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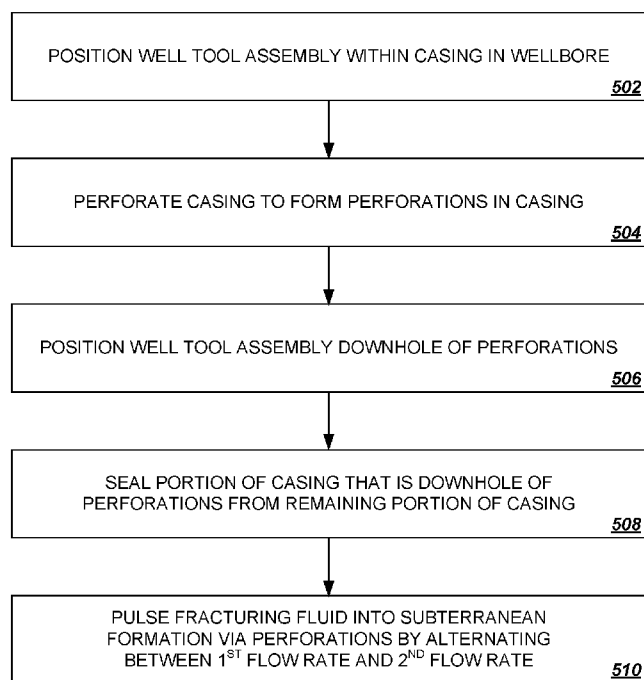


FIG. 5

500

(57) Abstract: A subterranean zone penetrated by a wellbore is hydraulically fractured. A well tool assembly is positioned within a casing installed in the wellbore. The well tool assembly includes a perforation tool and a resettable packer. The casing is perforated, such that fluid can be conducted from inside the casing to the subterranean zone through the perforations. The well tool assembly is positioned at a location within the casing that is downhole of the perforations. A portion of the casing that is downhole of the perforations is sealed with the resettable packer. A fracturing fluid is pulsed into the subterranean zone via the perforations by alternating between a first flow rate and a second flow rate. The second flow rate is in a range of from about 10% to about 40% of the first flow rate. The fracturing fluid is free of proppant.

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PROPPANT-FREE HYDRAULIC FRACTURING

CLAIM OF PRIORITY

[0001] This application claims priority to U.S. Patent Application No. 16/423,853 filed on May 28, 2019, the entire contents of which are hereby incorporated
5 by reference.

TECHNICAL FIELD

[0002] This disclosure relates to hydraulically fracturing subterranean zones, and more specifically with proppant-free fracturing fluid.

BACKGROUND

10 [0003] Hydraulic fracturing is a process of stimulating a well through one or more fractured rock formations. The process involves injection of a fracturing fluid into a wellbore to create fractures, so that fluids can flow more freely through the rock formation. Hydraulic fracturing can increase the mobility of trapped hydrocarbons and therefore increase recovery of hydrocarbons from a reservoir. There are challenges in
15 hydraulic fracturing caused by wide variability of the propagation of the fractures within a subterranean zone. The propagation can depend on mechanical stresses in the reservoir and the fracture properties of the rocks.

SUMMARY

[0004] This disclosure describes technologies relating to hydraulically
20 fracturing subterranean zones, and more specifically with proppant-free fracturing fluid. Certain aspects of the subject matter described can be implemented as a method for hydraulically fracturing a subterranean zone penetrated by a wellbore. A well tool assembly is positioned within a casing installed in the wellbore. The well tool assembly includes a perforation tool and a resettable packer. The casing is perforated with the
25 perforation tool to form perforations in the casing, such that fluid can be conducted from inside the casing to the subterranean zone through the perforations. The well tool assembly is positioned at a location within the casing that is downhole of the perforations. A portion of the casing that is downhole of the perforations is sealed with the resettable packer from a remaining portion of the casing. A fracturing fluid is pulsed
30 into the subterranean zone via the perforations by alternating between flowing the

fracturing fluid into the casing at a first flow rate and flowing the fracturing fluid into the casing at a second flow rate. The first flow rate is equal to or less than 6 barrels per minute. The second flow rate is in a range of from about 10% to about 40% of the first flow rate. The fracturing fluid is free of proppant and has a viscosity that is substantially equal to that of water.

[0005] This, and other aspects, can include one or more of the following features.

[0006] The perforations can be a first cluster of perforations. The resettable packer can be unset to unseal the portion of the casing that is downhole of the first cluster of perforations. The well tool assembly can be positioned at a location within the casing that is uphole of the first cluster of perforations. The casing can be perforated with the perforation tool to form a second cluster of perforations in the casing uphole of the first cluster of perforations. The well tool assembly can be positioned at a location within the casing that is downhole of the second cluster of perforations. A portion of the casing that is downhole of the second cluster of perforations can be sealed with the resettable packer from a remaining portion of the casing. The fracturing fluid can be pulsed into the subterranean zone via the second cluster of perforations by alternating between flowing the fracturing fluid into the casing at the first flow rate and flowing the fracturing fluid into the casing at the second flow rate. The resettable packer can be unset to unseal the portion of the casing that is downhole of the second cluster of perforations.

[0007] The well tool assembly can remain within the casing throughout implementation of the method.

[0008] Each cluster of perforations can span a portion of the casing that is at most 1.5 meters in longitudinal length.

[0009] Each cluster of perforations can include at most 12 perforations.

[0010] The fracturing fluid can be flowed into the casing at the first flow rate for at most 5 minutes before alternating to the second flow rate.

[0011] The fracturing fluid can be flowed into the casing at the second flow rate for at most 1.5 minutes before alternating to the first flow rate.

[0012] Pulsing the fracturing fluid into the subterranean zone can include alternating between flowing the fracturing fluid into the casing at the first flow rate and flowing the fracturing fluid into the casing at the second flow rate, such that each of the

first flow rate and the second flow rate occur at least 5 times.

[0013] Pulsing the fracturing fluid into the subterranean zone can include alternating between flowing the fracturing fluid into the casing at the first flow rate and flowing the fracturing fluid into the casing at the second flow rate until at least 2,000
5 barrels of fracturing fluid have been flowed into the subterranean zone via the respective cluster of perforations.

[0014] Certain aspects of the subject matter described can be implemented as a method for hydraulically fracturing a subterranean zone having a matrix permeability of at most 100 nanoDarcy and a clay content of at most 60 volume %. A fracturing fluid
10 is injected into the subterranean zone at a first flow rate that is equal to or less than 6 barrels per minute. The fracturing fluid is free of proppant and has a viscosity that is substantially equal to that of water. The fracturing fluid is injected into the subterranean zone at a second flow rate that is in a range of from about 10% to about 40% of the first flow rate. The fracturing fluid is injected into the subterranean zone, alternating between
15 the first flow rate and the second flow rate.

[0015] This, and other aspects, can include one or more of the following features.

[0016] The fracturing fluid can be injected into the subterranean zone at the first flow rate for at most 5 minutes.

20 [0017] The fracturing fluid can be injected into the subterranean zone at the second flow rate for at most 1.5 minutes.

[0018] The fracturing fluid can be injected into the subterranean zone, alternating between the first flow rate and the second flow rate at least 5 times.

[0019] The fracturing fluid can be injected into the subterranean zone,
25 alternating between the first flow rate and the second flow rate until at least 2,000 barrels of fracturing fluid have been injected into the subterranean zone.

[0020] Certain aspects of the subject matter described can be implemented as a system for hydraulically fracturing a subterranean zone penetrated by a wellbore. The system includes a well tool assembly, a fracturing fluid, and a pump. The well tool
30 assembly includes a perforation tool and a resettable packer. The perforation tool is configured to form perforations in a casing installed within the wellbore. The resettable packer is configured to reversibly seal a portion of the casing from a remaining portion of the casing while a fracturing fluid is injected into the subterranean zone via the

perforations. The well tool assembly is configured to remain within the casing during hydraulic fracturing. The fracturing fluid is free of proppant and has a viscosity that is substantially equal to that of water. The pump is configured to flow the fracturing fluid into the subterranean zone via the perforations formed by the perforation tool by pulsing the fracturing fluid into the casing between a first flow rate and a second flow rate, thereby hydraulically fracturing the subterranean zone. The first flow rate is equal to or less than 6 barrels per minute. The second flow rate is in a range of from about 10% to about 40% of the first flow rate.

[0021] This, and other aspects, can include one or more of the following features.

[0022] The perforation tool can be configured to form the perforations in the casing across a portion of the casing that is at most 1.5 meters in longitudinal length.

[0023] The perforations can include a cluster of at most 15 perforations.

[0024] The details of one or more implementations of the subject matter of this disclosure are set forth in the accompanying drawings and the description. Other features, aspects, and advantages of the subject matter will become apparent from the description, the drawings, and the claims.

DESCRIPTION OF DRAWINGS

[0025] FIG. 1 is a schematic diagram of an example system for hydraulically fracturing a subterranean zone.

[0026] FIG. 2 is a schematic diagram of an example well tool apparatus that can be used to perforate a tubing.

[0027] FIGs. 3A, 3B, 3C, 3D, 3E, 3F, 3G, 3H, 3J, 3K, and 3L show a progression of an example hydraulic fracturing operation.

[0028] FIG. 4A is a schematic diagram of an example well that has been hydraulically fractured.

[0029] FIG. 4B is a graph showing pressure and flow rate of fracturing fluid vs. time for the hydraulic fracturing process for the well shown in FIG. 4A.

[0030] FIG. 5 is a flow chart of an example method for hydraulically fracturing a subterranean zone.

[0031] FIG. 6 is a flow chart of an example method for hydraulically fracturing a subterranean zone.

DETAILED DESCRIPTION

[0032] This disclosure describes hydraulic fracturing stimulation of wells, and more specifically, of wells in ultra-low matrix permeability unconventional resources, such as shale. The matrix permeability of shale reservoirs can be 100 nanoDarcy (nD) or less (for example, 50 nD or less), and the clay content of such reservoirs can be 60 volume percent (vol. %) or less. The systems and methods described can be implemented to increase well productivity with smaller hydraulic fracturing fluid volumes injected at smaller flow rates without proppant in comparison to traditional methods. The systems and methods described can be implemented to induce reservoir self-propping, thereby allowing the reservoir to be fractured with a fracturing fluid that is free of proppant. Fractures in subterranean formations can be created by intermittent/pulsed injections of fracturing fluid (that is, alternating between different flow rates) to induce fracture tip degradation, elongation, and failure. The pulsed mechanism causes the shale reservoir rock to fail at lower stress than would be predicted from its natural mechanical strength, due to the induced fatigue by the pulsed injections.

[0033] To facilitate Continuous Multi-Stage Execution of Hydraulic Fracturing Stimulation, the present disclosure is conducted with a defined tool assembly to allow multiple stimulation stages to be completed. The elimination of proppant which is a hurdle in continuous multi-stage perforating operations opens limitless frac stages to be stimulated.

[0034] The subject matter described in this disclosure can be implemented in particular implementations, so as to realize one or more of the following advantages. The methods and systems described in this disclosure can be implemented to improve productivity of a well and increase the estimated ultimate recovery (EUR) of the well. Perforation of adjacent virgin zones along the lateral (for example, multi-stage perforating operations) can be continuous, that is, without interruptions (for example, interruptions associated with running perforation tools into and out of the wellbore between fracturing stages in conventional hydraulic fracturing operations). The use of a proppant-free fracturing fluid can require fewer fracturing service equipment than conventional hydraulic fracturing methods and systems. For example, implementation of the subject matter can eliminate the need for gel hydration units for transporting gel and mixing of the gel, the need for proppant storage and proppant delivery, and the need for high pressure pump trucks. The pulsed injections of the fracturing fluid can require

less fracturing fluid volume to be used in comparison to conventional hydraulic fracturing methods and systems. Therefore, by implementing the methods and systems described in this disclosure, both capital and operational costs can be saved. By implementing the methods and systems described in this disclosure, conductive fractures
5 can be created and remain in the zone of interest within the subterranean zone (in contrast to conventional hydraulic fracturing methods and systems that may create fractures that extend beyond the zone of interest). Keeping the conductive fractures in the zone of interest can lead to increased productivity and less costs. Utilizing a proppant-free, low viscosity fracturing fluid can reduce or eliminate the tendency of
10 fracture growth (for example, beyond the zone of interest), hence facilitating long (that is, along the longitudinal axis of the wellbore) in-zone fractures, which can increase reservoir contact area and in turn, improve well productivity. The pulsed injections of the fracturing fluid induces cyclic loading that can enhance fracture tip fatigue and lateral extension, which can cause fracture surface area in the zone of interest to increase.
15 Utilizing low viscosity fracturing fluids can eliminate the need of various additives (such as viscosifying agents) and can also conserve water. The methods and systems described in this disclosure can be implemented to eliminate the risks associated with screen out during hydraulic fracturing operations.

[0035] FIG. 1 depicts an example well 100 constructed in accordance with the
20 concepts herein. The well 100 extends from the surface 106 through the Earth 108 to one more subterranean zones of interest 110 (one shown). The well 100 enables access to the subterranean zones of interest 110 to allow recovery (that is, production) of fluids to the surface 106 and, in some implementations, additionally or alternatively allows fluids to be placed in the Earth 108. In some implementations, the subterranean zone
25 110 is a formation within the Earth 108 defining a reservoir, but in other instances, the zone 110 can be multiple formations or a portion of a formation. The subterranean zone can include, for example, a formation, a portion of a formation, or multiple formations in a hydrocarbon-bearing reservoir from which recovery operations can be practiced to recover trapped hydrocarbons. In some implementations, the subterranean zone
30 includes an underground formation of naturally fractured or porous rock containing hydrocarbons (for example, oil, gas, or both). In some implementations, the well can intersect other suitable types of formations, including reservoirs that are not naturally fractured. For simplicity's sake, the well 100 is shown as a vertical well, but in other

instances, the well 100 can be a deviated well with a wellbore deviated from vertical (for example, horizontal or slanted). An example of a deviated well 100 is shown in FIG. 4A.

[0036] Referring back to FIG. 1, in some implementations, the well 100 is a gas well that is used in producing natural gas from the subterranean zones of interest 110 to the surface 106. While termed a “gas well,” the well need not produce only dry gas, and may incidentally or in much smaller quantities, produce liquid including oil and/or water. In some implementations, the well 100 is an oil well that is used in producing crude oil from the subterranean zones of interest 110 to the surface 106. While termed an “oil well,” the well not need produce only crude oil, and may incidentally or in much smaller quantities, produce gas and/or water. In some implementations, the production from the well 100 can be multiphase in any ratio, and/or can produce mostly or entirely liquid at certain times and mostly or entirely gas at other times. For example, in certain types of wells it is common to produce water for a period of time to gain access to the gas in the subterranean zone. The concepts herein, though, are not limited in applicability to gas wells, oil wells, or even production wells, and could be used in wells for producing other gas or liquid resources, and/or could be used in injection wells, disposal wells, or other types of wells used in placing fluids into the Earth.

[0037] The wellbore of the well 100 is typically, although not necessarily, cylindrical. All or a portion of the wellbore is lined with a tubing, such as casing 112. The casing 112 connects with a wellhead at the surface 106 and extends downhole into the wellbore. The casing 112 operates to isolate the bore of the well 100, defined in the cased portion of the well 100 by the inner bore of the casing 112, from the surrounding Earth 108. The casing 112 can be formed of a single continuous tubing or multiple lengths of tubing joined (for example, threadedly and/or otherwise) end-to-end. In FIG. 1, the casing 112 has perforations 120 in the subterranean zone of interest 110 to allow fluid communication between the subterranean zone of interest 110 and the bore of the casing 112. In some implementations, the casing 112 is omitted or ceases in the region of the subterranean zone of interest 110. This portion of the well 100 without casing is often referred to as “open hole.”

[0038] The wellhead defines an attachment point for other equipment to be attached to the well 100. For example, FIG. 1 shows well 100 with a Christmas tree attached the wellhead. The Christmas tree includes valves used to regulate flow into or

out of the well 100. The well 100 can include a source of fluid 150 (for example, fracturing fluid 150). The source of fluid 150 can be connected to the wellhead. The well 100 can include a pump 104 that can be used to pump fluid from the source of fluid 150 into the bore of the casing 112. This way, fracturing fluid 150 can be flowed from the surface 106, into the casing 112, and into the subterranean zone 110 via the perforations 120 in the casing 112. The fracturing fluid 150 can be flowed into the subterranean zone 110 through intermittent or pulsed injections of the fracturing fluid 150 (for example, by alternating between different flow rates). Conversely, fluid (for example, oil, gas, water, or any combination of these) can flow from the subterranean zone 110, into the bore of the casing 112 through the perforations 120, and up to the surface 106. In some implementations, the pump 104 is configured to flow the fracturing fluid 150 into the subterranean zone 110 via the perforations 120 by pulsing the fracturing fluid 150 into the casing 112 between a first flow rate and a second flow rate (different from the first flow rate). In some implementations, the pump 104 is configured to flow the fracturing fluid 150 into the subterranean zone 110 via the perforations 120 by pulsing the fracturing fluid 150 into the casing 112 between multiple small flow rates and multiple large flow rates. The pump 104 can continue to flow the fracturing fluid 150 into the subterranean zone 110 until a pre-determined fracturing stage volume has been injected into the zone 110. The pump 104 can include a flow control device (such as a control valve) to adjust the flow rate of fracturing fluid 150 between the first flow rate and the second flow rate. In some implementations, the flow control device can adjust the flow rate of fracturing fluid 150 between multiple small flow rates and multiple large flow rates. In some implementations, the first (large) flow rate is equal to or less than 6 barrels per minute. In some implementations, the second (small) flow rate is in a range of from about 10% to about 40% of the first flow rate. Flowing the fracturing fluid 150 into the subterranean zone 110 results in hydraulically fracturing the subterranean zone 110. By keeping the hydraulic fracture contained in the subterranean zone 110, less fluid 150 can be used, as non-reservoir subterranean zones (that is, zones that do not contain fluids of interest, such as hydrocarbons) are not fractured.

[0039] The fracturing fluid 150 is free of proppant. The fracturing fluid 150 has a viscosity that is substantially equal to that of water. In some implementations, the fracturing fluid 150 has a viscosity of 5 centipoise (cP) or less. In some

implementations, the fracturing fluid 150 has a viscosity in a range of from approximately 0.85 cP to approximately 1.0 cP. The fracturing fluid 150 can include water. In some implementations, the fracturing fluid 150 includes one or more additives. Some non-limiting examples of suitable additives include friction reducers (such as polyacrylamide or low gel loading polymers), surfactants (such as non-ionic, cationic, and amphoteric surfactants), and clay stabilizers (such as potassium chloride and quaternary salts).

[0040] In particular, casing 112 is commercially produced in a number of common sizes specified by the American Petroleum Institute (the “API”), including 4-1/2, 5, 5-1/2, 6, 6-5/8, 7, 7-5/8, 16/8, 9-5/8, 10-3/4, 11-3/4, 13-3/8, 16, 116/8 and 20 inches, and the API specifies internal diameters for each casing size.

[0041] The well 100 can also include a well tool apparatus 102 residing in the wellbore, for example, at a depth that is nearer to subterranean zone 110 than the surface 106. The apparatus 102 is of a type configured in size and robust construction for installation within the well 100. The apparatus 102 can be configured to fit in, and (as discussed in more detail below) in certain instances, seal to the inner diameter of one of the specified API casing sizes. Of course, the apparatus 102 can be made to fit in and, in certain instances, seal to other sizes of casing or tubing or otherwise seal to a wall of the well 100.

[0042] Additionally, the construction of the components of the apparatus 102 are configured to withstand the impacts, scraping, and other physical challenges the apparatus 102 will encounter while being passed hundreds of feet/meters or even multiple miles/kilometers into and out of the well 100. For example, the apparatus 102 can be disposed in the well 100 at a depth of up to 20,000 feet (6,096 meters). Beyond just a rugged exterior, this encompasses having certain portions of any electronics being ruggedized to be shock resistant and remain fluid tight during such physical challenges and during operation. Additionally, the apparatus 102 is configured to withstand and operate for extended periods of time (e.g., multiple weeks, months or years) at the pressures and temperatures experienced in the well 200, which temperatures can exceed 400°F / 205°C and pressures over 2,000 pounds per square inch, and while submerged in the well fluids (for example, gas, water, or oil). Finally, the apparatus 102 can be configured to interface with one or more of the common deployment systems 118, such as jointed tubing (that is, lengths of tubing joined end-to-end, threadedly and/or

otherwise), a sucker rod, coiled tubing (that is, not-jointed tubing, but rather a continuous, unbroken and flexible tubing formed as a single piece of material), or wireline with an electrical conductor (that is, a monofilament or multifilament wire rope with one or more electrical conductors, sometimes called e-line) and thus have a corresponding connector (for example, a jointed tubing connector, coiled tubing connector, or wireline connector). In some implementations, the apparatus 102 can be implemented to alter characteristics of a wellbore by a mechanical intervention at the source. The apparatus 102 can be implemented to effect increased well production.

[0043] The apparatus 102 can operate in a variety of downhole conditions of the well 100. For example, the initial pressure within the well 100 can vary based on the type of well, depth of the well 100, production flow from the perforations into the well 100, and/or other factors. In some examples, the pressure in the well 100 proximate a bottomhole location is sub-atmospheric, where the pressure in the well 100 is at or below about 14.7 pounds per square inch absolute (psia), or about 101.3 kiloPascal (kPa). The apparatus 102 can operate in sub-atmospheric well pressures, for example, at well pressure between 2 psia (13.8 kPa) and 14.7 psia (101.3 kPa). In some examples, the pressure in the well 100 proximate a bottomhole location is much higher than atmospheric, where the pressure in the well 100 is above about 14.7 pounds per square inch absolute (psia), or about 101.3 kiloPascal (kPa). The apparatus 102 can operate in above atmospheric well pressures, for example, at well pressure between 14.7 psia (101.3 kPa) and 5,000 psia (34,474 kPa).

[0044] Referring to FIG. 2, the well tool apparatus 102 includes a perforation tool 102a and a resettable packer 102b. The perforation tool 102a is configured to perforate a tubing (such as the casing 112) to form one or more perforations in the tubing. For example, the perforation tool 102a can perforate the casing 112 to form perforations in the casing 112, such that fluid can be conducted from inside the casing 112 (such as from the inner bore of the casing 112) to the subterranean zone 110 through the perforations. The perforation tool 102a can include a jetting device. In some implementations, the jetting device uses abrasive material to aid in perforating the tubing. In some implementations, the perforation tool 102a includes a perforating gun and an explosive.

[0045] In some implementations, the perforation tool 102a is configured to perforate a portion of the tubing (for example, the casing 112) that spans at most 1.5

meters in longitudinal length of the tubing at a time. In other words, a single use of the perforation tool 102a can result in forming perforations in a portion of the tubing that spans at most 1.5 meters in longitudinal length of the tubing. The perforation tool 102a can be used multiple times to perforate additional portions of the tubing. For example, the perforation tool 102a can be moved to another location within the tubing to perforate another portion of the tubing that spans at most 1.5 meters in longitudinal length of the tubing. In some implementations, the perforation tool 102a is configured to form at most 12 perforations in the tubing (for example, the casing 112) at a time. In other words, a single use of the perforation tool 102a can result in forming a single fracturing stage with at most 12 perforations in the tubing. The perforation tool 102a can be used multiple times to form additional perforations (additional fracturing stages) in the tubing. In some implementations, the perforation tool 102a is configured to form at most 12 perforations in a portion of the tubing (for example, the casing 112) that spans at most 1.5 meters in longitudinal length of the tubing at a time. In some implementations, the perforation tool 102a is configured to form at least 5 perforations in the tubing (for example, the casing 112) at a time.

[0046] The resettable packer 102b can divide the well 100 into an uphole zone above the resettable packer 102b and a downhole zone below the resettable packer 102b. FIG. 1 shows the apparatus 102 positioned in the open volume of the bore of the casing 112. The wall of the well 100 includes the interior wall of the casing 112 in portions of the wellbore having the casing 112, and in some implementations, can include an open hole wellbore wall in uncased portions of the well 100. The resettable packer 102b is configured to seal against the wall of the wellbore, for example, against the interior wall of the casing 112 in the cased portions of the well 100 or against the interior wall of the wellbore in the uncased, open hole portions of the well 100. In certain instances, the resettable packer 102b can form a gas- and liquid-tight seal in the well 100. For example, the resettable packer 102b can be configured to at least partially seal against an interior wall of the wellbore to separate (completely or substantially) a pressure in the well 100 downhole of the resettable packer 102b from a pressure in the well 100 uphole of the resettable packer 102b. The resettable packer 102b can be unset to unseal the well 100. The resettable packer 102b can be re-positioned to another location within the well 100 to seal the well 100 at that location. In other words, the resettable packer 102b is reusable. The resettable packer 102b can include a release mechanism for

retrieval of the resettable packer 102b in cases where the resettable packer 102b may become stuck.

[0047] FIGs. 3A through 3L are a progression of stages showing how the well tool apparatus 102 can be used to hydraulically fracture the subterranean zone 110. FIG. 3A shows the well tool apparatus 102 positioned at a zone of interest (such as the subterranean zone 110) within the casing 112. The perforation tool 102a is used to perforate the casing 112. FIG. 3B shows the casing 112 with perforations 120a formed by the perforation tool 102a. FIG. 3C shows the well tool apparatus 102 positioned downhole of the perforations 120a. In FIG. 3D, the resettable packer 102b is used to seal against the interior wall of the casing 112 to seal a portion of the casing 112 that is downhole of the resettable packer 102b from a remaining portion of the casing 112 (that is, the portion of the casing 112 that is uphole of the resettable packer 102b, including the perforations 120a). Fracturing fluid 150 can be flowed from the surface and into the inner bore of the casing 112. The fracturing fluid 150 can flow into the subterranean zone 110 through the perforations 120a to fracture the subterranean zone 110. The resettable packer 102b that is sealing against the interior wall of the casing 112 prevents the fracturing fluid 150 from flowing into the portion of the casing that is downhole of the resettable packer 102b. FIG. 3E shows the fractures 121a formed as a result of injecting the fracturing fluid 150 into the subterranean zone 110. The resettable packer 102b can be unset to unseal the well 100. The well tool apparatus 102 is then free to move (for example, to be taken out of the well 100 or to be positioned at another location within the well 100).

[0048] Additional perforations can be formed in the casing 112 at another location in the subterranean zone 110 to hydraulically fracture that location of the subterranean zone 110. FIG. 3F shows the well apparatus tool 102 positioned at another location, uphole of the perforations 120a (and fractures 121a). The perforation tool 102a is used again to perforate the casing 112. FIG. 3G shows the casing 112 with perforations 120b formed by the perforation tool 102a. FIG. 3H shows the well tool apparatus 102 positioned downhole of the perforations 120b. The resettable packer 102b is positioned uphole of the perforations 120a. In FIG. 3J, the resettable packer 102b is used to seal against the interior wall of the casing 112 to seal a portion of the casing 112 that is downhole of the resettable packer 102b (including the perforations 120a and fractures 121a) from a remaining portion of the casing 112 (that is, the portion of the

casing 112 that is uphole of the resettable packer 102b, including the perforations 120b). Fracturing fluid 150 can be flowed from the surface and into the inner bore of the casing 112. The fracturing fluid can flow into the subterranean zone 110 through the perforations 120b to fracture the subterranean zone 110. The resettable packer 102b that is sealing against the interior wall of the casing 112 prevents the fracturing fluid 150 from flowing into the portion of the casing that is downhole of the resettable packer 102b. For example, the fracturing fluid 150 can flow into the subterranean zone 110 through the perforations 120b, but not the perforations 120a which are downhole of the resettable packer 102b. FIG. 3K shows the fractures 121b formed as a result of injecting the fracturing fluid 150 into the subterranean zone 110. The resettable packer 102b can be unset to unseal the well 100. The well tool apparatus 102 is then free to move (for example, to be taken out of the well 100 or to be positioned at another location within the well). FIG. 3L shows the well 100 with perforations (120a, 120b) formed in the casing 112 by the well tool assembly 102 and fractures (121a, 121b) formed in the subterranean zone 110 by injection of the fracturing fluid 150 after the well tool assembly 102 has been removed from the well 100.

[0049] Although shown in FIGs. 3A through 3L in relation to a vertical well, the same concepts can be applied to a deviated well (such as a horizontal well). FIG. 4A shows an example of a horizontal well. The casing has been perforated (for example, using the perforation tool 102a of the well tool assembly 102), and fracture stages (121a, 121b, 121c, 121d) have been formed in the subterranean zone 110 (for example, by injecting the fracturing fluid 150 through the perforations). FIG. 4B is a graph showing the relationship of injection pressure and flow rate of the fracturing fluid 150 during the fracturing process of the well shown in FIG. 4A.

[0050] FIG. 5 is a flow chart of a method 500 for hydraulically fracturing a subterranean zone (such as the subterranean zone 110). The well tool assembly 102 can be used to implement the method 500. An example of a progression of method 500 is shown in FIGs. 3A through 3E. At step 502, the well tool assembly 102 is positioned within a casing (112) installed in a wellbore. At step 504, the perforation tool 102a of the well tool assembly 102 is used to perforate the casing 112. Perforations (for example, perforations 120a shown in FIG. 3B) are formed in the casing 112, such that fluid can be conducted from inside the casing 112 to the subterranean zone 110 through the perforations 120a.

[0051] At step 506, the well tool assembly 102 is positioned at a location within the casing 112 that is downhole of the perforations 120a (an example is shown in FIG. 3C). At step 508, a portion of the casing 112 that is downhole of the perforations 120a is sealed from a remaining portion of the casing 112 using the resettable packer 102b of the well tool assembly 102. The resettable packer 102b is used to seal against the interior wall of the casing 112 to seal a portion of the casing 112 that is downhole of the resettable packer 102b from a remaining portion of the casing 112 that is uphole of the resettable packer 102b (which includes the perforations 120a).

[0052] At step 510, a fracturing fluid (150) is pulsed into the subterranean zone 110 via the perforations 120a by alternating between flowing the fracturing fluid 150 into the casing 112 at a first flow rate and flowing the fracturing fluid 150 into the casing 112 at a second flow rate (different from the first flow rate). In other words, the fracturing fluid 150 can be pulsed into the subterranean zone 110 using the pump 104 (alternating between a large first flow rate and a small second flow rate). As mentioned previously, the fracturing fluid 150 is free of proppant and has a viscosity that is substantially equal to that of water. The first flow rate is equal to or less than 6 barrels per minutes. In some implementations, the first flow rate is in a range of from about 4 barrels per minute to 6 barrels per minute. The second flow rate is in a range of from about 10% to about 40% of the first flow rate. For example, in cases where the first flow rate is 6 barrels per minute, the second flow rate is in a range of from about 0.6 barrels per minute to about 2.4 barrels per minute. Neither the first flow rate nor the second flow rate need to be constant throughout step 510. For example, the first flow rate can vary throughout step 510 in a range of from about 4 barrels per minute to 6 barrels per minute. For example, the second flow rate can vary throughout step 510 in a range of from about 10% to about 40% of the first flow rate.

[0053] In some implementations, the fracturing fluid 150 is flowed into the casing 112 at the first flow rate for at least 1 minute before alternating to the second flow rate. In some implementations, the fracturing fluid 150 is flowed into the casing 112 at the first flow rate for at most 5 minutes before alternating to the second flow rate. For example, the fracturing fluid 150 is flowed into the casing 112 at the first flow rate for at least 1 minute and at most 5 minutes before alternating to the second flow rate. For example, the fracturing fluid 150 is flowed into the casing 112 at the first flow rate for at least 3 minutes and at most 5 minutes before alternating to the second flow rate.

[0054] In some implementations, the fracturing fluid 150 is flowed into the casing 112 at the second flow rate for at least 30 seconds before alternating to the second flow rate. In some implementations, the fracturing fluid 150 is flowed into the casing 112 at the second flow rate for at most 1.5 minutes before alternating to the first flow rate. For example, the fracturing fluid 150 is flowed into the casing 112 at the second flow rate for at least 30 seconds and at most 1.5 minutes before alternating to the first flow rate. For example, the fracturing fluid 150 is flowed into the casing 112 at the second flow rate for at least 1 minute and at most 1.5 minutes before alternating to the first flow rate.

[0055] In some implementations, pulsing the fracturing fluid 150 into the subterranean zone 110 at step 510 includes alternating between flowing the fracturing fluid 150 into the casing 112 at the first flow rate and flowing the fracturing fluid 150 into the casing 112 at the second flow rate, such that each of the first flow rate and the second flow rate occur at least 5 times (for example, 5 times, 6 times, 7 times, 8 times, 9 times, 10 times, or more). In some implementations, pulsing the fracturing fluid 150 into the subterranean zone 110 at step 510 includes alternating between flowing the fracturing fluid 150 into the casing 112 at the first flow rate and flowing the fracturing fluid 150 into the casing 112 at the second flow rate until a pre-determined volume of fracturing fluid 150 has been injected into the casing 112. The pre-determined volume of fracturing fluid 150 can depend on one or more of the following factors: thickness of the reservoir (that is, radial distance of the zone of interest from the casing 112), desired length of the hydraulic fractures, and reservoir leak-off characteristics. In some implementations, the pre-determined volume of fracturing fluid 150 is at least approximately 2,000 barrels. In some implementations, the pre-determined volume of fracturing fluid 150 is at most 20,000 barrels. For example, pulsing the fracturing fluid 150 into the subterranean zone 110 at step 510 continues until at least 2,000 barrels of fracturing fluid 150 have been injected into the casing 112.

[0056] This paragraph outlines one specific example of an implementation of step 510. The first flow rate is 5 barrels per minute, and the second flow rate is 1 barrel per minute. The fracturing fluid 150 is flowed into the casing 112 (through the perforations 120a and into the subterranean zone 110) at the first flow rate for 4 minutes and then at the second flow rate for 1 minute. The fracturing fluid 150 is flowed into the casing 112, alternating between the first flow rate for 4 minutes and the second flow

rate for 1 minute for 10 iterations (that is, for a total of 10 instances of first flow rate for 4 minutes and 10 instances of second flow rate for 1 minute). Therefore, in this example, step 510 spans 50 minutes with a total volume of 210 barrels injected into the casing 112.

5 [0057] The cyclic loading of step 510 creates fractures (121a) in the subterranean formation 110. The mechanism at step 510 can cause fracture degradation at fracture tips and therefore increase fracture half length. After pulsing the fracturing fluid 150 into the subterranean zone 110, the resettable packer 102b can be unset to unseal the casing 112. The well tool assembly 102 can then be moved, for example, out of the well
10 100 or to another location within the casing 112. In some implementations, the well tool assembly 102 is positioned at another location within the casing 112 that is uphole of the perforations 120a, and the method 500 is repeated. FIGs. 3F through 3L show an example progression of the method 500 being repeated to form the second set of perforations 120b and fractures 121b. FIG. 4A shows an example result after
15 implementing method 500 on a horizontal well 100. For the example shown in FIG. 4A, method 500 was repeated 4 times at 4 locations within the casing 112 to form four sets of fractures (121a, 121b, 121c, 121d) in the subterranean zone 110.

[0058] FIG. 6 is a flow chart of a method 600 for hydraulically fracturing a subterranean zone (such as the subterranean zone 110) that has a matrix permeability of
20 at most 100 nD and a clay content of at most 60 vol. % (for example, a shale reservoir). Method 600 applies to implementations where the perforations have already been formed in the casing 112 (by using the well tool assembly 102 or another perforation tool).

[0059] At step 602, a fracturing fluid (150) is injected into the subterranean zone
25 110 at a first flow rate that is equal to or less than 6 barrels per minute. As mentioned previously, the fracturing fluid 150 is free of proppant and has a viscosity that is substantially equal to that of water. In some implementations, the fracturing fluid 150 is injected into the subterranean zone 110 at the first flow rate for at least 1 minute at step 602. In some implementations, the fracturing fluid 150 is injected into the
30 subterranean zone 110 at the first flow rate for at most 5 minutes at step 602. For example, the fracturing fluid 150 is injected into the subterranean zone 110 at the first flow rate for at least 1 minute and at most 5 minutes at step 602. For example, the fracturing fluid 150 is injected into the subterranean zone 110 at the first flow rate for at

least 3 minutes and at most 5 minutes at step 602.

[0060] At step 604, the fracturing fluid 150 is injected into the subterranean zone 110 at a second flow rate that is in a range of from about 10% to about 40% of the first flow rate. In some implementations, the fracturing fluid 150 is injected into the subterranean zone 110 at the second flow rate for at least 30 seconds at step 604. In some implementations, the fracturing fluid 150 is injected into the subterranean zone 110 at the second flow rate for at most 1.5 minutes at step 604. For example, the fracturing fluid 150 is injected into the subterranean zone 110 at the second flow rate for at least 30 seconds and at most 1.5 minutes at step 604. For example, the fracturing fluid 150 is injected into the subterranean zone 110 at the second flow rate for at least 1 minute and at most 1.5 minutes at step 604.

[0061] Steps 602 and 604 are then sequentially repeated. Steps 602 and 604 are repeated to provide pulsations of fracturing fluid 150 injection into the subterranean zone 110 until a single fracturing stage is complete. In some implementations, steps 602 and 604 are sequentially repeated at least 5 times (for example, 5 times, 6 times, 7 times, 8 times, 9 times, 10 times, or more). In some implementations, steps 602 and 604 are sequentially repeated until a pre-determined volume of fracturing fluid 150 has been injected into the subterranean zone 110. Once the pre-determined volume of fracturing fluid 150 has been injected into the subterranean zone 110, a single fracturing stage is complete. For example, steps 602 and 604 are sequentially repeated until at least 2,000 barrels of fracturing fluid have been injected into the subterranean zone 110.

[0062] The fracturing fluid 150 can be injected into the subterranean zone 110 at steps 602 and 604, for example, by flowing the fracturing fluid 150 from the surface 106, into the casing 112 and through the perforations 120 (or 120a or 120b) by using the pump 104.

[0063] In this disclosure, the terms “a,” “an,” or “the” are used to include one or more than one unless the context clearly dictates otherwise. The term “or” is used to refer to a nonexclusive “or” unless otherwise indicated. The statement “at least one of A and B” has the same meaning as “A, B, or A and B.” In addition, it is to be understood that the phraseology or terminology employed in this disclosure, and not otherwise defined, is for the purpose of description only and not of limitation. Any use of section headings is intended to aid reading of the document and is not to be interpreted as limiting; information that is relevant to a section heading may occur within or outside

of that particular section.

[0064] In this disclosure, “approximately” means a deviation or allowance of up to 10 percent (%) and any variation from a mentioned value is within the tolerance limits of any machinery used to manufacture the part. Likewise, “about” and “substantially”
5 can also allow for a degree of variability in a value or range, for example, within 10%, within 5%, or within 1% of a stated value or of a stated limit of a range.

[0065] Values expressed in a range format should be interpreted in a flexible manner to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed
10 within that range as if each numerical value and sub-range is explicitly recited. For example, a range of “0.1% to about 5%” or “0.1% to 5%” should be interpreted to include about 0.1% to about 5%, as well as the individual values (for example, 1%, 2%, 3%, and 4%) and the sub-ranges (for example, 0.1% to 0.5%, 1.1% to 2.2%, 3.3% to 4.4%) within the indicated range. The statement “X to Y” has the same meaning as
15 “about X to about Y,” unless indicated otherwise. Likewise, the statement “X, Y, or Z” has the same meaning as “about X, about Y, or about Z,” unless indicated otherwise.

[0066] While this disclosure contains many specific implementation details, these should not be construed as limitations on the subject matter or on what may be claimed, but rather as descriptions of features that may be specific to particular
20 implementations. Certain features that are described in this disclosure in the context of separate implementations can also be implemented, in combination, in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations, separately, or in any suitable sub-combination. Moreover, although previously described features
25 may be described as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can, in some cases, be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

[0067] Particular implementations of the subject matter have been described.
30 Nevertheless, it will be understood that various modifications, substitutions, and alterations may be made. While operations are depicted in the drawings or claims in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated

operations be performed (some operations may be considered optional), to achieve desirable results. Accordingly, the previously described example implementations do not define or constrain this disclosure.

CLAIMS

WHAT IS CLAIMED IS:

1. A method for hydraulically fracturing a subterranean zone penetrated by a wellbore, comprising:

5 positioning a well tool assembly within a casing installed in the wellbore, the well tool assembly comprising a perforation tool and a resettable packer;

 with the perforation tool, perforating the casing to form a plurality of perforations in the casing, such that fluid can be conducted from inside the casing to the subterranean zone through the plurality of perforations;

10 positioning the well tool assembly at a location within the casing that is downhole of the plurality of perforations;

 with the resettable packer, sealing a portion of the casing that is downhole of the plurality of perforations from a remaining portion of the casing; and

 pulsing a fracturing fluid into the subterranean zone via the plurality of
15 perforations by alternating between flowing the fracturing fluid into the casing at a first flow rate that is equal to or less than 6 barrels per minute and flowing the fracturing fluid into the casing at a second flow rate that is in a range of from about 10% to about 40% of the first flow rate, wherein the fracturing fluid is free of proppant and has a viscosity that is substantially equal to that of water.

20

2. The method of claim 1, wherein the plurality of perforations is a first plurality of perforations, and the method further comprises:

 unsetting the resettable packer to unseal the portion of the casing that is downhole of the first plurality of perforations;

25 positioning the well tool assembly at a location within the casing that is uphole of the first plurality of perforations;

 with the perforation tool, perforating the casing to form a second plurality of perforations in the casing uphole of the first plurality of perforations;

 positioning the well tool assembly at a location within the casing that is
30 downhole of the second plurality of perforations;

 with the resettable packer, sealing a portion of the casing that is downhole of the second plurality of perforations from a remaining portion of the casing;

pulsing the fracturing fluid into the subterranean zone via the second plurality of perforations by alternating between flowing the fracturing fluid into the casing at the first flow rate and flowing the fracturing fluid into the casing at the second flow rate; and

5 unsetting the resettable packer to unseal the portion of the casing that is downhole of the second plurality of perforations.

3. The method of claim 2, wherein the well tool assembly remains within the casing throughout implementation of the method.

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4. The method of claim 3, wherein each plurality of perforations spans a portion of the casing that is at most 1.5 meters in longitudinal length.

5. The method of claim 4, wherein each plurality of perforations comprises at most 12
15 perforations.

6. The method of claim 2, wherein the fracturing fluid is flowed into the casing at the first flow rate for at most 5 minutes before alternating to the second flow rate.

20 7. The method of claim 6, wherein the fracturing fluid is flowed into the casing at the second flow rate for at most 1.5 minutes before alternating to the first flow rate.

8. The method of claim 7, wherein pulsing the fracturing fluid into the subterranean zone comprises alternating between flowing the fracturing fluid into the casing at the
25 first flow rate and flowing the fracturing fluid into the casing at the second flow rate, such that each of the first flow rate and the second flow rate occur at least 5 times.

9. The method of claim 7, pulsing the fracturing fluid into the subterranean zone comprises alternating between flowing the fracturing fluid into the casing at the first
30 flow rate and flowing the fracturing fluid into the casing at the second flow rate until at least 2,000 barrels of fracturing fluid have been flowed into the subterranean zone via the respective plurality of perforations.

10. A method for hydraulically fracturing a subterranean zone having a matrix permeability of at most 100 nanoDarcy and a clay content of at most 60 volume %, the method comprising:

5 a) injecting a fracturing fluid into the subterranean zone at a first flow rate that is equal to or less than 6 barrels per minute, wherein the fracturing fluid is free of proppant and has a viscosity that is substantially equal to that of water;

b) injecting the fracturing fluid into the subterranean zone at a second flow rate that is in a range of from about 10% to about 40% of the first flow rate; and

c) sequentially repeating steps a) and b).

10

11. The method of claim 10, wherein the fracturing fluid is injected into the subterranean zone at step a) for at most 5 minutes.

12. The method of claim 11, wherein the fracturing fluid is injected into the subterranean zone at step b) for at most 1.5 minutes.

15

13. The method of claim 12, wherein steps a) and b) are sequentially repeated at step c) at least 5 times.

14. The method of claim 12, wherein steps a) and b) are sequentially repeated at step c) until at least 2,000 barrels of fracturing fluid have been injected into the subterranean zone.

20

15. A system for hydraulically fracturing a subterranean zone penetrated by a wellbore, the system comprising:

25

a well tool assembly comprising:

a perforation tool configured to form a plurality of perforations in a casing installed within the wellbore; and

a resettable packer configured to reversibly seal a portion of the casing from a remaining portion of the casing while a fracturing fluid is injected into the subterranean zone via the plurality of perforations, wherein the well tool assembly is configured to remain within the casing during hydraulic fracturing;

30

a fracturing fluid that is free of proppant and has a viscosity that is substantially equal to that of water; and

5 a pump configured to flow the fracturing fluid into the subterranean zone via the plurality of perforations formed by the perforation tool by pulsing the fracturing fluid into the casing between a first flow rate that is equal to or less than 6 barrels per minute and a second flow rate that is in a range of from about 10% to about 40% of the first flow rate, thereby hydraulically fracturing the subterranean zone.

10 16. The system of claim 15, wherein the perforation tool is configured to form the plurality of perforations in the casing across a portion of the casing that is at most 1.5 meters in longitudinal length.

15 17. The system of claim 16, wherein the plurality of perforations comprises at most 12 perforations.

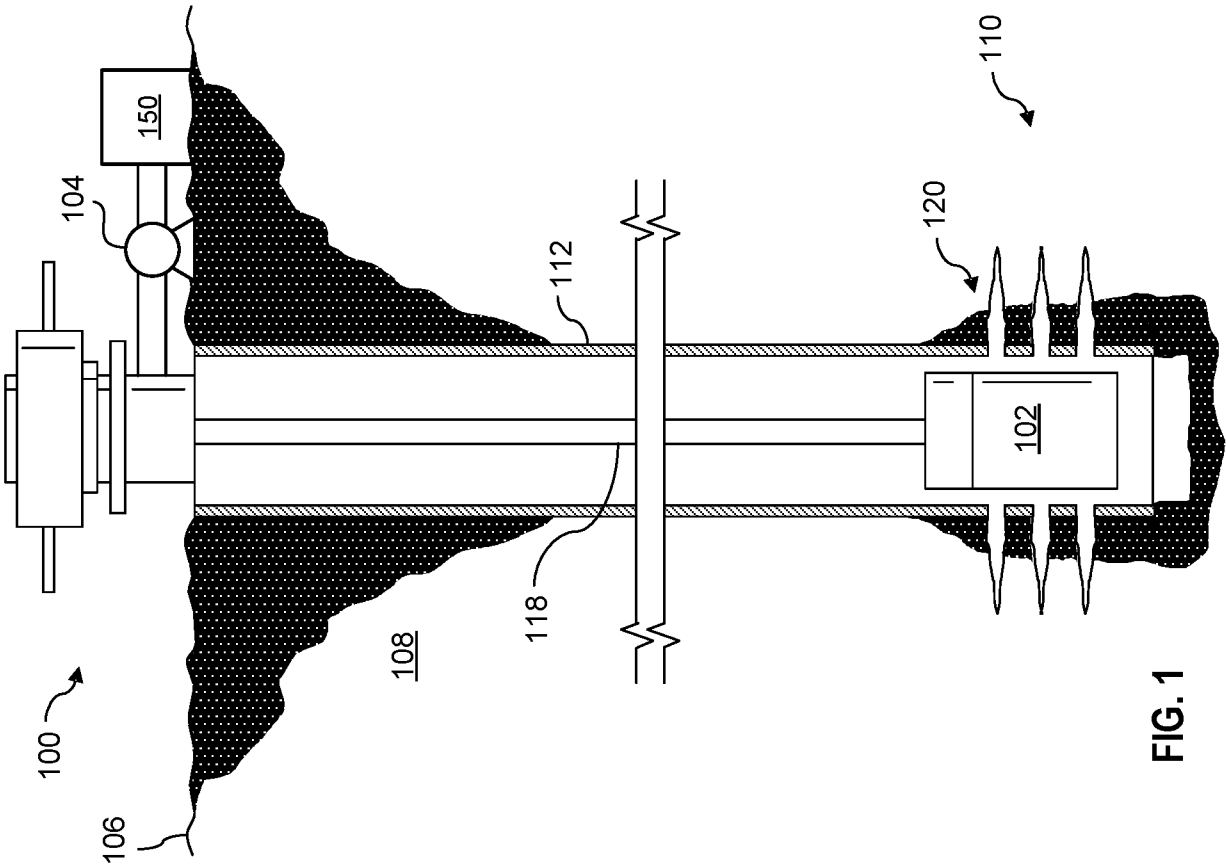
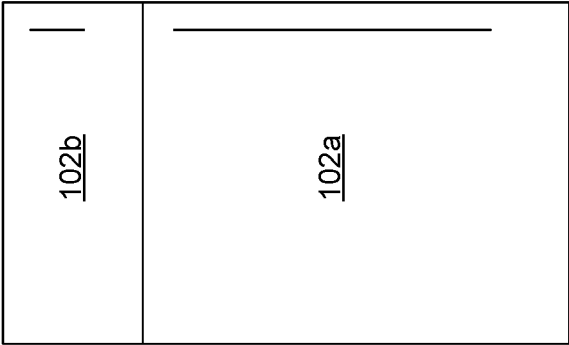


FIG. 1



102

FIG. 2

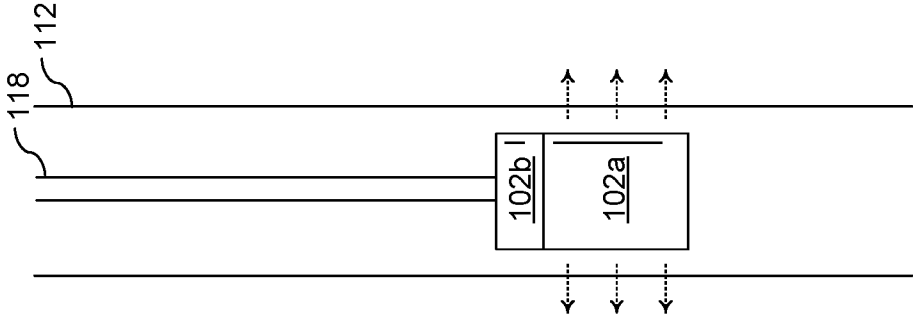


FIG. 3A

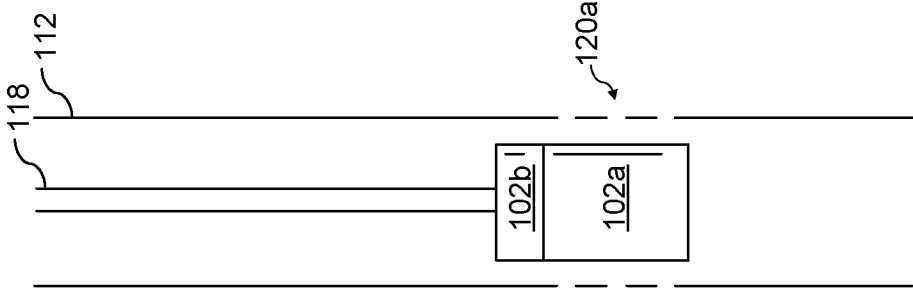


FIG. 3B

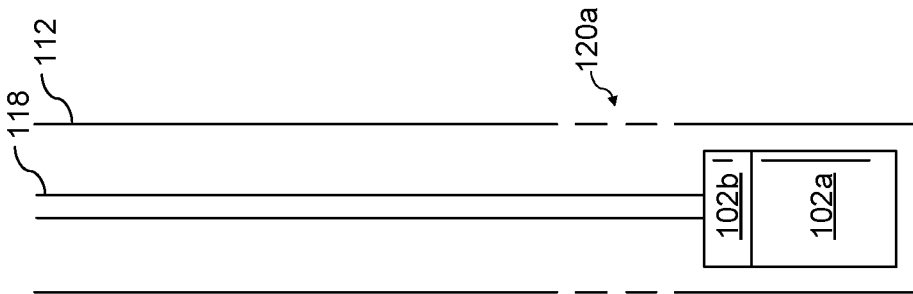


FIG. 3C

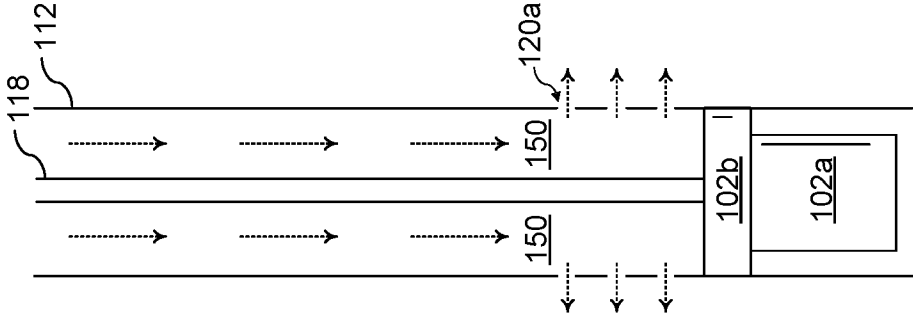


FIG. 3D

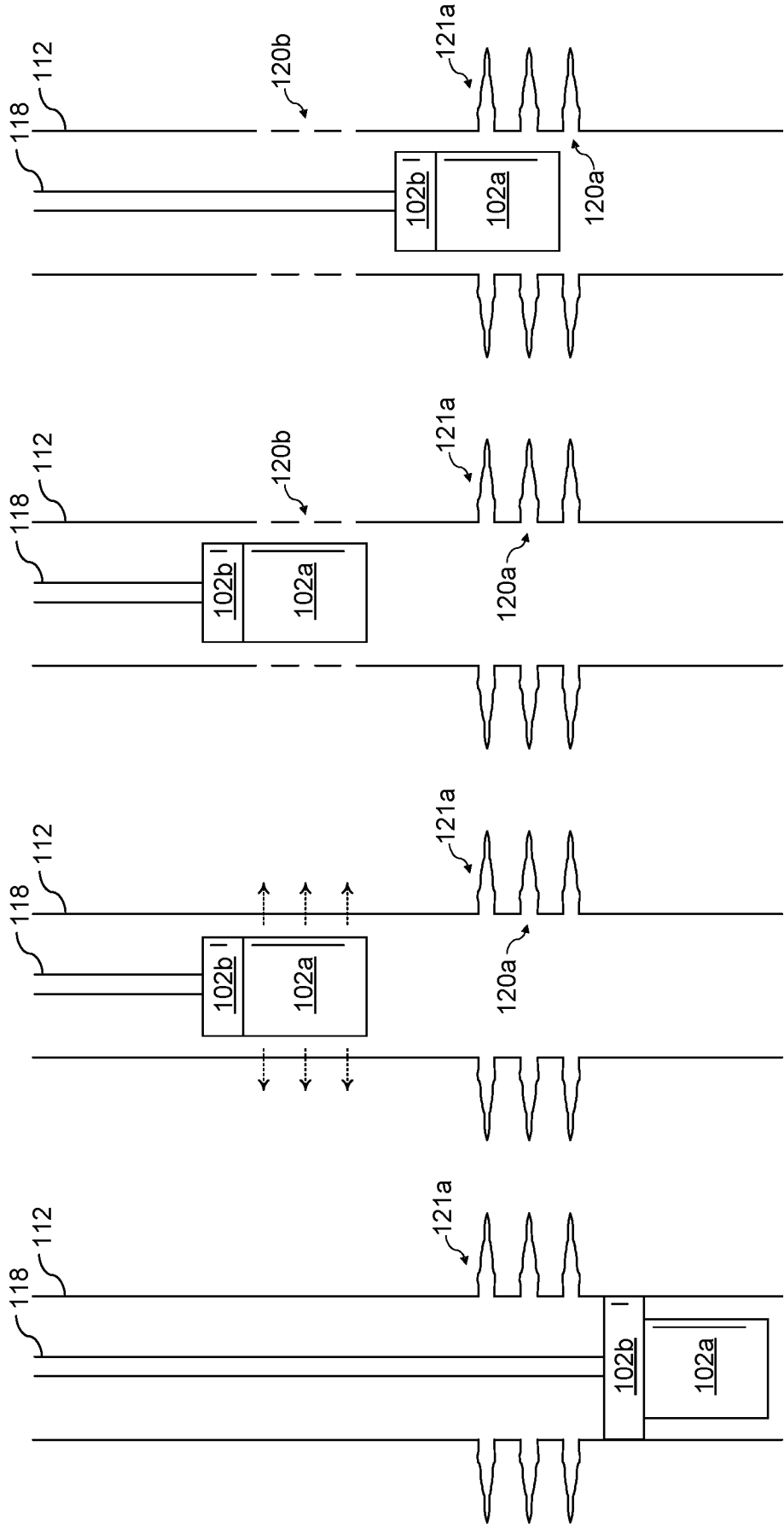


FIG. 3E

FIG. 3F

FIG. 3G

FIG. 3H

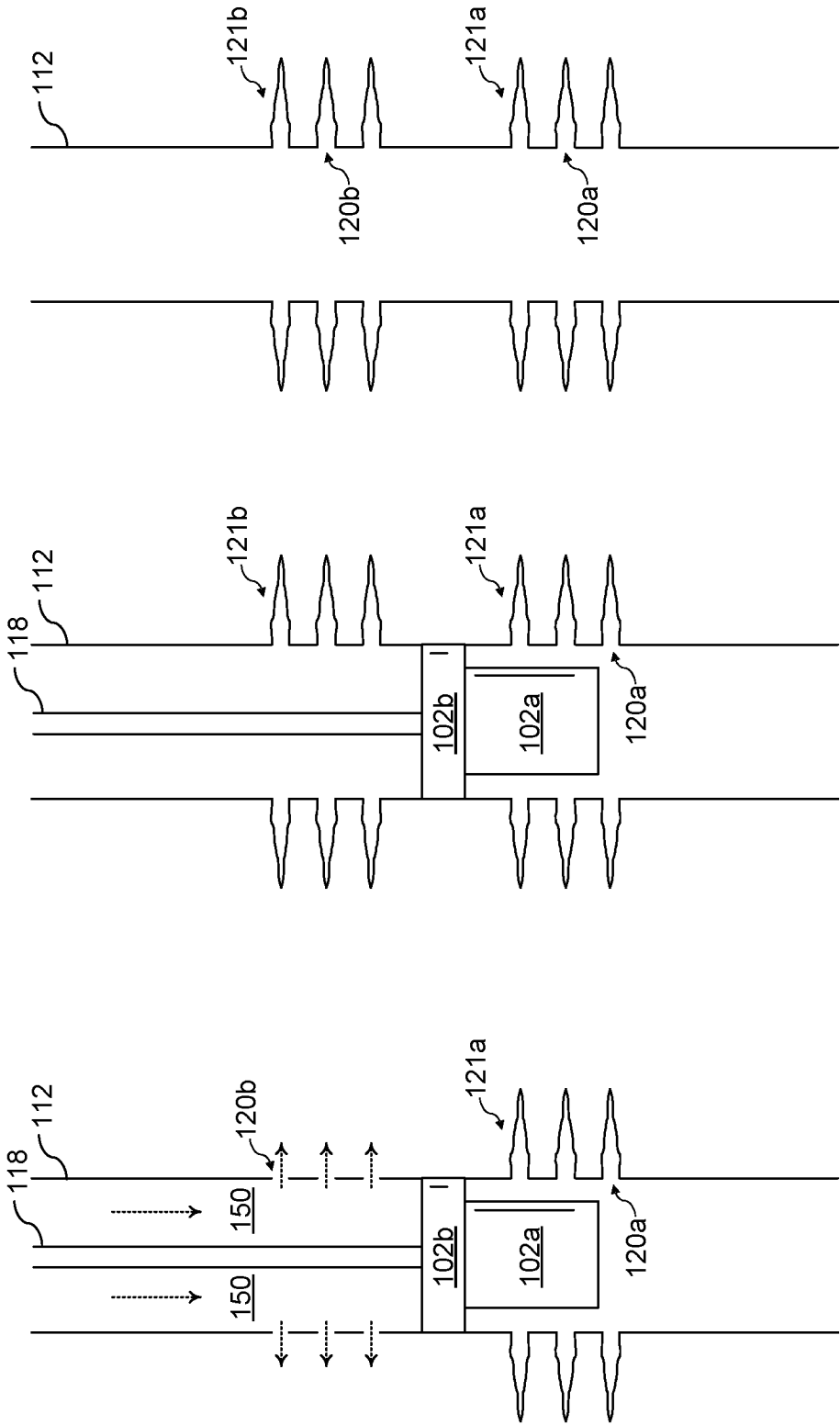


FIG. 3J

FIG. 3K

FIG. 3L

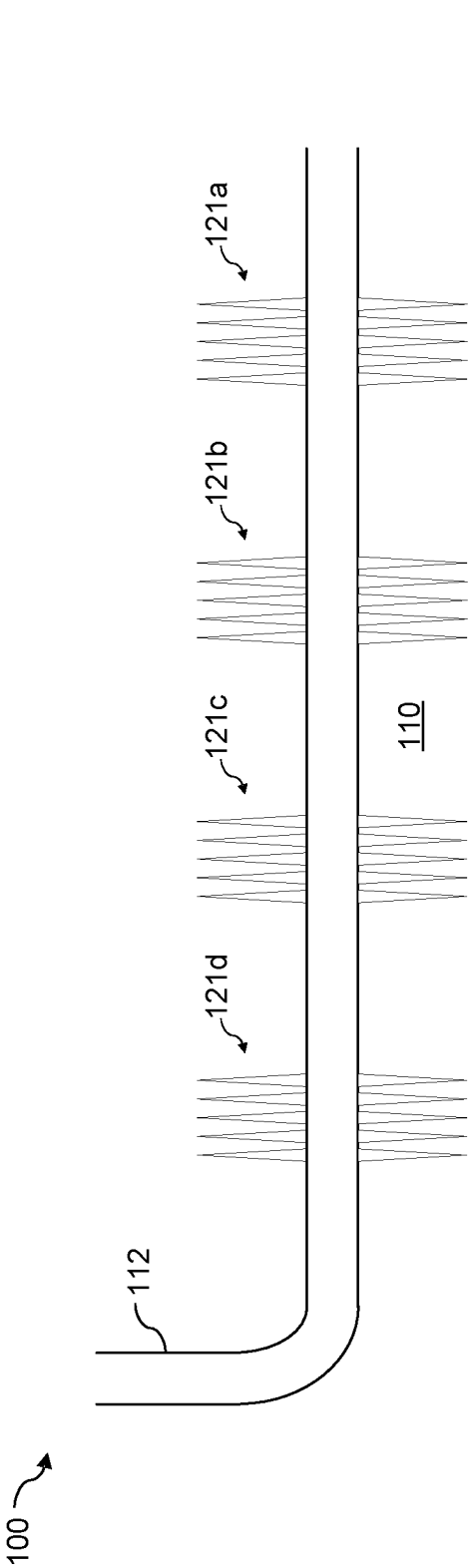


FIG. 4A

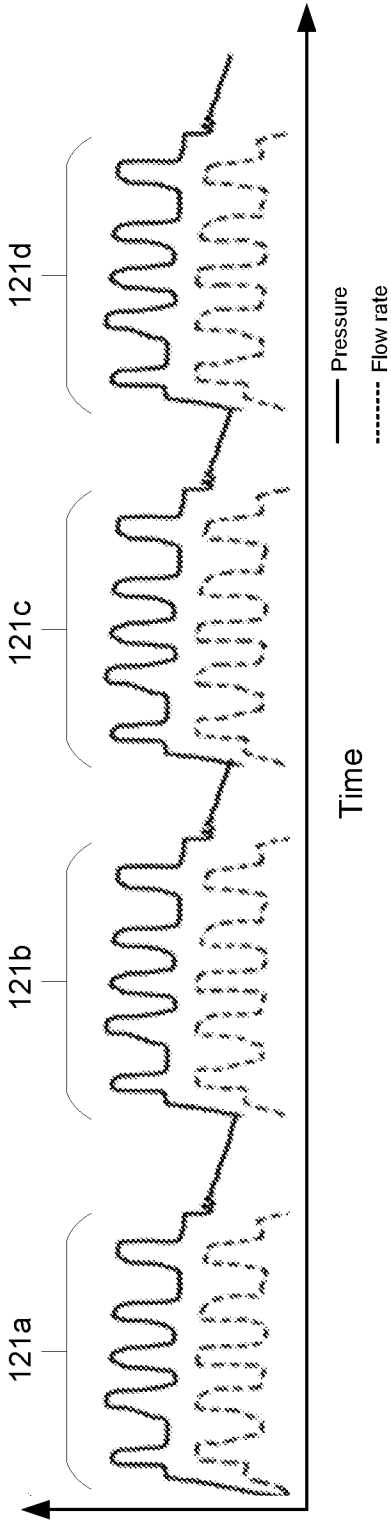


FIG. 4B

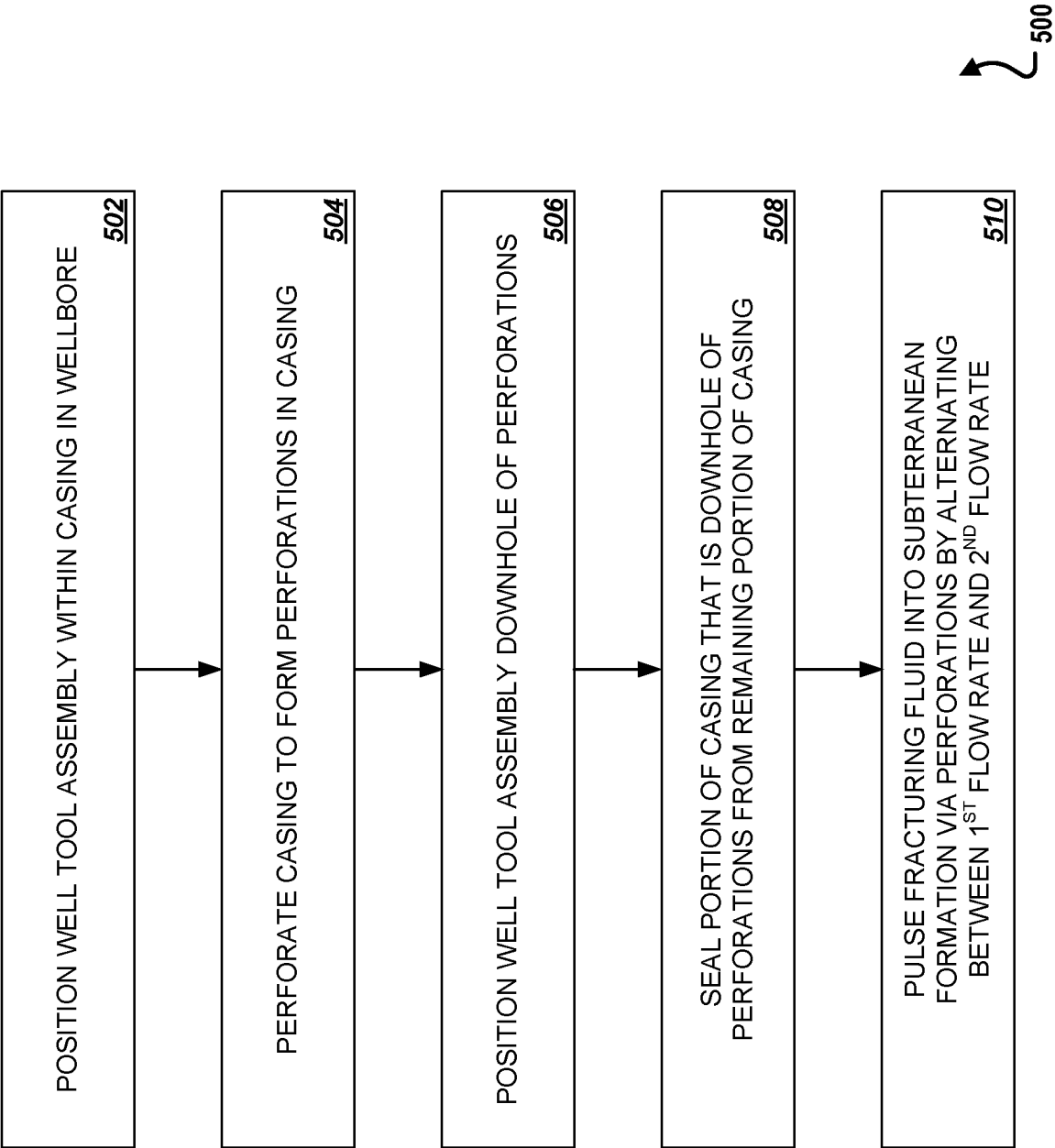


FIG. 5

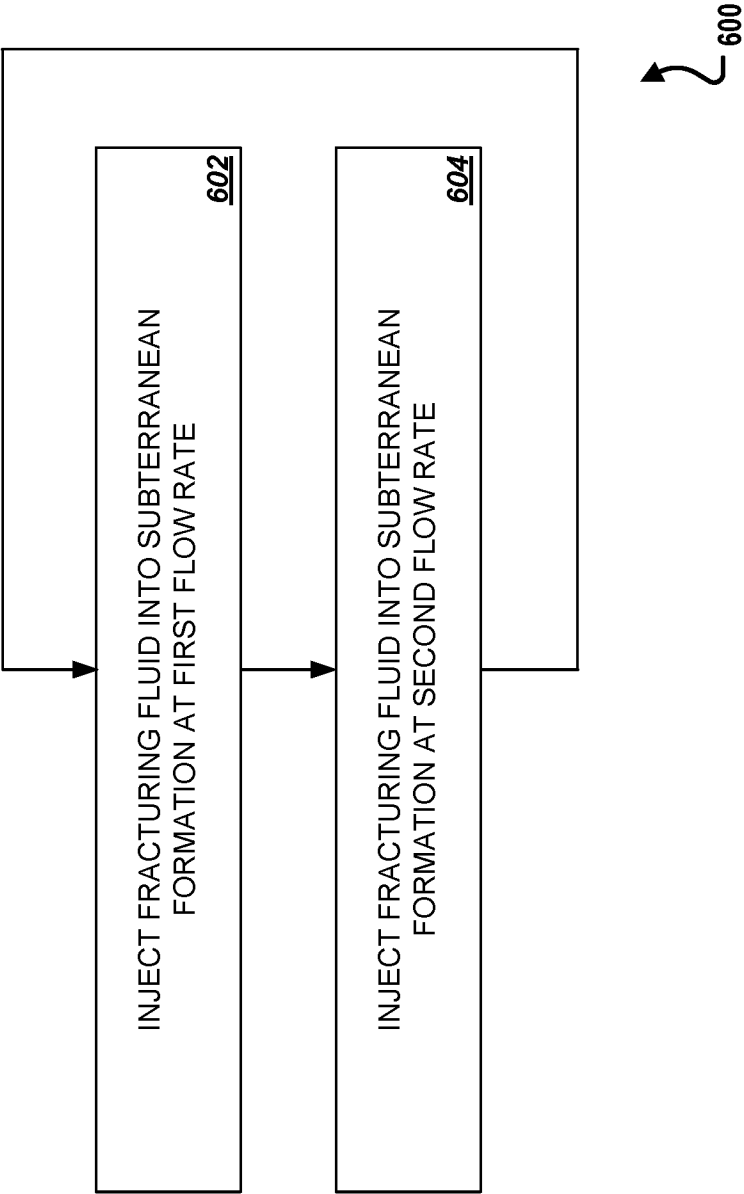


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/034701

A. CLASSIFICATION OF SUBJECT MATTER

INV. E21B43/26 E21B43/14 E21B33/12 E21B43/11
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016/061016 A1 (CIEZOBKA JORDAN [US] ET AL) 3 March 2016 (2016-03-03) paragraphs [0008] - [0011], [0013], [0029] - [0032], [0035], [0039] -----	1-17
Y	EP 2 282 002 A2 (EXXONMOBIL UPSTREAM RES CO [US]) 9 February 2011 (2011-02-09) paragraph [0056]; figures 2A-3F -----	1-17
A	US 2018/187538 A1 (WALTERS HAROLD GRAYSON [US] ET AL) 5 July 2018 (2018-07-05) paragraphs [0023] - [0028]; figure 2 -----	1-17
A	US 2015/075779 A1 (WALTERS HAROLD GRAYSON [US] ET AL) 19 March 2015 (2015-03-19) paragraphs [0078] - [0080]; figure 5 -----	1-17



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

25 August 2020

Date of mailing of the international search report

04/09/2020

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Hennion, Dmitri

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2020/034701

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