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(54) Title: SEPARATION SYSTEM TO SEPARATE PHASES OF DOWNHOLE FLUIDS FOR INDIVIDUAL ANALYSIS

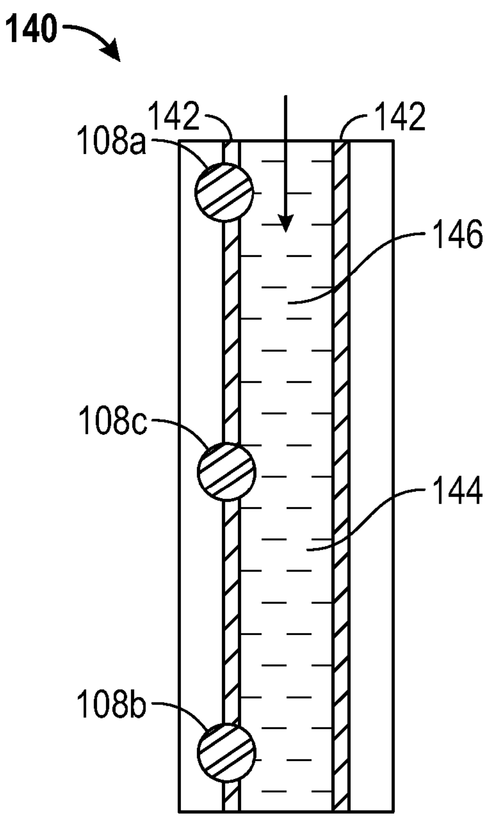

FIG. 3

(57) Abstract: An apparatus for sampling a fluid in a borehole may include a vessel configured to be disposed in a borehole and at least one sensor in communication with one phase of the plurality of phases in the vessel. The vessel separates the fluid into a plurality of phases.

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TITLE: SEPARATION SYSTEM TO SEPARATE PHASES OF DOWNHOLE FLUIDS FOR INDIVIDUAL ANALYSIS

FIELD OF THE DISCLOSURE

[0001] This disclosure pertains generally to investigations of underground formations and more particularly to systems and methods for evaluating downhole fluids.

BACKGROUND OF THE DISCLOSURE

[0002] Commercial development of hydrocarbon fields requires significant amounts of capital. Before field development begins, operators desire to have as much data as possible in order to evaluate the reservoir for commercial viability. While data acquisition during drilling provides useful information, it is often also desirable to conduct further testing of the hydrocarbon reservoirs in order to obtain additional data. Therefore, after a borehole for a well has been drilled, the hydrocarbon zones are usually tested with tools that acquire fluid samples, *e.g.*, liquids from the formation. These fluids may be multi-phase fluids; i.e., fluids that are a mixture of water, hydrocarbons, and / or solids. The multi-phase nature of these fluids may reduce the accuracy of evaluation of a particular phase.

[0003] In one aspect, the present disclosure addresses the need to separate one or more phases of a downhole fluid.

SUMMARY OF THE DISCLOSURE

[0004] In one aspect, the present disclosure provides an apparatus for sampling a fluid in a borehole. The apparatus may include a vessel configured to be disposed in a borehole, the vessel being further configured to separate the fluid into a plurality of phases without substantially affecting a structure of at least one of the separated phases; and at least one sensor in communication with one phase of the plurality of phases in the vessel.

[0005] In another aspect, the present disclosure provides a method for sampling a fluid in a borehole. The method may include separating the fluid into a plurality of phases in a vessel positioned in the borehole without substantially affecting a structure of at least one of the separated phases; and estimating a parameter of interest relating to at least one phase separated from the fluid while the at least one phase is in the vessel.

[0006] Examples of certain features of the disclosure have been summarized rather broadly in order that the detailed description thereof that follows may be better understood and in order that the contributions they represent to the art may be appreciated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] For a detailed understanding of the present disclosure, reference should be made to the following detailed description of the embodiments, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, wherein:

FIG. 1 shows a schematic of a centrifugal-type of separator according to one embodiment of the present disclosure;

FIG. 2 shows a schematic of a thermal separator according to one embodiment of the present disclosure; and

FIG. 3 shows a schematic of a separator that uses reactive surfaces according to one embodiment of the present disclosure;

FIG. 4 shows a schematic of a membrane-based separator according to one embodiment of the present disclosure;

FIG. 5 illustrates a schematic of a formation evaluation system that includes a separator according to one embodiment of the present disclosure.

DETAILED DESCRIPTION

[0008] In aspects, the present disclosure relates to devices and methods to evaluate downhole fluids. As used herein, the term downhole fluid is generally any fluid found in a drilled wellbore and /or any fluid that resides in the formation. Downhole fluids include but are not limited to, naturally occurring fluids such as oil, gas, and water, as well as engineered fluids such as drilling fluids and surface injected fluids. The teachings may be advantageously applied to a variety of systems in the oil and gas industry, water wells, geothermal wells, surface applications and elsewhere. Merely for clarity, certain non-limiting embodiments will be discussed in the context of hydrocarbon producing wells.

[0009] Referring initially to **Fig. 1**, there is schematically illustrated one embodiment of a test tool **100** that may be used to actively separate a fluid into two or more homogeneous materials or phases (*e.g.*, a polar phase, a nonpolar phase, an aqueous phase, a liquid hydrocarbon, a gas hydrocarbon, water, etc.). As discussed in further detail below, the separation may be performed without substantially affecting a structure of one or more of the substances making up the several phases. That is, after the separation, one or more than one of the separated phases still retains the same molecular structure as prior to the separation (e.g., minimal molecular dissolution or association). Of course, a minimal amount of change may be encountered in the post-separated phase, but not to a degree that affects the ability to use the post-separated phase to acquire information relating to that phase prior to separation. Thus, the pre-separation and post-separation phases are structurally similar.

[0010] The tool **100** may be used to evaluate one or more characteristics of the separated phase(s) and also estimate one or more parameters relating to the separation process (*e.g.*, pressure, temperature, etc.). The tool **100** may include an inlet **102** through which a fluid **103** enters an active separation chamber **104** and outlets **106a,b** through which the separated phases **107a,b** exit the separation chamber **104**. The tool **100** may include a variety of sensors configured to estimate one or more desired parameters. For example, a sensor **108**a may be used to estimate a characteristic of a first phase component (*e.g.*, oil) , and a sensor **108b** may be used to estimate a characteristic of a second phase component (*e.g.*, water). Other phase components (*e.g.*, condensates) may be evaluated with similar sensors (not shown). Also, sensors **108c** may be used to estimate one or more environmental parameters (*e.g.*, pressure, temperature, rotational speed, fluid flow rate, fluid velocity, etc.). In embodiments, the test tool **100** may include a separator **110** that uses rotation to separate the fluid into two or more phase components. The separator **110** may include an enclosure **112,** which may be drum-shaped**,** that is rotated by a suitable motor **114**.

[0011] During operation, the fluid **103** flows via the inlet **102** into the enclosure **112**, which is rotated by the motor **114**. The centrifugal forces generated by the rotating enclosure **112** separates phases based on relative density. In other embodiments, the separation may be performed independent of orientation. As shown, the relatively lighter phase **107a** (*e.g.*, oil) separates and exits via outlet **106**a and the relatively denser phase **107b** (*e.g.*, water) separates and exits via outlet **106**b.

[0012] Further, in some embodiments, the enclosure **112** may be oriented to allow gravity to also separate the phases based on relative density. For example, the tool **100** may include an orientation sensor (not shown) that provides an indication of verticality and an orientation device (not shown) that orients the device such that more dense phases collect at a particular location in the chamber **104**.

[0013] In conjunction with the separation process, the sensors **108a-c** may generate information relating to one or more parameters of the fluid **103**, the separated phase components **107a,b** and / or the environmental conditions associated with the tool **100**. 'Information' may be data in any form and may be "raw" and / or "processed," *e.g.*, direct measurements, indirect measurements, analog signal, digital signals, etc. It should be appreciated that the information provided by the sensors **108a,b** is indicative of a state, condition, or property of the separated phase immediately after separation, but before the separated phase has exited the tool **100**. Also, the sensors **108c** may provide information relating to the conditions under which the separation occurred. Thus, in aspects, the tool **100** may provide information that includes at least a property of one or more separated components and the conditions that caused the separation.

[0014] The sensors **108a,b** may be configured to generate information regarding the chemical composition(s) or material properties(s) of the separated phases **107a,b**. This information may relate to properties that include, but are not limited to, one or more of: (i) pH, (ii) H_2S, (iii) density, (iv) viscosity, (v) thermal conductivity, (vi) electrical resistivity, (vii) chemical composition, (viii) reactivity,

(ix) radiofrequency properties, (x) surface tension, (xi) infra-red absorption, (xii) ultraviolet absorption, (xiii) refractive index, and (xiv) rheological properties.

[0015] The separation of the phase components may be performed by a number of different devices and techniques in addition to the centrifugal separator shown in **Fig. 1**. For example, the tool **100** may include a cyclonic separator wherein the fluid **103** is spun in a spiral or helix-like manner in the chamber **104**. Still other non-limiting embodiments of separators are discussed below.

[0016] Referring now to **Fig. 2**, there is shown a thermal separator **120** that includes a distillation column **122**. In some embodiments, cooling devices such as thermoelectric elements **124a,b** may be used to remove heat from the fluid **123** in the column **122**. A thermoelectric elements **124a,b** may be formed of a suitable material (*e.g.*, bismuth telluride) that when energized by an electrical circuit **126** transfers heat across a space against a temperature gradient (or Peltier effect). A suitable power source **128** may provide electrical power. In other embodiments, heat may be applied by suitable heating elements to separate phases in the distillation column **122**. In addition to or instead of thermal separation, electrostatic forces may be used to separate phase components based on the electric charge of the components. As discussed previously, sensors **108a-c** may be used to obtain desired information relating to the fluid and / or environment in the distillation column **122**.

[0017] Referring now to **Fig. 3**, there is shown a column **140** that includes one or more reactive column surfaces **142** that define a flow conduit **144** where the separator **140** is used for chromatographic purposes, *e.g.*, high performance liquid chromatography, ion exchange chromatography, hydrophobic interaction chromatography, gel filtration chromatography, and combinations thereof. Chromatography is used to separate phases of a liquid. The liquid, *i.e.*, the mobile phase, is poured or dripped through a column surface **142**, *i.e.*, the stationary phase. The column surfaces **142** may interact with a targeted phase of the fluid **146**. As the fluid **146** flows along the column surface **142**, the targeted phase of the fluid **146** interacts with the column surface **142** and is retained by the column surface **142**, which allows the remainder of the fluid **146** to continue flowing through the column **140**. Thus, the targeted phase of the fluid **146** is separated from the remainder of the fluid **146**. Chromatography may be used by designing the column surfaces **142** to interact with the fluid **146** based on dipole-dipole interactions, ionic interactions or molecule sizes. As discussed previously, sensors **108a-c** may be used to obtain desired information relating to the fluid and / or environment in the flow conduit **144**.

[0018] For example, the column surfaces **142** may attract oil or water (*e.g.*, lipophilic, hydrophobic, hydrophilic), cause a phase component to coalesce, and / or cause a desired flow regime. For instance, the surfaces may be a combination of hydrophilic and superhydrophobic surfaces that allow water to coalesce and then flow along a predefined channel. Similar combination of surface may be designed using oleophilic and oleophobic surfaces. In embodiments, the column surfaces **142** may be configured to operate according to HPLC (high performance liquid chromatography). HPLC is generally an automated system having fluids applied in a precise manner with controlled flow rates at high pressures. The column surfaces **142** may be a matrix of specially fabricated glass or plastic beads coated with a uniform layer of chromatographic material. HPLC allows for high speed, high resolution, and reproducibility of the separation.

[0019] The column **140** may also be configured for ion exchange chromatography where oppositely charged molecules are bound to the column surfaces **142** to allow a targeted phase to be separated from the fluid **146**. For example, if the targeted phase is water to be separated from the fluid **146**, charged or ionic molecules would be bound to the column surfaces **142**. Water would bind to the ionic molecules and the remainder of the fluid **146** would flow through the column **140**.

[0020] The column **140** may also be configured for hydrophobic interaction chromatography where the column surfaces **142** are impregnated with nonpolar groups. The nonpolar groups may interact with the hydrophobic phase of the fluid **146**, which causes the hydrophobic phase to bind to the column surfaces **142** and allows the charged phase to flow through the column **140**. An embodiment of this may include the oil phase being separated from the fluid **146**, so that the remainder of the fluid **146** flows through the column **140**.

[0021] The column **140** may be configured for size exclusion chromatography where molecules are separated according to the size and/or shape of the molecules within the targeted phase of the fluid **146**. In this instance, the column surface **142** may have gel beads with pores of a specified size range. The pores may retain molecules of a particular wettability, size and/or shape of the fluid **146**. For example, as is known, an oil molecule is size-wise larger than a water molecule. Thus, the pores of the column surfaces **146** may be configured to be penetrable by water but relatively impenetrable by oil. Such a column surface **142** then would retain water but allow the oil to flow through the column **140**.

[0022] Referring now to **Fig. 4**, there is shown a separator **160** that includes a permeable material **162** that separates a chamber **164** into a pre-separation section **166** and a post-separation section **168**. In one embodiment, the material may be a membrane **162** that has a permeability selected to allow passage of only a selected phase component (*e.g.*, a hydrocarbon). A piston **170** or other suitable movable member reduces the volume in the pre-separation section **166** to generate a pressure differential that forces the selected phase component through the membrane **162** and into the post-separation section **168**. In other embodiments, a vacuum pump (not shown) may be used to reduce pressure in the post-separation section **168**. In other embodiments, the material **162** may be beads, or a sponge-like material. As discussed previously, sensors **108a-c** may be used to obtain desired information relating to the fluid and / or environment in the membrane separator **160**. Other embodiments of using membrane separation may use pistons or other pressurizing mechanisms to force the fluid through a membrane which selectively filters molecules. The membrane may be porous, micro-porous, or nano-porous.

[0023] It should be appreciated that the above illustrative separation techniques separate the phases without substantially affecting a structure of one or more of the substances making up the several phases. Separation processes involving pressure reduction below bubble point or cooling can cause condensate to in a liquid. However, the liquid and / or the condensate in those processes may undergo a chemical structural change that may make it difficult or impossible to acquire information relating to the fluid prior to such a separation process. The separation techniques of the present disclosure, however, retain the pre-separation structure of phase substance(s) even after separation.

[0024] The teachings of the present disclosure may be used in a variety of surface and sub-surface applications. Merely for convenience, there is shown in **Fig. 5**, a tool configured to characterize a fluid that is configured for sub-surface applications. **Fig. 5** schematically illustrates a wellbore system **10** deployed from a rig **12** into a borehole **14**. While a land-based rig **12** is shown, it should be understood that the present disclosure may be applicable to offshore rigs and subsea formations. The wellbore system **10** may include a carrier **16** and a wellbore tool **20**. Merely for ease of discussion, the wellbore tool **20** is shown as a fluid analysis tool. The fluid analysis tool **20** may include a probe **22** that contacts a borehole wall **24** for extracting formation fluid from a formation **26**. Extendable pads or ribs **28** may be used to laterally thrust the probe **22** against the borehole wall **24**. The fluid analysis tool **20** may include a pump **30** that pumps formation fluid from formation **26** via the probe **22**. Formation fluid travels along a flow line to one or more sample containers **32** or to line **34** from which the formation fluid exits to the borehole **14**. The fluid may have one or more pre-existing phase components (*i.e.*, that exist prior to separation). The tool **20** may include a separator **100** as described previously to separate one or more phase components from the fluid extracted from the formation **26**. A programmable controller may be used to control one or more aspects of the operation of the tool **20**. For example, the wellbore system **10** may include a surface controller **40** and / or a downhole controller **42**.

[0025] In one mode of operation, the tool **20** is positioned downhole and operated to extract fluid from the formation **26**. The fluid from the formation (or formation fluid) may be a multi-phase fluid. Thus, the extracted fluid is conveyed to the separator tool **100**. The separator tool **100** separates at least one phase from the extracted fluid. Referring now to **Figs. 1** and **5**, during the separation phase, the sensors **108a,b** estimate one or more phase properties of the separated phases before the separated fluids have exited the separator tool **100**. The sensors **108a,b** provide information about the post-separated phase(s) that may be used to characterize the properties of the phases prior to separation.

[0026] At the same time, the sensors **108c** acquire information that can be used to evaluate the environmental conditions under which the phase separation occurred.

[0027] In some embodiments, the wellbore system **10** may be a drilling system that configured to form the borehole **14** using tools such as a drill bit (not shown). In such embodiments, the carrier **16** may be a coiled tube, casing, liners, drill pipe, etc. In other embodiments, the wellbore system **10** may use a non-rigid carrier. In such arrangements, the carrier **16** may be wirelines, wireline sondes, slickline sondes, e-lines, etc. The term "carrier" as used herein means any device, device component, combination of devices, media and/or member that may be used to convey, house, support, or otherwise facilitate the use of another device, device component, combination of devices, media and/or member.

[0028] The controller **40, 42** may include an information processor that is in data communication with a data storage medium and a processor memory. The data storage medium may be any standard computer data storage device, such as a USB drive, memory stick, hard disk, removable RAM, EPROMs, EAROMs, flash memories and optical disks, or other commonly used memory storage system known to one of ordinary skill in the art including Internet based storage. The data storage medium may store one or more programs that when executed causes information processor to execute the disclosed method(s). Signals indicative of the parameter may be transmitted to a surface controller **40**. These signals may also, or in the alternative, be stored downhole in a data storage device and may also be processed. In one example, wired pipe may be used for transmitting information.

[0029] The term "carrier" as used in this disclosure means any device, device component, combination of devices, media and/or member that may be used to convey, house, support or otherwise facilitate the use of another device, device component, combination of devices, media and/or member. As used herein, the term “fluid” and “fluids” refers to one or gasses, one or more liquids, and mixtures thereof.

[0030] While the foregoing disclosure is directed to the one mode embodiments of the disclosure, various modifications will be apparent to those skilled in the art. It is intended that all variations be embraced by the foregoing disclosure.

THE CLAIMS

We claim:

1. An apparatus for sampling a fluid in a borehole, comprising:

- a vessel configured to be disposed in the borehole, the vessel being further configured to separate the fluid into a plurality of phases without substantially affecting a structure of at least one of the separated phases; and
- at least one sensor in communication with one separated phase in the vessel.

2. The apparatus of claim 1, wherein the at least one sensor comprises a plurality of sensors, each sensor being in communication with a different phase of the plurality of phases.

3. The apparatus of claim 1, wherein the at least one sensor is configured to generate signals representative of a parameter of interest relating to the one phase.

4. The apparatus of claim 1, further comprising an environmental sensor configured to estimate at least one environmental parameter.

5. The apparatus of claim 1, wherein the vessel includes a separator separating the fluid into the plurality of phases.

6. The apparatus of claim 5, wherein the separator is configured to spin the fluid.

7. The apparatus of claim 5, wherein the separator includes a permeable material configured to separate the fluid into the plurality of phases.

8. The apparatus of claim 5, wherein the separator includes at least one material configured to interact with one phase of the plurality of phases.

9. The apparatus of claim 8, wherein the interaction is one of: (i) attraction, (ii) repulsion, (iii) a molecular interaction; (iv) chemical interaction, (v) physical interaction, and (vi) ionic interaction.

10. The apparatus of claim 5, wherein the separator changes a temperature of the fluid.

11. The apparatus of claim 1, wherein the one phase is selected from at least one of: (i) an aqueous phase, (ii) a hydrocarbon, (iii) a precipitate; (iv) a nonpolar phase, and (v) a polar phase.

12. The apparatus of claim 1, wherein the one phase is selected from one of: (i) a solid, (ii) a liquid, and (iii) a gas.

13. A method for sampling a fluid in a borehole, comprising:

- separating the fluid into a plurality of phases in a vessel positioned in the borehole without substantially affecting a structure of at least one of the separated phases; and
- estimating a parameter of interest relating to at least one separated phase fluid while the at least one phase is in the vessel.

14. The method of claim 13, further comprising estimating an environmental parameter while the fluid is being separated.

15. The method of claim 13, wherein the parameter of interest is estimated while the fluid is being separated.

16. The method of claim 13, further comprising discharging the separated phases from the vessel after estimating the parameter of interest.

17. The method of claim 13 wherein the fluid is separated by a chromatographic procedure.

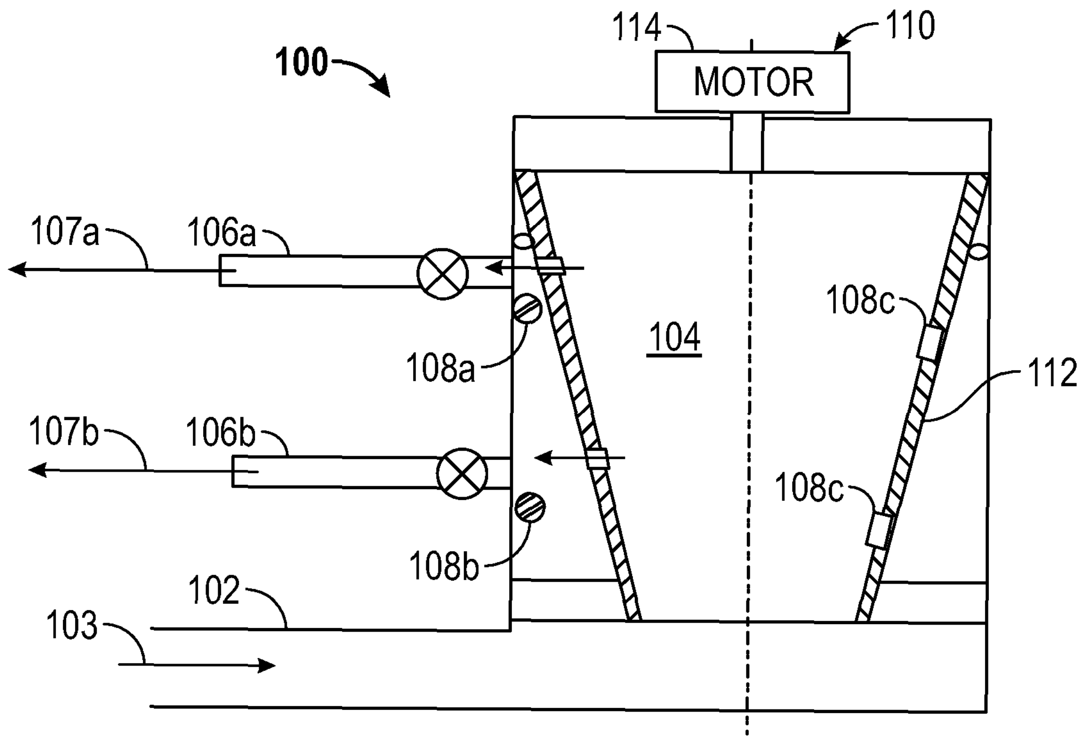
100
114
110
MOTOR
107a
106a
108a
104
108c
112
107b
106b
108c
108b
102
103

FIG. 1

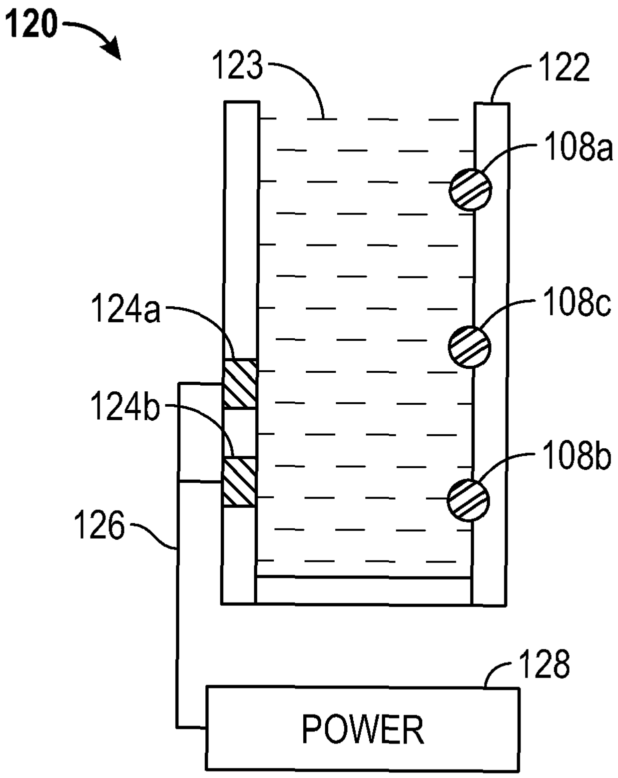
120
123
122
108a
108c
124a
124b
108b
126
128
POWER

FIG. 2

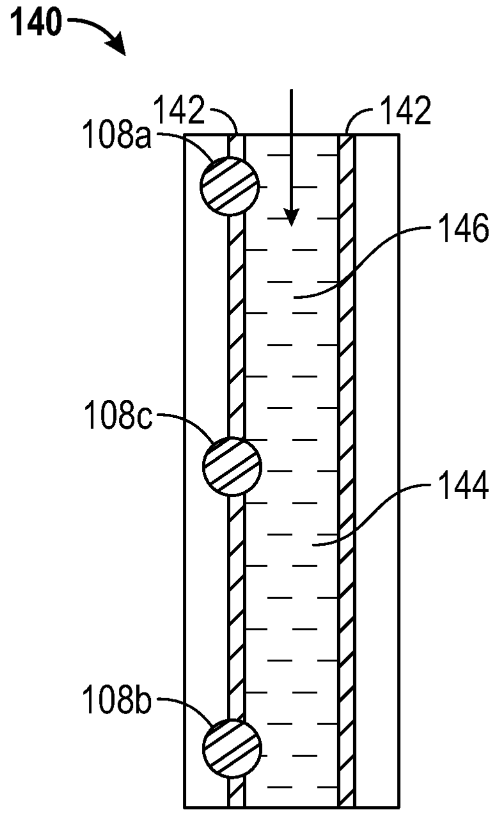
140
142
142
108a
146
108c
144
108b

FIG. 3

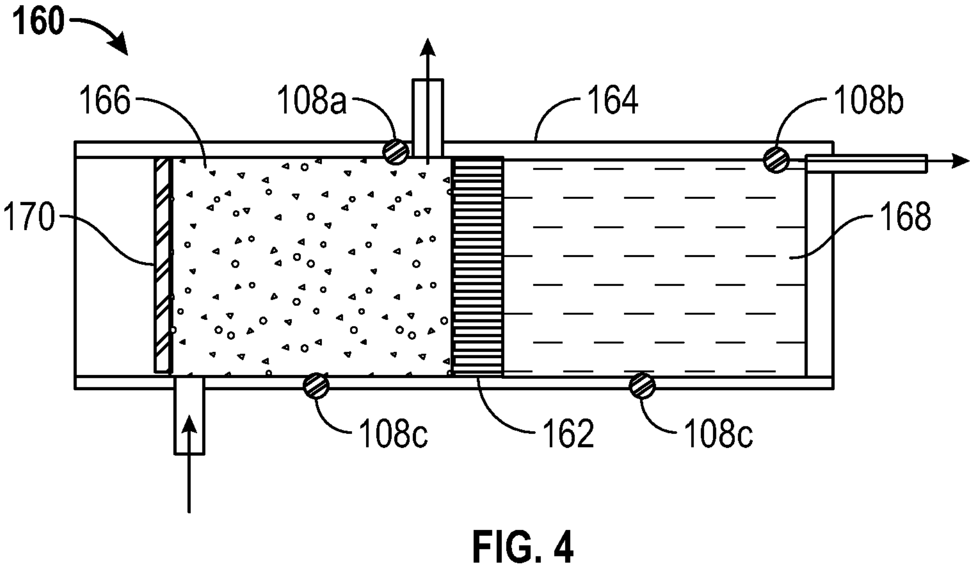
160
166
108a
164
108b
170
168
108c
162
108c

FIG. 4

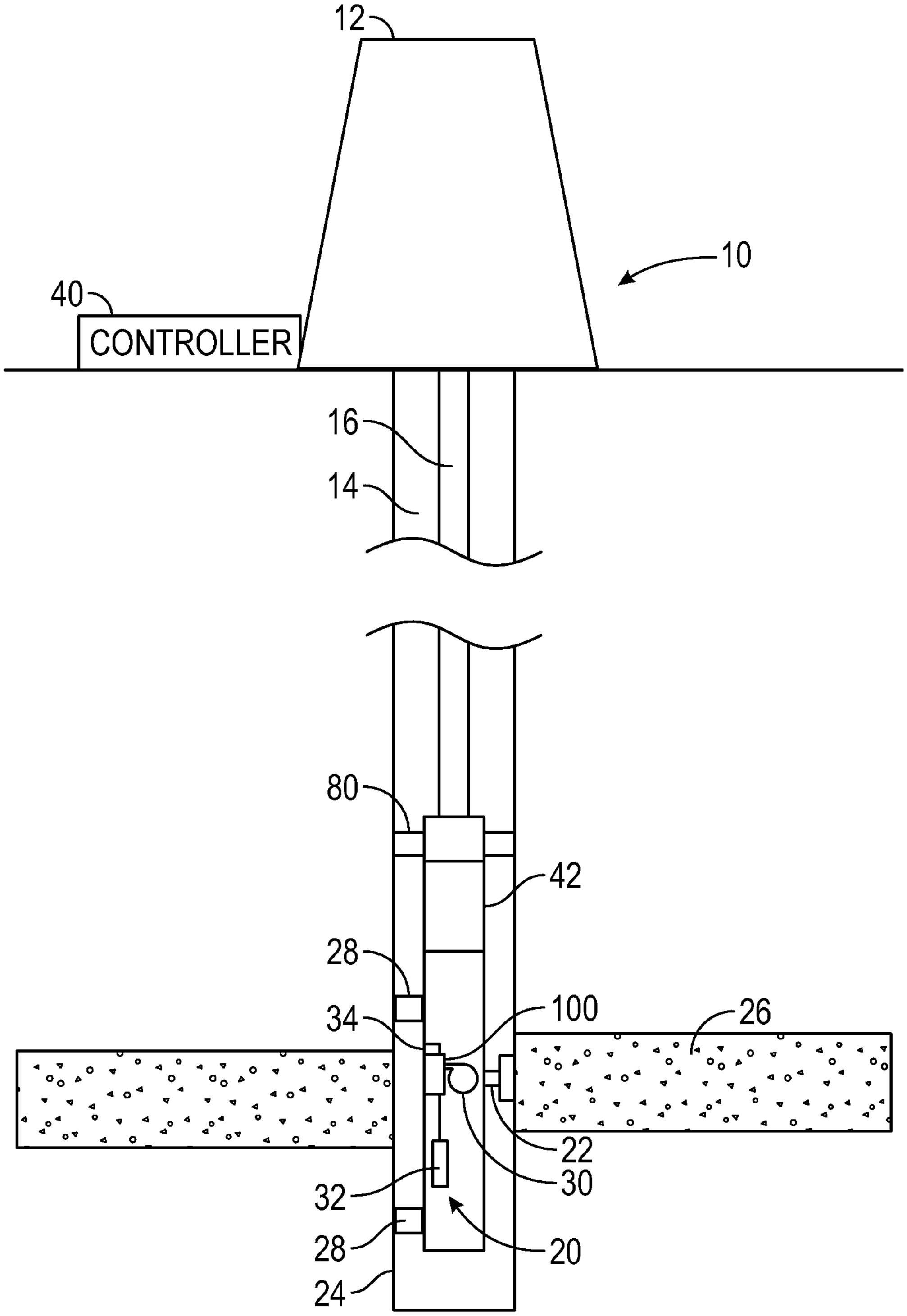

FIG. 5