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(54) **Title**: CNT FIBER BASED IMPEDANCE SPECTROSCOPY FOR CHARACTERIZING DOWNHOLE FLUIDS

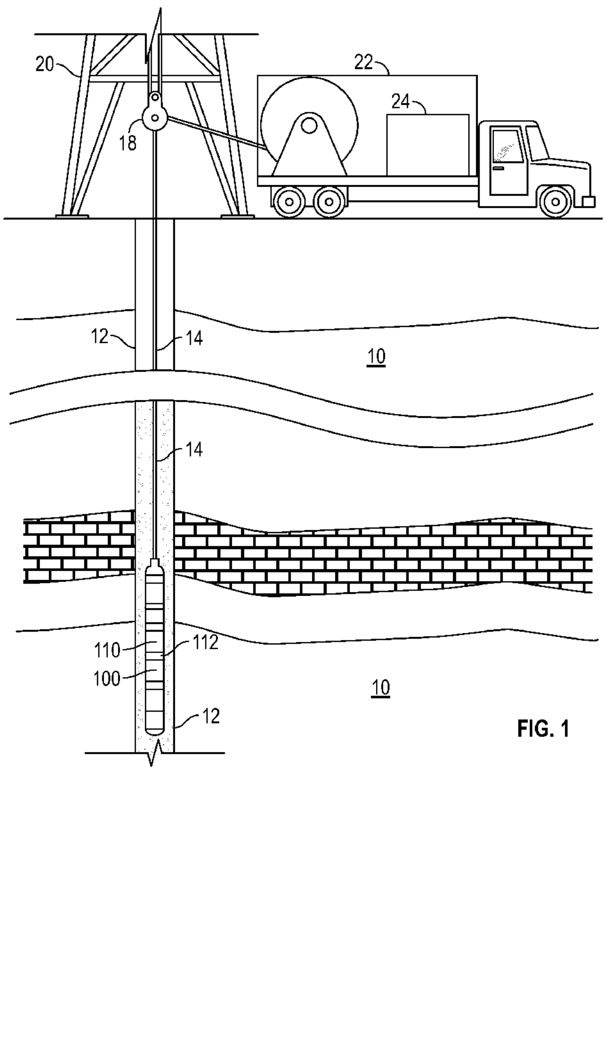

FIG. 1

(57) **Abstract**: The present disclosure relates to an apparatus and method for estimating a parameter of interest of a downhole fluid using a fluid analysis module. The fluid analysis module may include: at least one nano element and a processor configured to estimate an impedance of the at least one nano element. The fluid analysis module may include an AC power supply configured to supply electrical signals at a plurality of frequencies through the at least one nano element. The method may include bringing the downhole fluid into contact with the at least one nano element; supplying electrical signals through the at least one nano element at a plurality of frequencies; generating impedance information for the at least one nano element in response to the electrical signals; and estimating the at least one parameter of interest using the impedance information.

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TITLE: CNT FIBER BASED IMPEDANCE SPECTROSCOPY FOR CHARACTERIZING DOWNHOLE FLUIDS

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FIELD OF THE DISCLOSURE

[0001] This disclosure generally relates to estimating at least one parameter of a downhole fluid.

BACKGROUND OF THE DISCLOSURE

[0002] Fluid evaluation techniques are well known. Broadly speaking, analysis of fluids may provide valuable data indicative of formation and wellbore parameters. Many fluids, such as formation fluids, production fluids, and drilling fluids, contain a large number of components with a complex composition.

[0003] The complex composition of such fluids may be sensitive to changes in the environment, e.g., pressure changes, temperature changes, contamination, etc. Thus, retrieval of a sample may cause unwanted separation or precipitation within the fluid. Additionally, some components of the fluid may change state (gas to liquid, or liquid to solid) when removed to surface conditions. If precipitation or separation occurs, it may not be possible to restore the original composition of the fluid.

SUMMARY OF THE DISCLOSURE

[0004] In aspects, this disclosure generally relates to analysis of downhole fluids. More specifically, this disclosure relates to analysis of fluids using a response of at least one nano element to electrical signals at a plurality of frequencies.

[0005] One embodiment according to the present disclosure includes a method of estimating a parameter of interest of a downhole fluid, the method comprising: estimating the parameter of interest based on an impedance of at least one nano element using a processor, the at least one nano element being in contact with the downhole fluid and responsive to a plurality of frequencies.

[0006] Another embodiment according to the present disclosure includes an apparatus for estimating at least one parameter of a downhole fluid, the apparatus comprising: at least one nano element configured to be in contact with the downhole fluid; and a processor configured to estimate the impedance of the at least one nano element over a plurality of frequencies.

[0007] 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

[0008] 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 fluid analysis module deployed in a borehole along a wireline according to one embodiment of the present disclosure;

Fig. 2 shows a schematic of a fluid analysis module according to one embodiment of the present disclosure;

Fig. 3 shows a schematic of a fluid analysis module according to another embodiment of the present disclosure;

Fig. 4 shows a schematic of a fluid analysis module according to another embodiment of the present disclosure;

Fig. 5 shows a schematic of a fluid analysis module according to another embodiment of the present disclosure;

Fig. 6 shows a schematic of a fluid analysis module with a probe extending into an earth formation according to another embodiment of the present disclosure;

Fig. 7 shows a flow chart of a method for analyzing a fluid using a fluid analysis module according to one embodiment of the present disclosure; and

Fig. 8 shows a graph of a real part of complex impedance varying with frequency for a fluid as estimated in one embodiment using a fluid analysis module according to one embodiment of the present disclosure.

DETAILED DESCRIPTION

[0009] This disclosure generally relates to analysis of fluids. In one aspect, this disclosure relates to analysis of fluids using an estimated impedance over a range of frequencies when an AC voltage is applied to a nano element in contact with a downhole fluid. Herein, the term "nano element" relates to an object that is less than one micrometer along at least one dimension. Nano elements may include, but are not limited to, nano particles, nanotubes, nano fibers, nano thin films, and nano wires.

[0010] Nano elements may have large surface area to volume ratios, which may enable the nano element composed of a material with a mass and a volume to have a much larger surface area than another element of the identical material with an identical mass that has its smallest dimension in the micrometer range or larger. The larger surface area means that the nano element may have more contact with the molecules of a fluid sample through adsorption than larger elements.

[0011] Some nano elements may be composed of materials that allow the conduction of electricity. The large number of particles adsorbed to the surface of the nano element may alter the electrical conductivity of the nano element, such as altering the impedance of the nano element. In the science of impedance spectroscopy, a nano element may be scanned over a range of frequencies in order to determine if the spectrum impedance (complex resistance) changes when the nano element is in contact with another substance, such as a fluid. Thus, when an AC voltage is applied to the nano element over a plurality of frequencies, the nano element may exhibit a signature impedance-frequency relationship. The plurality of frequencies may include, but is not limited to, a range of about 1 kHz to about 100 MHz. When the nano element is placed in contact with a fluid, the impedance-frequency relationship may change, and the change may be specific to at least one parameter of the fluid. Thus, parameters of the fluid may be estimated from the change in impedance characteristics of the nano element. Several non-limiting embodiments of an apparatus configured to use the proposed technique are described below.

[0012] Referring initially to **FIG. 1**, there is schematically represented a cross-section of a subterranean formation **10** in which is drilled a borehole **12**. Suspended within the borehole **12** at the bottom end of a carrier **14**, such as a wireline, is a downhole assembly **100**. In some embodiments, the carrier **14** may be rigid, such as a coiled tube, casing, liners, drill pipe, etc. In other embodiments, the carrier **14** may be non-rigid, such as wirelines, wireline sondes, slickline sondes, e-lines, drop tools, self-propelled tractors, 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. The carrier **14** is often carried over a pulley **18** supported by a derrick **20**. Wireline deployment and retrieval is performed by a powered winch carried by a service truck **22**, for example. A control panel **24** interconnected to the downhole assembly **100** through the carrier **14** by conventional means controls transmission of electrical power, data/command signals, and also provides control over operation of the components in the downhole assembly **100**. The data may be transmitted in analog or digital form. Downhole assembly **100** may include a fluid analysis module **112**. Downhole assembly **100** may also include a sampling device **110**. Herein, the downhole assembly **100** may be used in a drilling system (not shown) as well as a wireline. While a wireline conveyance system has been shown, it should be understood that embodiments of the present disclosure may be utilized in connection with tools conveyed via rigid carriers (e.g., jointed tubular or coiled tubing) as well as non-rigid carriers (e.g., wireline, slickline, e-line, etc.). Some embodiments of the present disclosure may be deployed along with Logging While Drilling/Measurement While Drilling tools. In some embodiments, the device may be configured for installation in a borehole **12**.

[0013] **FIG. 2** shows an exemplary embodiment for a fluid analysis module **112** for testing one or more downhole fluids. Fluid analysis module **112** may include a housing **220** with a channel **230** configured to allow a fluid **210** to enter a chamber **240**. The fluid **210** may include, but is not limited to, one of: (i) a drilling fluid, (ii) a formation fluid, (iii) a production fluid, and combinations thereof. The fluid **210** in chamber **240** may include one or more nano elements **250** configured to be suspended in the fluid **210**. The fluid analysis module **112** may also include a power supply **260** and a processor **270** configured to estimate an impedance across a pair of electrodes **280** positioned to transmit and receive an electric current across at least part of chamber **240**. Processor **270** may include an impedance analyzer. In some embodiments, the power supply **260** may be configured to supply AC power. The AC power may include one or more types of waveforms including, but not limited to, one or more of: (i) sinusoidal, (ii) square, (iii) triangular, and (iv) impulse. In some embodiments, the power supply **260** may include a waveform function generator. In some embodiments, at least one of the nano elements **250** may include at least one carbon nanotube. In some embodiments, nano elements **250** may include one or more of: (i) a graphene, (ii) carbon, (iii) nickel, (iv) gold, (v) silicon, and (vi) diamond. In some embodiments, fluid **210** may be a downhole fluid from the borehole **12**. In some embodiments, passage of the at least one nano element **250** out of the chamber **240** may be prevented by screens (not shown) dimensioned to allow the passage of the fluid **210** into and out of the chamber **240** but not passage of the at least one nano element **250**.

[0014] **FIG. 3** shows another embodiment for the fluid analysis module **112**. In this embodiment, fluid analysis module **112** may include housing **220** with a channel **230** configured to allow a fluid **210** to enter a chamber **240**. Nano element **350** may be coupled to electrical leads **380** extending from at least one wall of chamber **240**. The electrical leads **380** may be electrically coupled to power supply **260** and processor **270**. Nano element **350** may be suspended in fluid **210**. In some embodiments, at least one of the nano elements **350** may include at least one carbon nanotube. The at least one nano element **350** may include a physical characteristic of being resilient, rigid, or flexible. In embodiments that include a plurality of nano elements, the plurality of nano elements may include a combination of physical characteristics.

[0015] **FIG. 4** shows another embodiment for the fluid analysis module **112**. This embodiment includes nano element **350** suspended in fluid **210** between two conductors **480**. In some embodiments, nano element **350** may hang between the conductors **480** in a shallow curve (such as a catenary). In some embodiments, nano element **350** may be held taught between the conductors **480**. In some embodiments, nano element **350** may be stretched between the conductors **480**.

[0016] **FIG. 5** shows another embodiment for the fluid analysis module **112**. In this embodiment, at least one nano element **350** may be exposed to a fluid **520** in the space between housing **220** and borehole wall **12**. The fluid **520** may include, but is not limited to, one of: (i) a drilling fluid, (ii) a formation fluid, (iii) a production fluid, and combinations thereof. The conductors **480** and the at least one nano element **350** may be positioned in a recessed potion **530** of housing **220** configured to protect the at least one nano element **350** from damage due to impact with the borehole wall **12**. In another embodiment, a first nano element **350** may be exposed to fluid **520** while a second nano element **350** may be isolated from fluid **520**, such that the second nano element **350** may be used to estimate reference information under ambient conditions in the borehole **12**. The reference information may include impedance information.

[0017] **FIG. 6** shows another embodiment for the fluid analysis module **112**. The at least one nano element **350** may be positioned in a fracture **640** in earth formation **10**. A probe **620** may be configured to be extended from housing **220** into the earth formation **10**. Probe **620** may also be configured to be retracted to housing **220**. The at least one nano element **350** may be in contact with formation fluid **650** and coupled to conductors **480**. The conductors **480** may run from power supply **260** and processor **270** to the at least one nano element **350** through probe **620**.

[0018] In some embodiments, the at least one nano element **250**, **350** may include a plurality of nano elements that may form a larger structure, such as a matrix of nano elements. In some embodiments, the larger structure may have a smallest dimension on the order of one nanometer to one millimeter. In other embodiments, the smallest dimension of the larger structure may exceed one millimeter.

[0019] **FIG. 7** shows a flow chart of a method **700** for estimating a parameter of interest based of a downhole fluid **210**, **520**, **650** using embodiments of the fluid analysis module **112**. In step **710**, the downhole fluid **210**, **520**, **650** may be placed in contact with the surface of a nano element **250**, **350**. In step **720**, electrical signals may be passed through at least one nano element **250**, **350** using a plurality of different frequencies. In some embodiments, the electrical signals may be generated by power source **260**. In step **730**, a processor **270** may generate information indicative of the impedance of the at least one nano element **250**, **350**. In some embodiments, the processor **270** may include an impedance analyzer. In step **740**, the at least one parameter of interest may be estimated using the impedance information. The at least one parameter of interest may include, but is not limited to, at least one of: chemical composition, density, thermal conductivity, electrical conductivity, electrical capacitance, temperature, pressure, flow velocity, magnetic permeability, and electrical permittivity. The estimation of the at least one parameter of interest may include using a characteristic frequency of a substance in the downhole fluid or the downhole fluid as a whole.

[0020] **FIG. 8** shows a graph of an impedance estimated using the one embodiment of the present disclosure. Curve **810** shows the relationship of a real part of complex impedance with frequency. At a characteristic frequency, f_c, the real part of the impedance may reach a minimum value, which may be used to characterize the downhole fluid **210**, **520**, **650**. While the present teachings have been discussed in the context of hydrocarbon producing wells, it should be understood that the present teachings may be applied to geothermal wells, groundwater wells, subsea analysis, surface based sensing, etc. Also, the present teachings may be applied to downhole installations for wellbore fluid monitoring and surface-based fluid recovery and analysis.

[0021] 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.

CLAIMS

What is claimed is:

1. A method of estimating a parameter of interest of a downhole fluid, the method comprising:

    estimating the parameter of interest based on an impedance of at least one nano element using a processor, the at least one nano element being in contact with the downhole fluid and responsive to a plurality of frequencies.

2. The method of claim 1, further comprising:

    applying an AC voltage to the at least one nano element.

3. The method of claim 2, wherein the AC voltage is applied over the plurality of frequencies:

4. The method of claim 2, wherein the AC voltage is applied one of: (i) momentarily in a transient manner and (ii) continuously.

5. The method of claim 1, wherein the processor includes an impedance analyzer.

6. The method of claim 1, wherein the parameter of interest includes at least one of: chemical composition, density, thermal conductivity, electrical conductivity, electrical capacitance, temperature, pressure, flow velocity, magnetic permeability, and electrical permittivity.

7. The method of claim 1, further comprising:

    comparing the impedance with reference impedance information.

8. The method of claim 7, further comprising:

    estimating the reference impedance information using at least one additional nano element.

9. The method of claim 1, wherein the at least one nano element includes at least one of: (i) a nano particle, (ii) a nano fiber, (iii) a nano wire, (iv) a nano thin film, and (v) a nanotube.

10. The method of claim 1, wherein the at least one nano element includes at least one of: (i) a graphene, (ii) carbon, (iii) nickel, (iv) gold, (v) silicon, and (vi) diamond.

11. The method of claim 1, wherein the downhole fluid includes at least one hydrocarbon.

12. An apparatus for estimating at least one parameter of a downhole fluid, the apparatus comprising:

    at least one nano element configured to be in contact with the downhole fluid; and

    a processor configured to estimate the impedance of the at least one nano element over a plurality of frequencies.

13. The apparatus of claim 12, further comprising:

    a power source configured to supply AC voltage to the at least one nano element.

14. The apparatus of claim 13, wherein the AC voltage is supplied over the plurality of frequencies:

15. The apparatus of claim 12, further comprising:

    at least one additional nano element configured to estimate reference impedance information.

16. The apparatus of claim 12, wherein the processor includes an impedance analyzer.

17. The apparatus of claim 12, wherein the parameter of interest includes at least one of: chemical composition, density, thermal conductivity, electrical conductivity, electrical capacitance, temperature, pressure, flow velocity, magnetic permeability, and electrical permittivity.

18. The apparatus of claim 12, wherein the at least one nano element includes at least one of: (i) a nano particle, (ii) a nano fiber, (iii) a nano wire, (iv) a nano thin film, and (v) a nanotube.

19. The apparatus of claim 12, wherein the at least one nano element includes at least one of: (i) a graphene, (ii) carbon, (iii) nickel, (iv) gold, (v) silicon, and (vi)

diamond.

20. The apparatus of claim 12, further comprising:

    a nonconductive structure configured to structurally support at least one of the at least one nano element.

21. The apparatus of claim 12, wherein the downhole fluid includes at least one hydrocarbon.

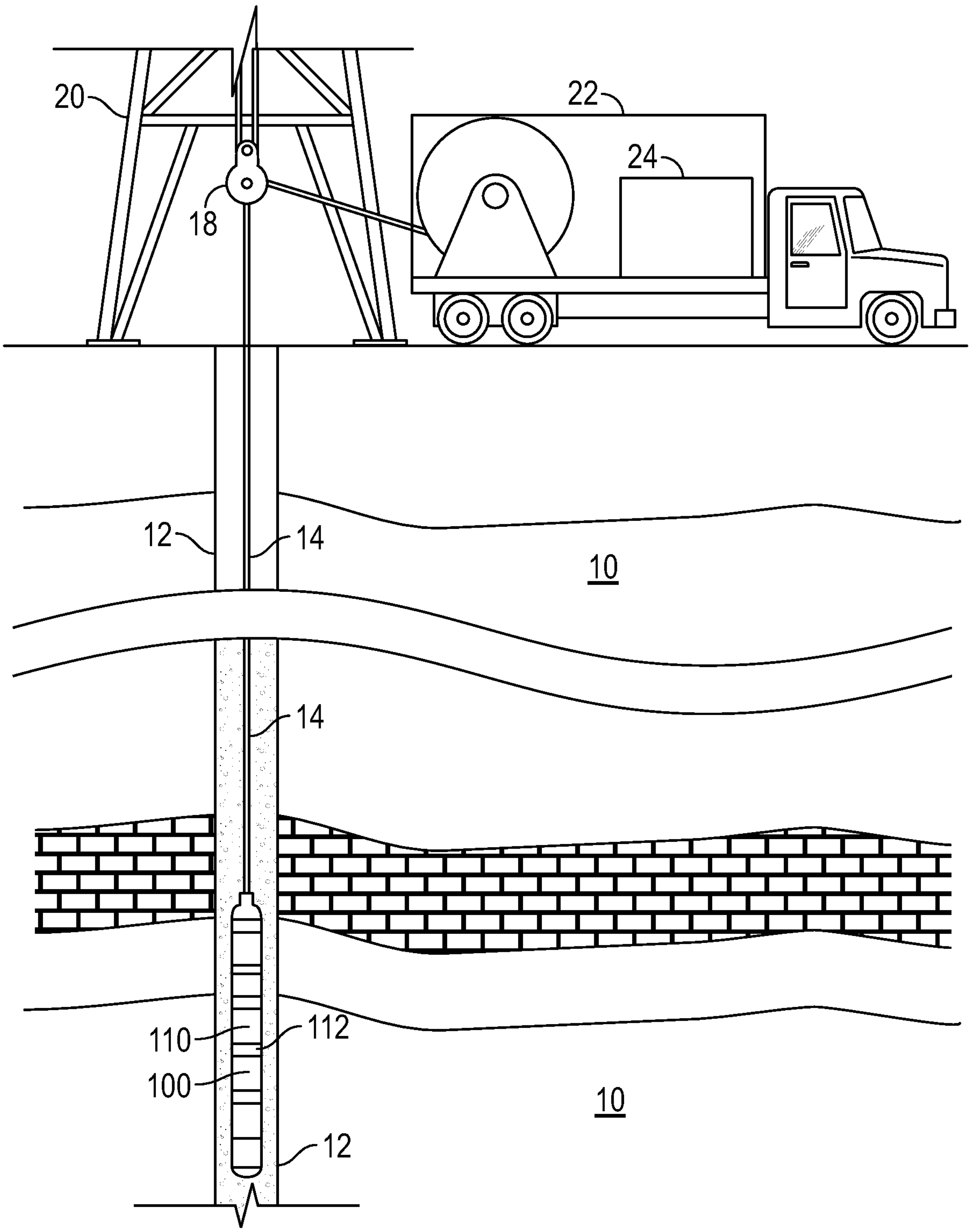
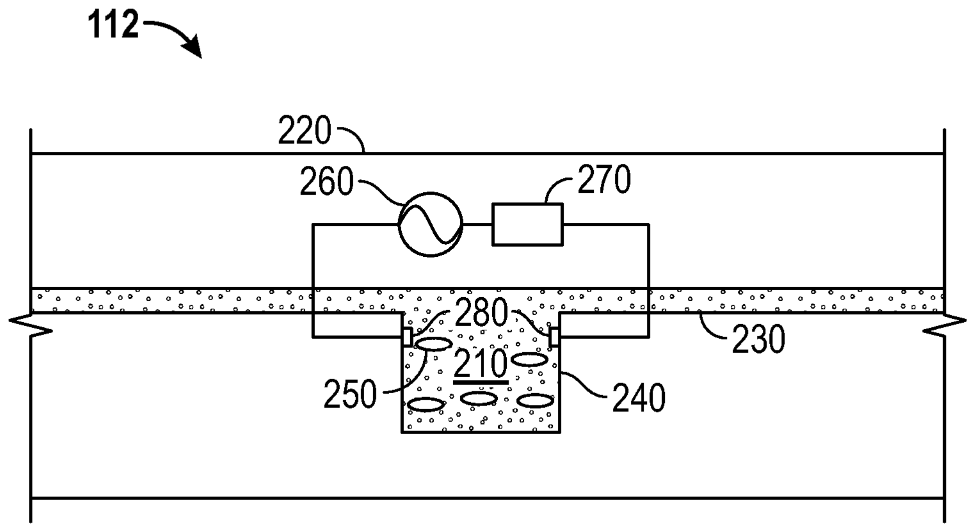


FIG. 1


112
220
260
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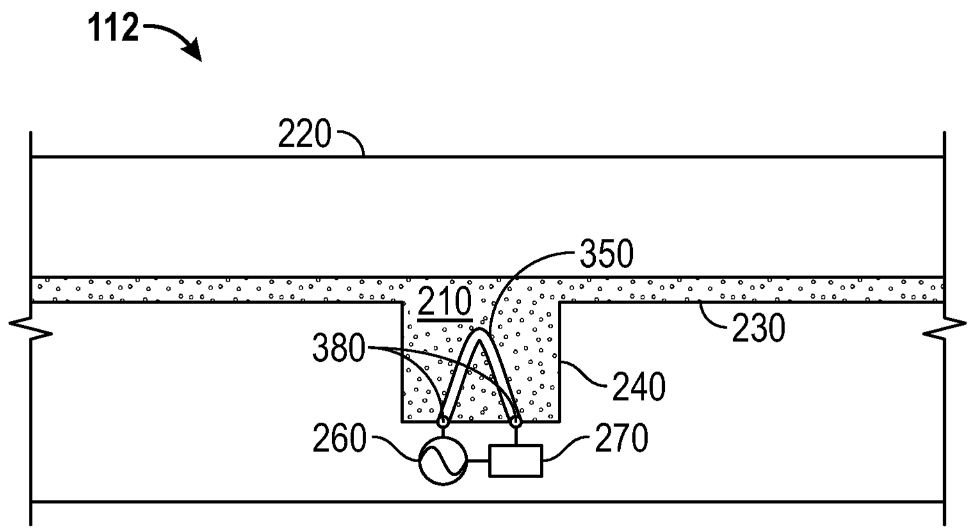
280
230
210
250
240

FIG. 2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230
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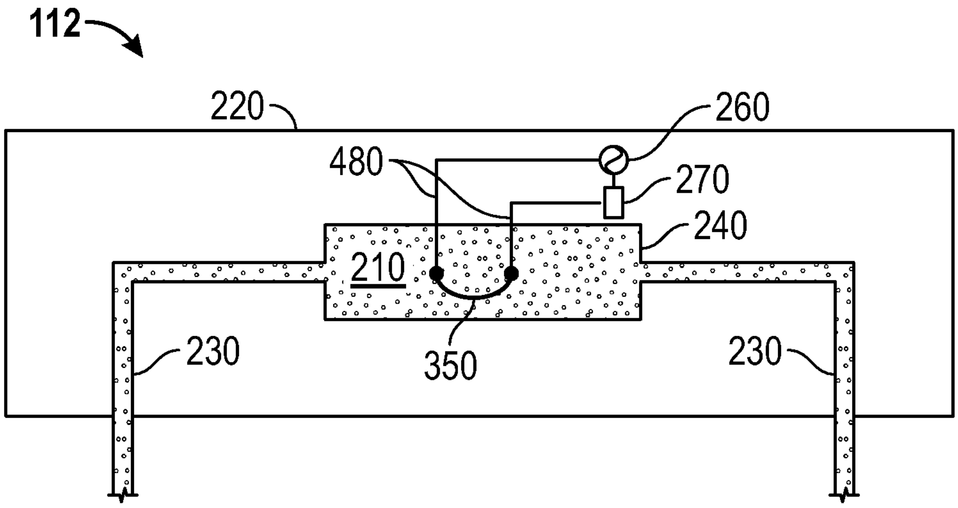
FIG. 3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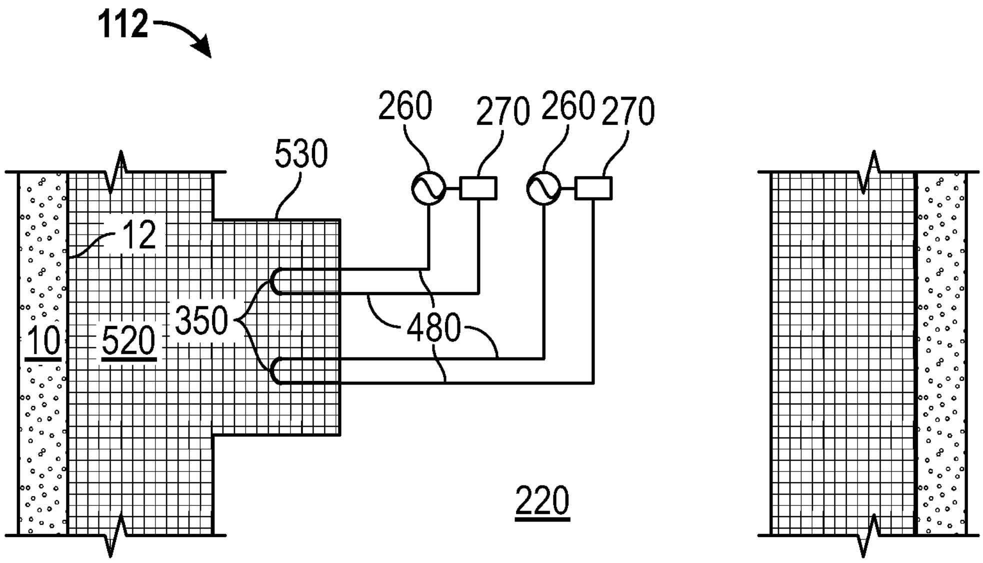
210
350
230
230

FIG. 4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270
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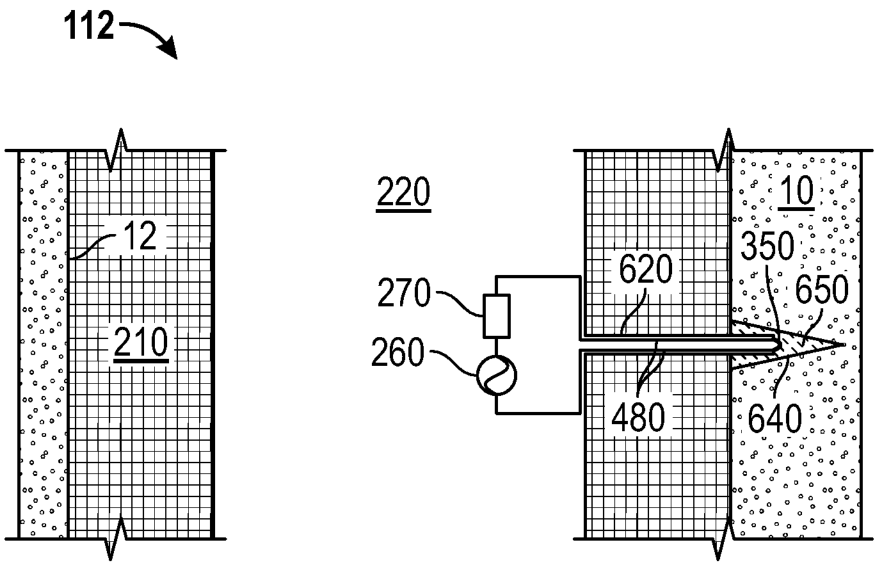
530
12
350
10
520
480
220

FIG. 5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620
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350
650
640

FIG. 6

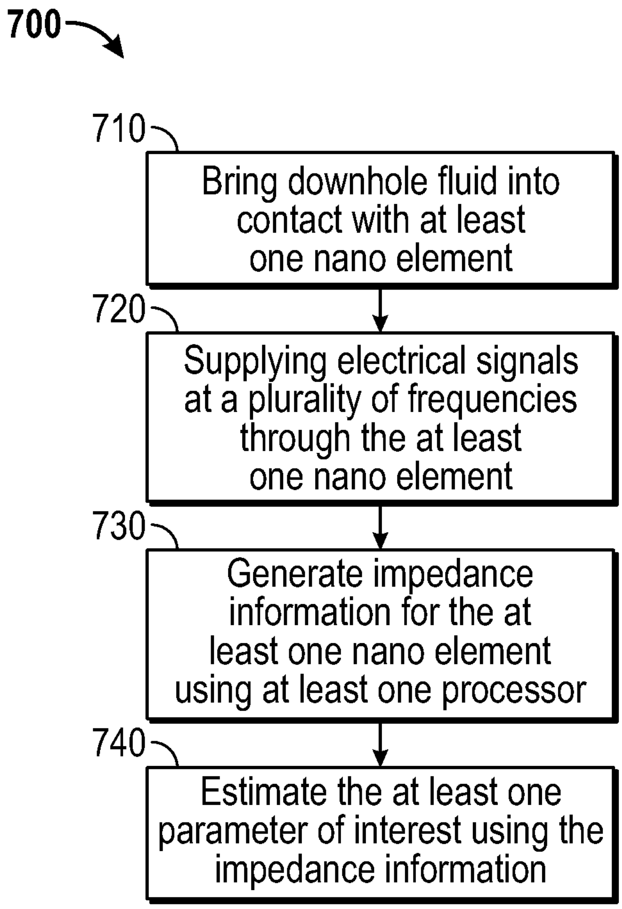
700
710
Bring downhole fluid into contact with at least one nano element
720
Supplying electrical signals at a plurality of frequencies through the at least one nano element
730
Generate impedance information for the at least one nano element using at least one processor
740
Estimate the at least one parameter of interest using the impedance information

FIG. 7

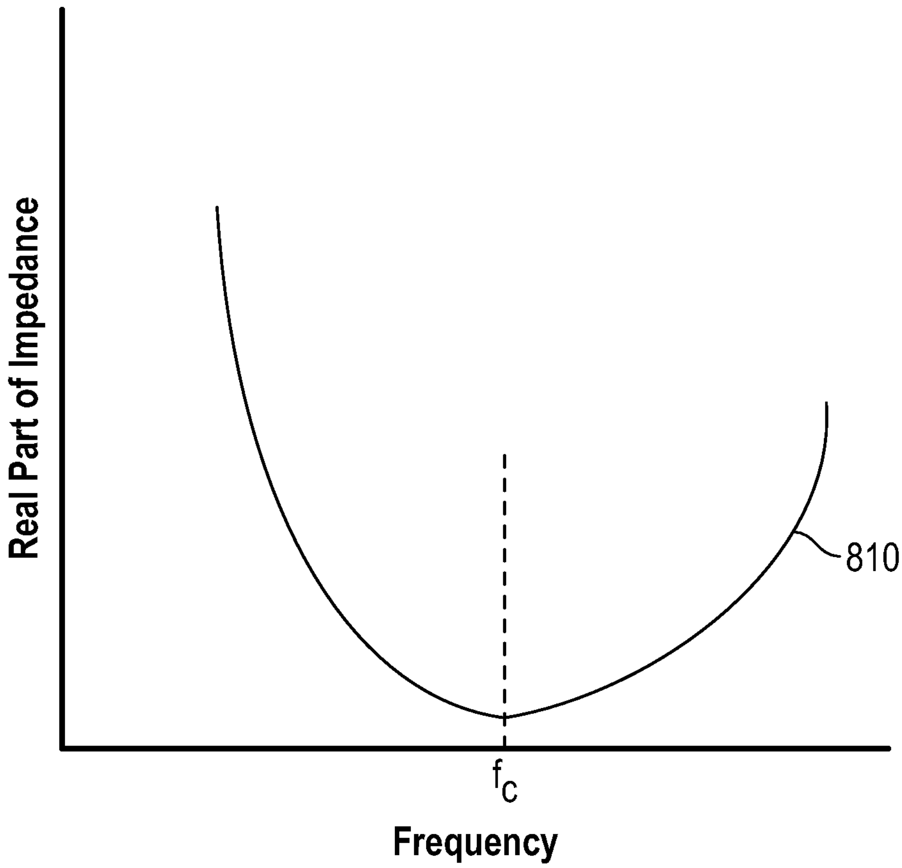

FIG. 8