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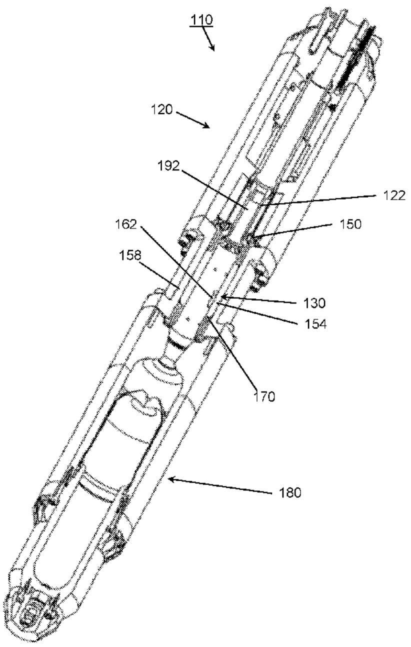


FIG. 8

(57) **Abstract:** An apparatus for generating acoustic waves within a medium to stimulate oil recovery within an oil reservoir, the apparatus being operable with a single moving part - a central rotor, and where the rotor further includes a "conduit" through which the supply fluid passes.

[Continued on next page]

**Declarations under Rule 4.17:**

— *as to the identity of the inventor (Rule 4.17(i))*
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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# OIL RECOVERY TOOL AND SYSTEM

**[0001]** This application claims priority under 35 U.S.C. §119(e) to the following provisional patent applications by Applicant Hydroacoustics, Inc.: U.S. Provisional Application No. 62/627,310 for an OIL RECOVERY TOOL by R. Valtierra et al., filed February 7, 2018; and U.S. Provisional Application No. 62/659,825 for an OIL RECOVERY TOOL by R. Valtierra, filed April 19, 2018; and also claims priority under 35 U.S.C. §120 from co-pending U.S. Patent Application No. 16/263,136 for a FLUID SENSOR AND PUMPJACK CONTROL SYSTEM by R. Valtierra et al., filed January 31, 2019, all of the above being hereby incorporated by reference in their entirety.

## TECHNICAL FIELD

**[0002]** The disclosed systems and methods are directed to generating acoustic waves. A downhole oil recovery tool provides a seismic source to enhance oil recovery. The systems and methods disclosed herein enhance oil recovery by means of vibratory stimulation, for example, to diminish capillary forces and encourage the rate of migration and coalescence of retained oil within the porous media of an oil reservoir.

## BACKGROUND AND SUMMARY

**[0003]** After an oil well has been in operation for a time, its productivity often diminishes to a point at which the operation of the well is marginal or economically unfeasible. It is frequently the case, however, that substantial quantities of crude oil remain in the ground in the regions of these unproductive wells but cannot be liberated by conventional techniques. Often methods for efficiently increasing the productivity of a well are considered, provided they can be performed economically. Often a borehole can serve as an injection or monitor well and may allow for the insertion of a down hole seismic pressure wave generator.

**[0004]** Many methods have been discovered for improving the oil recovery efficiency, including those disclosed in US Patent 8,113,278 to DeLaCroix et al., for a SYSTEM AND METHOD FOR ENHANCED OIL RECOVERY USING AN IN-SITU SEISMIC ENERGY GENERATOR (Feb. 14, 2012), which is hereby incorporated by reference in its entirety. Nonetheless, large volumes of hydrocarbons remain in oil rich formations after secondary, or even tertiary recovery methods have been employed. It is believed that a major factor causing the retention of the hydrocarbons in such formations is an inability to direct sufficient pressure forces on the hydrocarbon droplets residing in the pore spaces of the formations. Conventional oil recovery is typically accomplished in a two tier process, the primary or initial method is reliant on the natural flow or pumping of the oil within the well bore until depletion. Once the free flowing oil has been removed a secondary method is required. Generally an immiscible fluid such as water is forced into an injection borehole to flush the oil contained within the strata into a production well. In the past it has not been cost effective to employ tertiary or enhanced oil recovery (also referred to as EOR) methods, even though up to seventy percent of the total volume of oil may still remain in an abandoned oil well after conventional oil recovery techniques are used.

**[0005]** Another technique that has been employed to increase the recovery of oil employs the introduction of low frequency vibration energy. Low frequency vibration from surface or downhole sources has been used to influence liquid hydrocarbon recoveries from subterranean reservoirs. This type of vibration, at source-frequencies generally less than 1 KHz, has been referred to in the literature as sonic, acoustic, seismic, p-wave, or elastic-wave well stimulation. For example, stimulation by low frequency vibration has been effectively utilized to improve oil production from water flooded reservoirs. Examples from the literature also suggest that low frequency stimulation can accelerate or improve ultimate oil recovery. Explanations for why low frequency stimulation makes a difference vary, however, it is believed that the introduction of vibrational energy causes the coalescence of oil droplets and re-establishment of a continuous oil phase due to the dislodging of oil droplets from the formation so they can re-combine and coalesce. Additionally it is believed that the sound waves reduce capillary forces by altering surface and interfacial tensions, and thereby free the droplets and/or enable them to coalesce. For example, U.S. Pat. No. 5,184,678 to Pechkov et al. issued Feb. 9, 1993 discloses a method and apparatus for stimulating fluid production in a producing well utilizing an acoustic energy transducer disposed in the well bore within a producing zone. However, Pechkov only teaches that ultrasonic irradiating removes fines and decreases the well fluid viscosity in the vicinity of the perforations by agitation, thereby increasing fluid production from an active well.

**[0006]** Ultrasonic waves can improve and/or accelerate oil production from porous media. The problem with ultrasonic waves is that in general, the depth of penetration or the distance that ultrasonic waves can move into a reservoir from a source is limited to no more than a few feet, whereas low frequency or acoustic waves can generally travel hundreds to thousands of feet through porous rock. While sonic stimulation methods and apparatus to improve liquid hydrocarbon flow have achieved some success in stimulating or enhancing the production of liquid hydrocarbons from subterranean formations, the acoustic energy transducers used to date have generally lacked sufficient acoustic power to provide a significant pulsed wave. Thus, there remains a continuing need for improved methods and apparatus that utilize sonic energy to stimulate or enhance the production of liquid hydrocarbons from subterranean formations. Acoustic energy is emitted from the acoustic energy transducer in the form of pressure waves that pass through the liquid hydrocarbons in the formation so that the mobility of the liquid hydrocarbon is improved and flows more freely to the well bore. By way of definition an elastic-wave is a specific type of wave that propagates within elastic or visco-elastic materials. The elasticity of the material facilitates propagation of the wave, and when such waves occur within the earth they are generally referred to as seismic waves.

**[0007]** The value of a barrel of oil and the demand for oil has created a greater interest in tertiary enhanced oil recovery methods to further oil availability through the revitalization of older wells, even including those that have been abandoned due to a high ratio of water compared to the volume of total oil produced, or commonly called the water cut.

The primary intent of enhanced oil recovery is to provide a means to initiate the flow of previously entrapped oil by effectively increasing the relative permeability of the oil embedded formation and reducing the viscosity and surface tension of the oil. Numerous enhanced oil recovery technologies are currently practiced in the field including thermodynamics, chemistry and mechanics. Several of these methods have been found to be commercially viable with varying degrees of success and limitations. Heating the oil with steam has proven be an effective means to reduce the viscosity, provided there is ready access to steam energy, and accounts for over half of the oil currently recovered. The use of chemical surfactants and solvents, such as $CO_2$, to reduce the surface tension and viscosity, while effective, are not widely used due to cost, contamination and environmental concerns. However, seismic stimulation lacks any of the aforementioned limitations and continues to be explored as a viable enhanced oil recovery technique.

**[0008]** The low-frequency vibration of reservoir rock formations is thought to facilitate enhanced oil recovery by (i) diminishing capillary forces, (ii) reducing the adhesion between rocks and fluids, and (iii) causing coalescence of oil droplets and enable them to flow within the water flood. Studies at the Los Alamos National Laboratory conducted by Peter Roberts have indicated that this process can increase oil recovery over substantially large areas of a reservoir at a significant lower cost than other enhanced oil recovery stimulation methods.

**[0009]** The systems and methods disclosed herein provide a low-cost tertiary solution to facilitate the reclamation of oil that had previously been uneconomical to retrieve. It is, therefore, a general object of the disclosed embodiments to enable the use of downhole vibratory seismic sources capable of generating elastic-wave vibration stimulation within a previously abandoned oil field in order to extract the immobile oil. By employing an apparatus for generating acoustic waves, further oil recovery is stimulated within an oil deposit in fluid contact with a borehole into which the acoustic wave source can be placed.

**[0010]** In accordance with the disclosed embodiments, disclosed is an electro-hydraulic seismic pressure wave source configured as an oil recovery tool. The operation of the disclosed oil recovery tool is facilitated by reducing the mechanical complexity of the tool while at the same time improving its overall reliability. The improvements include integration of a frameless motor into the tool, where the motor is specifically designed to operate in a water saturated environment. The rotor of the motor is directly attached to drive a rotating valve that is responsible for creating the seismic wave. The valve is designed with at least one and likely multiple ports for releasing the seismic energy. In one embodiment the oil recovery tool may include smaller ports along its length to implement a tapered hydraulic bearing. With a tapered bearing the valve uses pressurized water as the “bearing” material to reduce friction and may thereby eliminate the need for custom fabricated mechanical bearings. With the coupled rotor and valve, and tapered bearing, the tool is essentially reduced to a single moving (rotating) part. Additionally, the rotor is designed with a hollow shaft that, when attached to the valve, provides a direct path for pressurized supply water entering the tool to flow to the valve. This allows for greater fluid flow and reduction in possible cavitation (bubbles forming in the water). Additional water passages in and around the motor stator provide cooling to the motor during tool operation. Additionally, integration of the frameless, water-saturated motor; allows the tool to be reduced in diameter relative to prior down-hole tools, thereby allowing it to be employed in a larger range of well bore diameters starting at about 4 inches.

**[0011]** Disclosed in embodiments herein is an oil recovery tool for imparting seismic wave energy within an oil reservoir, in the form of a wave, so as to alter the capillary forces of residual oil comprising: a housing; a source of pressurized fluid; and a frameless, brushless motor, operatively located within said housing to receive the pressurized fluid and generate the seismic waves.

**[0012]** Further disclosed in embodiments herein is an apparatus for generating acoustic waves within a medium to stimulate oil recovery within an oil reservoir, comprising: an elongated and generally cylindrical housing suitable for passing through a borehole; an accumulator; a source of pressurized fluid; an energy transfer section, wherein the energy transfer section may be inclusive of the pressure transfer valve, and further including, a frameless motor; a hollow-shaft rotor having an output port; and a stator having a corresponding output port whereby fluid energy is transferred upon alignment of said rotor and stator ports, wherein the frameless motor is operatively connected to the hollow-shaft rotor and where fluid passes therethrough to the accumulator; and a pressure transfer valve, wherein the pressurized fluid is stored within said accumulator and subsequently transferred, thereby releasing seismic wave energy via the ports into the fluid surrounding the apparatus.

**[0013]** Also disclosed herein is a method for generating seismic pressure wave energy within an oil saturated strata, comprising: placing an acoustic wave generator in contact with a fluid within the strata; accumulating fluid pressure energy within the acoustic wave generator; and periodically releasing and transferring pressure energy with said generator to create wave energy that is transferred by the fluid into a porous medium of the strata, wherein releasing and transferring energy is accomplished by a frameless motor driving a rotary valve generator, said valve generator employing a hollow shaft for fluid passage, whereby the relative relationship of output ports on both a rotor and a stator within the fluid generator controls the release and transfer of a systematic pressure pulse to create the seismic pressure wave energy.

**[0014]** Further disclosed herein is an oil recovery system for enhancing the recovery of oil within a reservoir, including: a source of pressurized fluid; a submersible oil recovery tool for imparting seismic wave energy within the oil reservoir, in the form of a wave, so as to alter the capillary forces of residual oil therein, comprising, a housing; and a frameless, brushless motor, operatively located within said housing to receive the pressurized fluid and generate the seismic waves; and a control system suitable for monitoring and controlling the system components including at least the oil recovery tool and the source of pressurized fluid in order to produce seismic waves within the reservoir.

**[0015]** Also disclosed herein is a system for generating acoustic waves within a medium to stimulate oil recovery within an oil reservoir, comprising: a source of pressurized fluid, wherein said source of pressurized fluid includes a replenishable fluid reservoir and a pressurization system for pressurizing the fluid from said reservoir and passing the pressurized fluid through a conduit, the conduit terminating at an opposite end at an oil recovery tool, said oil recovery tool including; an elongated and generally cylindrical housing suitable for passing through a borehole; an accumulator; an energy transfer section including, a frameless motor, a hollow-shaft rotor having an output port, and a stator having a corresponding output port whereby fluid energy is transferred upon alignment of said rotor and stator ports, wherein the frameless motor is operatively connected to the hollow-shaft rotor and where fluid passes therethrough to the accumulator; a pressure transfer valve, wherein the pressurized fluid is stored within said accumulator and subsequently transferred, thereby releasing seismic wave energy via the ports into the fluid surrounding the apparatus; and a control system suitable for monitoring and controlling at least the oil recovery tool and the source of pressurized fluid in order to produce seismic waves within the reservoir.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0016]** FIGS. 1 – 3 are front, side and top illustrations of an embodiment of the oil recovery tool;

FIGS. 4 and 5 are, respectively, cross-sectional views of FIGS. 1 and 2 along lines A-A and B-B;

FIGS. 6 and 7 are, respectively, cross-sectional top views of FIGS. 4 and 5 along lines C-C and D-D;

FIG. 8 is a partial cut-away illustration of an embodiment of the oil recovery tool;

FIGS. 9 and 10 are enlarged cross-sectional illustrations of alternative embodiments for the motor assembly and port portions of the oil recovery tool;

FIGS. 11 – 13 are illustrations of various components for an exemplary drive motor for the oil recovery tool of FIG. 1, with FIG. 12 depicting a cross-section along lines A-A of FIG. 11;

FIGS. 14 – 17 are illustrations of various embodiments and applications for a venturi-based sensor in accordance with the disclosed system and method;

FIGS. 18 - 19 are, respectively, illustrative examples of a method of installing a venturi sensor, and monitoring and control circuitry for incorporating the sensor into a pumpjack well system;

FIGS. 20 – 24 are illustrative graphs of exemplary pressure and capacitance data generated by the disclosed sensor and control system; and

FIGS. 25 – 27 provide schematic illustrations of an exemplary oil recovery system and method employing venturi sensors and an oil recovery tool in accordance with an embodiment of the disclosed oil recovery system.

**[0017]** The various embodiments described herein are not intended to limit the disclosure to those embodiments described. On the contrary, the intent is to cover all alternatives, modifications, and equivalents as may be included within the spirit and scope of the various embodiments and equivalents set forth. For a general understanding, reference is made to the drawings. In the drawings, like references have been used throughout to designate identical or similar elements. It is also noted that the drawings may not have been drawn to scale and that certain regions may have been purposely drawn disproportionately so that the features and aspects could be properly depicted.

## BEST MODE FOR CARRYING OUT THE INVENTION

**[0018]** Early oil recovery tool (ORT) embodiments employed pressurized fluid released in pulses as described herein. Such tools required complex mechanical components and internal fluid pathways, bearings with seals to provide fluid to the tool and to produce suitable seismic energy or waves. Earlier tools also required a separate pump(s) in order to gather and pressurize fluid.

**[0019]** *Oil Recovery Tool*

**[0020]** The oil recovery tool embodiments **110** described herein may be employed for imparting seismic wave energy (e.g., in the form of a wave) within an oil reservoir, so as to alter the capillary forces of residual oil. The tool comprises: a housing **112**; a source of pressurized fluid **114** and electrical power. And, as described relative to FIGS. 1 – 13, the housing integrates a frameless, brushless motor, operatively located within the housing to receive the pressurized fluid and turn a rotor relative to a stator and align respective ports therein to generate the seismic waves.

**[0021]** In accordance with the improved embodiments depicted in FIGS. 1 – 13, an electro-hydraulic seismic pressure wave source is illustrated, configured as an oil recovery tool **110**. The operation of the disclosed oil recovery tool **110** is facilitated by reducing the mechanical complexity of the tool while at the same time improving its overall reliability. The improvements include integration of a frameless motor assembly **120** into the tool, where the motor is specifically designed to operate in a water-saturated environment. The rotor **122** of the motor is directly attached to drive the rotor of a rotating valve assembly **130** that is responsible for creating the seismic wave. The valve assembly is designed with multiple ports **134** (**166**) for releasing the seismic energy, and with the addition of smaller ports **136** along its length to implement a tapered hydraulic bearing. The ports have a cross-sectional slot shape, but may also have shapes such as circles, squared notches, etc. in order to alter the profile and characteristics of the generated seismic wave.

**[0022]** The valve assembly rotor **122** may be supported for rotation relative to the surrounding stator using any of a number of possible bearing techniques, including frictionless materials such as Teflon® to support surfaces of the rotor. Also contemplated are customized rolling bearings employing conventional inner and outer rings supported by balls or rollers and including seals to reduce friction due to bearing contamination. In another embodiment a tapered bearing valve uses pressurized water (from source **114**, flowing through the motor assembly **120** and the rotor **154**) as the "bearing" material to reduce friction and thereby eliminate the need for custom fabricated mechanical bearings and associated seals. With the coupled rotor and valve assembly, and tapered bearing, the tool is essentially reduced to a single moving (rotating) part – the rotor **154** of the valve assembly, driven by the attached rotor **122** of frameless motor **120**. Additionally, both rotors are designed with a hollow shaft or core **126** that, when attached to the valve assembly, provides a direct path for pressurized supply water entering the tool **110** to flow through the motor to the valve assembly and the accumulator **180**. This allows for greater fluid flow and reduction in possible cavitation (bubbles forming in the water). Additional water passages in and around the motor stator (e.g., passages **116** in FIGS. 9 - 10) provide cooling to the motor during tool operation. Additionally, integration of the frameless, water-saturated motor; allows the tool outer housing **112** to be reduced in diameter relative to prior tool designs, thereby allowing the current embodiment to be employed in a range of smaller well diameters, with bore diameters starting as small as about 4.0 inches.

**[0023]** Turning to FIGS. 1, 4-5 and 8 – 10 specifically, depicted therein are cross sectional and cut-away illustrations of the oil recovery tool (ORT) **110** embodiments and the assembled mechanical components. Specific components are labeled and include, for example, motor assembly **120**, upper bearing surface **150**, rotor **154**, stator **158**, rotor port or orifice **162**, stator port or orifice **166**, lower bearing surface **170**, and pressure accumulator **180**. From FIGS. 1 – 10 one can see how the motor assembly and rotating valve are operatively coupled together into a single rotating part and how they are compactly integrated into tool **110**.

**[0024]** Considering FIGS. 9 and 10, depicted are enlarged views of the motor assembly **120** in two alternative embodiments of the tool **110**. The motor stator **156** and rotor **122** are shown and the rotor rotates within the stator. The interface **128** to valve **130** is depicted along with a custom threaded screw **190**, which attaches the motor rotor to the valve. As more fully illustrated in FIGS 11 – 13, the rotor includes a core surrounded by permanent magnets **127**. The rotor rotates inside of the stator. In one embodiment the stator includes the motor windings, which receive power to control operation of the motor from the surface via wires passing through the bulkhead. In the illustrated embodiment of FIGS. 1 - 8, in order to increase the downhole range (depth) of the tool **110**, a motor controller **194** may also be incorporated within the tool housing such that the electrical connections to the surface need only include power and control signals. The motor controller **194** is part of a small printed circuit board or similar electronics assembly that is suitable to installation within housing **112**, and the motor assembly **120** is connected to and powered-by the controller via wires **196**.

**[0025]** Referring to FIG. 10, the alternative design of the motor assembly section **120** of the tool **110** is illustrated. In the alternative design, certain components are modified or added, some in order to adapt tool **110** to higher pressures with an extended downhole depth. The modifications further serve to prevent water ingress into the controller chamber and eliminate erosion of the potting material caused by pressurized liquid. Some of the changes include a stator **158** that is no longer potted in place. Also, O-rings **152** are larger (e.g., longer and/or thicker) to accommodate higher operating pressures of up to 4000 psi, and to provide increased isolation of the motor stator from the casing and surrounding components. The motor assembly **120** may include a longer or extended titanium sleeve **144** needed to accommodate the additional isolation O-rings **152** located at the top and bottom of the motor stator chamber. The stator **156** of motor assembly **120** is also biased in an upward position by a spacer **146** pressed against the lower end of the stator by a wave spring **148** resting on shoulder **150**. The ring-shaped spacer **146** further protects the motor potting material from damage by wave spring **148**, by distributing the spring load and thereby reducing vibration and pulsing being transmitted directly from the spring to the potting material.

**[0026]** Calling attention to the screw **190**, the hollow aspect of the screw can be seen to illustrate a passage **192** for water to be fed to the valve directly through the motor. Depicted in red is a custom bulkhead connector **198** used to route electrical wiring from the motor out of the tool **110**.

**[0027]** Turning next to FIGS. 11 – 12, depicted therein are details of the frameless motor assembly **120**. There are inner (e.g., titanium) and outer (e.g., stainless steel) metal “shells” **144**, **222** and **224** respectively, placed adjacent the stator **158** along with potting resin **230** to protect the motor against environmental wear, corrosion and stress resulting from high pressure water, water flow induced wear, etc. As previously noted relative to the embodiment of FIG. 10, the motor stator **158** may be isolated from the environment by the O-ring seals **152**.

**[0028]** In summary, the oil recovery tool **110** is an apparatus for generating acoustic / seismic waves within a medium to stimulate oil recovery within an oil reservoir. The oil recovery tool embodiments **110** described include: an elongated and generally cylindrical housing **112** suitable for passing through a borehole (not shown). The housing may be made from one or a combination of materials including stainless steel (304, 409 or 2507) or plated steel (e.g., electroless nickel, nickel-boron or SeaTEC 100). The tool includes an accumulator **180** for accumulating a reservoir of pressurized fluid, for example, from a surface source. In one embodiment the accumulator **180** includes commercial off the shelf components, such as a rubber bladder that decouples the pulsations from the pressure supply source. While various techniques may be employed to provide an accumulator to collect pressurized fluid for release through the ports, in one embodiment of the tool, the pressure is released multiple times (e.g., twice) during each complete rotation (360º) of the rotor **122**; where the ports are generally closed but opened for about 5º - 15º of each half-rotation. The effective area of the port or opening (e.g., axial length x rotational length), in conjunction with the accumulator size and fluid pressure, govern the pressure drop, and associated acoustic energy release over each discharge cycle. It is also possible that a wider or a longer slot **162, 166** (greater area), all other aspects being constant, will reduce the average pressure in the accumulator. In addition to the port size, the port shapes may be customized to change the harmonic content and the nature of the acoustic pulse created by the tool.

**[0029]** The tool also includes an energy transfer section inclusive of the pressure transfer valve and includes the frameless motor **120**, a hollow-shaft rotor **154** having an output port, and a stator **158** having a corresponding output port whereby accumulated fluid energy is transferred through the output ports upon alignment of the rotor and stator ports, and where the frameless motor is operatively connected to the hollow-shaft rotor (and fluid passes therethrough to the accumulator). A pressure transfer valve is employed, wherein the pressurized fluid is stored within the accumulator and subsequently transferred, thereby releasing seismic wave energy to the surrounding borehole fluid/strata via the ports.

**[0030]** As will be appreciated, a method for generating a pressure wave within an oil saturated strata using the oil recovery tool **110** may comprise: placing the tool in contact with a fluid within the strata; accumulating fluid pressure energy (e.g., an acoustic wave) within the tool; and periodically releasing and transferring pressure energy with the tool to create wave energy via releasing the fluid into a porous medium of the strata, where releasing and transferring energy is accomplished by the frameless motor driving a rotary valve generator – the tool employing a hollow shaft for fluid passage, whereby the relative relationship of output ports on both a rotor and a stator within the housing controls the release and transfer of a systematic pressure pulse or wave.

**[0031]** *Output Monitoring*

**[0032]** Having described the oil removal tool, attention is turned to a fluid sensing system suitable for sensing the fluid being removed from a well. Referring to FIGS. 14 - 17, depicted therein are various views of a fluid sensor **610**. In the illustrated example, fluid sensor **610** includes a 2-dimensional venturi **620**, where the venturi causes pressurized fluid(s) pumped therethrough to take the form of a controlled thickness of non-stratified fluid as the fluid flows. The 2-dimensional venturi **620** reduces or eliminates stratification of the fluid flowing therethrough as a result of the combination of the 2-dimensional venturi region and the "necking" down of the incoming cylindrical fluid passage **622** into a thin, planar region **624**. Venturi **620** also includes a first fluid pressure sensor **630** located on inlet **632** to the venturi to measure a pressure for the pumped input fluid. A second fluid pressure sensor **640** is located on the outlet side **642** of the venturi **620** to measure a pressure of the output fluid. It will be noted that one or both sensors **630** and **640** may also be suitable for sensing the temperature of the fluid passing thereby in order to provide fluid temperature data as well as pressure data.

**[0033]** In one embodiment, venturi **620** may be 3D printed from stereolithography-compatible resin or similar non-magnetic material. It is also contemplated that the venturi may be injection-molded or machined using other well-known techniques. For durability, the venturi or other sensor components may be incorporated into a metal pipe (e.g., FIG. 14) and potted using a durable epoxy resin. The pressure sensors **630** and **640** are sensors that may be obtained from TE Connectivity company, for example Part No. MS5803-05BA. While a fluid sensor **610** made with polymeric components such as polyvinyl chloride (PVC), etc.) may be suitable for relatively limited (low) pressures in ranges of up to 50 psi or even 70 psi, it will be appreciated that the fluid sensor may also be designed for use in higher-pressure applications exceeding 70 psi. For example, with alternative materials and seals (e.g., thicker-walled steel or stainless steel components, high-pressure gaskets and seals, etc.), the disclosed sensor may be employed on pressurized wells and the like. In such an embodiment, use of a differential pressure probe(s) is contemplated to handle the increased range of pressures that the venturi sensor may experience.

**[0034]** Another aspect of the 2-dimensional venturi **620** is that it provides large planar regions **624** on either side thereof to which a capacitive sensor **660** is attached adjacent the venturi. More specifically, the capacitive sensor includes a pair of parallel conductive metal plates **664** (e.g., made of copper, brass, etc., and of approximately 5 sq. in. and 0.01 in. thickness) located on each side of the 2-dimensional venturi. In one embodiment copper plates are employed as it is easy to cut them to the appropriate size, and a conventional solder may be employed to attach electrical wire leads to the sensor plates **664**. A capacitance measured between the plates is output as a dielectric strength of the fluid flowing through the venturi, where the capacitance allows for the characterization of the fluid – and in particular the ability to distinguish between the presence of water versus oil flowing through the sensor by the relative difference in dielectric strength.

**[0035]** Using the pressure differential measures as a difference between the outputs of the first pressure sensor **630** and the second pressure sensor **640**, it is possible to determine a fluid flow rate as a result of both the size of the 2-dimensional venturi and/or calibration of the venturi itself. Accordingly, the fluid sensor **610** allows the device to determine a fluid flow rate as a function of the input fluid pressure from sensor **630** and output fluid pressure from sensor **640**.

**[0036]** In one embodiment, such as that depicted in FIGS. 14 and 17, the sensor **610** is contained within a housing **670**, which is outfitted with standard threaded nipples **672** or similar couplings **674** on either end thereof in order to provide the sensor as a complete unit suitable for being plumbed or retrofitted in-line into a pumpjack well piping system such as depicted in FIG. 18. Moreover, as a result of the depicted design, the venturi **620** and sensor **610** are completely self-draining after the pumpjack is shut down, thereby avoiding fluid (e.g., water) collection and potential damage to the sensor due to freezing conditions, etc. As previously suggested, the use of a 2-dimensional venturi design, in combination with the necking-down of the cylindrical pipe cross-section to a linear slit at the entrance to the venturi (see e.g., end view of planar region **624** in FIG. 16), avoids fluid stratification. Another characteristic of the disclosed sensor embodiment is the maximization of the capacitive plate surface area while maintaining a compact sensor assembly.

**[0037]** Having described the details of the fluid sensor **610**, attention is also turned to FIGS. 18 - 19, which are provided to illustrate an embodiment of a pumpjack monitoring and control system, as well as the data collected from the system and processed. More specifically, a pumpjack monitoring and control system **610**, such as depicted in FIGS. 18 - 19 may consist of or include an in-line fluid sensor **610** in a housing **670**, where the sensor is operatively coupled or plumbed, for example via couplings 674, to receive the fluid output of a pumpjack **720** connected to a wellhead. In the depicted configuration, sensor **610** is used to generate and output pressure and capacitance signals in response to the fluid output, the output signals being transmitted via a wire or cable **726** to control and logging circuitry within the venturi electrical controller **740**. The fluid sensor, as described above, includes a first fluid pressure sensor at the inlet to the venturi, a second fluid pressure sensor at an outlet of the venturi, and a capacitive sensor along the 2-dimensional venturi, where the capacitive sensor includes a pair of parallel conductive metal plates on each side of the 2-dimensional venturi.

**[0038]** The system **710** also consists of or comprises a controller **740**, operating a micro-processor or similar microcontroller **754** in accordance with a set of pre-programmed instructions. The controller **740** includes a printed circuit board **750**, with an I/O port that receives output from the fluid sensor **710** via the cable **726** connected at port **728**, and processes the output signals. In addition to data retrieval the connections to other devices may enable the exchange of information other than sensor data, including programmatic upgrades and the like. In one operating mode, the controller **740** (e.g., a single board computer available from Texas Instruments company) may operate simply as a data collection device, receiving and storing the sensor output signals in memory (not shown), including converting the signals from an analog output into a digital value for storage. Also included is a pin-type plug or port (e.g., 4-pin) **764**, providing wired connectivity for to the pumpjack (e.g., power and motor control signals). Wireless connectivity is also provided via a localized Bluetooth or Wi-Fi connection between the controller and a portable computing device (not shown), and also contemplated is a mobile telephony or satellite link that may be integrated into controller **240** to facilitate remote data exchange. Furthermore, a digital display **260** may be provided with controller **240**, to provide status or operational information as well as real-time output of pressure or other data. Although not shown it will be appreciated that the system **210** further includes a power source, which may include one or more batteries for primary or backup power.

**[0039]** Referring briefly to FIGS 18 - 19, in one embodiment the venturi sensor may include an embedded digital controller with which it communicates with controller **740** via a digital UART signal (e.g., RS232). The venturi sensor system sends pre-digitized values for pressure, temperature, and capacitance to the controller. The electronics assembly is placed into an enclosure such as a pipe, and is then filled (potted) with epoxy. A center electronics board includes the microcontroller, which communicates with the pressure sensors **630, 640**, measures capacitance, stores and transmits a digital stream of sensor data to the pumpjack controller **740**. Two outer boards, **830, 840** may be used for mounting the pressure sensors. Alternatively, as illustrated in FIG. 15, the pressure sensors **630** and **640** are directly coupled to the electronics board **618** via a wired harness or bus. For example, employed in one embodiment is a digital bus **650** (ribbon cable) that the microcontroller uses to communicate with the pressure sensors. The embedded digital controller is primarily employed to convert the analog sensor signals to digital signals in order to mitigate noise that is usually associated with a transmitted analog signal (especially when measuring capacitance). Lastly, the ability to sense temperature of the fluid flowing through the sensor allows for a more accurate characterization of the fluid pressures.

**[0040]** In another embodiment, the controller, or another computer processor (not shown) to which the controller **740** is linked (wired (e.g., port **728**)or wirelessly), may use the output signals to monitor the pumpjack output and, based upon such signals, analyze and report the performance of the pumpjack as, for example, depicted in FIGS. 20 – 24. Moreover, the controller or other computer may process the output signals to totalize the amount of oil and/or water pumped from the wellhead over a period of time based upon the differential pressure data between the first and second pressure sensors. As noted above, the pumpjack monitoring and control system may include a wireless transceiver for communicating data with another computerized device.

**[0041]** The pumpjack monitoring and control system **710** may also process the data from the sensor **610** and modify the operation of the pumpjack to optimize extraction of oil from the wellhead. For example, the system may be employed to determine, based upon real-time output signals from sensor **610**, whether oil, water or gas are being pumped and passed through the sensor. And, based upon such a determination the pumpjack operation may be continued, stopped or otherwise adjusted accordingly. As an example, upon detecting the pumping of oil, the operation of the pumpjack is continued whereas upon the detection of water or gas the operation of the pumpjack may be stopped or modified. In one embodiment, the system determines or distinguishes the type of fluid in the sensor based upon the pressure and capacitance signals being generated by the sensor. For example, the system may employ one or more of the following rules:

a) oil = high stroke pressure in combination with low capacitance; b) water = high stroke pressure in combination with high capacitance; and/or

c) gas = low stroke pressure in combination with low/oscillating capacitance.

**[0042]** As illustrated in FIG. 20, for example, each stroke of the pumpjack creates a pressure “spike” in the differential pressure (**610**) between the input and output sensors (**630** and **640**, respectively). And, when the fluid transitions from oil to water, at approximately 80 seconds in the chart, the change in the pressure profile (slight decrease in peak pressure due to water) is concurrent with a similar increase in the measured capacitance (also consistent with water instead of oil being present in the 2D-venturi).

**[0043]** As illustrated in FIG. 21, the observed differential (or absolute) pressure initially increases (e.g., pressure buildup region **410**) above a nominal level when the pumpjack starts and begins to pump fluid through the sensor. And when the accumulated fluid in the well has been pumped off (e.g., well pumped-off region **420**), the pressure decreases back to near the nominal pressure level as shown in FIG. 22.

**[0044]** FIG. 23 is provided to illustrate how the controller records a time-series for the entire pumping cycle. Collection of the data allows for post processing to calculate the volume/water cut data, which can then be employed to facilitate greater accuracy of measurements. Any time fluid is pumped from a well it is expected that the fluid may be a combination of oil and water. Typically, “water cut” is the ratio or percentage of oil/water that was pumped. For example, for the well tested (see e.g., FIG. 23), upwards of 95-percent of the fluid being pumped may be water. Thus, the water cut would be characterized as 95-percent. The availability and analysis of data collected across entire pumping cycles facilitates the use of “learning”, including comparison against prior data and pattern detection within the data, to facilitate adjustment of control parameters based upon past performance data for the pumpjack/well. And, as suggested above and in FIG. 24, the data from the sensor might also be used to allow the system to detect the presence of gas or foam within the fluid pumped from the well and passed through the sensor. For example, region **430** of the graph shows a combination of low pressure plus low/oscillating capacitance that may indicate the presence of foaming or gas.

**[0045]** *Oil Recovery System*

**[0046]** Having described both an oil-recovery tool and an output monitoring system suitable for use in an oil field **1110**, attention is now turned to FIGS. 25 - 27. Depicted in FIG. 25 are a plurality of wells **1120**, each having associated therewith a pump or other mechanism for extracting and collecting liquids (including oil) from the well. At least one of the wells also has a ground-level monitoring system **1130** such as depicted in FIGS. 14 – 19 operatively associated with the well, whereby the monitoring system is capable of generating data indicative of the amount of oil being produced from the well **1120**. The ground-level monitoring system may also be capable of storing and/or transmitting data indicative of the oil volumes and related information to remote station **1150** via one or more communications channels (wired, wireless (e.g., satellite, microwave, WiFi, etc.)). The remote station **1150** includes both a computer system and data storage capability, wherein the computer system is capable of parsing and analyzing the collected data from one or more of the wells in field **1110** in order to assess performance of the field and particular wells over time and in response to various processes and treatments. One of such treatments may include the use of seismic or acoustic energy to stimulate the oil field in a manner suitable to increase the output of the wells and thereby improve the performance of the oil field in general.

**[0047]** Referring also to FIG 26, depicted therein is an oil recovery system **1210**, where an oil recovery tool **110** is employed within a borehole **1240** (e.g., at or below the fluid level), and is controlled by the system **1250** as depicted in FIG. 26. The oil recovery system **1210** for enhancing the recovery of oil within a reservoir, includes a source of pressurized fluid **1260**, a submersible oil recovery tool **110** for imparting seismic wave energy within the oil reservoir **1110**, in the form of a wave, so as to alter the capillary forces of residual oil therein, and a control system **1250** suitable for monitoring and controlling the system components including at least the oil recovery tool and the source of pressurized fluid in order to produce or generate seismic / acoustic wave energy within the reservoir. The oil recovery tool **110** includes a housing and a frameless, brushless motor, operatively located within the housing, as described in detail above, to receive the pressurized fluid and, in response to electrical power, generate the seismic / acoustic energy waves by release of pressurized fluid through aligned ports of the rotor and stator.

**[0048]** The source of pressurized fluid includes a replenishable fluid (e.g., water) reservoir **1264**, a pressurization system for pressurizing the fluid from the reservoir and passing the pressurized fluid through a conduit **1268** to the oil recovery tool **110**. The pressurization system includes a pump **1272** driven by motor **1270**, in combination with a filter **1274**, along with at least one sensor **1276** (e.g., fluid supply pressure (**P**) from pump, fluid flow rate (**F**) to oil recovery tool, pump motor current (**A**), fluid back pressure ($\mathbf{P_B}$) at filter, etc.)) generating a signal and sending said signal to said control system.

**[0049]** As illustrated in FIG. 26, control system **1250** further includes a programmable logic controller **1280**, a single-board computer **1282**, and at least one external communication transceiver (Tx/Rx **1284**) (e.g., WiFi, Bluetooth, Ethernet, satellite modem (Irridium). The programmable logic controller uses a multi-core microcontroller and provides low-level controls by interfacing with and providing control signals and/or power (e.g., control/contactor for motors) to both the pump motor **1270** and the frameless, brushless motor in the oil recovery tool **110**, and where the single-board computer is operatively connected to exchange commands and data with the programmable logic controller to effectuate various operations of the oil recovery system **1210** in order to consistently produce the seismic wave energy. In one embodiment the single-board computer **1282** employs a Linux-based operating system and stored programmatic instructions are employed for a plurality of functions. As will be appreciated, the oil recovery system, through the external communication transceiver, and in conjunction with the single-board computer, enables both autonomous and remote control of the oil recovery system. Such remote control may be effectuated via remote station **1150** as depicted in FIG. 25, whereby the operation, control and monitoring of system **1210** can be accomplished remotely, or at a centralized control console. Among other data, the oil recovery system permits the remote monitoring of operating parameters of the system (e.g., sensor data, control status, system faults, etc.) and facilitates the remote generation of commands to adjust certain parameters (e.g., the recovery tool motor speed (i.e., frequency). The ability to be able to adjust the operation of the oil recovery tool has the potential to avoid time and cost to conduct pre-studies of the oil field in order to pre-determine desirable operating characteristics. Indeed, the oil recovery tool can be deployed within a field and, with the previously-described monitoring equipment, the operations can be monitored and adjusted so as to optimize the performance and “tune” it for an oil field.

**[0050]** In order to provide for reliable performance, various components of the system may be optimized. For example conduit **1268,** used to provide the pressurized fluid to oil recovery tool **110** is capable of handling a fluid pressure of up to at least 1500 psi, although normal operating pressures are typically in the range of about 250 to about 350 psig.

Furthermore, in one embodiment, the conduit may be formed of a flexible (windable) material suitable for repeatedly being wound and unwound upon a reel to raise and lower the tool within the borehole, where the conduit further serves as an umbilical connection attached to and capable of lowering and raising the oil recovery tool relative to a borehole **1240** to adjust its depth. Alternatively, instead of being flexible, the conduit may be formed of a generally rigid material (e.g., stainless steel stringers with piping assembled end-to-end), where the stainless steel stringers with piping serve as an umbilical connection to, and capable of lowering and raising, the oil recovery tool relative to the borehole.

**[0051]** In summary, the system depicted in FIGS. 25 - 25 is capable of generating acoustic waves within a fluid medium to stimulate oil recovery within an oil reservoir. The system includes a source of pressurized fluid **1260**, wherein the source includes a replenishable fluid (e.g., water) reservoir **1264** and a pressurization system (motor **1270**, pump **1272**, filter **1274**, and sensors **1276**) for pressurizing the fluid from the reservoir and passing the pressurized fluid through the conduit, the conduit **1268** terminating at an opposite end at the oil recovery tool **110**. And, as described above, the oil recovery tool is generally retained with an elongated and generally cylindrical housing suitable for passing through a borehole. The tool itself includes an accumulator; an energy transfer section *(may be inclusive of the pressure transfer valve),* a frameless motor, a hollow-shaft rotor having an output port, and a stator having a corresponding output port whereby fluid energy is transferred upon alignment of the rotor and stator ports, and where the frameless motor is operatively connected to the hollow-shaft rotor so that fluid passes therethrough to the accumulator. The frameless motor is powered from the surface via the programmable logic controller via current-carrying wires associated with a conduit.

**[0052]** As described the oil recovery tool, and the frameless motor therein, operate as a pressure transfer valve, wherein the pressurized fluid is stored within the accumulator and subsequently transferred through the ports into the surrounding fluid, thereby releasing seismic wave energy into the fluid surrounding the tool. The control system **1250** is suitable for monitoring and controlling at least the oil recovery tool and the source of pressurized fluid in order to produce the seismic waves within the reservoir. The oil recovery system **1210** produces a seismic wave at a frequency between about 10 – 100 Hz, and more preferably between 20 – 40 Hz.

**[0053]** As will be appreciated, the programmable logic controller **1280** and the single-board computer **1282** each include respective programmatic instructions for their operation, and the single-board computer includes programmatic instructions suitable for interfacing with and controlling certain operations of the programmable logic controller. As previously described relative to FIG. 27, the system may also include remote computer or computing station **1150**, the remote computer including a storage medium suitable to storing programmatic instructions where the instructions facilitate a remote connection to the single-board computer **1282** via a communications channel selected from the group consisting of WiFi, Bluetooth®, Ethernet, and satellite modem. Using the remote computer, it is possible to both monitor the production of wells using a ground-level monitoring system **1130**, as well as control and adjust the seismic output of the oil recovery tool **110**, in order to optimize the output of oil field **1110**.

**[0054]** The various components described relative to system **1210**, depicted in FIGS. 25 – 27, need to reliably operate even though subject to power fluctuations and outages. To assure that the system **1210** is capable or returning to operation after a shutdown, one of the programmable logic controller and/or the single-board computer include non-volatile memory (NVM) suitable for storing data generated by the system. In one embodiment, the stored data includes an indication of whether the system is performing a restart after one of at least two events (e.g., a planned power-down or a blackout power-down).

**[0055]** With respect to FIG. 27, at the top of the figure a ground-level monitoring system **1130** is shown producing output from a sensor such as a venturi-type sensor, where the data may be processed (e.g., classified) by processor **1252** so as to characterize an amount or rate of oil produced from the associated well. The oil production data is then passed or further processed (e.g., remote station **1150**) where the oil production data is compared and contrasted, and an algorithm or other artificial intelligence operations may be employed to determine whether adjustments should be made on the operating parameters of oil recovery system **1210**, whereby the remote station may relay new parameter settings (e.g., frequency, pressure, depth) back to the recovery system in order to optimize performance of the oilfield. It will be further appreciated that the remote station may process input from a plurality of well monitoring systems, and that the oil production data from such monitoring systems may be concurrently used to optimize production of a series of wells in a field, even though one or more wells may not themselves be optimized. In summary, a classifier (e.g., processor **1252**) analyzes the raw data output from the venturi sensors in monitoring system **1130** to automatically detect the oil/water transition and totalize the oil production from the sensor data. The oil production data is then fed to the remote station where an advanced algorithm and/or artificial intelligence system gathers the production data and adjusts the output of the oil recovery system and tool automatically to optimize oil field performance autonomously.

**[0056]** As another alternative, some or all of the components depicted in FIG. 25, including a motorized reel **1300** for raising and lowering the flexible conduit, may be trailer-mounted in order to make the system **1210** more portable. And, in implementing a trailerable embodiment, it may also be possible to include alternative, uniform and/or backup power systems so that down-time due to interruptions in power to the system location can be reduced or eliminated.

**[0057]** It should be understood that various changes and modifications to the embodiments described herein will be apparent to those skilled in the art. Such changes and modifications can be made without departing from the spirit and scope of the present disclosure and without diminishing its intended advantages. It is therefore anticipated that all such changes and modifications be covered by the instant application.

**CLAIMS:**

1. An oil recovery system for enhancing the recovery of oil within a reservoir, including:

a source of pressurized fluid;

a submersible oil recovery tool for imparting seismic wave energy within the oil reservoir, in the form of a wave, so as to alter the capillary forces of residual oil therein,comprising,

a housing; and

a frameless, brushless motor, operatively located within said housing to receive the pressurized fluid and generate the seismic waves; and

a control system suitable for monitoring and controlling the system components including at least the oil recovery tool and the source of pressurized fluid in order to produce seismic waves within the reservoir.

2. The oil recovery system according to claim 1, wherein said source of pressurized fluid includes:

a replenishable fluid reservoir;

a pressurization system for pressurizing the fluid from said reservoir and passing the pressurized fluid through a conduit to the oil recovery tool.

3. The oil recovery system according to claim 2, wherein said pressurization system includes a pump in combination with a filter, along with at least one sensor generating a signal and sending said signal to said control system.

4. The oil recovery system according to claim 1, wherein said control system includes:

a programmable logic controller;

a single-board computer; and

at least one external communication transceiver,

wherein the programmable logic controller provides low-level controls by interfacing with and providing control signals and/or power to both the pump motor and the frameless, brushless motor in the oil recovery tool, and where the single-board computer is operatively connected to exchange commands and data with the programmable logic controller to effectuate various operations of the oil recovery system in order to consistently produce the seismic wave energy.

5. The oil recovery system according to claim 4 wherein said external communication transceiver, in conjunction with said single-board computer, enables both autonomous and remote control of the oil recovery system.

6. The oil recovery system according to claim 2, wherein said conduit is capable of handling a fluid pressure of up to at least 1500 psi.

7. The oil recovery system according to claim 6, wherein said conduit is formed of a flexible material suitable to be repeatedly wound and unwound upon a reel.

8. The oil recovery system according to claim 7, wherein said conduit further serves as an umbilical connection to and capable of lowering and raising said oil recovery tool relative to a borehole.

9. The oil recovery system according to claim 6, wherein said conduit is formed of a generally rigid material.

10. The oil recovery system according to claim 9, wherein said conduit further serves as an umbilical connection to and capable of lowering and raising said oil recovery tool relative to a borehole.

11. A system for generating acoustic waves within a medium to stimulate oil recovery within an oil reservoir, comprising:

a source of pressurized fluid, wherein said source of pressurized fluid includes a replenishable fluid reservoir and a pressurization system for pressurizing the fluid from said reservoir and passing the pressurized fluid through a conduit, the conduit terminating at an opposite end at an oil recovery tool, said oil recovery tool including;

an elongated and generally cylindrical housing suitable for passing through a borehole;

an accumulator;

an energy transfer section including,

a frameless motor,

a hollow-shaft rotor having an output port, and

a stator having a corresponding output port whereby fluid energy is transferred upon alignment of said rotor and stator ports, wherein the frameless motor is operatively connected to the hollow-shaft rotor and where fluid passes therethrough to the accumulator;

a pressure transfer valve, wherein the pressurized fluid is stored within said accumulator and subsequently transferred, thereby releasing seismic wave energy via the ports into the fluid surrounding the apparatus; and

a control system suitable for monitoring and controlling at least the oil recovery tool and the source of pressurized fluid in order to produce seismic waves within the reservoir.

12. The system according to claim 11, wherein said the seismic wave produced by the oil recovery tool has a frequency between about 10 – 100 Hz, and more preferably between 20 – 40 Hz.

13. The recovery system according to claim 11, wherein said pressurization system includes a pump in combination with a filter, along with at least one sensor generating a signal and sending said signal to said control system.

14. The system according to claim 13, wherein said control system includes:

a programmable logic controller;

a single-board computer; and

at least one external communication transceiver,

wherein the programmable logic controller provides low-level controls by interfacing with and providing control signals and/or power to both the pump motor and the frameless, brushless motor in the oil recovery tool, and where the single-board computer is operatively connected to exchange commands and data with the programmable logic controller to effectuate various operations of the oil recovery system in order to consistently produce the seismic wave energy.

15. The oil recovery system according to claim 14 wherein the external communication transceiver, in conjunction with said single-board computer enables both autonomous and remote control of the oil recovery system.

16. The oil recovery system according to claim 14, wherein said programmable logic controller and said single-board computer each include respective programmatic instructions for the operation thereof, and where said single-board computer includes programmatic instructions suitable for interfacing with and controlling certain operations of the programmable logic controller.

17. The oil recovery system according to claim 16, further including a remote computer, said remote computer including a storage medium suitable to storing programmatic instructions therein, said programmatic instructions facilitating a remote connection to the single-board computer via a communications channel selected from the group consisting of WiFi, Bluetooth®, Ethernet, and satellite modem.

18. The system according to claim 16 wherein at least one of said programmable logic controller and said single-board computer include non-volatile memory (NVM) suitable for storing data generated by said system, wherein said stored data includes an indication of whether the system is performing a restart after one of at least two events).

19. A method for generating seismic pressure wave energy within an oil saturated strata, comprising:

placing an acoustic wave generator in contact with a fluid within the strata;

accumulating fluid pressure energy within the acoustic wave generator; and

periodically releasing and transferring pressure energy with said generator to create wave energy that is transferred by the fluid into a porous medium of the strata, wherein releasing and transferring energy is accomplished by a frameless motor driving a rotary valve generator, said valve generator employing a hollow shaft for fluid passage, whereby the relative relationship of output ports on both a rotor and a stator within the fluid generator controls the release and transfer of a systematic pressure pulse to create the seismic pressure wave energy.

20. An oil recovery tool for imparting seismic wave energy within an oil reservoir, in the form of a wave, so as to alter the capillary forces of residual oil comprising:

a housing;

a source of pressurized fluid;

a frameless, brushless motor, operatively located within said housing to receive the pressurized fluid and generate the seismic waves.

21. An apparatus for generating acoustic waves within a medium to stimulate oil recovery within an oil reservoir, comprising:

an elongated and generally cylindrical housing suitable for passing through a borehole;

an accumulator;

a source of pressurized fluid;

an energy transfer section including,

a frameless motor;

a pressure transfer valve, wherein the pressurized fluid is stored within an accumulator and subsequently transferred, thereby releasing seismic wave energy via a hollow-shaft rotor having an output port, and a stator having a corresponding output port whereby fluid energy is transferred upon alignment of said rotor port and stator port, wherein the frameless motor is operatively connected to the hollow-shaft rotor and where fluid passes therethrough to the accumulator.

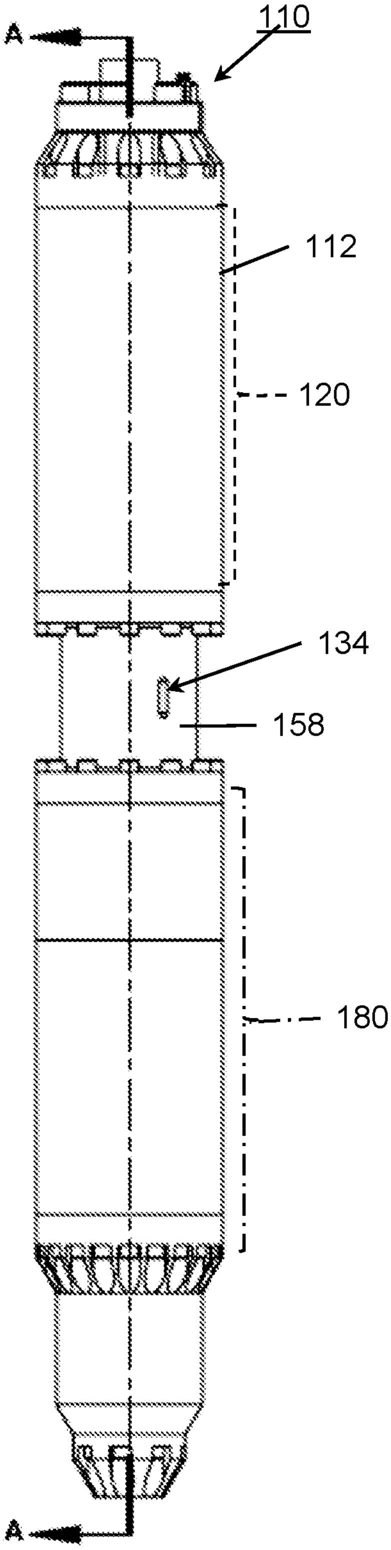



FIG. 1

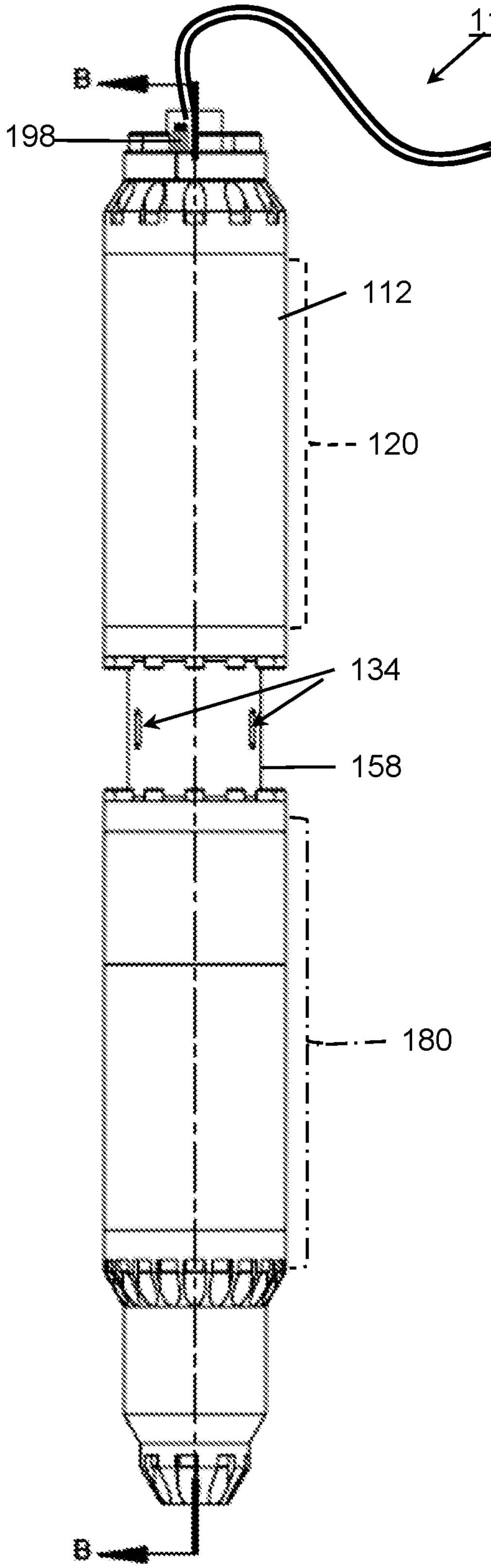



FIG. 2

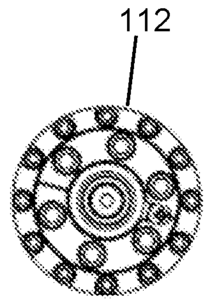



FIG. 3

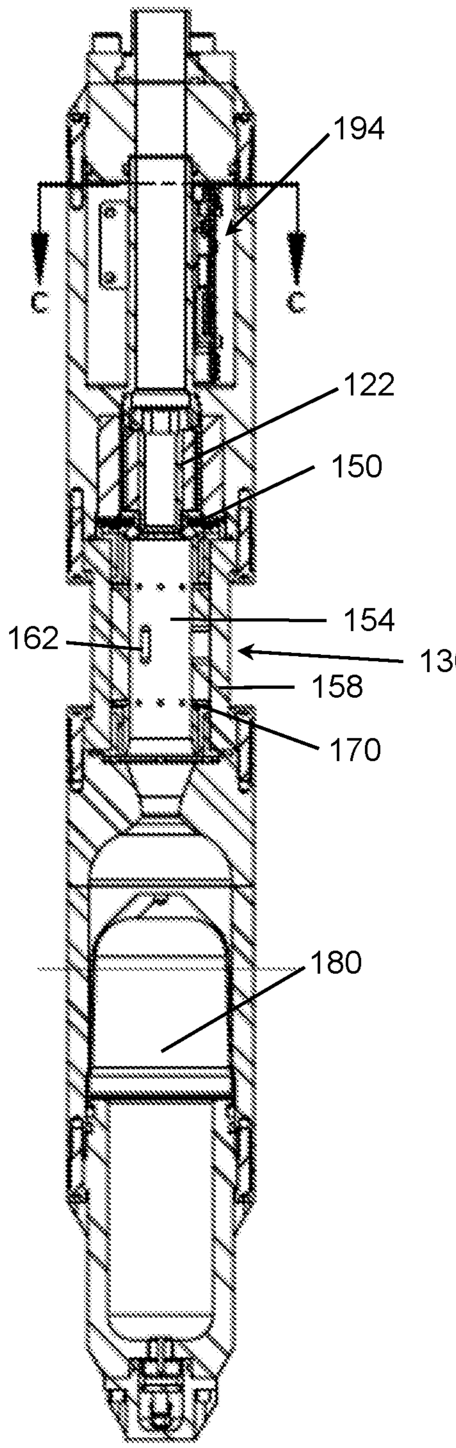


FIG. 4

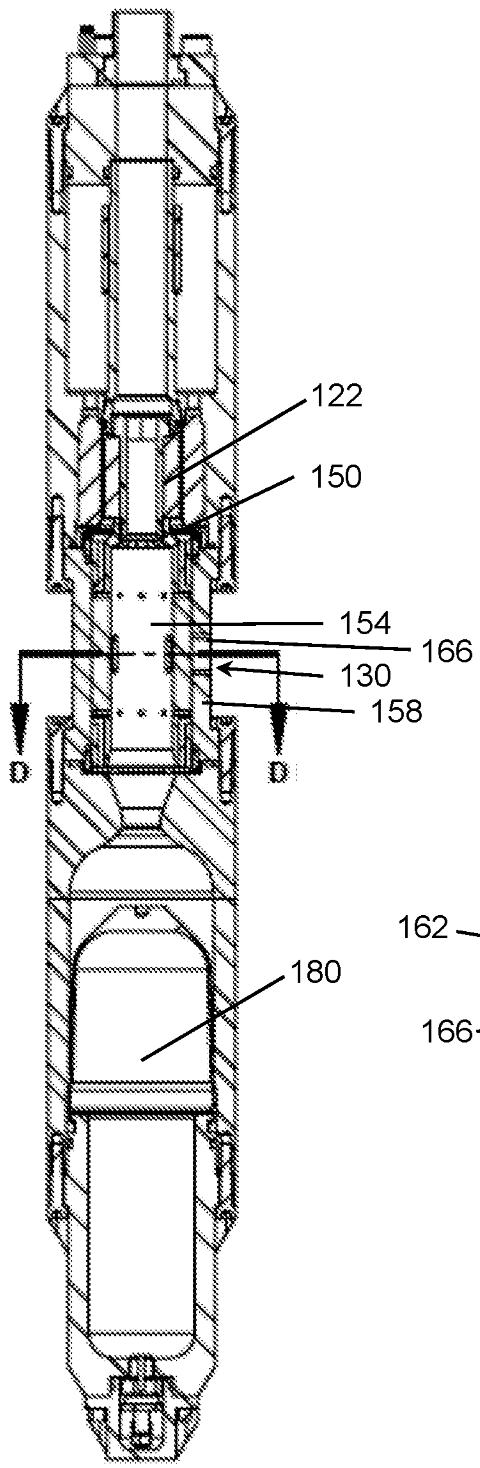


FIG. 5

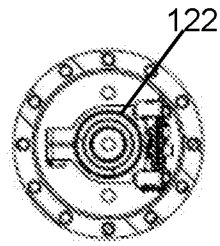


FIG. 6

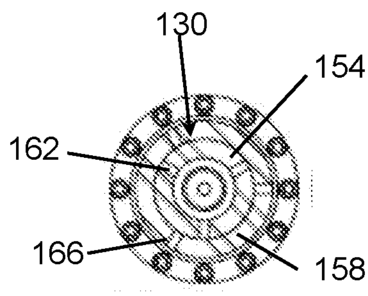


FIG. 7

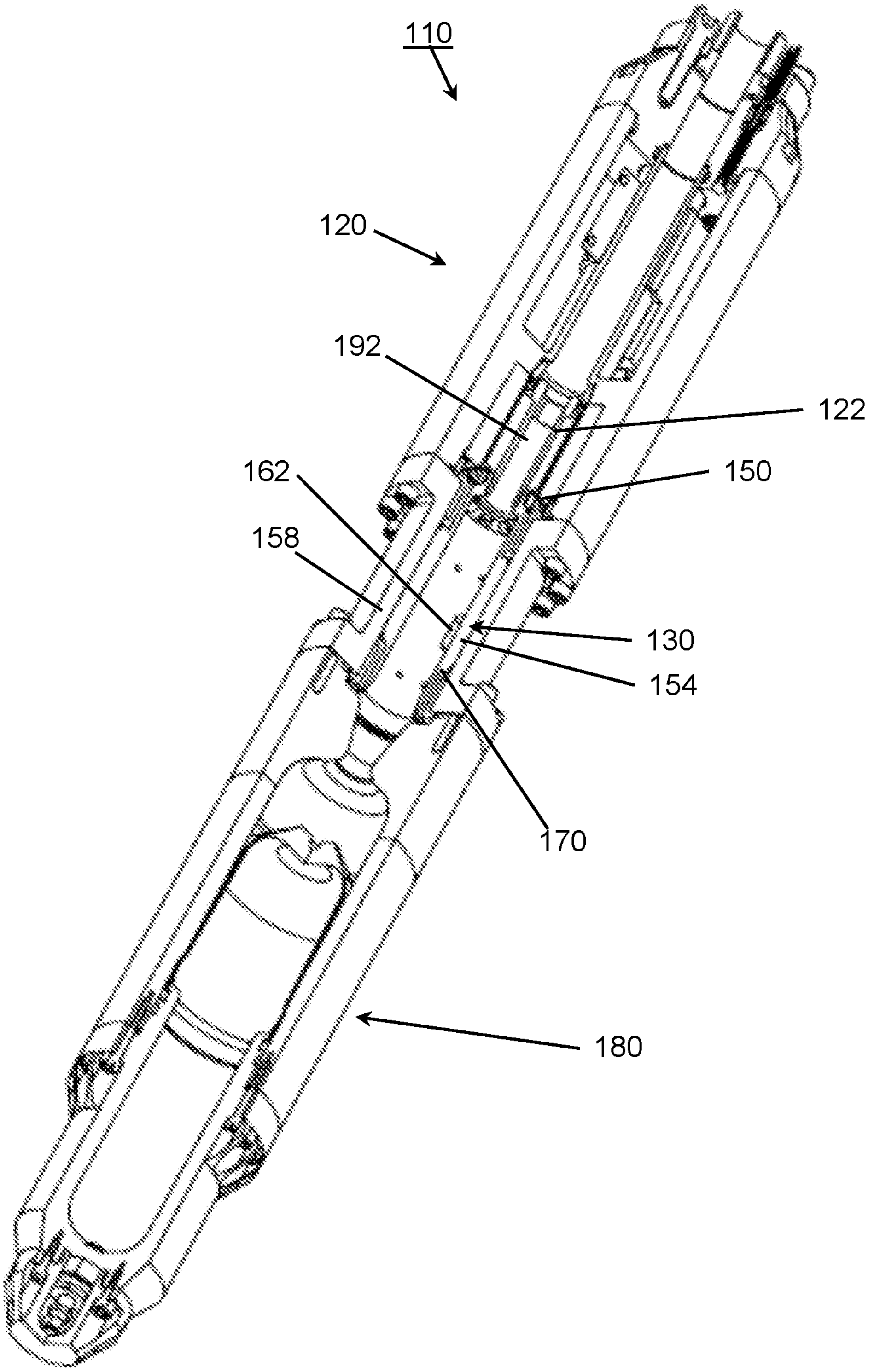
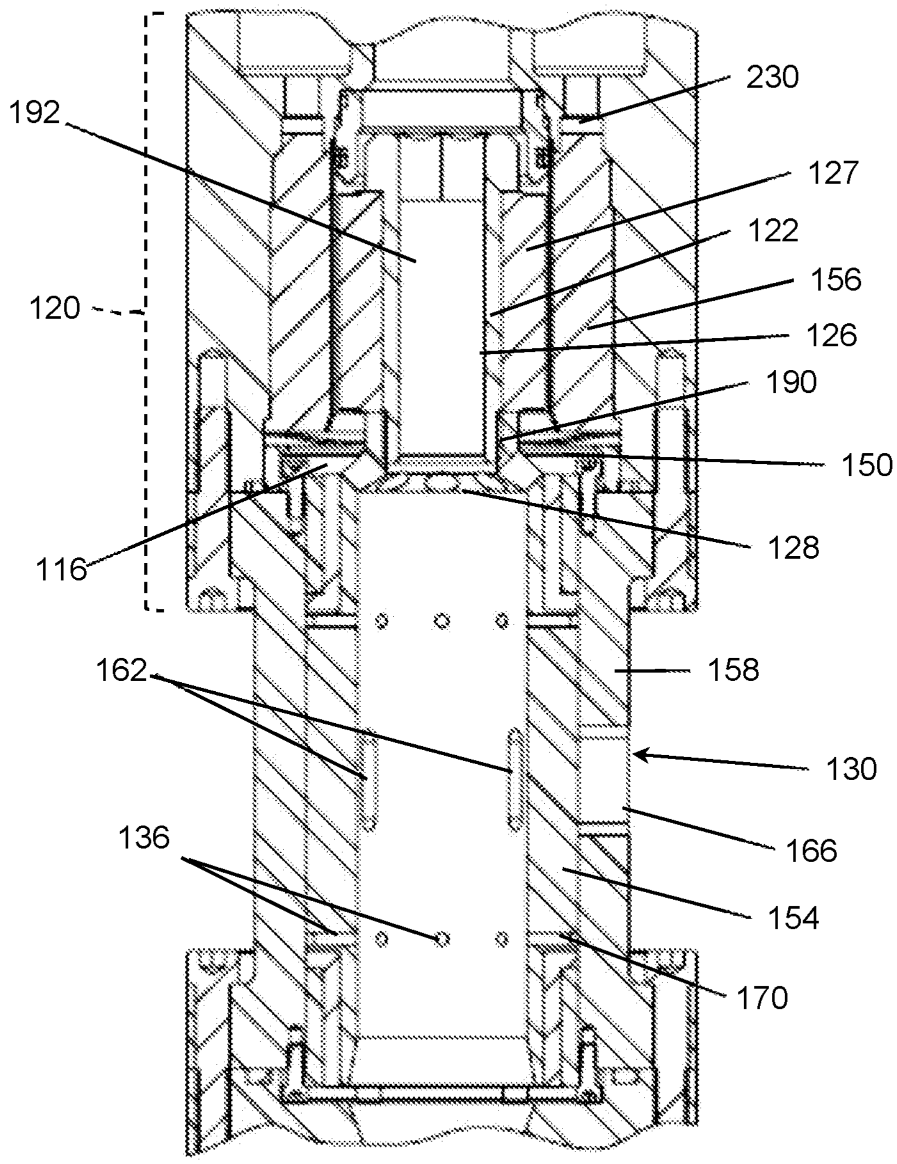



FIG. 8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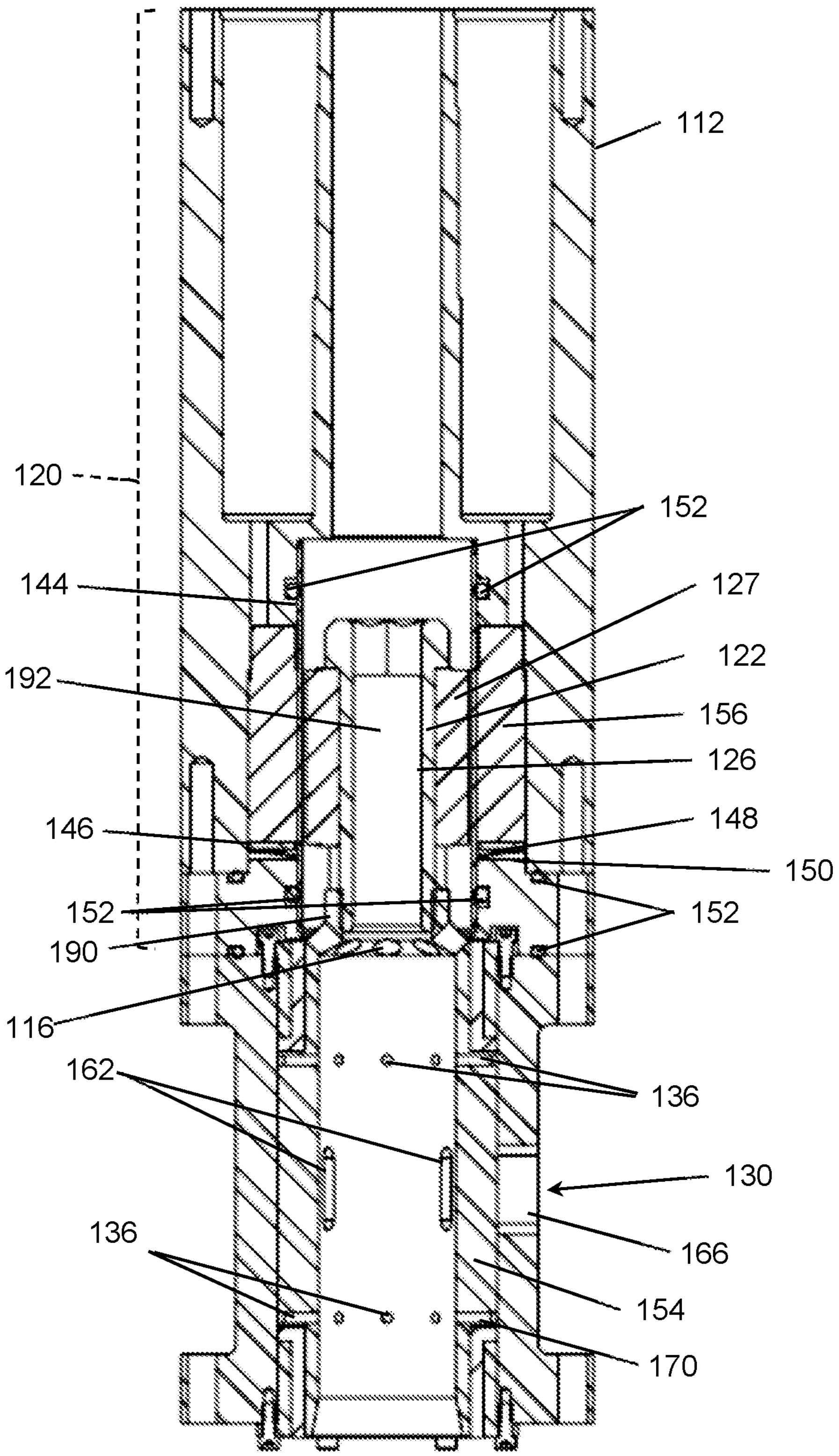
136
154
170

FIG. 9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170

FIG. 10

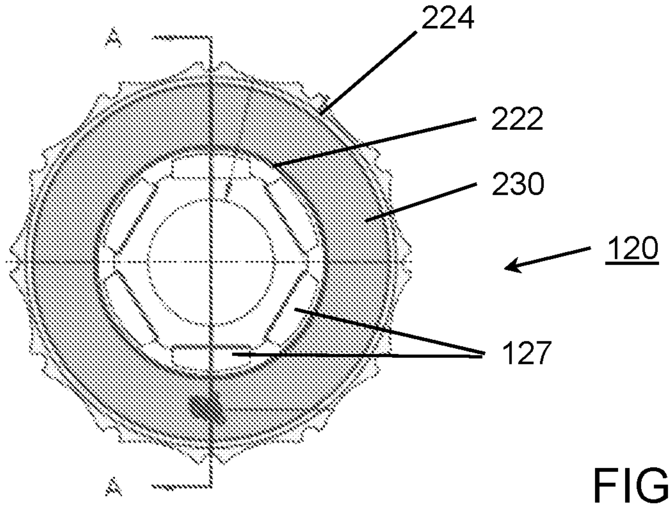



FIG. 11

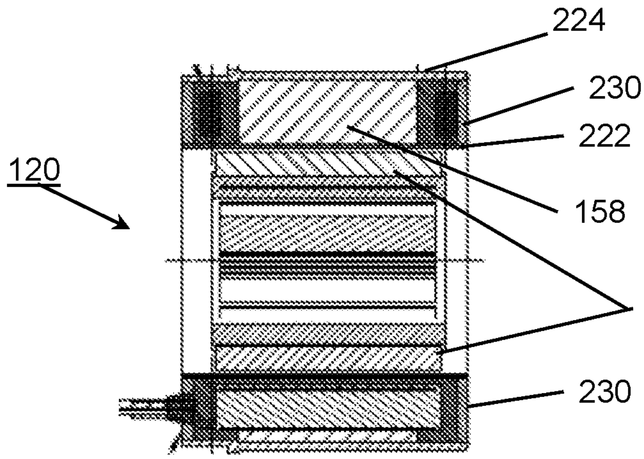



FIG. 12

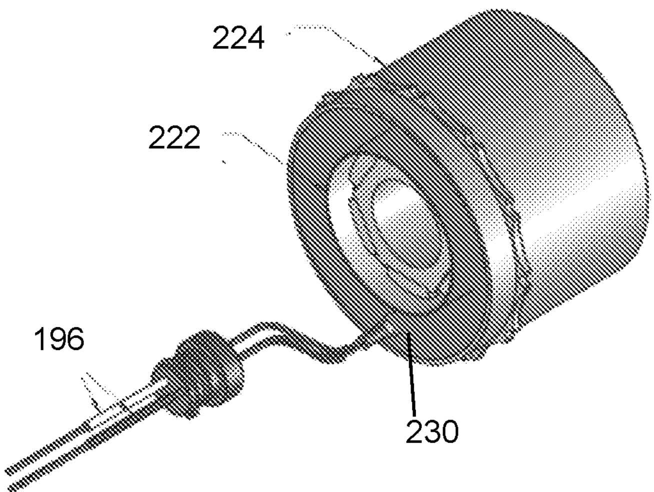



FIG. 13

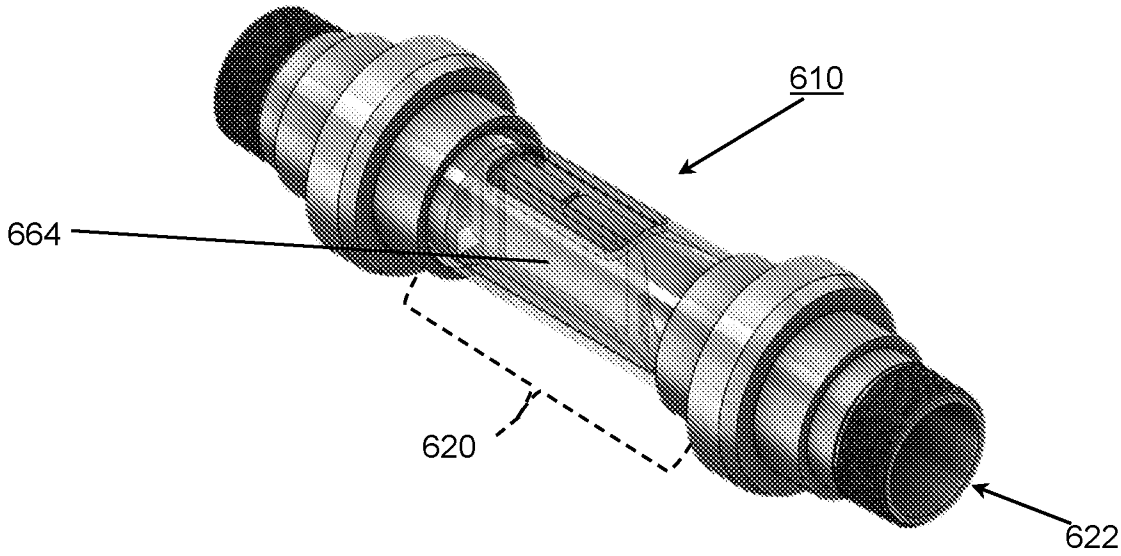

610
664
620
622

FIG. 14

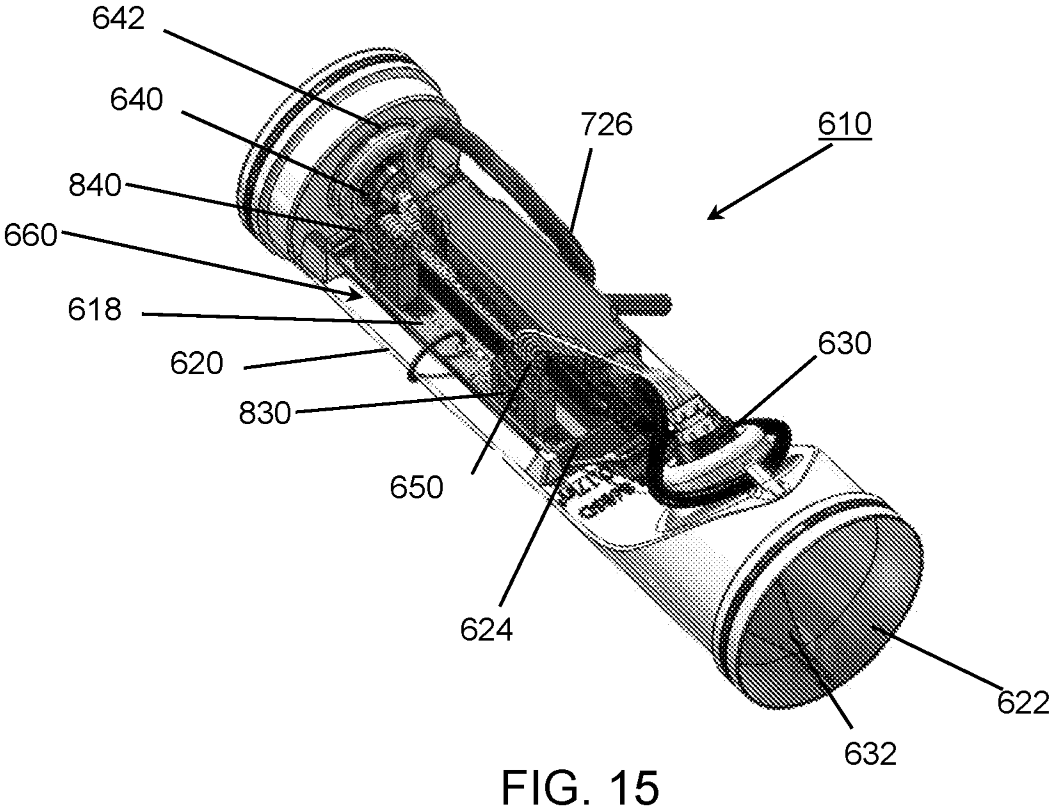

642
640
840
660
618
620
830
650
624
726
610
630
622
632

FIG. 15

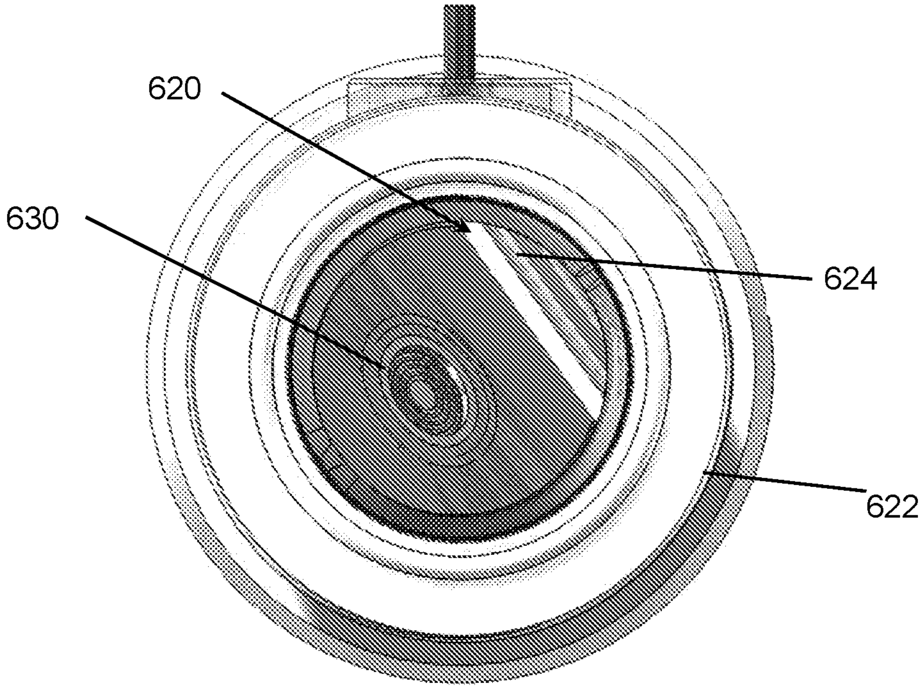
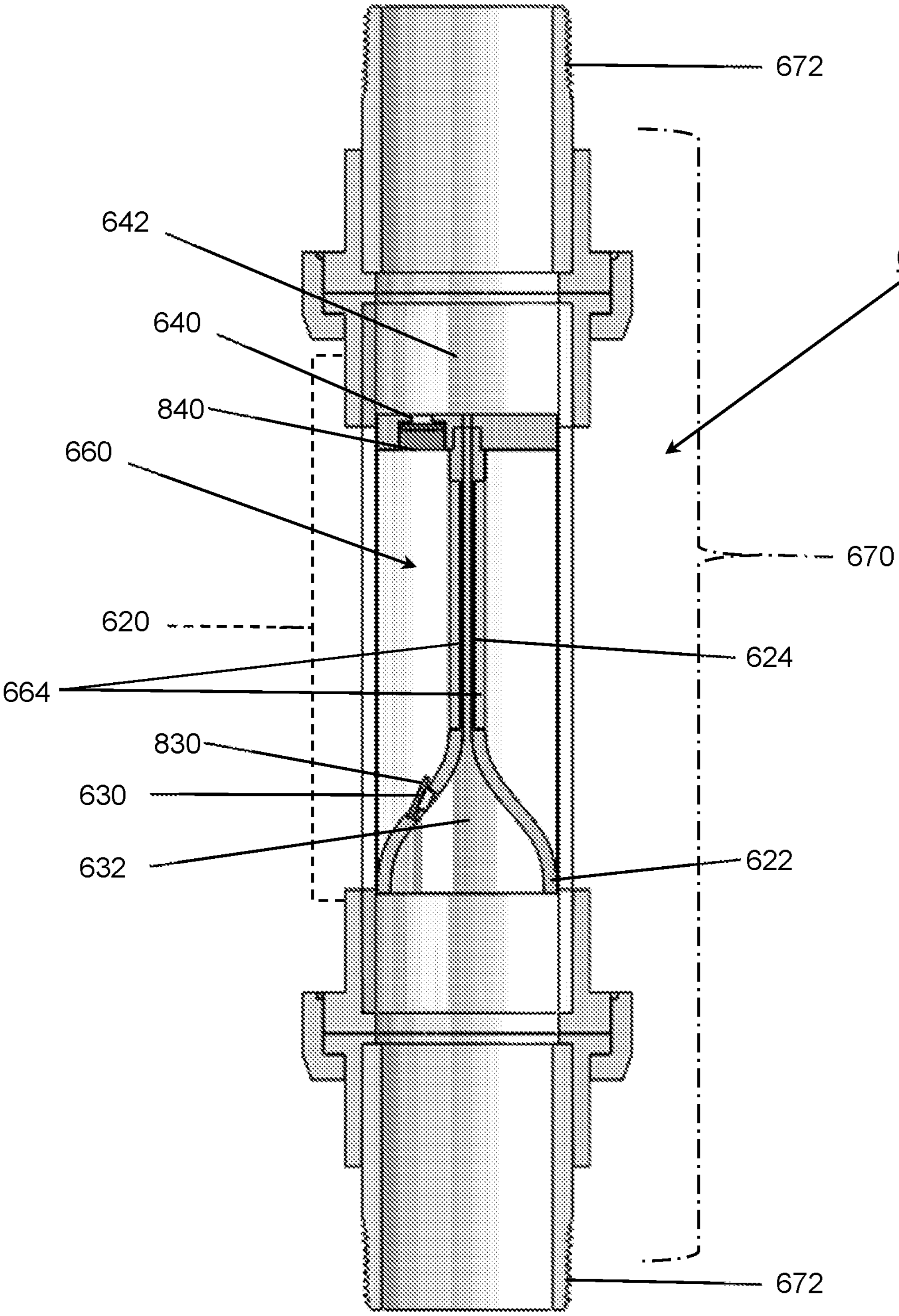



FIG. 16




FI G. 17

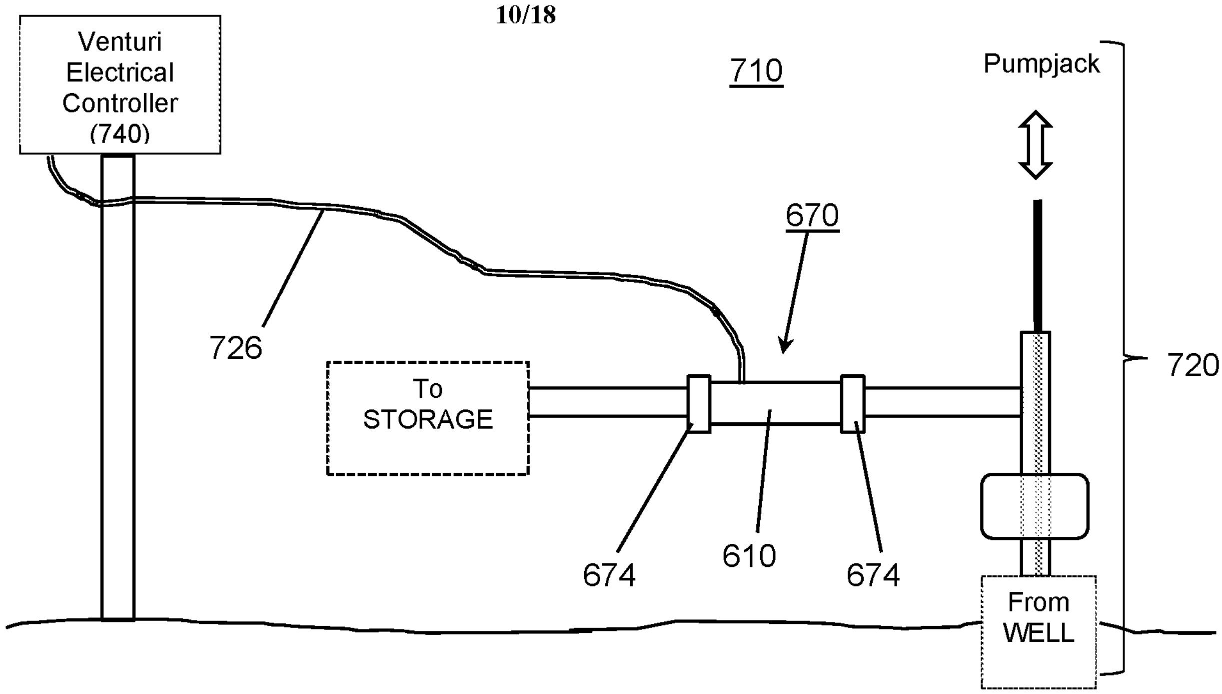

Venturi
Electrical
Controller
(740)
710
Pumpjack
670
726
To
STORAGE
720
674
610
674
From
WELL

FIG. 18

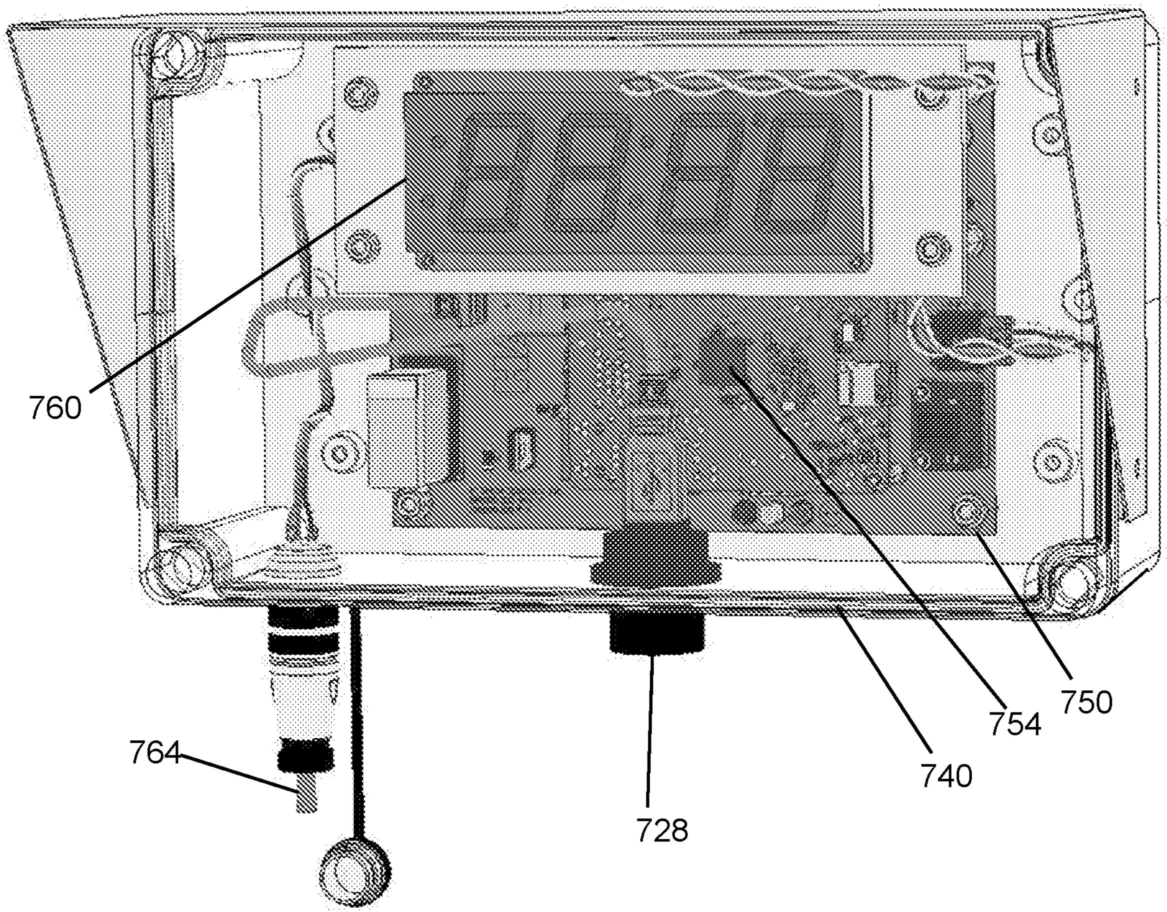

760
754
750
764
740
728

FIG. 19

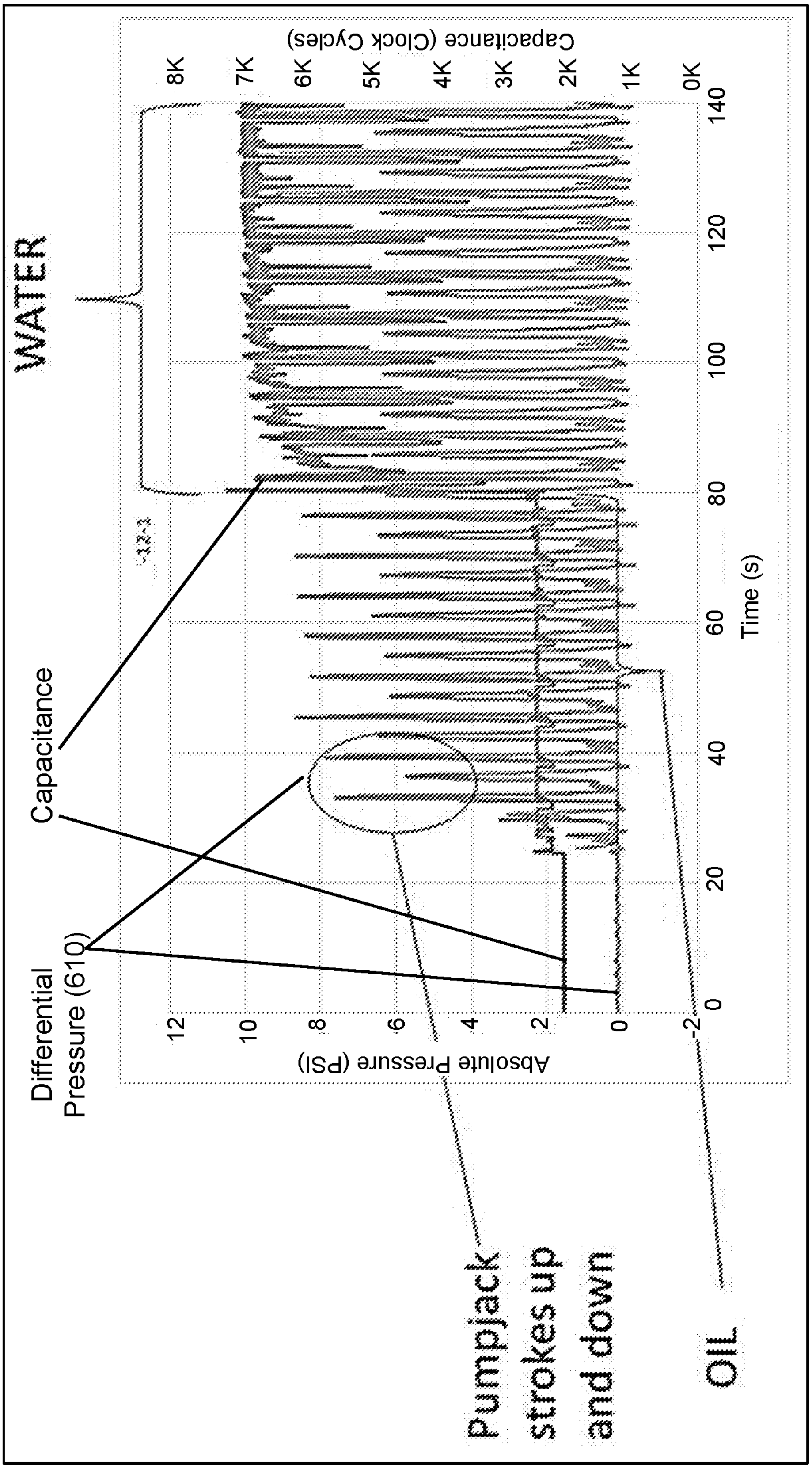

WATER
Capacitance
Differential Pressure (610)
Pumpjack strokes up and down
OIL
Capacitance (Clock Cycles)
8K
7K
6K
5K
4K
3K
2K
1K
0K
Absolute Pressure (PSI)
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120
140
Time (s)

FIG. 20

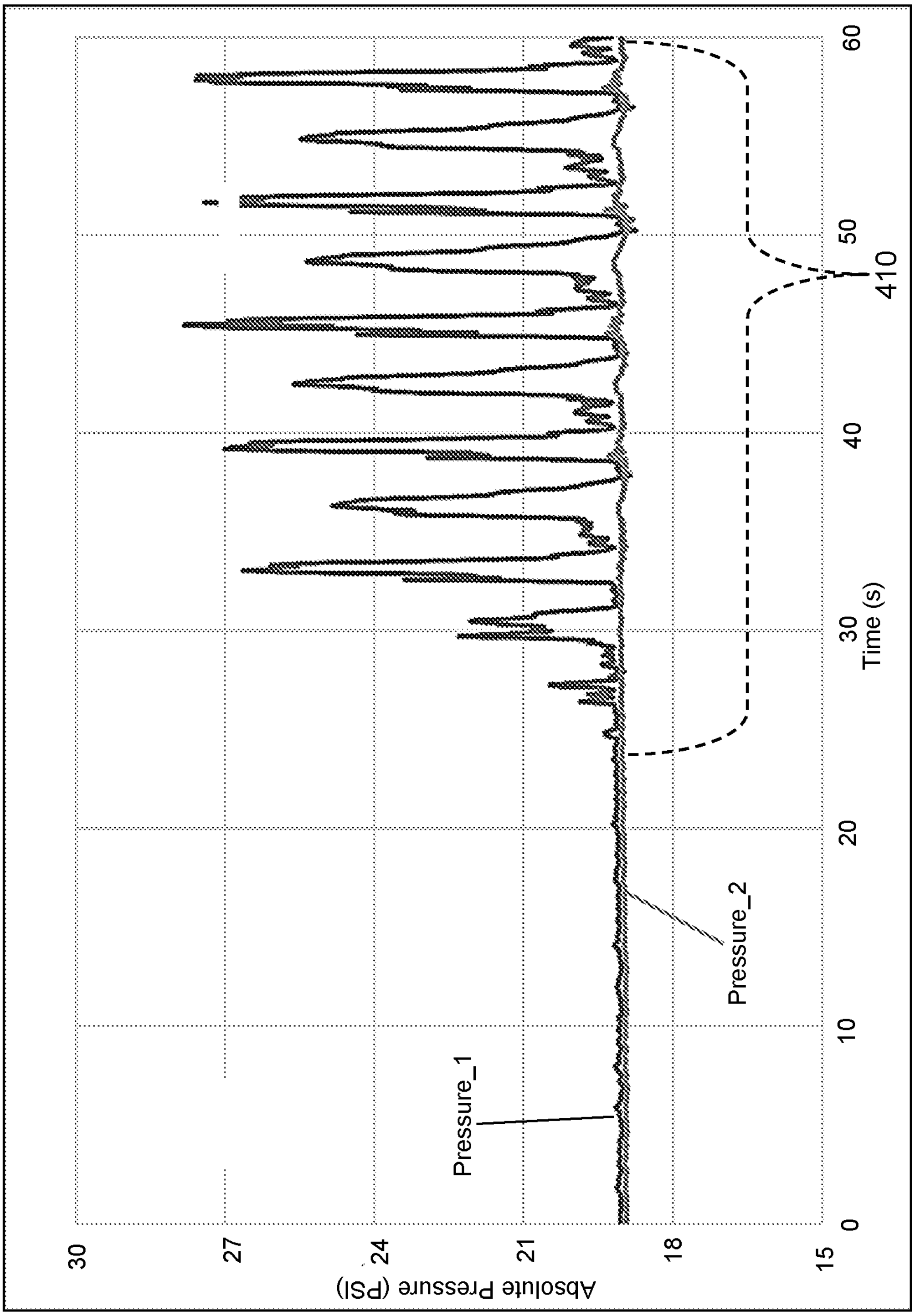

Absolute Pressure (PSI)
30
27
24
21
18
15
Time (s)
0
10
20
30
40
50
60
Pressure_1
Pressure_2
410

FIG. 21

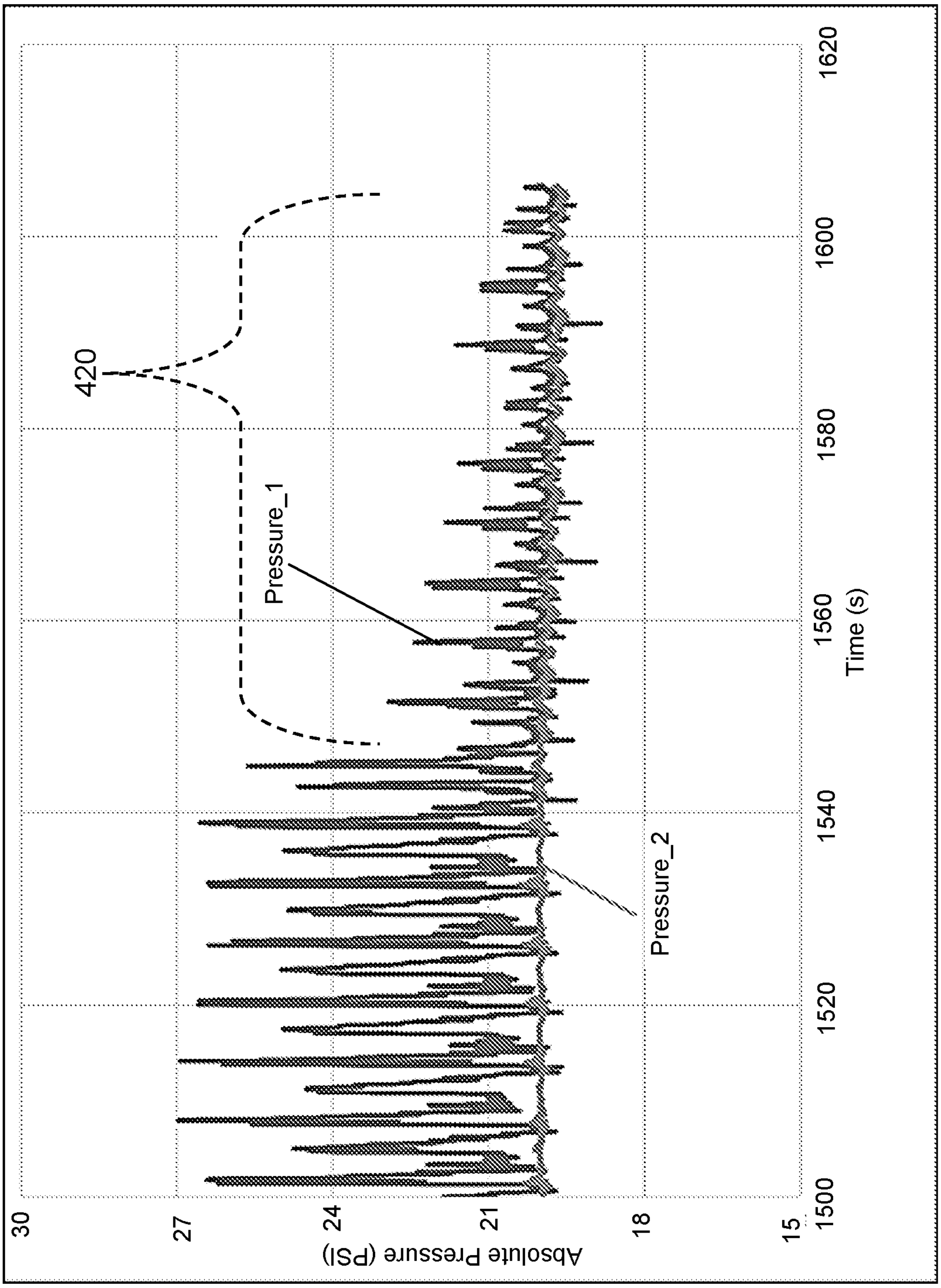

420
Pressure_1
Pressure_2
Absolute Pressure (PSI)
30
27
24
21
18
15
1500
1520
1540
1560
1580
1600
1620
Time (s)

FIG. 22

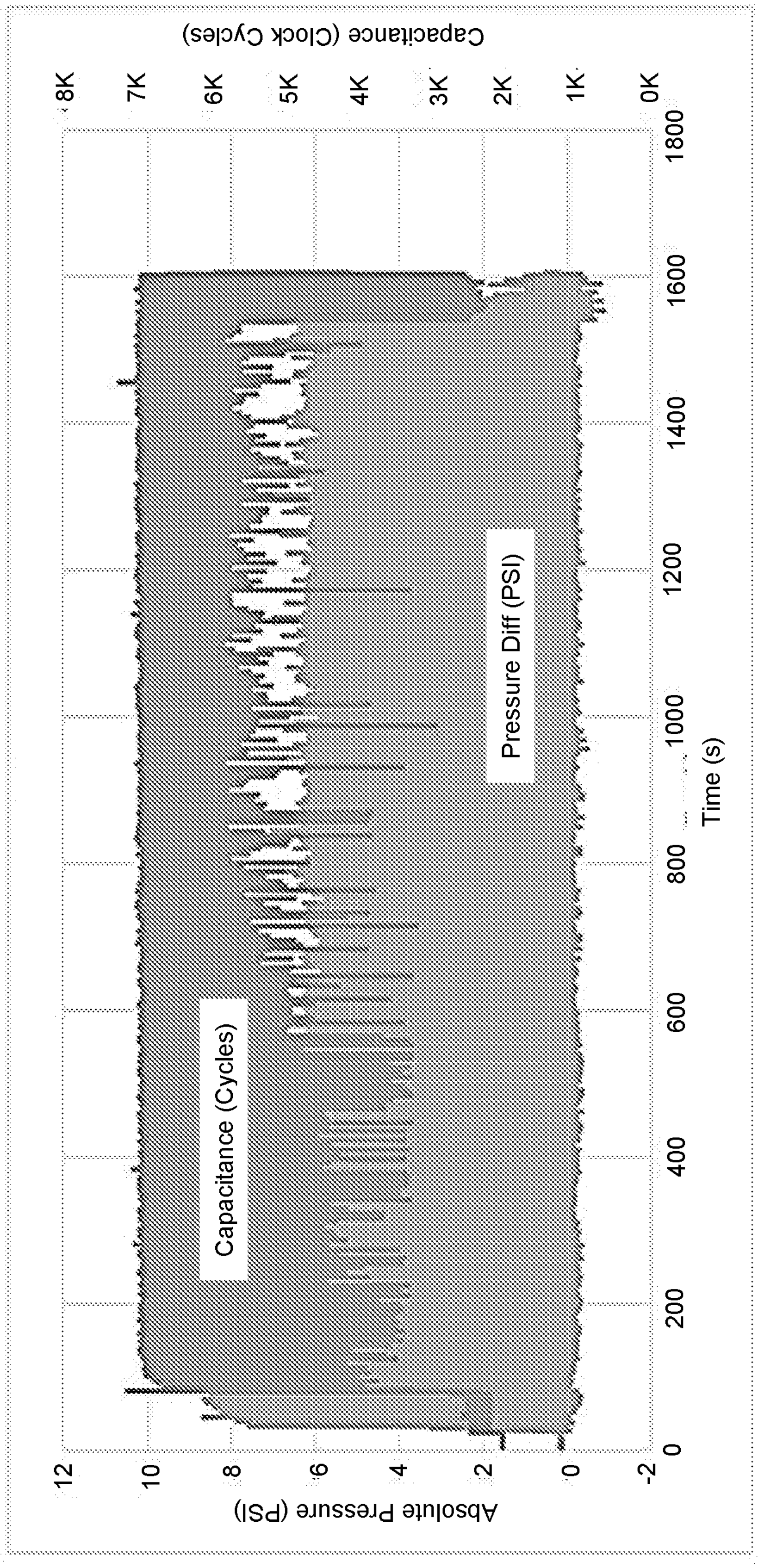

Capacitance (Clock Cycles)
8K
7K
6K
5K
4K
3K
2K
1K
0K
Capacitance (Cycles)
Pressure Diff (PSI)
12
10
8
6
4
2
0
-2
Absolute Pressure (PSI)
0
200
400
600
800
1000
1200
1400
1600
1800
Time (s)

FIG. 23

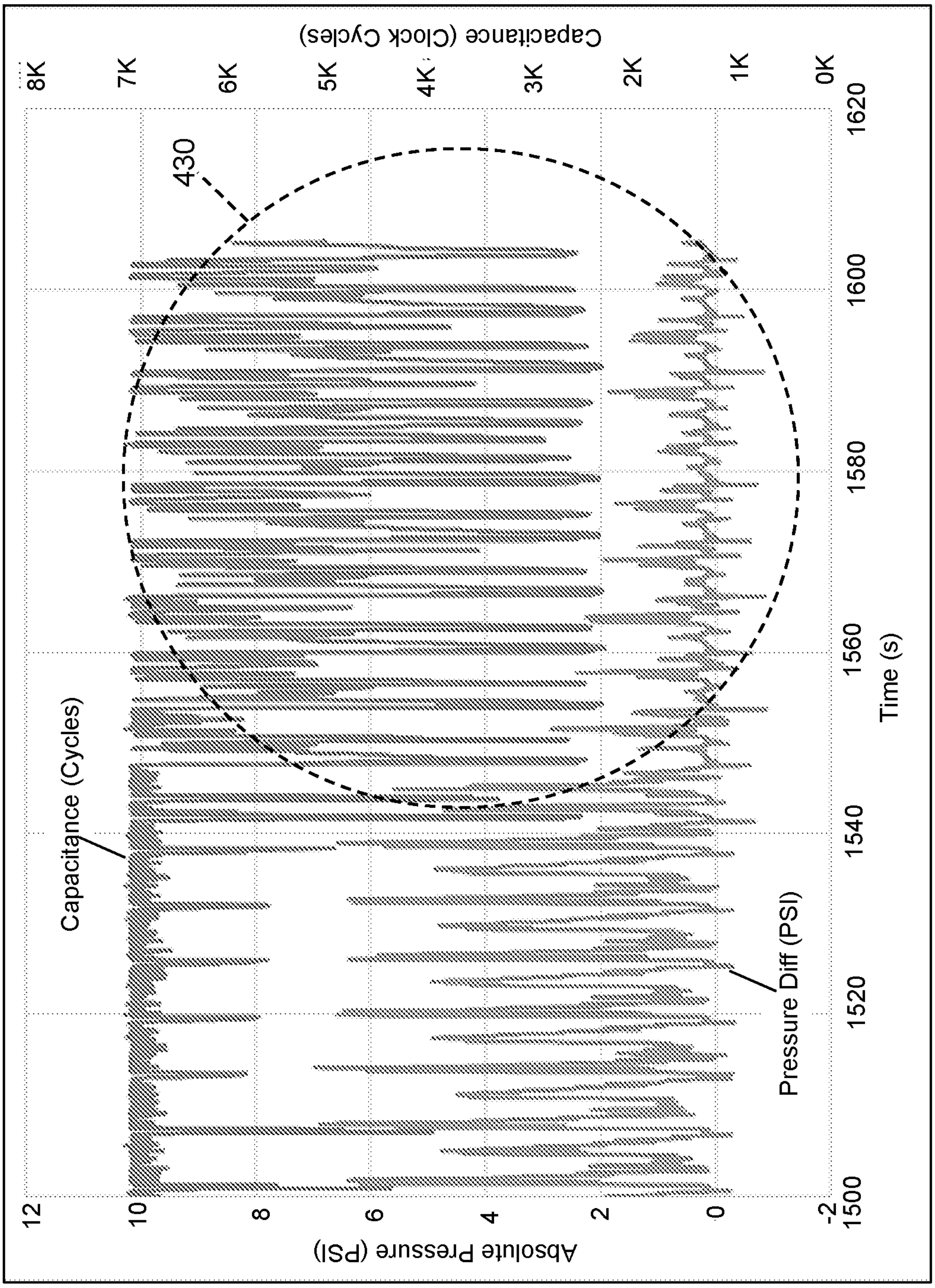

Capacitance (Cycles)
Pressure Diff (PSI)
430
Absolute Pressure (PSI)
Capacitance (Clock Cycles)
Time (s)
12
10
8
6
4
2
0
-2
1500
1520
1540
1560
1580
1600
1620
8K
7K
6K
5K
4K
3K
2K
1K
0K

FIG. 24

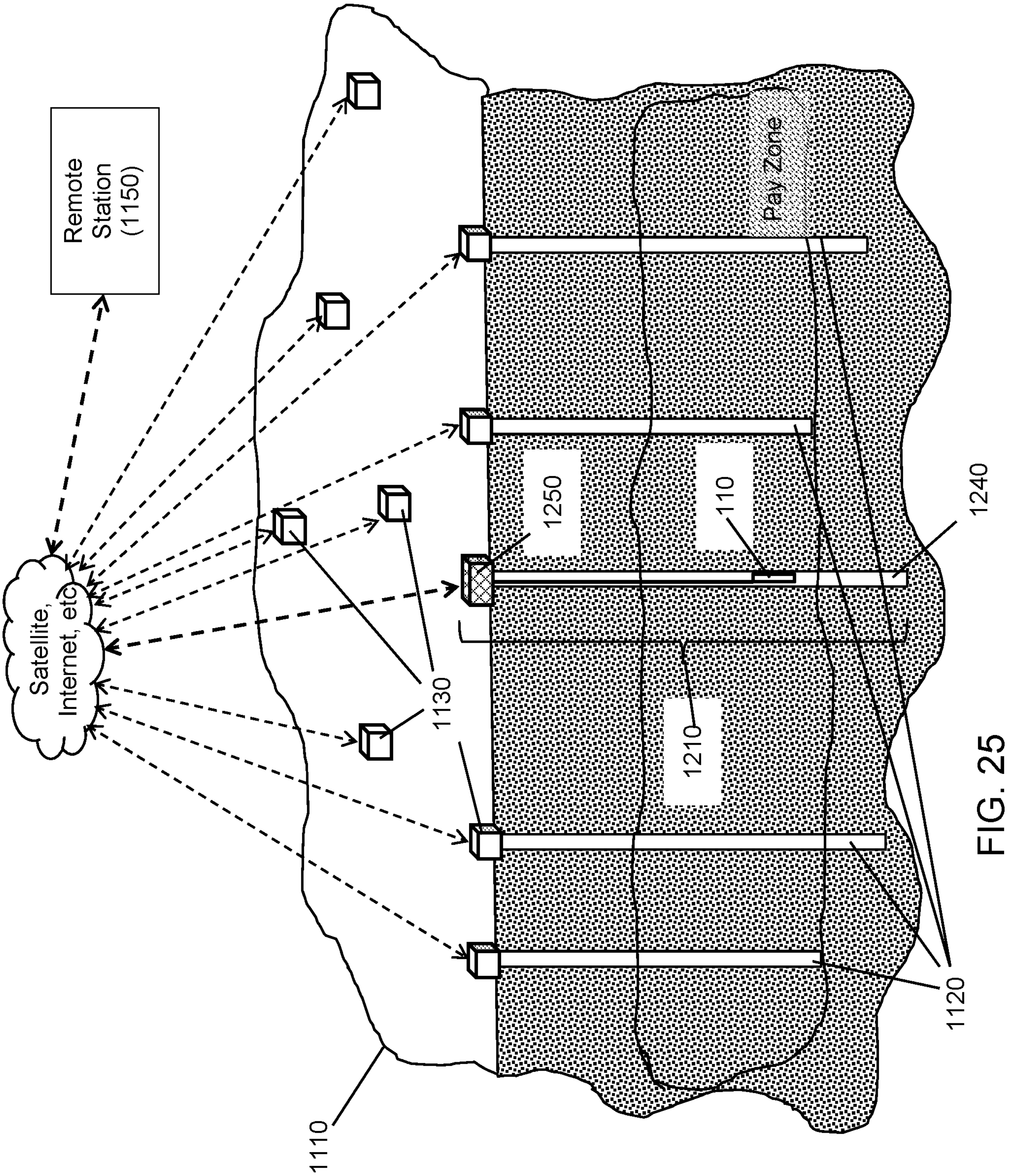

Remote Station (1150)
Satellite, Internet, etc
Pay Zone
1250
110
1240
1210
1130
1120
1110

FIG. 25

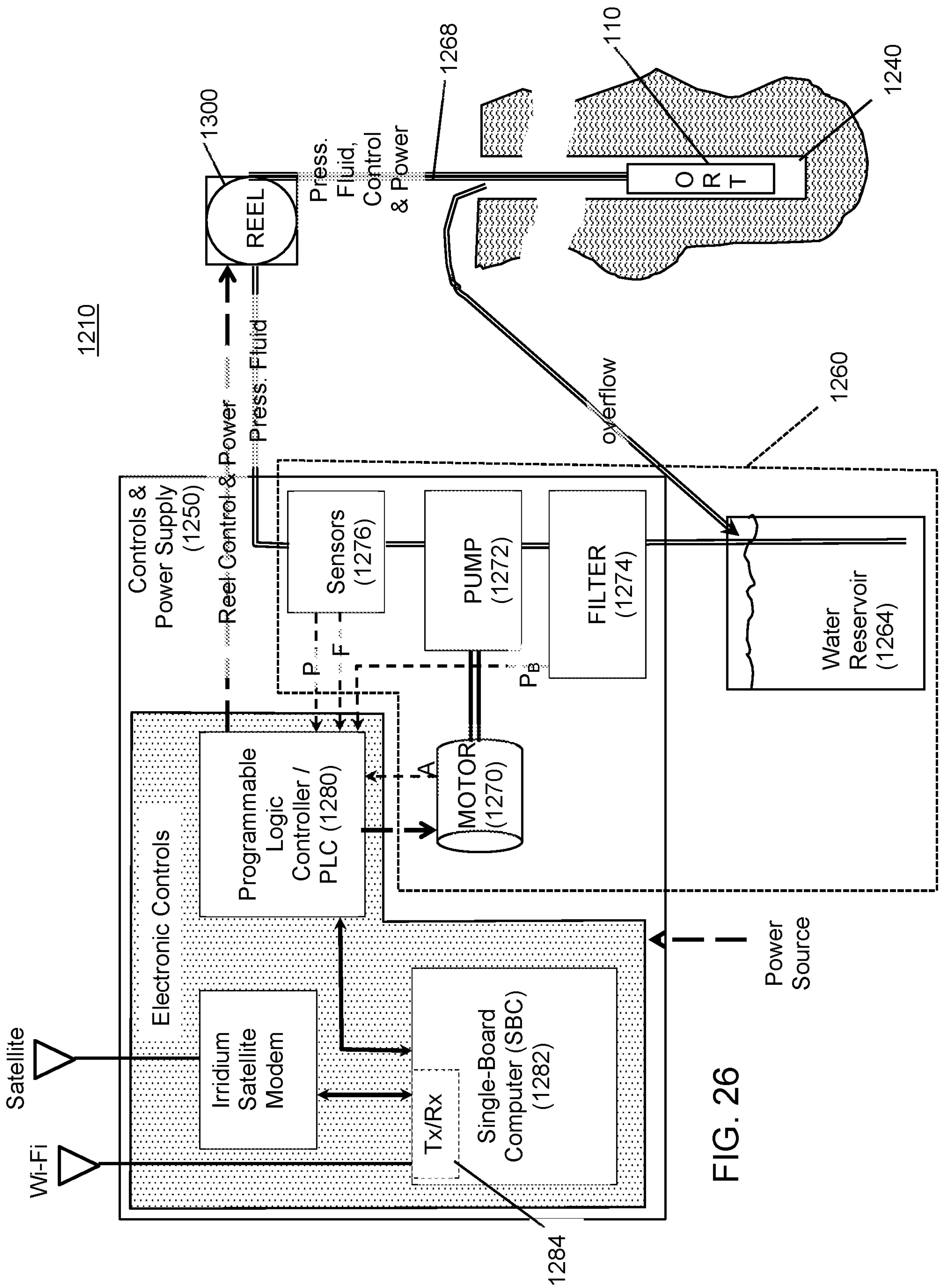

1210
1300
REEL
1268
110
1240
Press. Fluid, Control & Power
O R T
Reel Control & Power
Press. Fluid
overflow
1260
Controls & Power Supply (1250)
Sensors (1276)
PUMP (1272)
FILTER (1274)
Water Reservoir (1264)
P
F
$P_B$
A
MOTOR (1270)
Programmable Logic Controller / PLC (1280)
Electronic Controls
Irridium Satellite Modem
Single-Board Computer (SBC) (1282)
Tx/Rx
Satellite
Wi-Fi
Power Source
1284

FIG. 26

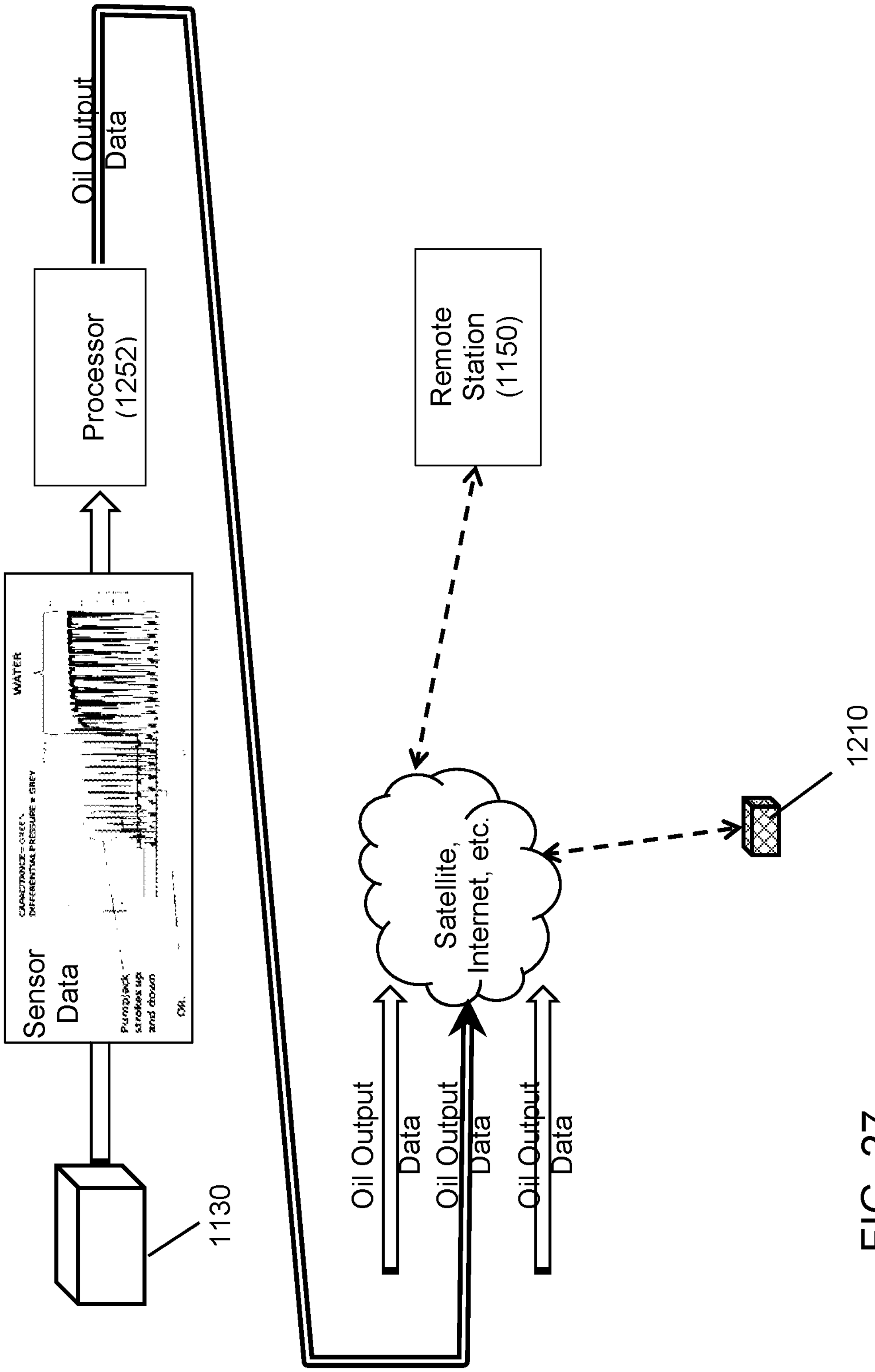

Sensor Data
WATER
Processor (1252)
Oil Output Data
Remote Station (1150)
Satellite, Internet, etc.
Oil Output Data
Oil Output Data
Oil Output Data
1130
1210

FIG. 27

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 19/17014

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - E21B 28/00, E21B 43/00, E21B 44/00, E21B 19/06 (2019.01)
CPC - E21B 28/00, E21B 43/00, E21B 44/00, E21B 19/06, E21B 43/003

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)
See Search History Document

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X<br>---<br>Y<br>---<br>A | US 2009/0200019 A1 (DeLaCroix et al.) 13 August 2009 (13.08.2009) Entire document especially para [0027], [0030]-[0036] and figs. 3-7 | 19, 21<br>---<br>1-3, 6-9, 11-13, 20<br>---<br>4-5, 10, 14-18 |
| Y<br>---<br>A | US 2009/0065197 A1 (Eslinger) 12 March 2009 (12.03.2009) Entire document especially para [0015], [0018]-[0019], [0028]-[0033] and fig. 1 | 1-3, 6-9, 11-13<br>---<br>4-5, 10, 14-18 |
| Y<br>---<br>A | US 2016/0115753 A1 (Magnum Oil Tools International, Ltd.) 28 April 2016 (28.04.2016) Entire document especially para [0036], [0056] and figs. 1 and 7A | 1-3, 6-9, 20<br>---<br>4-5, 10 |
| Y | US 4,523,644 A (Dismukes) 18 June 1985 (18.06.1985) Entire document especially col 3, ln 48 - col 4, ln 29 and fig. 1 | 7, 8 |
| A | US 2015/0075867 A1 (National Oilwell Varco, L.P.) 19 March 2015 (19.03.2015) Entire document | 1-21 |
| A | US 2014/0216727 A1 (Kasyanov et al.) 7 August 2014 (07.08.2014) Entire document | 1-21 |
| A | US 2010/0290313 A1 (Groves) 18 November 2010 (18.11.2010) Entire document | 1-21 |
| A | US 2014/0305877 A1 (SanuWave, Inc.) 16 October 2014 (16.10.2014) Entire document | 1-21 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance
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"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 | Date of mailing of the international search report |
|---|---|
| 9 April 2019 | 01 MAY 2019 |

| Name and mailing address of the ISA/US | Authorized officer: |
|---|---|
| Mail Stop PCT, Attn: ISA/US, Commissioner for Patents<br>P.O. Box 1450, Alexandria, Virginia 22313-1450<br>Facsimile No. 571-273-8300 | Lee W. Young<br>PCT Helpdesk: 571-272-4300<br>PCT OSP: 571-272-7774 |