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(71) Applicant *(for FR only)*: **SERVICES PETROLIERS SCHLUMBERGER** [FR/FR]; 42 Rue Saint Dominique, F-75007 Paris (FR).

(71) Applicant *(for CA only)*: **SCHLUMBERGER CANADA LIMITED** [CA/CA]; 525 - 3rd Avenue S.w., Calgary, AB T2P 0G4 (CA).

(71) Applicant *(for GB, JP, NL only)*: **SCHLUMBERGER HOLDINGS LIMITED** [GB/GB]; P.O. Box 71, Craigmuir Chambers Road Town, Tortola (VG).

(71) Applicant *(for AL, AM, AU, AZ, BG, BY, CO, CZ, DE, DK, GR, HU, ID, IE, IL, IT, KG, KP, KR, KZ, LT, MD, MX, MY, NO, NZ, OM, PL, RO, RU, SI, SK, TJ, TM, TN, TR, TT, UA, UZ, ZA only)*: **SCHLUMBERGER TECHNOLOGY B.V.** [NL/NL]; Parkstraat 83-89, NL-2514 JG The Hague (NL).

(71) Applicant *(for all designated States except AL, AM, AU, AZ, BG, BY, CA, CO, CZ, DE, DK, FR, GB, GR, HU, ID, IE, IL, IS, IT, JP, KG, KP, KR, KZ, LT, MD, MX, MY, NL, NO, NZ, OM, PL, RO, RU, SI, SK, TJ, TM, TN, TR, TT, UA, US, UZ, ZA)*: **PRAD RESEARCH AND DEVELOPMENT LTD.** [GB/GB]; P.O. Box 71, Craigmuir Chambers Road, Tortola (VG).

(71) Applicant *(for IS only)*: **SCHLUMBERGER TECHNOLOGY CORPORATION** [US/US]; One Hampshire Street, Cambridge, MA 02139 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **ABOU EL AZM, Hisham** [EG/FR]; 1719 Rue Mesnil, F-75116 Paris (FR). **AKRAM, Agha Hassan** [PK/PK]; #7, Street 42, F-8/1, Islamabad, 75116 (PK).

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(54) Title: SELECTIVE ZONAL TESTING USING A COILED TUBING DEPLOYED SUBMERSIBLE PUMP

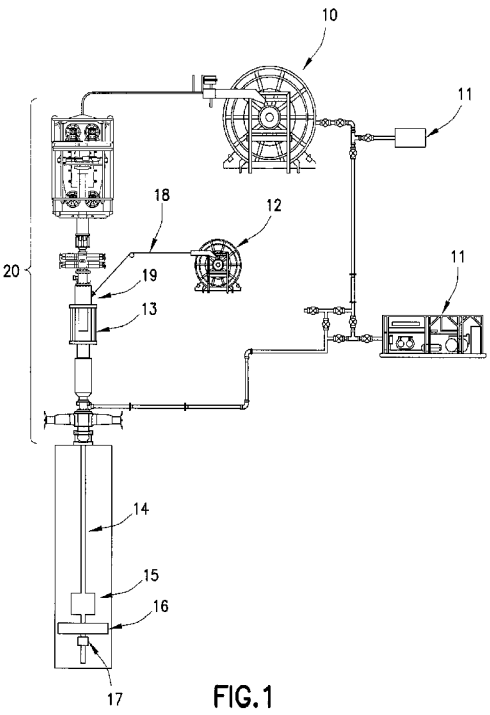


FIG.1

(57) Abstract: An apparatus for measuring a property of a formation comprising a coiled tubing unit having one or more downhole sensors capable of being lowered into a wellbore, a submersible pump capable of being lowered into a wellbore by the coiled tubing unit, means to power the submersible pump, and a packer lowered into the wellbore by the coiled tubing unit to isolate a formation. A method of servicing a hydrocarbon well using one or more sensors, one or more packers, and a submersible pump, all lowered on coiled tubing into a well that penetrates a predetermined formation; and using surface well testing equipment, determining a property of a formation while flowing the well assisted by the submersible pump and using flow data measured using the surface well testing equipment integrated with pressure data measured using the one or more sensors lowered into the well penetrating the formation on the coiled tubing; treating the formation by pumping fluid into the formation using the coiled tubing; and repeating the determining a property of the formation while flowing the well as described above, wherein the coiled tubing remains deployed within the well throughout the determining, treating, and repeating the determining processes.

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(74) **Agent**: **BATZER, William B.**; Schlumberger Technology Corporation, One Hampshire Street, Cambridge, MA 02139 (US).

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SELECTIVE ZONAL TESTING USING A COILED TUBING DEPLOYED SUBMERSIBLE PUMP

Field of the Invention:

[0001] This invention is generally related to the testing of hydrocarbon wells, and more particularly to methods and apparatus associated with the testing of hydrocarbon wells that utilize a submersible pump deployed on coiled tubing to transport the hydrocarbons from the formation up the wellbore.

Background of the Invention:

[0002] When a well is producing hydrocarbons to surface and its performance is not as expected, the well is often tested to determine the direct causation of this lack of flow rate. This is normally characterized by a dimensionless factor called skin, which quantifies the production efficiency of a formation. The wellbore damage or flow restriction must then be assessed to determine an appropriate method to treat the damage effectively. This damage can be the result of many conditions such as but not limited to solid or mud-filtrate invasion, perforating debris, inadequate perforations, near or far wellbore damage and low permeability formations. Stimulation methods such as fracturing or acidizing are typically used to attempt to increase formation productivity. Another test may be performed after stimulation to evaluate the effectiveness of the treatment.

[0003] To properly treat a damaged well, we first need to understand the origin and nature of the damage. One way to achieve this is by analyzing well test data.

[0004] One of the preferred methods used in well test interpretation is pressure transient analysis (also called "PTA"). This method combines flow rate and bottomhole pressure measurements obtained by flowing the well through instruments at the surface and by

recording the bottomhole pressure with the well shut-in. Both measurements (flowing and shut-in) are recorded at one or a plurality of time periods depending on the complexity of the study. The pressure and pressure derivative curves are compared to known type-curves to determine the skin and permeability. After the treatment is formulated and executed, a post stimulation test may be conducted to record a final skin.

[0005] To better understand the reservoir using surface well testing and coiled tubing stimulating services to optimize production, the two services can be integrated. The ability to evaluate, treat, and test a well has been a long desired industry goal.

[0006] This can be accomplished by using enhanced Coiled Tubing Services as the means to stimulate and test a well. The coiled tubing is run down the well with a downhole assembly comprising one or more sensors and any other equipment and instruments needed during the well test. A packer (seal cups, swab cup assemblies or set of packers) included in the coiled tubing bottomhole assembly is normally set above the formation, in the case of one packer/seal cup or straddling the formation in the case of two packers, one top packer and a lower swab cup or two swab cup assemblies. Included in this bottomhole assembly (referred to as a "BHA" and also known as a downhole assembly) are one or more gauges that are used to acquire the downhole pressure and temperature.

[0007] The coiled tubing can now transport fluids to and from the well (allowing acidizing or fracturing fluids to be pumped into the well and allowing reservoir fluids from the well to flow to the surface, etc.) with the assistance of surface equipment where the flow rate is measured. To test, stimulate, and test again all through coiled tubing offers a great reduction in rig time and a much needed method to understand complex wells.

[0008] The use of coiled tubing as a mean to well test a particular formation is not new to the industry. Such operations are disclosed in several U.S. patents mentioned hereinafter and included in their entirety by reference such as: U.S. Patent No. 5,287,741 entitled "Methods of Perforating and Testing Wells Using Coiled Tubing", issued February 22, 1994 to Schultz et al; U.S. Patent No. 5,638,904 entitled "Safeguarded Method and Apparatus for Fluid Communication Using Coiled Tubing, With Application to Drill Stem Testing", issued June 17, 1997 to Misselbrook and Sask; U.S. Patent No. 6,520,255 entitled "Method and apparatus for stimulation of multiple formation intervals", issued on February. 18, 2003 to Randy C. Tolman et al; U.S. Patent No. 6,959,763 entitled "Method and apparatus for integrated horizontal selective testing of wells", issued on November 1, 2005 to Hook and Ramsey; U.S. Patent No. 6,675,892 entitled "Well Testing Using Multiple Pressure Measurements" issued on June 13, 2004 to Fikri Kuchuk, et al.; and Published U.S. Patent Application No. 20070044960 entitled "Methods, systems and apparatus for coiled tubing testing" published on March 1, 2007 on behalf of John Lovell et al.

[0009] However a large percentage of wells currently on production or waiting to be studied are sufficiently depleted or the damage is so extensive that the reservoir pressure is not enough to drive the flow of formation fluids out to surface by itself in adequate volumes (if any at all) to perform a representative test.

[0010] The present invention aims to describe an apparatus and a method for testing wells that have, without assistance, insufficient reservoir drive to enable sufficient fluid flow to surface as to generate enough information in order to representatively test the well.

Summary of the Invention:

[0011] The present invention comprises an apparatus for measuring a property of a formation comprising a coiled tubing unit having one or more downhole sensors capable of

being lowered into a wellbore, a submersible pump capable of being lowered into a wellbore by the coiled tubing unit, means to power the submersible pump and a packer lowered into the wellbore by the coiled tubing unit to isolate a formation of interest. The apparatus may further comprise surface well testing equipment capable of measuring flow rate data, means for transmitting the sensor measurements to a server capable of collecting, storing, and retransmitting the measured data, and means for transmitting the measurements to a processing unit capable of calculating the properties of the formation.

[0012] The apparatus of the present invention includes at least one sensor to be lowered into the wellbore by the coiled tubing unit, wherein the sensors are selected from a group of sensors that measure pressure, temperature, flowrate, spectroscopy, viscosity, H2S concentration, CO2 concentration, bubble count, a dielectric property, gas/oil ratio, water/gas ratio, water/oil ratio and gamma ray radiation.

[0013] The apparatus of the present invention includes a submersible pump. The submersible pump may be powered by a submersible pump cable lowered from surface along with the coiled tubing. The submersible pump cable may or may not be clamped to the outside of the coiled tubing along its length. The submersible pump cable may or may not be clamped to the coiled tubing as the coiled tubing is lowered into a wellbore. If the submersible pump cable is to be clamped to the coiled tubing as it is lowered into the wellbore, a work window device designed to be deployed together with the coiled tubing pressure control equipment that allows access to both the coiled tubing and the submersible pump cable may be used. The work window can be closed to preserve pressure integrity of the surface pressure control system when desired. The submersible pump cable may or may not be deployed through a stuffing box to preserve pressure integrity of the surface pressure control system.

[0014] In one embodiment of the present invention, a packer is located below the submersible pump. The packer may be a straddle type packer, wherein the straddle packer has a pup joint in between that allows fluid from the outside to enter the pup joint. The pup joint that allows fluid from the outside to enter the pup joint may be a perforated or slotted pup joint situated in between the straddle packer.

[0015] An alternate apparatus of the present invention may have one packer and further comprise a pup joint that allows fluid from the outside to enter the pup joint and a swab cup or flow restrictor assembly below the pup joint.

[0016] The apparatus has at least one sensor located inside the joint below the packer or located inside the joint above the pup joint in between the straddle packer that allows fluid to enter. The sensors are selected from a group of sensors that measure pressure, temperature, flowrate, spectroscopy, viscosity, H2S concentration, CO2 concentration, bubble count, a dielectric property, gas/oil ratio, water/gas ratio, water/oil ratio and gamma ray radiation.

[0017] In one embodiment, the apparatus may have at least one pressure and temperature sensor located in the submersible pump. A safety valve may be located above the submersible pump and an emergency release sub may also be located above or below the submersible pump.

[0018] The present invention also comprises a method of servicing a hydrocarbon well using one or more sensors, a packer or straddle packer and a submersible pump all lowered on coiled tubing into a well that penetrates a formation; and surface well testing equipment, that includes determining a property of a formation while flowing the well assisted by the submersible pump and using flow data measured using the surface well testing equipment

integrated with pressure data measured using the one or more sensors lowered into the well penetrating the formation on the coiled tubing; treating the formation by pumping fluid into the formation using the coiled tubing; and repeating the determining a property of a formation while flowing the well assisted by the submersible pump and using flow data measured using the surface well testing equipment integrated with pressure data measured using the one or more sensors lowered into the well penetrating the formation on the coiled tubing; wherein the coiled tubing remains deployed within the well throughout the determining, treating, and repeating the determining processes. The method of servicing a hydrocarbon well described above may resolve a property of the formation determined while flowing the well assisted by the submersible pump and using flow data measured using the surface well testing equipment integrated with pressure data measured using the one or more sensors lowered into the well penetrating the formation on the coiled tubing; which may be included within a report that is created prior to treating the formation by pumping fluid into the formation using the coiled tubing

[0019] A further embodiment of the present invention is a method of servicing a hydrocarbon well as described above wherein one or more process parameters in the treatment process of the formation by pumping fluid into the formation using the coiled tubing is determined based on determining a property of a formation while flowing the well assisted by the submersible pump and using flow data measured using the surface well testing equipment integrated with pressure data measured using the one or more sensors lowered into the well penetrating the formation on the coiled tubing.

Brief description of the drawings:

[0020] The present invention is illustrated by way of example and not intended to be limited by the figures of the accompanying drawings in which like references indicate similar elements and in which:

[0021] Figure 1 shows an example embodiment of the present invention.

[0022] Figure 2 shows an example embodiment of the present invention wherein the wellhead surface equipment rig up and a detail of the work window is shown.

[0023] Figure 3 shows one embodiment of the present invention's assembly that might be lowered into a wellbore for testing a formation.

Detailed description of the invention:

[0024] Figure 1 shows an exemplary embodiment of the present invention, wherein a coiled tubing unit *10*, lowers into a wellbore a submersible pump *15* via coiled tubing *14*. Below the submersible pump *15* a packer *16* is activated to isolate a particular formation to be tested. As used herein, the term "packer" can also alternatively refer to swab cup or seal cup assemblies that serve the same purpose of isolating regions on opposing sides of the packer. The submersible pump *15* is activated to assist fluid from the formation to flow in sufficient quantity as to test the formation. A set of sensors *17* is integrated into the bottomhole assembly of the coiled tubing. A submersible pump cable spooling unit *12* feeds the submersible pump cable *18* through a T sub *19* located in the surface pressure equipment *20*, the submersible pump cable *18* is clamped to the coiled tubing *14* using a work window *13* to access both the coiled tubing *14* and the submersible pump cable *18*. One or more properties of the formation are measured by the sensors *17*, such properties by way of example but not to limit this disclosure are pressure, temperature, flowrate, spectroscopy, viscosity, H2S concentration, CO2 concentration, bubble count, a dielectric property, gas/oil ratio, water/gas ratio, water/oil ratio and gamma ray radiation. The surface well testing equipment *11* measures flow rate data on the surface.

[0025] Figure 2 shows an exemplary embodiment of the present invention, wherein most of the surface pressure equipment is shown. The submersible pump cable *22* enters the surface pressure equipment via a T sub, which may or may not have means to control pressure such as a stuffing box, and it is accessed through a work window 23. The work window 23 is used to access the coiled tubing 21 and the submersible pump cable 22 to be able to clamp the submersible pump cable to the coiled tubing 21 using a clamp 24. The work window can be closed if and when desired, to preserve the pressure integrity of the surface pressure control equipment.

[0026] Figure 3 depicts an exemplary embodiment of the present invention, wherein an example of a coiled tubing bottomhole assembly for the current invention is shown. The bottomhole assembly is lowered into the wellbore and positioned in place in front of the formation to be studied by coiled tubing *30*. The submersible pump cable *31* is lowered along with the coiled tubing *30* to provide power to the submersible pump *32* and to allow communication between the sensors housed in the bottomhole assembly and the surface processing unit. The sensors may be housed above, below or in the submersible pump. In the example shown in Figure 3, the sensors *38* are housed in a pup joint above the joint *35* that is designed to allow fluid to enter the system. Joint *35* is designed to allow fluid to enter the system and it is often called a perforated or slotted pup joint. In the present example embodiment shown in Figure 3, a safety valve *33* is deployed below the pump, the safety valve can be closed if needed to restrict fluid from entering the coiled tubing. This is a common safety practice within the industry. Below the safety valve 33, an emergency release sub *39* is depicted. A shear activated release sub is commonly used. Its function is to release the assembly situated above the emergency release sub *39*, should the operation need to do so (for example a stuck packer *34*), from the assembly situated below the emergency release sub *39* hence freeing the coiled tubing *30* to be retrieved to surface. Also shown in Figure 3 is a packer *34* to isolate the open formation *36* to be tested, the packer *34* can be replaced by a swab cup or seal cup assembly. Below packer *34* are a series of joints, the number and length of joints will depend on the length of the open formation to be tested plus a predetermined extra length of joints to provide a safety margin. Among these joints is a joint that allows fluid to enter the bottomhole assembly. To straddle the formation *36* to be tested, a swab cup or seal cup assembly *37*, as shown in figure 3, can be used; alternatively a second packer (i.e. a straddle packer, not shown) can be used replacing the shown swab cup assembly.

[0027] A person of ordinary skill in the art will recognize the use and functionality of surface pressure control equipment as a device or group of devices designed to contain fluid under pressure inside a wellbore while related equipment is moved in or out of the wellbore. Accordingly a person of ordinary skill in the art will recognize the use and functionality of a coiled tubing safety valve and a emergency release sub. The first is a device to restrict fluid from entering the coiled tubing and the second device is used to release the assembly situated above the emergency release sub should the operation need to do so from the assembly situated below the emergency release sub.

[0028] While the invention is described through the above exemplary embodiments, it will be understood by those of ordinary skill in the art that modification to and variation of the illustrated embodiments may be made without departing from the inventive concepts herein disclosed. It would be possible, for instance, to use a battery operated pump and a wireless communication system to start the test; a fluid sample chamber may be lowered into the wellbore; seal cups or swab cup assemblies can be used instead of packer or straddle packer; the position of the sensors, emergency release sub, packers, pup joints, safety valves, etc can vary in it relative position to each other and the amount thereof used in the string as described in the above exemplary embodiments. Accordingly, the invention should not be viewed as limited except by the scope of the appended claims.

Claims:

1. An apparatus for measuring a property of a formation comprising:
    i. a coiled tubing unit having one or more downhole sensors capable of being lowered into a wellbore;
    ii. a submersible pump capable of being lowered into a wellbore by said coiled tubing unit;
    iii. means to power the submersible pump; and,
    iv. a packer lowered into said wellbore by said coiled tubing unit to isolate a formation.

2. An apparatus as in claim 1, further comprising surface well testing equipment capable of measuring flow rate data.

3. An apparatus as in claim 1, further comprising means for transmitting said sensors measurements to a server capable of collecting, storing, and retransmitting the measured data.

4. An apparatus as in claim 1, further comprising means for transmitting the measurements to a processing unit capable of calculating the properties of the formation.

5. An apparatus as in claim 1, wherein said sensors are sensors from the group comprising pressure, temperature, flow, spectroscopy, viscosity, H2S, CO2, bubble count, dielectric, venturi, gas/oil ratio, water/gas ratio, water/oil ratio and gamma.

6. An apparatus as in claim 1, wherein said submersible pump is powered by a cable lowered from surface with the coiled tubing.

7. An apparatus as in claim 6, wherein said submersible pump cable is clamped to the outside of the coiled tubing and along its length.

8. An apparatus as in claim 7, wherein said cable is clamped to the coiled tubing as the coiled tubing is lowered into a wellbore.

9. An apparatus as in claim 7, wherein said cable is clamped to the coiled tubing through a work window device designed to be deployed together with the coiled tubing surface pressure control equipment that allows access to both the coiled tubing and the submersible pump cable; said work window can be closed to preserve pressure integrity of the surface pressure control system when desired.

10. An apparatus as in claim 6, wherein the submersible pump cable is deployed through a stuffing box to preserve pressure integrity of the surface pressure control system.

11. An apparatus as in claim 1, wherein the packer is located below the submersible pump.

12. An apparatus as in claim 1, wherein the packer is a straddle type packer.

13. An apparatus as in claim 12, wherein the straddle packer has a pup joint in between said straddle packer that allows fluid from the outside to enter said pup joint.

14. An apparatus as in claim 12, wherein the straddle packer has a perforated or slotted pup joint in between said straddle packer.

15. An apparatus as in claim 1, further comprising a pup joint that allows fluid from the outside to enter said pup joint and a swab cup assembly below said pup joint.

16. An apparatus as in claim 1 or 12, wherein the packer is replaced by a swab cup assembly.

17. An apparatus as in claim 1, wherein at least one pressure sensor is located inside the joint below the packer.

18. An apparatus as in claim 1, wherein at least one flow sensor is located inside the join below the packer.

19. An apparatus as in claim 1, wherein at least one Gas-Oil Ratio sensor is located inside the join below the packer.

20. An apparatus as in claim 1, wherein at least one temperature sensor is located inside the join below the packer.

21. An apparatus as in claim 1, wherein at least one pressure sensor is located inside the joint above the pup joint in between the straddle packer that allows fluid to enter.

22. An apparatus as in claim 1, wherein at least one flow sensor is located inside the join above the pup joint in between the straddle packer that allows fluid to enter.

23. An apparatus as in claim 1, wherein at least one Gas-Oil Ratio sensor is located inside the joint above the pup joint in between the straddle packer that allows fluid to enter.

24. An apparatus as in claim 1, wherein at least one temperature sensor is located inside the joint above the pup joint in between the straddle packer that allows fluid to enter.

25. An apparatus as in claim 1, where in at least one pressure and temperature sensor is located in the submersible pump.

26. An apparatus as in claim 1, wherein a safety valve is located above the submersible pump.

27. An apparatus as in claim 1, wherein an emergency release sub is located above the submersible pump.

28. A method of servicing a hydrocarbon well using one or more sensors, one or more packers, and a submersible pump, all lowered on coiled tubing into a well that penetrates a formation; and surface well testing equipment, comprising:

    i. determining a property of a formation while flowing the well assisted by said submersible pump and using flow data measured using said surface well testing equipment integrated with pressure data measured using said one or

more sensors lowered into said well penetrating said formation on said coiled tubing;

ii. treating said formation by pumping fluid into said formation using said coiled tubing; and

iii. repeating said determining a property of a formation while flowing the well assisted by said submersible pump and using flow data measured using said surface well testing equipment integrated with pressure data measured using said one or more sensors lowered into said well penetrating said formation on said coiled tubing; wherein said coiled tubing remains deployed within said well throughout said determining, treating, and repeating said determining processes.

29. A method of servicing a hydrocarbon well in accordance with claim 28, wherein said property of said formation determined in process i) is included within a report that is created prior to process ii).

30. A method of servicing a hydrocarbon well in accordance with claim 28, wherein one or more process parameters in said treatment process ii) is determined based on said property of said formation determined in process i).

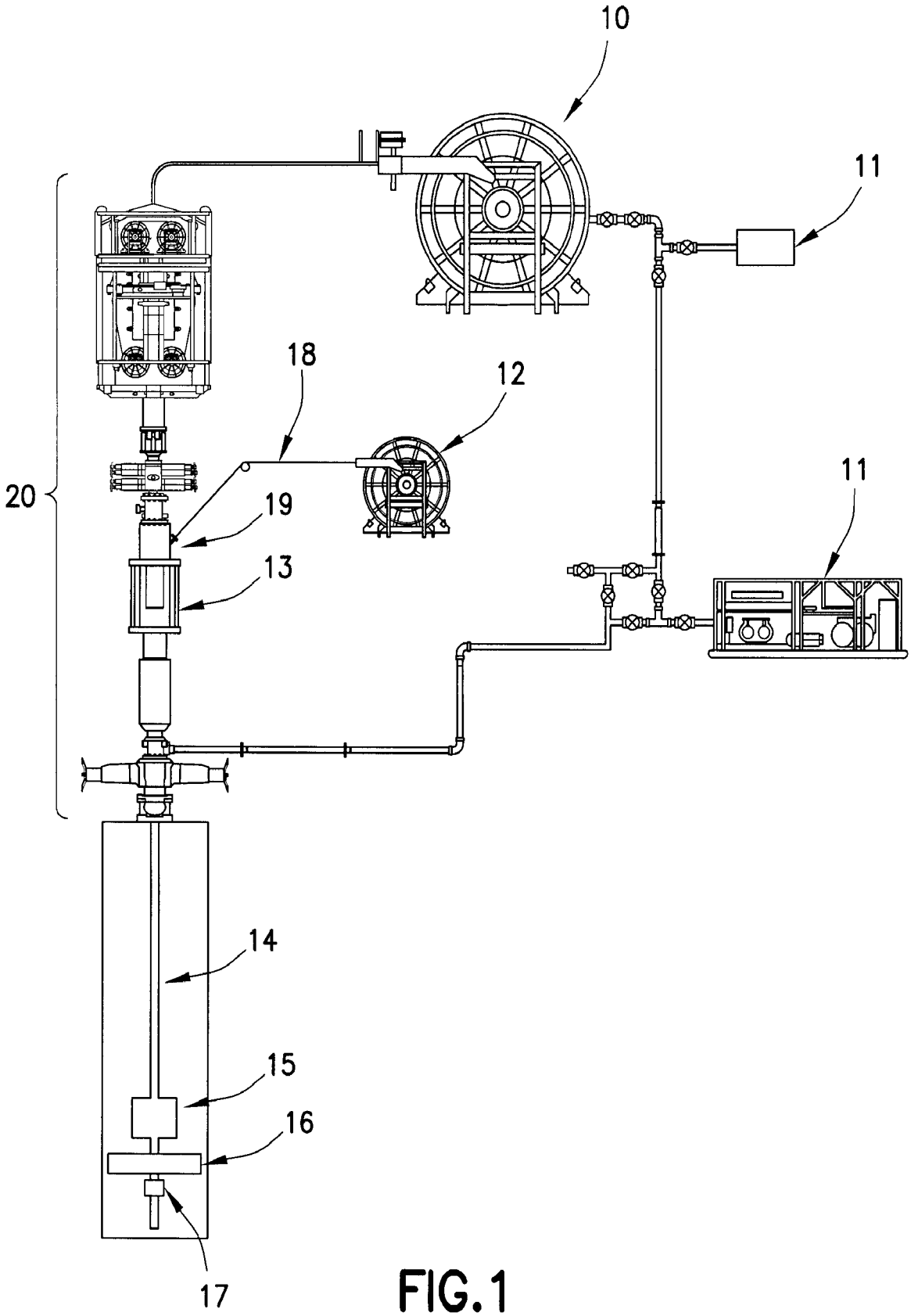


FIG.1

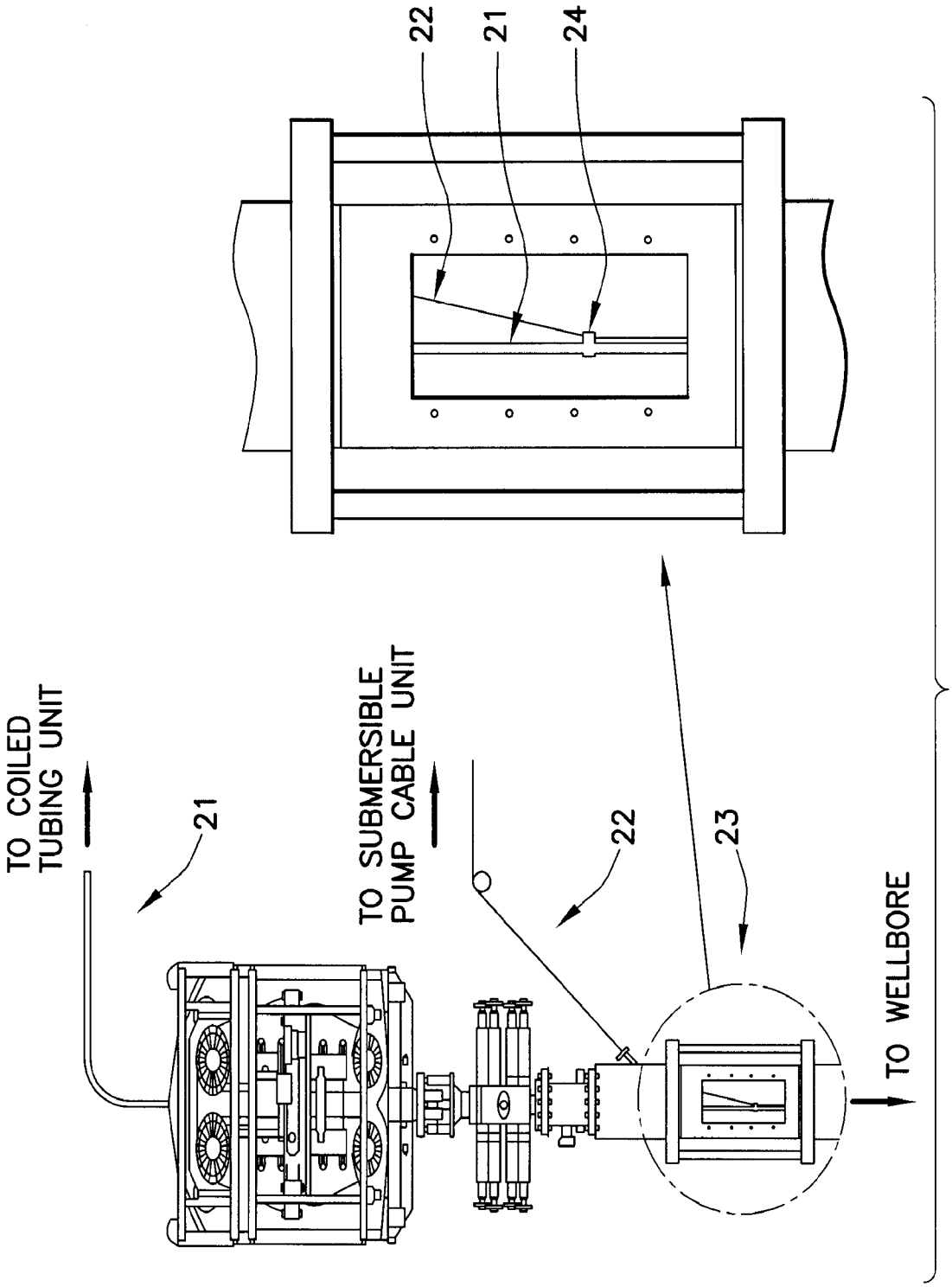

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24
TO COILED TUBING UNIT
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TO SUBMERSIBLE PUMP CABLE UNIT
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TO WELLBORE

FIG.2

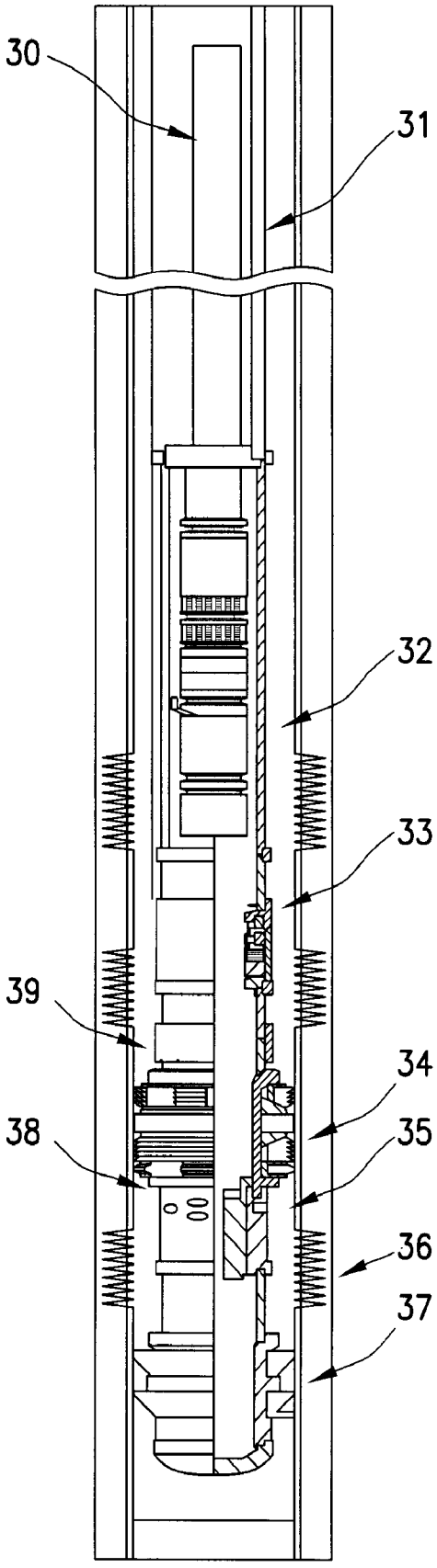


FIG.3