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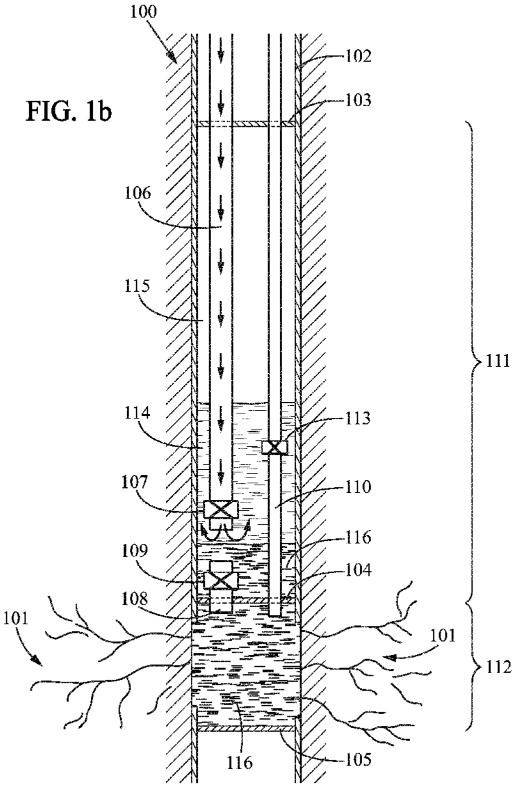
(54) Title: METHOD FOR EXTENDING A NETWORK OF EXISTING FRACTURES

FIG. 1b



(57) Abstract: The present invention relates to a method for extending a network of existing fractures in a subterranean formation. This method comprises pumping a first fluid into a pressurized volume to pressurize a compressible fluid in said pressurized volume to a predetermined pressure and releasing a second fluid out of the pressurized volume in a confined volume connected to the existing fractures, the second fluid being released due to a relaxation of the pressurized compressible fluid in the pressurized volume. Moreover, the release of second fluid exerts pressures in the existing fractures exceeding a fracturing threshold of the subterranean formation.

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METHOD FOR EXTENDING A NETWORK OF EXISTING FRACTURES

BACKGROUND OF THE INVENTION

[0001] The present invention relates to method for fracturing of rocks in geological formations.

[0002] The approaches described in this section could be pursued, but are not necessarily approaches that have been previously conceived or pursued. Therefore, unless otherwise indicated herein, the approaches described in this section are not prior art to the claims in this application and are not admitted to be prior art by inclusion in this section. Furthermore, all embodiments are not necessarily intended to solve all or even any of the problems brought forward in this section.

[0003] In order to increase or restore the rate at which fluids, such as petroleum, water, or natural gas can be produced from subterranean natural reservoirs, one may need to fracture rocks in subterranean formation.

[0004] Reservoirs are typically porous sandstones, lime stones or dolomite rocks, but also include "unconventional reservoirs" such as shale rock or coal beds. Rock fracturing enables the production of natural gas and oil from rock formations deep below the earth's surface (generally, deeper than 1,000m).

[0005] At such depth or in particular configurations, there may not be sufficient permeability or reservoir pressure to allow natural gas and oil to flow from the rock into the wellbore at economic rates. Thus, creating conductive fractures in the rock is useful to extract gas from shale reservoirs because of the extremely low natural permeability of shale. Fractures provide a conductive path connecting a larger volume of the reservoir to the well.

[0006] In order to fracture the rock, one may use:

- “Pulse(s) fracturing” techniques: these techniques allow fracturing by generating pressure pulse(s) applied to the geological formation. These pulses me be generated by the release of a shot, consumable switch, a burn through diaphragm or an explosive valve. For instance, it may involve the use of electric line or tubing-conveyed tools to ignite a propellant charge, similar in composition to solid rocket fuel, which is positioned across the formation. The propellant burns within a few milliseconds and creates a high-pressure gas pulse. These techniques are usually known as “extreme overbalance”;

- “Hydraulic fracturing” techniques: these techniques allow fracturing rocks by pumping a fluid into a wellbore at a sufficient rate to increase the downhole pressure. Thus, the downhole pressure exceeds the pressure of the failure of the rock. In these techniques, the operators often inject proppant, a material such as grains of sand, ceramic, or other particulates, that prevent the fractures from closing when the injection is stopped and the pressure of the fluid is reduced.

[0007] These techniques are widely in use, but mainly aimed at creating a fracture network where none is present, and have some important limitations. Such methods have drawbacks.

[0008] The “pulse” techniques do not allow an accurate control of the created fractures and the extent of the created fractures is limited by the energy contained in the pulse used. Even in case of a plurality of pulses, the small energy of each pulse limits the ability to create long fractures.

[0009] The “hydraulics fracturing” techniques need important pumping means at the surface to increase and maintain for several hours the pressure in the borehole so that the pressure exceeds the pressure of the failure of the rock. Moreover, the control of the pressure may be difficult in such techniques. Finally, the use of proppant (including a lot of chemical additives) is considered as polluting. The use of proppant also induces a number of constraints such as a control of a constant flux pump rate (flow velocity), of the pH of the carrier fluid and of various other rheological factors. For instance, the use of industrial water is, in practice, mandatory to validate these constraints.

[0010] There is thus a need for allowing the extension of a multidirectional fracture network from an existing initial fracture network with minimal pumping equipment at the surface and with minimum impact on the environment.

SUMMARY OF THE INVENTION

[0011] The invention relates to a method for extending a network of existing fractures in a subterranean formation, comprising:

/a/ pumping a first fluid into a pressurized volume to pressurize a compressible fluid in said pressurized volume to a predetermined pressure;

/b/ releasing a second fluid out of the pressurized volume in a confined volume connected to the existing fractures, the second fluid being released due to a relaxation of the pressurized compressible fluid in the pressurized volume.

[0012] The release of second fluid exerts pressures in the existing fractures exceeding a fracturing threshold of the subterranean formation.

[0013] The first and second fluid can be the same fluid. They may also be different fluids with specific characteristics (such as density, viscosity, etc.).

[0014] The compressible fluid typically is a gas such as nitrogen.

[0015] The release of the second fluid creates a pulse: a wave of excessive pressure / compression propagates in the fluids contained in the confined volume and then exerts pressure on the existing fractures.

[0016] The pumping equipment at the surface may be smaller than the pumping equipment for standard hydraulic fracturing as an intermediate volume acts as a buffer and may accumulate the forces/pressures and release them in a fraction of a second.

[0017] The fracturing method may enable the extension of a multidirectional fracture network from an existing initial fracture network. This extension may be done in such a way that the curvature radius of fractures reorientation toward the preferential fracture plane can be controlled.

[0018] The method may provide pulses with large energy.

[0019] The release may also be controlled by parameters in a group of comprising at least:

- a maximum pressure exerted on the existing fractures,
- a duration of the release,

- a pressure profile exerted on the existing fractures,
- a time between two consecutive releases.

[0020] Thus, each pulse may be adapted to fracture all fractures connected with the wellbore. The maximum pressure and the duration/rise time of each pulse may be set so that the fracturing direction for each pulse remains as close as possible to the existing fracture orientation.

[0021] In addition, the time between two consecutive releases may be adjusted so that fractures do not close back.

[0022] For fractures existing initially away from the preferential fracture plane, reorientation toward the preferential fracture plane may occur. It may be controlled by the amplitude and rise time of the pressure pulses, as well as the subsequent quick falloff at the end of each pulse. This control can be further enhanced by the use of high viscosity fluid.

[0023] Hence, it is possible to reduce or even avoid the use of proppant (including a lot of chemical additives) and the use of industrial water for hydraulic fracturing. Therefore, the proposed method is less polluting than the standard hydraulic fracturing.

[0024] In a specific embodiment, the method may further comprise:

/c/ prior to the release of the second fluid, extracting a third fluid from the confined volume so as to reduce the pressure in the confined volume below a confined pressure.

[0025] The confined pressure may be the pressure of the pressurized volume or any pressure below the pressure of the pressurized volume.

[0026] The extraction may be realized through a pumping process.

[0027] The third fluid may be either the first fluid or the second fluid or a different fluid from the first and second fluids.

[0028] Thus, if the pressure of the fluid in the confined volume is below the pressure of the pressurized volume, the release of the fluid from the pressurized volume into the confined volume may create waves of excessive-pressure (“hammer effect”).

[0029] The confined pressure may be below the predetermined pressure.

[0030] In one embodiment, the steps (i.e. /a/ and /b/ or /a/, /b/ and /c/) of the method may be executed a plurality of times. The repetition may induce an incremental effect with better results than a single powerful pulse.

[0031] The first fluid and second fluid may be a same fluid.

[0032] In a specific embodiment, the second fluid may have a higher viscosity than a viscosity of the first fluid.

[0033] Viscosity is a physical measure of the resistance of a fluid which is being deformed by, for instance, shear stress or tensile stress.

[0034] This difference in the fluid viscosity may facilitate the control of the fracturing. The high viscosity fluid (the second fluid) may be pushed by a less viscous fluid (the first fluid).

[0035] As the first fluid may be less viscous, it may be easy to pump it from the surface into the borehole and may minimize the energy dissipation during the pumping phase.

[0036] As the second fluid is “thicker”, the efficiency of the fracturing may be improved as the fluid may maintain the fracture open during a long time.

[0037] The second fluid may have a higher density than a density of the first fluid. Moreover the duration of a pulse is adapted to mitigate fingering instability formed at an interface between the first fluid and second fluid.

[0038] A fingering instability may be also known as Rayleigh-Taylor instability. It is an instability of an interface between two fluids of different densities, which occurs when the lighter fluid is pushing the heavier fluid.

[0039] Moreover, solid particles may be added with the first fluid or the second fluid.

[0040] These solid particles, injected in the fracture with the fluids, may help the fractures to remain open after the pulse.

[0041] In one embodiment, the predetermined pressure may be below the fracturing threshold.

[0042] Thus, the pressure in the pressurized volume may be reduced and pumping means at the surface may be downsized.

[0043] The invention also relates to a device for extending existing fractures comprising:

- an upper packer and a lower packer within a borehole, defining a confined volume with the sides of the borehole, said confined volume being adapted to be connected to the existing fractures ;
- a pressurized volume located in the wellbore containing a compressible fluid;
- pumping means adapted to inject a first fluid in the pressurized volume so as to pressurize the compressible fluid in said pressurized volume to a predetermined pressure;
- a first surface-controlled valve for controlling the first fluid circulation from the surface to the pressurized volume;
- a second surface-controlled valve for controlling the second fluid circulation between the pressurized volume and the confined volume.

[0044] Moreover, the device may further comprise:

- extracting means adapted to pump a third fluid from the confined volume so as to reduce the pressure in the confined volume below a confined pressure.

[0045] Other features and advantages of the method and apparatus disclosed herein will become apparent from the following description of non-limiting embodiments, with reference to the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0046] The present invention is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings, in which like reference numerals refer to similar elements and in which:

- Figure 1a is a schematic overview of a borehole comprising a device for extending existing fractures in a specific embodiment;
- Figure 1b shows an example of a pumping step of the invention according to a given embodiment;
- Figure 1c shows an example of an extracting step of the invention according to a given embodiment;
- Figure 1d shows an example of a releasing step of the invention according to a given embodiment;
- Figures 2a to 2d details the principle of fingering instability;
- Figure 3 is a second schematic overview of a borehole comprising a device for extending existing fractures in another specific embodiment.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0047] Figure 1a is a schematic overview of a borehole comprising a device for extending existing fractures in a specific embodiment

[0048] In Figure 1a, a borehole has been drilled in a subterranean formation 100. Fractures 101 exist in this subterranean formation. Inside the borehole, a casing 102 has been installed and is connected to the fracture 101, for instance, thru perforations (not represented). Perforations are made for instance with explosives to blast holes in the casing and cement sheet

[0049] In the casing, different volumes may be defined. A first volume 111, referenced as the pressurized volume, is defined by a cylinder delimited with the side of the casing 102, a first plug/disk 103 installed inside the casing (this first plug/disk 103 may be in the wellhead at the very top of the well or an additional plug in the wellbore) and an upper packer 104. A second volume 112, referenced as the confined volume is defined by a cylinder delimited with the side of the casing 102, the upper packer 104 and bridge plug 105 similar to a lower packer.

[0050] Moreover, a first tubing 106 is installed in the casing 102, passes through the first plug 103 and has an end in the pressurized volume 111. This first tubing may be used to inject a fluid into the pressurized volume 111. To control the injection of the fluid into the pressurized volume 111, pumping equipment may be installed at the surface near the borehole. To avoid returns of fluids, a valve 107 is installed in the tubing 106 and may be commanded from the surface or by automatic means to avoid any flowing of fluid back in the tubing.

[0051] A second tubing 108 is also inserted in the casing 102 to allow communication of fluids between the pressurized volume 111 and the confined volume 112. The second tubing and the first tubing may be part of the same tubing. Moreover, in order to ease the assembling and the un-assembling, the second tubing may be mechanically connected to the first tubing so that the removal of the first tubing implies the removal of the second tubing. This second tubing may be used to release a fluid from the pressurized volume 111 into the confined volume 112. To control the release of the fluid into the confined volume 112, a valve 109 is installed in the second tubing 108 and may be commanded from the surface or by automatic means to avoid any flowing of fluid back in the tubing.

[0052] A third tubing 110 is also inserted in the casing 102 to allow communication of fluid between the confined volume 112 and the surface. This third tubing may be used to extract a fluid from the confined volume 112 in order to reduce the pressure in this volume 112. To control the extraction of the fluid, a valve 113 is installed in the third tubing 110 and may be commanded from the surface or by automatic means to avoid any flowing of fluid back in the tubing. This third tubing and the extraction step is, most of the time, optional.

[0053] Figure 1b shows an example of a pumping step of the invention according to a given embodiment.

[0054] During a pumping step according to this embodiment, the valve 107 is opened while the others valves are closed (i.e. 109 and 113). Then, pumping equipment at the surface of the borehole injects a fluid 114 into the pressurized volume 111. This injection increases the volume of fluids in the pressurized volume and then compresses compressible fluid 115 (above the first fluid 114) in this volume 111. Advantageously, the compressible fluid 115 may be gas (air, nitrogen or other gas). Therefore the pressure in the pressurized volume increases.

[0055] The pressurized volume may also contain, prior to the pumping step, a viscous fluid 116 (represented below the injected fluid in the Figure 1b) which is more viscous than the injected fluid 114. It stays at the bottom of the pressurized volume 111 as its density is higher than the density of the injected fluid 114.

[0056] The confined volume may also be filled, prior to the pumping step, with the viscous fluid 116. An additional tubing (not represented in this figure) may be used to inject the viscous fluid 116 in one of the volumes (111, 112) if the viscous fluid 116 is depleted.

[0057] The viscous fluid 116 may be replaced with a “normal” fluid such as the injected fluid 114.

[0058] Figure 1c shows an example of an extracting step of the invention according to a given embodiment. This step may be optional.

[0059] During an extracting step according to this embodiment, the valve 113 is opened while the others valves are closed (i.e. 109 and 107). This step aims at reducing the pressure of the confined volume 112 prior to the release step.

[0060] In one embodiment, it is possible to open the valve 113: if the pressure in the confined volume 112 is higher than the hydrostatic pressure of the fluid 116 in the tubing 110, a portion of the viscous fluid 116 is extracted through this tubing 110 in the surface direction.

[0061] In a different embodiment, it is possible to open the valve 113 and to ease the extraction with pumping means at the surface. The pumping means may create a depression in the tubing 110 and then extract a portion of the fluid 116 in the confined volume.

[0062] Figure 1d shows an example of a releasing step of the invention according to a given embodiment.

[0063] During a releasing step according to this embodiment, the valve 109 is opened while the others valves are closed (i.e. 113 and 107). Thus, due to the difference of pressure in the pressurized volume 111 and in the confined volume 112, a viscous fluid 116 is released from the pressurized volume into the confined volume. As the valve 109 may be fully opened in fractions of second, a wave of excessive-pressure is transmitted in the fluid of the confined volume and then transmitted to the existing fractures 101 of the subterranean formation 100. These pulses exceed the fracturing pressure (or fracturing threshold) of the rock and further propagates existing fractures in the formation.

[0064] The interface between the viscous fluid and the injected fluid is, in this embodiment, in the pressurized volume. Nevertheless, it is possible to set this interface in the confined volume. In such situation, the release fluid is the normal fluid and not the viscous fluid as described above.

[0065] Figures 2a to 2d details the principle of fingering instability. The fingering instability is also known as the Rayleigh–Taylor instability, or RT instability. This instability is an instability of an interface between two fluids of different densities, which occurs when the lighter fluid is pushing the heavier fluid.

[0066] Figure 2a details an interface between two fluids 201 and 202, the fluid 201 being lighter fluid and the fluid 202 being the heavier fluid. In Figure 2a, the interface between these two fluids is plane and no force is applied on the fluid 201 to push the fluid 202.

[0067] A constant force is applied at time t=0 on the first fluid 201 in order to push the second fluid 202 in the direction $-\vec{y}$. Due to the force applied, a complex hydrodynamic effect induces an intrusion of the first fluid 201 into the second fluid 202 (see Figure 2b, at time $t=t_0$).

[0068] If the force are maintained, this phenomena is amplified (see Figure 2c and 2d, at time $t=2t_0$ and $t=3t_0$) and instability and vortex are created ("mushroom cap").

[0069] It is advantageous to control this intrusion to avoid any instability. Thus, it is possible to limit the duration of each pulse to mitigate the fingering instability formed at the interface between the two fluids. For instance, tests may be conducted on fluids to limit the y-domain of the space where the two different fluids may be found at the same time ([-0.05; 0.05] for the Figure 2b, [-0.12; 0.12] for the Figure 2c and [-0.21; 0.21] for the Figure 2d).

[0070] Figure 3 is a second schematic overview of a borehole comprising a device for extending existing fractures in another specific embodiment.

[0071] This embodiment does not provide any tubing for extracting fluid from the confined volume 112. In Figure 1a, a borehole has been drilled in a subterranean formation 100. Fractures 101 exist in this subterranean formation. Inside the borehole, a casing 102 has been installed and is connected to the fracture 101, for instance, thru perforations (not represented) in order to ease the fracturing process.

[0072] In the casing, different volumes may be defined. A first volume 111, referenced as the pressurized volume, is defined by a cylinder delimited with the side of the casing 102, a plug/disk 103 installed inside the casing (this first plug/disk 103 may be the wellhead at the very top of the well or an additional plug in wellbore) and an upper packer 104. A second volume 112, referenced as the confined volume is defined by a cylinder delimited with the side of the casing 102, the upper packer 104 and bridge plug 105 similar to a lower packer.

[0073] Moreover, a tubing 301 is installed in the casing 102, has an end in the confined volume 112. This tubing 301 has been pre-perforated in a section 300 inside the pressurized volume 111 adapted to let the fluid inside the tubing flowing in the pressurized volume (and vice-et-versa).

[0074] This tubing may be used to inject a fluid into the pressurized volume 111 or in the confined volume 112.

[0075] To control the injection of the fluid into the pressurized volume 111, pumping equipment may be installed at the surface near the borehole. To avoid returns of fluids, a valve 107 is installed in the tubing 301, above the perforated section 300 and may be commanded from the surface or by automatic means to avoid any flowing of fluid back in the tubing.

[0076] The lower end of the tubing 301 also allows communication of fluids between the pressurized volume 111 and the confined volume 112. The lower end of the tubing 106 may be used to release a fluid from the pressurized volume 111 into the confined volume 112.

[0077] To control the release of the fluid into the confined volume 112, a valve 109 is installed in the lower end of the tubing 301 and may be commanded from the surface or by automatic means to avoid any flowing of fluid back in the tubing.

Therefore, during the pumping step, the valve 109 is closed and the valve 107 is opened so that the fluid passes through the perforations of the perforated section 300 from the tubing 301 into the pressurized zone. During the releasing step, the valve 107 is closed and the valve 109 is opened so that the fluid passes through the perforations of the perforated section 300 from the pressurized volume into the confined volume.

[0078] A person skilled in the art will readily appreciate that various parameters disclosed in the description may be modified and that various embodiments disclosed may be combined without departing from the scope of the invention.

[0079] For instance, the device of the invention has been described with three distinct tubings but other embodiment is possible. A similar device may be realized with one single tubing and a plurality of valves:

- a single tubing may be inserted in the casing with two openings : one in the pressurized volume and one in the confined volume;

- three valves: a first valve controlling the flow through the opening in the pressurized volume, a second valve controlling the flow through the opening in the confined volume, and a third valve in the tubing above the opening in the pressurized volume and controlling the flow in the tubing.

[0080] In this last situation, the pumping step may be realized when the first and third valves are opened and the second valve is closed. The extraction step may be realized when the first and second valves are opened and the third valve is closed. The releasing step may be realized when the third and second valves are opened and the first valve is closed.

CLAIMS

1. A method for extending a network of existing fractures in a subterranean formation, comprising:

/a/ pumping a first fluid into a pressurized volume to pressurize a compressible fluid in said pressurized volume to a predetermined pressure;

/b/ releasing a second fluid out of the pressurized volume in a confined volume connected to the existing fractures, the second fluid being released due to a relaxation of the pressurized compressible fluid in the pressurized volume;

wherein the release of second fluid exerts pressures in the existing fractures exceeding a fracturing threshold of the subterranean formation.

2. The method according to claim 1, wherein the release is controlled by parameters in a group of comprising at least:

- a maximum pressure exerted in the existing fractures,
- a duration of the release,
- a pressure profile exerted in the existing fractures,
- a time between two consecutive releases.

3. The method according to any of the preceding claims, wherein the method further comprises:

/c/ prior to the release of the second fluid, extracting a third fluid from the confined volume so as to reduce the pressure in the confined volume below a confined pressure.

4. The method according to claim 3, wherein the confined pressure is below the predetermined pressure.

5. The method according to any of the preceding claims, wherein the steps of the method are executed a plurality of times.

6. The method according to claim 5, wherein the time between two consecutive releases is adjusted so that fractures don't fully close back.

7. The method according to any of the preceding claims, wherein the first fluid and second fluid are a same fluid.

8. The method according to any of the preceding claims, wherein the second fluid ~~have~~ has a higher viscosity than a viscosity of the first fluid.

9. The method according to any of the preceding claims, wherein the second fluid has ~~have~~ a higher density than a density of the first fluid, and wherein the duration of a pulse is adapted to mitigate fingering instability formed at an interface between the first fluid and second fluid.

10. The method according to any of the preceding claims, wherein solid particles are added with the first fluid and/or the second fluid.

11. The method according to any of the preceding claims, wherein the predetermined pressure is below the fracturing threshold.

12. A device for extending existing fractures comprising:

- an upper packer and a lower packer within a borehole, defining a confined volume with the sides of the borehole; said confined volume being adapted to be connected to the existing fractures ;
- a pressurized volume located in the wellbore containing a compressible fluid;

- pumping means adapted to inject a first fluid in the pressurized volume so as to pressurize the compressible fluid in said pressurized volume to a predetermined pressure;
- a first surface-controlled valve for controlling the first fluid circulation from the surface to the pressurized volume;
- a second surface-controlled valve for controlling the second fluid circulation between the pressurized volume and the confined volume.

13. The device according to claim 12, wherein the device further comprises:

- extracting means adapted to pump the third fluid from the confined volume so as to reduce the pressure in the confined volume below a confined pressure.

FIG. 1a

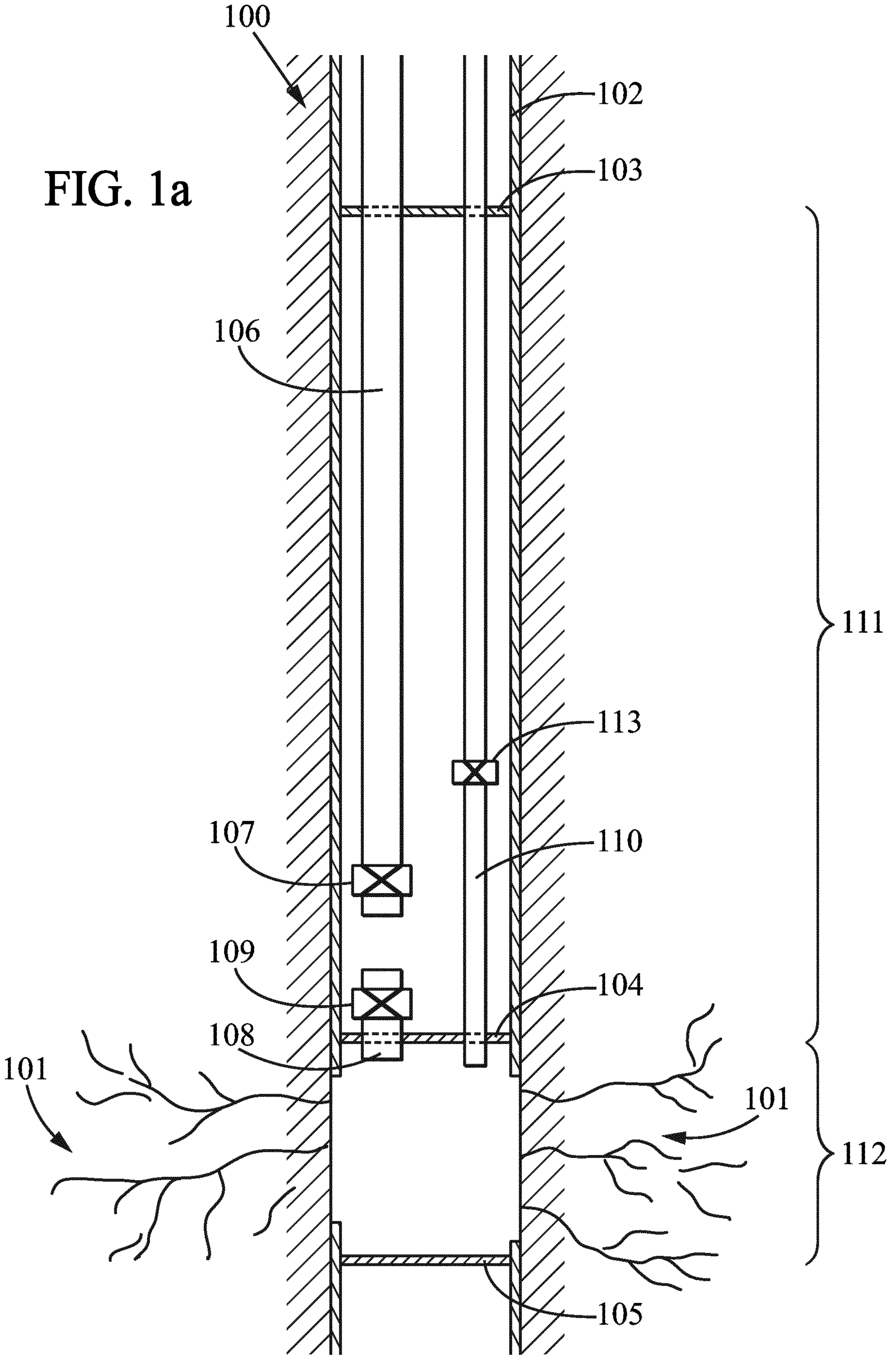

FIG. 1b

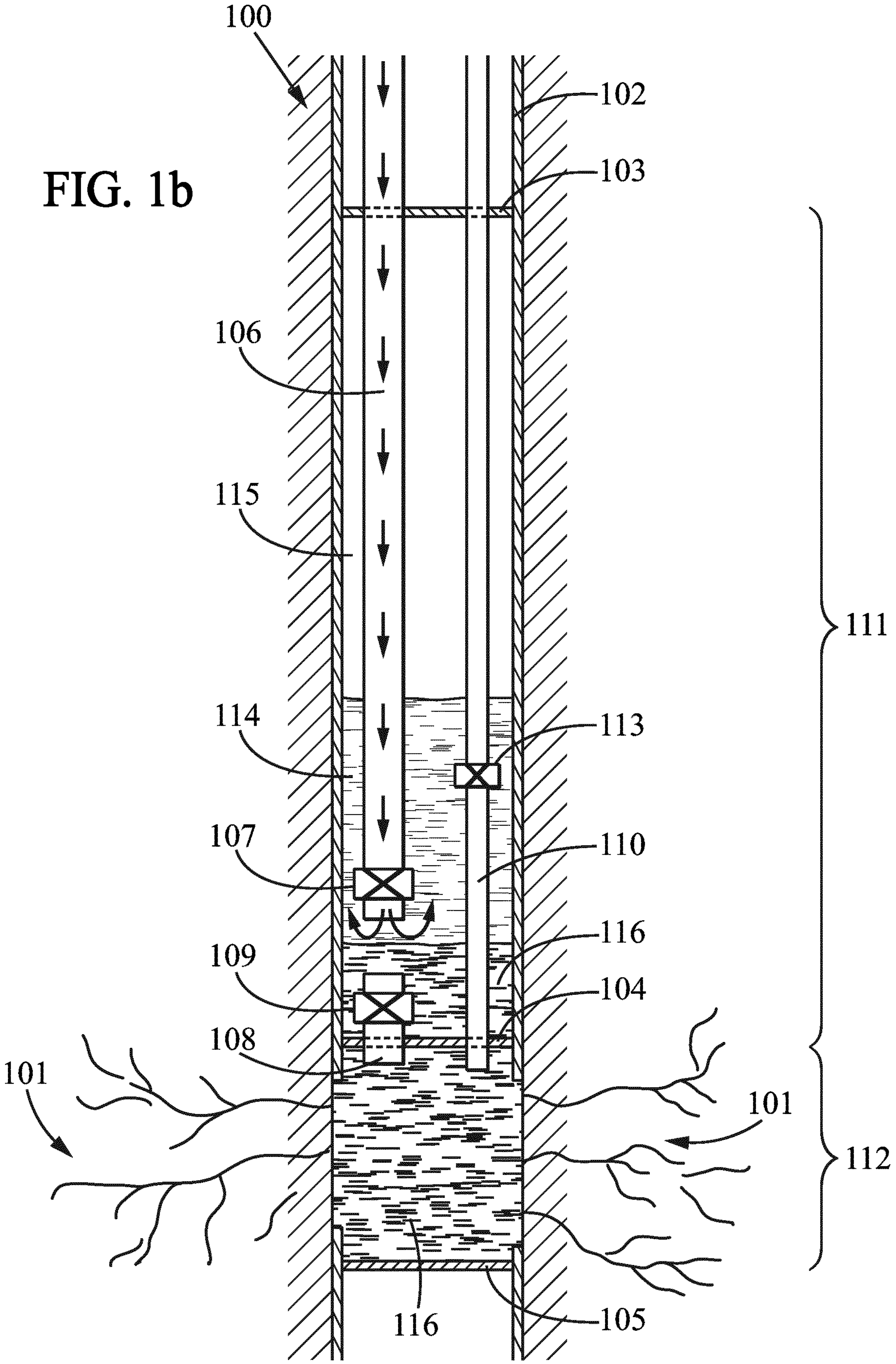
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FIG. 1c

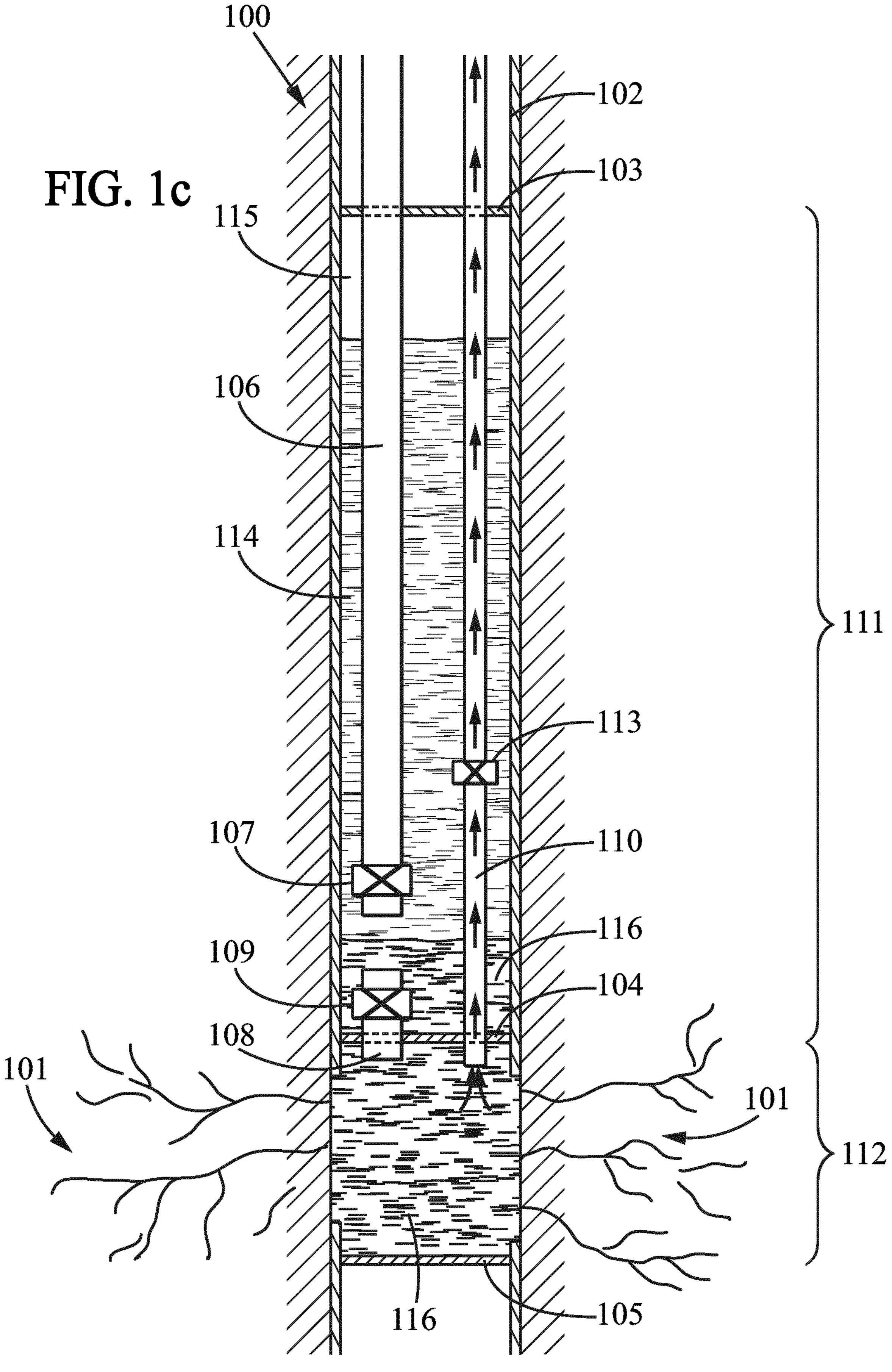
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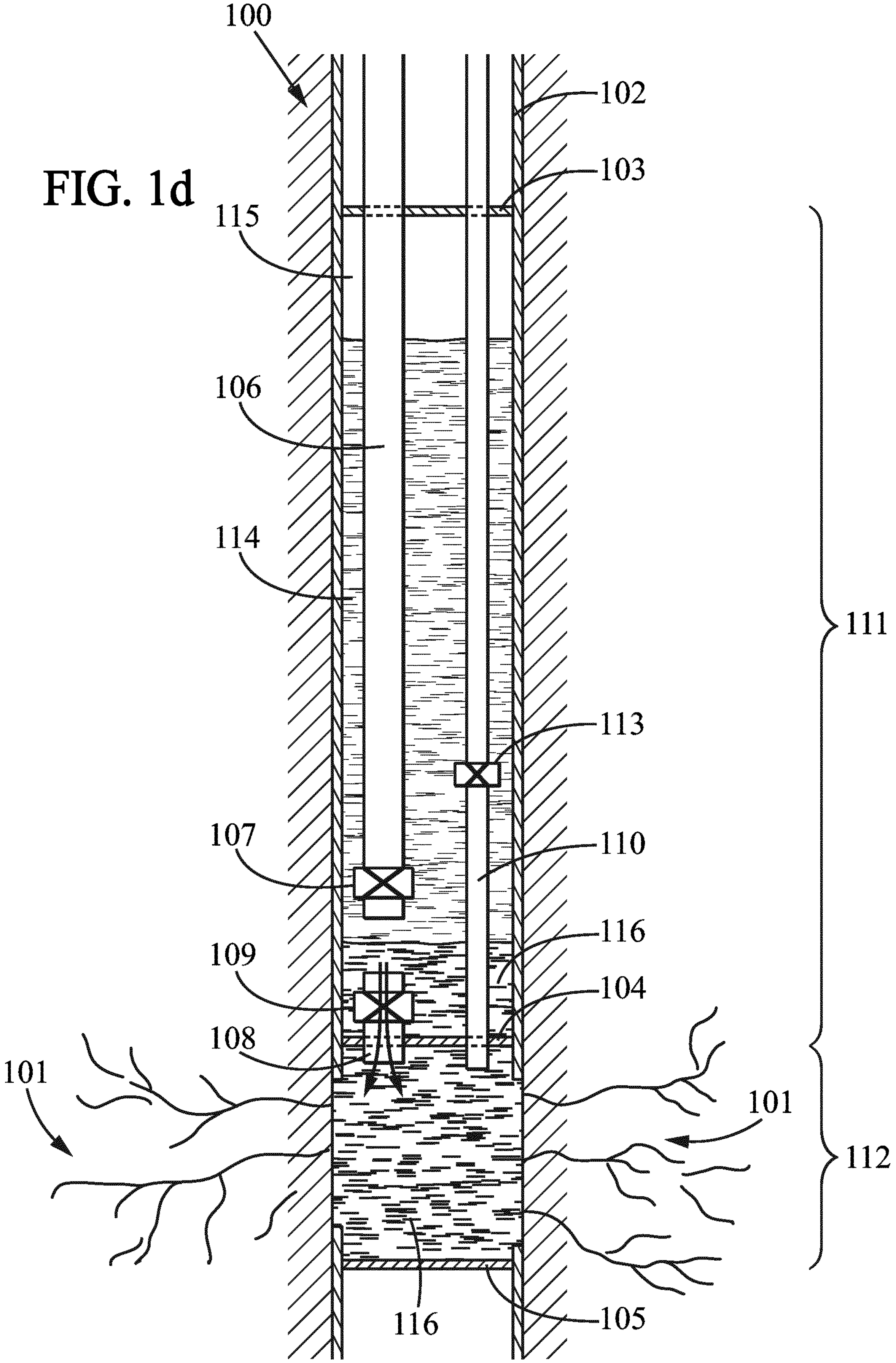
FIG. 1d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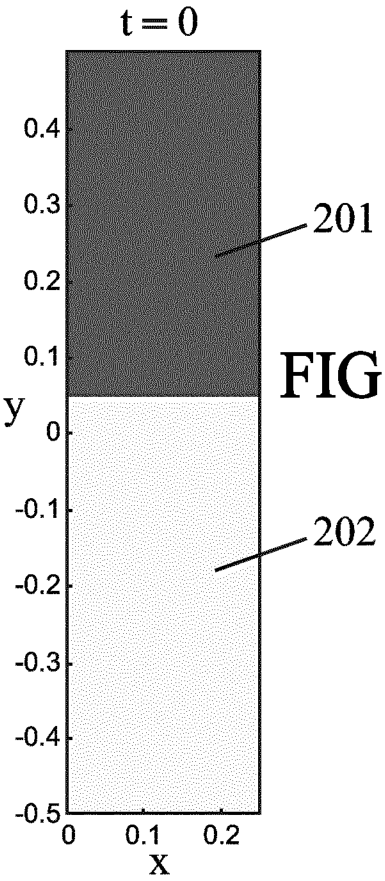

FIG. 2a

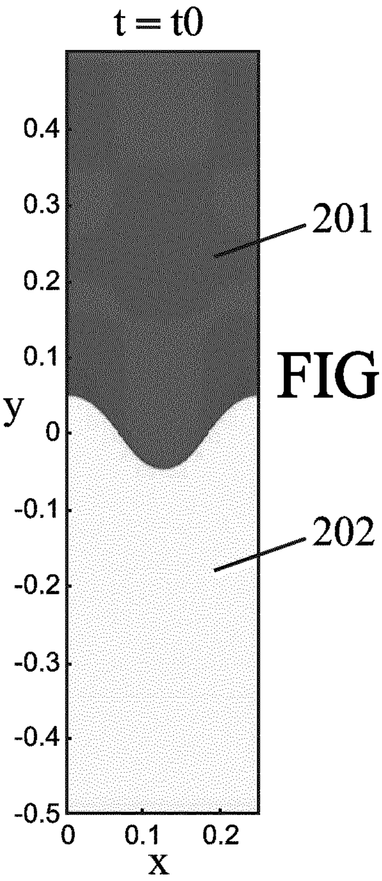

FIG. 2b

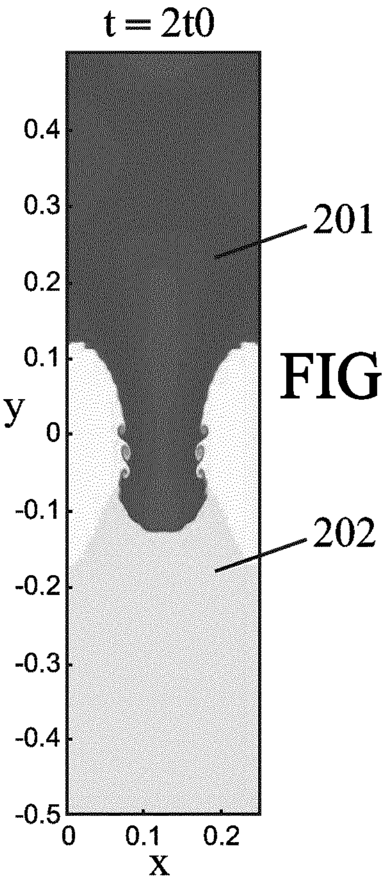

FIG. 2c

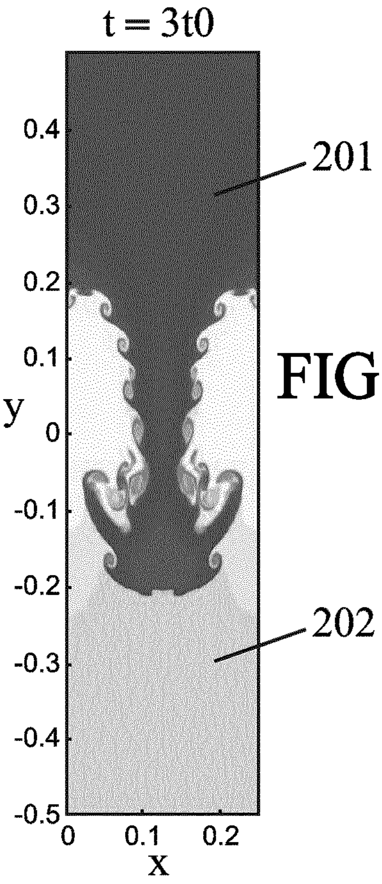

FIG. 2d

FIG. 3