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(54) **METHOD OF CONDUCTING IN SITU MEASUREMENTS OF PROPERTIES OF A RESERVOIR FLUID**

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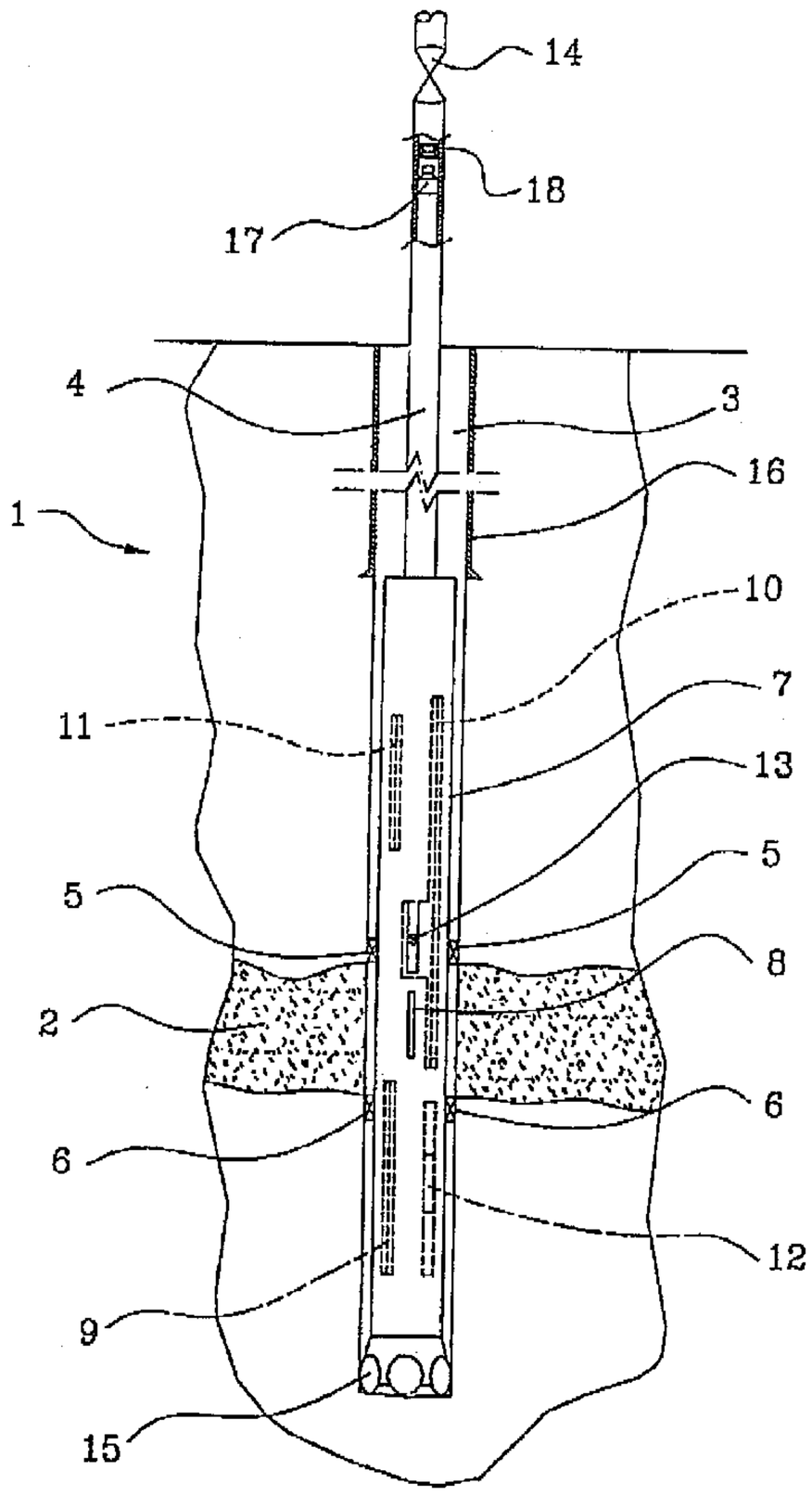
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(57) **ABSTRACT**

When conducting in situ measurements etc. of the properties/parameters of a reservoir fluid, possibly in connection with analyses,use is made of a measuring instrument/apparatus-containing casing (**7**) at the upstream end of a drill string (**4**), which casing has a combined inlet/outlet facing the hydrocarbon-containing layer (**2**) of the reservoir and is in fluid communication with the bore of the drill string (**4**), in which is disposed a reciprocally sliding piston (17), the top of which—opposite the side for inflow of reservoir fluid (RF)—may be acted on by pressure through a pressurisable fluid (water or N_2) in order, on completion of the measurements, to force the reservoir fluid (RF) previously accommodated in the bore of the drill string back into the oil-containing layer of the reservoir. By so doing, a considerably capacity for accommodation of fluid is made available, represented by a drill string (**4**) upstream of a given point (the piston), with possibilities for return to source of an enormous volume of fluid. This is highly suited for subsea measuring apparatuses/instruments that—in order to give results with a very high degree of accuracy—require very large flow rates of test fluid.



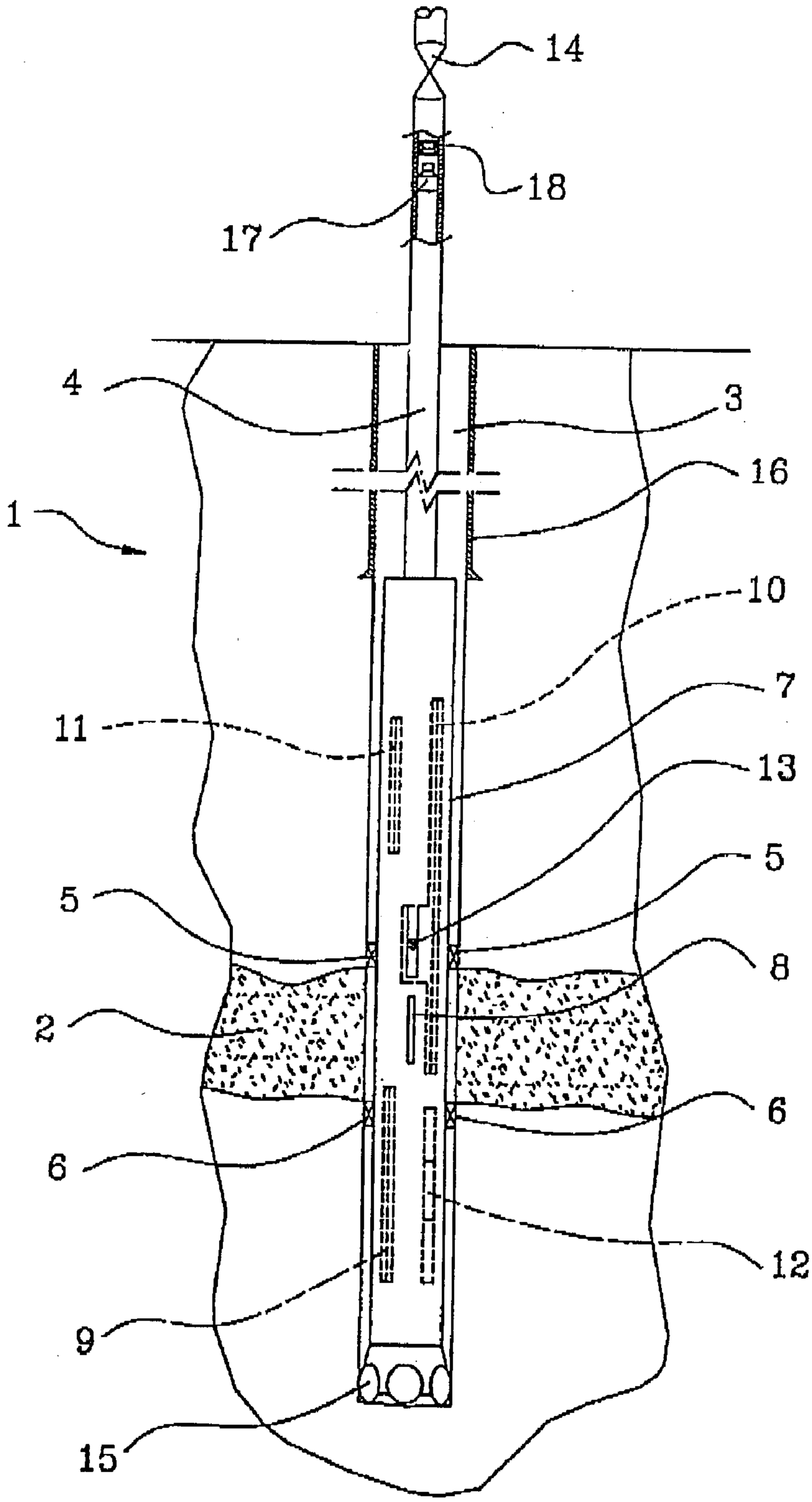


Fig. 1

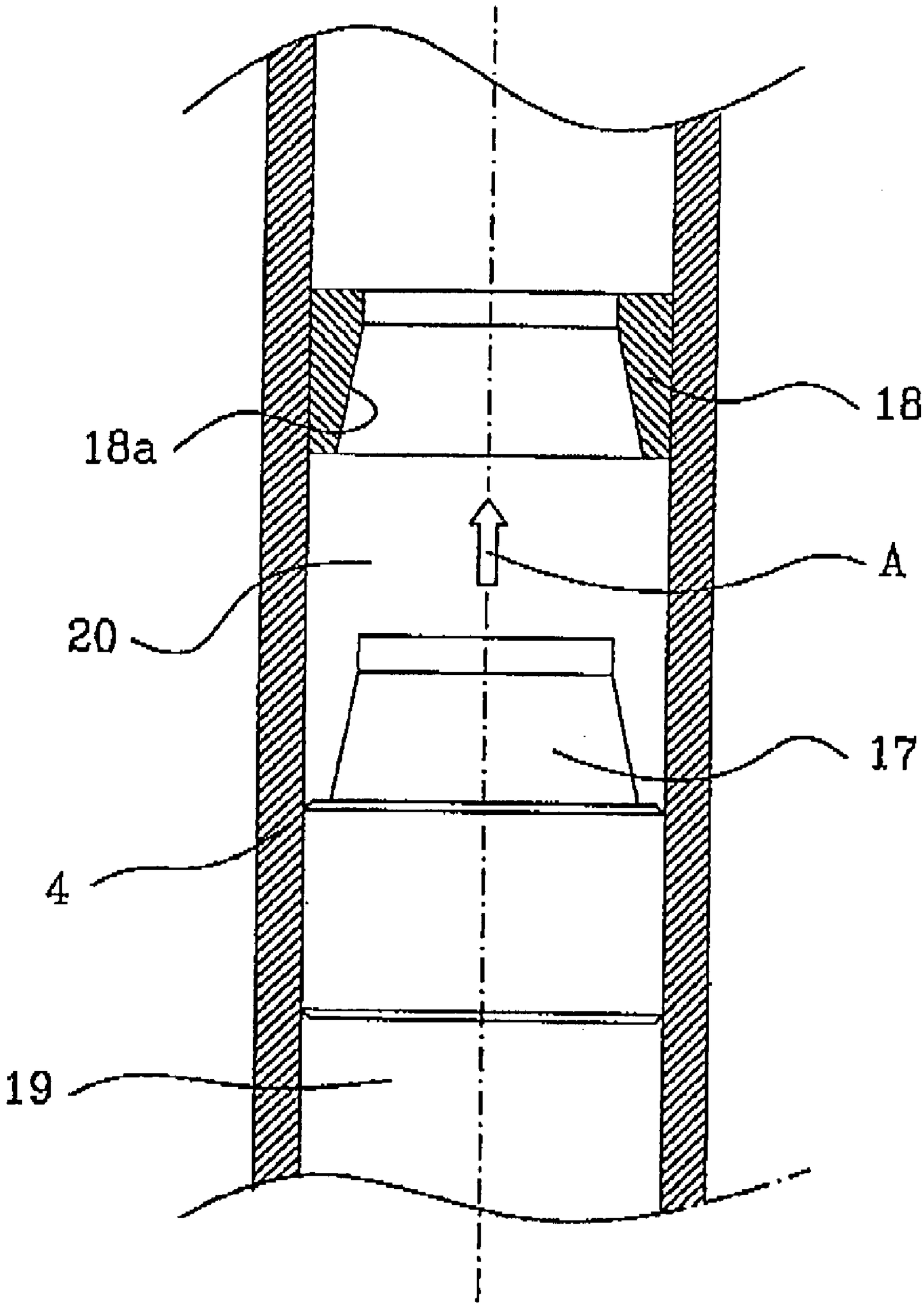


Fig. 2

METHOD OF CONDUCTING IN SITU MEASUREMENTS OF PROPERTIES OF A RESERVOIR FLUID

[0001] The invention regards a method of conducting in situ measurements of properties of reservoir fluids by means of measuring instruments/apparatuses enclosed in a casing connected to the outer, free end of a string of tubulars in a wellbore/well that extends at least down to the hydrocarbon-containing layer of the reservoir, where the inherent pressure of the reservoir fluid (the reservoir pressure) ensures the inflow of reservoir fluid to the instrument/apparatus casing through an inlet or possibly a combined inlet/outlet, and where signals that are generated via electronics etc. on the basis of measurement results obtained in situ, are transmitted further to the surface position, possibly for further analysis.

[0002] The use of new technology for, among other things, drilling and production in ground formations with high temperatures and pressures, the injection of water and gas to increase the degree of recovery, multiphase production on the seabed and transport of produced hydrocarbons through seabed pipelines place increasingly stringent demands on the exactitude of the knowledge that is required of the physical and chemical properties of the gas, oil and water to be produced from the deposit. Previously, such knowledge of the reservoir fluid in the ground formation was normally obtained through full production testing. Today however, there is a definite tendency towards an increased use, of various sampling tools that may be run into and out of the well during drilling, by means of a wire string. However this last method allows fewer possibilities for obtaining data regarding relevant reservoir fluid parameters than that which is possible with full production testing.

[0003] The above methods each have different advantages and disadvantages. The strong point of full production testing is that data may be collected from a large volume of reservoir fluid, ensuring highly reliable data. The main weak point is the great costs incurred, for instance when hiring a rig and other necessary equipment. Another significant disadvantage is that it will be necessary somehow to handle the large volume of reservoir fluid that is transported up to the surface. At present, this is normally done by burning the oil and gas, which is damaging to the environment. Consequently, the oil companies aim to cease such burning after 2003. Essential advantages of the use of sampling and measuring equipment that is lowered into the well by a wire string, is that it allows continuous sampling of the reservoir fluid during drilling, and that it may be carried out at a considerably lower cost than full production testing. In addition, there is no need to burn oil and gas. As already mentioned, the main weak point of the equipment is the limitations on what the equipment can provide in the way of data regarding relevant reservoir fluid parameters. As an example, it is not possible to obtain essential data regarding the flow conditions in the reservoir fluid. Also, the equipment can not be used in connection with saturated gas reservoirs, as the pressure and temperature can not be stabilised. This weakness is further enhanced in consequence of very small volumes of reservoir fluid being extracted, and of the equipment having to be manipulated from the surface. The latter fact may in addition lead to the measurement results for the reservoir fluid becoming unreliable. Such errors in the measurement results may among other things be due to the equipment not being positioned correctly in the reservoir during sampling, to the reservoir fluid at the sampling location having been contaminated by the drill fluid used during drilling, and to sand that follows the reservoir fluid upon sampling causing cracks and leakage in the equipment.

[0004] Conducting such in situ measurements by means of measuring instruments/apparatuses is known per se, where the instruments/apparatuses are enclosed in a casing that is lowered into the area of the hydrocarbon-containing layer of a reservoir by a tubular string that may be lowered/raised in a wellbore/well, and where the instrument/apparatus casing has an inlet, e.g. incoming in a combined inlet/outlet, for the forced entry of the reservoir fluid under utilisation of the inherent pressure of this in situ (the reservoir pressure). Likewise, leading the reservoir fluid that was admitted to the instrument/apparatus casing in which the measurements were conducted by means of suitable instruments/apparatuses, back to the hydrocarbon-containing layer of the reservoir is known per se.

[0005] Thus U.S. Pat. No. 5,095,745 describes a sampling tool with an analysis chamber, which following the analysis delivers the well fluid back to the isolated oil-containing layer. More specifically, this US patent specification discloses a method and an apparatus/tool for testing subsea formations, in particular formations exhibiting a very particular permeability. This known device comprises a well fluid-receiving chamber provided with a piston that may be moved in a reciprocal motion in the chamber. The length of stroke for the piston is very limited and is determined by the dimensions of the chamber in the axial direction of the piston, and the device is therefore unsuitable for certain measurements that require the passage of a substantial volume of fluid into and through the casing of the measuring instrument in the space of a certain period of time.

[0006] U.S. Pat. No. 5,201,220 describes a gas detector module with a flow line that returns the formation fluid to the well after analysis. In this known test arrangement, test fluid (multiphase fluid, possibly containing gas) that is temporarily collected in the angled pipe of the detector has no other means of escape than being returned to the well after analysis. A multi-core cable in this subsea arrangement is only intended for transmission of electrical signals, and the processing system is located at a higher level than the wellbore, possibly at a surface position. This known arrangement is however not usable for in situ measurements that require a considerable flow of reservoir fluid through the measuring instrument, where it flows through at a relatively high rate of flow for a long period of time so that the volume of fluid that has flowed through the measuring instrument, respectively instruments, possibly continuously, over a period of measurement or period of measurement and analysis represents a substantial volume, which due to its scale will entail problems both in terms of receiving, handling and, in due time returning to the oil-containing layer of the reservoir, which is the layer from which the test fluid in the form of reservoir liquid was initially taken.

[0007] U.S. Pat. No. 5,799,733 describes a system in which no provisions have been made for return of the liquid reservoir fluid to the exact same hydrocarbon-containing layer from which it was previously taken for measurement/analysis purposes. This known system is to allow fluid

sampling and measurements, and comprises a powered formation pump as an essential component. The subsea-operating device that forms part of this system, and which includes said pump, is connected to a production string. During operation, the production string provides the transfer of motive fluid that is pumped from a surface position to drive the subsea rotary motor for the formation pump. Pumping of in situ fluid to be tested into a sampling pipe takes place via said pump.

[**0008**] As mentioned above however, subsea tests and in situ measurements/analyses do exist, which in order to ensure results with a high degree of accuracy—require a flow of considerable reservoir volumes per unit time through the respective measuring apparatuses, and also require the throughflow time to be considerably longer than that which generally applies to such subsea tests.

[**0009**] According to the present invention, the conditions of such in situ subsea fluid tests have been made suitable for large throughflow volumes and long throughflow periods for said measuring instruments/apparatuses, so that a substantial volume of reservoir fluid may be received and handled from the start of the test and until the end of it, and where provisions are also made for return of this substantial volume of test fluid to the original hydrocarbon-containing layer of the reservoir.

[**0010**] More specifically, said object is realised by a method of the type mentioned at the beginning, where, moreover, the procedure is as stated in the characterising part of claim 1.

[**0011**] In accordance with the present invention, measurements such as flow or volume measurements are thus initiated with the instrument/apparatus casing in said in Situ position and in fluid communication with the string of tubulars, which measurements are of the type that—in order to obtain measurement results with a high degree of accuracy—require the respective measuring instrument positioned in situ to have a throughflow of a substantial volume of test fluid for a considerable throughflow period. This substantial volume of fluid is then received and handled for subsequent return to the original oil-containing layer of the reservoir, by being passed into the string of tubulars in fluid communication with the measuring instruments/apparatuses-containing casing. The flow of the test fluid into the inlet of the instrument casing (combined inlet/outlet) takes place in a known manner under utilisation of the inherent pressure of the reservoir fluid (the reservoir pressure), which also ensures that liquid fluids that have flowed through a respective measuring instrument is led further into and up through the bore of the string, in which is arranged a freely reciprocating piston that may be influenced by pressurised fluid both upstream (by the reservoir fluid when it flows out of the oil-containing layer) and downstream (from a fluid such as water or N_2) on the opposite, upper side of the piston, which fluid may be pressurised by pumping action and increase the pressure in the bore of the string at the downstream end of the piston, so that a build-up of pressure takes place here, which pressure will, after a while, exceed the pressure of the reservoir fluid by the upstream end of the piston. This effects a downward movement of the piston and a displacement of the underlying test reservoir fluid, which is gradually forced back into the instrument casing and thence out into the hydrocarbon-containing layer of the reservoir.

[**0012**] So during the measurement/analysis process, a piston separates the reservoir fluid, which has had an opportunity to flow through respective measuring instruments in the casing and then up into the bore of the tubular string, from water or N_2.

[**0013**] Said water or N_2 is also used to force drilling mud/fluid from the drill string or production string and out into the surrounding annulus formed between the tubular string and the borehole wall.

[**0014**] After perforation in a manner that is known per so, the piston will travel upward upon admission of reservoir fluid at a rate that is controlled by a valve/choke. The inflow of reservoir fluid can thereby be measured by reading the volume of fluid (preferably water or N_2) that has flowed into a tank on the surface during the inflow. When the reservoir fluid. has risen in the string to a level where the fluid has reached the safety valve, often called BOP, on the seabed or the surface, the piston is brought to a halt in a seat inserted in the tubular string. All the desired tests have then been conducted downhole, and the reservoir fluid is forced back to the reservoir as indicated above.

[**0015**] Uniform pressure data are obtained, due to the stabilised flow rate into the instrument casing. Further that the sampling, flow or volume measurements or the other analyses can be carried out by use of whatever equipment is available at any time, to allow as much data as possible regarding relevant reservoir fluid parameters to be collected, that trace elements allow reliable flow measurements to be conducted in the reservoir fluid that has been introduced into the tubular string, and that the reservoir fluid may be returned from the tubular string to the ground formation following completion of the sampling, flow and volume measurements or the other analyses.

[**0016**] A more detailed account of a preferred embodiment of the invention will be given with reference to the appended drawings, in which:

[**0017**] **FIG. 1** shows a schematic cutout in the lower part of an exploration well being drilled in a ground formation;

[**0018**] **FIG. 2** is a large-scale detail drawing, partly with a section through the tubular string, and in which the piston movably arranged in the bore of this, and stationary seat for same, may be seen.

[**0019**] The well is drilled by means of drilling equipment comprising a drill bit **15** with an associated drill string **4**, the in situ sampling, and flow and volume measurements or the other analyses in the reservoir fluid being carried out by use of equipment provided inside an associated casing **7** that encloses the drill string above the drill bit **15**. The well is sealed off in an area by the hydrocarbon-containing layer **2** of the formation by means of packings **5**, **6** that are arranged externally on the casing **7** and have expanded to abut the wall of the borehole in a sealing manner. Some parts of the casing have been omitted, so that certain components of the equipment for sampling, flow and volume measurements or other analyses can be indicatively outlined in the figure.

[**0020**] In the embodiment of the invention, it is adapted to use in in situ sampling, flow and volume measurements, and any other analysis in reservoir fluid that is encountered in a ground formation **1** during drilling of an exploration well **3** for hydrocarbons but there is obviously nothing to prevent

the present invention from being used in a different context, e.g. in a ground formation that has already been put into full production. As mentioned above, the aim is, among other things, for typical properties or parameters of the reservoir fluid that is encountered in the ground formation **1** to be determined with the greatest possible degree of accuracy, without a large volume of hydrocarbons having to be brought out of the well **3** and up to the surface. Thus the well **3** is sealed off in an area immediately above and below (by **5** and **6**) the hydrocarbon-containing layer **2** of the ground formation **1**. Then reservoir fluid from the hydrocarbon-containing layer **2** is introduced to a drill string **4** that has at least been passed through the sealed-off area of the well **3**. The sampling, the flow and volume measurements and the other analyses in the reservoir fluid are conducted in the sealed-off area of the well **3**. Preferably this will only take place when the drill string **4** has been closed off and filled with incoming reservoir fluid. With that, the sampling and respective measurements or analyses are only conducted after a large volume of reservoir fluid has been introduced into the drill string **4**. This allows samples or measurements to be taken in a reservoir fluid that has stabilised after drilling, and which essentially contains no drill fluid. This as a consequence of, among other things, the previously mentioned piston **17** separating the reservoir fluid RV in chamber **19** below the piston **17** from the above water or N_2.

[**0021**] Said water or N_2 may in an initial position or in a transitional position be pressurised in order to force drilling mud/fluid from the drill string/production string **4** and out into the annulus **3**. Following perforation, the piston **17** will travel upward (arrow A) into the string **4** as reservoir fluid RV is admitted into the drilling section **19** located below the piston **17** and expands as the piston **17** is moved up. After the sampling and respective measurements have been completed through use of the sampling, measuring or analysis equipment **9-12** that has been introduced into the well **3** together with the drill string **4**, the reservoir fluid from the drill string **4** is returned to the hydrocarbon-containing layer **2** of the ground formation **1** in a suitable manner. Then the sampling, measuring or analysis equipment **912** is withdrawn from the well **3** along with the drill string **4**, in order to allow the small amount of reservoir fluid that comes up to the surface with it to be examined more closely in the laboratory. This avoids a large volume of reservoir fluid having to be carried to the surface, as mentioned previously.

[**0022**] It should be mentioned that the well **3** is only sealed off following a stop in drilling after the respective hydrocarbon-containing layer **2** of the ground formation **1** has been passed. The drilling may if necessary continue down towards underlying layers (not shown), in order for these to be sampled, measured or analysed in a similar manner.

[**0023**] Prior to the sampling, flow and volume measurements or the other analyses, the well **3** will normally be logged and washed out before being sealed off. The washout can be carried out by means of a detergent that is circulated in the well **3**. When reservoir fluid is then introduced into the drill string **4**, the drill fluid is circulated out through a suitable valve between the drill string **4** and the annulus formed between the wall of the borehole and the drill string **4**, and the drill fluid is transported further from the annulus for storage in tanks or similar (not shown) on the surface. By so doing, the drill fluid is replaced by a gas/liquid (N_2/water) that is known and prepared for the test phase by use of added trace elements. A mention is made above of the fact that the sampling, flow and volume measurements or the other analyses is are conducted continuously, and after the drill string has been filled with reservoir fluid in a controlled manner by means of a downhole valve. However this does not prevent the sampling, flow and volume measurements or the other analyses from being carried out at another appropriate time. This may for instance be the case when it is desirable that continuous measurements be carried out during the introduction of the reservoir fluid into the drill string **4**.

[**0024**] For the rest, the set of figures show an exploration well **3** drilled in a manner that is known per se, by means of a drill bit **15** with an associated drill string **4**, and in which the pressure is equalised during drilling by use of a drill fluid with added trace elements. The drill string **4** may for instance be coiled tubing etc. Above the drill bit **15**, the drill string **4** is enclosed in an associated casing **7** having a length that may be greater than the height of the hydrocarbon-containing layer **2** of the ground formation **1**. The casing **7** may be made from steel that is highly resistant against the effects of an acid environment with a high content of chlorides. The respective end of the casing part **7** is attached to the drill string **4**, or possibly the drill bit **15**, in a pressure tight manner. Moreover, the well **3** may be equipped with a liner **16** that has either been terminated above or passed through the hydrocarbon-containing layer **2**. In the latter case, the liner must be perforated at said layer **2** before samples can be taken.

[**0025**] As mentioned, the casing **7** is provided with external expandable packings **5**, **6** spaced apart by a distance corresponding to the depth of the oil-containing layer **2**, so as to allow the well **3** to be sealed off. The respective packings **5**, **6** are positioned by the upper and lower side of the hydrocarbon-containing layer **2**. It is obviously possible to position the packings **5**, **6** in a different manner from that which is shown, for instance by a middle section of said layer **2** only. The packings **5**, **6** may be of any suitable type. It should be mentioned that the casing part **7** is centred in the well **3** when the packings **5**, **6** are expanded to sealing engagement with the wall of the borehole. The length of the casing part **7** and the positioning of the packings **5**, **6** are determined on the basis of prior seismic investigations of the ground formation **1**. Otherwise, the casing part **7** is provided with at least one openable port **8** or similar to allow the reservoir fluid to be admitted to and returned from the drill string **4** via the casing part **7**.

[**0026**] Inside the casing part **7**, the drill string **4** is equipped with a suitable valve arrangement **13** designed to let the reservoir fluid pass into or out of the drill string **4** during the introduction from and return to the ground formation **1**. Furthermore, the upper end of the drill string **4** is provided with a further valve arrangement **14** designed to let the drill fluid pass into or out of the drill string, depending on whether reservoir fluid is being introduced into or returned from this, as described earlier. When there is reservoir fluid in the drill string **4**, the drill fluid is stored e.g. in tanks (not shown) on a drill ship (not shown). In addition, the latter valve arrangement **14** is designed so as to allow the drill string **4** to be closed off when the added reservoir fluid has reached the upper valve arrangement **14** (as an example,

a BOP), or at any other required level in the drill string **4**, by a fluid-separating piston **17** (not shown) being brought to a halt in a seat **18**.

[**0027**] Furthermore, the casing **7** is provided with the equipment necessary for taking the samples and conducting the measurements that are required in order to map out the relevant properties or parameters of the reservoir fluid.

[**0028**] Said sampling and measuring equipment is selected from that which is commercially available at any time. Clearly, the casing **7** may be equipped with other sampling and measuring equipment than that referred to in the following. Sampling may for instance be conducted by use of single-phase containers **9** for oil, gas and water. Measurements of e.g. temperature, pressure, H_2SO and SO_4 contents, pH-conductivity, density and Cl-value etc. may be conducted by means of a sensor string system **10**. PVT-values (pressure, volume, temperatures), IR (infrared radiation) may be measured by means of an acoustic resonance spectroscopy sensor system **11**. In order to measure the flow in the reservoir fluid, the casing part has equipment **12** for addition of suitable trace elements for oil, gas and water in the reservoir fluid, and said trace element may be added to the reservoir fluid. Preferably, the addition takes place while the drill string **4** is being filled and until this has been filled with reservoir fluid and closed off by the upper valve arrangement **14**. For the rest, the casing **7** is equipped with an acoustic communication system (not shown) to allow a large number of sensor systems for various types of measurements to be placed in the casing part in the desired combinations. Said communication system consists of small and intelligent communication units that are connected to the various sensors in the casing **7**. Thereby, the measurement results from the respective sensors may be transmitted acoustically to a logging or telemetry unit (not shown) on the surface without the use of a communication cable. This is advantageous, as the transmission of signals by cable is normally highly problematic in small diameter tools, due to the complexity of the sensors or moving parts in the tool. When the sampling and measuring of the reservoir fluid has been completed and the reservoir fluid has been returned from the drill string **4** to the ground formation **1**, the casing **7** with associated equipment **9-12** is pulled up to the surface together with the drilling equipment, whereupon the equipment in question is disconnected from the casing **7** and brought to the laboratory for a more detailed examination of the reservoir fluid.

[**0029**] In the description of the embodiment, it is stated that the reservoir fluid is introduced into and returned from the drill string **4**. There may however be cases in which the present invention is used in such a context that the drill string is e.g. a production string or an associated test string running along the drill string **4**, preferably between the drill bit **15** and the valve arrangement **14** by the surface.

[**0030**] Furthermore, a case may be envisaged in which it is more appropriate for the casing **7** to be positioned further up the drill string, instead of in the position shown down by the drill bit **15**. Likewise, more than the one casing part **7** shown may be provided, each with associated equipment for sampling and measuring, **60** that simultaneous samples and measurements may be taken from different layers of the ground formation.

[**0031**] The significant travelling distance of the piston **17** up through the drill string **4** is limited in such a manner that when the reservoir fluid RV, due to its inherent pressure (the reservoir pressure), has risen high enough in the drill string **4** for the fluid to reach the blowout preventer on the seabed or the surface, the-piston **17** is halted in a seat **18** having a through passage **18***a* in the axial direction of the drill string, **FIG. 2**. In the string section **20** above the piston, the bore of the string is preferably filled with water or N_2.

1. A method of conducting in situ measurements of properties of reservoir fluid by means of measuring instruments/apparatuses enclosed in a casing (**7**) connected to the outer, free end of a tubular string (**4**) that is movable in a wellbore/well (**3**) extending at least down to the hydrocarbon-containing layer (**2**) of the reservoir, where the inherent pressure of the reservoir fluid (the reservoir pressure) ensures the inflow of reservoir fluid into the instrument/apparatus casing (**7**) through an inlet (**8**), or possibly a combined inlet/outlet, and where signals that are generated electronically on the basis of measurements obtained in situ are passed on to the surface position, possibly for further analysis, charactarised in that measurements are initiated with the instrument/apparatus casing (**7**) in said in situ position and in fluid communication with the drill string (**4**), e.g. flow and/or volume measurements of the type that—in order to achieve measurement results with a high degree of accuracy—require a substantial volume of fluid, normally in the form of a multiphase fluid to pass through a passage with a given cross section in the respective measuring instrument/apparatus, which substantial volume of fluid in the form of reservoir fluid downstream of the respective measuring instrument/apparatus, referred to the direction of flow, is led from said instrument/apparatus casing (**7**) into the drill string (**4**) that is in fluid communication with same, again while utilising the inherent pressure of the reservoir fluid, the drill string (**4**) in use exhibiting such longitudinal extent and cross section of bore as enables it to accommodate a substantial volume of reservoir fluid that has flowed through the respective measuring instrument/apparatus for measurement purposes, and that a piston that may reciprocate freely in the bore of the drill string (**4**) and may be acted on from both sides by compressed fluid, is positioned so as to start in its upstream position at the start of the measuring operations, which position is immediately downstream of the instrument/apparatus casing, by means of reservoir fluid flowing into the bore of the drill string, which fluid has passed through said in situ measuring instrument/apparatus, is forced in the direction away from the instrument/apparatus casing (**7**) by the inherent pressure of this fluid, the downstream fluid is pressurised at the close of the measuring operation in order to reverse the direction of travel of the piston, the in the downstream direction displaced piston forcing the reservoir fluid admitted into the drill string out again into the hydrocarbon-containing layer (**2**), in a manner that is known per se.

2. A method according to claim 1, characterised in that the drill string (**4**) is closed off by a valve arrangement (**14**) at its upper end when it has been filled with reservoir fluid that has passed through a measuring apparatus in the casing (**7**) in the hydrocarbon-containing layer (**2**) of the reservoir.

3. A method according to claim 1 or **2**, characterised in that trace elements are added to the reservoir fluid that is introduced into the drill string, from a trace element feeder disposed in the casing (**7**).

4. A method according to claim 1, characterised in that—in an initial operation—mud/drill fluid in the drill string **(4)** on the upstream side of the piston (referred to the bottom of the well) is forced out into the annulus by said water/N_2 in the drill string **(4)** on the opposite side of the piston (downstream side), whereupon the bore of the drill string is ready to accommodate the reservoir fluid as it enters after having passed through a measuring apparatus for flow and volume measurements in the casing **(7)**.

5. A method according to claim 1, characterised in that the piston is brought to a halt in its upward movement in the drill string **(4)** by means of an internally thereof positioned seat/stop **(18)** with a through opening, against which seat the piston abuts and which seat is placed at a significant distance downstream of the apparatus/instrument casing **(7)**.

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