood as teaching the person skilled in the art that any of the C_3-C_8 hydrocarbons ***may*** be considered an NGL.

In the Board's preliminary view, the scope of the phrase "cryogenic conditions" is not evident from the claim language itself or the specification.

The dictionary definition of Cryogenic is defined as from −150 °C (−238 °F) to absolute zero (−273 °C or −460 °F), the temperature at which molecular motion comes as close as theoretically possible to ceasing completely.

It is the preliminary view of the Board that the abovementioned phrase can be understood as teaching the person skilled in the art that a cryogenic process occurs at temperatures from −150 °C (−238 °F) to absolute zero (−273 °C or −460 °F).

Further, in our assessment of obviousness below, all the elements of the claims have been considered to be essential and taken into account.

Substantial New Question of Patentability

Novelty

Principles of Law

The admissibility of prior art in assessing novelty is set out in subsection 28.2(1) of the *Patent Act*.

In *Sanofi* at paragraphs 24-27 and 33-37, the Supreme Court stated that in order to be anticipatory, a single piece of prior art must both:

- disclose the invention of the patent in question; and
- enable a skilled reader to make the invention using the prior art reference and common knowledge, allowing for some (uninventive and not unduly burdensome) trial and error experimentation to make it work.

Analysis of the Claims

It is the preliminary opinion of the Board that claims 2,3,8,10-13,16,18,21,22 and 27 encompass subject-matter disclosed in the prior art before the claim date and do not comply with paragraph 28.2(1)(*b*) of the Patent Act.

Novelty in view of Pastor

Pastor discloses all the elements of claims 2,3,8,10-13,16,18,21,22 and 27 as established below.

With regard to claim 2, Pastor teaches a method comprising: receiving a carbon dioxide recycle stream(CO_2 gas stream 25), wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids(column 3, line 51 - the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons"); and separating the carbon dioxide recycle stream(distillation column 3 separates the CO_2 gas stream 25) into a purified carbon dioxide recycle stream(overhead product stream 21) and a natural gas liquids stream(bottoms product 26), wherein the purified carbon dioxide recycle stream includes the carbon dioxide, wherein the natural gas liquids stream includes the natural gas liquids(column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons'; see above Claim Construction issue, an NGL ***may*** be any of C_3-C_8), and wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions (Pastor does not subject any stream to cryogenic conditions(see above Claim Construction issue); furthermore Pastor does not describe isolating either methane or ethane, for which cryogenic conditions are conventionally used; additionally, Pastor utilizes propane as a refrigerant for condenser 7 (see column 4 line 29), and propane refrigerant is not considered to provide cryogenic conditions), membranes(Pastor does not mention using membranes), and carbon dioxide recovery solvents(Pastor does not use solvents in the process; the background section of Pastor discusses solvent use as being problematic, see column 1, lines 47 to 55) between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

With regard to the additional features of claim 3, Pastor teaches that the carbon dioxide recycle stream comprises natural gas(column 3, line 51 - the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons"; and TABLE I, "feed", which contains C_1 and C_2), and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream(column 3, line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons').

With regard to the additional features of claim 8, Pastor teaches that separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises: receiving the carbon dioxide recycle stream at a separation column (CO_2 gas stream 25 is received at distillation column 3); reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler (reboiler 5) to generate the natural gas liquids stream (column 4, line 14 -" The bottom portion of the column is equipped with a reboiler 5 ... the bottoms product 26 flows from the bottom of the column"); and condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream (column 4 line 27 to 29 - "the overhead vapors 10 flow to an overhead condenser 7 which cools and

partially condenses the overhead vapors", condenser 7 operates in tandem with reflux drum 19 to yield the overhead product stream 21).

With regard to claim 10, Pastor teaches a system comprising: piping configured to receive a recycle stream($C0_2$ gas stream 25), wherein the recycle stream includes an injection gas(column 3, lines 47 to 49- system is for treatment of a "hydrocarbon rich CO_2 gas for injection into an oil bearing formation") and C_3 to C_8 hydrocarbons(column 3, line 51- the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons; and TABLE I, which shows the "feed" containing CO_2 and C_3 to C_7+); and a separator coupled to the piping and configured to separate the recycle stream(distillation column 3 separates the CO_2 gas stream 25) into a purified recycle stream(overhead product stream 21) and a natural gas liquids stream(bottoms product 26, and column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons"), wherein the purified recycle stream includes the injection gas (TABLE I, which shows "overhead product" containing the CO_2), wherein the natural gas liquids stream includes the C_3-C_8 hydrocarbons(TABLE I, showing "bottoms product" containing C_3 to C_7+), and wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions (Pastor does not subject any stream to cryogenic conditions(see above Claim Construction issue); furthermore Pastor does not describe isolating either methane or ethane, for which cryogenic conditions are conventionally used; additionally, Pastor utilizes propane as a refrigerant for condenser 7 (see column 4 line 29), and propane refrigerant is not considered to provide cryogenic conditions), membranes(Pastor does not mention using membranes), and carbon dioxide recovery solvents(Pastor does not use solvents in the process; the background section of Pastor discusses solvent use as being problematic, see column 1, lines 47 to 55) between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

With regard to the additional features of claim 11, Pastor teaches that the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water (column 3, lines 47 to 49 - " ... a hydrocarbon rich CO_2 gas for injection into an oil-bearing formation").

With regard to the additional features of claim 12, Pastor teaches that the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column (distillation column 3 is a separation column).

With regard to the additional features of claim 13, Pastor teaches that the recycle stream (CO_2 gas stream 25) comprises C_1 to C_2 hydrocarbons (column 3 lines 51 to 53 - 'the feed stream may contain a mixture of carbon dioxide, methane, ethane ... "), and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream (TABLE I, showing "overhead product" containing C_1 to C_2).

With regard to the additional features of claim 16, Pastor teaches that the separator comprises a separation column(distillation column 3 is a separation column), a reboiler (reboiler 5), and a condenser(condenser 7), wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream (column 4, line 14 "The bottom portion of the column is equipped with a reboiler 5 ... the bottoms product 26 flows from the bottom of the column"), and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream(condenser 7 operates in tandem with reflux drum 19 to yield the overhead product stream 21).

With regard to claim 18, Pastor teaches a method comprising: receiving a carbon dioxide recycle stream(CO_2 gas stream 25), wherein the carbon dioxide recycle stream includes carbon dioxide, natural

gas, and natural gas liquids(column 3, line 51 - the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons ... "); and separating the carbon dioxide recycle stream (distillation column 3 separates the CO_2 gas stream 25) into a purified carbon dioxide recycle stream(overhead product stream 21) and a natural gas liquids stream (bottoms product 26), wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas(TABLE 1, showing "overhead product" containing CO_2, C_1 and C_2), wherein the natural gas liquids stream comprises the natural gas liquids, wherein the natural gas comprises C_1 to C_2 hydrocarbons, and wherein the natural gas liquids comprise C_3-C_8 hydrocarbons(TABLE 1, showing "bottoms product" containing C_3 to C_7+).

With regard to claim 21, Pastor teaches a set of process equipment configured to: receive a carbon dioxide recycle stream (stream 25), wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids (column 3, line 51 - the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons ... "); and separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream (overhead product stream 21) and a natural gas liquids stream(bottoms product 26), wherein the purified carbon dioxide recycle stream includes the carbon dioxide, wherein the natural gas liquids stream includes the natural gas liquids (column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons"), and wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions (Pastor does not subject any stream to cryogenic conditions(see above Claim Construction issue); furthermore Pastor does not describe isolating either methane or ethane, for which cryogenic conditions are conventionally used; additionally, Pastor utilizes propane as a refrigerant for condenser 7 (see column 4 line 29), and propane refrigerant is not considered to provide cryogenic conditions), membranes(Pastor does not mention using membranes), and carbon dioxide recovery solvents(Pastor does not use solvents in the process; the background section of Pastor discusses solvent use as being problematic, see column 1, lines 47 to 55) between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

With regard to the additional features of claim 22, Pastor teaches that the carbon dioxide recycle stream comprises natural gas(column 3, line 51 - the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons"; and TABLE I, "feed", which contains C_1 and C_2), and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream(column 3, line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons").

With regard to the additional features of claim 27, Pastor teaches that separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises: receiving the carbon dioxide recycle stream at a separation column (CO_2 gas stream 25 is received at distillation column 3); reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler (reboiler 5) to generate the natural gas liquids stream (column 4, line 4 –"The bottom portion of the column is equipped with a reboiler 5 ... the bottoms product 26 flows from the bottom of the column"); and condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream (column 4 line 27 to 29 - "the overhead vapors 10 flow to an overhead condenser 7 which cools and partially condenses the overhead vapors", condenser 7 operates in tandem with reflux drum 19 to yield the overhead product stream 21).

Obviousness

Principles of Law

Section 28.3 of the *Patent Act* sets out the conditions under which a claim may be found to be obvious:

> 28.3 The subject-matter defined by a claim in an application for a patent in Canada must be subject-matter that would not have been obvious on the claim date to a person skilled in the art or science to which it pertains, having regard to
>
> (*a*) information disclosed more than one year before the filing date by the applicant, or by a person who obtained knowledge, directly or indirectly, from the applicant in such a manner that the information became available to the public in Canada or elsewhere; and
>
> (*b*) information disclosed before the claim date by a person not mentioned in paragraph (a) in such a manner that the information became available to the public in Canada or elsewhere.

Pursuant to paragraph 28.3(*b*), a patent claim will be invalid if, based on information that was available to the public before the claim date, its subject-matter would have been obvious to a person skilled in the art or science to which it pertains. In *Sanofi* at paragraph 67, the Supreme Court of Canada outlines a four-step approach to be followed when assessing obviousness:

> (1) Identify (a) the notional "person skilled in the art"; and (b) the relevant common general knowledge of that person;
>
> (2) Identify the inventive concept of the claim in question or if that cannot readily be done, construe it;
>
> (3) Identify what, if any, differences exist between the matter cited as forming part of the "state of the art" and the inventive concept of the claim or the claim as construed; and
>
> (4) Viewed without any knowledge of the alleged invention as claimed, do those differences constitute steps which would have been obvious to the person skilled in the art or do they require any degree of invention?

This approach has been applied in the following analysis.

Analysis of the Claims

(1) Identify (a) the notional "person skilled in the art"; and (b) the relevant common general knowledge of that person.

For the purposes of the assessment of obviousness, the person skilled in the art in step 1(a) is as discussed above in respect of claim construction. Likewise, the common general knowledge in step 1(b) is as defined in the context of claim construction. The Board also notes that the critical date for obviousness is the claim date, whereas for claim construction it is the publication date.

(2) Identify the inventive concept of the claim in question or if that cannot readily be done, construe it

For the purposes of the assessment of obviousness, the Board has taken into account the combination of features of all of issued claims 1-28.

(3) Identify what, if any, differences exist between the matter cited as forming part of the "state of the art" and the inventive concept of the claim or the claim as construed

It is the Board's preliminary opinion that the following differences are present between independent claims 1,19,20 and the state of the art, as presented by Pastor or Jarrell or Ryan:

- Pastor does not teach separating a feed stream into the carbon dioxide recycle stream and a heavy hydrocarbon stream, wherein the heavy hydrocarbon stream includes C_8+ hydrocarbons;
- Jarrell does not teach separating the carbon dioxide recycle stream into a sour NGL rich stream and a purified carbon dioxide recycle stream, or separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream; and
- Ryan does not teach a feed stream, wherein the feed stream includes carbon dioxide, C_1 to C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_8+ hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons; or separating the feed stream into a heavy hydrocarbon stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon stream includes substantially all of the C_8+ hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream.

The differences with respect to the dependent claims will be addressed below at step 4 after consideration of the independent claims.

(4) Viewed without any knowledge of the alleged invention as claimed, do those differences constitute steps which would have been obvious to the person skilled in the art or do they require any degree of invention?

Obviousness with respect to **Jarrell , in view of Ryan**

In our preliminary view, claim 1 does not comply with section 28.3 of the *Patent Act*. This claim is directed to subject-matter that would have been obvious at the claim date to a person skilled in the art or science to which it pertains with respect to Jarrell, in view of Ryan.

With regards to claim 1, Jarrell teaches a method comprising: receiving a hydrocarbon feed stream (Figure 5.1, stream output by "producer"), wherein the hydrocarbon feed stream includes carbon dioxide, natural gas liquid (NGL), and heavy hydrocarbons, wherein the NGL includes C_3-C_8 hydrocarbons, and wherein the heavy hydrocarbons include C_9+ hydrocarbons (Figure 5. 1, stream output by "producer" would contain carbon dioxide and a wide range of hydrocarbons, including C_3 to C_8+); separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream (Figure 5.1, stream at "oil sales", and Figure 5.4, stream at "oil sales") and a carbon dioxide recycle stream (Figure 5.1, stream entering "CO_2

extraction plant"), wherein the heavy hydrocarbon rich stream includes most of the C_9+ hydrocarbons in the hydrocarbon feed stream, and wherein the carbon dioxide recycle stream includes most of the carbon dioxide and most of the C_3-C_8 hydrocarbons in the hydrocarbon feed stream(Figure 5.1, stream at "oil sales" would include most of C_9+ hydrocarbons, and stream at "CO_2 extraction plant" would include most of the carbon dioxide and most of the C_3-C_8 hydrocarbons); combining a carbon dioxide makeup stream from a source external to the method with the purified carbon dioxide recycle stream (Fig. 5.1, "CO_2 point delivery"); and subsequently injecting the combined carbon dioxide makeup stream and the purified carbon dioxide recycle stream into a subterranean formation (Figure 5.1, "CO_2 injection"), wherein the hydrocarbon feed stream and the carbon dioxide recycle stream, are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the heavy hydrocarbon rich stream, the purified carbon dioxide recycle stream, and the carbon dioxide rich stream(5.5.1-5.5.3 teach alternatives that do not require cryogenic conditions, membranes and solvents), wherein the carbon dioxide is not removed from the hydrocarbon feed stream and is not removed from the carbon dioxide recycle stream prior to CO_2 Extraction plant (Figure 5. 1 does not show net removal of CO_2 between "Production Well" and "CO_2 Extraction plant').

Jarrell does not explicitly teach separating the carbon dioxide recycle stream into a sour NGL rich stream and a purified carbon dioxide recycle stream, or separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream. Jarrell does teach that sweet gas is produced from the CO_2 Extraction Plant (see "Sweet Gas" line at the "CO_2 Extraction Plant" in Figure 5.1).

Ryan discloses distilling a carbon dioxide recycle stream that "is derived from one or more prior separation processes"(column 5, lines 53-57). Ryan teaches separating the carbon dioxide recycle stream (distillative column 14 separates line 12)into a sour NGL rich stream (line 32) and a purified carbon dioxide recycle stream (line 20), wherein the sour NGL rich stream includes some of the C_3-C_8 hydrocarbons in the carbon dioxide recycle stream(column 6, lines 7 to 9 "the bottom product stream, containing C_2+ and the C_3-C_6 additive and hydrogen sulfide, is withdrawn through line 32"), and wherein the purified carbon dioxide recycle stream includes most of the carbon dioxide in the carbon dioxide recycle stream (column 5 lines 65 to 66 "an enriched carbon-dioxide overhead product stream is removed overhead through line 20"); separating the sour NGL rich stream (distillative column 38 separates line 32) into a sweet NGL rich stream (line 60, TABLE 1, bottoms stream 60 contains no H_2S and is therefore sweet) and a carbon dioxide rich stream(line 44), wherein the sweet NGL rich stream includes the substantially all of the C_3-C_8 hydrocarbons in the source NGL rich stream(column 6 lines 19 to 24 "bottom product stream containing the C_3 -C_6 additive agent is removed through line 48 into a reboiler 50, where a portion is recycled through line 52 to the bottom of the column, while another portion is removed by line 60"), and wherein the carbon dioxide rich stream includes substantially all of the carbon dioxide in the sour NGL rich stream (TABLE 1, "overhead stream 44" contains all CO_2 of feed stream 36);, and wherein the carbon dioxide recycle stream, and the sour NGL rich stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the heavy hydrocarbon rich stream, the purified carbon dioxide recycle stream, the sweet NGL rich stream, and the carbon dioxide rich stream (No cryogenic conditions, membranes or solvents are taught).

Ryan teaches distilling a carbon dioxide recycle stream that "is derived from one or more prior separation

processes" (column 5, lines 53-57) and Jarrell teaches a separation process that results in a carbon dioxide recycle stream. While Jarrell provides a high-level disclosure of CO_2 injection processes, in practising such processes the skilled person would look to specific examples of the individual stages and Ryan provides a specific example of a distillation process. It would have been obvious to look to such a reference to provide a working system and to improve the extraction of CO_2 from the process of Jarrell by utilizing the double CO_2 extraction process.

Therefore, it is the Board's preliminary view that it would have been obvious to a person skilled in the art to utilize the CO_2 extraction method of Jarrell with the double CO_2 extraction process taught in Ryan.

Obviousness with respect to **Pastor, in view of Ryan**

The requester alleges that claims 4,5,14,23 and 24 do not comply with section 28.3 of the *Patent Act* as the subject-matter would have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to document Pastor in view of Ryan.

In our preliminary review, with regard to claims 4-5 and 23-24, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with Ryan. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with methane/CO_2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping H_2S in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13). The removal of the H_2S gas from the purified carbon dioxide recycle stream would result in a decrease in the miscibility of the recycle stream and limit the recycle gases injection effectiveness. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of Ryan.

In our preliminary review, with regard to claims 14, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with Ryan. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with methane/CO_2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping H_2S in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13; Table 1 does not teach any H_2S in the Bottoms Product (NGL)). Since there is no acid in the NGL steam, there is no need to add an acid removal step. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of Ryan.

Obviousness with respect to **Pastor, in view of Ozero**

In our preliminary view, claims 6,7,25 and 26 do not comply with section 28.3 of the *Patent Act*. These claims are directed to subject-matter that would have been obvious at the claim date to a person skilled in the art or science to which it pertains with respect to Pastor, in view of Ozero.

With regard to the additional features of claims 6 and 25, Pastor does not teach dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

Ozero also teaches dehydrating the carbon dioxide recycle stream (stream 10) before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids

stream (Figure 1, feed gas stream 10 is dehydrated in dryer unit 22 before being separated into a purified carbon dioxide recycle stream and a natural gas liquids stream).

A person skilled in the art, looking to increase the efficiency of the CO_2/NGL separation of Pastor, would look to the teachings of Ozero to remove water from the feed stream prior to separation. Therefore, it is the Board's preliminary view that it would have been obvious to a person skilled in the art to utilize the dehydration process taught in Ozero with the CO_2 extraction method of Pastor.

With regard to the additional features of claims 7 and 26, Pastor teaches compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream(column 2, lines 55-57). Pastor does not teach adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

Ozero teaches compressing the carbon dioxide recycle stream [stream 10] before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream (Figure 1, feed gas stream 10 is compressed by feed gas compressor unit 12 prior to being separated into CO_2 product stream 20 and NGL-containing bottoms stream 64); and adding additional carbon dioxide to the purified carbon dioxide recycle stream (CO_2 product stream 20) to form a carbon dioxide injection stream (column 5 lines 10 to 18 - CO_2 product stream 20 "is preferably mixed with fresh CO_2 before being reinjected into the petroleum-bearing subsurface).

A person skilled in the art, looking to increase the efficiency of the CO_2/NGL separation of Pastor, would look to the teachings of Ozero to add additional carbon dioxide to the purified carbon dioxide stream in order to compensate for carbon dioxide sequestration that inevitably occurs in the carbon dioxide miscibility flood process. Therefore, it is the Board's preliminary view that it would have been obvious to a person skilled in the art, to utilize the additional carbon dioxide stream as taught in Ozero with the CO_2 extraction method of Pastor.

Obviousness with respect to **Pastor in view of the general common knowledge**
The requester alleges that claims 9,17 and 28 do not comply with section 28.3 of the *Patent Act* as the subject-matter would have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to document Pastor in view of the general common knowledge.

In our preliminary review, with regard to claims 9,17 and 28, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with the adjusted C_3 amounts identified as common general knowledge. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with methane/CO_2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping C_3 (propane) in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13; Table 1 teaches substantially all of the C_3(propane) is located in the overhead gas). Adjusting the amount of C_3(propane), so that the amount of C_3 in the NGL stream is greater than the amount of C_3 in the purified carbon dioxide recycle stream hydrocarbons would result in a decrease in the miscibility of the recycle stream and limit the recycle gases injection effectiveness. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of general common knowledge.

Obviousness with respect to **Pastor, in view of Jarrell**

In our preliminary view, claims 15 and 19 do not comply with section 28.3 of the *Patent Act*. These claims are directed to subject-matter that would have been obvious at the claim date to a person skilled in the art or science to which it pertains with respect to Pastor, in view of Jarrell.

With regard to the additional features of claim 15, Pastor does not teach separating the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_9+ hydrocarbons; and dehydrating the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

Jarrell teaches receiving a feed stream (Figure 5. 1, stream output by "producer'); separating the feed stream into the recycle stream and a heavy hydrocarbons stream (Figure 5. 1, stream at "oil sales", and Figure 5.4, stream at "oil sales'), wherein the heavy hydrocarbons stream includes C_9+ hydrocarbons (Figures 5. 1 and 5.4, streams at "oil sales" would include C9+ hydrocarbons); and dehydrating the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream (Figure 5.1, "production separators", which separate out "water and oil", and see Section 5.5.1, "four basic chemical products are used to dehydrate gas: glycol, calcium chloride, glycerol and solid dessicants"; glycol is considered in the art to be the predominant dehydration solvent; see also Figure 5.8, showing "dehydrator" positioned directly upstream from "NGL column" separator).

A person skilled in the art, looking to increase the efficiency of the CO_2/NGL separation of Pastor, would look to the teachings of Jarrell to provide a carbon dioxide miscibility flood process in which CO_2 is separated from NGL liquids in a cost-effective manner by using a single distillation tower, and in which water is removed prior to CO_2-NGL separation to improve the efficiency of the $C0_2$-NGL separation. Jarrell also provides a more complete view of a CO_2 flooding process, including the initial known separation of CO_2 recycle and heavy hydrocarbon streams. Therefore, it is the Board's preliminary view that it would have been obvious to a person skilled in the art, to utilize the CO_2 extraction method of Pastor with the process taught in Jarrell.

With regard to claim 19, Pastor teaches a method comprising: receiving a carbon dioxide recycle Stream (stream 25), wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids(column 3, line 51- the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons"); separating the carbon dioxide recycle stream (distillation column 3 separates stream 25)into a purified carbon dioxide recycle stream(overhead product stream 21) and a natural gas liquids stream (bottoms product 26), wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids (column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons").

Pastor does not explicitly teach that the carbon dioxide recycle stream originates from separating a feed stream into the carbon dioxide recycle stream and a heavy hydrocarbon stream, wherein the heavy

hydrocarbon stream includes C_9+ hydrocarbons. Pastor teaches that it is known in the art to use multiple recovery methods to maximize petroleum recovery (column 1, lines 14-22).

Jarrell teaches that it is known in the art to separate the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a carbon dioxide recycle stream (Figure 5.1, stream at "oil sales"), wherein the heavy hydrocarbon stream includes C_9+ hydrocarbons (Figure 5.1, the heavy hydrocarbon stream at "oil sales" would include C_9+ hydrocarbons). Jarrell provides a more complete view of the gas processing steps of a CO_2 flooding process in which a system such as that of Pastor would be used.

A person skilled in the art, looking to apply the teachings of Pastor in the complete CO_2 flooding context, would look to the teachings of Jarrell. Therefore, it is the Board's preliminary view that it would have been obvious to a person skilled in the art to utilize the carbon dioxide recycle stream created from Jerrell with the process taught in Pastor.

Obviousness with respect to **Ryan , in view of Jarrell**

In our preliminary view, claim 20 does not comply with section 28.3 of the *Patent Act*. This claim is directed to subject-matter that would have been obvious at the claim date to a person skilled in the art or science to which it pertains with respect to Ryan, in view of Jarrell and the relevant common general knowledge of the said person.

With regard to claim 20, Ryan teaches receiving a carbon dioxide recycle stream (line 152), wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids (column 10 line 59, "a feed stream, consisting essentially of CO_2, ethane and C_3+, is introduced by line 152"); separating the carbon dioxide recycle stream (distillation column 150 separates line 152) into a purified carbon dioxide recycle stream (line 160) and a natural gas liquids stream (line 168), wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas (column 10 line 66, "a mixture, composed essentially of CO_2 and ethane, is removed as an overhead product stream by line 160"), and wherein the natural gas liquids stream (line 168) comprises the natural gas liquids (column 11 line 2, "a bottom product stream, comprising primarily propane, together with any recycled liquid additive agent introduced into the condenser or upper part of the column 150, is withdrawn by line 168"), wherein the purified carbon dioxide recycle stream (line 160) includes substantially all of the C_2 hydrocarbons from the carbon dioxide recycle stream (TABLE VII, showing "overhead stream 160" containing all of C_2 in "feed stream 152") and the natural gas liquids stream (line 168) includes substantially none of the C_2 hydrocarbons from the carbon dioxide recycle stream (TABLE VII, showing "bottom stream 168" containing no C_2), and wherein the purified carbon dioxide recycle stream (line 160) includes substantially none of the C_3 hydrocarbons from the carbon dioxide recycle stream (TABLE VII, showing "overhead stream 160" containing only about 10% of C_3 in "feed stream 152") and the natural gas liquids stream includes substantially all of the C_3 hydrocarbons from the carbon dioxide recycle stream (TABLE VII, showing "bottom stream 168" containing about 90% of C_3 in "feed stream 152"). It would have been obvious to modify the operating conditions of Ryan, such as lowering the operating temperature of reboiler 164 or condenser 156, to increase the amount of C_3 in the bottom stream 168 to near 100% to increase the yield of C_3 in propane output line 182).

Ryan does explicitly teach receiving a feed stream, wherein the feed stream includes carbon dioxide, C_1 to

C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_9+ hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons; or separating the feed stream into a heavy hydrocarbon stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon stream includes substantially all of the C_9+ hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream. However, Ryan does teach that "the feed stream is derived from one or more prior separation processes" (see column 5, lines 53 to 57).

Jarrell teaches receiving a feed stream (Figure 5.1, stream output by "producer"), wherein the feed stream includes carbon dioxide, C_1 to C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_9+ hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons (Figure 5.1, these hydrocarbons would all be present in stream output by "producer'). Jarrell also teaches separating the feed stream into a heavy hydrocarbon stream (Figure 5. 1, stream at "oil sales", and Figure 5.4, stream at "oil sales") and a carbon dioxide recycle stream (Figure 5. 1, stream at "CO_2 extraction plant'), wherein the heavy hydrocarbon stream includes substantially all of the C_9+ hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream (Figure 5. 1, heavy hydrocarbon stream at "oil sales" would include substantially all of the C_9+ hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons), wherein the heavy hydrocarbon stream includes substantially none of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream (Figures 5. 1 and 5.4, streams at "oil sales" would have this composition), and wherein the carbon dioxide recycle stream includes substantially all of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream (Figure 5.1, stream at "CO_2 extraction plant" would have this composition). Jarrell provides a more complete view of the gas processing steps of a CO_2 flooding system, including the prior separation processes discussed in Ryan.

A person skilled in the art, looking to implement the teachings of Ryan in an overall CO_2 flooding context, would look to the teachings of Jarrell. Therefore, it is the Board's preliminary view that it would have been obvious to a person skilled in the art, to utilize the carbon dioxide recycle stream created from Jerrell with the process taught in Ryan.

Conclusion

The Board is of the preliminary opinion that claims 2,3,8,10-13,16,18,21,22 and 27 lack novelty and do not comply with section 28.2 of the Patent Act. Further, the Board is of the preliminary opinion that claims 1,6,7,15,19,20,25 and 26 lack an inventive step and do not comply with section 28.3 of the *Patent Act*. In view of the results of this assessment, a substantial new question of patentability is raised with respect to these claims.

Responses

If the Patentee wishes to propose new or amended claims in response to this letter, then in accordance with section 123 of the *Patent Rules*, they must be numbered consecutively in Arabic numerals, beginning with the number immediately following the number of the last claim of the issued patent.

Under Subsection 48.2(5) of the *Patent Act*, the Patentee may, within 3 months from the date of the notice, respond with a submission to the Board.

Stephen MacNeil	Member	Member
Member	William Byrne	Sean Wilkinson

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General Correspondence (Patent)

008
RS

Date: September 11, 2020 2:40:13 PM

Application Number

2949039

Title of invention

ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS

Applicant(s) or Inventor Name(s)

Applicant or Inventor Name

Sender

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Correspondence Instructions

In response to the Letter from the Re-examination Board (Report) dated June 12, 2020 concerning the Request for Re-Examination of Patent Number 2,949,039 issued March 12, 2019, kindly amend this application as follows:

Please replace the claim pages currently on file with claim pages 53 to 61 containing claims 29 to 51, enclosed herewith. A marked up version of the original set of claims is also being submitted.

Date Reçue/Date Received 2020-09-11
file:///ecprint-prod.ic.gc.ca/patdata/ec/patent/inbasket/ToBeStamped/pgc_IPWaterloo_20200911144013479_7203599615830106295.html[2020-09-14 7:55:03 AM]

Reconsideration of the Patent is kindly requested having regard to the foregoing amendments and the enclosed comments.

Applicant respectfully requests consideration of the above submission and allowance of claims 29 through 51. Pursuant to the Examiner's requisition under Subsection 48.2(2) of the Patent Act, Patentee has provided the above amendments and/or arguments to address the defects alleged by the Re- Examination Board. It is respectfully submitted that the application complies with the Patent Act and Rules.

Early and favourable consideration of this patent is respectfully requested.

Description of Fee

No fee has been entered.
Total Fee Payment: $0.00

Payment method

No Charge

Attachments

1. K8001075CADIV6_-_Response_to_re-exam_report_2020JUN12.pdf
Other

2. K8001075CADIV6_-_Claims_with_tracked_changes.pdf
Other

3. K8001075CADIV6_-_Amended_claims_for_response_to_re-exam_report_2020JUN12.pdf
Other

Transmission Identifier: pgc_IPWaterloo_20200911144013479

Date: September 11, 2020 2:40:13 PM

Commissioner of Patents
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Gatineau, Quebec
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Application Number: 2949039
Title of invention: ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS
Applicant(s) or Inventor(s) Name(s): PILOT ENERGY SOLUTIONS, LLC
PILOT ENERGY SOLUTIONS, LLC
Reference Number: K8001075CADIV6

Date Reçue/Date Received 2020-09-11
file:///ecprint-prod.ic.gc.ca/patdata/ec/patent/inbasket/ToBeStamped/pgc_IPWaterloo_20200911144013479_7203599615830106295.html[2020-09-14 7:55:03 AM]

Instructions: In response to the Letter from the Re-examination Board (Report) dated June 12, 2020 concerning the Request for Re-Examination of Patent Number 2,949,039 issued March 12, 2019, kindly amend this application as follows:

Please replace the claim pages currently on file with claim pages 53 to 61 containing claims 29 to 51, enclosed herewith. A marked up version of the original set of claims is also being submitted.

Reconsideration of the Patent is kindly requested having regard to the foregoing amendments and the enclosed comments.

Applicant respectfully requests consideration of the above submission and allowance of claims 29 through 51. Pursuant to the Examiner's requisition under Subsection 48.2(2) of the Patent Act, Patentee has provided the above amendments and/or arguments to address the defects alleged by the Re- Examination Board. It is respectfully submitted that the application complies with the Patent Act and Rules.

Early and favourable consideration of this patent is respectfully requested.

Attached are the following documents:
1. K8001075CADIV6_-_Response_to_re-exam_report_2020JUN12.pdf

Other
2. K8001075CADIV6_-_Claims_with_tracked_changes.pdf

Other
3. K8001075CADIV6_-_Amended_claims_for_response_to_re-exam_report_2020JUN12.pdf

Other

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file:///ecprint-prod.ic.gc.ca/patdata/ec/patent/inbasket/ToBeStamped/pgc_IPWaterloo_20200911144013479_7203599615830106295.html[2020-09-14 7:55:03 AM]

IN THE CANADIAN INTELLECTUAL PROPERTY OFFICE

In The Matter of Canadian Patent:

Category	:	**Regular**
Patentee	:	**Pilot Energy Solutions, LLC**
Patent No.	:	**2,949,039**
Issued	:	**March 12, 2019**
Title	:	**ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS**
Your File	:	**RX-137/20**
Our File	:	**K8001075CADIV6**
Date	:	**September 11, 2020**

The Commissioner of Patents
Place du Portage I
50 Victoria Street, Room C-114
Gatineau, Quebec K1A 0C9

RESPONSE TO RE-EXAMINATION NOTICE

Dear Commissioner of Patents:

In response to the Letter from the Re-examination Board ("Report") dated June 12, 2020 concerning the Request for Re-Examination of Patent Number 2,949,039 issued March 12, 2019, kindly amend this application as follows:

IN THE CLAIMS:

Please replace the claim pages currently on file with claim pages 53 to 61 containing claims 29 to 51, enclosed herewith. A marked up version of the original set of claims is also being submitted.

Response to Requisition under Subsection 48.2(5) of the *Patent Act*

Reconsideration of the Patent is kindly requested having regard to the foregoing amendments and the following comments.

As part this submission, Applicant has amended original claims 2 to 12, 14 to 17, and 21 to 28, which in accordance with section 45.1 of the Patent Rules are now numbered 29 to 51. The amended claims do not enlarge the scope of the claims of the Patent, in accordance with subsection 48.3(2) of the Patent Rules. No new subject matter has been introduced by making any of the amendments herein. Original Claims 1 to 28 have now been cancelled.

Date Reçue/Date Received 2020-09-11

REMARKS

In the Report, the Canadian Intellectual Property Office ("CIPO") has taken the position that US Patent No. 4,753,666 to Pastor et al. ("Pastor"), non-patent reference "Practical Aspects of CO_2 Flooding", Society of Petroleum Engineers (SPE) Monograph Series, vol. 22 (published in 2002) 214 pp. Ch. 5 by Jarrell et al. ("Jarrell"), US Patent No. 4,428,759 to Ryan et al. ("Ryan"), and US Patent No. 4,595,404 to Ozero et al. ("Ozero") present a substantial new question of patentability with regard to claims 1 to 28. In response to the Report, Applicant submit the following remarks.

I. Discussion of Claim Amendments:

Independent claims 29, 37, and 44 (based on original claims 2, 10, and 21, respectively) have been amended to include some of the limitations previously recited in dependent claims 9, 17, and 28. Claim 29 now reads:

> 29. A method comprising:
> receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C_3 hydrocarbons, and natural gas liquids; and
> separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,
> wherein the purified carbon dioxide recycle stream includes the carbon dioxide,
> wherein the natural gas liquids stream includes the natural gas liquids,
> wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,
> **wherein the purified carbon dioxide recycle stream includes** the carbon dioxide, the methane, the ethane, and **a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream**,
> wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,
> **wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream**, and
> **wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons**.

(Emphasis added).

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As shown above, claim 29 requires that a purified carbon dioxide recycle stream includes a first portion of C_3 hydrocarbons from a carbon dioxide recycle stream, that a natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, and that the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons. New Claims 37 and 44 contain similar limitations.

The Re-examination Requestor alleged that claims 9, 17, and 28 were unpatentable over U.S. Patent 4,753,666 (*Pastor*) in view of general common knowledge (p. 13 of the Report). However, the Re-examination Board stated that "Pastor teaches the importance of keeping C_3 (propane) in the overhead gas to offset the effect of the inclusion of methane" (p. 13 of the Report). Accordingly, the Re-examination Board stated that claims 9, 17, and 28 were patentable over *Pastor* in view of general common knowledge (*See Report, p. 13)*. New claims 36, 43, and 51 contain the limitations of original claims 9, 17, and 28 that were not incorporated into new claims 29, 37, and 44. Furthermore, claims 30 and 33 to 35 depend from independent claim 29, claims 38, 39, 41, and 42 depend from independent claim 37, and claims 45 and 48 to 51 depend from independent claim 44. As such, Applicant submits that claims 29 to 30, 33 to 35, 37 to 39, 41 to 42, 44 to 45, and 48 to 51 are allowable.

Original dependent claims 4, 14, and 23 have been re-written in independent form as new claims 31, 40 and 46. Claim 31 reads:

> 31. A method comprising:
> receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, and natural gas liquids; and
> separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

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wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, and the ethane,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the carbon dioxide recycle stream comprises H_2S, and

wherein **separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the H_2S into the natural gas liquids stream**.

(Emphasis added).

As shown above, claim 31 includes the subject matter of separating a carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream includes separating H_2S into the natural gas liquids stream. Claims 40 and 46 contain similar limitations.

The Re-examination Requestor alleged that claims 4, 14, and 23 were unpatentable over *Pastor* in view of U.S. Patent 4,428,759 (*Ryan*) (p. 12 of the Report). However, the Re-examination Board stated that "Pastor teaches the importance of keeping H_2S in the overhead gas to offset the effect of the inclusion of the methane" (p. 12 of the Report). Accordingly, the Re-examination Board stated that the subject matter of claims 4, 14, and 23 were patentable over *Pastor* in view of *Ryan* (p. 12 of the Report). Furthermore, claim 32 depends from claim 31 and claim 47 depends from claim 46. As such, claims 31-32, 40, and 46-47 are allowable.

In light of the above, Applicant submits that the claims 29-51 are allowable subsequent to the amendments proposed herein based on the arguments outlined above.

II. Conclusion

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Applicant respectfully requests consideration of the above submission and allowance of claims 29 through 51. Pursuant to the Examiner's requisition under Subsection 48.2(2) of the Patent Act, Patentee has provided the above amendments and/or arguments to address the defects alleged by the Re- Examination Board. It is respectfully submitted that the application complies with the Patent Act and Rules.

Early and favourable consideration of this patent is respectfully requested

Respectfully submitted,

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PROPOSED CLAIM AMENDMENTS

Original Claim 1. (Cancelled)

Original Claim 2. (New Claim 29) A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C_3 hydrocarbons, ~~dioxide~~ and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids, [[and]]

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream, ~~stream.~~

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,

wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, and

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wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

Original Claim 3. (New Claim 30) The method according to claim 29, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

Original 4. (New Claim 31) A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, and the ethane,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

~~The method according to claim 2,~~ wherein the carbon dioxide recycle stream comprises H_2S, and ~~acid gas, and~~

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wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the H_2S ~~acid gas~~ into the natural gas liquids stream.

Original Claim 5. (New Claim 32) The method according to claim [[4]]31, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S ~~acid gas~~ stream.

Original Claim 6. (New Claim 33) The method according to claim 29, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

Original Claim 7. (New Claim 34) The method according to claim 29, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

Original Claim 8. (New Claim 35) The method according to claim 29, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

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reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

Original Claim 9. (New Claim 36) The method according to claim 2~~9~~, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, ~~wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and~~ wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

Original Claim 10. (New Claim 37) A system comprising:

piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas, methane, ethane, [[gas]] and C_3 to C_8 hydrocarbons; and

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a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas,

wherein the natural gas liquids stream includes the C_3 to C_8 ~~C_3-C_8~~ hydrocarbons, [[and]]

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream, ~~stream.~~

wherein the purified recycle stream includes the injection gas, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the recycle stream,

wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

Original Claim 11. (New Claim 38) The system according to claim [[10]]37, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

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Original Claim 12. (New Claim 39) The system according to claim [[10]]37, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

13. (Cancelled)

Original Claim 14. (New Claim 40) A system comprising:

piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas, methane, ethane, and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas, the methane, and the ethane,

wherein the natural gas liquids stream includes the C_3 to C_8 hydrocarbons,

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream,

~~The system according to claim 10,~~ wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S ~~acid gas~~ stream, and

wherein the sweet natural gas liquids stream includes the C_3 to C_8 hydrocarbons. ~~C_3-C_8 hydrocarbons, and~~

~~wherein the acid gas stream includes H_2S and/or CO_2.~~

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Original Claim 15. (New Claim 41) The system according to claim [[10]]37, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

Original Claim 16. (New Claim 42) The system according to claim [[10]]37, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

Original Claim 17. (New Claim 43) The system according to claim [[10]]37, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, ~~wherein the purified recycle stream includes substantially all of the injection gas, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream, wherein the natural gas liquids stream includes substantially none of the injection gas and a second portion of the C_3 hydrocarbons from the recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of~~

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~~the C_3 hydrocarbons from the recycle stream than the first portion of the C_3 hydrocarbons, and~~ wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

18.-20. (Cancelled)

Original Claim 21. (New Claim 44) A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C_3 hydrocarbons, ~~dioxide~~ and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids, [[and]]

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream, ~~stream.~~

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,

wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,

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wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

Original Claim 22. (New Claim 45) The set of process equipment according to claim [[21]]44, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

Original Claim 23. (New Claim 46) A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, and the ethane,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

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~~The set of process equipment according to claim 21,~~ wherein the carbon dioxide recycle stream comprises H_2S, and ~~acid gas, and~~

wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

Original Claim 24. (New Claim 47) The set of process equipment according to claim [[23]]46, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S ~~acid gas~~ stream.

Original Claim 25. (New Claim 48) The set of process equipment according to claim [[21]]44, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

Original Claim 26. (New Claim 49) The set of process equipment according to claim [[21]]44, further configured to:

compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

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Original Claim 27. (New Claim 50) The set of process equipment according to claim [[21]]44, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

Original Claim 28. (New Claim 51) The set of process equipment according to claim [[21]]44, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, ~~wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and~~ wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

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CLAIMS

29. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C_3 hydrocarbons, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,

wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

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30. The method according to claim 29, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

31. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, and the ethane,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the carbon dioxide recycle stream comprises H_2S, and

wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the H_2S into the natural gas liquids stream.

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32. The method according to claim 31, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream.

33. The method according to claim 29, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

34. The method according to claim 29, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

35. The method according to claim 29, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

36. The method according to claim 29, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first

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portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

37. A system comprising:

piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas, methane, ethane, and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas,

wherein the natural gas liquids stream includes the C_3 to C_8 hydrocarbons,

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream,

wherein the purified recycle stream includes the injection gas, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the recycle stream,

wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

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38. The system according to claim 37, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

39. The system according to claim 37, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

40. A system comprising:

piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas, methane, ethane, and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas, the methane, and the ethane,

wherein the natural gas liquids stream includes the C_3 to C_8 hydrocarbons,

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream,

wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream, and

wherein the sweet natural gas liquids stream includes the C_3 to C_8 hydrocarbons.

41. The system according to claim 37, wherein the system is further configured to:

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receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

42. The system according to claim 37, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

43. The system according to claim 37, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

44. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C_3 hydrocarbons, and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

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wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,

wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

45. The set of process equipment according to claim 44, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

46. A set of process equipment configured to:

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receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, and the ethane,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the carbon dioxide recycle stream comprises H_2S, and

wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

47. The set of process equipment according to claim 46, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream.

48. The set of process equipment according to claim 44, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

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Date Reçue/Date Received 2020-09-11

49. The set of process equipment according to claim 44, further configured to:

compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

50. The set of process equipment according to claim 44, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

51. The set of process equipment according to claim 44, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

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Date Reçue/Date Received 2020-09-11

March 12, 2021

Our file no.: **RX-137/20**

GOWLING WLG (CANADA) LLP
CIPO@gowlingwlg.com

Dear Sir/Madam:

Re: Request for Re-examination of Patent no. 2,949,039

Title:	**ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS**
Patentee:	PILOT ENERGY SOLUTIONS, LLC
Your file no.:	**K8001075CADIV6**
Requester:	MARKS & CLERK CANADA

In accordance with subsection 48.3(1) of the *Patent Act*, the Re-examination Board ("the Board") has commenced a re-examination of issued claims 1-28 of Canadian Patent number 2,949,039 (hereinafter "the '039 patent").

The Board has reviewed the response of the Patentee dated September 11, 2020 to the Board's notice of June 12, 2020 and provides the preliminary opinion below relating to issued claims 1-28 and proposed new claims 29-51.

Prior Art

In the request for re-examination, the Requester has brought to the attention of the Board the following prior art consisting of:

(1) US 4,753,666 (Pastor et al., hereinafter "Pastor");
(2) "Practical Aspects of CO_2 Flooding", Society of Petroleum Engineers (SPE) Monograph Series, vol. 22, (published in 2002) 214 pp. ch. 5;(Jarrell et al., hereinafter "Jarrell");
(3) US 4,428,759 (Ryan et al., hereinafter "Ryan");
(4) US 4,595,404 (Ozero et al., hereinafter "Ozero")

Description Of References Applied

Please see the Board's notice of June 12, 2020 discussing documents 1 through 4.

Claim Construction

Claims construction is antecedent to considerations of both validity and infringement issues. (*Whirlpool Corp v Camco Inc,* 2000 SCC 67 at para 43 [*Whirlpool*]).

Person Skilled in the Art

As set out in the Board notice of June 12, 2020, the Board considers the person skilled in the art to be a person or team skilled and knowledgeable in the field of oil and gas production and carbon dioxide recovery and reinjection. The Patentee did not dispute this view.

Common General Knowledge

The skilled person is considered to be equipped with the common general knowledge; that is, the subset of the prior art that is generally known by persons skilled in the relevant art at the relevant time (*Sanofi-Synthelabo Canada Inc v Apotex Inc*, 2008 SCC 61 [*Sanofi*] at para 37.

As set out in the Board notice of June 12, 2020, the Board considers that the relevant common general knowledge of the notional person skilled in the art includes:

- the knowledge of injecting carbon dioxide to enhance recovery of heavy hydrocarbons;
- the knowledge of separation methods and equipment used for isolating carbon dioxide, Natural Gas Liquids (NGL), and heavy hydrocarbons from a hydrocarbon feed stream;
- the knowledge of the varying composition of the hydrocarbon feed stream.

The Patentee did not dispute this view.

Scope of certain claim terms

In the Board's notice of June 12, 2020 we set out a preliminary analysis of the scope of certain terms used in the issued claims that, in our view, required some clarification. The Board wrote:

> In *Whirlpool* at paragraph 44, the Supreme Court of Canada stated that claims should be given a purposive construction:
>
> > ... A patent specification should be given a purposive construction rather than a purely literal one derived from applying to it the kind of meticulous verbal analysis in which lawyers are too often tempted by their training to indulge. The question in each case is: whether persons with practical knowledge and experience of the kind of work in which the invention was intended to be used, would understand that strict compliance with a particular descriptive word or phrase appearing in a claim was intended by the patentee to be an essential requirement of the invention so that any variant would fall outside the monopoly claimed, even though it could have no material effect upon the way the invention worked.
>
> Claim no. 1 of the '039 Patent states at line 14:

> separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream, wherein the sweet NGL rich stream includes the substantially all of the C_3-C_8 hydrocarbons in the source NGL rich stream. [Emphasis added]

In the Board's preliminary view, the scope of the phrase "source NGL rich stream" is not evident from the claim language itself. It is not clear if the stream is a new stream or if an error has occurred and the stream is the sour NGL rich stream. However, we take the reference to "source NGL rich stream" to be an error. It is our preliminary view that this should have referred to "sour NGL rich stream."

Claim no. 2 of the '039 Patent states:

> 2. A method comprising:
> receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and
> separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,
> wherein the purified carbon dioxide recycle stream includes the carbon dioxide,
> wherein the natural gas liquids stream includes the natural gas liquids, and
> wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream. [Emphasis added]

In the Board's preliminary view, the scope of the phrase "natural gas liquids stream" is not evident from the claim language itself.

The specification of the '039 Patent teaches:
Pg. 4, lines 2-7

> The term "natural gas liquids" or NGLs may refer to natural gases that may be liquefied without refrigeration, and may include C_3 -C_8 hydrocarbons. Both natural gas and NGL are terms known in the art and are used herein as such. In contrast, the term "heavy hydrocarbons" may refer to any hydrocarbon that may exist in a liquid phase under atmospheric or downhole conditions, and generally includes liquid crude oil, which may comprise C_9+ hydrocarbons, branched hydrocarbons, aromatic hydrocarbons, and combinations thereof.

It is the preliminary view of the Board that the abovementioned phrase can be understood as teaching the person skilled in the art that any of the C_3-C_8 hydrocarbons ***may*** be considered an NGL.

In the Board's preliminary view, the scope of the phrase "cryogenic conditions" is not evident from the claim language itself or the specification.

The dictionary definition of Cryogenic is defined as from −150 °C (−238 °F) to absolute zero

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(−273 °C or −460 °F), the temperature at which molecular motion comes as close as theoretically possible to ceasing completely.

It is the preliminary view of the Board that the abovementioned phrase can be understood as teaching the person skilled in the art that a cryogenic process occurs at temperatures from −150 °C (−238 °F) to absolute zero (−273 °C or −460 °F).

The above claim construction was not disputed by the Applicant in its response dated September 11, 2020. We therefore apply it in our analyses below.

Further, we have applied the same preliminary claim construction to the proposed new claims 29-51.

In our assessments of novelty and obviousness below, all the elements of the claims have been considered to be essential and taken into account.

Issued claims 1-28 of the '039 patent

Novelty

Principles of Law

The admissibility of prior art in assessing novelty is set out in subsection 28.2(1) of the *Patent Act*.

In *Sanofi* at paragraphs 24-27 and 33-37, the Supreme Court stated that in order to be anticipatory, a single piece of prior art must both:

disclose the invention of the patent in question; and

enable a skilled reader to make the invention using the prior art reference and common knowledge, allowing for some (uninventive and not unduly burdensome) trial and error experimentation to make it work.

Analysis

Novelty in view of Pastor

In our notice of June 12, 2020, we indicated that, in our preliminary view, claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27 lack novelty in view of Pastor; that notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view.

It is the preliminary opinion of the Board that **claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27** encompass subject-matter disclosed in the prior art before the claim date and do not comply with **paragraph 28.2(1)(*b*) of the *Patent Act***.

Obviousness

Principles of Law

Section 28.3 of the *Patent Act* sets out the conditions under which a claim may be found to be obvious:

> 28.3 The subject-matter defined by a claim in an application for a patent in Canada must be subject-matter that would not have been obvious on the claim date to a person skilled in the art or science to which it pertains, having regard to
>
> (*a*) information disclosed more than one year before the filing date by the applicant, or by a person who obtained knowledge, directly or indirectly, from the applicant in such a manner that the information became available to the public in Canada or elsewhere; and
>
> (*b*) information disclosed before the claim date by a person not mentioned in paragraph (a) in such a manner that the information became available to the public in Canada or elsewhere.

Pursuant to paragraph 28.3(*b*), a patent claim will be invalid if, based on information that was available to the public before the claim date, its subject-matter would have been obvious to a person skilled in the art or science to which it pertains. In *Sanofi* at paragraph 67, the Supreme Court of Canada outlines a four-step approach to be followed when assessing obviousness:

> (1) Identify (a) the notional "person skilled in the art"; and (b) the relevant common general knowledge of that person;
>
> (2) Identify the inventive concept of the claim in question or if that cannot readily be done, construe it;
>
> (3) Identify what, if any, differences exist between the matter cited as forming part of the "state of the art" and the inventive concept of the claim or the claim as construed; and
>
> (4) Viewed without any knowledge of the alleged invention as claimed, do those differences constitute steps which would have been obvious to the person skilled in the art or do they require any degree of invention?

This approach has been applied in the following analysis.

Analysis

In our notice of June 12, 2020, we indicated that, in our preliminary view, claim 1 would have been obvious having regard to Jarrell, in view of Ryan; that notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view.

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In our notice of June 12, 2020, we indicated that, in our preliminary view, claims 6, 7, 25 and 26 would have been obvious having regard to Pastor, in view of Ozero; that notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view.

In our notice of June 12, 2020, we indicated that, in our preliminary view, claims 15 and 19 would have been obvious having regard to Pastor, in view of Jarrell; that notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view.

In our notice of June 12, 2020, we indicated that, in our preliminary view, claim 20 would have been obvious having regard to Ryan, in view of Jarrell and the relevant common general knowledge of the person skilled in the art; that notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view.

In our notice of June 12, 2020, we indicated that in our preliminary view, contrary to the Requester's assertion, claims 4, 5, 14, 23 and 24 would have been non-obvious, as the subject-matter would not have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to Pastor in view of Ryan. The Patentee has not disputed the Board's preliminary view.

In our notice of June 12, 2020, we indicated that in our preliminary view, contrary to the Requester's assertion, claims 9, 17 and 28 would have been non-obvious, as the subject-matter would not have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to Pastor in view of the common general knowledge. The Patentee has not disputed the Board's preliminary view.

It is therefore the preliminary opinion of the Board that **claims 1, 6, 7, 15, 19, 20, 25 and 26** would have been obvious and do not comply with **paragraph 28.3(b) of the *Patent Act***.

Proposed Claims 29-51

The Principles of Law followed for the newly-proposed claims are identical to those presented above in relation to the issued claims.

Further, we take the person skilled in the art and the relevant common general knowledge to be the same for the assessment below of the newly-proposed claims.

Novelty and Obviousness

Analysis

Pastor is considered the closest prior art and discloses a process of separating a carbon dioxide recycle stream into a purified carbon dioxide (overhead gas) stream and a natural gas stream (bottoms product) In order to overcome the problems associated with methane/CO2 distillation, Pastor's process leaves the methane in the overhead gas. To offset the effect of methane in the overhead gas, H2S, ethane, propane and a portion of butane remain in the overhead gas. The separation process of Pastor does not teach utilizing cryogenics or membranes.

Proposed Independent claim 29

Proposed independent claim 29 is based on issued independent claim 2; in our preliminary view, Pastor is the closest prior art in relation to proposed claim 29.

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The Patentee has built on independent claim 2 by adding that the carbon dioxide recycle stream includes methane, ethane, and C3 hydrocarbons, and further adding that the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes a second portion of the C3 hydrocarbons from the carbon dioxide recycle stream, and wherein the second portion of the C3 hydrocarbons contains a molar percentage of the C3 hydrocarbons that is greater than a molar percentage of the C3 hydrocarbons of the first portion of the C3 hydrocarbons.

Regarding Pastor with respect to issued claim 2, the Board notice of June 12, 2020 read in part:

> With regard to claim 2, Pastor teaches a method comprising: receiving a carbon dioxide recycle stream(CO2 gas stream 25), wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids(column 3, line 51 - the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons"); and separating the carbon dioxide recycle stream(distillation column 3 separates the CO2 gas stream 25) into a purified carbon dioxide recycle stream(overhead product stream 21) and a natural gas liquids stream(bottoms product 26), wherein the purified carbon dioxide recycle stream includes the carbon dioxide, wherein the natural gas liquids stream includes the natural gas liquids(column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons'; see above Claim Construction issue, an NGL **may** be any of C3-C8), and wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions (Pastor does not subject any stream to cryogenic conditions(see above Claim Construction issue); furthermore Pastor does not describe isolating either methane or ethane, for which cryogenic conditions are conventionally used; additionally, Pastor utilizes propane as a refrigerant for condenser 7 (see column 4 line 29), and propane refrigerant is not considered to provide cryogenic conditions), membranes(Pastor does not mention using membranes), and carbon dioxide recovery solvents(Pastor does not use solvents in the process; the background section of Pastor discusses solvent use as being problematic, see column 1, lines 47 to 55) between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream. [Emphasis in original]

Thus the arrangement of proposed claim 29 differs from Pastor in that it specifies that a mole percentage of C3 hydrocarbons in the natural gas liquids stream is greater than that in the purified carbon dioxide recycle stream. This is the opposite of what Pastor teaches; TABLE I in Pastor shows a mole percentage of C3 hydrocarbons in the natural gas liquids stream ('Bottoms Product') as being much less than that in the purified carbon dioxide stream ('Overhead Product').

None of Jarrell, Ryan, or Ozero suggest a separation providing a purified CO2 stream comprising all of the CO2 from the recycle stream, as well as methane and ethane. Ozero does provide a stream comprising CO2, methane, ethane, and propane (28, Fig. 1); however, it is not the primary purified CO2 stream. One skilled in the art would not be led from any combination of these documents to the characterizing feature of proposed claim 29. In view of the above, the preliminary opinion of the Board is that proposed independent claim 29 is novel and non-obvious.

Proposed independent claim 31

Proposed independent claim 31 is based on issued dependent claim 4; in relation to issued dependent claim 4, the Board notice of June 12, 2020 read in part:

> In our preliminary review, with regard to claims 4-5 and 23-24, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with Ryan. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with

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> methane/CO2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping H2S in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13). The removal of the H2S gas from the purified carbon dioxide recycle stream would result in a decrease in the miscibility of the recycle stream and limit the recycle gases injection effectiveness. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of Ryan.

Thus it was the preliminary opinion of the Board that issued claim 4 is non-obvious in view of Pastor, having regard of Ryan.

Proposed independent claim 31 is based on issued dependent claim 4; the Patentee has built on issued dependent claim 4 by adding that carbon dioxide recycle stream and the purified carbon dioxide recycle stream each include methane and ethane; and also by clarifying that the acid gas is H2S. Proposed independent claim 31 therefore represents a narrowing of issued dependent claim 4.

In the preliminary opinion of the Board, Pastor is the closest prior art document to the subject-matter of proposed independent claim 31. As Pastor does not disclose all the features of proposed independent claim 31, it is, in our preliminary view novel.

Further, it is the preliminary opinion of the Board is that proposed independent claim 31 is non-obvious, for the same reasons set out above as to why issued claim 4 is non-obvious and in light of the added features.

In view of the differences in respect of issued claim 4, discussed above, proposed independent claim 31 is not redundant in view of issued dependent claim 4.

Proposed independent claim 37

Proposed independent claim 37 is based on issued independent claim 10; the Board notice of June 12, 2020 gave the preliminary opinion that issued independent claim 10 was not novel in view of Pastor. In our preliminary view, Pastor is the closest prior art in relation to proposed claim 37.

To arrive at proposed independent claim 37, the Patentee has built on issued independent claim 10 by adding that the recycle stream further includes methane and ethane; and that the purified recycle stream includes the injection gas, the methane, the ethane, and a first portion of the C3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream, wherein the natural gas liquids stream includes a second portion of the C3 hydrocarbons from the recycle stream, and wherein the second portion of the C3 hydrocarbons contains a molar percentage of the C3 hydrocarbons that is greater than a molar percentage of the C3 hydrocarbons of the first portion of the C3 hydrocarbons.

As discussed above in relation to proposed independent claim 29, the subject matter of the proposed claim differs from that of Pastor in that it specifies that a mole percentage of C3 hydrocarbons in the natural gas liquids stream is greater than that in the purified carbon dioxide recycle stream. This is the opposite of what Pastor teaches; TABLE I in Pastor shows a mole percentage of C3 hydrocarbons in the natural gas liquids stream ('Bottoms Product') as being much less than that in the purified carbon dioxide stream ('Overhead Product').

In view of the above, and the reasoning given in the discussion above relating to proposed claim 29, the preliminary opinion of the Board is that proposed independent claim 37 is novel and non-obvious.

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Proposed independent claim 40

Proposed independent claim 40 is based on issued dependent claim 14; in relation to issued dependent claim 14, the Board notice of June 12, 2020 read in part:

> In our preliminary review, with regard to claims 14, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with Ryan. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with methane/CO2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping H2S in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13; Table 1 does not teach any H2S in the Bottoms Product (NGL)). Since there is no acid in the NGL steam, there is no need to add an acid removal step. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of Ryan.

Thus it was the preliminary opinion of the Board that issued claim 14 is non-obvious in view of Pastor, having regard of Ryan, and common general knowledge.

Proposed independent claim 40 is based on issued dependent claim 14; the Patentee has built on issued dependent claim 14 by adding that carbon dioxide recycle stream and the purified carbon dioxide recycle stream each include methane and ethane; and also by clarifying that the acid gas is H2S. Therefore, proposed independent claim 40 represents a narrowing of issued dependent claim 14.

In the preliminary opinion of the Board, Pastor is the closest prior art document to the subject-matter of proposed independent claim 40. As Pastor does not disclose all the features of proposed independent claim 40, it is in our preliminary view novel.

Further, in, the preliminary opinion of the Board, proposed independent claim 40 would have been non-obvious for the reasons set out above as to why issued claim 14 would not have been obvious, and in light of the added features.

In light of the added features, proposed independent claim 40 differs from issued dependent claim 14, and thus there is no redundant claiming.

Proposed independent claim 44

Proposed independent claim 44 is based on issued dependent claim 21; the Board notice of June 12, 2020 gave the preliminary opinion that issued dependent claim 21 was not novel in view of Pastor. In our preliminary view, Pastor is the closest prior art in relation to proposed claim 44.

To arrive at proposed independent claim 44, the Patentee has built on issued independent claim 21 by adding that the carbon dioxide recycle stream further includes methane and ethane and C3 hydrocarbons; and that the purified recycle stream includes the injection gas, the methane, the ethane, and a first portion of the C3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream, wherein the natural gas liquids stream includes a second portion of the C3 hydrocarbons from the recycle stream, and wherein the second portion of the C3 hydrocarbons contains a molar percentage of the C3 hydrocarbons that is greater than a molar percentage of the C3 hydrocarbons of the first portion of the C3 hydrocarbons.

As discussed above in relation to proposed independent claim 29, the subject matter of the proposed claim differs from that of Pastor in that it specifies that a mole percentage of C3 hydrocarbons in the natural gas liquids stream is greater than that in the purified carbon dioxide recycle stream. This is the opposite of what Pastor teaches; TABLE I in Pastor shows a mole percentage of C3 hydrocarbons in the natural gas

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liquids stream ('Bottoms Product') as being much less than that in the purified carbon dioxide stream ('Overhead Product').

In light of the above, and the reasoning given in the discussion above relating to proposed claim 29, the preliminary opinion of the Board is that proposed independent claim 44 is novel. and non-obvious.

Proposed independent claim 46

Proposed independent claim 46 is based on issued dependent claim 23; in relation to issued dependent claim 23, the Board notice of June 12, 2020 read in part:

> In our preliminary review, with regard to claims 4-5 and 23-24, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with Ryan. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with methane/CO2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping H2S in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13). The removal of the H2S gas from the purified carbon dioxide recycle stream would result in a decrease in the miscibility of the recycle stream and limit the recycle gases injection effectiveness. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of Ryan.

Thus it was the preliminary opinion of the Board that issued claim 23 is non-obvious in view of Pastor, having regard of Ryan, and common general knowledge.

Proposed independent claim 46 is based on issued dependent claim 23; the Patentee has built on issued dependent claim 23 by adding that carbon dioxide recycle stream and the purified carbon dioxide recycle stream each include methane and ethane; and also by clarifying that the acid gas is H2S. Therefore, proposed independent claim 46 represents a narrowing of issued dependent claim 23.

In the preliminary opinion of the Board, Pastor is the closest prior art document to the subject-matter of proposed independent claim 46. As Pastor does not disclose all the features of proposed independent claim 46, it is in our preliminary view novel.

Further, the preliminary opinion of the Board is that proposed independent claim 46 is non-obvious for the reasons set out above in relation to issued claim 23 and in light of the added features.

In light of the added features, proposed independent claim 46 differs from issued dependent claim 23, and thus there is no redundant claiming.

Proposed dependent claims 30, 32-36, 38-39, 41-43, 45, and 47-51

As it is the preliminary opinion of the Board that all proposed independent claims are novel and non-obvious, so too it is the Board's preliminary opinion that all proposed dependent claims are novel and non-obvious.

Summary of Proposed Claims Analysis

It is the preliminary opinion of the Board that proposed **claims 29-51** are novel and comply with **paragraph 28.2(1)(b) of the *Patent Act***.

It is the preliminary opinion of the Board that proposed **claims 29-51** are non-obvious and comply with **paragraph 28.3(b) of the *Patent Act***.

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Summary

It is the preliminary opinion of the Board that issued **claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27** encompass subject-matter disclosed in the prior art before the claim date and do not comply with **paragraph 28.2(1)(*b*) of the *Patent Act***.

It is the preliminary opinion of the Board that issued **claims 1, 6, 7, 15, 19, 20, 25 and 26** would have been obvious and do not comply with **paragraph 28.3(b) of the *Patent Act***.

It is the preliminary opinion of the Board that issued **claims 4, 5, 9, 14, 17, 23, 24, and 28** are non-obvious and do comply with **paragraph 28.3(*b*) of the *Patent Act***.

It is the preliminary opinion of the Board that the subject-matter of proposed **claims 29-51** is novel and does comply with **paragraph 28.2(1)(*b*) of the *Patent Act***.

It is the preliminary opinion of the Board that proposed **claims 29-51** would have been non-obvious and comply with **paragraph 28.3(b) of the *Patent Act***.

Indefiniteness

There is indefiniteness in the proposed claims, which, if issued would result in claims contrary to **subsection 27(4) of the *Patent Act***.

> Proposed **claims 30 and 45** each reads in part: "*wherein the carbon dioxide recycle stream comprises natural gas*" (emphasis added). The respective independent claims, from which each of these claims depends, has specified that "*the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C3 hydrocarbons, and natural gas liquids*". Indefiniteness arises as it appears that each dependent claim is more broad than its respective independent claim; it is not clear whether natural gas – which is mostly methane – is included within the list presented in each independent claim, or additional thereto.
>
> **Claim 46**; the term 'acid gas' has no antecedent.

Proposed cancellation of issued claims 1-28

In the Patentee's response of September 11, 2020 at page 1, a statement was made that original claims 1 to 28 were cancelled. However, pursuant to subsection 48.4(1) of the *Patent Act*, claims may only be cancelled by the issuance of a re-examination certificate by the Board at the conclusion of the re-examination proceeding:

> 48.4 (1) On conclusion of a re-examination proceeding in respect of a claim of a patent, the re-examination board shall issue a certificate
>
> (a) cancelling any claim of the patent determined to be unpatentable;
>
> (b) confirming any claim of the patent determined to be patentable; or
>
> (c) incorporating in the patent any proposed amended or new claim determined to be patentable.

Per our preliminary opinion set out above in respect of the issued claims, issued claims 4, 5, 9, 14, 17, 23,

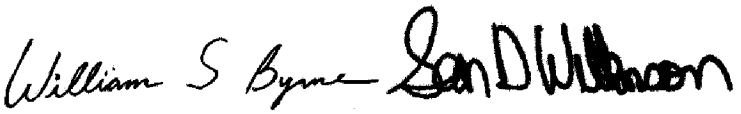
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24 and 28 would remain part of the issued patent upon their final confirmation in a re-examination certificate.

Responses

The Patentee may, within **3** months from the date of this letter, respond with a submission to the Board.

If the Patentee wishes to propose new or amended claims in response to this letter, then in accordance with section 45.1 of the *Patent Rules*, they must be numbered consecutively beginning with the number immediately following the number of the last claim of the issued patent.

Chairperson	**Member**	**Member**
Stephen MacNeil	William Byrne	Sean Wilkinson

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General Correspondence (Patent)

031
ser

Date: June 8, 2021 4:42:12 PM

Application Number

2949039

Title of invention

ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS

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Communicate by: Electronic Mail (Non secure)

Correspondence Instructions

In response to the Letter from the Re-examination Board (Report) dated March 12, 2021 concerning the Request for Re-Examination of Patent Number 2,949,039 issued March 12, 2019, kindly amend this application as follows:

Please replace the claim pages currently on file with claim pages 53 to 75 containing claims 1 to 60, enclosed herewith. A marked up version of the previous set of claims is also being submitted.

Date Reçue/Date Received 2021-06-08
file:///ecprint-prod.ic.gc.ca/patdata/ec/patent/inbasket/ToBeStamped/pgc_IPWaterloo_20210608164212728_9553286991561062173.html[2021-06-09 8:17:11 AM]

Response to Requisition under Subsection 48.2(5) of the Patent Act
Reconsideration of the Patent is kindly requested having regard to the foregoing amendments and the enclosed comments.

Applicant respectfully requests consideration of the above submission and allowance of claims 4, 5, 9, 14, 17, 23, 24, 28, and 29 through 60. Pursuant to the Examiner's requisition under Subsection 48.3(1) of the Patent Act, Patentee has provided the above amendments and/or arguments to address the defects alleged by the Re- Examination Board. It is respectfully submitted that the application complies with the Patent Act and Rules.

Early and favourable consideration of this patent is respectfully requested.

Description of Fee

No fee has been entered.
Total Fee Payment: $0.00

Payment method

No Charge

Attachments

1. K8001075CADIV6 - Response to re-exam review 2021MAR12.pdf
Other

2. K8001075CADIV6 - Claims for response to Re-Examination Review tracked.pdf
Other

3. K8001075CADIV6 - Claims for response to Re-Examination Review clean.pdf
Other

Transmission Identifier: pgc_IPWaterloo_20210608164212728

Date: June 8, 2021 4:42:12 PM

Commissioner of Patents
50 Victoria Street
Place du Portage
Phase I
Gatineau, Quebec
Canada
K1A 0C9

Application Number: 2949039
Title of invention: ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS
Applicant(s) or Inventor(s) Name(s): PILOT ENERGY SOLUTIONS, LLC
PILOT ENERGY SOLUTIONS, LLC

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file:///ecprint-prod.ic.gc.ca/patdata/ec/patent/inbasket/ToBeStamped/pgc_IPWaterloo_20210608164212728_9553286991561062173.html[2021-06-09 8:17:11 AM]

Reference Number: K8001075CADIV6

Instructions: In response to the Letter from the Re-examination Board (Report) dated March 12, 2021 concerning the Request for Re-Examination of Patent Number 2,949,039 issued March 12, 2019, kindly amend this application as follows:

Please replace the claim pages currently on file with claim pages 53 to 75 containing claims 1 to 60, enclosed herewith. A marked up version of the previous set of claims is also being submitted.

Response to Requisition under Subsection 48.2(5) of the Patent Act
Reconsideration of the Patent is kindly requested having regard to the foregoing amendments and the enclosed comments.

Applicant respectfully requests consideration of the above submission and allowance of claims 4, 5, 9, 14, 17, 23, 24, 28, and 29 through 60. Pursuant to the Examiner's requisition under Subsection 48.3(1) of the Patent Act, Patentee has provided the above amendments and/or arguments to address the defects alleged by the Re- Examination Board. It is respectfully submitted that the application complies with the Patent Act and Rules.

Early and favourable consideration of this patent is respectfully requested.

Attached are the following documents:
1. K8001075CADIV6 - Response to re-exam review 2021MAR12.pdf

Other
2. K8001075CADIV6 - Claims for response to Re-Examination Review tracked.pdf

Other
3. K8001075CADIV6 - Claims for response to Re-Examination Review clean.pdf

Other

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IN THE CANADIAN INTELLECTUAL PROPERTY OFFICE

In The Matter of Canadian Patent:

Category	:	**Regular**
Patentee	:	**Pilot Energy Solutions, LLC**
Patent No.	:	**2,949,039**
Issued	:	**March 12, 2019**
Title	:	**ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS**
Your File	:	**RX-137/20**
Our File	:	**K8001075CADIV6**
Date	:	**June 8, 2021**

The Commissioner of Patents
Place du Portage I
50 Victoria Street, Room C-114
Gatineau, Quebec K1A 0C9

RESPONSE TO RE-EXAMINATION REVIEW

Dear Commissioner of Patents:

In response to the Letter from the Re-examination Board ("Report") dated March 12, 2021 concerning the Request for Re-Examination of Patent Number 2,949,039 issued March 12, 2019, kindly amend this application as follows:

IN THE CLAIMS:

Please replace the claim pages currently on file with claim pages 53 to 75 containing claims 1 to 60, enclosed herewith. A marked up version of the previous set of claims is also being submitted.

Response to Requisition under Subsection 48.2(5) of the *Patent Act*

Reconsideration of the Patent is kindly requested having regard to the foregoing amendments and the following comments.

As part this submission, Applicant has cancelled previously introduced claims 30 and 45, without prejudice. The remaining claims have been renumbered. New Claims 50 to 60 have been added which are directed at the subject matter of original claims 6 to 8, 11 to 13, 15, 16, and 25 to 27 with different claim dependencies. The amended and added claims do not enlarge the scope of the claims of the Patent, in accordance with subsection 48.3(2) of the Patent Rules. No new subject matter has been introduced by making any of the amendments herein.

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REMARKS

In the Report, the Canadian Intellectual Property Office ("CIPO") CIPO has taken the position that claims 4, 5, 9, 14, 17, 23, 24, and 28 are non-obvious and do comply with paragraph 28.3(b) of the Patent Act, and that previously presented claims 29 to 51 are novel and non-obvious. CIPO has further taken the position that claims 1 to 3, 6 to 8, 10 to 13, 15, 16, 18 to 22, and 25 to 27 fail to comply with either of paragraphs 28.2(1)(b) or 28.3(b) of the *Patent Act* in view of either US Patent No. 4,753,666 to Pastor et al. ("Pastor"), non-patent reference "Practical Aspects of CO_2 Flooding", Society of Petroleum Engineers (SPE) Monograph Series, vol. 22 (published in 2002) 214 pp. Ch. 5 by Jarrell et al. ("Jarrell"), US Patent No. 4,428,759 to Ryan et al. ("Ryan"), and US Patent No. 4,595,404 to Ozero et al. ("Ozero").

While original claims 4, 9, 14, 17, 23, and 28 are dependent claims, the text of the independent claims from which they depend is still considered part of these dependent claims according to section 30.01.04 of the Manual of Patent Office Practice (MOPOP). As such, Applicant submits that original claims 4, 9, 14, 17, 23, and 28 are patentable. Applicant has added new claims 50 to 52 which are directed to the subject matter of original claims 6 to 8 but depending from patentable Claim 4. Applicant has added new claims 53 to 57 which are directed to the subject matter of original Claims 11 to 13 and 15 to 16 but depending from patentable Claim 14. Applicant has added new Claims 58 to 60 which are directed to the subject matter of original claims 25 to 27 but depending from patentable Claim 23. Applicant submits that claims 50 to 60 are patentable at least due to their dependence from original claims 4, 14, and 23. As such, new claims 50 to 60 are allowable subsequent to the amendments proposed herein based on the arguments outlined above.

In the Report, CIPO has stated that previously presented claims 30 and 45 are indefinite due to the inclusion of the term "natural gas", and that claim 46 is indefinite because the term "acid gas" has no antecedent. Applicant has cancelled previously presented claims 30 and 45, rendering their proposed indefiniteness rejection moot. Applicant has amended claim 44 (formerly claim 46) to replace the term "acid gas" with the term "H2S" to address the Board's comment.

II. Conclusion

Applicant respectfully requests consideration of the above submission and allowance of claims 4, 5, 9, 14, 17, 23, 24, 28, and 29 through 60. Pursuant to the Examiner's requisition under Subsection

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48.3(1) of the Patent Act, Patentee has provided the above amendments and/or arguments to address the defects alleged by the Re- Examination Board. It is respectfully submitted that the application complies with the Patent Act and Rules.

Early and favourable consideration of this patent is respectfully requested

Respectfully submitted,

Gowling WLG (Canada) LLP

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CLAIMS

1. A method comprising:

receiving a hydrocarbon feed stream, wherein the hydrocarbon feed stream includes carbon dioxide, natural gas liquid (NGL), and heavy hydrocarbons, wherein the NGL includes C3-C8 hydrocarbons, and wherein the heavy hydrocarbons include C9+ hydrocarbons;

separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon rich stream includes most of the C9+ hydrocarbons in the hydrocarbon feed stream, and wherein the carbon dioxide recycle stream includes most of the carbon dioxide and most of the C3-C8 hydrocarbons in the hydrocarbon feed stream;

separating the carbon dioxide recycle stream into a sour NGL rich stream and a purified carbon dioxide recycle stream, wherein the sour NGL rich stream includes some of the C3-C8 hydrocarbons in the carbon dioxide recycle stream, and wherein the purified carbon dioxide recycle stream includes most of the carbon dioxide in the carbon dioxide recycle stream;

separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream, wherein the sweet NGL rich stream includes the substantially all of the C3-C8 hydrocarbons in the source NGL rich stream, and wherein the carbon dioxide rich stream includes substantially all of the carbon dioxide in the sour NGL rich stream;

combining a carbon dioxide makeup stream from a source external to the method with the purified carbon dioxide recycle stream; and

subsequently injecting the combined carbon dioxide makeup stream and the purified carbon dioxide recycle stream into a subterranean formation,

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wherein the carbon dioxide is not removed from the hydrocarbon feed stream and is not removed from the carbon dioxide recycle stream prior to separating the carbon dioxide recycle stream into the sour NGL rich stream and the purified carbon dioxide recycle stream, and

wherein the hydrocarbon feed stream, the carbon dioxide recycle stream, and the sour NGL rich stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the heavy hydrocarbon rich stream, the purified carbon dioxide recycle stream, the sweet NGL rich stream, and the carbon dioxide rich stream.

2. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

3. The method according to claim 2, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon

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dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

4. The method according to claim 2, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

5. The method according to claim 4, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

6. The method according to claim 2, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

7. The method according to claim 2, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

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8. The method according to claim 2, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

9. The method according to claim 2, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C3 hydrocarbons contains a greater amount of the C3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C3 hydrocarbons, and wherein the first portion of the C3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

10. A system comprising:

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piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas and C3 to C8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas,

wherein the natural gas liquids stream includes the C3-C8 hydrocarbons, and

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream.

11. The system according to claim 10, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

12. The system according to claim 10, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

13. The system according to claim 10, wherein the recycle stream comprises C1 to C2 hydrocarbons, and wherein the separator is configured to separate the C1 to C2 hydrocarbons into the purified recycle stream.

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14. The system according to claim 10, wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream, wherein the sweet natural gas liquids stream includes the C3-C8 hydrocarbons, and wherein the acid gas stream includes H2S and/or CO2.

15. The system according to claim 10, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C9+ hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

16. The system according to claim 10, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

17. The system according to claim 10, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified recycle stream includes substantially all of the injection gas, substantially all of the methane, and a first portion of the C3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the

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purified recycle stream, wherein the natural gas liquids stream includes substantially none of the injection gas and a second portion of the C3 hydrocarbons from the recycle stream, wherein the second portion of the C3 hydrocarbons contains a greater amount of the C3 hydrocarbons from the recycle stream than the first portion of the C3 hydrocarbons, and wherein the first portion of the C3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

18. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas,

wherein the natural gas liquids stream comprises the natural gas liquids,

wherein the natural gas comprises C1 to C2 hydrocarbons, and

wherein the natural gas liquids comprise C3-C8 hydrocarbons.

19. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;

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separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids; and

separating a feed stream into the carbon dioxide recycle stream and a heavy hydrocarbon stream, wherein the heavy hydrocarbon stream includes C9+ hydrocarbons.

20. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids;

receiving a feed stream, wherein the feed stream includes carbon dioxide, C1 to C2 hydrocarbons, C3-C8 hydrocarbons, C9+ hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons; and

separating the feed stream into a heavy hydrocarbon stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon stream includes substantially all of the C9+ hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream, wherein the heavy hydrocarbon stream includes substantially none of the carbon dioxide, the C1 to C2 hydrocarbons, and the C3-C8 hydrocarbons from the feed stream, and wherein the carbon dioxide

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recycle stream includes substantially all of the carbon dioxide, the C1 to C2 hydrocarbons, and the C3-C8 hydrocarbons from the feed stream,

wherein the purified carbon dioxide recycle stream includes substantially all of the C2 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially none of the C2 hydrocarbons from the carbon dioxide recycle stream, and

wherein the purified carbon dioxide recycle stream includes substantially none of the C3 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially all of the C3 hydrocarbons from the carbon dioxide recycle stream.

21. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

22. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the

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purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

23. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

24. The set of process equipment according to claim 23, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

25. The set of process equipment according to claim 21, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

26. The set of process equipment according to claim 21, further configured to:

compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

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27. The set of process equipment according to claim 21, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

28. The set of process equipment according to claim 21, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C3 hydrocarbons contains a greater amount of the C3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C3 hydrocarbons, and wherein the first portion of the C3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

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29. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C_3 hydrocarbons, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,

wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

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~~30. The method according to claim 29, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.~~

~~31~~30. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, and the ethane,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the carbon dioxide recycle stream comprises H_2S, and

wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the H_2S into the natural gas liquids stream.

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~~32~~31. The method according to claim ~~30~~31, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream.

~~33~~32. The method according to claim 29, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

~~34~~33. The method according to claim 29, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

~~35~~34. The method according to claim 29, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

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~~36~~35. The method according to claim 29, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

~~37~~36. A system comprising:

piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas, methane, ethane, and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas,

wherein the natural gas liquids stream includes the C_3 to C_8 ~~C_3-C_8~~ hydrocarbons,

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream,

wherein the purified recycle stream includes the injection gas, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the recycle stream,

wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the recycle stream, and

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wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

~~38~~37. The system according to claim ~~37~~36, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

~~39~~38. The system according to claim ~~37~~36, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

~~40~~39. A system comprising:

piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas, methane, ethane, and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas, the methane, and the ethane,

wherein the natural gas liquids stream includes the C_3 to C_8 hydrocarbons,

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream,

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wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream, and

wherein the sweet natural gas liquids stream includes the C_3 to C_8 hydrocarbons.

~~41~~40. The system according to claim ~~37~~36, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

~~42~~41. The system according to claim ~~37~~36, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

~~43~~42. The system according to claim ~~37~~36, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

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4443. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C_3 hydrocarbons, and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,

wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

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~~45. The set of process equipment according to claim 44, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.~~

~~46~~44. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, and the ethane,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the carbon dioxide recycle stream comprises H_2S, and

wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the H_2S ~~acid gas~~ into the natural gas liquids stream.

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4745. The set of process equipment according to claim 4644, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream.

4846. The set of process equipment according to claim 44, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

4947. The set of process equipment according to claim 4443, further configured to:

compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

5048. The set of process equipment according to claim 4443, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

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~~5149~~. The set of process equipment according to claim ~~4443~~, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

50. The method according to claim 4, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

51. The method according to claim 4, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

52. The method according to claim 4, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

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condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

53. The system according to claim 14, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

54. The system according to claim 14, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

55. The system according to claim 14, wherein the recycle stream comprises C_1 to C_2 hydrocarbons, and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream.

56. The system according to claim 14, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

57. The system according to claim 14, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the

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reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

58. The set of process equipment according to claim 23, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

59. The set of process equipment according to claim 23, further configured to:

compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

60. The set of process equipment according to claim 23, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

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CLAIMS

1. A method comprising:

receiving a hydrocarbon feed stream, wherein the hydrocarbon feed stream includes carbon dioxide, natural gas liquid (NGL), and heavy hydrocarbons, wherein the NGL includes C3-C8 hydrocarbons, and wherein the heavy hydrocarbons include C9+ hydrocarbons;

separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon rich stream includes most of the C9+ hydrocarbons in the hydrocarbon feed stream, and wherein the carbon dioxide recycle stream includes most of the carbon dioxide and most of the C3-C8 hydrocarbons in the hydrocarbon feed stream;

separating the carbon dioxide recycle stream into a sour NGL rich stream and a purified carbon dioxide recycle stream, wherein the sour NGL rich stream includes some of the C3-C8 hydrocarbons in the carbon dioxide recycle stream, and wherein the purified carbon dioxide recycle stream includes most of the carbon dioxide in the carbon dioxide recycle stream;

separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream, wherein the sweet NGL rich stream includes the substantially all of the C3-C8 hydrocarbons in the source NGL rich stream, and wherein the carbon dioxide rich stream includes substantially all of the carbon dioxide in the sour NGL rich stream;

combining a carbon dioxide makeup stream from a source external to the method with the purified carbon dioxide recycle stream; and

subsequently injecting the combined carbon dioxide makeup stream and the purified carbon dioxide recycle stream into a subterranean formation,

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wherein the carbon dioxide is not removed from the hydrocarbon feed stream and is not removed from the carbon dioxide recycle stream prior to separating the carbon dioxide recycle stream into the sour NGL rich stream and the purified carbon dioxide recycle stream, and

wherein the hydrocarbon feed stream, the carbon dioxide recycle stream, and the sour NGL rich stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the heavy hydrocarbon rich stream, the purified carbon dioxide recycle stream, the sweet NGL rich stream, and the carbon dioxide rich stream.

2. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

3. The method according to claim 2, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon

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dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

4. The method according to claim 2, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

5. The method according to claim 4, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

6. The method according to claim 2, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

7. The method according to claim 2, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

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8. The method according to claim 2, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

9. The method according to claim 2, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C3 hydrocarbons contains a greater amount of the C3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C3 hydrocarbons, and wherein the first portion of the C3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

10. A system comprising:

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piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas and C3 to C8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas,

wherein the natural gas liquids stream includes the C3-C8 hydrocarbons, and

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream.

11. The system according to claim 10, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

12. The system according to claim 10, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

13. The system according to claim 10, wherein the recycle stream comprises C1 to C2 hydrocarbons, and wherein the separator is configured to separate the C1 to C2 hydrocarbons into the purified recycle stream.

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14. The system according to claim 10, wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream, wherein the sweet natural gas liquids stream includes the C3-C8 hydrocarbons, and wherein the acid gas stream includes H2S and/or CO2.

15. The system according to claim 10, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C9+ hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

16. The system according to claim 10, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

17. The system according to claim 10, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified recycle stream includes substantially all of the injection gas, substantially all of the methane, and a first portion of the C3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the

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purified recycle stream, wherein the natural gas liquids stream includes substantially none of the injection gas and a second portion of the C3 hydrocarbons from the recycle stream, wherein the second portion of the C3 hydrocarbons contains a greater amount of the C3 hydrocarbons from the recycle stream than the first portion of the C3 hydrocarbons, and wherein the first portion of the C3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

18. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas,

wherein the natural gas liquids stream comprises the natural gas liquids,

wherein the natural gas comprises C1 to C2 hydrocarbons, and

wherein the natural gas liquids comprise C3-C8 hydrocarbons.

19. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;

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separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids; and

separating a feed stream into the carbon dioxide recycle stream and a heavy hydrocarbon stream, wherein the heavy hydrocarbon stream includes C9+ hydrocarbons.

20. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids;

receiving a feed stream, wherein the feed stream includes carbon dioxide, C1 to C2 hydrocarbons, C3-C8 hydrocarbons, C9+ hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons; and

separating the feed stream into a heavy hydrocarbon stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon stream includes substantially all of the C9+ hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream, wherein the heavy hydrocarbon stream includes substantially none of the carbon dioxide, the C1 to C2 hydrocarbons, and the C3-C8 hydrocarbons from the feed stream, and wherein the carbon dioxide

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recycle stream includes substantially all of the carbon dioxide, the C1 to C2 hydrocarbons, and the C3-C8 hydrocarbons from the feed stream,

wherein the purified carbon dioxide recycle stream includes substantially all of the C2 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially none of the C2 hydrocarbons from the carbon dioxide recycle stream, and

wherein the purified carbon dioxide recycle stream includes substantially none of the C3 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially all of the C3 hydrocarbons from the carbon dioxide recycle stream.

21. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

22. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the

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purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

23. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

24. The set of process equipment according to claim 23, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

25. The set of process equipment according to claim 21, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

26. The set of process equipment according to claim 21, further configured to:

compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

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27. The set of process equipment according to claim 21, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

28. The set of process equipment according to claim 21, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C3 hydrocarbons contains a greater amount of the C3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C3 hydrocarbons, and wherein the first portion of the C3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

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29. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C_3 hydrocarbons, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,

wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

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30. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, and the ethane,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the carbon dioxide recycle stream comprises H_2S, and

wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the H_2S into the natural gas liquids stream.

31. The method according to claim 30, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream.

32. The method according to claim 29, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

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33. The method according to claim 29, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

34. The method according to claim 29, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

35. The method according to claim 29, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

36. A system comprising:

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piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas, methane, ethane, and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas,

wherein the natural gas liquids stream includes the C_3 to C_8 ~~C_3-C_8~~ hydrocarbons,

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream,

wherein the purified recycle stream includes the injection gas, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the recycle stream,

wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

37. The system according to claim 36, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

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38. The system according to claim 36, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

39. A system comprising:

piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas, methane, ethane, and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas, the methane, and the ethane,

wherein the natural gas liquids stream includes the C_3 to C_8 hydrocarbons,

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream,

wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream, and

wherein the sweet natural gas liquids stream includes the C_3 to C_8 hydrocarbons.

40. The system according to claim 36, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

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dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

41. The system according to claim 36, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

42. The system according to claim 36, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

43. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, C_3 hydrocarbons, and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids,

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wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream,

wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream,

wherein the natural gas liquids stream includes a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, and

wherein the second portion of the C_3 hydrocarbons contains a molar percentage of the C_3 hydrocarbons that is greater than a molar percentage of the C_3 hydrocarbons of the first portion of the C_3 hydrocarbons.

44. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, methane, ethane, and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

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wherein the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, and the ethane,

wherein the natural gas liquids stream includes the natural gas liquids,

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream,

wherein the carbon dioxide recycle stream comprises H_2S, and

wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the H_2S into the natural gas liquids stream.

45. The set of process equipment according to claim 44, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an H_2S stream.

46. The set of process equipment according to claim 44, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

47. The set of process equipment according to claim 43, further configured to:

compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

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add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

48. The set of process equipment according to claim 43, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

49. The set of process equipment according to claim 43, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

50. The method according to claim 4, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

51. The method according to claim 4, further comprising:

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compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

52. The method according to claim 4, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

53. The system according to claim 14, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

54. The system according to claim 14, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

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55. The system according to claim 14, wherein the recycle stream comprises C_1 to C_2 hydrocarbons, and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream.

56. The system according to claim 14, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

57. The system according to claim 14, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

58. The set of process equipment according to claim 23, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

59. The set of process equipment according to claim 23, further configured to:

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compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

60. The set of process equipment according to claim 23, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

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September 10, 2021

Our file no.: **RX-137/20**

GOWLING WLG (CANADA) LLP
50 Queen Street North, Suite 1020
KITCHENER Ontario
N2H 6M2

Dear Sir/Madam:

Re: Request for Re-examination of Patent no. 2,949,039

Title:	**ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS**
Patentee:	PILOT ENERGY SOLUTIONS, LLC
Your file no.:	**K8001075CADIV6**
Requester:	MARKS & CLERK CANADA

In accordance with subsection 48.3(3) of the *Patent Act*, the Re-examination Board ("the Board") has completed a re-examination of issued claims 1-28 of Canadian Patent number 2,949,039 (hereinafter "the '039 patent").

Procedural History

The Board received a compliant request for Re-examination of all of issued claims 1-28 of the '039 Patent on February 26th, 2020 ("the Request"). In a notice dated June 12th, 2020 ("the Notice"), the Board gave notice under subsection 48.2(4) of the *Patent Act* that the Request raised a substantial new question of patentability with respect to issued claims 1-3, 6, 7, 8, 10-13, 15-16, 18-22, 25, 26 and 27. In particular, the Board indicated that a substantial new question of novelty was raised with respect to issued claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27 and the Board indicated that a substantial new question of obviousness was raised with respect to issued claims 1, 6, 7, 15, 19, 20, 25 and 26.

Pursuant to subsection 48.2(5) of the *Patent Act*, the Patentee submitted a reply to the Notice on September 11, 2020 ("the First Reply"). The Patentee submitted proposed claims 29-51 with the First Reply. The Patentee also made submissions with respect to the patentability of proposed claims 29-51.

On March 12, 2021, the Board sent a letter ("the Second Stage Letter") to the Patentee in response to the

First Reply. In the Second Letter the Board considered the Patentee's submissions and maintained that, in its preliminary view, claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27 would have lacked novelty and do not comply with paragraph 28.2(1)(b) of the *Patent Act* and claims 1, 6, 7, 15, 19, 20, 25 and 26 would have been obvious and therefore do not comply with paragraph 28.3(b) of the *Patent Act*. The Board further set out its preliminary view that proposed claims 29-51 would have been novel at the claim date and therefore comply with paragraph 28.2(1)(b) of the *Patent Act* and that proposed claims 29-51 would have been non-obvious and comply with paragraph 28.3(b) of the *Patent Act*.

The Board also indicated that proposed claims 30 and 45 submitted with the First Reply are indefinite and do not comply with subsection 27(4) of the *Patent Act*.

The Patentee submitted a subsequent reply to the Second Stage Letter on June 8, 2021 ("the Second Reply"). The Patentee amended the proposed claims by canceling claims 30 and 45, and submitted new proposed claims 50-60.

As discussed below, the Board has considered the Patentee's submissions and concludes that claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27 would have lacked novelty at the claim date and do not comply with paragraph 28.2(1)(b) of the *Patent Act* and claims 1, 6, 7, 15, 19, 20, 25 and 26 would have been obvious and therefore do not comply with paragraph 28.3(b) of the *Patent Act.* Additionally, the Board concludes that the proposed claims 29-60 are patentable in view of the prior art of record and shall be incorporated into the '039 Patent as per paragraph 48.4(1)(c) of the *Patent Act*.

Prior Art

In the request for re-examination, the Requester has brought to the attention of the Board the following prior art consisting of:

(1) US 4,753,666 (Pastor et al., hereinafter "Pastor");
(2) "Practical Aspects of CO_2 Flooding", Society of Petroleum Engineers (SPE) Monograph Series, vol. 22, (published in 2002) 214 pp. ch. 5;(Jarrell et al., hereinafter "Jarrell");
(3) US 4,428,759 (Ryan et al., hereinafter "Ryan");
(4) US 4,595,404 (Ozero et al., hereinafter "Ozero")

Description Of References Applied

Pastor discloses a process of separating a carbon dioxide recycle stream into a purified carbon dioxide (overhead gas) stream and a natural gas stream (bottoms product) In order to overcome the problems associated with methane/CO2 distillation, Pastor's process leaves the methane in the overhead gas. To offset the effect of methane in the overhead gas, H2S, ethane, propane and a portion of butane remain in the overhead gas. The separation process of Pastor does not teach utilizing cryogenics or membranes.

Jarrell discloses processing steps used at each stage of a CO2 flooding process, beginning with generating a production stream at the "production well", separating the production stream into an oil (i.e. heavy hydrocarbon) -containing stream and a gas stream, separating the gas stream into a recovered carbon dioxide stream and a natural gas liquids stream, and reinjecting the recovered carbon dioxide stream into

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the "injection well". An oil stream and a natural gas liquids stream are sold as "oil sales" and "NGL sales", respectively.

Ryan discloses a process of separating a carbon dioxide recycle stream into a purified carbon dioxide (overhead gas) stream and a natural gas stream (bottoms product). Ryan's process teaches a distillative technique involving recycling a small portion of a bottom product stream of a second distillation column, typically a C3 to C6 stream, to a first distillation column, wherein the overhead stream is not significantly contaminated by the recycled bottom product stream, to adjust column operating conditions and effect energy savings.

Ozero pertains to a process for regeneration of a carbon dioxide gaseous stream such used in a carbon dioxide miscibility flood process. Ozero's process dehydrates the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

Claim Construction

Claims construction is antecedent to considerations of both validity and infringement issues. (*Whirlpool Corp v Camco Inc,* 2000 SCC 67 at para 43 [*Whirlpool*]).

Person Skilled in the Art

As set out in the Notice, the Board considers the person skilled in the art to be a person or team skilled and knowledgeable in the field of oil and gas production and carbon dioxide recovery and reinjection. The Patentee did not dispute this view in the First Reply or the Second Reply.

Common General Knowledge

The skilled person is considered to be equipped with the common general knowledge; that is, the subset of the prior art that is generally known by persons skilled in the relevant art at the relevant time (*Sanofi-Synthelabo Canada Inc v Apotex Inc*, 2008 SCC 61 [*Sanofi*] at para 37.

As set out in the Board notice of June 12, 2020, the Board considers that the relevant common general knowledge of the notional person skilled in the art includes:

- the knowledge of injecting carbon dioxide to enhance recovery of heavy hydrocarbons;
- the knowledge of separation methods and equipment used for isolating carbon dioxide, Natural Gas Liquids (NGL), and heavy hydrocarbons from a hydrocarbon feed stream;
- the knowledge of the varying composition of the hydrocarbon feed stream.

The Patentee did not dispute this view in the First Reply or the Second Reply.

Scope of certain claim terms

In the Board's notice of June 12, 2020 we set out a preliminary analysis of the scope of certain terms used in the issued claims that, in our view, required some clarification. The Board wrote:

> In *Whirlpool* at paragraph 44, the Supreme Court of Canada stated that claims should be given a purposive construction:

> ... A patent specification should be given a purposive construction rather than a purely literal one derived from applying to it the kind of meticulous verbal analysis in which lawyers are too often tempted by their training to indulge. The question in each case is: whether persons with practical knowledge and experience of the kind of work in which the invention was intended to be used, would understand that strict compliance with a particular descriptive word or phrase appearing in a claim was intended by the patentee to be an essential requirement of the invention so that any variant would fall outside the monopoly claimed, even though it could have no material effect upon the way the invention worked.

Claim no. 1 of the '039 Patent states at line 14:

> separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream, wherein the sweet NGL rich stream includes the substantially all of the C_3-C_8 hydrocarbons in the source NGL rich stream. [Emphasis added]

In the Board's preliminary view, the scope of the phrase "source NGL rich stream" is not evident from the claim language itself. It is not clear if the stream is a new stream or if an error has occurred and the stream is the sour NGL rich stream. However, we take the reference to "source NGL rich stream" to be an error. It is our preliminary view that this should have referred to "sour NGL rich stream."

Claim no. 2 of the '039 Patent states:

> 2. A method comprising:
> receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and
> separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,
> wherein the purified carbon dioxide recycle stream includes the carbon dioxide,
> wherein the natural gas liquids stream includes the natural gas liquids, and
> wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream. [Emphasis added]

In the Board's preliminary view, the scope of the phrase "natural gas liquids stream" is not evident from the claim language itself.

The specification of the '039 Patent teaches:
Pg. 4, lines 2-7

> The term "natural gas liquids" or NGLs may refer to natural gases that may be liquefied without refrigeration, and may include C_3 -C_8 hydrocarbons. Both natural gas and NGL are terms known in the art and are used herein as such. In contrast, the term "heavy hydrocarbons" may refer to any hydrocarbon that may exist in a liquid phase under atmospheric or downhole conditions, and

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> generally includes liquid crude oil, which may comprise C_9+ hydrocarbons, branched hydrocarbons, aromatic hydrocarbons, and combinations thereof.

It is the preliminary view of the Board that the abovementioned phrase can be understood as teaching the person skilled in the art that any of the C_3-C_8 hydrocarbons ***may*** be considered an NGL.

In the Board's preliminary view, the scope of the phrase "cryogenic conditions" is not evident from the claim language itself or the specification.

The dictionary definition of Cryogenic is defined as from −150 °C (−238 °F) to absolute zero (−273 °C or −460 °F), the temperature at which molecular motion comes as close as theoretically possible to ceasing completely.

It is the preliminary view of the Board that the abovementioned phrase can be understood as teaching the person skilled in the art that a cryogenic process occurs at temperatures from −150 °C (−238 °F) to absolute zero (−273 °C or −460 °F).

The above claim construction was not disputed by the Applicant in the First Reply or the Second Reply. We therefore apply it in our analyses below.

Further, we have applied the same claim construction to the proposed new claims 29-60.

In our assessments of novelty and obviousness below, all the elements of the claims have been considered to be essential and taken into account.

Issued claims 1-28 of the '039 patent

Novelty

Principles of Law

The admissibility of prior art in assessing novelty is set out in subsection 28.2(1) of the *Patent Act*.

In *Sanofi* at paragraphs 24-27 and 33-37, the Supreme Court stated that in order to be anticipatory, a single piece of prior art must both:

> disclose the invention of the patent in question; and
>
> enable a skilled reader to make the invention using the prior art reference and common knowledge, allowing for some (uninventive and not unduly burdensome) trial and error experimentation to make it work.

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Analysis

Novelty in view of Pastor

In the Notice and the Second Stage Letter, we indicated that, in our preliminary view, claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27 would have lacked novelty in view of Pastor; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

It is the opinion of the Board, for the reasons set out in the Notice, that **claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27** encompass subject-matter disclosed in the prior art before the claim date and do not comply with **paragraph 28.2(1)(b) of the *Patent Act***.

Obviousness

Principles of Law

Section 28.3 of the *Patent Act* sets out the conditions under which a claim may be found to be obvious:

> 28.3 The subject-matter defined by a claim in an application for a patent in Canada must be subject-matter that would not have been obvious on the claim date to a person skilled in the art or science to which it pertains, having regard to
>
> (*a*) information disclosed more than one year before the filing date by the applicant, or by a person who obtained knowledge, directly or indirectly, from the applicant in such a manner that the information became available to the public in Canada or elsewhere; and
>
> (*b*) information disclosed before the claim date by a person not mentioned in paragraph (a) in such a manner that the information became available to the public in Canada or elsewhere.

Pursuant to paragraph 28.3(*b*), a patent claim will be invalid if, based on information that was available to the public before the claim date, its subject-matter would have been obvious to a person skilled in the art or science to which it pertains. In *Sanofi* at paragraph 67, the Supreme Court of Canada outlines a four-step approach to be followed when assessing obviousness:

> (1) Identify (a) the notional "person skilled in the art"; and (b) the relevant common general knowledge of that person;
>
> (2) Identify the inventive concept of the claim in question or if that cannot readily be done, construe it;
>
> (3) Identify what, if any, differences exist between the matter cited as forming part of the "state of the art" and the inventive concept of the claim or the claim as construed; and
>
> (4) Viewed without any knowledge of the alleged invention as claimed, do those differences constitute steps which would have been obvious to the person skilled

in the art or do they require any degree of invention?

This approach has been applied in the following analysis.

Analysis

In the Notice and the Second Stage Letter, we indicated that, in our preliminary view, claim 1 would have been obvious having regard to Jarrell, in view of Ryan; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

In the Notice and the Second Stage Letter, we indicated that, in our preliminary view, claims 6, 7, 25 and 26 would have been obvious having regard to Pastor, in view of Ozero; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

In the Notice and the Second Stage Letter, we indicated that, in our preliminary view, claims 15 and 19 would have been obvious having regard to Pastor, in view of Jarrell; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

In the Notice and the Second Stage Letter, we indicated that, in our preliminary view, claim 20 would have been obvious having regard to Ryan, in view of Jarrell and the relevant common general knowledge of the person skilled in the art; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

In the Notice and the Second Stage Letter, we indicated that in our preliminary view, contrary to the Requester's assertion, claims 4, 5, 14, 23 and 24 would have been non-obvious, as the subject-matter would not have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to Pastor in view of Ryan; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view.

In the Notice and the Second Stage Letter, we indicated that in our preliminary view, contrary to the Requester's assertion, claims 9, 17 and 28 would have been non-obvious, as the subject-matter would not have been obvious at the claim date to a person skilled in the art or science to which it pertains having regard to Pastor in view of the common general knowledge; the Notice may be referred to for the specifics of the Board's reasoning. The Patentee has not disputed the Board's preliminary view in the First Reply or the Second Reply.

It is therefore the opinion of the Board that **claims 1, 6, 7, 15, 19, 20, 25 and 26** would have been obvious and do not comply with **paragraph 28.3(b) of the *Patent Act***.

Proposed Claims 29-60

The Principles of Law followed for the proposed claims submitted with the Second Reply are identical to those presented above in relation to the issued claims.

Further, we take the person skilled in the art and the relevant common general knowledge to be the same for the assessment below of the proposed claims submitted with the Second Reply.

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Novelty and Obviousness

Analysis

Pastor is considered the closest prior art and discloses a process of separating a carbon dioxide recycle stream into a purified carbon dioxide (overhead gas) stream and a natural gas stream (bottoms product). In order to overcome the problems associated with methane/CO2 distillation, Pastor's process leaves the methane in the overhead gas. To offset the effect of methane in the overhead gas, H2S, ethane, propane and a portion of butane remain in the overhead gas. The separation process of Pastor does not teach utilizing cryogenics or membranes.

Proposed Independent claim 29

Proposed independent claim 29 is based on issued independent claim 2; in our preliminary view, Pastor is the closest prior art in relation to proposed claim 29.

The Patentee has built on independent claim 2 by adding that the carbon dioxide recycle stream includes methane, ethane, and C3 hydrocarbons, and further adding that the purified carbon dioxide recycle stream includes the carbon dioxide, the methane, the ethane, and a first portion of the C3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes a second portion of the C3 hydrocarbons from the carbon dioxide recycle stream, and wherein the second portion of the C3 hydrocarbons contains a molar percentage of the C3 hydrocarbons that is greater than a molar percentage of the C3 hydrocarbons of the first portion of the C3 hydrocarbons.

Regarding Pastor with respect to issued claim 2, the Notice and the Second Stage Letter read in part:

> With regard to claim 2, Pastor teaches a method comprising: receiving a carbon dioxide recycle stream(CO2 gas stream 25), wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids(column 3, line 51 - the stream contains "a mixture of carbon dioxide, methane, ethane, propane, butanes, and heavier hydrocarbons"); and separating the carbon dioxide recycle stream(distillation column 3 separates the CO2 gas stream 25) into a purified carbon dioxide recycle stream(overhead product stream 21) and a natural gas liquids stream(bottoms product 26), wherein the purified carbon dioxide recycle stream includes the carbon dioxide, wherein the natural gas liquids stream includes the natural gas liquids(column 3 line 55 - "the overhead stream contains substantially all of the carbon dioxide, methane, ethane and propane, and the bottoms stream contains substantially all of said heavier hydrocarbons'; see above Claim Construction issue, an NGL **may** be any of C3-C8), and wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions (Pastor does not subject any stream to cryogenic conditions(see above Claim Construction issue); furthermore Pastor does not describe isolating either methane or ethane, for which cryogenic conditions are conventionally used; additionally, Pastor utilizes propane as a refrigerant for condenser 7 (see column 4 line 29), and propane refrigerant is not considered to provide cryogenic conditions), membranes(Pastor does not mention using membranes), and carbon dioxide recovery solvents(Pastor does not use solvents in the process; the background section of Pastor discusses solvent use as being problematic, see column 1, lines 47 to 55) between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream. [Emphasis in original]

Thus the arrangement of proposed claim 29 differs from Pastor in that it specifies that a mole percentage of C3 hydrocarbons in the natural gas liquids stream is greater than that in the purified carbon dioxide recycle stream. This is the opposite of what Pastor teaches; TABLE I in Pastor shows a mole percentage of C3 hydrocarbons in the natural gas liquids stream ('Bottoms Product') as being much less than that in

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the purified carbon dioxide stream ('Overhead Product').

None of Jarrell, Ryan, or Ozero suggest a separation providing a purified CO2 stream comprising all of the CO2 from the recycle stream, as well as methane and ethane. Ozero does provide a stream comprising CO2, methane, ethane, and propane (28, Fig. 1); however, it is not the primary purified CO2 stream. One skilled in the art would not be led from any combination of these documents to the characterizing feature of proposed claim 29. In view of the above, the opinion of the Board is that proposed independent claim 29 would have been novel and non-obvious at the claim date.

Proposed independent claim 30

Proposed independent claim 30 is based on issued dependent claim 4; in relation to issued dependent claim 4, the Notice and the Second Stage Letter read in part:

> In our preliminary review, with regard to claims 4-5 and 23-24, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with Ryan. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with methane/CO2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping H2S in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13). The removal of the H2S gas from the purified carbon dioxide recycle stream would result in a decrease in the miscibility of the recycle stream and limit the recycle gases injection effectiveness. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of Ryan.

Thus it was the preliminary opinion of the Board that issued claim 4 is non-obvious in view of Pastor, having regard of Ryan.

Proposed independent claim 30 is based on issued dependent claim 4; the Patentee has built on issued dependent claim 4 by adding that carbon dioxide recycle stream and the purified carbon dioxide recycle stream each include methane and ethane; and also by clarifying that the acid gas is H2S. Proposed independent claim 30 therefore represents a narrowing of issued dependent claim 4.

In the opinion of the Board, Pastor is the closest prior art document to the subject-matter of proposed independent claim 30. As Pastor does not disclose all the features of proposed independent claim 30, it would have been, in our view, novel at the claim date.

Further, it is the opinion of the Board that proposed independent claim 30 would have been non-obvious, for the same reasons set out above as to why issued claim 4 would have been non-obvious and in light of the added features.

In view of the differences in respect of issued claim 4, discussed above, proposed independent claim 30 is not redundant in view of issued dependent claim 4.

Proposed independent claim 36

Proposed independent claim 36 is based on issued independent claim 10; the Notice and the Second Stage Letter gave the preliminary opinion that issued independent claim 10 was not novel in view of Pastor. In our view, Pastor is the closest prior art in relation to proposed claim 36.

To arrive at proposed independent claim 36, the Patentee has built on issued independent claim 10 by adding that the recycle stream further includes methane and ethane; and that the purified recycle stream includes the injection gas, the methane, the ethane, and a first portion of the C3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar

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percentage of the methane in the purified recycle stream, wherein the natural gas liquids stream includes a second portion of the C3 hydrocarbons from the recycle stream, and wherein the second portion of the C3 hydrocarbons contains a molar percentage of the C3 hydrocarbons that is greater than a molar percentage of the C3 hydrocarbons of the first portion of the C3 hydrocarbons.

As discussed above in relation to proposed independent claim 29, the subject matter of proposed claim 36 differs from that of Pastor in that it specifies that a mole percentage of C3 hydrocarbons in the natural gas liquids stream is greater than that in the purified carbon dioxide recycle stream. This is the opposite of what Pastor teaches; TABLE I in Pastor shows a mole percentage of C3 hydrocarbons in the natural gas liquids stream ('Bottoms Product') as being much less than that in the purified carbon dioxide stream ('Overhead Product').

In view of the above, and the reasoning given in the discussion relating to proposed claim 29, the opinion of the Board is that proposed independent claim 36 would have been novel and non-obvious at the claim date.

Proposed independent claim 39

Proposed independent claim 39 is based on issued dependent claim 14; in relation to issued dependent claim 14, the Notice and the Second Stage Letter read in part:

> In our preliminary review, with regard to claims 14, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with Ryan. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with methane/CO2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping H2S in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13; Table 1 does not teach any H2S in the Bottoms Product (NGL)). Since there is no acid in the NGL steam, there is no need to add an acid removal step. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of Ryan.

Thus it was the preliminary opinion of the Board that issued claim 14 is non-obvious in view of Pastor, having regard of Ryan, and common general knowledge.

Proposed independent claim 39 is based on issued dependent claim 14; the Patentee has built on issued dependent claim 14 by adding that carbon dioxide recycle stream and the purified carbon dioxide recycle stream each include methane and ethane; and also by clarifying that the acid gas is H2S. Therefore, proposed independent claim 39 represents a narrowing of issued dependent claim 14.

In the opinion of the Board, Pastor is the closest prior art document to the subject-matter of proposed independent claim 39. As Pastor does not disclose all the features of proposed independent claim 39, it would have been, in our view, novel at the claim date.

Further, in the opinion of the Board, proposed independent claim 39 would have been non-obvious for the reasons set out above as to why issued claim 14 would not have been obvious, and in light of the added features.

In light of the added features, proposed independent claim 39 differs from issued dependent claim 14, and thus there is no redundant claiming.

Proposed independent claim 43

Proposed independent claim 43 is based on issued dependent claim 21; the Notice and the Second Stage

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Letter gave the preliminary opinion that issued dependent claim 21 was not novel in view of Pastor. In our view, Pastor is the closest prior art in relation to proposed claim 43.

To arrive at proposed independent claim 43, the Patentee has built on issued independent claim 21 by adding that the carbon dioxide recycle stream further includes methane and ethane and C3 hydrocarbons; and that the purified recycle stream includes the injection gas, the methane, the ethane, and a first portion of the C3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the purified recycle stream, wherein the natural gas liquids stream includes a second portion of the C3 hydrocarbons from the recycle stream, and wherein the second portion of the C3 hydrocarbons contains a molar percentage of the C3 hydrocarbons that is greater than a molar percentage of the C3 hydrocarbons of the first portion of the C3 hydrocarbons.

As discussed above in relation to proposed independent claim 29, the subject matter of the proposed claim differs from that of Pastor in that it specifies that a mole percentage of C3 hydrocarbons in the natural gas liquids stream is greater than that in the purified carbon dioxide recycle stream. This is the opposite of what Pastor teaches; TABLE I in Pastor shows a mole percentage of C3 hydrocarbons in the natural gas liquids stream ('Bottoms Product') as being much less than that in the purified carbon dioxide stream ('Overhead Product').

In light of the above, and the reasoning given in the discussion relating to proposed claim 29, the opinion of the Board is that proposed independent claim 43 would have been novel and non-obvious at the claim date.

Proposed independent claim 44

Proposed independent claim 44 is based on issued dependent claim 23; in relation to issued dependent claim 23, the Notice and the Second Stage Letter read in part:

> In our preliminary review, with regard to claims 4-5 and 23-24, the Board was unable to identify any incentive for a person skilled in the art to combine the teachings of Pastor with Ryan. Pastor's separation process specifically teaches keeping methane in the overhead gas to overcome known problems associated with methane/CO2 distillation (Column 6, lines 5-9). Pastor teaches the importance of keeping H2S in the overhead gas to offset the effect of the inclusion of the methane (Column 6, lines 9-13). The removal of the H2S gas from the purified carbon dioxide recycle stream would result in a decrease in the miscibility of the recycle stream and limit the recycle gases injection effectiveness. It is therefore our preliminary opinion that the requirements of Sanofi are not met for Pastor, in view of Ryan.

Thus it was the preliminary opinion of the Board that issued claim 23 is non-obvious in view of Pastor, having regard of Ryan, and common general knowledge.

Proposed independent claim 44 is based on issued dependent claim 23; the Patentee has built on issued dependent claim 23 by adding that carbon dioxide recycle stream and the purified carbon dioxide recycle stream each include methane and ethane; and also by clarifying that the acid gas is H2S. Therefore, proposed independent claim 44 represents a narrowing of issued dependent claim 23.

In the opinion of the Board, Pastor is the closest prior art document to the subject-matter of proposed independent claim 44. As Pastor does not disclose all the features of proposed independent claim 44, it would have been, in our view, novel at the claim date.

Further, the opinion of the Board is that proposed independent claim 44 would have been non-obvious for the reasons set out above in relation to issued claim 23 and in light of the added features.

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In light of the added features, proposed independent claim 44 differs from issued dependent claim 23, and thus there is no redundant claiming.

Proposed dependent claims 31-35, 37-38, 40-42, and 45-60

As it is the opinion of the Board that all proposed independent claims would have been novel and non-obvious, so too it is the Board's opinion that all proposed dependent claims would have been novel and non-obvious.

Summary of Proposed Claims Analysis

It is the opinion of the Board that proposed **claims 29-60** would have been novel at the claim date and comply with **paragraph 28.2(1)(b) of the *Patent Act***.

It is the opinion of the Board that proposed **claims 29-60** would have been non-obvious and comply with **paragraph 28.3(b) of the *Patent Act***.

Conclusions for the issued claims 1-28

It is the opinion of the Board that issued **claims 2, 3, 8, 10-13, 16, 18, 21, 22 and 27** encompass subject-matter disclosed in the prior art before the claim date and do not comply with **paragraph 28.2(1)(b) of the *Patent Act***.

It is the opinion of the Board that issued **claims 1, 6, 7, 15, 19, 20, 25 and 26** would have been obvious and do not comply with **paragraph 28.3(b) of the *Patent Act***.

It is the opinion of the Board that issued **claims 4, 5, 9, 14, 17, 23, 24, and 28** would have been non-obvious and do comply with **paragraph 28.3(b) of the *Patent Act***.

Conclusions for the proposed claims 29-60

It is the opinion of the Board that the subject-matter of proposed **claims 29-60** would have been novel at the claim date and does comply with **paragraph 28.2(1)(b) of the *Patent Act***.

It is the opinion of the Board that proposed **claims 29-60** would have been non-obvious and comply with **paragraph 28.3(b) of the *Patent Act***.

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Completion of the Re-Examination

Please find enclosed a Certificate of Re-examination issued under subsection 48.4(1) of the *Patent Act*, cancelling claims 1-3, 6-8, 10-13, 15-16, 18-22, and 25-27 of CA Patent number 2,949,039, and incorporating proposed claims 29-60 submitted by the Patentee in the Second Reply.

Please also find enclosed a Registration Certificate indicating that the enclosed Certificate of Re-examination has been registered as an "Other Document" against CA Patent number 2,949,039.

Under section 48.5 of the *Patent Act*, no appeal may be taken from the decision of the Re-examination Board after three (3) months from the date a copy of the Certificate of Re-examination is sent by registered mail to the Patentee.

Chairperson	**Member**	**Member**
Stephen MacNeil	William Byrne	Sean Wilkinson

c.c. **Marks & Clerk Canada**
100 Simcoe Street, Suite 200
Toronto, Ontario
Canada
M5H 3G2

PILOT EXHIBIT 2013, PAGE 378

Innovation, Sciences et Développement économique Canada
Office de la propriété intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

BUREAU DES BREVETS
CONSTAT DE RÉEXAMEN

PATENT OFFICE
CERTIFICATE OF RE-EXAMINATION

N° de brevet - Patent No: **2,949,039**

Par la présente, les soussignés certifient que le brevet susmentionné a été réexaminé selon les paragraphes 48.1 à 48.3 de la *Loi sur les brevets* et que le Conseil de réexamen convient de ce qui suit:

The undersigned hereby certify that the above-noted patent has been re-examined pursuant to section 48.1 to 48.3 of the *Patent Act* and that the Re-examination Board has determined the following:

(i)	Les revendications/ Claims	1-3, 6-8, 10-13, 15-16, 18-22 and 25-27	du brevet susmentionné sont non brevetables et sont rejetées / are unpatentable and are cancelled from the above noted patent.
(ii)	Les revendications / Claims	4, 5, 9, 14, 17, 23, 24 and 28	du brevet susmentionné sont brevetables / of the above noted patent are hereby confirmed to be patentable.
(iii)	Les nouvelles revendications / New claims	29-60	(soumises le 8 juin 2021 / submitted June 8, 2021) sont brevetables et font partie du brevet susmentionné à compter de ce jour / are patentable and have been incorporated into the above noted patent as of this date.

Stephen MacNeil	William Byrne	Sean Wilkinson
Président	Membre	Membre
Chairperson	Member	Member

Daté à Gatineau (Québec), ce 10e jour de septembre, 2021
Dated at Gatineau, Quebec, this 10th day of September, 2021

Courtoisie - Certificat d'enregistrement (document(s) connexe(s))
Courtesy - Certificate of Registration (Related Document(s))

GOWLING WLG (CANADA) LLP
CIPO@gowlingwlg.com

Détails du certificat Certificate Details	
Date du certificat: Certificate Date:	2021/09/10
N° d'enregistrement: Registration N°:	05830058
Votre n° de référence: Your Reference N°:	K8001075CADIV6

Document enregistré:	AUTRE DOCUMENT
Document Registered:	OTHER DOCUMENT

Les dossiers du Bureau des brevets indiquent qu'un document a été enregistré relativement à la (aux) demande(s) et/ou au(x) brevet(s) suivants:

Patent Office records indicate that a document has been registered for the following application(s) and/or patent(s):

Brevets/Patents:

2,949,039

22 September 2017 (22-09-2017)

GOWLING WLG (CANADA) LLP
1020 - 50 Queen Street North
P.O.Box 2248
KITCHENER Ontario
N2H 6M2

Application No.	:	**2,949,039**
Owner	:	PILOT ENERGY SOLUTIONS, LLC
Title	:	**ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS**
Classification	:	E21B 43/40 (2006.01)
Your File No.	:	**K8001075CADIV6**
Examiner	:	Sorin Muntean

YOU ARE HEREBY NOTIFIED OF A REQUISITION BY THE EXAMINER IN ACCORDANCE WITH SUBSECTION 30(2) OF THE *PATENT RULES*. IN ORDER TO AVOID ABANDONMENT UNDER PARAGRAPH 73(1)(*a*) OF THE *PATENT ACT*, A WRITTEN REPLY MUST BE RECEIVED WITHIN THE **SIX (6)** MONTH PERIOD AFTER THE ABOVE DATE.

This application has been examined as originally filed.

The number of claims in this application is 24.

Document Cited:

D1:* US4563202 Yao et al. 7 January 1986 (07-01-1986)

* document cited by a foreign patent office

The examiner has identified the following defects in the application:

Claims 18, 20-21 and 23 encompass subject-matter that was disclosed in D1 before the claim date and do not comply with paragraph 28.2(1)(*b*) of the *Patent Act*. D1 discloses a method comprising: receiving a carbon dioxide recycle stream (feed 10, fig. 2) wherein the carbon dioxide recycle stream includes carbon dioxide (column 3, lines 3-6), natural gas (column 5, lines 22-26), and natural gas liquids (column 4, lines 20-31); and separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream (column 4, lines 38-46) and a natural gas liquids stream (column 4, lines 38-46), wherein the purified carbon dioxide recycle stream (72) includes the carbon dioxide and the natural gas (column 6, lines 30-50), and wherein the natural gas liquids stream comprises the natural gas liquids (column 6, lines 6-16). D1 further discloses that the carbon dioxide recycle stream comprises acid gas (H_2S), and wherein separating the carbon

dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream (stream 64). D1 further discloses the step of separating the natural gas liquids stream into an acid gas stream (75) and a sweet natural gas liquids stream (73). D1 further discloses that separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises: receiving the carbon dioxide recycle stream at a separation column; re-boiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream (whole column 5).

In view of the foregoing defects, the applicant is requisitioned, under subsection 30(2) of the *Patent Rules*, to amend the application in order to comply with the *Patent Act* and the *Patent Rules* or to provide arguments as to why the application does comply.

Under section 34 of the *Patent Rules*, any amendment made in response to this requisition must be accompanied by a statement explaining the nature thereof, and how it corrects each of the above identified defects.

Sorin Muntean
patent examiner
819-639-7875

As per CIPO Client Service Standards, a response to a telephone enquiry or voice mail should be provided by the end of the next business day. In the event that attempts to reach the examiner are unsuccessful, the examiner's Section Head, Alain Lauzon, can be reached at 819-576-2617.

For general inquiries: 1-866-997-1936 or for more options see http://www.ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/wr00006.html.

CIPO values your feedback and invites you to complete a short and anonymous ongoing survey on patent examination products and services. You can access the survey at the following link: http://ic.sondages-surveys.ca/s/SCB-OPS/langeng.

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The Examination Search Report is provided for reference only and is not part of any requisition made by the examiner in accordance with the *Patent Act* or *Rules*. The applicant is not required to respond to the information contained in the Examination Search Report.

Examination Search Report

Box I: General Information			
Application No.	2,949,039	Search Report Date	2017-09-21
Title	ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS		
Examiner	Muntean Sorin	Search Conducted?	Yes

Box II: Family Prosecution		
Family Member	File Wrapper Reviewed	Status of Prosecution
US2011/0197629	2017-09-21	In Progress
CA2949014	2017-09-21	In Progress
CA2949058	2017-09-21	In Progress
CA2949051	2017-09-21	In Progress
US8505332	2017-09-21	Completed
CA2739366	2017-09-21	Completed

Box III: Search History			
Claims Searched	1-24	Date of Search	2017-09-21

Type of Search Conducted (select all that apply):

Canadian first to file search	■	Supplemental/top up search	□
Inventor/applicant search	■	Non laid open search	□
Comprehensive search	■	In-house searcher	□

Search History from Databases Consulted:

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##### QUESTEL-ORBIT ##########
7      63     (  6) AND (NATURAL D GAS+)
6      258    (  5) AND RECYCL+
5      2814   ( (METHOD+)/TI/AB/IW/CLMS/DESC/ODES/TX AND (STREAM+)/TI/AB/IW/CLMS/TX AND
(CARBON+)/TI/AB/IW/CLMS/DESC/ODES/TX AND (DIOXIDE+)/TI/AB/IW/CLMS/DESC/ODES/TX AND
(NATURAL+)/TI/AB/IW/CLMS/DESC/ODES/TX AND (GAS+)/TI/AB/IW/CLMS/TX ) AND (E21B)/IPC
4      3      (E21B)/IPC AND ( (PRIM D ERIC)/IN/OIN/INH/INV )
3      1      (US4563202) /PN
2      33035  ..SIMILARITY  SS 1 RANKED 1
1      1      (CA2949039) /PN
Intellect
(((filing-date <= 2012-05-06 <AND> filing-date > 1000-01-01)) <AND> (filing-date >
2006-05-06)) <and> ((E21B 43/40  <IN> ipc) <OR> (E21B 43/16  <IN> ipc))
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Results 1 - 20 of 297 returned, 297 hits total.

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Date: March 20, 2018 3:37:30 PM

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Commissioner of Patents
50 Victoria Street
Place du Portage
Phase I
Gatineau, Quebec
Canada
K1A 0C9

Application Number: 2949039
Title of invention: ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS
Applicant or Inventor Name: PILOT ENERGY SOLUTIONS, LLC
Reference Number: K8001075CADIV6

Instructions: This is in response to the Office Action of September 22, 2017 in which a reply is due by March 22, 2018.

Please replace the claims pages presently on file and substitute therefor claim pages 53 to 63 submitted herewith.

Should the fees submitted with this letter be insufficient to cover all of the fees for which payment is explicitly or implicitly requested by this submission, the Commissioner is hereby authorized to charge the amount of the insufficiency to Deposit Account No. 600000109 or Deposit Account No. 600000107 in the name of Gowling WLG (Canada) LLP.

Attached are the following documents:
1. k8001075CADIV6_-_response_to_OA_dated_Sept_2017.pdf

Other
2. k8001075CADIV6_-_amended_claims.pdf

Other

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Transmission Identifier: pgc_IPWaterloo_20180320153730508

IN THE CANADIAN INTELLECTUAL PROPERTY OFFICE

In The Matter of Canadian Patent Application:

Applicant	:	**Pilot Energy Solutions, LLC**
Serial No.	:	**2,949,039**
Filing Date	:	**May 6, 2011**
Title	:	**ENHANCED NATURAL GAS LIQUID RECOVERY PROCESS**
Our File	:	**K8001075CADIV6**
Date	:	**March 20, 2018**

The Commissioner of Patents
Place du Portage I
50 Victoria Street, Room C-114
Gatineau, Quebec K1A 0C9

OFFICE ACTION RESPONSE

This is in response to the Office Action of September 22, 2017 in which a reply is due by March 22, 2018. Please amend the above-identified application as follows:

IN THE CLAIMS

Please replace the claims pages presently on file and substitute therefor claim pages 53 to 63 submitted herewith.

REMARKS

Claims 18, 20, 21 and 23 have been rejected as not complying with paragraph 28.2(1)(b) of the *Patent Act* since the Examiner has stated that the subject matter of these claims is disclosed in US Patent No. 4,563,202 to Yao et al. ("D1"). In order to obtain a Notice of Allowance, these claims have now been cancelled without prejudice. Retraction of Examiner's rejection of Claims 18, 20, 21 and 23 is respectfully requested.

Claim 2 has been amended to include the word "and" after the first occurrence of the term "natural gas liquids;" and to remove the word "and" after the first wherein clause. Claim 10 has been amended to include the word "and" after the first occurrence of the phrase "hydrocarbons;" and to remove the word "and" after the first wherein clause. Claim 17 has been amended to replace the term "C3" with the term "C_3". Original Claims 19, 22 and 24 (now Claims 18 to 20) have been re-written in independent form as the Examiner has not rejected the subject matter of these claims.

New Claims 21 to 28 are directed at system claims relating to the subject matter of allowable claims 2 to 9. As such, it is respectfully submitted that new claims 21 to 28 are also patentable over the cited art.

Applicant respectfully submits that this application is now in a position for a Notice of Allowance, which Applicant respectfully requests.

Should the fees submitted with this letter be insufficient to cover all of the fees for which payment is explicitly or implicitly requested by this submission, the Commissioner is hereby authorized to charge the amount of the insufficiency to Deposit Account No. 600000109 or Deposit Account No. 600000107 in the name of Gowling WLG (Canada) LLP.

Respectfully submitted,

Pilot Energy Solutions, LLC

_____
Gowling WLG (Canada) LLP
Agents for Applicant

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JW

CLAIMS

1. A method comprising:

receiving a hydrocarbon feed stream, wherein the hydrocarbon feed stream includes carbon dioxide, natural gas liquid (NGL), and heavy hydrocarbons, wherein the NGL includes C_3-C_8 hydrocarbons, and wherein the heavy hydrocarbons include C_{9+} hydrocarbons;

separating the hydrocarbon feed stream into a heavy hydrocarbon rich stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon rich stream includes most of the C_{9+} hydrocarbons in the hydrocarbon feed stream, and wherein the carbon dioxide recycle stream includes most of the carbon dioxide and most of the C_3-C_8 hydrocarbons in the hydrocarbon feed stream;

separating the carbon dioxide recycle stream into a sour NGL rich stream and a purified carbon dioxide recycle stream, wherein the sour NGL rich stream includes some of the C_3-C_8 hydrocarbons in the carbon dioxide recycle stream, and wherein the purified carbon dioxide recycle stream includes most of the carbon dioxide in the carbon dioxide recycle stream;

separating the sour NGL rich stream into a sweet NGL rich stream and a carbon dioxide rich stream, wherein the sweet NGL rich stream includes the substantially all of the C_3-C_8 hydrocarbons in the source NGL rich stream, and wherein the carbon dioxide rich stream includes substantially all of the carbon dioxide in the sour NGL rich stream;

combining a carbon dioxide makeup stream from a source external to the method with the purified carbon dioxide recycle stream; and

subsequently injecting the combined carbon dioxide makeup stream and the purified carbon dioxide recycle stream into a subterranean formation,

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wherein the carbon dioxide is not removed from the hydrocarbon feed stream and is not removed from the carbon dioxide recycle stream prior to separating the carbon dioxide recycle stream into the sour NGL rich stream and the purified carbon dioxide recycle stream, and

wherein the hydrocarbon feed stream, the carbon dioxide recycle stream, and the sour NGL rich stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the heavy hydrocarbon rich stream, the purified carbon dioxide recycle stream, the sweet NGL rich stream, and the carbon dioxide rich stream.

2. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

3. The method according to claim 2, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the purified carbon

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dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

4. The method according to claim 2, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

5. The method according to claim 4, further comprising separating the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

6. The method according to claim 2, further comprising dehydrating the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

7. The method according to claim 2, further comprising:

compressing the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

adding additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

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8. The method according to claim 2, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

9. The method according to claim 2, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

10. A system comprising:

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piping configured to receive a recycle stream, wherein the recycle stream includes an injection gas and C_3 to C_8 hydrocarbons; and

a separator coupled to the piping and configured to separate the recycle stream into a purified recycle stream and a natural gas liquids stream,

wherein the purified recycle stream includes the injection gas,

wherein the natural gas liquids stream includes the C_3-C_8 hydrocarbons, and

wherein the recycle stream, the purified recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified recycle stream and the natural gas liquids stream.

11. The system according to claim 10, wherein the injection gas comprises carbon dioxide, nitrogen, methane, ethane, air, and/or water.

12. The system according to claim 10, wherein the separator is configured to separate the recycle stream into the purified recycle stream and the natural gas liquids stream using a phase separator and/or a column.

13. The system according to claim 10, wherein the recycle stream comprises C_1 to C_2 hydrocarbons, and wherein the separator is configured to separate the C_1 to C_2 hydrocarbons into the purified recycle stream.

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14. The system according to claim 10, wherein the system is further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream, wherein the sweet natural gas liquids stream includes the C_3-C_8 hydrocarbons, and wherein the acid gas stream includes H_2S and/or CO_2.

15. The system according to claim 10, wherein the system is further configured to:

receive a feed stream;

separate the feed stream into the recycle stream and a heavy hydrocarbons stream, wherein the heavy hydrocarbons stream includes C_{9+} hydrocarbons; and

dehydrate the recycle stream using a dehydration solvent before separating the recycle stream into the purified recycle stream and the natural gas liquids stream.

16. The system according to claim 10, wherein the separator comprises a separation column, a reboiler, and a condenser, wherein the separation column receives the recycle stream, wherein the reboiler receives a first portion of the recycle stream from the separation column and generates the natural gas liquids stream, and wherein the condenser receives a second portion of the recycle stream from the separation column and generates the purified recycle stream.

17. The system according to claim 10, wherein the purified recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified recycle stream includes substantially all of the injection gas, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the recycle stream, wherein a molar percentage of the injection gas in the purified recycle stream is greater than a molar percentage of the methane in the

purified recycle stream, wherein the natural gas liquids stream includes substantially none of the injection gas and a second portion of the C_3 hydrocarbons from the recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.

18. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids; and

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas,

wherein the natural gas liquids stream comprises the natural gas liquids,

wherein the natural gas comprises C_1 to C_2 hydrocarbons, and

wherein the natural gas liquids comprise C_3-C_8 hydrocarbons.

19. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;

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separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids; and

separating a feed stream into the carbon dioxide recycle stream and a heavy hydrocarbon stream, wherein the heavy hydrocarbon stream includes C_{9+} hydrocarbons.

20. A method comprising:

receiving a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide, natural gas, and natural gas liquids;

separating the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream, wherein the purified carbon dioxide recycle stream includes the carbon dioxide and the natural gas, and wherein the natural gas liquids stream comprises the natural gas liquids;

receiving a feed stream, wherein the feed stream includes carbon dioxide, C_1 to C_2 hydrocarbons, C_3-C_8 hydrocarbons, C_{9+} hydrocarbons, branched hydrocarbons, and aromatic hydrocarbons; and

separating the feed stream into a heavy hydrocarbon stream and a carbon dioxide recycle stream, wherein the heavy hydrocarbon stream includes substantially all of the C_{9+} hydrocarbons, the branched hydrocarbons, and the aromatic hydrocarbons from the feed stream, wherein the heavy hydrocarbon stream includes substantially none of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream, and wherein the carbon dioxide

recycle stream includes substantially all of the carbon dioxide, the C_1 to C_2 hydrocarbons, and the C_3-C_8 hydrocarbons from the feed stream,

wherein the purified carbon dioxide recycle stream includes substantially all of the C_2 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially none of the C_2 hydrocarbons from the carbon dioxide recycle stream, and

wherein the purified carbon dioxide recycle stream includes substantially none of the C_3 hydrocarbons from the carbon dioxide recycle stream and the natural gas liquids stream includes substantially all of the C_3 hydrocarbons from the carbon dioxide recycle stream.

21. A set of process equipment configured to:

receive a carbon dioxide recycle stream, wherein the carbon dioxide recycle stream includes carbon dioxide and natural gas liquids; and

separate the carbon dioxide recycle stream into a purified carbon dioxide recycle stream and a natural gas liquids stream,

wherein the purified carbon dioxide recycle stream includes the carbon dioxide,

wherein the natural gas liquids stream includes the natural gas liquids, and

wherein the carbon dioxide recycle stream, the purified carbon dioxide recycle stream, and the natural gas liquids stream are not subjected to cryogenic conditions, membranes, and carbon dioxide recovery solvents between being received and being separated into the purified carbon dioxide recycle stream and the natural gas liquids stream.

22. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises natural gas, and wherein separating the carbon dioxide recycle stream into the

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purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the natural gas into the purified carbon dioxide recycle stream.

23. The set of process equipment according to claim 21, wherein the carbon dioxide recycle stream comprises acid gas, and wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream includes separating the acid gas into the natural gas liquids stream.

24. The set of process equipment according to claim 23, further configured to separate the natural gas liquids stream into a sweet natural gas liquids stream and an acid gas stream.

25. The set of process equipment according to claim 21, further configured to dehydrate the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream.

26. The set of process equipment according to claim 21, further configured to:

compress the carbon dioxide recycle stream before separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream; and

add additional carbon dioxide to the purified carbon dioxide recycle stream to form a carbon dioxide injection stream.

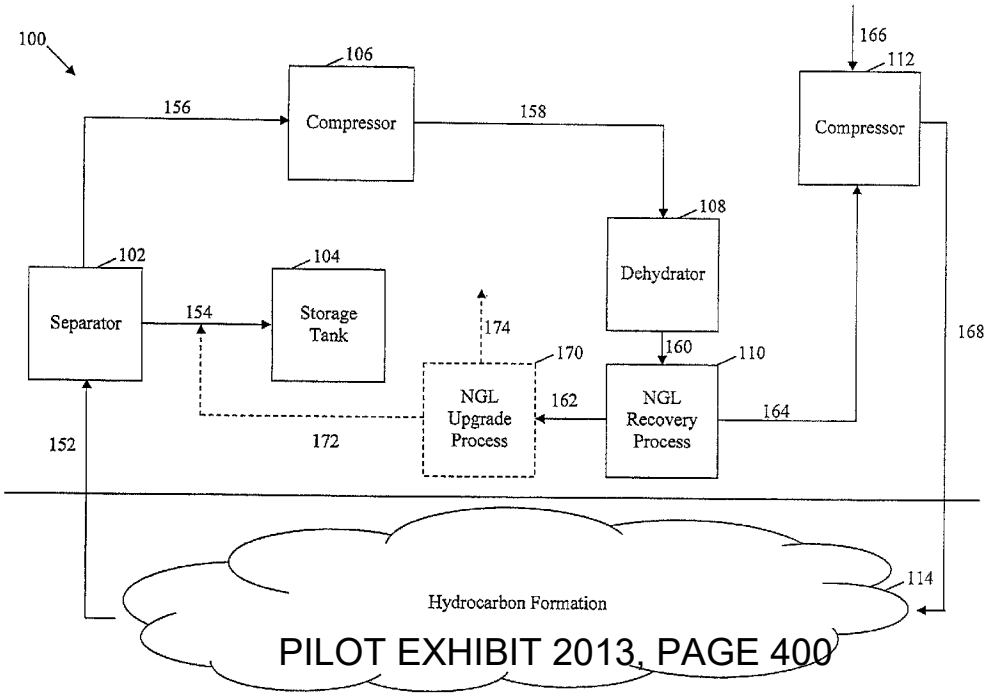
27. The set of process equipment according to claim 21, wherein separating the carbon dioxide recycle stream into the purified carbon dioxide recycle stream and the natural gas liquids stream comprises:

receiving the carbon dioxide recycle stream at a separation column;

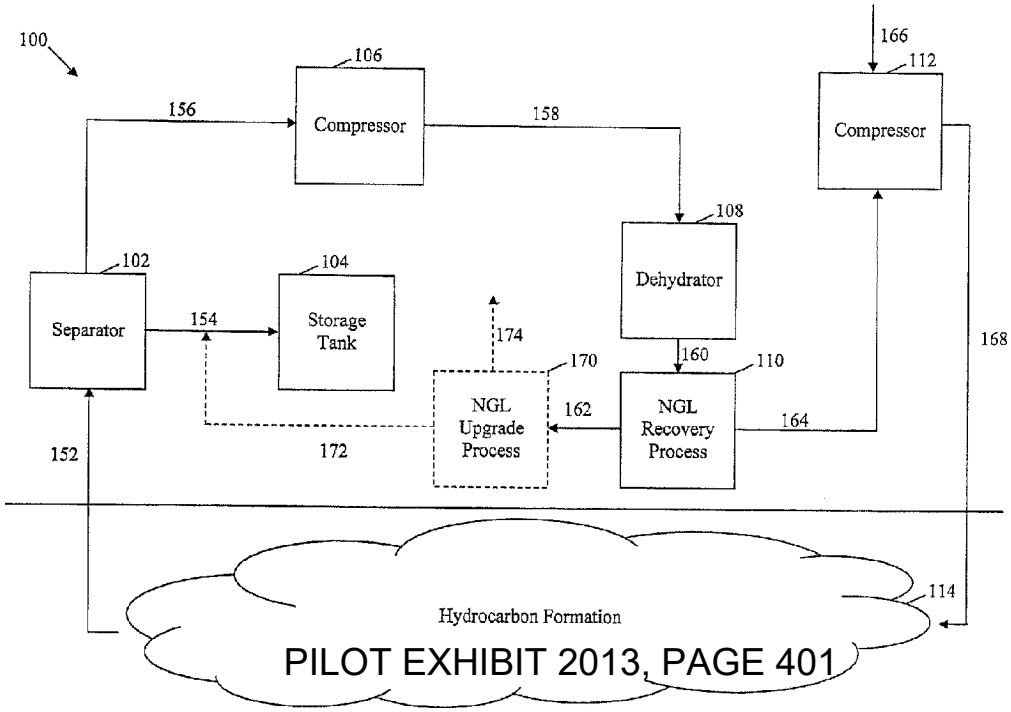
reboiling a portion of the carbon dioxide recycle stream received from the separation column with a reboiler to generate the natural gas liquids stream; and

condensing another portion of the carbon dioxide recycle stream received from the separation column with a condenser to generate the purified carbon dioxide recycle stream.

28. The set of process equipment according to claim 21, wherein the purified carbon dioxide recycle stream is suitable for reinjection into a subterranean formation in an enhanced oil recovery process, wherein the purified carbon dioxide recycle stream includes substantially all of the carbon dioxide, substantially all of the methane, and a first portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein a molar percentage of the carbon dioxide in the purified carbon dioxide recycle stream is greater than a molar percentage of the methane in the purified carbon dioxide recycle stream, wherein the natural gas liquids stream includes substantially none of the carbon dioxide and a second portion of the C_3 hydrocarbons from the carbon dioxide recycle stream, wherein the second portion of the C_3 hydrocarbons contains a greater amount of the C_3 hydrocarbons from the carbon dioxide recycle stream than the first portion of the C_3 hydrocarbons, and wherein the first portion of the C_3 hydrocarbons includes approximately 0.8 mole % to 3.2 mole % of the purified carbon dioxide recycle stream, and wherein the second portion of the C_3 hydrocarbons includes approximately 17.2 mole % to 28 mole % of the natural gas liquids stream.



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