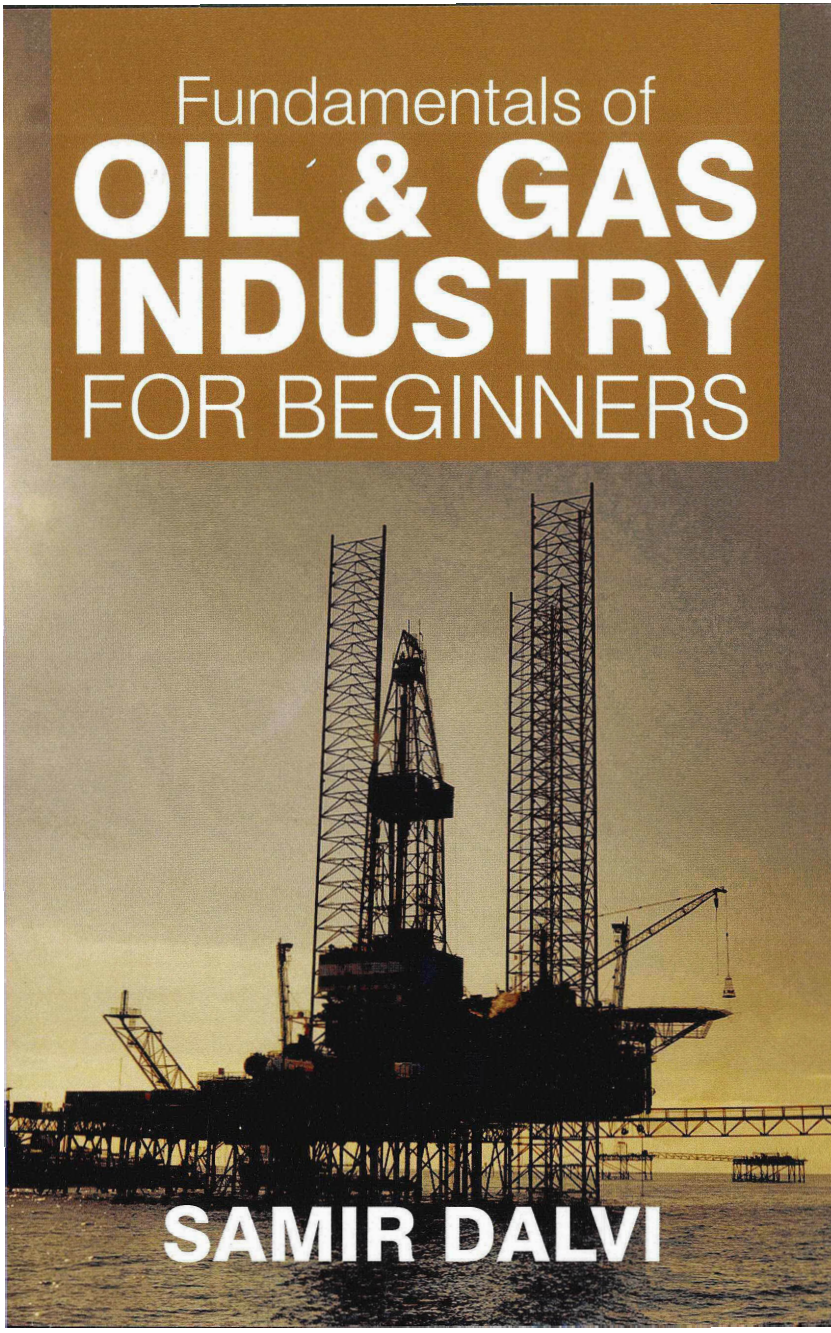

Fundamentals of
OIL & GAS
INDUSTRY
FOR BEGINNERS
SAMIR DALVI

FUNDAMENTALS OF OIL & GAS INDUSTRY FOR BEGINNERS | Samir Dalvi

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PREFACE

I began my career in the Oil and Gas Industry many years ago. As a novice in this sector, I had a lot of difficulty in understanding various processes, equipment and requirements of the upstream oil and gas industry. I searched for a lot of books which are meant to explain the fundamentals of the oil and gas sector. Of course, there are a number of books which offer detailed explanations of a particular process or operation in the industry, but there was no book which offered a broad perspective of the entire oil and gas sector. There was no book meant for beginners. Having realized this, it crossed my mind that I should write a book which would compile information on the oil and gas industry, which a beginner often needs.

This book will introduce a beginner to the chronological sequence of operations that are performed, starting from the exploration and surveying for prospective oil fields, drilling for oil, commissioning of platforms, to oil production and preliminary processing to transportation of oil to the refinery. Apart from this, I have added a separate chapter dedicated to non-conventional sources of oil and gas. This chapter was intentionally added, with the purpose of introducing the reader to this prospective field of producing oil and gas, which will be instrumental after exhaustion of conventional oil fields.

The information in this book is correct and verified to the best of my knowledge. But, there may be some deficiency as no one can claim 100% perfection. If readers find such shortcomings, they are most welcome to contact me via email at samirdalvi.norge@gmail.com. All these comments will be verified and necessary changes will be incorporated in the coming editions. Before I conclude, I would like to say that this book does not cover any detailed study of the oil and gas field but instead, gives the beginner a bird's eye view to visualize the working of the entire upstream oil and gas industry.

Kind Regards
Samir Dalvi
Sunday, April 11, 2015

1 | Introduction to the Oil and Gas Industry

1.1. Prelude

Petroleum Products have become an inseparable part of our everyday life. The application of hydrocarbons touches every aspect of our daily activities be it cooking (Fuel Gas), traveling (Transportation Fuels), electricity and much more. The development of the hydrocarbon industry started in the latter half of the 20th Century. It would not be inappropriate to say that it was this period that the oil and gas industry was born. Even though there is some evidence that suggests the use of hydrocarbons in the past 1500 years or so, the development of oil and gas industry was meteoric. The more prominent among many of the events that triggered the development of this industry was the Industrial Revolution of the 16th Century and the demand of authentic and quick modes of transport and logistics during the colonial era of American and European powers.

World War II was highly disastrous, as it took the life of nearly 60 million people. But, it proved to be an important milestone in the growth of the Hydrocarbon industry. Though the war was destructive, its effect on technological advancement was constructive. During the course of the war, a number of scientific inventions were made in the field of welding technology, metallurgy, organic chemistry, chemistry, electronics and computation and numerous other fields. These inventions like many other sectors, paved the way for the growth and development of the oil and gas sector, too. We will see some examples of how this Great War shaped the oil and gas industry. The offshore oil and gas industry started its evolutions after the 60's. The modern offshore platforms are the direct descendents of the Thames sea forts.

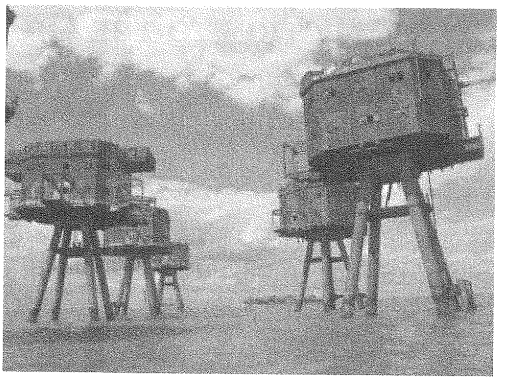


Fig. 1.1: 1p Thames Sea Forts

The Thames sea forts, or the Maunsell Fort, were fortified towers built in the Thames and Mersey estuaries by the British Navy. The British feared a naval and aerial invasion by Nazi Germany. Another example is the Fischer-Tropsch Process which was developed during the First World War to produce liquid petroleum from Coal. This was augmented and used by the Axis Powers i.e., Nazi Germany and its allies, during World War II to fuel their war machines and planes with synthetic petroleum, as they were poorer in crude oil production.

1.2. HISTORY OF OIL

1.2.1. During Ancient and Medieval Times: The exact origin and early history of petroleum is not known and still is a subject of historical research. However, there are various theories on the existence and application of petroleum and natural gas. We will consider the most common among them. The word petroleum is derived from the Greek Word meaning "Rock Oil". In the olden days, Petroleum was called *Naphtha*. The Zoroastrian Persians called it "naft". The Ukrainian word **нафта** (lit. nafta) and the Russian word **нефть** (lit. neft') mean "crude oil". There is a strong opinion (via Greek, which means all sorts of Petroleum) that the word Naphtha is originally derived from the name of Vedic god Apam Napat (popularly known as *AGNI*). The word Agni in Sanskrit means fire. It closely resembles to Latin ignis (the root of

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English word Ignite), Russian огонь (*ogon*), Polish "ogień," Lithuanian - *ugnis* - all with the meaning 'fire'.

In earlier times, petroleum was used in its raw state without refining. Historical records suggest that the Chinese had drilled oil wells to a depth of around 250 meters in 347 CE or earlier. The Chinese were using Natural Gas for boiling water and heat generated from burning oil was used for evaporating the brine for making salt. Petroleum was popularly known in China and Japan as burning water. Ancient Mesopotamia had its share of Eternal Flames, which were most likely maintained by gaseous hydrocarbons that seeped to the surface from the depths where they had been formed. The Egyptians bought asphalt from the peoples of the Dead Sea area to balm their deceased. Greece and Rome used petroleum for cosmetic purposes, warfare and illumination. The ancient Indian art of warfare of using burning arrows at belligerents used petroleum soaked cotton warped around the head of arrow. These burning arrows were used to set enemy cities and army supplies ablaze. It has also been reported that the glorious ancient Indian Civilization like the Mayan civilization, the Incas of Pre-colonial American history (before 1500 C.E.) had developed techniques of extracting and refining hydrocarbons. They used it in rituals, for medicinal purposes and as a base for paints. However, the development of hydrocarbon industry had to wait till the advent of industrial revolution.

1.2.2. In Modern Times: The petroleum industry of modern times distinguishes itself from the earlier one in the sense that the modern industry uses refined petroleum products instead of directly using it in its crude form. The modern oil industry started its evolution in the primitive days of the industrial revolution. The development of the oil industry expedited after the invention of internal combustion engine. In the earlier days of development of IC engines scientists experimented with using alcohol as the fuel for engine, but soon this idea was replaced by gasoline (Petrol) which has comparatively higher degree of calorific value than alcohol. Gasoline Engines were essential for designing successful aircraft. Ships driven by oil could move up to twice as fast as their coal-fired counterparts, a vital military advantage.

The exploration for oil wells began in the 19th Century. Imperial Russia produced 3500 Tons of oil in 1825 and doubled its output by the mid-century. In 1849, Russian Engineer F.N.SEMYENOV used a cable

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tool to drill an oil well on the Apsheron Peninsula. After oil drilling began in Russian province of Azerbaijan in 1848, two large pipelines were built in the Russian Empire: the 833 Kilometres long pipeline to transport oil from the Caspian to the Black Sea port of Batumi and 162 Kilometres long pipeline to carry oil from Chechnya to the Caspian. Almost around 200 refineries were set up in the Russian Empire by the end of 1884. At the end of the 19th Century the oil production of imperial Russia dominated the world, its production entirely from the Apsheron peninsula accounted for nearly half of the world's production. The American Oil industry started 10 years later to Imperial Russia, in 1859 when Colonel Edwin Drake drilled his "Famous Oil Well of Pennsylvania". The Drake Well was located in a quite farm country in the Pennsylvania province of United States. These wells were shallow by modern standards, but could come up with quite a large production. In the picture from the Tar Farm, oil creek valley, the Phillips Well on the right was flowing initially at 4000 barrels per day in October 1861, and the Woodford Well on the left came in at 1500 barrels in July, 1862. Readers can notice the many wooden tanks in the photo. These tanks were used to collect oil. At that time, barrel sizes were not standardized. Today, though, one barrel is 159 liters. The American oil industry developed exponentially, and later on, overtook Russia, and became the world's largest producer of oil by the first quarter of 20th Century.



Fig. 1.2: 2 p Oil Industry of Imperial Russia Baku in 1890

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The beginning of the second half of the 20th Century saw the oil production being shifted to offshore, when the "Superior Oil Company" of US commissioned the world's first offshore oil platform off the gulf coast of Louisiana in 1947.



Fig. 1.3: 3p Lake of Oil in Baku

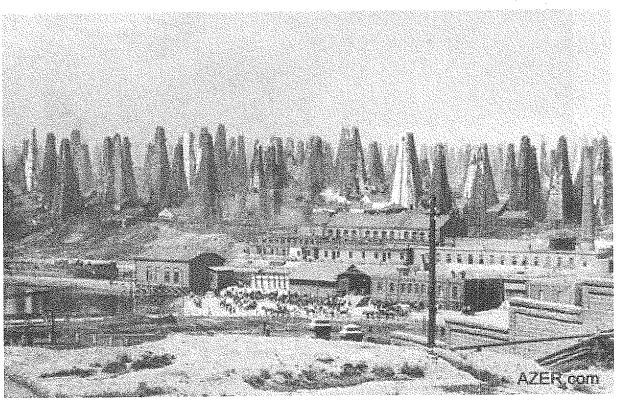


Fig. 1.4: 4p Congested Oil Derricks in the region, Noble Oil Wells in Balakhani a suburb of Baku

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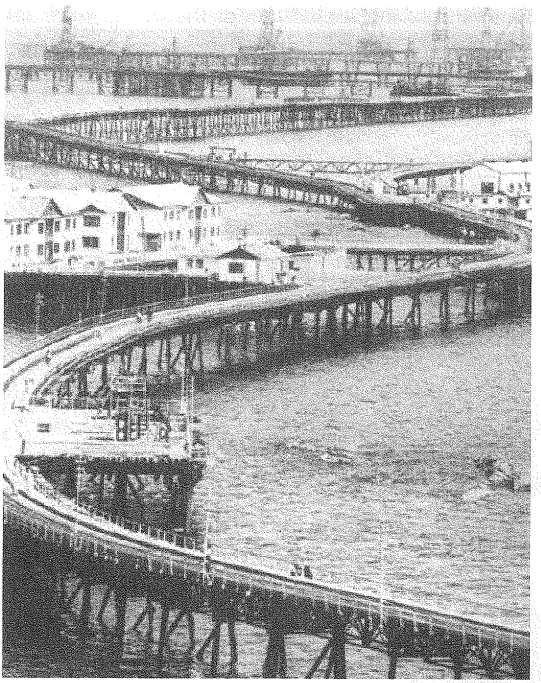


Fig. 1.5: 5p 100 Kms offshore pipeline in Caspian Sea during the Soviet Era

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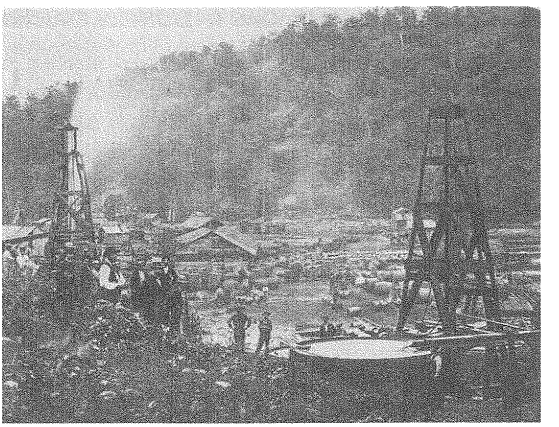


Fig. 1.6: 6p Colonel Drake's Oil Well in Pennsylvania province drilled in 1859

1.3. Scope of the Hydrocarbon Industry in Modern Times.

The arena covered by the Hydrocarbon industry is difficult to measure, be it transportation fuel, plastics, synthetic rubber, synthetic coke for thermal power generation, fuel for cooking and illumination among other things, which are products directly provided by the hydrocarbon industry. There are over thousands of products and byproducts that come from the hydrocarbon sector, paints and varnishes, cosmetics, some medicines and synthetic fibers are manufactured from the refined byproducts, obtained from crude distillation. The size and branches along with the offshoots are increasing day by day, which in turn has increased the production demand from hydrocarbon industry. So to meet the ever increasing demand, some non-conventional sources of hydrocarbon are being worked out. Heavy crude, oil shale and tar sands are some of the examples. We will be discussing these non-conventional hydrocarbon sources in the seventh chapter.

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1.4. How is the oil and gas industry organized?

Numerous activities and processes are involved starting from the exploration for oil to the production of finished products (Petrol, diesel, jet fuel, kerosene, natural gas etc.) from oil refineries. All these activities are grouped together in different segments. The first segment consists of activities that start with the exploration and concludes with the preliminary processing of crude oil and gas. The final product of this segment is sent to the refinery. This first segment is called the upstream hydrocarbon sector. Activities such as refining and distribution of finished products are grouped under the second segment, which is called the downstream hydrocarbon sector. For the sake of simplicity, we can say that the entire hydrocarbon industry is broadly classified into the Upstream and Downstream hydrocarbon industry. However, apart from this broad classification, API further precisely classifies it into 5 sub categories.[1]

Classification of petroleum industry according to API

1.4.1. Upstream Hydrocarbon (i.e. Exploration and Production Sector): This industrial sector includes all activities that are undertaken right from searching for the potential petroleum reservoirs that may be underground or underwater oil or gas fields, to the preliminarily processing of crude oil and gas. Once the reservoir is found and properly estimated for the sufficient quantity of hydrocarbons, then by means of high-tech drilling technology, the exploratory wells are drilled followed by regular production from the wells. The crude oil is pre-processed before being sent to the oil refinery. This pre-processing is done mainly to remove impurities such as water, solid particles such as drill chips, mud etc. also the raw natural gas is desulphurized (if it is a sour gas) so that it can be conveniently stored or transported through pipelines. After preprocessing, the crude/gas is then stored in large storage tanks. This semi-treated crude/gas is then sent to metering stations from where it is transferred to refineries. The metering stations are the demarcation point from where our upstream sector terminates with the beginning of downstream industry. The metering point is also

1 The American Petroleum Institute (API) categories the entire petroleum sector into different classes. (Web Link: http://www.api.org/aboutoilgas/sectors/index.cfm)

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called custody transfer since it indicates the transfer of product custody from upstream to downstream industry.

The scope of our book is also concerned with upstream hydrocarbon industry.

1.4.2. Downstream Hydrocarbon (i.e. Refining and distribution): The Downstream industry originates from the point where custody transfer takes place. The downstream sector is broader in size as compared to upstream. Since it involves the refining of crude oil into hundreds and thousands of products, this sector covers the refineries and the distribution / transportation and marketing of finished petroleum products. Sometimes, the downstream sector is broken down further into midstream and downstream. The refining activities are grouped under midstream whereas the distribution of petroleum products by means of pipeline network and tankers is grouped under downstream sector. But for the sake of simplicity, the refining and distribution activities are grouped under downstream industry. The downstream industry touches consumers through thousands of products such as petrol, diesel, jet fuel, heating oil, asphalt, lubricants, synthetic rubber, plastics, fertilizers, antifreeze, pesticides, pharmaceuticals, natural gas and propane.

1.4.3. Marine: The Marine Segment involves all aspects of transporting petroleum and petroleum products by water, including port operations, maritime firefighting and oil spill response. Oil tankers make up a major portion of this segment.

1.4.4. Pipelines: This is an important sector classified by API. It covers the network of pipelines which are used for carrying raw gas and crude oil from land or offshore oilfields to the refinery, and again after refining, to the retail outlets. Transportation by pipelines is considered to be one of the most efficient ways of moving liquid and gaseous hydrocarbons. The most important among these is that the pipelines should work continuously for 365 days of the year.

1.4.5. Service and supply: Service and supply companies are an integral part of the oil and natural gas industry. Many of these are local companies that provide oil and gas services to operations in their area, while others are global manufacturers selling products for oil and gas operations around the world. They include:

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1.4.5.1. Manufacturers of equipment used in all aspects of the oil and natural gas industry. This includes manufacturers of some of the most technologically advanced equipment used in the search for oil and gas. It also includes the equipment that allows the industry to operate in an environmentally safe way. Apart from this, it also consists of manufacturers of equipments that are used in refineries as well as in oil and natural gas exploration and production. For example, K. Lund and Larsen and Toubro.

1.4.5.2. Drilling contractors, who supply both the drilling rigs and the crews that search for oil and natural gas both onshore and offshore. Economists often measure the health of the industry based on the number of drilling rigs that are operating both on land and in the waters off the Outer Continental Shelf in the ocean. These drilling rigs undertake the initial search for oil and gas, and when their work is completed, they move on to the next site. For example, the Baker Hughes Oil Company.

1.4.5.3. Service companies that assist oil and gas producers in maintaining the facilities that keep oil and natural gas production flowing. For example, Schlumber

1.4.5.4. Research and development and Design Engineering: It includes the Engineering companies that design and support the sophisticated oil and natural gas operations, including those operations that improve the refining capacity of existing refineries or companies that design complex systems for oil and natural gas exploration and production. For example, Aker Solutions

1.4.5.5. Inspection companies that provide qualified inspectors in all areas of the industry, including aboveground storage tank inspectors and pipeline inspectors.

For example, Engineers India Ltd.

1.5. Process Flow of a Typical Upstrem Oil and Gas Production Process

The figure below explains the various stages that the well stream undergoes right from extraction, separation of gas, water and oil, its metering, storage and offloading. There are numerous oil and gas wells throughout the globe. They differ in size, depth, capacity and type of facility (onshore or offshore). It may be located in shallow 20 meters

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of water depth or it can be 10,000 dollar onshore wells or even a 10 billion dollar offshore structure. In spite of such a wide variety many parts of the processes applicable to these wells are similar in principle. The entire process is actually divided into two sub processes, namely, the **main process** and **auxiliary process**. Details of this are illustrated below.

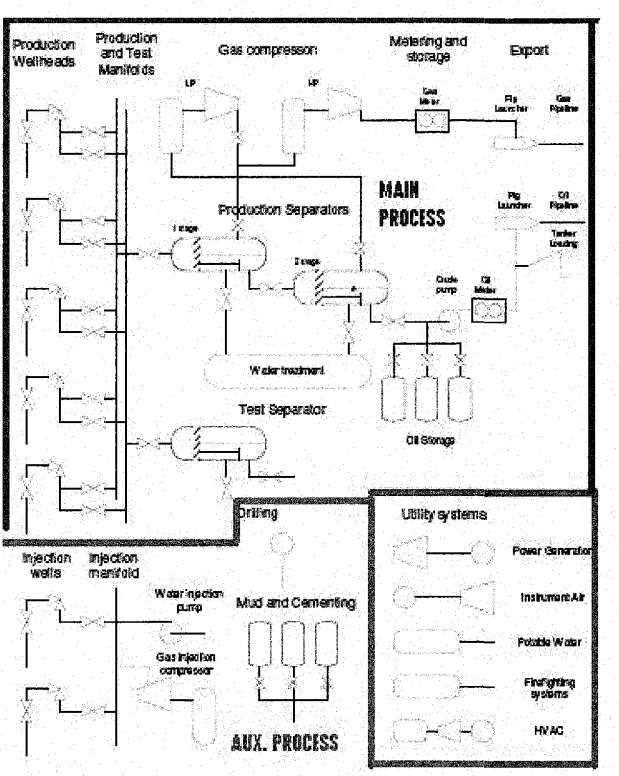


Fig. 1.7: 7p A short overview of pre processing of oil/gas before sending it to refinery

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1.5.1. Main process: The main process has two parts.

1.5.1.1. Well head: There are a number of wells connected to the production and test manifold. As can be seen from the diagram, in a distributed production system this would be called as the gathering system.

1.5.1.2. Separation: The major component of the main process is the separation process, often called as the Gas Oil Separation Plant (GOSP). The well stream coming from any oil or gas installation contains raw gas (methane, butane, propane etc.), condensates (medium density hydrocarbons) and crude oil. Apart from this, the well stream contains a number of other unwanted constituents such as sea water, carbon dioxide, salts sulphur and sand. The purpose of the GOSP is to remove these impurities and supply clean marketable products.

1.5.2. Auxiliary process: The systems grouped under this category are separate from the main process but essential for the functioning of main process. It includes the following components:

1.5.2.1. Utility System: Provides energy water, air, and steam and many other utilities to the plant.

1.5.2.2. Injection System: This system injects water or gas into the production wells to get the enhanced oil recovery.

1.5.2.3. Drilling: These systems are used for drilling on oil rigs. Apart from this, the others include mud and cementation. This was a short overview of the entire process. Each of this components discussed above will be explained in greater details in the subsequent chapters.

1.6. Hydrocarbon Industry and Global Environment.

The birth of modern hydrocarbon industry was accompanied with pollution as its fellow companion. As the hydrocarbon industry grew over the years, so did its adverse effect on the environment. Today's petroleum industry, both upstream and downstream has caused serious environmental challenges. The most devastating among these effects is climate change which has challenged the existence of life on this planet. Apart from this, there are many adverse effects on our planet, such as decreasing rainfall, loss of land fertility for agriculture, and pollution of water bodies. Each of these effects has posed a serious question on the quality of drinking water, and overall, the negative effect of

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pollution has reduced the immunity of today's humans. We will be having glimpses into the impact of petroleum industry on the global environment in this chapter. A majority of pollution problems in the downstream industry while refining crude oil, gas or transportation of finished goods, will be omitted in this section, though the major share of pollution crises are caused during crude refining and further stages of treatment and distribution of finished products, as the focus of this book is to cover the upstream sector.

1.6.1. Global Warming and climate Change: The temperature of our planet has increased by more than 1 degree Fahrenheit from 1900. The speed of warming has increased almost 3 times after 1970. This increase in earth's average temperature is called Global Warming. Global warming has resulted in climate change, which has affected the annual pattern of rainfall and extreme variations in temperatures that has brought up chilling cold or severely hot seasons. Most scientists around the world have agreed on a common opinion that human activities are responsible for this increase in earth's temperature. The emission of green house gases such as carbon dioxide, methane and nitrous oxide from vehicle exhausts, industrial processing and power plants are responsible for global warming and climate change.

Greenhouse gases absorb most of the radiation from the sun, but arrests some of the heat in the earth's atmosphere from radiating back to the space, thus heating the earth. This has resulted in the melting of ice glaciers in Polar Regions which has resulted in drastic rise in sea level. We can take the example of the Sundarbans, the only natural habitat of Bengal tigers. The Sundarbans will be submerged under water due to the increasing sea levels in the Bay of Bengal, due to the melting of ice in the Himalayas, which is a result of climate change and global warming.

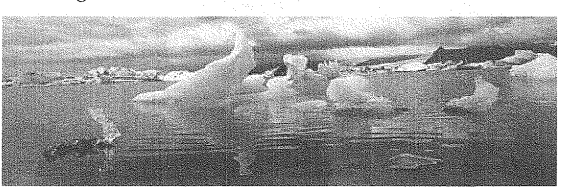


Fig. 1.8: 8p Rising temperature of earth has resulted in melting of mountains of Ice slides in Polar Regions and Himalayas

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The solution to global warming is to minimize, or if possible, to eliminate the use of fossil fuels such as petroleum and coal, which are primary sources for releasing greenhouse gases. Various other means for replacing the fossil fuels are being experimented with, today. The most promising among them are Bio fuels and Solar Cells. But these are still under development stage. It will probably take around 20 years, say, till 2030, for them to get commercialized.

1.6.2. Different types of pollution due to extraction, production and refining of Petroleum.

In this segment, we will be discussing various kinds of pollution that take places due to activities of the petroleum industry.

1.6.2.1. Air Pollution: The quality of air that we inhale today is much more degraded than what our ancestors had some 100 years before. This has happened due to the obvious reason that we have aggravated the use of fossil fuels. The carbon monoxide that comes primarily from the exhaust of the petrol engine is highly toxic and the frequent inhaling of it in the automobile exhaust prone streets is the chief source of lung cancer, asthma and Tuberculosis.

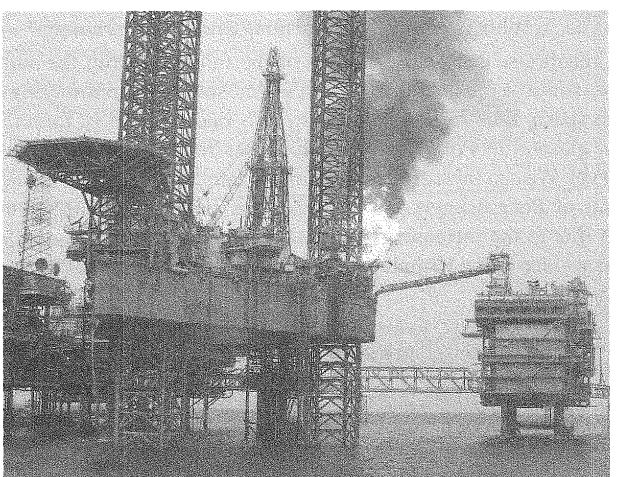


Fig. 1.9: 9p Air Pollution from Flare Stack at an Offshore Platform

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Every day, tons of green house gases and particulate matter are disposed in the atmosphere due to exploration and refining of petroleum. The particulate carbon and other impurities have resulted in acid rain and black snow fall. These are highly disastrous to the environmental eco system.



Fig. 1.10: 10p Air Pollution from an Oil Refinery

1.6.2.2. Water Pollution: The waste water from refineries and the produced water from the pretreatment of crude oil in onshore plant are responsible for water pollution. The wastewater in most cases in not properly treated in effluent treatment plant. This improperly treated water when discharged into rivers and fresh water streams has a deteriorating effect on the aquatic life and on the entire ecosystem of river as a whole. The Thane Belapur Creek is the best example of the worst kind of water pollution. In the early eighties, the waste water from refineries and number of chemical plant in Navi Mumbai Belapur Industrial Belt (located in Maharashtra State – India) was released into thane creek; this had a catastrophic effect on the aquatic species of fish and other marine vegetation. Today, the creek has turned into a sump of gutter with no existence of aquatic life in any form.

1.6.2.3. Pollution at sea: The Pollution at sea is mainly caused during the exploration and production of oil on the offshore oil rig. The transportation of oil and finished petroleum products may pollute the sea, if, due to an accident, oil is released from the oil tanker ship through an oil spill. The pretreatment of oil produces thousands of

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barrels of produced water. Apart from this, water is injected into the wells and the rest is returned to the sea. These things result in polluting sea water. The operation of the oil platform releases sanitary waste that is dumped into the sea. During the drilling operation, thousands of tons of debris are produced. This debris has a number of radioactive substances, rock particles, mud and other things. Dumping this solid waste into the sea has posed a serious threat to marine flora and fauna at sea.

1.7. THE FUTURE OF HYDROCARBON INDUSTRY.

Hydrocarbons or Petroleum are non-renewable forms of energy. They are bound to get exhausted in the near future, somewhere around 2040,[2] if the consumption of petroleum follows the current trend. It takes billions of years for an oil reservoir to mature. For example, a reservoir that is about 6 crore years old is considered young and unsuitable for hydrocarbon recovery. On the other hand, a mature reservoir has approximately an age of 10 to 20 crore years. As the global petroleum reserves start depleting, the price of oil will go on increasing exponentially, and we would be force to develop some other alternative for oil. Perhaps no one will be able to use oil till the reserves are over, due to the sky rocketing prices of oil that will occur in a final phase of global reservoir exhaustion. The extensive use of petroleum has resulted in climate change due to global warming. This has also pressurized governments of many developed nations to engineer national energy programs for the development of other sustainable energy sources that are less harmless to the environment. Today, around 60% of the world's energy demand and 96% of fuelling the transportation industry is met with petroleum. This trend of consumption is difficult to maintain in the future. Some argue that with the advancement of technology in the future, petroleum would produced at an economically and environmentally sound manner from resources that are currently impracticable for oil production, such as oil shale and tar sands. It is estimated that both the Canadian tar sands and United States oil shale deposits represent potential reserves with

2. The BP Statistical Review of World Energy 2007 Web Link: http://en.wikipedia.org/wiki/Petroleum_industry#Environmental_impact_and_future_shortages)

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just as much oil as current liquid petroleum deposits.[3] Efforts are being concentrated on the development of renewable energy sources as they being increasing environmental friendly compared to fossil fuels.

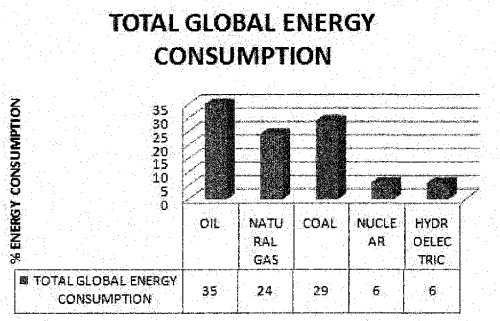


Fig. 1.11: 11p Today's Global Energy Consumption

Definitely, petroleum will be replaced with renewable sources of energy such as bio-petroleum and bio-diesel, but huge amount of research will be necessary to make this alternative to petroleum, cheap and economical to end users.

REFERENCES

Books

Offshore Engineering An Introduction.
By Angus Mather, Published by Witherby and Comapnay Limited, 32-36 Aylesbury Street London, UK.

Oil and Gas production Handbook.
By Håvard Devold, ABB

Environmental Technology in Oil Industry.
By S.T.Orszulik, Printed and Published by Blackie Academic and professional, and imprint of Chapman 7 Hall, Boundary Row, London, UK.

3. From an article written by Lambertson, Giles (16th Feb, 2008) in Construction equipment Guide (Web URL: http://www.constructionequipmentguide.com/Oil-Shale-Ready-to-Unlock-the-Rock/10092/

Profrac Holding Corporation
U.S. Well Services, LLC
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Ex. 1010, p. 26 of 111

Beyond Oil and Gas: The Methanol Economy
By George Andrew Olah, Alain Goeppert, G. K. Surya Prakash

INTERNET

From Wikipedia

Petroleum, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Petroleum (Last Accessed on Monday, September 21, 2009)

Petroleum Industry, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Petroleum_industry (Last Accessed on Monday, September 21, 2009)

Oil Shale, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Oil_shale (Last Accessed on Monday, September 21, 2009)

Bioenergy, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Bioenergy (Last Accessed on Monday, September 21, 2009)

Biofuels, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Biofuel (Last Accessed on Monday, September 21, 2009)

Global Warming, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Global_warming (Last Accessed on Monday, September 21, 2009)

Environmental Issues with Petroleum, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Environmental_issues_with_petroleum (Last Accessed on Monday, September 21, 2009)

From Other Websites.

Oil Home Basics, retrieved from website of Energy Information Administration. URL: http://tonto.eia.doe.gov/kids/energy.cfm?page=oil_home-basics (Last Accessed on Monday, September 21, 2009)Introduction to Oil Basics, Exploring the debate over peak oil.

Profrac Holding Corporation IPR2023-01319 Ex. 1010, p. 27 of 111
U.S. Well Services, LLC

URL: http://www.oilscenarios.info/oilbasics.htm (Last Accessed on Monday, September 21, 2009)

Main Article "What is Oil Shale?" Published by Oil Shale and Tar Sands Proagrammatic EIS Information Center.

URL: http://ostseis.anl.gov/guide/oilshale/index.cfm (Last Accessed on Monday, September 21, 2009)

Main Article 'Effects of Global Warming' retrieved from the website of an NGO Global Warming .org. URL: http://www.globalwarming.org.in/# (Last Accessed on Monday, September 21, 2009)

Petroleum and Environment, retrived from World Petroleum Council. URL: http://www.world-petroleum.org/education/exprod/index.html (Last Accessed on Monday, September 21, 2009)

Petroleum Industry and its ecological impacts, retrieved from ecological Journal Do Or Die Published from UK. URL: http://www.eco-action.org/dod/no7/59-65.html (Last Accessed on Monday, September 21, 2009)

Main Article 'Petroleum' Published by Environmental Literary Council. URL: http://www.enviroliteracy.org/article.php/77.html (Last Accessed on Monday, September 21, 2009)

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2 | Oil and Gas Reservoir

2.1. Introduction

The oil and gas reservoir is a sub-surface pool of hydrocarbons that are contained in porous rock formations. The reservoirs were formed when the naturally occurring hydrocarbons were trapped among the rock formations with lower permeability. This rock containing organic matter that turned into petroleum rock is referred to as the source rock. Oil and natural gas are contained in the tiny pore spaces in these source rocks, similar to water in a sponge. For extracting hydrocarbons (Oil and Gas), this petroleum rock is punctured by drilling a bore through it and then tubing is inserted into it to extract the formed hydrocarbons.

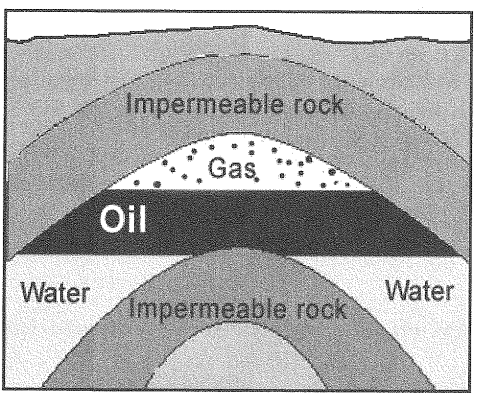


Fig 2.1.12p Diagrammatic representation of a Petroleum Reservoir. Photo Courtesy, msnucleus.org

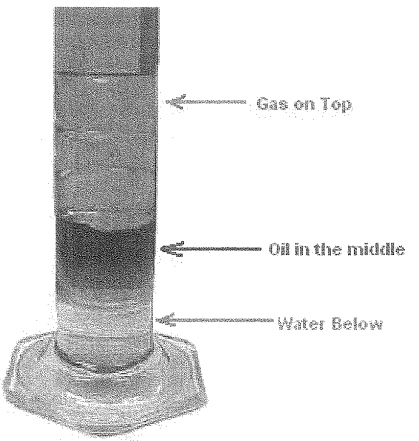


Fig. 2.2.13p Liquids Separated By Density. Photo Courtesy, msnucleus.org

Some reservoirs are only hundreds of feet below the surface, while others are thousands of feet underground. Many offshore wells are drilled in thousands of feet of water and penetrate tens of thousands of feet into the sediments below the sea floor. Most reservoirs contain oil, gas, and water. Gravity acts on the fluids and separates them in the reservoir according to their density, with the gas on top, the oil next, and then water. (similar to the photo shown on right 2.2.13p). However, other parameters, such as fluid or rock properties and solubility will restrict complete gravitational separation.

2.2. CRUDE OIL

Crude oil is properly known as petroleum, and is a kind of fossil fuel. The crude is composed of five principle components, namely, Carbon, Hydrogen, Oxygen, Nitrogen and Sulphur. They all exist in the form of long chains of complex organic mixture. Of this, carbon and hydrogen are the desired whereas others are unwanted and need to be removed. But it is practically impossible to completely eliminate these undesirable components. However, they can only be controlled and reduced.

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2.2.1. Classification of Crude oil: The crude oil is generally classified into 3 ways by the petroleum industry:

Firstly, by the geographical location from where the crude has been extracted. The crude oil extracted from different regions varies in property, appearance, density and molecular structure. In this way, crude is branded from the location where it is extracted such as West Texas intermediate (WTI) for North American Oil, Brent Blend for European oil from North Sea and Dubai-Oman for Middle eastern oil. More information on this can be found in article "2.2.2 Crude Oil Benchmark". The geographical location for classifying crude oil is utmost important because it involves transportation cost to refinery.

Secondly, its density which is specified by API Gravity Number, thicker the crude, the lower the API gravity number and vice versa (i.e. higher the API gravity lighter is the crude). Lighter crude (i.e. oil with low density) is mostly desirable as it has higher yield for Petrol or gasoline. Heavy crude is difficult for transportation, extraction and refining, also its processing involves lot of environmental concerns.

Third, depends on sulphur content i.e. sweet crude (Lower Sulphur Content) and Sour Crude (Higher Sulphur Content). Crude has sulphur content below 0.5% and is considered sweet, whereas above 0.5% is called Sour Crude. Sweet crude is desirable as it requires fewer efforts for refining compared to sour one to meet the sulphur standards imposed on fuels by the consuming countries.

2.2.2. Crude Oil Benchmark: Crude Oil Benchmarks are the reference points which are useful for grading the crude oils by comparing them with respect to Crude extracted from a particular region. A benchmark crude is standard for a specific region. There are primarily three benchmarks, WTI, Brent Blend and Dubai Oman. The Crude Benchmark serves the purpose for pricing the crude depending upon their grade.

2.2.2.1. West Texas Intermediate (WTI): It is also known as Texas Light Sweet crude. This crude is the benchmark for North American Crude Oil. WTI is light crude with 0.24% sulphur making it sweet also. Its properties make it ideal for refining in United States. WTI has an API gravity of around 39.6.

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2.2.2.2. Brent Blend or Brent Crude: This is a benchmark for European crude from the North Sea. This benchmark is a mixture of crude oil from 15 different oilfields in the North Sea. These oil fields are located in the Oseberg, Ekofisk and Long Forties regions of the North Sea. The name Brent comes from the name of a sea bird Brent Goose, as the major operator of North Sea region Shell UK, had a policy of naming all their fields after birds. The Brent Crude is somewhat inferior to WTI. It falls next to WTI when it comes to superiority. It contains 0.37% of sulphur, classifying it as sweet crude but not as sweet as WTI. Brent crude has an API of around 38.06

2.2.2.3. Dubai Crude: Dubai crude is a benchmark crude for Middle Eastern crude. It is light sour crude extracted from Dubai. This crude is inferior in quality when compared to the two kinds of crude that have been explained above i.e., WTI and Brent Crude. Dubai crude is mostly used for pricing the Persian Gulf crude oil export for Asia. Apart from the three prominent Benchmarks for crude oil there are some other blends such as OPEC Basket used by OPEC, Tapis Crude which is a Malaysian crude oil used as Benchmark in Singapore, Bonny Light [This is a very high grade Crude with high API gravity (32.9) and very low sulphur content (0.16%) produced in Nigerian Delta] used in Nigeria and Isthmus-34 Light in Mexico.

2.2.3. API Gravity: API Gravity is the measure of how heavy or light a crude oil is when compared to water. In other words, API gravity of particular crude is nothing but merely measurement of the specific gravity or the density of that crude. API gravity is a pure number which indicates the type of crude i.e. whether heavy, medium or light. The API number is inversely proportional to the density of crude, which means that the higher the API Number for a given crude, the lighter it will be in density. Conversely, as the crude becomes heavier the lower will be its API Number. Mathematically API Gravity has no units. Generally, the premium crude oil which has highest price and is most suitable for refining falls between 40 and 45 API Gravity number, Above 45 degrees the crude is not suitable for refinery. The crude oil classified as Light, Medium and heavy by using API Gravity number is explained below.

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- Light crude oil is defined as having an API gravity higher than 31.1°API
- Medium oil is defined as having an API gravity between 22.3°API and 31.1°API
- Heavy oil is defined as having API gravity below 22.3°API.
- Crude below the API gravity of 10 is considered extra heavy crude.

2.3. Oil/Gas Reserves:

Oil reserves are the estimated quantities of crude oil that are claimed to be recoverable under existing economic and operating conditions.

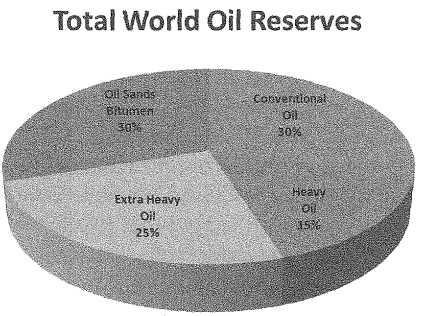


Fig. 2.3.14p Current Oil Reserves of the world. Photo Courtesy, The Market Oracle

2.3.1. Recovery Factor

The total amount of oil in an oil reservoir is known as 'oil in place'. However, because of reservoir characteristics and limitations in petroleum production technology, only a fraction of this oil can be brought to the surface, and it is only this producible fraction that is considered to be a reserve. The ratio of reserves to oil in place for a given field is often referred to as the recovery factor. The recovery factor

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of a field may change over time, based on operating history and in response to changes in technology and economics. The recovery factor may also rise over time if additional investment is made in enhanced oil recovery techniques such as gas or water-flooding.

2.3.2. Types of Oil Reserves

All reserve estimates involve uncertainty, depending on the amount of reliable geological and engineering data available and the interpretation of those data. The relative degree of uncertainty can be expressed by dividing reserves into two principle classifications – proved and unproved. The most commonly accepted definitions of these are based on those approved by the Society of Petroleum Engineers (SPA) and the World Petroleum Council (WPC) in 1997.

2.3.2.1. Proved Reserves

Proved reserves are claimed with reasonable certainty (80% to 90% confidence) to be recoverable in the future years by specified techniques. Industry specialists refer to this as P90 (i.e. having a 90% certainty of being produced). Proved reserves are also known in the industry as 1P. Proved reserves are further subdivided into Proved Developed (PD) and Proved Undeveloped (PUD). PD Reserves are reserves that can be produced with existing wells and perforations or from additional reservoirs where minimal additional investment (Operating Expense) is required. PUD reserves require additional capital investment (drilling new wells, installing gas compression, etc.) to bring the oil and gas to the surface.

2.3.2.2. Unproved Reserves

Unproved reserves can further be divided into two subcategories – probable and possible to indicate the relative degree of uncertainty about their existence. Probable reserves are either unsubstantial claims or based on median estimates of the accumulation that are more likely to be recovered than not (50% confidence). Industry specialists refer to this as P50 (i.e. having a 50% certainty of being produced). Proved plus probable reserves are known in the industry as 2P. Possible

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reserves ideally have a chance of being developed under favorable circumstances. Industry specialists refer to this as P10 (i.e. having a 10% certainty of being produced). Proved plus probable plus possible reserves are known in the industry as 3P.

2.4. Formation of Oil and Gas.

Oil that we used today was formed inside the earth's crust from buried organic matter some million years ago. The process of oil formation goes on continuously, even today. A young reservoir (e.g. 60 million years) often has heavy crude, needs another 60 to 75 million years to get matured and fit for producing a quality hydrocarbon. This is why oil is called a non-renewable form of energy resources.

2.4.1. Story of Formation

In prehistoric times, conditions for oil formation have been particularly favorable. Oil from the North Sea was formed during the Jurassic period about 150 million years ago, long before people roamed the earth. During this period seas and swampy areas were rich in microscopic plants, algae and animals. When these died, they slowly sank to the bottom forming thick sediments layers of organic material, which was trapped under a layer of mud covering it. In this way oil and gas was formed from the anaerobic decay of organic material under conditions of increased temperature and pressure. With the layers of mud preventing air from reaching the organic material, the organic material could not rot in the same way as organic material rots away in a compost heap. The pressure on organic material increased as the layers of mud became thicker, and so the organic material was pushed deeper and deeper and it was subjected to increased pressure and elevated temperature. These conditions proved favorable for micro-organisms that can live without oxygen, which started acting on the organic material. In these conditions, which can be compared to the state within a pressure cooker, crude oil and gas was formed.

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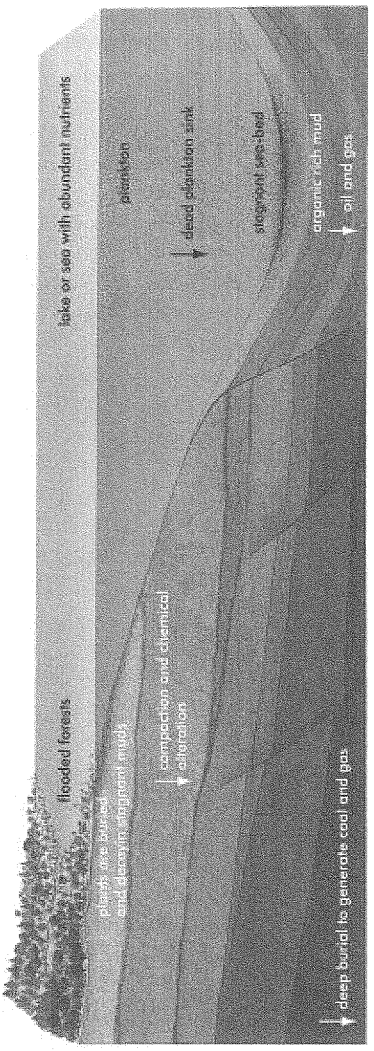


Fig. 2.4.15p Story of Oil and Gas Formation Photo Courtesy, Oil and Gas UK

Oil formed first, and then as the temperature and pressure increased at greater depth, gas started forming. The whole pressurized, airless process lead to the formation of dark substance called '**Kerogen**'.

The cellulose and woody part of plants were eventually converted to coal and woody Kerogen. Rocks containing sufficient organic substances, to generate oil and gas in this way, are generally known as source rocks. As the source rock temperature increases, chains of hydrocarbon chemicals use this heat energy to separate from the Kerogen, forming waxy and viscous heavy oil. As the temperature rises at greater depths, the chains of hydrocarbons become shorter and separate, to form light oil and gas. Oil and gas is formed as a result of a precise sequence of environmental conditions:

- The presence of organic materials.
- Organic remains being trapped and preserved in the sediment. They are buried at greater depths where they are subjected to intense pressure and high temperature where they are slowly "broiled".

2.4.2. Migration of Oil and Gas.

Once formed, oil and gas migrates form the source rock. There are two reasons why this happens.

1. The oil and gas expands, increasing the pressure in the rock and then tries to escape.
2. Being less dense than surrounding rock and water, it tends to rise upwards. This is a slow process. It takes millions of years for the oil and gas to rise a few kilometers.

So, what happens to the migrating oil and gas? Having no seal above the source rock, the oil and gas slowly rises and escapes at the surface. This does happens on occasions but, when it does, no oil and gas deposits can build up. A permeable rock has pores that are connected and so allows oil and gas to flow through. The pores in the rock are spaces that occur between the individual rock particles. This porous rock is called the 'reservoir'.

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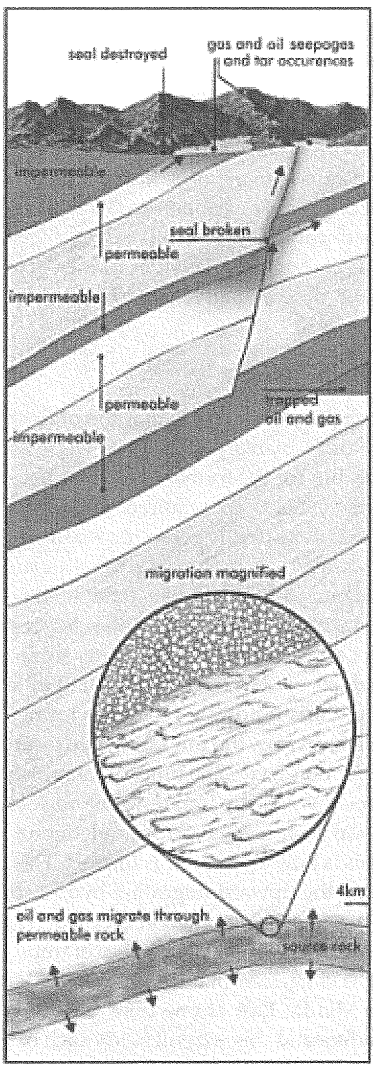


Fig. 2.5.16p Migration of Oil and Gas. Photo Courtesy, Oil and Gas UK

Impermeable rocks are the ones which are bereft of pores or any tiny openings. It is this impermeable rock which acts as a positive seal upon the reservoir rock and prevents the escape of hydrocarbons (oil and gas). A lot of people assume that crude oil is a "lake" beneath the earth's surface, but it's actually held in pores of porous rock, similar to water held in a sponge. Once formed, crude oil and gas slowly rise upwards, seeping into the tiny pores in a porous rock. Eventually, the oil and gas reaches a layer of impermeable rock and is trapped. In the absence of impermeable rock, the oil and gas eventually advances towards the surface and no oil reserve is formed. This impermeable layer which seals the upwards advancing hydrocarbon is called the seal.

2.4.3. Trapping of Oil and Gas

We have seen in our previous articles that the oil is formed from the organic remains of dead plants and animals who were buried some million years before. But for the formation of an oil/gas reservoir three important geological elements are required. They are a **reservoir rock**, **source rock** and most importantly a **cap, or seal rock**. Hydrocarbons are formed in the source rock, they rise up as they are formed, being lighter than the surround matter, they tend to migrate from high pressure deeper zones of earth to comparatively lesser pressure regions within earth's crust i.e. nearer to the earth's outer surface. If the upward migrating hydrocarbons are not restricted at all, they simply come out above the ground and this is how an oil seep is formed. So in order to form a hydrocarbon reservoir, the migrating hydrocarbons need to be trapped below the ground level. The function of arresting this upward migrating oil is done by specific impermeable rock structures which act as a seal. This seal rock results in accumulation of the arrested oil and gas and thus this is how a reservoir is formed. This arrangement of arresting or retaining the upward migrating hydrocarbon in reservoir is called Trap and the entire phenomenon is called Trapping of oil and gas. A reservoir cannot develop in the absence of traps. We will take an example for this, It is suggested that the Ohio River Valley could have as much oil as the Middle East at one time, but that escaped due to lack of traps. To understand this we will study each of these geological elements in details. Let us see.

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a) **Reservoir Rock:** Reservoir rock is mostly sandstone which has a lot of pore spaces located within it to store the oil. Oil can freely move through these spaces. In the photo the purple Colour spaces indicates the pores, these are the areas where the oil fits into the reservoir rock.

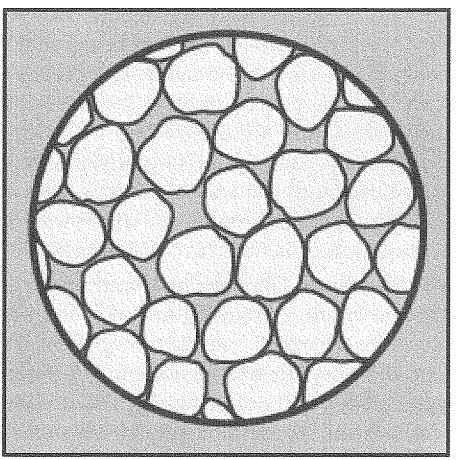


Fig. 2.6.17p Structure of Reservoir Rock Photo Courtesy, priweb.org

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It is similar to a sponge which is soaked with water. Limestone's and dolomite, some of which are the skeletal remains of ancient coral reefs, are other examples of reservoir rocks.

b) **Source Rock:** In petroleum geology, the Source Rock is the organic rich rock which can produce or has the ability to produce hydrocarbons. They are organic rich sediments that may have been deposited in a variety of environments including deep water marine, lacustrine and deltaic. Biological remains of plants and aquatic animals sank to the bottom of seafloor as they died, where they were mixed up with clay and sand. In a span of over millions and billions of years they were buried deeper and deeper due to addition of new layer of beds on the seafloor, they solidified into a rock which was rich in organic sediments. This rock is called as 'source rock'.

c) **Traps or Seal Rock:** Once the hydrocarbons begin to migrate through a reservoir, continuing to rise in the water or till the earth's surface, a barrier is needed to stop them. If such a barrier is absent, the reservoir will be nothing but a transit zone and the hydrocarbons will not be able to accumulate. To stop the hydrocarbons, an impermeable rock called a seal or a cap rock, is necessary above the reservoir. Cap rocks are often clays and sometimes layers of crystallized salt. In our next discussion, we will see the different ways in which the hydrocarbons are trapped i.e., different types of traps.

2.4.3.1. Different Types of Traps: Hydrocarbon traps are broadly classified as structural traps, statigraphic traps and combination traps. However it is very difficult to classify this phenomenon of 'trapping of oil' so rigidly as it involves numerous other parameters and conditions. In real life, it has a combined set of conditions from both types, i.e., structural and statigraphic. This has the combination of events from both categories that are grouped separately as the third type of trap i.e., combination trap. Let us see how these traps are classified.

a) **Structural traps**: Structural traps are formed due to deformations in rocks as a result of the erosion or folding of the rock. There are three types of traps that are grouped under structural traps. They are:

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i) **Anticline Traps**: These occur where rocks have been pushed or folded by powerful forces within the earth's crust. An anticline is an example of rocks which were previously flat but have been bent into an arch. Oil that finds its way into a reservoir rock that has been bent into an arch will flow to the crest of the arch and get stuck, provided, of course, that there is a trap rock above the arch to seal the oil in place. The impermeable rock traps the crude oil, preventing it from flowing away like an unturned bucket.

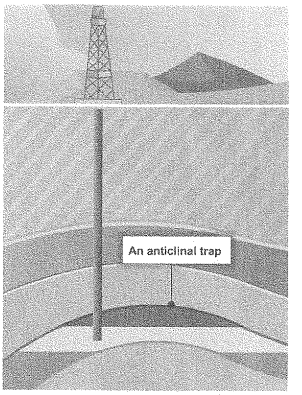


Fig.2.7: 18p Anticline Trap Photo Courtsey, criticalissuesform.org

ii) **Fault Traps**: It is created where a reservoir rock slides past another impermeable rock, to form a sort of dam trapping the flow of the moving oil.

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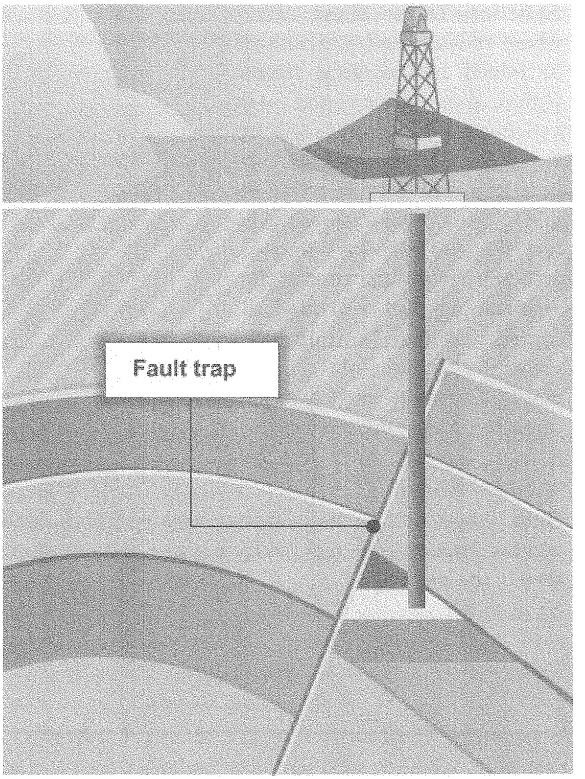


Fig.2.8: 19p Fault Trap Photo Courtesy, criticalissuesform.org

b) **Stratigraphic traps**: Stratigraphic traps are formed when the reservoir bed is overlapped and sealed by another bed of impermeable rock, thus trapping the migrating hydrocarbons. Stratigraphic traps are also said to be formed when the permeability or porosity changes within the reservoir bed itself.

c) **Combination traps**: The name implies that a combination trap is formed when two or more trapping mechanisms come together to create the trap. In reality, many successful oil traps are combination traps.

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2.4.3.2. Salt Domes: They are formed by a combination of rock movements forcing a layer of rock salt up through the layer of rock above. If one of these layers of rock is porous, oil and gas may become trapped by the salt dome which forms an impermeable plug.

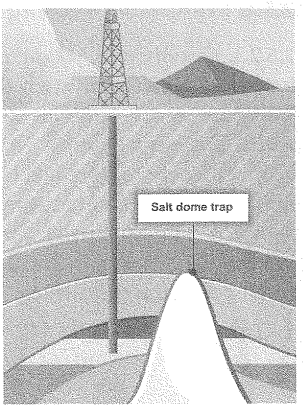


Fig.2.9: 20p Salt Dome Trap Photo Courtesy, criticalissuesform.org

2.5. SEARCHING FOR RESERVOIR.

The first and perhaps the activity of prime importance in an Upstream Hydrocarbon Sector is the searching for a hydrocarbon reservoir. This task precedes other activities (Drilling, Testing, Production and Offloading). The efficiency and profitability of the entire sector is directly proportional to the accuracy and precision of the end results from a search task. To be specific, the real challenge is to plan the exact location of drilling to harness the maximum possible capability of the reservoir. It is the accuracy of the search task that decides the 'Recovery Factor' and more details of the reservoir. Inaccurate search results have caused incidents where after drilling kilometers of depth, no oil or gas was found.

2.5.1. The Search for Oil and Gas Begins.

Drilling for oil is an extremely expensive business and has to be approached scientifically. Rock structures that contain oil or gas are hidden from view by the sea or other rock layer, and thus, we can't just go around drilling holes and hoping to strike one, luckily. This is the point where the role of geologist and geophysicist becomes instrumental. A geologist examines the composition of rocks where they are and the formations they make. A geophysicist uses the physical characteristics of rocks, their magnetic and gravitational properties, and how sound waves travel through different kinds of rocks.

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2.5.2. Exploration Techniques

2.5.2.1. Gravity and Magnetic Surveys: There are definite differences between igneous rocks (which were formed when hot molten magma from the earth's interior cooled and solidified) and sedimentary rocks. Sedimentary rocks were formed when small, worn particles of sediment were compressed together. We know that sedimentary rocks are less dense in comparison with heavy igneous rocks, which contain a lot of magnetic minerals. These differences can be detected by remote sensing surveys that are carried out from ships, without making direct contact with the rock structures beneath the sea.



Fig. 2.10: 21p Gravity and Magnetic Survey carried out by means of Aircrafts

Aerial photography can also deliver useful basic information. Aircrafts can be used to accurately measure the gravitational pull of the earth over an area. Small differences in the gravitational pull are caused by variations in the density of the underlying rocks, because some rocks are more magnetic than others, we can also measure variations in the strength of the earth's magnetic field. Different surveying techniques can be used to locate the particular rock formations that might contain trapped oil. Geologists and geophysicists can built up a detailed picture of the rock structures, using the results from these techniques. General survey techniques cover large areas quite quickly and easily and help to build a broad picture of the underlying rock structures. If the results are encouraging, a second stage of explorations is undertaken and a more detail seismic survey is carried out.

2.5.2.2. The Seismic Survey: A seismic survey involves firing pulses of sound energy down through the layers of rock beneath the earth and recording the energy that is "bounced back" by the rock layers below the surface. The way in which the sound energy travels back, depends on the kinds of rocks and the structures they form (It's a bit like bouncing a ball on different surfaces; we will experience a different bounce on the playground, grass, sand or against a sloping surface).

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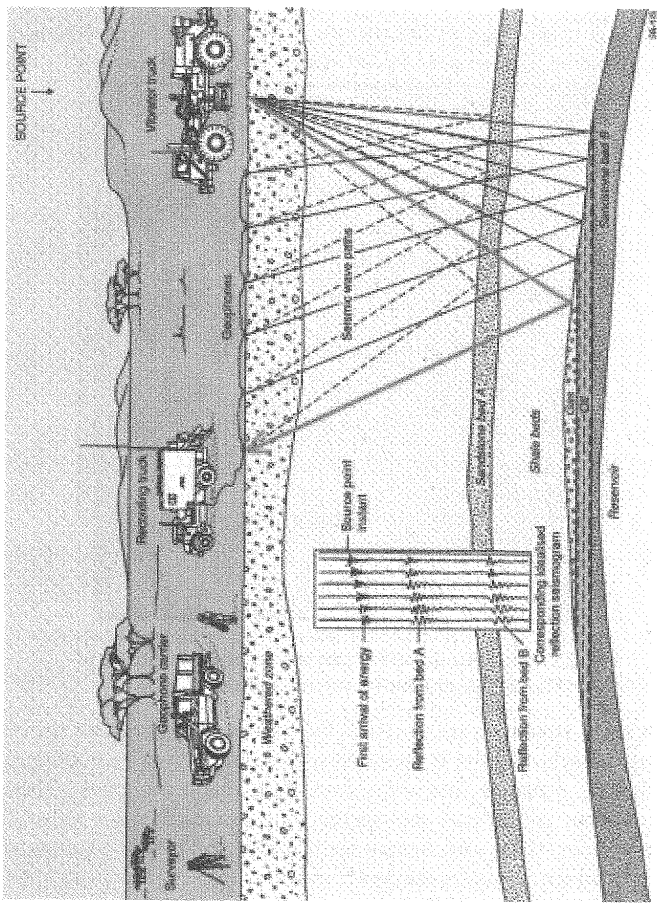


Fig. 2.11.22p Seismic Survey carried out on land Photo Courtesy, www.energyindustryphotos.com

2.5.2.3. Seismic Survey at Sea: This method is based upon the measurement of time taken by an echoed sound wave. Once the time is known, the depth of the seafloor and the location of a source rock can be anticipated. In offshore areas, these surveys are undertaken by ships which have submerged air or water guns at its rear end. These guns or wave projector probes fire blasts of shock waves into the water.

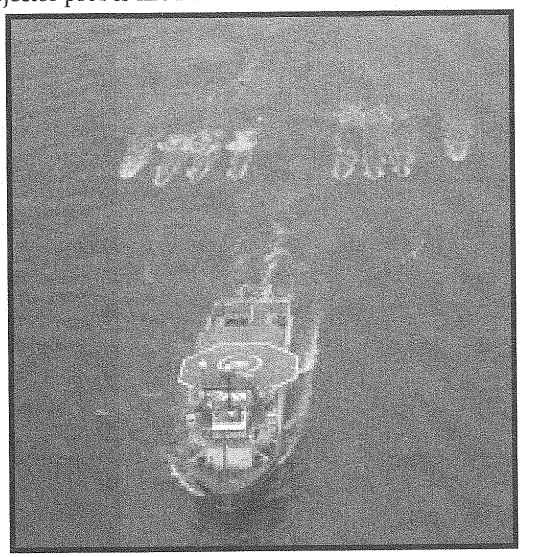


Fig. 2.12.23p Seismic survey carried out at sea by means of Marine vessel Photo Courtesy, Oil and Gas UK

A set of streamers are towed to the back of ship at certain meters in length. Each streamer is provided with dense array o hydrophones; which are sensitive listening devices like microphones. These hydrophones collect and receive the sonic waves that are reflected from sea floor. These sonic signals are recorded and send to a computer program which calculates the depth and other important aspects of the sea floor.

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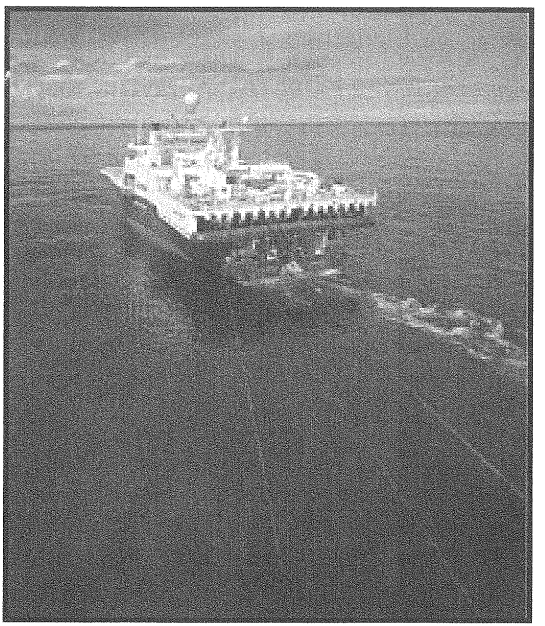


Fig. 2.13.24p Rear end of ship showing the attached strings which tethers hydrophones with ship Photo Courtesy, Oil and Gas UK

2.5.3. Assessment for Protection of Marine Environment.

Several things have to be considered before conducting a seismic survey at sea. One of these is the effect on birds, fish, and mammals like whales or dolphins, plant life and other creatures that live on the seabed. A full environmental assessment is therefore carried out before any seismic survey is started. This involves making a detailed study of the site to see whether whales migrate through the area and if so, at what time of year. In fact, everything that could possibly be affected by our activities is examined. At the end of this process, marine biologists produce an environmental report. This report shows how damage to the site can be minimized and if possible avoided completely. It might also mean that work cannot be carried out during certain months of

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the year, when fishing is going on, and also during a certain period of breeding or migrating seasons.

2.6. Data Acquisition, Interpretation and Processing End Results of Survey.

The seismic recording at sea uses COMMON DEPTH POINT (CDP) method. In this, seismic shots are fired at regular intervals. Shots are usually timed to occur at a distance equal to the separation of hydrophone groups. The shots which are fired from different points strike and are reflected from a common depth point back to the surface where it is collected by hydrophones.

The hydrophones are actually submerged below an array of streamers which are coupled to the back of a surveying vessel (See Photo 2.12.23p). These streamers are provided with GPS sensors that constantly record the position of the streamers relative to the vessel and the earth. The data acquired in form of echoed sonic waves by 3D-Sesmic survey is then passed on for interpretation which is done by dedicated software and the computer workstations which are essential tool for interpreting date quickly and to produce desired 3D graphics files.

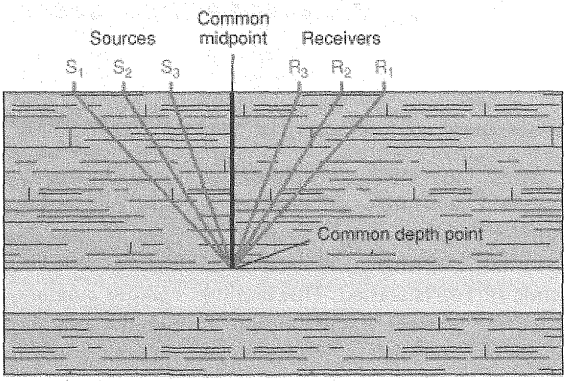


Fig. 2.14.25p Common Depth Point method Photo Courtesy, Schlumberger

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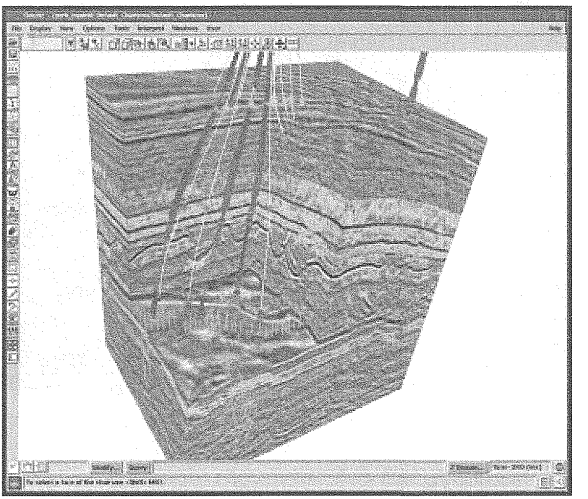


Fig. 2.15.26p Reservoir Modeling Software's

Recent developments have taken visualization to new horizons with the advent of virtual reality rooms, allowing 3D subsurface images to be viewed from almost any angle, allowing the picture of subsurface geometry to be quickly seen. Also, different development options, such as the impact of various drilling targets can be simulated. This has considerably reduced the time in exploration phase. It provides more accurate picture of the reservoir enabling us to drill at exact location so as to get the optimum production from a given reservoir.

2.7. Evaluating the Oil and Gas Filed.

Before deciding whether to develop a field, the company must estimate how much oil and gas can be recovered and how easily they can be produced. Here, the Recovery Factor plays an important role. Higher the recovery factor, the more the favourable conditions for developing a given field. Recovery Factor is determined by various factors such as reservoir dimensions, pressure, and the nature of hydrocarbons.

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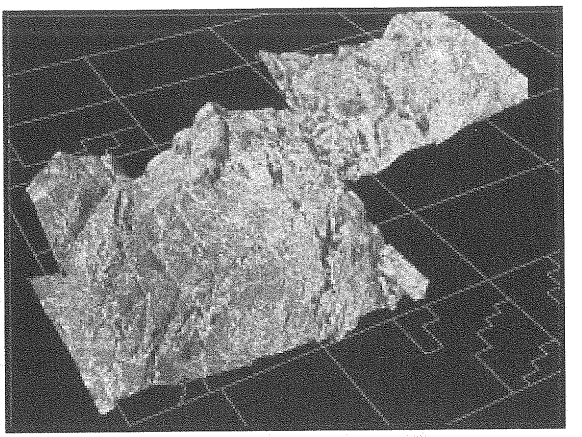


Fig. 2.16.27 3D Model of Reservoir Rock developed from the inputs obtained from survey Photo Courtesy, Oil and Gas UK

Pressure is the driving force in oil and gas production. Oil flow from the well is powered by the difference in pressures within the reservoir and the well, which can be thought of as a column of low surface pressure let into the highly pressurized reservoir. If the permeability of reservoir rock is good then reservoir fluids flows easily. Oil, gas and water will be driven out of well and up to the surface, by the natural pressure of the well. Expansion of the gas cap and water drives oil towards the well bore. Gas and water occupy the space vacated by the oil. In case of reservoirs with insufficient natural drive energy, water or gas is injected to maintain the reservoir pressure.

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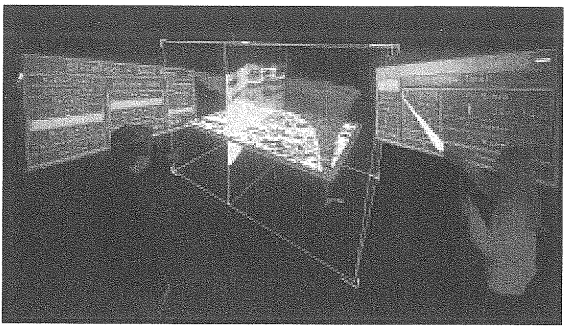


Fig. 2.17.26p Reservoir Simulation in Virtual Reality Rooms
Photo Courtesy, Oil and Gas UK

Each oil and gas reservoir is a unique system of rocks and fluids that must be understood before the production is planned. Petroleum engineers use all the data collected from the survey which is correctly interpreted and accurately processed. This data is used to develop a mathematical model of the reservoir. Computer simulation of the different production techniques are tried on the reservoir model to understand the reservoir behavior during production for each of these techniques, of these the most optimum method of recovery is selected. Factors, such as construction requirements, cost inflation and future oil prices are also considered when deciding whether to develop an oil or gas field. When the company is satisfied with the plans for development and production, then the plan needs be approved by the government body, which monitors all the aspects of offshore development. After this phase of 'exploration and planning to develop an oil field' is complete, the next challenge is to drill a well and make it ready for production which is explained in the next chapter.

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REFERENCES

Books

Offshore Engineering an Introduction.
By Angus Mather, Published by Witherby and Company Limited, 32-36 Aylesbury Street London, UK.

Oil and Gas production Handbook.
By Håvard Devold, ABB

Petroleum Geology: Developments in Petroleum Science 16
By R.E.Chapman, Published by ELSEVIER SCIENCE PUBLISHING COMPANY INC., New York.

Environmental Technology in Oil Industry.
By S.T.Orszulik, Printed and Published by Blackie Academic and professional, and imprint of Chapman 7 Hall, Boundary Row, London, UK.

Internet

From Wikipedia

Petroleum Reservoir, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Petroleum_reservoir (Last Accessed on Tuesday, October 20, 2009)

API Gravity, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/API_gravity (Last Accessed on Tuesday, October 20, 2009)

Petroleum Industry, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Petroleum_industry (Last Accessed on Tuesday, October 20, 2009)

Classification of Petroleum, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Petroleum#Classification (Last Accessed on Tuesday, October 20, 2009)

Profrac Holding Corporation
U.S. Well Services, LLC
IPR2023-01319
Ex. 1010, p. 53 of 111

Benchmark (Crude Oil), Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Benchmark_(crude_oil) (Last Accessed on Tuesday, October 20, 2009)

Light Crude Oil, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Light_crude_oil (Last Accessed on Tuesday, October 20, 2009)

Brent Crude, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Brent_Crude (Last Accessed on Tuesday, October 20, 2009)

Bonny Light Oil, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Bonny_Light_oil (Last Accessed on Tuesday, October 20, 2009)

Dubai Crude, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Dubai_Crude (Last Accessed on Tuesday, October 20, 2009)

Isthmus-34 Light, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Isthmus-34_Light (Last Accessed on Tuesday, October 20, 2009)

West Texas Intermediate, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/West_Texas_Intermediate (Last Accessed on Tuesday, October 20, 2009)

Tapis Crude, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Tapis_crude (Last Accessed on Tuesday, October 20, 2009)

Sweet Crude Oil, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Sweet_crude_oil (Last Accessed on Tuesday, October 20, 2009)

Hydrocarbon Exploration, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Hydrocarbon_exploration (Last Accessed on Tuesday, October 20, 2009)

From Other Websites.

What is an oil or natural gas reservoir? Wikipedia, from an educational resources website by SPE (Society of Petroleum Engineers).
URL: http://www.energy4me.org/questions/what_is_a_reservoir.htm (Last Accessed on Tuesday, October 20, 2009)

Formation of Oil and Gas, retrieved from Oil and Gas UK.
URL: http://www.oilandgas.org.uk/education/students/origins.cfm (Last Accessed on Tuesday, October 20, 2009)

Overview of Bonny Light Crude oil, retrieved from Chevron.
URL: http://crudemarketing.chevron.com/overview.asp?bonnylight (Last Accessed on Tuesday, October 20, 2009)

Origins of Oil and Gas, retrieved from Oil and Gas UK.
URL: http://www.oilandgasuk.co.uk/education/storyofoil/geological-01.cfm (Last Accessed on Tuesday, October 20, 2009)

Different Types of Hydrocarbon Traps, retrieved from Planet Energies.com.
URL: http://www.planete-energies.com/content/oil-gas/fields/hydrocarbon.html (Last Accessed on Tuesday, October 20, 2009)

Main article Structural Traps, retrieved from education resources website of Paleontological Research Institution.
URL: http://www.priweb.org/ed/pgws/systems/traps/structural/structural.html (Last Accessed on Tuesday, October 20, 2009)

Main Article "What is Oil Shale?" Published by Oil Shale and Tar Sands Program EIS Information Center.
URL: http://ostseis.anl.gov/guide/oilshale/index.cfm (Last Accessed on Monday, September 21, 2009)

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3 | Oil Well

3.1. INTRODUCTION

An oil well is a term used for any perforation through the earth's surface designed to find and release both petroleum oil and gaseous hydrocarbon. An oil well can also be described as a hole pierced through reservoir rock and pipes inserted to extract the hydrocarbon content of the reservoir. Practically speaking, oil or gas well is a 4" or 8" NPS pipe commencing out of the land or water surface, which has a number of objects mounted on its top end, called well head and Xmas tree.

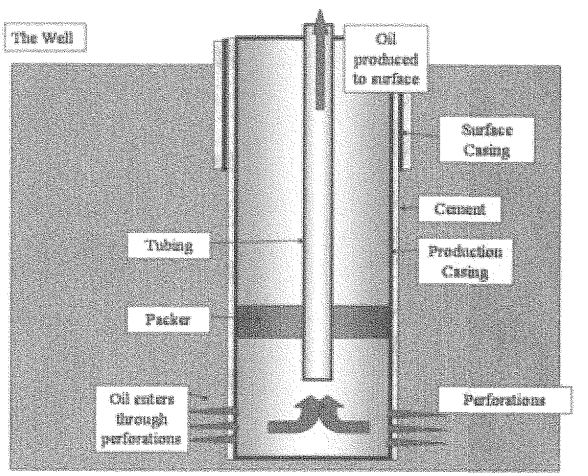


Fig.3.1: 29p A typical oil well with its different components

3.2. LIFE OF WELL

The chronological stages through which the well passes from its creation, sustenance till its desolation can be grouped into five segments, which are termed as life of well.

3.2.1. Drilling: The earliest oil wells were drilled percussively by hammering a cable tool into the earth. Soon after, cable tools were replaced with rotary drills, which could drill bore holes to much greater depths and in lesser time. The exploration and 3D – seismic survey evaluates the locations where we can drill to tap out the hydrocarbons [Readers are requested to go through the segment on exploration .i.e. "2.4 Searching for Reservoir]. Drilling is carried out by means of equipment called rig. The rig can be mounted on the mobile units for onshore or floating vessels in case of offshore. The main components of the drilling rig (As Shown in Fig. 3.2.30p) are the Derrick Floor, Draw-works, Drive and mud handling. The control and power can be hydraulic or electric. We will elaborate on these components that are part of rig in bit detail. Only important parts will be discussed. Let us see how they function.

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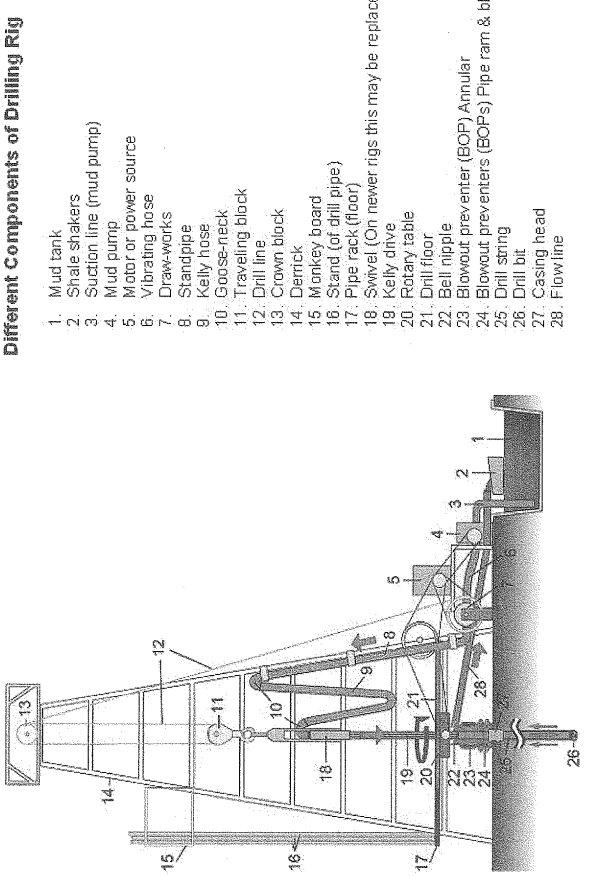


Fig. 3.2.30p Different Parts of an Oil Drilling Rig

3.2.1.1. Derrick: It is a rigid tower-like structure which supports the drilling apparatus. It is quite tall enough to accommodate newer drilling pipe sleeves that are inserted as the drilling progresses.

3.2.1.2. Main Power System: The main purpose of this system is to fulfill the energy demands of the oil producing unit. Normally, the wells (both onshore and offshore) are situated in remote locations, either several nautical miles from the shore or in a remote desert or in some cases even in valleys. In such a scenario, the unit requires a dedicated power station and distribution system. The unit which generates power for the oil producing station is called Main Power System. It is composed on two main components.

a. **Diesel Engine**: It is used as a prime mover for driving the electric generator.
b. **Electric Generators**: Power generated by electric generator is feed to the distribution system

3.2.1.3. Mechanical System:

a. **Traveling Block**: It consists of a set of sheaves that reciprocates in the derrick. The wire rope threaded through them is fastened back to the stationary crown blocks, located on top of the derrick. This pulley system gives great mechanical advantage to the action of the wire rope drilling line, enabling heavy loads (drill string, casing and liners) to be lifted out or lowered into the well bore[1].

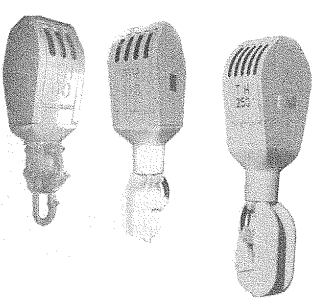


Fig.3.3.31p Traveling Blocks Photo Courtesy: Rugao Yaou Import and Export Trade Co. Ltd

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b) **Rotary Table**: The Rotary table, also known as 'Turn Table', is the mechanical device on a drilling rig (shown in number 20 and in blue colour in the diagram above) which turns the drill bit in clockwise direction (when viewed from the top). It provides the necessary drilling torque to drilling strings during the process of drilling.

c) **Drilling bit**: It is the cutting or boring element used in drilling oil and gas wells. Most bits used in rotary drilling are roller-cone bits. The bit consists of the cutting elements and the circulating element. The circulating element permits the passage of drilling fluid and uses the hydraulic force of the fluid stream to improve drilling rates. The fluid injected through the drill bit is called

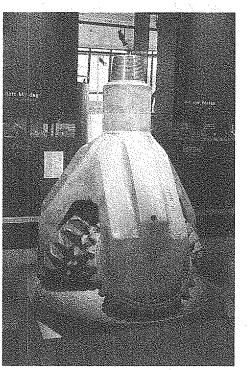


Fig.3.4.32p Drill Bit

'Mud'. The mud is injected under pressure at the drilling zone which helps in removal of chips (crushed rock pieces) and helps in cooling the drill bit[2].

d) **Drill String**: A drill string on an oil rig is an assembly of drill pipe, bit and drill collar which is connected to the rotation device (Coupling). The string of drill pipe transmits drilling fluid (via the mud pumps) and rotational power (via the Kelly drive or top drive) to the drill bit. The drill string is hollow so that the drilling fluid can be pumped down through it and circulated back up the annulus (void between the drill string and the formation).

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3.2.1.4. Swivel: It is a mechanical device that suspends the entire weight of the drill string. The swivel allows for the rotation of the drill string beneath it but its upper portion (which is connected to rope pulley from hoisting appliance) is stationery. The swivel has rotary coupling in it whose function is to permit high-volume flow of high-pressure drilling mud from the fixed portion to the rotating drill string without leaking.

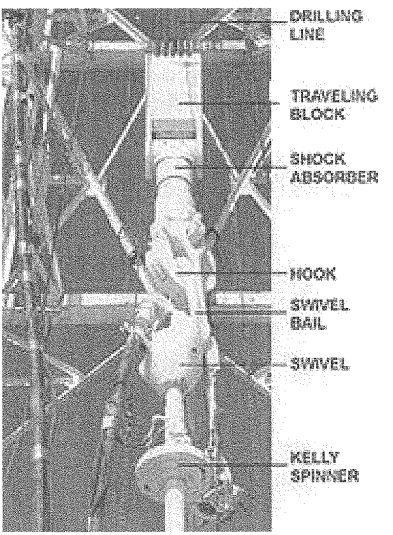


Fig.3.5.33p Drilling operation at work

3.2.1.5. Kelly Drive: Kelly Drive is a device used on oil drilling rigs. It has three important components Kelly bush, Kelly itself and Kelly hose. Kelly is a long square or hexagonal steel bar with a hole drilled through the middle for a fluid (Drilling Mud) path. It is used to transmit rotary motion from Kelly bushing to the drill-string, while allowing the drill-string to be lowered or raised during rotation. The Kelly goes through the Kelly bushing, which is driven by the rotary table. The Kelly bushing has an inside profile matching the Kelly's outside profile (either square or hexagonal), but with a sliding fit such that the Kelly can freely move up and down inside. Kelly hose is the one which supplies the pressurized drilling mud to the drilling zone through the

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hollow drill-string and bit. The top portion of the Kelly bush is fastened to the swivel by means of left-hand threads, this is especially important as it prevents loosening of Kelly since it is subjected to the right hand drilling torque. Together, they are referred to as a Kelly drive.

3.2.1.6. Cooling and Lubrication System: The drilling operation involves a lot of heat generation at the cutting zones where the drill bit actually crushes the rock. This heat generated by friction between the tool and material being cut needs to be dissipated. For this purpose coolant is needed. Drilling mud is used to perform the twin function of coolant and lubricant, this fluid is injected under high pressure through the hollow drill bit to the drilling zone. A drilling rig has a separate system dedicated for cooling and lubrication of the drill bit. This system plays a vital role, the efficient cooling and lubrication system gives efficient drilling results and increases the life of drill. Let us study the important constituents of this system.

a. **Drilling Mud:** A mixture of clay, water, chemical additives, and weighting materials that flushes rock cuttings from a well, lubricates and cools the drill bit, maintains the required pressure at the bottom of the well, prevents the wall of the borehole from crumbing or collapsing, and prevents other fluids from entering the well bore[3].

b. **Mud Sump:** It is a large tank used to store the drilling mud on the rig. Apart from the rig this tanks can also be found in the mud mixing plants. In case of land rigs, they are usually made of fabricated steel tanks which have number of partitions within it. The holding capacity of each partition is about 200 barrels. In case of offshore rigs, the mud sump is a part of drilling rig and consists of huge capacity up to about 1000 barrels. In the primitive days, the open earthen pits where most popular which were directly excavated into ground but today this kind of pits have become absolute because of its devastating effect on environment. Today, earthen pits are used only to store used or waste mud and cuttings prior to disposal and remediation of the site of the pit.

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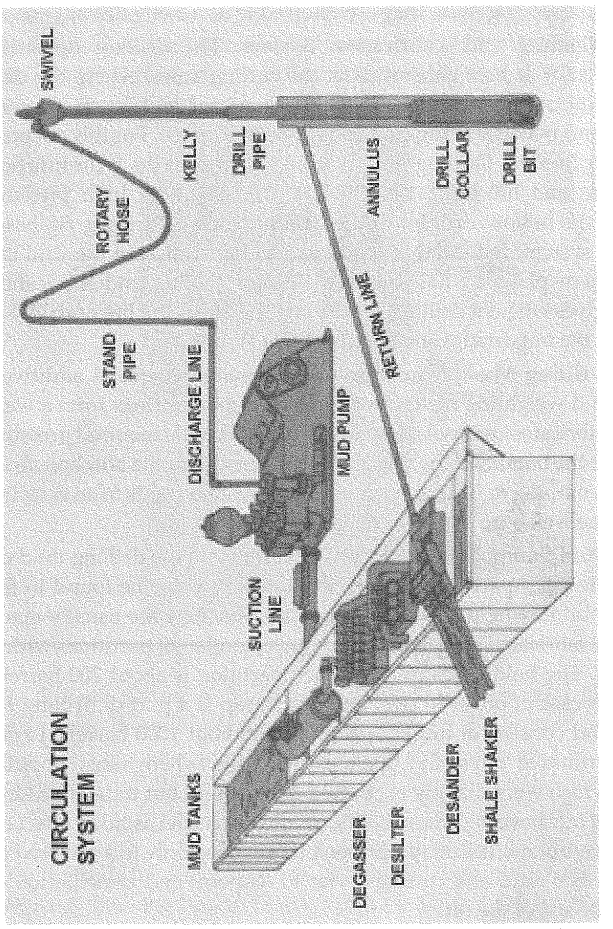


Fig.3.6: 34p A typical Mud circulation system used on Oil Drilling Rigs
Photo Courtesy: Oil Spill Solutions, http://www.oilspillsolutions.org/drilling.htm

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c. **Mud Circulation Pump and hose:** Mud Pump is a slurry pump whose function is to pump the pressurized drilling mud into the drilling zone via the hollow drilling string and drill bit. The pump is also accompanied with the mud hose as can be seen in the sketch above. The mud pump is a high pressure piston pump (with pressure up to 500 Kg/cm^2). It comes in duplex and triplex pistons, with the later ones (Triples i.e. with three piston/plungers) the most preferred once for oil drilling rig. The body of the pump is made by assembling the two independent sub-assemblies. These sub-assemblies are called power end and fluid end respectively. The fluid end consists of piston cylinder and non-return valve, the pumping chamber etc which are parts with more wear and tear. The drive end consists of the crank and connecting rod arrangement which converts the rotary motion into the reciprocating motion required for the piston. The fluid end requires frequent replacement of parts; this is why mud pump comes in two sub assembly, to facilitate the dismantling of fluid end without disturbing the drive end. The mud pumps are high pressure pumps, which involves lot of vibrations and water hammer. In order to cope with this, two separate pulsation dampeners are provided in suction and discharge line of the pump

d. **Shale Shakers:** It is an important device that is used on the drilling rig. Its main function is to separate the rock chips also called as drill cuttings from the returning drill fluid used for boring holes into the earth. It composes of a wire-cloth screen which vibrates as drilling fluid from the return line is passed over top of it. The liquid phase of the mud and solids smaller than the wire mesh pass through the screen, while larger solids are retained on the screen and eventually fall off the back of the device and are discarded as shown in the photo of Shale Shakers.

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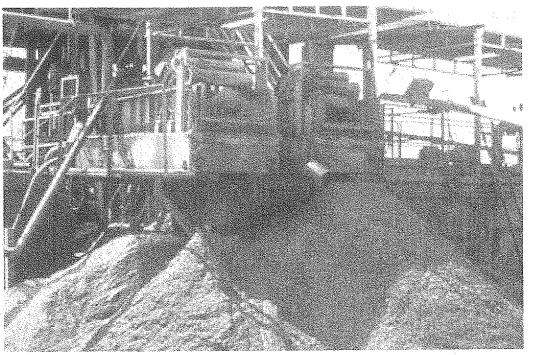


Fig.3.7: 35p Shale Shakers at work

e) **Vibrating Mud Screen**: It is a part of Shale Shaker. It consists of a screen in which has the cloth and wire, the screen is vibrated by means of solenoid or mechanically by eccentrics or unbalanced spinning weights. This vibrating screen is used to remove sand and cuttings from drilling mud as it flows out of a borehole.

3.2.1.7. Miscellaneous Components

Blow out Preventer: The Blow-Out Preventer (BOP) is the most important safety device that is used during well-drilling operations. It is a large valve that is fitted on top of the surface well head. During the drilling or well intervention process this valve is closed, as the drilling proceeds into deeper zones the formation pressure may suddenly increase and the pressurized fluid may enter the well bore. If this happens, the situation goes beyond the control of the drilling crew. In such times, the BOP releases the excessive pressure of formation. Meanwhile, the drilling crew gets sufficient time to control the formation pressure. Generally, a high density mud is supplied into the well bore until a column of adequate fluid pressure is being placed on the influx zone. After the situation is under control of the crew then the BOP can be opened for operations to resume. The invention and use of BOPs were instrumental in the end of oil gushers, which were dangerous and costly. The phenomenon of 'Oil Gushers' is discussed separately in section 8.5 of chapter 8 readers can refer it for more details.

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3.2.1.8. Casings: Casings are the steel pipes that are placed in an oil or gas well as drilling progresses, to prevent the wall of the hole from caving in during drilling, to prevent seepage of fluids, and to provide a means of extracting petroleum if the well is productive[4]. Most functions of casings are discussed in the section 3.2.2 Casings and Completion of this chapter.

3.2.1.9. Crown Block: It consists of an assembly of fixed set of sheaves or pulleys mounted on a rigid steel structure beams at the top of the derrick. The drilling line is run over the sheaves down to the hoisting drum. The opposite end of the crown block is the traveling block. The crown block and traveling block together with the steel rope (called drill line) provides the ability to lift hundreds and thousands of tons of load (primarily of the drill strings and bits) in the derrick.

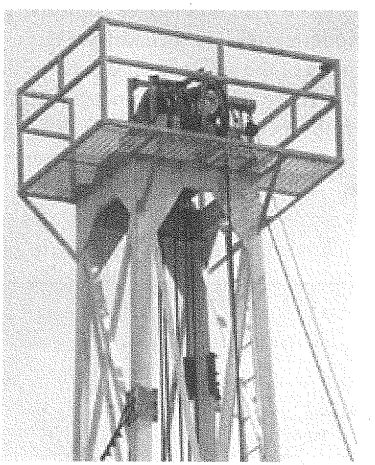


Fig.3.8: 36p Crown Block Photo Courtesy: OSHA

The drilling operation takes place somewhat like this.

- The drill bit, aided by the weight of drill string and the drill collars above it, breaks up the earth.
- Drilling fluid is pumped through the hollow drill string to the drilling zone. It performs important function of cooling the bit, washing the chipped rock pieces and also lubricating the bit.

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- The drilling string is assembled from pipe segments about 30 meters(100 fts) long normally with conical inside threads at one end and outside at the other. As each 30 meter segment is inserted in the string.

3.2.2. Deviation Drilling: Intentionally drilling at an angle other than vertical to reach different parts of formation is called deviation drilling. Controlled directional drilling makes it possible to reach subsurface areas laterally remote from the point where the bit enters the earth. It often involves the use of a drill motor driven by mud pressure mounted directly on the cone (Mud Motor, Turbo Drill and Dyna-Drill), whip stocks: a steel casing that will bend between the drill pipe and cone, or other deflecting rods. It is also used for horizontal wells and multiple completions, where one well may split into several bores. It is a well which has sections more than 80 degrees from the vertical is called a horizontal well. Modern wells are drilled with large horizontal offsets to reach different parts of the structure and achieve higher production. The world record is more than 15 kilometers. Multiple completions allow production from several locations.

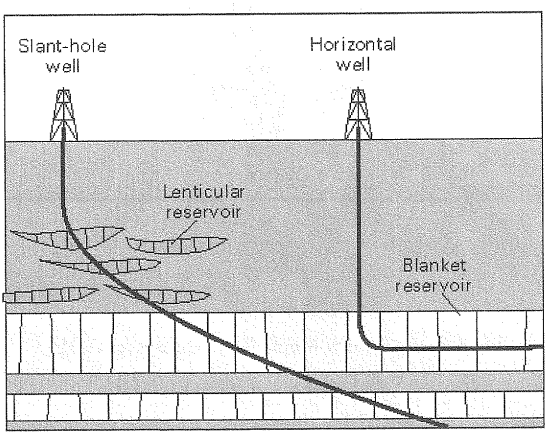


Fig.3.9: 37p Deviation Drilling for drilling at an angle

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3.2.3. Casing and Completion

3.2.3. Completion of Well: After the well is drilled, the most important stage in the well's life is completion. The completion of the well is the process in which the well is finished and made ready so that it can produce oil and gas. Completion of an oil well is accomplished in four important phases. These phases are given below.

3.2.3.1. Casing the well

'Casing a well' is the first stage in the process of completing a well. After a hole is drilled, a group of pipes telescopically placed one inside the other are inserted into the freshly drilled hole. These pipes are called casing. The oil reservoir is similar to a wet sponge soaked with water. The bottom-most part of the casing tube which is in the production zone should be provided with perforations (without compromising much on strength of casing) so that the hydrocarbon formation can enter the production tube.

a. Functions of Casings

The important functions performed by casing are mentioned below.

- The purpose of casing is to provide sufficient strength to the sides of the well hole.
- It also acts as a barrier and avoids sand, stone and other debris from falling sidewise and clogging the well.
- It prevents the seeping of hydrocarbons (oil and gas) into the surrounding surface through the sides of the hole.
- It not only provides structural integrity to the well, but also isolates potentially dangerous high pressure zones from each other and from the surface above.
- Conversely, it also eliminates other fluids such as underground salt water deposit's to seep into the well and thus protects the quality of formation from getting contaminated.

In most wells, the diameter of the well hole decreases the deeper it is drilled, leading to a type of conical shape that must be taken into account when installing casing. After the casing is installed, the space between casing and bore hole known as "Annulus" is filled with the cement to get a sealing effect this is called cementing a well.

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b. **Different types of Casings**

i) **Conductor Casing**: Conductor Casing is the first string of pipe that is inserted into the ground (in case of onshore well) prior to drilling operation. The purpose of conductor casing is to prevent the caving of edges of the well hole at the starting point. The casing is generally a short length pipe which is hammered into the ground. The purpose of installing the conductor casing is because most wells onshore are drilling into unconsolidated loose sedimentary rocks. They became consolidated and dense as we go deeper and deeper. In offshore, the casing comes with surrounding structure which is installed on sea bed by means of ROVs. Conductor casing is also called as drive pipe or simply conductor pipe.

ii) **Surface Casing**: Surface casing is the second pipe that is installed next to conductor casing. It is somewhat smaller in diameter, but longer than the conductor casing. It is installed from the top of conductor casing and fits inside the conductor casing. Its length may range from few meters and maximum up to 600 meters. The principal purpose of surface casing is to protect the onshore fresh water sources from getting contaminated by the hydrocarbon seepage and salt water that comes from deeper parts of earth. Besides, this it also acts as a channel for the returning drilling mud and it also protects the drilled bore from getting damaged during drilling. Surface casing, like conductor casing is also cemented in place with blow out preventer attached on its top. Apart from this the surface casing provides structural strength to the remaining casings which are suspended at the top and inside of the surface casing.

iii) **Intermediate Casing**: Intermediate casing comes after the surface casing and is longer than the later. It is placed in between the surface casing and production casing. The primary purpose of intermediate casing is to minimize the hazards that come along with subsurface formations that may affect the well. These include abnormal underground pressure zones, underground shale, and formations that might otherwise contaminated the well, such as underground salt-water deposits. In many instances, even though there may be no evidence of an unusual underground formation, intermediate casing is run as insurance against the possibility of such a formation affecting the well. These intermediate casing areas may also be cemented into place for added protection.

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iv) **Liner String**: These casings are substitute for intermediate casings. They differ from the intermediate casing in the manner in which they are connected with the previous casing, as linear strings are fastened and not cemented (as that of intermediate casings). This feature of linear casing makes them less permanent than the intermediate casings and hence they are less frequently used.

v) **Production Casing**: This is the longest of all the casings that are installed in the oil or gas well. It runs from the surface of well to the deeper areas of oil reservoir where hydrocarbons are formed, it houses production tubing which is the conduit through which the hydrocarbons travels to the top of well. It is installed last after all the other strings (pipes) are installed. The size of the production casing depends on a number of considerations, including the lifting equipment that is to be used, the number of completions required, and the possibility of deepening the well at a later time. For example, if it is expected that the well will be deepened at a later date, then the production casing must be wide enough to allow the passage of a drill bit later on.

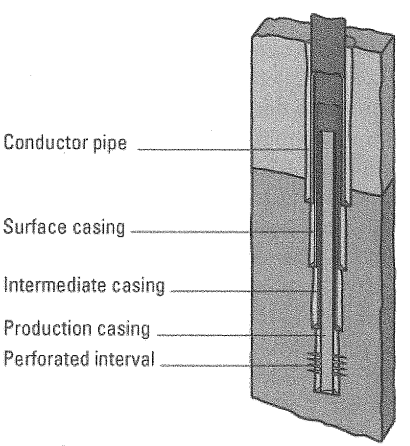


Fig.3.10: 38p Different Casings installed in Oil Well
Photo Courtesy: Schlumberger

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The production casing is the most crucial part of the well. It performs multiple functions, apart from acting as a channel for carrying hydrocarbons from bottom formations to the surface. It also acts as a barrier for other fluids and prevents them from intermingling with the hydrocarbons that are moving up. The production casing is generally cemented to place; it houses an important component of the oil well, the production tubing. The hydrocarbons are moved through this tube. This tubing may also be attached to pumping systems for more efficient extraction, should that be necessary.

3.2.3.2. Completion: Completion is the step that is next to casing the well. It is the process of making the well ready for production. There are different types of completion methods; selection of any one from these depends upon the characteristics and location of the hydrocarbon reservoir to be mined. We will see some of the important types of completion.

a) **Different types of completion**

i. **Open-Hole Completion**: Open-hole completions, also known as barefoot completions, are the ones in which there is no casing or pipe installed at the formation and the mud walls of a reservoir rock itself are exposed to formations. In this type, the produced fluids are free to rise up directly into the well bore. An open-hole completion consists of simply running the casing directly down into the formation, leaving the end of the piping open, without any other protective filter. Very often, this type of completion is used on formations that have been treated with hydraulic of acid fracturing. Since there are no casings installed at the bottom of well, the treatment of formation and well maintenance is more difficult task.

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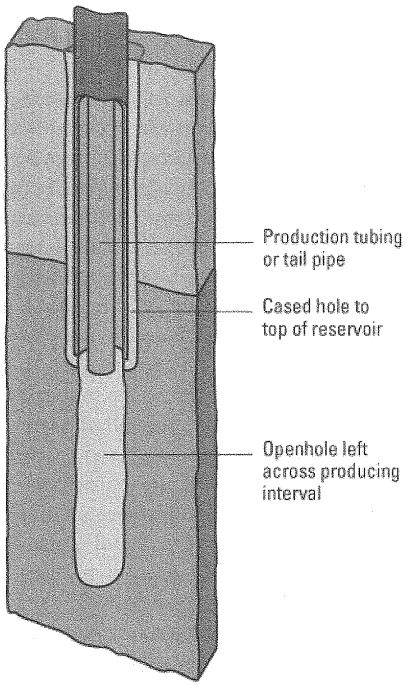


Fig.3.11: 39p An Open-hole Completion
Photo Courtesy: Schlumberger

ii. **Perforated Completion**: In this type, the portion of casing that lays inside the region surrounding formation is perforated with tiny holes along the sides that faces the formation, this allows the flow of hydrocarbons inside the well at the same time it protects the well bore by providing a suitable amount of support to sides of well. Previously, the process of making small holes on the sides of casing was done by means of specialized equipment called a perforating gun. These guns were lowered into the well and a series of iron bullets that pierce the casing and cement were fired; this was how the casing was perforated. Today, 'jet perforating' is preferred. This consists of small, electrically

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ignited charges, lowered into the well. When ignited, these charges poke tiny holes through the formation, in the same manner as bullet perforating.

iii. **Sand Exclusion Completions**: Sand Exclusion completions are applicable for those wells that are situated in areas where the reservoir rock contains large amount of loose sand. By installing the sand exclusion completion, it allows only the hydrocarbons to enter the well bore and restricts the sand from entering the well. The intrusion of sand inside the well has many ill effects on the performance of the well, as the sand clogs the well bore also it results in erosion of casing and equipment on top of well. This method uses a very simple technique for filtering the sand from produced fluids; yes the technique is the one we use in our day to day life for filtering the tea power from tea by using the wire mesh screen. Once the sand that comes from the well is analyzed we get the average size of sand particles accordingly a screen of filter slightly less than the particle size is placed inside the casing to arrest the sand from entering the well bore. The task of filtering the hydrocarbons from sand is also accomplished by adding a layer of specially sized gravel outside the casing to filter out the sand. Both of these types of sand barriers can be used in open hole and perforated completions.

iv. **Permanent Completion**: Permanent completions are those in which the completion and wellhead are assembled and installed only once. Installing the casing, cementing, perforating, and other completion work is done with small diameter tools to ensure the permanent nature of the completion. Completing a well in this manner can lead to significant cost savings compared to other types.

v. **Drain Hole Completion**: Drain hole completions are a form of horizontal or slant drilling. This type of completion consists of drilling out horizontally into the formation from a vertical well, essentially providing a 'drain' for the hydrocarbons to run down into the well. In certain cases, drilling a drain-hole completion may allow for more efficient and balanced extraction of the targeted hydrocarbons. These completions are more commonly associated with oil wells than with gas wells.

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3.2.3.3. Installing Well Head and Production Tree

Once the well is properly cased and all the casings (pipes) properly cemented at their respective positions the final step left out in completing a well is closing the well opening at the surface. The well opening is closed by installing specialized devices on the top opening of well, these devices are called as well head and production tree (also called Xmas tree or simply Christmas tree). The primary function of these is to control the formation pressure and flow. They also have necessary arrangements to carry out well logging and maintenance. These equipments/devices are explained in our next chapter.

3.2.3.4. Lifting and well Treatment

After a well is properly completed and is ready for production, the well engineer performs certain tests to find the rate of production from that well over its estimated life. To understand why this tests are required we will understand some basic facts about how the well produces, let us see; once the well is newly drilled and completed the underground formations have sufficient pressure to come up to the surface by its own. The well engineer on the basis of information gathered after study of the reservoir conducts a few tests. After manipulating the data obtained from the results of the test and other information is gathered, the well engineer determines the maximum amount of hydrocarbons that the well can produce in a 24 hour period. From this information, the well engineer determines the MER or the most efficient recovery rate. But this recovery rate is bound to decline as the reservoir will lose its pressure as the hydrocarbons are extracted from it. So the rate at which the production will decrease is also calculated this is called "decline rate" of well. This calculations form the basis for deciding when the well will need enhanced recovery methods in its life span. The well also needs treatment to ensure a smooth flow of production fluids. This treatment includes the injecting of acid, water and gases into the well to open up the formation and allow the petroleum to flow through the formation more easily. This topic will be explained in bit detail in our next chapter.

3.2.4. Production: This stage is most important in the well's life as revenue is generated, due to production of oil and gas. The well is

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properly cased and completed before beginning of this stage. The top of well is usually fitted with a group of valves called the production tree. The production tree serves the variety of purposes, like control and regulation of flow and pressure of well stream. It allows access to the well bore in case of maintenance work known as wire line operation. The outlet valve of production tree is connected to a network of pipes which carries oil / gas to metering station, from where it is piped to tanks for supplying product to refineries or natural gas compressor stations.

3.2.5. Abandonment: When the cost of production from a given well is not economical such that the well becomes a liability. It should be shut down which is termed as abandonment. In later stages of a well the reservoir pressure goes on depleting and a time comes when the well produces so poor that its running cost becomes greater than the revenue generated by the well. Under such circumstances, it becomes inevitable for the oil company to close down the well. This is called as 'Abandonment' of well. The process of abandonment begins with removal of production tube. The section of well bore is filled with cement to isolate the flow path between gas and water zones from each other, as well as the surface. Completely filling the well bore with cement is costly and unnecessary. The surface around the well is then excavated and the well head is removed, casings are cut off and a cap is welded in place. The remaining entire projection above the earth is then buried. The most important factor that governs the decision of abandonment is the economic scenario of the global oil market. Technological limitations also play a vital role in decision making. Recently, in United States the increased oil prices in global market combined with latest technological innovations paved the way for opening up of abandoned wells (closed somewhere in late 80's and early 90's) for lucrative production. Of course, some additional investment is required for Enhanced Oil Recovery system, or advanced drilling (deviation Drilling) technology.

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3.3. CLASSIFICATION OF WELLS.

3.3.1. On the basis of application of well stream i.e. for production or Injection.

Production wells are those that produce hydrocarbons. After some time, the reservoir pressure in production well depletes as a result of extracting hydrocarbons continuously. In such cases, an injection well is drilled into an underground water reserve which is used to inject its water into the production well. As a result of flooding, the oil is lighter than water and floats on water and can be easily pumped up by down hole pump. In some cases injection wells are used to build up the reservoir pressure so that oil comes up with its natural pressure.

3.3.2. On the basis of Produced Fluid.

Based on this criterion, wells can be classified into three different categories.

- **Oil Wells**: The conventional well is the oil well with associated gas dissolved in the oil.
- **Gas Wells**: There are certain wells which are purely drilled for gas and hence termed as gas wells. The natural gas that comes out from these wells is often termed as raw gas. It may contain traces of H_2S gas which needs some treatment for removing the impurities and making it safer to use.
- **Condensate Liquid**: In some cases, the well contains natural gas mixed with liquid condensate, these are termed as condensate wells. The condensate is a liquid hydrocarbon mixture which is separated from natural gas after the mixture is tapped out from well.

3.3.3. On the basis of its location i.e either on land or offshore.

In this way, wells are categorised as onshore wells and offshore wells. There is very little difference in the well itself.

3.3.3.1. Onshore Wells: By name itself, we can make out that these wells are located on land. The onshore wells are the most economical from the construction, production and offloading points of view. Onshore wells can be recognized by the donkey pump fitted on top of the well. These wells are most common in Middle East.

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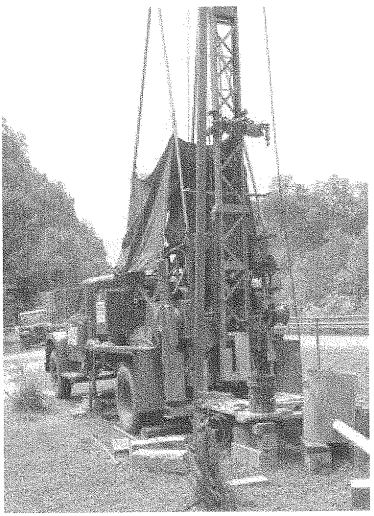


Fig.3.12.40p Onshore Drilling Rig

3.3.3.2. Offshore Wells: In the primitive days of the oil industry, most wells were drilled on land. With the advent of modern technology and the ever increasing oil demand, the need for exploring and extracting oil and gas from offshore areas became more and more lucrative. An offshore well targets a reservoir that happens to be underneath an ocean. Due to logistics, drilling an offshore well is far more costly than an onshore well. In Norway and Britain, about 95% of the oil and gas comes from the offshore wells in the oil rich continental shelf of North Sea.

3.3.4. By their Purpose in Contributing to the Development of a Resource.

In this way, the wells are divided as.

3.3.4.1. Production Wells: They are drilled primarily for producing oil or gas, once the producing structure and characteristics are determined.

3.3.4.2. Appraisal Wells: They are used to assess characteristics (such as flow rate) of a proven hydrocarbon accumulation.

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3.3.4.3. Exploration Wells: They are drilled purely for exploration (information gathering) purpose in a new area.

3.3.4.4. Wildcat Wells: They are drilled randomly in areas where little is known about the surface. These kinds of wells are common in early days of oil exploration. In modern times, oil exploration in many areas has reached a very mature phase and the chances of finding oil simply by drilling a random are very low, and much more effort is placed in exploration and appraisal wells.

3.4. Oil Extraction and Recovery.

The stages through which oil is extracted and recovered can be broadly classified into two categories. Primary recovery and Secondary recovery, Let us discuss this terms in details.

3.4.1. Primary Recovery: When the well is newly "drilled and completed" the oil is forced out to the surface with the natural pressure of reservoir. In this situation, it is sufficient to place a complex arrangement of valves (the production tree) on the well head to connect the well to a pipeline network for storage and processing. Usually, about 20% of the oil in a reservoir can be extracted using primary methods (i.e. oil comes out by means of the natural pressure of the well).

3.4.2. Secondary Recovery: After the oil from a reservoir is continuously extracted, the reservoir pressure depletes. This results in loss of some barrels of production compared to that produced during the primary recovery stages of well. Under such circumstances, we have to go for certain techniques which help to harness the maximum possible oil capability of reservoir. These techniques are called as 'EOR' (Enhanced Oil Recovery). Of course, the incorporation of these techniques requires additional investment. The decision to "go or not to go" for EOR techniques depends upon prevailing economic scenario of the global oil market. The techniques used under secondary recovery can be grouped as EOR and TEOR (Thermally Enhanced Oil Recovery). Together, primary and secondary recovery generally allows 25% to 35% of the reservoir's oil to be recovered.

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3.5. METHODS OF HARNESSING RESERVOIR CAPACITY (ENHANCED OIL RECOVERY AND THERMALLY ENHANCED OIL RECOVERY).

3.5.1. Enhanced Oil Recovery (EOR): Also called artificial lift, this technique is used for reservoir's which has lighter oil content. EOR can be grouped in two ways.

3.5.1.1. By pumping out the oil from reservoir by means of

a) Donkey Pump

b) Electrical Submersible Pump (ESP)

a) Donkey Pump: Donkey pumps are large cylinders with both fixed and moveable elements inside. The most important components are the barrel, valves (traveling and fixed) and the piston. It also has another 18 to 30 components which are called "fitting". The pump is designed to be inserted inside the tubing of a well and its main purpose is to gather fluids from beneath it and lift them to the surface.

b) Electric Submersible Pump (ESP): Electric submersible pumps consist of three parts, a downhole pump, motor, and electric power cable from the pump till the surface; it also contains the controls above the surface to operate the pump. The centrifugal pump (also called Downhole Pump) is suspended into the production tubing by mean of chord (Which carries the electric and control cables), the pump is coupled to a submersible electric motor that acts as a prime mover. The entire assembly (i.e. pump and motor) is submerged under produced fluids. ESP is widely accepted method of artificial lift. They can handle a wide range of flow rates (from 200 to 90,000 bpd[4*]) and lift requirements (from virtually zero to 10,000 ft [3000m] of lift).

3.5.1.2. By pressurizing reservoir through injection of external fluid inside the reservoir.

a) Water Injection.

b) Gas Lift.

a) Water Injection: In the water injection, the injected water is discharged through injection wells surrounding the production wells. The injected water creates a bottom water drive on the oil

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zone pushing the oil upwards. This is so, since oil is lighter than water, and floats easily on the surface of water. In earlier times water injection was carried out in later phase of reservoir life but now it is carried out in the earlier phases.

b) **Gas Lift:** Gas Lift injects gas into the well flow. The pressure in well falls off due to the back pressure from weight of the oil column in the tubing, thus a 150 MPa reservoir pressure at 1600 meters will fall to zero well head pressure if the specific gravity is 0.8. By injecting gas into this oil, the specific gravity is lowered and the well starts flowing.

3.5.2. Tertiary Recovery or Thermally Enhanced Oil Recovery (TEOR): This technique is suitable for reservoirs with heavy crude. We know that viscosity is inversely proportional to temperature. It decreases as the oil is heated. The heavy crude is made to flow by decreasing its viscosity through heating it by injecting steam in the reservoir. Steam injection is the most common form of TEOR, and is often done with a co-generation plant. In this type of co-generation plant, a gas turbine is used to generate electricity and the waste heat is used to produce steam, which is then injected into the reservoir. This form of recovery is used extensively to increase oil production in the San-Joaquin valley, which has very heavy crude oil. "In-Situ Burning" is another form of TEOR, but instead of steam, some of the oil is burned to heat the surrounding oil. "Carbon Dioxide flooding" method is also used to decrease the viscosity of heavy crude. Tertiary recovery allows another 5 to 15% of the reservoir's oil to be recovered. However, all the EOR and TEOR techniques are dependent on reservoir conditions and crude properties.

REFERENCES

Books

Offshore Engineering An Introduction.
By Angus Mather, Published by Witherby and Comapnay Limited, 32-36 Aylesbury Street London, UK.

Oil and Gas production Handbook
By Håvard Devold, ABB

Profrac Holding Corporation IPR2023-01319 Ex. 1010, p. 80 of 111
U.S. Well Services, LLC

No technical guide to Petroleum Geology, Exploration, Drilling and Production 2nd Edition.
By Norman J. Hyne, Published by Pennwell Corporation US.

Oil and Gas Exploration and Production Reserves, cost and contracts. Technip Editions. By IFP Publications, France.

Oil and Gas Production *in non-technical language*
By Martin S.Raymond and William L.Leffler, Published by Pennwell Corporation, US.

Oil Exploration in the Tropics
Published by: IUCN, Gland, Switzerland and Cambridge, UK

Drilling Technology *in Non-Technical Language*
Authored by Steve Devereaux, Published by PennWell Corporation US.

INTERNET

From Wikipedia

Oil Well, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Oil_well (Last Accessed on Thursday, December 10, 2009)

Extraction of Petroleum, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Extraction_of_petroleum#tertiary_recovery (Last Accessed on Thursday, December 10, 2009)

Drilling Fluid, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Drilling_fluid (Last Accessed on Thursday, December 10, 2009)

Enhanced Oil Recovery, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Enhanced_oil_recovery (Last Accessed on Thursday, December 10, 2009)

Well Drilling, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Well_drilling (Last Accessed on Thursday, December 10, 2009)

Profrac Holding Corporation IPR2023-01319 Ex. 1010, p. 81 of 111
U.S. Well Services, LLC

Kelly Drive, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Kelly_Drive (Last Accessed on Thursday, December 11, 2009)

List of Components of Oil Drilling Rig, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/List_of_components_of_oil_drilling_rigs (Last Accessed on Thursday, December 11, 2009)

Drilling Fluid, Wikipedia, The Free Encyclopedia.
URL: http://en.wikipedia.org/wiki/Drilling_fluid (Last Accessed on Thursday, December 11, 2009

Directional Drilling, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Directional_drilling (Last Accessed on Thursday, December 11, 2009

Donkey Pump, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Pumpjack (Last Accessed on Thursday, December 11, 2009

Submersible Pump, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Submersible_pump (Last Accessed on Thursday, December 11, 2009

Gas Lift, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Gas_lift (Last Accessed on Thursday, December 11, 2009

Drilling Engineering, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Drilling_engineering (Last Accessed on Thursday, December 11, 2009

Expandable Tubular Technology, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Expandable_Tubular_Technology?bcsi_scan_8F6E83C7F9885FA2=LLAMA/rIrfJmSxj1Ad/IB6cAAADcUj5Z (Last Accessed on Thursday, December 11, 2009

Oil Field, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Oil_field (Last Accessed on Thursday, December 11, 2009

Oil Field acronyms, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Oil_field_acronyms (Last Accessed on Thursday, December 11, 2009

Artificial Lift, Wikipedia, The Free Encyclopedia
URL: http://en.wikipedia.org/wiki/Artificial_lift (Last Accessed on Thursday, December 11, 2009

From Other Websites.

Information on "Drilling" published on the website of Oil and Gas UK,
Web URL: http://www.oilandgas.org.uk/education/storyofoil/exploration-02.cfm (Last Accessed on Saturday, December 19, 2009)

Main Article "From Wellhead to Burner Tip" retrieved from the web site of Natural Gas.org
Web URL: http://www.naturalgas.org/naturalgas/naturalgas.asp (Last Accessed on Saturday, December 19, 2009)

Main Topic "Well Drilling and different types of Drill" Retrieved from the web site of Online encyclopedia. Web URL: http://encyclopedia.thefreedictionary.com/Well+drilling (Last Accessed on Saturday, December 19, 2009)

Article "Famous Gushers of the world" Published on the website of San Joaquin Geological Society, Bakersfield, CA, and Titled 'History of Oil Industry'
URL: http://www.sjgs.com/gushers_world.html (Last Accessed on Thursday, August 13, 2009)

Information about Artificial Lift, retrieved from the web site of Schlumberger oil field glossary.
Web URL: http://www.slb.com/content/services/artificial/index.asp? (Last Accessed on Saturday, December 19, 2009)

Main topic "Oil Well and Life or stages of Oil well" retrieved from the web site of Oil and Gas Blog.
Web URL: http://oil-n-gas.blogspot.com/ (Last Accessed on Saturday, December 19, 2009)

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Information about "Vibrating Mud Screen" retrieved from the web site of Webster online dictionary. Web URL: http://www.websters-online-dictionary.org/vi/vibrating+screen.html (Last Accessed on Saturday, December 19, 2009)

Enhanced Oil recovery by steam injection retrieved from the web site of US Department of Energy. Web URL: http://fossil.energy.gov/education/energylessons/oil/oil4.html (Last Accessed on Saturday, December 19, 2009)

Main Article on Well Completion retrieved from web site of US department of Labour, Occupational Safety and Health Administration.
Web URL: http://www.osha.gov/SLTC/etools/oilandgas/well_completion/well_completion.html (Last Accessed on Saturday, December 19, 2009)

Endnotes

1 Description as per Sclumberger oil field glossary. Web Link: http://www.glossary.oilfield.slb.com/Display.cfm?Term= traveling%20block (Last Accessed on 6th December, 2009).

2 Definition of Drill bit as per OSHA. Web Link: http://www.osha.gov/SLTC/etools/oilandgas/illustrated_glossary/drill_bit.html (Last Accessed on 6th December, 2009).

3 Definition of Drilling mud as per Maverick Energy. Web Link: http://www.maverickenergy.com/lexicon2.htm (Last Accessed on 6th December, 2009).

4 bpd = Barrel per Day.

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4 | Equipments & Components on the Topside of the Well

4.1 Introduction.

So far, we have seen how the oil and gas reservoirs are developed, starting from exploration and drilling and right up until the completion of the well. In the previous chapters, we discussed how a well is made ready for production, but in the previous chapters we only concentrated on the components of the well that were below the ground. In this chapter, we will be focusing on the components of the well that are above the ground, and the components that perform the important function of regulating the formation pressure and flow of hydrocarbons. These components are termed as the topside components of the well. The assembly of these components originate where the production tubing terminates (at the ground surface) and ends where the distribution grid or piping for transporting of the oil starts. The most important assemblies on the topside of the well are the Wellhead and the Christmas Tree (Production tress) which are explained below.

4.2 Wellhead.

The Wellhead sits on the top-most portion of the well tubing that has just projected above the ground. Wellheads are designed and manufactured in a variety of ways and for numerous purposes. The important parameters that govern the design aspects of the wellhead are reservoir pressure, temperature, location (onshore/offshore), the well depth, the well size, the well control equipment interface, drilling method and the like. Many times, the wellhead and production trees (also known as Christmas tree) are confused and assumed to be the same piece, but they are actually separate pieces of equipment. Truly speaking, the wellhead acts as a mounting base for fixing the production tree. Production wells that require downhole pumps frequently do not utilize any tree due to the absence of any positive pressure in the well. Wellheads are cemented in place. However, for the exploration

wells, its wellhead equipment may be recovered for subsequent re-use. Wellhead equipment is designed to support the casing and tubing strings, which are also suspended from the Christmas tree. In this way, the wellhead provides a seal between the different strings and permits access to the annuli between them. The main components of a wellhead system include the casing head, casing spools, casing hangers, pack-offs and isolation seals, blow out preventer, test plugs, mud-line suspension systems, tubing heads, tubing hangers and tubing head adapters. Basic requirements for materials, dimensions, test procedures, and pressure ratings for wellheads are defined on "API Spec 6A: Specification for Wellhead and Christmas Tree Equipment from the American Petroleum Institute (API)".

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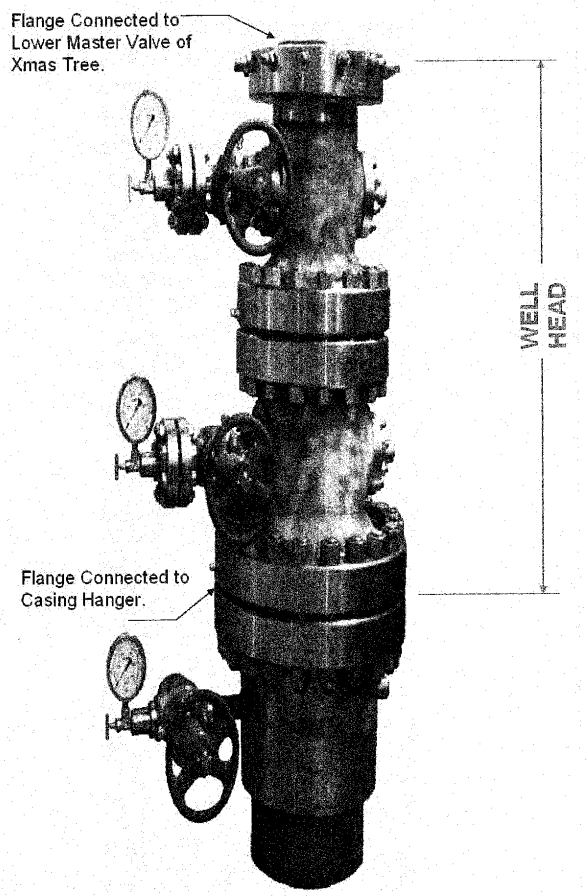


Fig.4.1.41p Actual Photograph of the well head
Photo Courtesy: http://triusenergy.com/images/glossary/wellhead.jpg

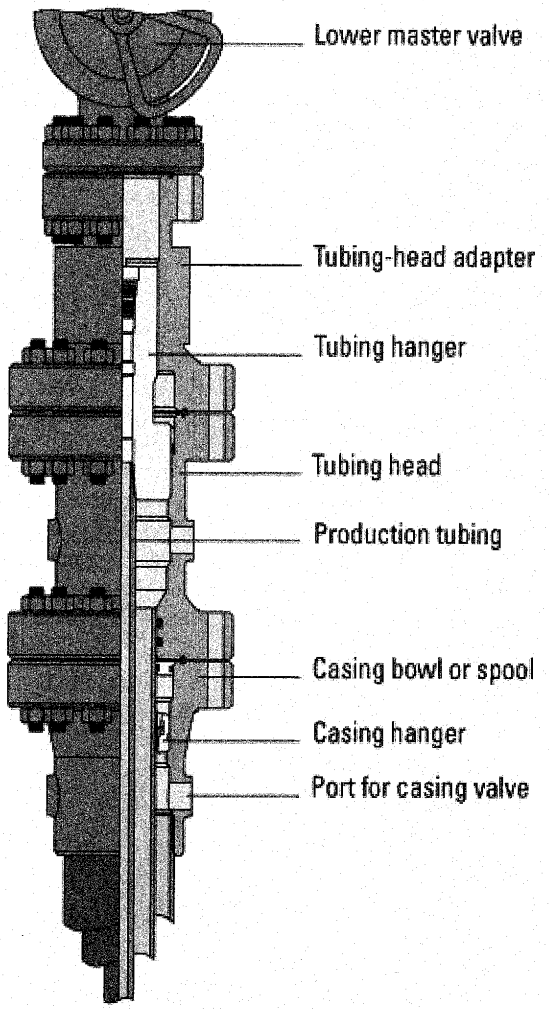


Fig.4.2: 42p Different Components of Well Head
Photo Courtesy: Schlumberger Oil field glossary

4.2.1. Functions performed by the Wellhead.

The wellhead performs the following functions.

1. The wellhead provides base for mounting the production tree.
2. It has BOP (Blow out Preventer) attached to it during drilling operation.
3. It also supports the downhole pump, if any.
4. It acts as a means of casing suspension. (Casing is permanently installed pipe used to line the well hole for pressure containment and collapse prevention etc).
5. It acts as a means of casing pressure isolation when multiple casing strings are installed.
6. It acts as a means of tubing suspension. (Tubing is removable pipe installed in the well).

4.3 PRODUCTION TREE OR XMAS TREE.

The production Tree is the heart of any hydrocarbon production system. It is the assembly of valves, fabricated spools and fittings that are clubbed as a complete set of assembly. It fits over an oil well, a gas well, a water injection well, a gas injection, a condensate well and all other types of the wells. A fully assembled and functional production tree resembles a decorated Christmas tree, hence the production tree is also called the Christmas tree or Xmas tree.

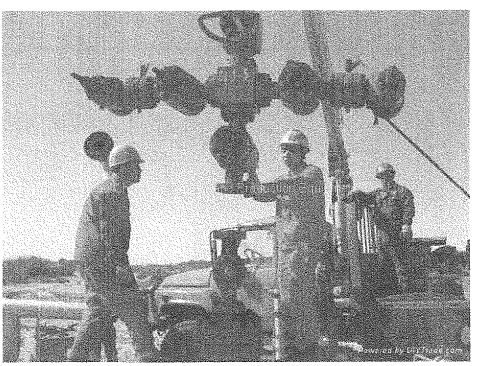


Fig.4.3.43p Production Tree being installed /Fitted on the well head
Photo Courtesy: Diy Trade

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A production Tree (Christmas or Xmas Tree) can be defined as an assembly of fittings and valves on top of the well head and casing which control the production rate of oil[1].

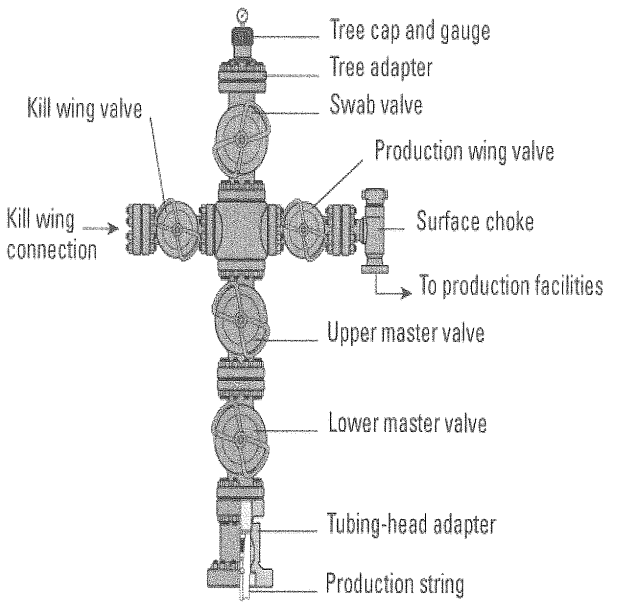


Fig.4.4.44p Diagrammatic representation of Production Tree or Christmas Tree
Photo Courtesy: Schlumberger Oil field glossary

4.3.1. Functions Performed by Production Tree.

1. The important function of a Tree is to control the flow into or out of the well, usually oil or gas.
2. It provides points for chemical injections.
3. It has facilities for the maintenance of the well by using well intervention techniques.
4. It provides well monitoring points [Such as pressure, temperature, corrosion, erosion, sand detection, flow rate, flow composition,

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valve and choke position feedback, connection points for devices such as Down-Hole Pressure and Temperature Transducer (DHPT) and the like].

4.3.2. Types of Production Trees.

4.3.2.1. Surface Tree: The production tree which is dry i.e., installed above the surface of water surface is called the surface tree. The surface tree may be an onshore tree or an offshore tree fitted on the topside structure.

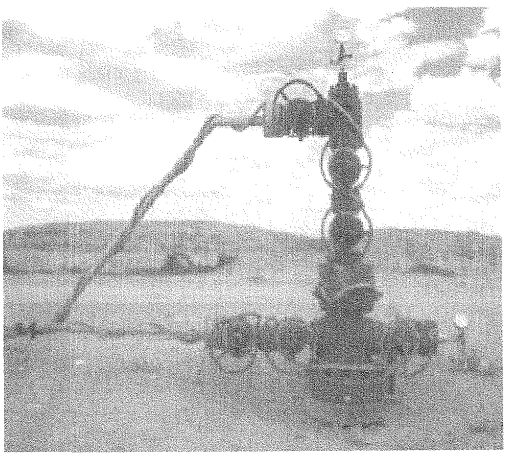


Fig.4.5.45p An Onshore Production Tree
Photo Courtesy: www.osha.gov

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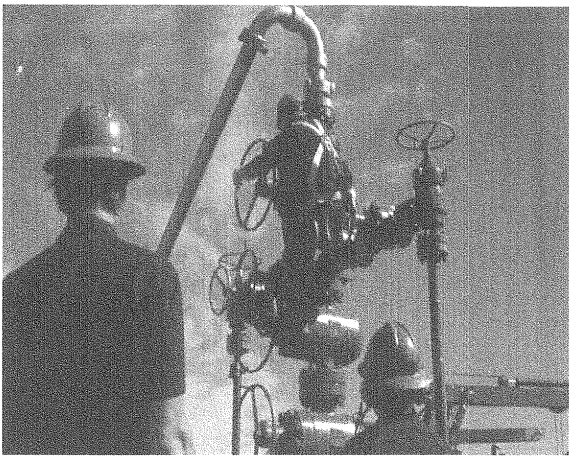


Fig.4.6.46p Onshore Production Tree During Well Maintenance
Photo Courtesy: http://oerb.com/Default.aspx?tabid=280&mid=1029&newsid1029=251

4.3.2.2. Subsea Tree: The subsea trees are located on subsea wellheads and are completely immersed under water. The subsea trees are frequently manufactured from a steel block with chests (cavities) machined into the block. These machined openings in the block carry the multiple valves, since in the absence of flanged gate valves and fabricated spools the subsea production tree hardly resembles the Christmas tree. In subsea trees, the entire control is automatic as the whole assembly is submerged several meters below the surface of the water. Subsea trees may range in size and weight from a few tons to approximately 70 tons for high pressure deepwater (> 1000 meters).

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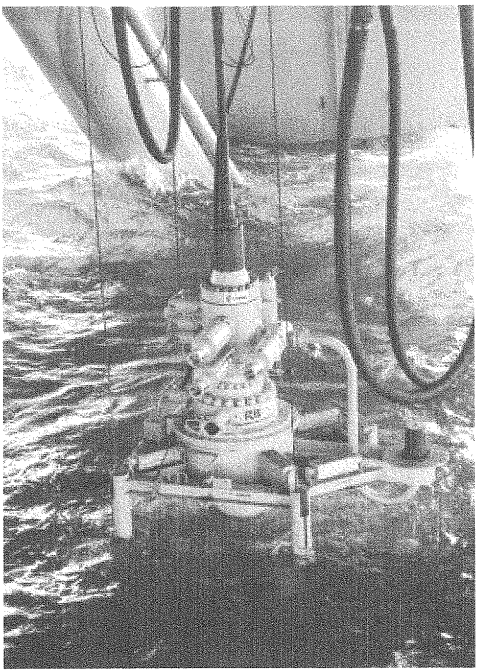


Fig.4.7.47p A Subsea Production Tree being installed
Photo Courtesy: Cameron

The subsea tree contains many additional accessories compared to surface trees. Typically, a subsea tree would have a choke (to regulate the flow) a flow line connection interface (a direct hydraulic, electro hydraulic or electric) and sensors for gathering data such as pressure, temperature, sand flow, erosion, multiphase flow, single phase flow such as water or gas. Though the surface and subsea production tree may differ in appearance and other aspects, most components are identical. The subsea tree with its flexible pipes is housed inside a steel template. This arrangement is especially intended to protect the entire assembly from mooring chains and ship anchors.

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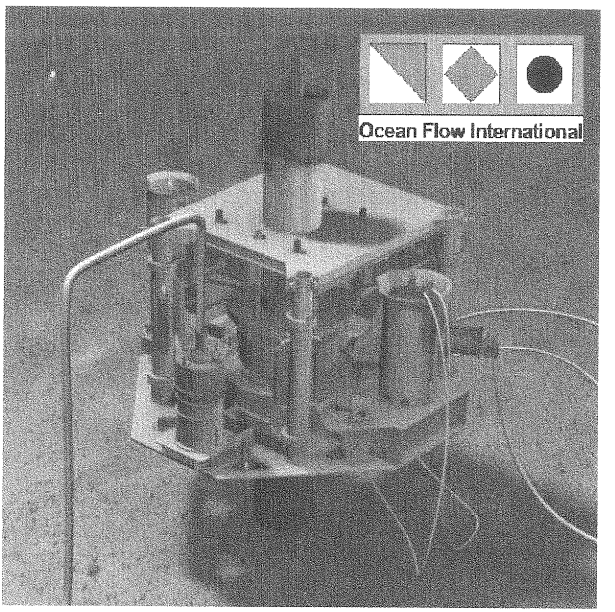


Fig.4.8.48p Subsea Production Tree during operation
Photo Courtesy: Ocean Flow International

4.3.3 Different Components of Production Tree

4.3.3.1. Master Valve or Valves: A master valve serves as a positive isolation between production tree and production tubing in the well head. In the latest designs, there are two master valves, referred to as upper and lower master valve. The lower master valve is opened first and closed last. The two master valves in a series ensure the minimum hydrocarbon leakage across the valve. Generally, the lower master valve is manually operated and upper master valve has remote (Pneumatic / Hydraulic) actuation which is properly controlled by sensors and transmitters. The signals from the actuated master valves are connected to ESD (Emergency Shut Down) System.

4.3.3.2. Wing Valve or Valves: The flow of hydrocarbons from the well is controlled by the wing valve. Wing valves as we can see from the photo (4.4.44 P Diagrammatic Representation of Production Tree) are

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valves that are offset to the master valve. They resemble two arms of the production tree, since the Wing Valves are located out of line to the main pipe of tree, wire line operation can be conveniently carried out without disturbing the production flow from the production Wing Valve. The left hand side valve is the Kill Wing Valve and is used for injecting chemicals into the well. Sometimes, the production tree is provided with only one wing valve. The right hand side valve is often called Flow Wing or Production Wing Valve; because it is from this valve the hydrocarbons are transferred from well to the storage or transportation pipe line. This valve has a remote operation which is controlled from the control room or control panel.

4.3.3.3. Swab Valve: This valve is located on the top of the production tree. It can be called the head of the entire tree. It is from this valve that the well intervention tools are inserted into the well. This valve is especially necessary for carrying out well maintenance. On top of the swab valve is a tree adapter and cap which mates with various equipments.

4.3.3.4. Choke Valve: This valve creates a variable restriction orifice that controls flow when the wing valve is fully open. The variable flow Choke valve is typically a large needle valve. The hand wheel of valve is calibrated in $1/64^{th}$ inch increment for adjusting the hydrocarbon flow. High quality steel is used for the valve body as it has to withstand high velocity well stream flow which contains highly abrasive materials in it.

4.3.3.5. Pressure Gauge: At the top of the tree i.e. above tree adapter and cap, is fitted a Pressure Gauge for indicating the well pressure. Apart from this; there are other instruments for monitoring temperature, flow etc.

4.4. MAINTENANCE OF THE WELL.

After a certain period of production, the well becomes less productive or malfunctioning. This happens due to the clogging of pores, residue sand growth in tubing, sand erosion and corrosion. Under such circumstances a major maintenance activity for such a well needs to be planned which is known as well workover and Intervention. This task may include replacement of tubing, new perforation, or provision of various additional arrangements such as gas lift or some new packages.

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4.4.1. Well Intervention and work over: Well work over or intervention are group of maintenance activities that are carried out during or after the productive life of an oil or gas well. The purpose of this is to enhance the productive efficiency of the well. Well intervention activities leads to altering the geometry of the well. Well intervention activities may range from cleaning up of sand from well to complete replacement of production casing (which means recompleting the well). Other than this well intervention also encompasses number of activities such as

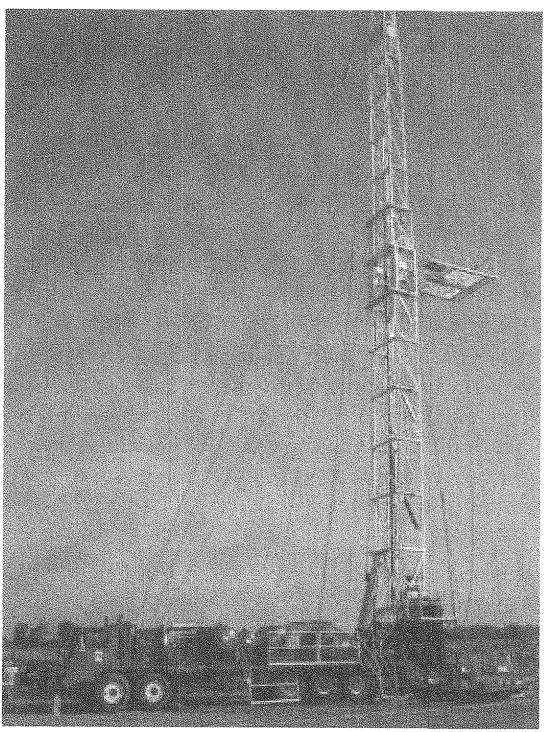


Fig. 4.9.49p A work over Rig in operation during Well Intervention
Photo Courtesy: www.osha.gov

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- Pumping of the well: This involves simply pumping fluids inside the well bore through the kill wing valve of the production tree. These fluids are chemicals used to inhibit the scales and hydrates, and to ensure smooth flow of hydrocarbons through the well. Apart from this Well Kill fluid (brine) is also pumped through the production tree to stop the upcoming hydrocarbon flow. This is done prior to well maintenance.
- Well Integrity: This is related to the maintenance of the well head and production tree.
- Subsea well Intervention: The well intervention performed for subsea wells is the most challenging one. Where the work over rig is mounted on a ship.

The well maintenance or work over is carried out by means of specially design rig called as Workover Rig.

4.4.1.1. Sand Cleanout: Sand Cleanout is the maintenance activity of removing accumulated sand from the well bore. This residue sand, which gets deposited in the production tubing, hinders the flow of production fluids from the well. The sand cleanout is carried by means of wireline operations and snubbing activity.

4.4.1.2. Repairing Liners and Casings: Liners and casing can be damaged by corrosion, abrasion, pressure, or other forces that create holes or splits. A packer[2] is run down the well to locate the hole in the casing. Fluid is pumped into the casing above the packer. A loss of pressure indicates a hole in the casing. The following are the principal methods for repairing casing:

- Squeeze cementing.
- Patching a liner.
- Replacing casing.
- Adding a liner.
- Opening collapsed casing.

4.4.1.3. Side Tracking: Sidetracking is the work over term for drilling a directional hole to bypass an obstruction in the well that cannot be removed or damage to the well, such as collapsed casing that cannot be repaired. Sidetracking is also done to deepen a well or to relocate the bottom of the well in a more productive zone, which is horizontally removed from the original well.

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4.4.1.4. Plug Back: Plug-back places a cement plug at one or more locations in a well to shut off flow from below the plug. Plug-back is also used before abandoning a well or before sidetracking is done.

4.4.1.5. Wire-line: The term wire line operations is a general term used in oil and gas industry and is applicable to tools that are suspended into the well by means of wire/cables during inspection and maintenance of the well. Wireline operations may include slick line[3] and electric line operations. Operations completed through the use of wireline include logging, perforating, setting of downhole tools, fishing, bailing, and swabbing. Of this some of the operations are discussed below.

4.4.1.6. Coil Tubing: Coil Tubing technology involves seamless steel tubing (often 1" to 3.25" in size) rolled over a reel, this reel when rotated pushes the steel tubing into the well bore during well intervention activity. In this case the steel tube does not depend on the weight of the down hole tool attached at the other end (end that is inside the well bore) for penetrating in the well bore but the force is provided by the unwinding action due to reel rotation. This is an advanced technology and eliminates the use of strings which comes in pieces and requires winch arrangement for lowering down into the well. Coiled tubing can be used as production tubing in depleted gas reservoirs. It is also used for injecting chemicals and cements into the well. Here a tool string is attached at the bottom of the coil, which is called as Bottom Hole Assembly (BHA). The chemicals travel through the tubing and are discharged out from the bottom tool string (which acts like a jetting nozzle). Since the entire tubing is a single piece component, there are no chances of leaking of fluids.

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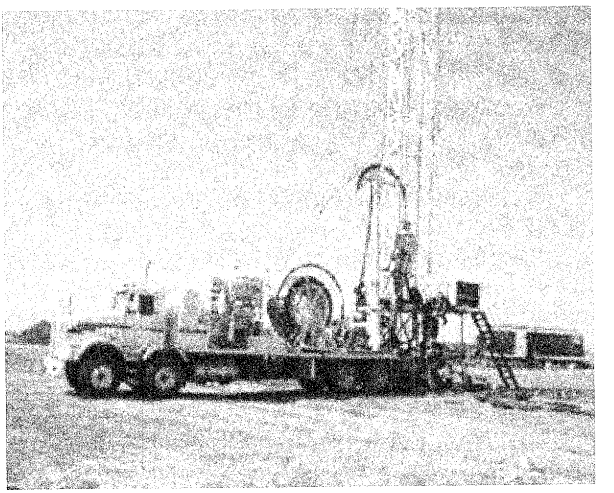


Fig. 4.10.50p Coiled Tubing Technology being used during a well Intervention work. Here we can see the tubing wound on the reel which is mounted on the truck
Photo Courtesy: www.osha.gov

Coil tubing has also been used as a cheaper version of work-over operations. It is used to perform openhole drilling and milling operations. It can also be used to fracture the well, a process where fluid is pressurized to thousands of psi on a specific point in a well to literally break the rock apart and allow the flow of production fluids. Coil tubing can perform almost any operation for oil well operations if used correctly.

4.4.1.7. Swabbing: Swabbing is the process of removing water, drilling mud and well kill fluid from the Oil/Gas well. Swabbing operation is done just after well completion or well maintenance activity is over, thus restoring production flow of the oil / gas well. The swabbing activity commences with insertion of wire rope through the swab valve (on the production tree) this wire rope has a cup assembly at it suspended end. The cup assembly after reaching the bottom of the well is then retracted and pulled up, during its return stroke the cup assembly acts like a piston and creates a seal inside the production tubing. Whatever fluid

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is trapped inside this cup like seal is pull out from the top of the well, this is how swabbing works.

4.4.1.8. Snubbing: Snubbing is a kind of heavy duty well intervention, where pipe strings are inserted into well bore by means of snubbing unit which generates the push and pull force for inserting or withdrawing the pipe strings. This force is created from a hydraulic unit within the snubbing unit. Due to the massive rig-up, it is only used for the most demanding operations where lighter intervention techniques do not offer the strength and durability. Unlike conventional drilling and completion operations, snubbing can be performed with the well still under pressure (not killed). When done so, it is called hydraulic workover. It can also be performed without removing the production tree from the wellhead.

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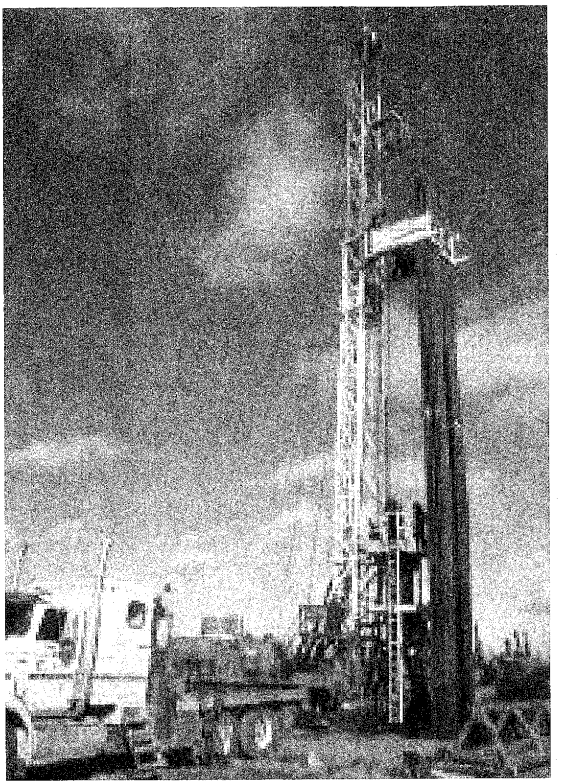


Fig. 4.11.51p Snubbing Rig
Photo Courtesy: www.osha.gov

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4.4.1.9. Hot Oiling: Hot Oiling process is a costly process and involves circulation of the heated crude through the production tubing to remove the paraffin tar deposits. This method involves heating the paraffin waxes in oil to the temperature above there melting point. The waxes in there liquid phase are now dissolved in the hot oil, when this return oil reaches the oiling unit, the paraffin waxes are separated from the oil. The circulation of crude oil is obtained by means of a hot oiling unit installed on a truck.



Fig. 4.12.52p Hot Oiling Truck
Photo Courtesy: www.osha.gov

4.4.2. Reservoir Simulation: Operations such as chemical injection, acid treatment, explosive blasting etc. that are carried out on reservoir to improve its productivity are called Reservoir Simulation. As we have seen that, a reservoir rock which holds the hydrocarbons resembles to a wet sponge socked in oil. If permeability of this sponge is good, oil can easily flow out, same is the case with reservoir rock. Under course of time as the productive life of the well proceeds; the portion of reservoir rock where the well has been drilled reduces its permeability. This happens due to the accumulation of particles and fluids that block the fractures and pores. Under such circumstances, reservoir simulation

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becomes inevitable. It not only increases the permeability of the well but also removes certain undesirable fluids that are trapped in well.

The various methods of reservoir simulation are given below.

4.4.2.1. Acid Fracturing: Acid like HCL (Hydrochloric Acid) is pumped into the reservoir in the proportion of 15% solution in water. Several 100 liters of acid is used. This acidic solution opens up the pores of reservoir which are clogged with calcareous material from calcium carbonate, which have been deposited around walls of the well. Acid fracturing thus enhances the overall permeability of the well.

4.4.2.2. Hydraulic Fracturing: In Hydraulic Fracturing, a specially blended liquid is pumped into well under high pressure. This liquid is mixed with propping agents such as sand grains, glass pieces, walnut shells and aluminum pallets before injecting into the well. Under high pressure the mixture fractures out the reservoir walls by means of propping agents. When pressure is released at the surface, the fractures partially close on the prop-pants, leaving channels for oil to flow into the well. The hydraulic pressure built up is created by means of a pump unit, which is installed on a truck. The truck also accommodates the pressure control system and hoses that are used to deliver the pressurized fluid to well. The entire unit is called Hydraulic fracturing unit. (See Fig 4.13.53p & Fig 4.14.54p)

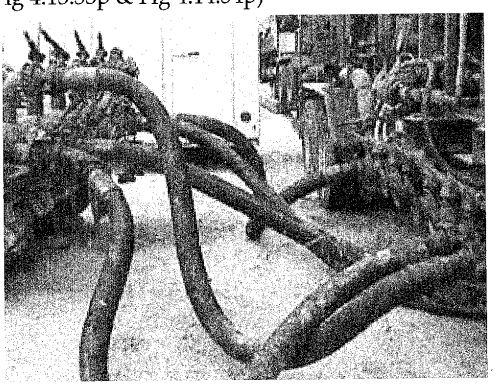


Fig. 4.13: 53p No. of flexible hoses that deliver the fracturing fluid from the pump unit to the well through the manifold

Photo Courtesy: www.osha.gov

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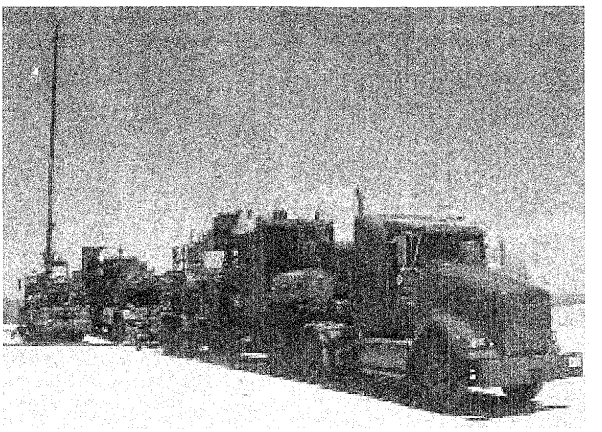


Fig. 4.14: 54p Fracturing Truck
Photo Courtesy: www.osha.gov

4.4.2.3. Perforating: The term perforating, in context of oil well refers to a well stimulating operation. In this method, the well casing and cement layer surrounding the pipe casing is pierced, in order to connect the well with reservoir. Once a well is cased, cemented and completed, it needs to be stimulated i.e. operation conducted to make the hydrocarbons flow inside the well from the reservoir. This is done by means of a tool called as perforating gun. This gun is attached to a wire line and is lowered inside the well bore, at reaching the required depth a series of bullets are fired from the perforating gun these bullets puncture the casing and cement and penetrate inside the reservoir walls. The holes made inside the casing acts a conduit through which the hydrocarbons, especially the oil flows from the surrounding reservoir and enters the well. The advantage of this method is that we can choose the region or portion of reservoir wherein we can get optimum hydrocarbons (by opening the casing at that point) and at the same time close the pores which are no longer effective. The disadvantage is that perforating can lead to "skin damage", where debris from the perforations can block the oil from entering into the well. In order to mitigate this, perforating is commonly done underbalanced (In places where the pressure inside the wellbore is lower than the reservoir pressure) as the higher

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formation pressure will cause a surge of fluids into the well at the point of perforating, hopefully carrying the debris with it.

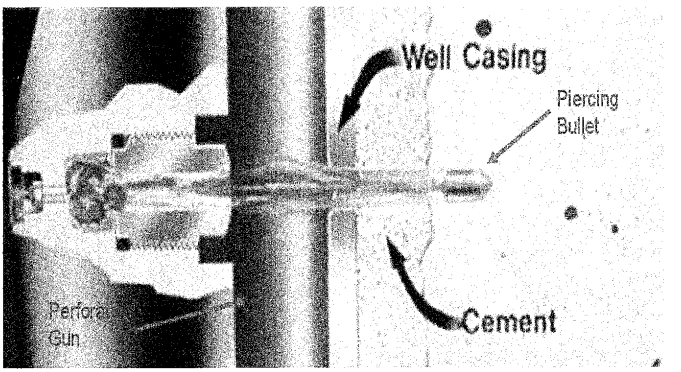


Fig. 4.15.55p Perforating Operation for Stimulating Well
Photo Courtesy: www.osha.gov

4.4.2.4. Explosive Fracturing: In this method the explosives are used to create a blast at the mouth of the well opening in reservoir rock. The energy liberated from the blast is used to fracture the formation. At the point of detonation, supersonic waves from high pressure gases crack the reservoir walls forcing fluids into the formation. Use of prop-pants is not required as rubbles prevent fractures from healing.

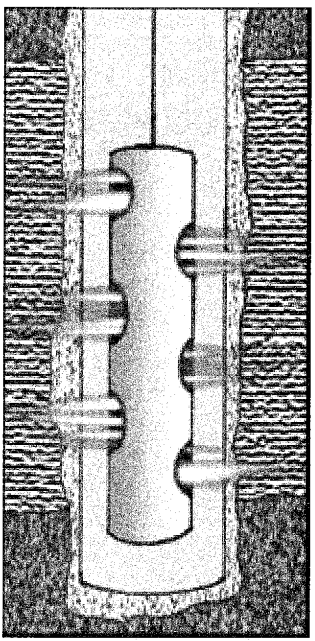


Fig. 4.16.56p Explosive Fracturing technique being used to open pores in oil reservoir
Photo Courtesy: www.osha.gov

There are certain techniques which flush out drill fluids from the well. These techniques are also covered under reservoir simulation.

4.4.3. Well Kill: Well Kill is the process of injecting a special fluid, which blocks the production tubing and stops the upward flow of the well stream. It is carried out to stop the well flow in the event of a major maintenance work which may involve removal of production tree and well head. In this method, a heavy liquid called as well kill fluid is injected into the well. The density of this fluid is several times greater than the hydrocarbons in well. The kill fluid accumulates in production tubing and creates a heavy liquid column exerting a downward counter pressure on hydrocarbon stream moving upwards. The well flow stops,

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when the back pressure generated by kill fluid is sufficient to suppress the upward hydrocarbon flow current. After the maintenance activity is over the kill fluid is removed from the tubing as a result the well starts flowing again.

REFERENCES

Books

Offshore Engineering An Introduction.
By Angus Mather, Published by Witherby & Comapnay Limited, 32-36 Aylesbury Street London, UK.

Oil and Gas production Handbook.
By Håvard Devold, ABB

Blowout and Well Control Handbook.
By Robert D. Grace, Published by Gulf Professional Publishing.

Drilling Engineering
By G. Robert Samuel, Published by Pennwell Corporation, Oklahoma, US.

Drilling Technology in non technical language.
By G. Steve Devereux, Published by Pennwell Corporation, Oklahoma, US.

Advance Blowout and Well Contorl
By Robert D. Grace, Published by Gulf Publishing Company Book Division, Houston, Texas, US.

Oil & Gas Production in non technical language.
By Martin S. Raymond and William L. Leffler, Published by Pennwell Corporation, Oklahoma, US.

Nontechnical Guide to Petroleum Geology, exploration, drilling and Production
By Norman J. Hyne, Published by Pennwell Corporation, Oklahoma, US.

Profrac Holding Corporation
U.S. Well Services, LLC
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Ex. 1010, p. 107 of 111

Well logging in non technical language 2nd Edition
By David E. Johnson and Kathyryne E. Pile, Published by Pennwell Corporation, Oklahoma, US.

Petroleum: An Energy Profile 1999
From Energy Information Administration, Energy Department of US Federal Government

INTERNET

Production Tree / Christmas Tree,
URL: http://aoscoly.com/web/pdf/gmp/wellhead%20and%20christmas%20tree.pdf
(Last Accessed on Wednesday, January 20, 2010)

Well Head,
URL: http://petrofed.winwinhosting.net/upload/IAI/17-20mar10/OffshoreoilandProd.pdf
(Last Accessed on Wednesday, January 20, 2010)

Coiled Tubing,
URL: http://www.rigzone.com/training/insight.asp?insight_id=324&c_id=22
(Last Accessed on Wednesday, January 20, 2010)

Well Intervention,
URL: http://www.spe-uk.org/Downloads/Past%20Presentations%20Aberdeen/JimWright-SPEAberdeenJanuarypresentation.pdf
(Last Accessed on Wednesday, January 20, 2010)

Well Workover,
URL: http://www.ok.gov/marginalwells/documents/C-17.E-Well%20Workover.pdf
(Last Accessed on Wednesday, January 20, 2010)

Bottom Hole Assembly
URL: http://www-odp.tamu.edu/publications/tnotes/tn31/pdf/bha.pdf
(Last Accessed on Wednesday, January 20, 2010)

Profrac Holding Corporation IPR2023-01319 Ex. 1010, p. 108 of 111
U.S. Well Services, LLC

Crown Block,
URL: http://www.wisegeek.com/what-is-a-crown-block.htm
(Last Accessed on Wednesday, January 20, 2010)

Well Kill,
URL: http://www.wellcontroltraining.org/well-control-training-kill-methods
(Last Accessed on Wednesday, January 20, 2010)

Perforation,
URL: http://www.usoilandgas.net/cementing.htm
(Last Accessed on Wednesday, January 20, 2010)

Subsea,
URL: http://www.oilandgasuk.co.uk/knowledgecentre/Subsea.cfm
(Last Accessed on Wednesday, January 20, 2010)

Drilling Engineering
URL: http://www.docstoc.com/docs/85727335/Drilling-Engineering-(PDF)
(Last Accessed on Wednesday, January 20, 2010)

Information on "Drilling" published on the website of Oil & Gas UK, Web URL: http://www.oilandgas.org.uk/education/storyofoil/exploration-02.cfm (Last Accessed on Wednesday, January 20, 2010)

Topic on "Christmas Tree" in Oil and Gas new letter. On Oil & Gas blog Web URL: http://www.mosburgoil-gas.com/html/body_hyne_10_99_2a.html
(Last Accessed on Wednesday, January 20, 2010)

Main Article "Wellhead and Christmas Tree" on Naturalgas.org
Web URL: http://www.naturalgas.org/naturalgas/well_completion.asp

(Last Accessed on Wednesday, January 20, 2010)
Information on "Christmas Tree and Wellhead" on Oilinisreal.com
Web URL: http://www.oilinisrael.net/top-stories/christmas-tree (Last Accessed on Wednesday, January 20, 2010)

Profrac Holding Corporation IPR2023-01319 Ex. 1010, p. 109 of 111
U.S. Well Services, LLC

Information on "Wireline Operation" on OSHA website managed by US federal government.
Web URL: http://www.osha.gov/SLTC/etools/oilandgas/servicing/special_services.html (Last Accessed on Wednesday, January 20, 2010)

Endnotes

1 Definition as per Glossary of oil and gas terms. Web Link: - http://oil-gas.state.co.us/cogis_help/glossary.htm (Last Accessed on 12th Jan, 2010).

2 *"A device that can be run into a wellbore with a smaller initial outside diameter that then expands externally to seal the wellbore. Packers employ flexible, elastomeric elements that expand. The two most common forms are the production or test packer and the inflatable packer. The expansion of the former may be accomplished by squeezing the elastomeric elements (somewhat doughnut shaped) between two plates, forcing the sides to bulge outward. The expansion of the latter is accomplished by pumping a fluid into a bladder, in much the same fashion as a balloon, but having more robust construction. Production or test packers may be set in cased holes and inflatable packers are used in open or cased holes. They may be run on wire line, pipe or coiled tubing. Some packers are designed to be removable, while others are permanent. Permanent packers are constructed of materials that are easy to drill or mill out."*Definition as per Sclumberger Oil Field Glossary. Web Link: -http://www.glossary.oilfield.slb.com/Display.cfm?Term=packer (Last Accessed on 16th Jan, 2010).

3 *"A thin nonelectric cable used for selective placement and retrieval of the wellbore hardware, such as plugs, gauges and valves located in side pocket mandrels. Valves and sleeves can also be adjusted using slick line tools. Partially collapsed tubing can be repaired using a tubing swage on slick line..."*Definition as per Sclumberger Oil Field Glossary. Web Link: -http://www.glossary.oilfield.slb.com/Display.cfm?Term=slickline (Last Accessed on 16th Jan, 2010).

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