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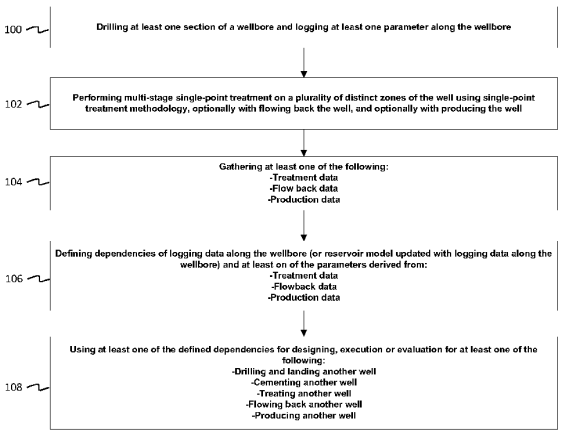
(54) Title: METHOD OF TREATING AN UNDERGROUND FORMATION FEATURING SINGLE-POINT STIMULATION

FIG. 1



(57) Abstract: Methods of treating an underground formation may include obtaining logging data for at least a section of a wellbore, treating a plurality of zones in at least a section of the wellbore using the multi-stage single-point fracturing operation, obtaining one or more of treatment data, flowback data, or production data for the treated plurality of zones, defining one or more dependencies between the obtained logging data and one or more of treatment data, flowback data, or production data, and using the dependencies to perform subsequent operations on the at least a section of a wellbore or in another wellbore. Methods may also include designing a completion string using dependencies defined from data obtained by performing a multi-stage single-point fracturing treatment on a plurality of zones in the at least a section of a wellbore.

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METHOD OF TREATING AN UNDERGROUND FORMATION FEATURING SINGLE-POINT STIMULATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority to U.S. Provisional Application, Serial No. 62/037,873, filed August 15, 2014, which is herein incorporated in its entirety.

BACKGROUND

[0002] Wellbore treatment methods often are used to increase hydrocarbon production by using a treatment fluid to affect a subterranean formation in a manner that increases oil or gas flow from the formation to the wellbore for removal to the surface. Treatment operations may include fracturing operations, matrix acidizing fracturing, and injection of chelating agents. Hydraulic fracturing involves injecting fluids into a subterranean formation at pressures sufficient to form fractures in the formation, with the fractures increasing flow from the formation to the wellbore. In chemical stimulation, flow capacity is improved by using chemicals to alter formation properties, such as increasing effective permeability by dissolving materials in or etching the subterranean formation. Wellbore treatments may be applied in open or cased hole in which a metal casing has been cemented in place in a drilled hole. In a cased wellbore, the casing (and cement if present) may be perforated in specified locations to allow hydrocarbon flow into the wellbore or to permit treatment fluids to flow from the wellbore to the formation.

[0003] To access hydrocarbon-rich intervals, treatment fluids may be directed to multiple zones of interest in a given wellbore passing through a formation. Within a single wellbore, there may be one or more zones of interest within various subterranean formations or multiple layers within a particular formation. Methods of targeting multiple zones often involve treating single or multiple zones within the well at time through the use of various fracturing technologies. For example, methods may involve multiple steps such as running a perforating gun down the wellbore to the target zones, perforating the target zones, removing the perforating gun, treating the target zones with a hydraulic fracturing fluid, and then isolating the perforated target zones. This process

may then subsequently repeated for all the target zones or a subset of target zones of interest until all the target zones are treated.

SUMMARY

[0004] This summary is provided to introduce a selection of concepts that are further described below in the detailed description.

[0005] In one aspect, methods of the present disclosure are directed to methods of treating an underground formation, including: obtaining logging data for at least a section of a wellbore; treating a plurality of zones in at least a section of the wellbore using the multi-stage single-point fracturing operation; obtaining one or more of treatment data, flowback data, or production data for the treated plurality of zones; defining one or more dependencies between the obtained logging data and one or more of treatment data, flowback data, or production data; and using the dependencies to design and perform subsequent operations on the at least a section of a wellbore or in another wellbore.

[0006] In another aspect, methods of the present disclosure are directed to methods of designing a completion string including: obtaining logging data from at least a section of a wellbore; performing a multi-stage single-point fracturing treatment on a plurality of zones in the at least a section of a wellbore; obtaining one or more selected from a group of treatment data, flowback data, and production data; defining one or more dependencies between the obtained logging data and the one or more selected from a group of treatment data, flowback data, and production data; designing a completion string using the defined one or more dependencies, and emplacing the designed completion string.

[0007] This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figure 1 is an example of a workflow demonstrating processes included in methods in accordance with embodiments described herein.

[0009] Figure 2 is an example of a workflow that includes providing a design for multi-stage completion system based on acquired logging data in accordance with embodiments described herein.

[0010] Figure 3 is an example of a workflow with a pre-defined design for a multi-stage completion system in accordance with embodiments described herein.

DETAILED DESCRIPTION

[0011] At the outset, it should be noted that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developer's specific goals, such as compliance with system related and business related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time consuming but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure. In addition, the compositions used/disclosed for use in the methods described herein can also include some components other than those cited.

[0012] In the present disclosure, numerical values should be read once as modified by the term "about" (unless already expressly so modified), and then read again as not so modified unless otherwise indicated in context. Also, in the present disclosure, it should be understood that a concentration range listed or described as being useful, suitable, or the like, is intended that any and every concentration within the range, including the end points, is to be considered as having been stated. For example, “a range of from 1 to 10” is to be read as indicating each and every possible number along the continuum between about 1 and about 10. Thus, even if specific data points within the range, or even no data points within the range, are explicitly identified or refer to only a few specific, it is to be understood that inventors appreciate and understand that any and all data points within the range are to be considered to have been specified, and that inventors possessed knowledge of the entire range and all points within the range. The statements made herein merely provide information related to the present disclosure and may not constitute prior art, and may describe some embodiments illustrating the disclosure.

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[0013] In one aspect, embodiments of the present disclosure are directed to methods of treating an underground formation penetrated by a well that utilize single-point fracturing techniques to stimulate the production of formation fluids and/or generate information regarding the fractured intervals of the wellbore. As used herein, "single-point fracturing" refers to a technique in which a targeted interval of a formation is treated through a single opening at a time, thus providing better control of the flow rate of the treatment fluid and allowing a direct opportunity to measure the changes in the formation associated with the single point of fracture the formation. Examples of an opening through which treatments may be delivered include a fracturing sleeve, kick-start valve, single perforated cluster, open hole wellbore interval isolated between two packers, including inflatable packers, and the like. In some embodiments suitable lengths or diameter of the opening may be within in the range 0.03-20ft (0.001-6.1m), 0.03-5ft (0.001-1.5m), or 0.03-2ft (0.001-0.61m); however, the ranges provided are merely guidelines and do not limit the present disclosure.

[0014] Single-point fracturing as used in methods in accordance with the present disclosure may enable diagnostics to be performed on a single wellbore in a formation, creating a convenient laboratory for the analysis of a range of treatments on similar intervals within a formation having similar mineralogical composition and physical characteristics, or using assaying a single treatment against intervals having differing composition and properties. The use of single-point fracturing may also translate to a decrease of the volume of a terminal flush substage required to clean the wellbore of particles (often referred to as overflush) prior to initiation of fracturing a successive wellbore treatment stage, or may even eliminate overflushing altogether in some instances.

[0015] Single-point fracturing may be contrasted with other fracturing techniques such as "plug-and-perf." During plug-and-perf fracturing, operation involves lowering a perforating gun loaded with explosive to a zone, igniting the gun(s) thus creating perforation through the tubing and the near wellbore. However, such techniques may be problematic in that an operator may underestimate the near wellbore connection and its effect on conductivity, and thus ultimately production. Common practice is often to

perforate 4-6 clusters, and push a proppant loaded fracturing fluid at fracture pressure to create and propagate fractures in the formation; it is estimated that 30 to 60% of these perforations do not produce hydrocarbons due to, for example, screen out, geological constraints, *etc*., and thus for every 100 perforations in a wellbore, commonly only 30 to 70 of the conventional perforations are useful for production.

[0016] Embodiments herein relate to a method for completing a well including completing a zone of a first well using a single-point fracturing technique, acquiring data from the completion of the first well, interpreting the data, tailoring an optimized design for completing a further well, and completing a further well with the tailored design. Some embodiments may benefit from drilling and acquiring data during the drilling of the first well (i.e., logging while drilling). In some embodiments, a plurality of zones (and at least three zones in more particular embodiments) are completed with single-point fracturing. In some embodiments, the data acquired includes injection flow rate, flow back rate, and/or production rate. In some embodiments, the drilling data (i.e., logging data) acquired are correlated with completion data including injection flow rate, flow back rate, and/or production rate. In some embodiments, the further wells are also completed using single-point fracturing workstring; however, the disclosure is not limited to the use of single-point fracturing alone, and other embodiments may use other fracturing techniques, such as plug-and-perf. In some embodiments, the tailoring includes modifying at least one of the following: drilling and landing another well, cementing another well, treating another well, flowing back another well, and producing another well.

[0017] Embodiments herein relate to methods for designing a well treatment including completing a zone of a first well, prior to or after, using a single-point fracturing technique, acquiring data from the completion of the first well, interpreting the data, and tailoring an optimized design for completing one further zone. In some embodiments, the optimized design includes at least one of the following: modifying the fracturing fluid composition, pumping acid, modifying the injection flow rate, drilling and landing another well, cementing another well, treating another well, flowing back another well, and producing another well.

[0018] Embodiments herein relate to a method for designing a completion string that includes completing a plurality of zones of a first well using a single-point fracturing technique, acquiring data from the completion of the first well, interpreting the data, and tailoring an optimized design for the completion string to be used in a further well. In some embodiments, the single-point fracturing string embeds sliding sleeves and the tailoring includes modifying the spacing of the sleeves. In some embodiments, the number of sleeves is reduced.

[0019] Methods of treating a wellbore in accordance with the present disclosure may include acquiring logging data along a wellbore section, treating the section using single-point fracturing methodology (treating one zone per stage), and then determining dependencies that exist between the acquired logging data and the data acquired during or after subsequent treatment operations. For example, data obtained from the treatment operation itself, such as changes in pressure or near-well permeability, or from subsequent operations including flowback operations in which data is acquired from injecting tracer fluids and measuring the return flow, or from the rate of fluid flow from production operations carried out in the treated wellbore.

[0020] In some embodiments, dependencies established from single-point fracturing operations in one or more intervals may be used to design subsequent operations for other wells drilled in the same or similar underground formations. By virtue of treating and measuring a single interval of the formation at a time, variations between the zonal response to the performed treatment and zonal properties (determined from the logging data, for example) may be detected. For example, the combination of the data obtained during the single-point fracturing operation may yield zonal mechanical properties such as Young's modulus, Poisson ratio, *in situ* stresses, including minimum *in situ* stress, mineralogy composition, hydrocarbon content, rock density, resistivity, particulate emission factor (PEF), and the like. Gathered data may be interpreted using computer-based systems in some embodiments, including commercially available software packages such as fracCADE available from Schlumberger, Petrel, Advanta, and the like.

[0021] Performing multi-stage single-point fracturing to prepare a sequence of clusters in a wellbore may be useful as a diagnostic operation in some embodiments, and may be used to acquire information on formation response to a given treatment based on the composition of a particular zone or interval. The data may then be used to tailor or optimize future treatment for additional wells that may be stimulated using a single-point treatment methodology or any other stimulation technique. In other embodiments, data obtained through the multi-stage single-point stimulation of a wellbore may be used to design completion strings and stimulation jobs for use in subsequent wellbores in the same formation or formations of similar composition and physical properties.

[0022] In some embodiments, methods in accordance with the present disclosure may also be applied to wellbores and wellbore sections that are substantially horizontal. As used herein, a horizontal well may be interpreted as including a substantially horizontal portion, which may be a cased or completed open hole, wherein the fracture is transversely or longitudinally oriented and thus generally vertical or sloped with respect to horizontal.

[0023] Single-point fracturing in accordance with embodiments disclosed herein may involve pumping a fluid above the fracturing pressure of the formation to be treated through a single entry to the formation. The entry may be a perforation, a valve, a sleeve, or a sliding sleeve. Often sliding sleeves in the closed position are fitted to the production liner, and the production liner is then placed in a hydrocarbon-bearing formation. The sliding sleeves may be opened and closed by a coil-tubing (CT) mounted shifting tool in some embodiments. Tools equipped with sliding sleeves may also include one or more packers that may be set below an opened sleeve providing a seal between the operating sleeve and other sleeves below. During operation, treatments may be performed by pumping fracturing fluid either down the annulus between CT string and wellbore tubular (e.g. casing) or by down the CT string or both.

[0024] In some embodiments, the sleeve or device controlling the treatment opening is activated by an object, such as a frac ball or dart, which is introduced into the wellbore from surface and the object is transported to the target zone by the flow field or

mechanically, for example, using a wireline or coiled tubing. When at the target location, the object is caught by the sliding sleeve or device and shifts the sleeve to the open position. The object remains in the sleeve, obstructing hydraulic communication from above to below. A fracture treatment is then circulated down the wellbore to the formation adjacent the open sleeve.

[0025] In some embodiments, a sealing device, such as a packer or cups, may be positioned below a sleeve on a completion string in order to isolate the lower portion of the wellbore. During operation, the sealing device is set and fluid is pumped into the fracture. Once pumping is completed, then the sealing device is unset and moved below the next zone (or sleeve) to be treated. Representative examples of sleeve-based systems are disclosed in U.S. Patent No. 7,387,165, U.S. Patent No. 7,322,417, U.S. Patent No. 7,377,321, U.S. Patent No. 2007/0107908, U.S. Patent No. 2007/0044958, U.S. Patent No. 2010/0209288, U.S. Patent No. 7,387,165, U.S. Patent No.2009/0084553, U.S. Patent No. 7,108,067, U.S. Patent No. 7,431,091, U.S. Patent No. 7,543,634, U.S. Patent No. 7,134,505, U.S. Patent No. 7,021,384, U.S. Patent No. 7,353,878, U.S. Patent No. 7,267,172, U.S. Patent No. 7,681,645, U.S. Patent No. 7,066,265, U.S. Patent No. 7,168,494, U.S. Patent No. 7,353,879, U.S. Patent No. 7,093,664, and U.S. Patent No. 7,210,533, which are hereby incorporated herein by reference.

[0026] In one or more embodiments, methods in accordance with the present disclosure include well completions in which a zone of a first well is stimulated using single-point fracturing techniques; acquiring data from the completion of the first well; interpreting the data; and using the data optimize the design for subsequent operations such as the completion and stimulation of additional wells. With particular respect to FIG. 1, an embodiment of a possible workflow is shown. The method may begin at 100 by establishing an initial reservoir model by obtaining the initial parameters of the wellbore, which may be obtained by logging a wellbore through use of dedicated logging tools or drill string equipped for logging-while-drilling (LWD). Information from the wellbore may then be compiled and used to design an appropriate completions or treatment operation for the well.

[0027] At 102, a multi-stage treatment is designed based on the generated reservoir model and executed on distinct zones of the well using a single-point treatment methodology. At 104, data gathered during single-point treatment, which may include production and flowback data, may be used to determine the effectiveness of the treatment. If necessary, the collected data may also be used to update the reservoir model to account for changes from fracturing or the presence of natural features such as faults, zonal variations, *etc.* At 106, the collected data is mapped to the logging data from the wellbore and used in 108 to design, execute, or evaluate subsequent wellbore operations. Subsequent operations may include, for example, drilling and landing additional wells, cementing jobs for another wells, planning treatments for other wells in the formation, flowing back into another well, or determining production parameters for another wells.

[0028] With respect to FIG. 2, a flowchart showing a method for executing the single-point fracturing technique in accordance with embodiments of the present disclosure is shown in which completions operations may be finalized prior to initiating the multi-stage single-point fracturing operation. Once a well site is selected, an operator may begin at 202 by drilling a well having at least one substantially horizontal trajectory while logging the well using logging-while-drilling or logging the well in a separate operation subsequent to drilling. The wellbore is then completed at 212 using techniques that are compatible with subsequent operations utilizing a single-point methodology.

[0029] The logging data 204 obtained is then used to develop and supplement an initial reservoir model 200 at 208. The initial reservoir model may in some cases be generated from existing data known for the formation. The updated reservoir model 210 is then used to design a multi-stage treatment using single-point fracturing methodologies. Next, at 214, a multi-stage treatment is designed on the basis of the logging information and executed on a plurality of distinct zones of the well at 218. Following treatment using single-point fracturing techniques, the operation may proceed by optionally initiating flow back into the well 222, *e.g.*, after the injection of a chemical tracers, to obtain flowback data 224 regarding the fracture flow performance and the frac fluid returning from various stages in the multi-stage treatment. In some embodiments,

optional production from the well may also be initiated at 226 following treatment or after testing flowback of the well in order to generate production data 228.

[0030] Next, at 230 dependencies may be established by comparing the logging data 304 and at least one of the treatment data 220, the flowback data 224, and the production data 228 obtained after single-point fracturing treatment. The dependencies obtained from the comparison of the available data may then be used in a number of subsequent operations in the same or other wells, including, but not limited to, drilling and landing, cementing operations, additional fracturing or refracturing treatments, flowback operations, and production.

[0031] With particular respect to FIG. 3, a more detailed flowchart showing a method for executing the single-point fracturing technique is shown. Once a well site is selected, an operator may begin at 302 by drilling a well and logging the well using logging-while-drilling or logging the well in a separate operation subsequent to drilling. The logging data 304 obtained is then used to develop and supplement an initial reservoir model 300 at 306. The initial reservoir model may be generated from existing data known for the formation in some cases. The updated reservoir model 308 is then used to design a multi-stage treatment using single-point fracturing methodologies.

[0032] In a next possible step 312, a completion string adapted for multi-stage fracturing is designed to fracture one or more intervals of the formation at 314 prior to performing single-point fracturing on a plurality of distinct zones of the well. Where completions operations have already finished, an operator may move directly to 318 and initiate the process of designing the multi-stage treatment using a single-point fracturing methodology. Following treatment using single-point fracturing techniques, the operation optionally may proceed by initiating flow back into the well 322, *e.g.*, after the injection of a radioactive tracer, in order to obtain flowback data 324 regarding the fluid conductivity throughout the near-wellbore formation. In some embodiments, optional production from the well may also be initiated at 326 following treatment or after testing flowback of the well in order to generate production data 328.

[0033] Next, at 330, dependencies may be established by comparing the logging data 304 and at least one of the treatment data 320, the flowback data 324, and the production data 328 obtained after single-point treatment. The dependencies obtained from the comparison of the available data may then be used in a number of subsequent operations in the same or another wells, including, but not limited to, drilling and landing, cementing operations, additional fracturing or refracturing treatments, flowback operations, and production.

[0034] Methods in accordance with the present disclosure may include the drilling a well prior to or during the logging of the well. Indeed, mud logging or logging while drilling, or subsequent logging operations may be used to define formation characteristics for at least one section of the drilled well as a function of depth. In one or more embodiments, well logs may be obtained through well logging techniques that are routinely employed including logging-while-drilling (LWD), by analyzing cuttings suspended carried to the surface by drilling fluid, or by using a memory logging tool (or real-time logging tool) that may be pumped down the drillstring after drilling the well to some target depth and then be retrieved to the surface with a drill bit assembly (*e.g.*, the Thrubit service commercially available from Schlumberger). In some embodiments, formation characteristics may be acquired after drilling by using open-hole logs such as resistivity logs, gamma-ray logs, density logs, neutron logs, photoelectric index logs, image logs, sonic scanner, cased-hole logging techniques such as the Sonic Scanner™ acoustic scanning platform commercially available from Schlumberger, induced resistivity logging, and other available well logging techniques.

[0035] It is noted that information for many formations may already be available from previous drilling information, and may be utilized to perform single-point fracturing based on existing data without the need for additional drilling. Results of the evaluation may also be combined with information relevant to the drilled well and obtained from other sources, such as seismic data, formation, and rock properties defined from offset wells and pilot holes, and the like.

[0036] Methods in accordance with the present disclosure may include completing at least one section of a drilled wellbore with a completion string that enables performing a single-point treatment sequence on that section of the well. In one or more embodiments, the completion string may be casing (cemented or including packers such as swellable packers). The casing may also include single-point fracturing ports such as sliding sleeves, burst-disks, or any other devices to create a single-point opening in a completion to establish communication with the formation. The formation characteristics involving post treatment may also be used after the completion, for example, using cased hole logging after completing the well with a completion string, *e.g.*, Sonic Scanner™, induction logging, and the like.

[0037] Once the well logging data is obtained from evaluating a given zone, a reservoir model may be constructed and updated as additional logging data for the formation is obtained. In one or more embodiments, the reservoir model may then be used to design a multi-stage single-point treatment for at least three sequential zones contained in one or more sections of a first drilled well. Such a treatment design may be based on usage of updated formation model or results of evaluation of the collected zonal information as discussed above. In one or more embodiments, a multi-stage single-point treatment may be designed on pre-determined zonal characteristics that allow an operator to select zones to be treated or avoided.

[0038] In one or more embodiments, single-point fracturing treatments may be performed to enable access to the target formation zones. In some embodiments, the first step may be to create a single perforating cluster on the tubing or casing string. For example, the perforating cluster may be created using a perforating gun, a jetting tool, casing cutting, sawing, filing, laser perforating, and the like. In some embodiments, the cluster is already present in the tubing such as when involving a sliding sleeve system, in such instance the sleeve is active or shifted to be in an open position. Fracturing fluids may be pumped down above the fracturing pressure in some embodiments, and may include viscosified hydraulic fracturing fluid, slick water, foam, energized fluid, fluid containing viscoelastic surfactants (VES fluids), linear gels, crosslinked fluids, gelled acid, gelled oils, liquefied gas, in-situ channelization fluids, and the like. Fracturing

treatments in accordance with the present disclosure may also include proppant stages wherein proppant may be sand, ceramic glass beads, mica, and the like.

[0039] In some embodiments, the treatment fluid may be pumped into the target zone below the fracturing pressure. For example, chemical fracturing treatments may be applied at or below fracturing pressure and may include matrix acidizing treatments such as hydrochloric acid, citric acid, acetic acid, and mud acid; chelating agents; scale inhibitors, and the like. Treatment fluids in accordance with the present disclosure may also include friction reducers, clay stabilizers, biocides, crosslinkers, breakers, corrosion inhibitors, and/or proppant flowback control additives. The treatment fluid may further include a product formed from degradation, hydrolysis, hydration, chemical reaction, or other process that occur during preparation of the treatment fluid or during the fracturing operation.

[0040] Treatment fluids in accordance with the present disclosure may also be modified to obtain additional formation related parameters. In one or more embodiments, the treatment design may include injecting tracing agents including radioactive and chemical tracers into the formation and measuring the rate of return of the tracing agent as a method to define the effectiveness of the treatment. For example, tracers may be complexes of radioactive materials such as rare earth metals that are injected in various zones in order to evaluate flowback and production performance of the zones through radiometric analysis of fluids as they flow back from the formation.

[0041] In one or more embodiments, the treatment designs may further include diagnostic tests to improve analysis of formation characteristics. Examples of such diagnostic tests are injectivity tests performed above and below fracturing pressure, drawdown tests, cycled injections/drawdowns, formation breakdown, step-up rate test, step down tests, flowback and pressure rebound tests, calibration injections with registration of pressure decline, injection of "calibration slugs of solids," and the like.

[0042] After the treatment fluid has been pumped, the single-point treated zone is then isolated and access to the following zone in the sequence is enabled. Here again, perforation may be made or the next sleeve may be opened. Various techniques may be

used. In embodiments, a coiled tubing (CT) is used to open a CT actuated fracturation sleeve in the next zone, still involving a sealing element to be set through or below the sleeve to be treated. In embodiments, the previous zone that was treated is isolated using for example bridge plug, ball sealers, sand plug, or by pumping zonal isolating bridging material such as particulates, fiber, flakes, and combination thereof.

[0043] In one or more embodiments, treatment fluids may also be modified between zones to optimize data gathering or to obtain different data from the formation. For example, a sequence of clusters may be designed such that a first single-point fracture and data collection is performed using a first treatment formulation or condition, and when the sequence progresses to the next region of interest, a second treatment or condition is used during the fracturing operation. While such approaches may find utility for treating formations containing zones of differing composition and physical characteristics, it is also envisioned that such an approach may be useful for diagnostic purposes in a formation having a homogenous composition and structure to assay optimal treatment conditions by varying treatments in a sequence of clusters. In some embodiments, multi-stage single-point treatments may be repeated in additional zones or other wells of similar composition until sufficient confidence of the accuracy of the data has been established.

[0044] In addition to modification of the treatment between clusters in a sequence, the spacing between the clusters may also be used to modify the design of the completion string in some embodiments. The space between single-point clusters, or sleeves in a wellbore may be arranged geometrically, for example, at an equidistant spacing that is every 50 feet, every 20 feet, every 10 feet, or every 2 feet. In some embodiments, geometric spacing of the clusters may be used in the event that the available data sets do not provide sufficient data regarding formation composition, where the formation is homogeneous, or where time is a constraining factor. In some embodiments, clusters may be placed according to pre-determined engineering criterion, at non-equidistant spacing, including placing clusters where it is anticipated that formation intervals will have similar or different mineralogy, near regions of general interest, or at intervals determined to be maximal production targets. For example, a multi-stage single-point

fracturing job may be designed such that clusters are spaced within zones having different composition in order to assay the efficacy of a particular treatment on the type of rock or structure in the zone.

[0045] Multi-stage operation may occur in the same well or in other wells. In some embodiments, experimental treatments may be applied at varying points in the well, or alternatively the treatment may be repeated at several intervals to determine the heterogeneity of the response to treatment across intervals.

[0046] Single-point fracturing allows measurement before, during, and after fracturing operations, allowing greater control over the information obtained from the formation. Characteristics obtained for the formation may include mechanical or mineralogical properties, breakdown pressure, logging and comparison to pressure data. In one or more embodiments, treatment of a single-point fracturing zone may be monitored using a number of measuring techniques in order to determine the dependencies between defined formation parameters and the results for each treated zone. Depending on the type of a treatment, measurements may depend on the nature of the fracturing treatment and may include measurement of pressure level, maximum injection rate achieved, Instantaneous Shut In Pressure (ISIP), fracture geometry, pressure evaluation, and the like.

[0047] In some embodiments, measurements may include analysis of bottomhole pressure data, including bottomhole pressure calculated from "deadstring" measurements, in which the level of bottomhole pressure is compared to that of the treated interval. Real-time microseismic diagnostics may also be used wherein microseismic events generated during fracturing are registered to provide an understanding of the position and geometry of the fractured zone. Real-time temperature logging methods in which distributed temperature sensors indicate the portion of a wellbore is being treated, such as fiber optic probes to measure the temperature profile during treatment, may also be used. In other embodiments, radioactive logging may be used in which a radioactive sensor is positioned in a wellbore prior running a treatment, and then detecting a signal from radioactive tracers added in the treatment fluid during the job. In yet another

embodiment, low frequency pressure wave (tubewave) analysis may be used to monitor fractures, obstacles in the wellbore, completion segments, *etc.*, by measuring the decay rates and resonant frequencies of free and forced pressure oscillations to determine the characteristic impedance and the depth of each reflection in the well.

[0048] In some embodiments, additional monitoring techniques may be used including bottomhole pressure gauges including real-time measurements and memory gauges, using microseismic monitoring, tiltimetry, real-time logging including temperature and gamma ray logging, monitoring pressure in surrounding wells for defining communication events, measuring fluid flow using in-line spinning flowmeters, and the like.

[0049] In one or more embodiments, measurements obtained from at least one of prior, during, or after single-point treatment may be used to establish dependencies or correlations between defined formation parameters and the treatment results for each affected zone. Examples of revealed dependencies may include: dependence of formation breakdown pressure or any other treatment pressure parameters on zone mineralogy, mechanical properties, or zonal logging data; dependencies of fracture geometry on injection pattern; presence of natural fractures; dependencies on leak off coefficients defined during diagnostic tests on rock fabric characteristics which may include presence of natural fractures; zone permeability; and the like.

[0050] In one or more embodiments, information obtained from one or more zones of a primary well may be used to design post-job well logging operations in the treated primary well or the information may be used to refine designs for treatments in neighboring or other wells, including those in formations having similar properties to those observed in the first well. Some examples may include temperature logging; this may be used for defining fracture height (typically for vertical well section); gamma ray logging in the case of injection of a radioactive sand that, for example, may be used for defining fracture height, or gamma ray logging of neighbor wells for establishing injection pattern in the formation for example when radioactive tracers were used.

[0051] In embodiments, it may be decided to flow back the well with analysis of flowback fluid including analysis of tracer content in a returning fluid. Flowback may be combined with wellbore clean out, drilling out operation (e.g. when frac plugs were used for zonal isolation between stages), nitrogen injection for unloading the well, workover operation typically performed on a well after treatment completion. Analysis of flowback fluid may include salinity, chloride content, elemental analysis and other parameters all of which can be used for making conclusion about percentage of fluid return, content of formation fluid in the flowback fluid, fracture height (e.g. in the case of presence of elements in a flowback fluid which are specific to some formation layers). Flowback operation may also be combined with logging the well. One of the examples may be production logging done for defining individual zone flowback rates and initial production profile. Results of evaluation of information collected during well flowback period can be used for further update of the formation model, defining dependencies with the results of the performed treatment in a manner described herein.

[0052] Once completions are finalized, the well may be prepared for production operations. Production operations may include installation of production string, change of wellhead equipment, installation of production tree, installation of wellbore equipment (*e.g.*, artificial lift equipment such as nitrogen/natural gas injectors or electric submersible pumps), and the like.

[0053] In one or more embodiments, post-flowback well logging of the treated well (or other wells), including production logging, may be used to generate production data that may reveal the relative success of the performed treatment. Production data in accordance with the present disclosure may be obtained by monitoring of fluid flow rates, including production rates, fluid composition, pressure including surface and bottomhole pressure, and the like.

[0054] Production operations may also be combined with logging operations, such as production logging, and may be performed on a treated well one or several times to define production rates and produced fluid composition for treated zones, in addition to any changes in production from treated zones. Production data logging in accordance

with embodiments of the present disclosure may also include defining production profile and fluid composition for each treated zone. Obtained production results may define dependencies between zonal production characteristics, previous formation parameters for each zone, treatment parameters, results of the performed treatment that were defined from post-treatment evaluation, treatment volumes, and the like.

[0055] Methods in accordance with the present disclosure may carry advantages over standard fracturing techniques in which multiple fracturing clusters are generated in a single operation, because single-point fracturing allows information from the formation to be gathered after each fracture stage, which in turn may be correlated with logging data obtained from the well. Thus, increased amounts of information regarding formation composition, formation pressure, and production volume may be gathered from a single well.

[0056] The skilled artisan will be able to tailor operations for a further well to be treated. Indeed, the data obtained through single-point fracturing and their interpretation will allow the skilled artisan to establish dependencies between formation characteristics of each treated zone, treatment parameters/achieved treatment results and production performance of each treated zone are further used for defining technical recommendations for improving well performance for considered reservoir. Such recommendations may include guidelines for zonal selection with the aim of minimizing treatment pressure or maximizing production performance or optimizing treatment economics; recommendations for volume and treatment schedule of a treatment stage, guidelines for well landing within formation, *etc*. Such another well can be completed and treated using single-point fracturing methodology or any other methodology including "plug and perf" technology.

[0057] In one or more embodiments, data acquired by drilling, completing, and measuring data from a first well, may be used to enable a further optimization of a fracturing process. Indeed, using single-point fracturing and obtaining relevant data for establishing dependencies will help in the choice of fluid flow rate and treatment fluid composition. In addition, data acquired from single-point fracturing may enable

optimization of completion string design, because dependencies may be used to optimize perforation depending on the zone, which may in turn contribute to more efficient hydrocarbon production. Similarly, an operator may tailor the placement and number of fracturing ports on a completion string depending on data obtained from a first diagnostic well, which can minimize sleeve shifting time, manufacturing cost, and fracturing fluid consumption.

[0058] While the disclosure has provided specific and detailed descriptions to various embodiments, the same is to be considered as illustrative and not restrictive in character. Only certain example embodiments have been shown and described. Those skilled in the art will appreciate that many modifications are possible in the example embodiments without materially departing from the disclosure. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims.

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CLAIMS

What is claimed:

1. A method of treating an underground formation, the method comprising:
   obtaining logging data for at least a section of a wellbore;
   treating a plurality of zones in at least a section of the wellbore using the multi-stage single-point fracturing operation;
   obtaining one or more of treatment data, flowback data, or production data for the treated plurality of zones;
   defining one or more dependencies between the obtained logging data and one or more of treatment data, flowback data, or production data; and
   using the dependencies to perform subsequent operations on the at least a section of a wellbore or in another wellbore.

2. The method of claim 1, wherein the at least a section of a wellbore has undergone completions operations prior to treating a plurality of zones in the at least a section of the wellbore.

3. The method of claim 1, wherein the method further comprises designing a multi-stage single-point fracturing operation on the plurality of zones in at least a section of the wellbore.

4. The method of claim 1, wherein the method further comprises:
   injecting a tracer into the underground formation following treating the wellbore section using the single-point fracturing operation; and
   obtaining flowback data from the well.

5. The method of claim 1, wherein the subsequent operations performed comprise one or more selected from a group consisting of drilling and landing another well, cementing another well, treating another well, flowing back another well, and producing another well.

6. The method of claim 1, treating the plurality of zones in at least a section of the wellbore using the multi-stage single-point fracturing operation comprises treating each zone, or a subset of zones, with differing treatments.

7. The method of claim 1, wherein the plurality of zones are of differing mineralogical composition.

8. The method of claim 1, further comprising: drilling the at least one section and logging while drilling the at least one section to obtain the logging data.

9. The method of claim 1, wherein the multi-stage single-point fracturing operation comprises emplacing a completion string in the wellbore having one or more fracturing ports.

10. The method of claim 7, wherein the completion string comprises two or more fracturing ports, and wherein the fracturing ports have a geometric spacing.

11. The method of claim 7, wherein the completion string comprises two or more fracturing ports, and wherein the spacing of the fracturing ports is selected to correlate with regions of interest in the underground formation.

12. The method of claim 1, wherein the completion string containing one or more single-point fracturing ports selected from one or more of a group consisting of sliding sleeves, burst-disks, and packers.

13. The method of claim 1, wherein the multi-stage single-point fracturing operation comprises one or more selected from a group consisting of slick water fracturing, foam fracturing, VES fluid fracturing, crosslinked fluid fracturing, gelled oil fracturing, and liquefied gas fracturing.

14. The method of claim 1, wherein the multi-stage single-point fracturing operation comprises a chemical treatment comprising one or more selected from a group consisting of matrix acidizing agents, hydraulic fracturing fluid, friction reducers, clay stabilizers,

biocides, crosslinkers, breakers, corrosion inhibitors, and proppant flowback control additives.

15. A method of designing a completion string, the method comprising:
obtaining logging data from at least a section of a wellbore;
performing a multi-stage single-point fracturing treatment on a plurality of zones in the at least a section of a wellbore;
obtaining one or more selected from a group consisting of treatment data, flowback data, and production data;
defining one or more dependencies between the obtained logging data and the one or more selected from a group consisting of treatment data, flowback data, and production data;
designing a completion string using the defined one or more dependencies; and
emplacing the designed completion string.

16. The method of claim 15, wherein the completion string is designed for use in another section of the wellbore or another wellbore

17. The method of claim 15, wherein designing the completion string comprises designing a completion string having one or more fracturing ports.

18. The method of claim 17, wherein the completion string comprises a plurality of fracturing ports, and wherein the fracturing ports have a geometric spacing.

19. The method of claim 17, wherein the completion string comprises a plurality of fracturing ports, and wherein the spacing of the fracturing ports is selected to correlate with regions of interest in an underground formation.

20. The method of claim 15, wherein the completion string comprises one or more selected from a group consisting of sliding sleeves, burst-disks, and packers.

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FIG. 1

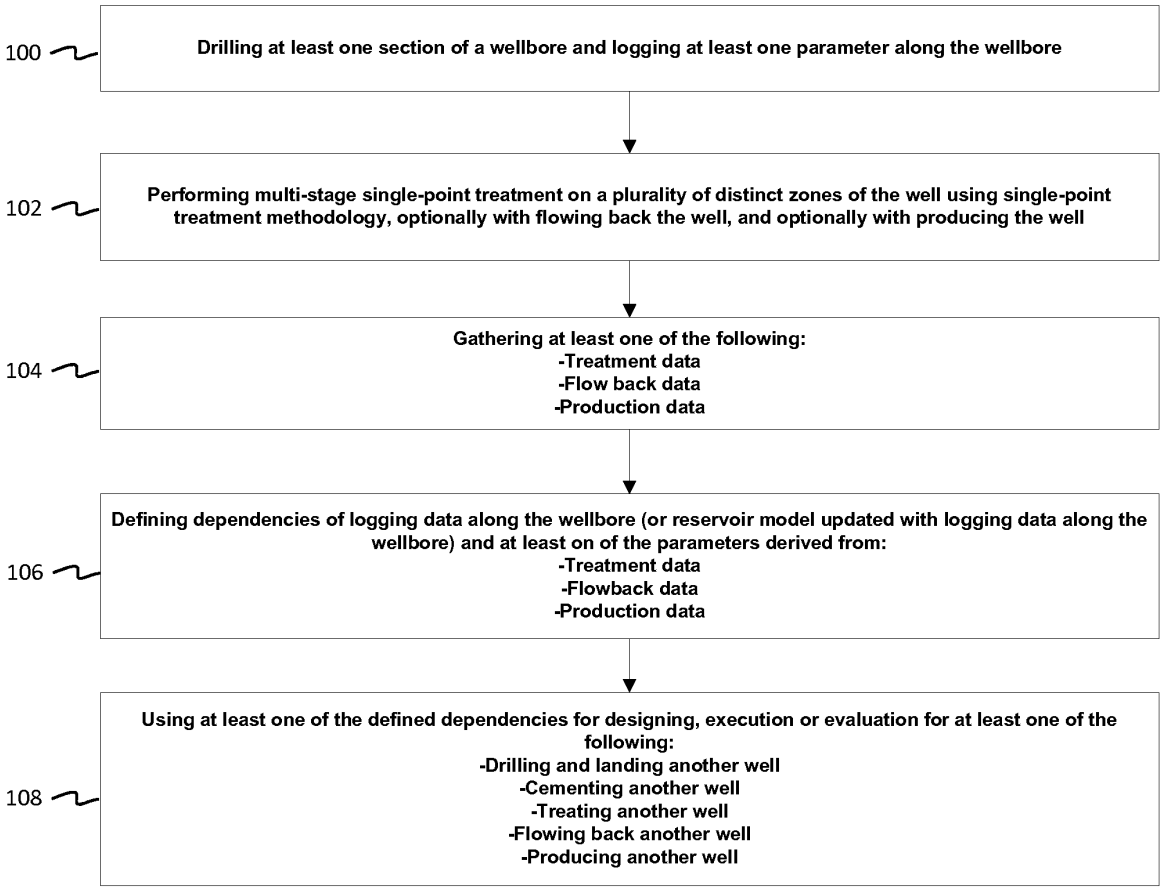

100
Drilling at least one section of a wellbore and logging at least one parameter along the wellbore
102
Performing multi-stage single-point treatment on a plurality of distinct zones of the well using single-point treatment methodology, optionally with flowing back the well, and optionally with producing the well
104
Gathering at least one of the following:
-Treatment data
-Flow back data
-Production data
106
Defining dependencies of logging data along the wellbore (or reservoir model updated with logging data along the wellbore) and at least on of the parameters derived from:
-Treatment data
-Flowback data
-Production data
108
Using at least one of the defined dependencies for designing, execution or evaluation for at least one of the following:
-Drilling and landing another well
-Cementing another well
-Treating another well
-Flowing back another well
-Producing another well

FIG. 2

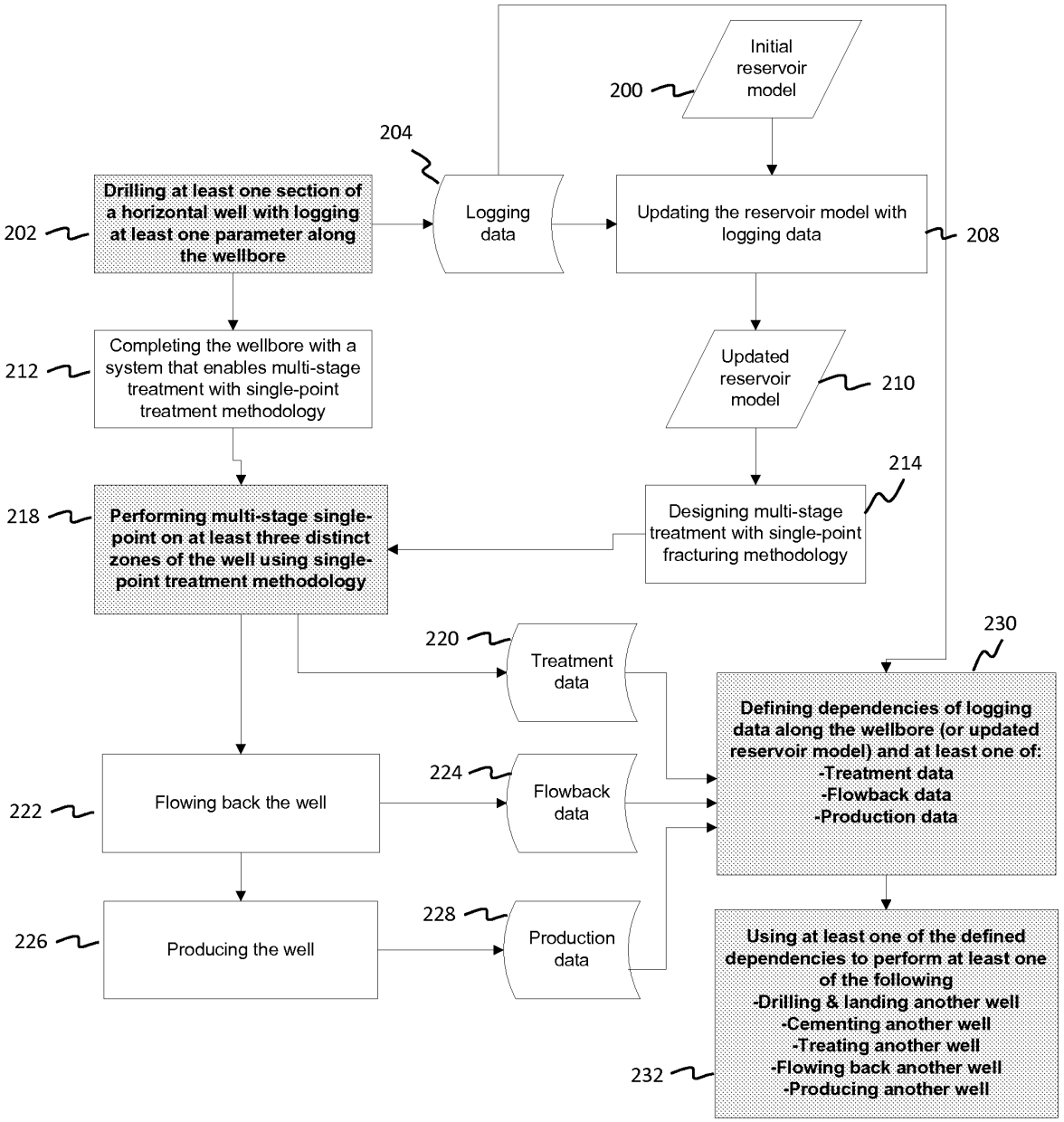

Initial reservoir model
200
204
Drilling at least one section of a horizontal well with logging at least one parameter along the wellbore
202
Logging data
Updating the reservoir model with logging data
208
Completing the wellbore with a system that enables multi-stage treatment with single-point treatment methodology
212
Updated reservoir model
210
214
Designing multi-stage treatment with single-point fracturing methodology
218
Performing multi-stage single-point on at least three distinct zones of the well using single-point treatment methodology
220
Treatment data
230
Defining dependencies of logging data along the wellbore (or updated reservoir model) and at least one of:
-Treatment data
-Flowback data
-Production data
224
Flowback data
222
Flowing back the well
228
Production data
226
Producing the well
Using at least one of the defined dependencies to perform at least one of the following
-Drilling & landing another well
-Cementing another well
-Treating another well
-Flowing back another well
-Producing another well
232

FIG. 3

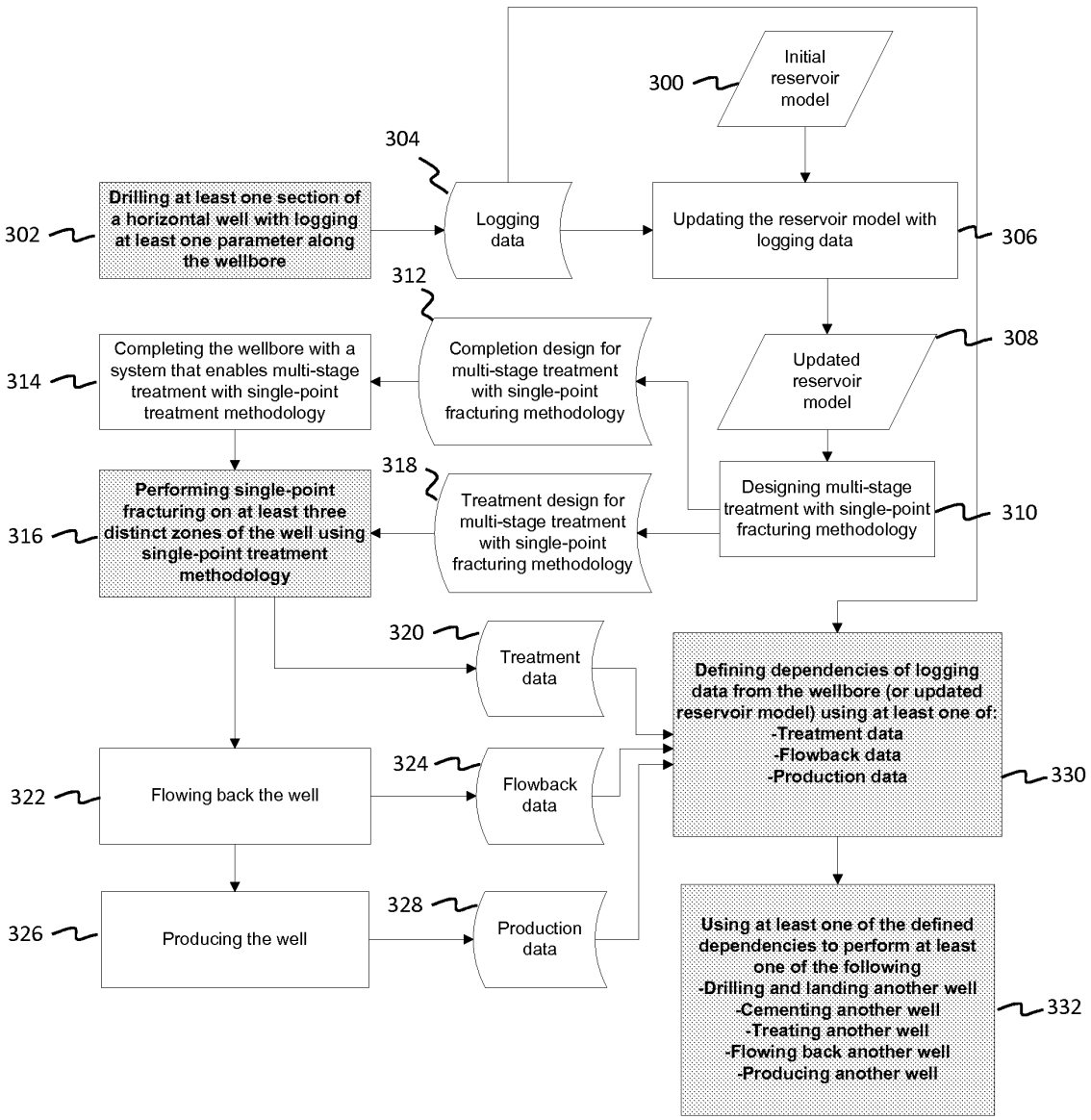
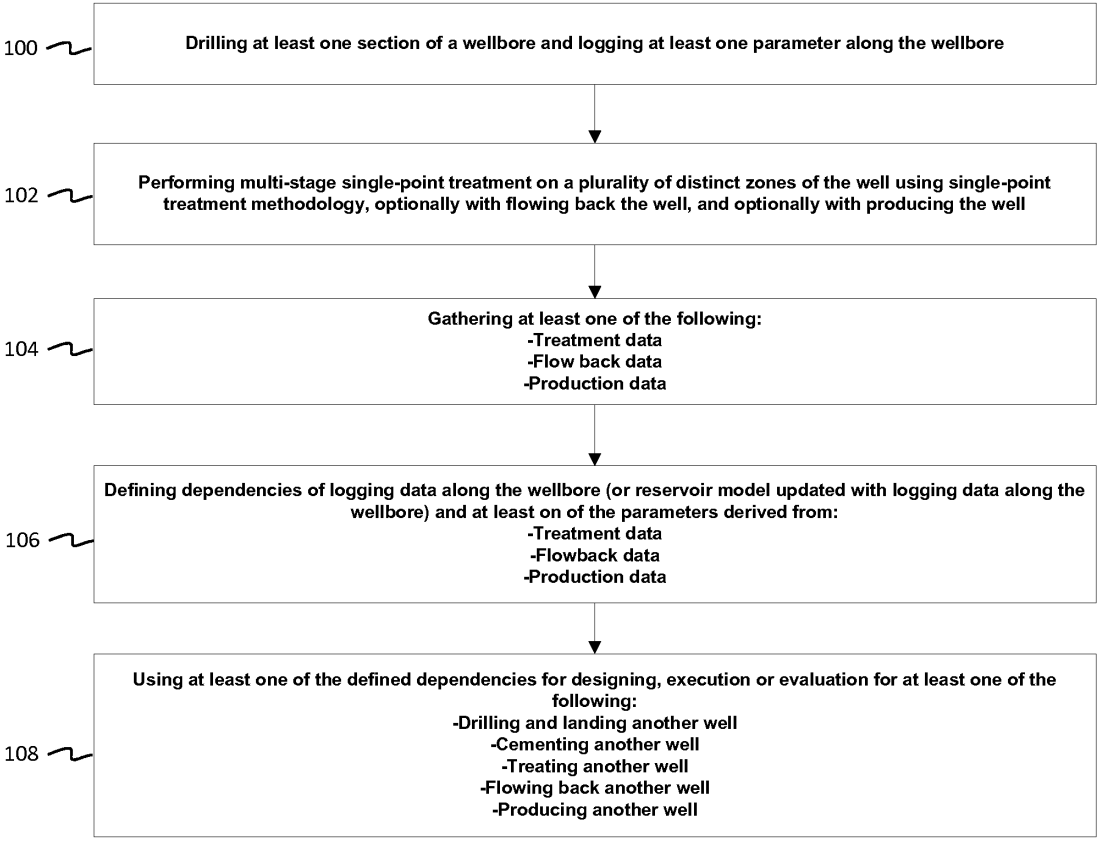

300
Initial reservoir model
304
Logging data
Updating the reservoir model with logging data
306
302
Drilling at least one section of a horizontal well with logging at least one parameter along the wellbore
312
Completion design for multi-stage treatment with single-point fracturing methodology
Updated reservoir model
308
314
Completing the wellbore with a system that enables multi-stage treatment with single-point treatment methodology
318
Treatment design for multi-stage treatment with single-point fracturing methodology
Designing multi-stage treatment with single-point fracturing methodology
310
316
Performing single-point fracturing on at least three distinct zones of the well using single-point treatment methodology
320
Treatment data
Defining dependencies of logging data from the wellbore (or updated reservoir model) using at least one of:
-Treatment data
-Flowback data
-Production data
330
322
Flowing back the well
324
Flowback data
326
Producing the well
328
Production data
Using at least one of the defined dependencies to perform at least one of the following
-Drilling and landing another well
-Cementing another well
-Treating another well
-Flowing back another well
-Producing another well
332

FIG. 1


100
Drilling at least one section of a wellbore and logging at least one parameter along the wellbore
102
Performing multi-stage single-point treatment on a plurality of distinct zones of the well using single-point treatment methodology, optionally with flowing back the well, and optionally with producing the well
104
Gathering at least one of the following:
-Treatment data
-Flow back data
-Production data
106
Defining dependencies of logging data along the wellbore (or reservoir model updated with logging data along the wellbore) and at least on of the parameters derived from:
-Treatment data
-Flowback data
-Production data
108
Using at least one of the defined dependencies for designing, execution or evaluation for at least one of the following:
-Drilling and landing another well
-Cementing another well
-Treating another well
-Flowing back another well
-Producing another well