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(54) **2d Well Testing with Smart Plug Sensors**

(57) An apparatus for characterising the permeability of a formation surrounding a wellbore, comprising: a drillstem test (DST) tool comprising, a packer for isolating a zone of the wellbore, a valve for controlling fluid into and out of the zone via the drill string of the tool and, a pressure gauge for detecting the pressure in the zone;

wherein the apparatus further comprises an array of at least two antennas arranged on the tool above the packer such that when in use each antenna of the array aligns with a corresponding pressure sensor placed in the formation to obtain pressure measurements and therefore allow horizontal and vertical permeability to be determined.

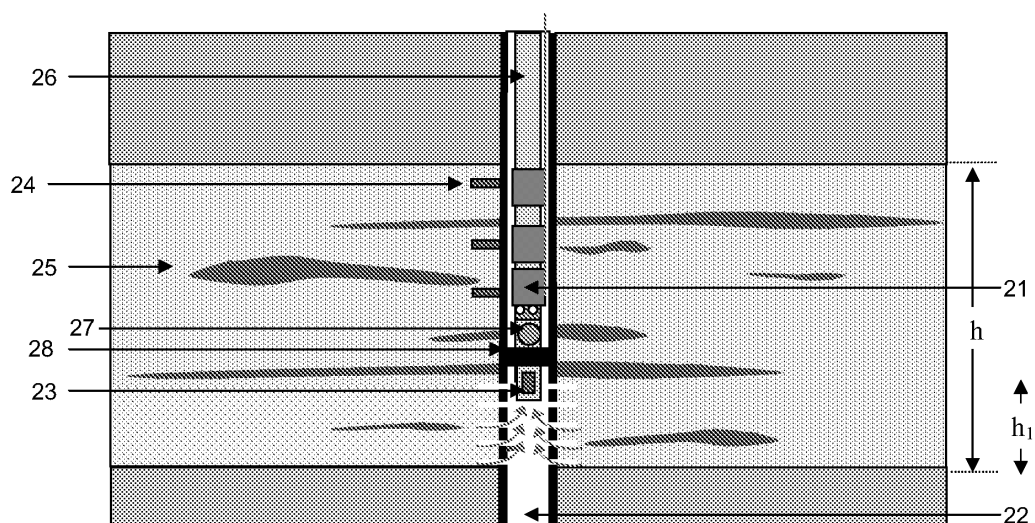


Figure 2

Description

Technical Field

5 **[0001]** This invention relates to an apparatus for characterising the permeability of a formation surrounding a borehole well. In particular permeability is determined by measuring the formation and borehole pressure in oil, gas or similar wells.

Background Art

10 **[0002]** Once a well has been drilled, a well test is usually performed to characterise the formation surrounding the borehole. Properties such as skin, permeability, porosity of a reservoir, and production capacity are some the properties used to characterise the formations. Knowing how fluids flow through a reservoir is important for managing hydrocarbons reserves. Fluid flow is governed by the permeability of the formations.

15 **[0003]** A conventional well test can determine formation properties from pressure measurements obtained by a drillstem test (DST) tool as shown in Figure 1. In a conventional well test operation transient well test conditions are applied to the well and the pressure below a tester valve is measured. The valve is shut off causing a pressure build up which is recorded. This build up is interpreted and can lead to the determination of a series of well/formation parameters such as: skin, permeability, reservoir pressure and distances to boundaries. However often formations are not homogenous in quality and will have layering features. In such cases the results obtained in terms of reservoir properties from testing the whole thickness, h , is representative of some average of the individual layer permeability which is not really useful to a reservoir engineer for assessing the potential of the well or the field under evaluation.

20 **[0004]** Such a test only provides a one dimensional characterization that is only valid for perfectly homogenous medium. Because most formations are not homogenous but rather show a layering structure, a single pressure measurement does not sufficiently characterize each individual layer component. In addition it is not possible to obtain a characterization of the vertical permeability from the results of a single probe.

25 **[0005]** It is also known to measure the pressure of formation surrounding the borehole using sensors placed into the formation. US6693553 describes deploying sensors into the formations as the wellbore is being drilled. An antenna that can communicate with the sensor is located on the downhole tool. US6070662 describes deploying sensors into the formations and placing an antenna in the casing to communicate with the sensor.

30 **[0006]** However these methods only result in a single pressure measurement and do not simultaneously measure the pressure at different depths of the borehole and therefore are not sufficient to characterise each individual layer component of a formation in a single test.

35 **[0007]** WO2006008172 describes a method for estimating the permeability distribution of a formation surrounding a borehole. An acoustic emitter located either on the surface in the borehole excites a portion of the formation with an acoustic signal. An acoustic receiver located within the borehole measures the acoustic response. This acoustic response can be used to assess a formation pressure from which the permeability of the formation can be estimated. Conventional well test pressure measurements can also be taken to estimate the permeability of the formation.

40 **[0008]** It is the object of the invention to provide an apparatus to characterise the permeability of the formation around a borehole. The invention proposes an apparatus and method for characterising the permeability of the formation in two dimensions, horizontally and vertically, by directly measuring both the borehole pressure and formation pressure.

Disclosure of the invention

45 **[0009]** A first aspect of the invention comprises an apparatus for characterising the permeability of a formation surrounding a wellbore, comprising; a drillstem test (DST) tool comprising, a pressure gauge for detecting the pressure in the well bore, a valve for controlling fluid into and out of the zone via the drill string of the tool and a packer for isolating a zone of the wellbore; wherein the apparatus further comprises an array of at least two antennas arranged on the tool above the packer such that when in use each antenna of the array aligns with a corresponding pressure sensor placed in the formation to obtain pressure measurements and therefore allow horizontal and vertical permeability to be determined.

50 **[0010]** The distance between each individual antenna of the array is determined by the placement of the sensors in the formation. Differing lengths of pipes making up the drill string can be used to alter the distance between the individual antennas.

55 **[0011]** The apparatus can further comprise an interrogating tool. The tool scans the array of antennas so that data obtained from each antenna is transmitted to the interrogating tool which conveys the information up to the surface.

[0012] Preferably the array of antenna is mounted on the outside of the DST tool.

[0013] Preferably the antennas can transmit and receive information from the sensors by wireless communication. The interrogating tool can also be used to transfer power to the sensors via the antennas. The wireless communication

and the transfer of power can be based on electromagnetic coupling or acoustic transmission.

[0014] A second aspect of the invention is a sensor system for characterising the permeability of a formation surrounding a wellbore in two dimensions, comprising: at least two sensors installed in the formation surrounding the wellbore; and an apparatus comprising, a drillstem test (DST) tool comprising, a packer for isolating a zone of the wellbore, a pressure gauge for detecting the pressure in the wellbore, a valve for controlling fluid into and out of the zone via the drill string of the tool, and an array of at least two antennas arranged on the DST tool above the packer such that each antenna of the array aligns with a corresponding pressure sensor in the formation.

[0015] A third aspect of the invention comprises a method for characterising the permeability of a formation surrounding a wellbore, comprising:

- inserting sensors into the formation surrounding the wellbore at various depths;
 - inserting an apparatus as described above in the wellbore;
 - isolating a zone of the wellbore;
 - changing the pressure in the zone by altering flow through the valve;
 - measuring the pressure of the formation at the location of each sensor and transmitting the data obtained to the array of antenna;
 - measuring the pressure in the zone with the pressure gauge; and
 - determining the horizontal and vertical permeability of the formation using the pressure measurements obtained.
- The method may be conducted in openhole or cased wells.

[0016] Preferably the spacing between the sensors is recorded as the sensors are inserted into the formation.

[0017] Preferably method further comprises positioning the antennas along the DST tool so that the spacing between the antennas is equal to the spacing between the sensors in the formation, before inserting the tool body down the wellbore.

[0018] The method can further comprise scanning the array of antennas with an interrogating tool to transfer the information from the antenna to the tool and to power the sensors.

[0019] Preferably the information from the interrogating tool is sent up-hole for surface recording and further analysis.

[0020] Preferably transmitting the data between the sensors and antenna is done by wireless mode. This can be electro-magnetic coupling or acoustic transmission.

[0021] Preferably the method is preformed using the system described above.

Brief description of the drawings

[0022] Figure 1 shows a conventional drillstem test tool arrangement.

[0023] Figure 2 shows a schematic of a two dimensional well test tool arrangement.

[0024] Figure 3 shows a schematic of a sensor plug used to detect the pressure in the formation.

[0025] Figure 4 shows an arrangement for data transmission between the sensor and array of antennas.

[0026] Figure 5 shows a schematic of the test well arrangement used to carry out the example.

[0027] Figure 6 shows the results of the wellbore and layers pressure responses of the test well.

Mode(s) for carrying out the invention

[0028] Referring to Figure 1 a conventional drill stem test tool 1 for measuring the wellbore pressure comprises a pressure gauge 2, a packer 3 and a tester valve 4. During a conventional well test, for determining properties of a formation surrounding a wellbore 5, the DST tool 1 is lowered down into a wellbore 5. The packer 3 is inflated to isolate the zone of interest, h, of the wellbore. The valve 4 is initially open and fluid can flow into the drillstring of the DST tool. The valve 4 is then closed to stop the fluid flow through the wellbore. A build up occurs below the valve 4, and the pressure is monitored as a function of time. The permeability of the reservoir is then estimated from the well test measurement. As the whole thickness, h, of the formation zone tested is often not homogenous in quality but instead comprises layering features, with separate layers of medium quality sands 6 and layers very good quality sands 7, surrounding the wellbore the result obtained merely indicates an average of the zone and does not characterise each individual layer component that may be present in the reservoir. This conventional test only provides a one dimensional horizontal characterisation of the permeability of the formation.

[0029] With reference to Figure 2 the DST tool 26 according to an embodiment of the invention comprises an array of antennas 21 located on the outside of the drill string of the tool, a pressure gauge 23, a valve 27 and packer 28. Each of the antennas 21 comprising the array are spaced apart to line up with a pressure sensor 24 in the formation 25 to receive data from the sensor. The pressure gauge 23 measures the pressure in the wellbore 22 in the perforated interval, h1, as for a conventional DST well test.

[0030] The spacing between the pressure sensors 24 is recorded as the sensors are inserted into the formation at

predetermined depths such that the spacing between each of the sensors 24 relative to each other is known. The distance between the sensors is recorded by differential measurements between the depths at which each sensor is inserted into the formation. This information is used to ensure that the antennas in the array are correctly spaced apart when preparing the tool for inserting down the wellbore so that the spacing between antennas on the array will be equal to the spacing between the sensors. These sensors 24, located at different depths of the formation, record the pressure within the formation at each of their locations. The data obtained from these measurements at different depths allows for the permeability of the formation to be characterised along the wellbore axis.

[0031] When the measurements from the sensors 24 in the formation are taken in combination with the pressure measurements obtained from the conventional DST test performed by the pressure gauge 23 a two dimensional characterisation of the permeability of the formation, in the horizontal and vertical direction, can be determined.

[0032] With reference to Figure 3 an example of a sensor plug 31, that can be inserted in the formation comprises a sensing element 32, an electronics platform 33 inside a protective housing and a communication element 34. The sensing element 32 senses the pressure in the formation and the communication element 34, such as an antenna, enables data to be received and transmitted from the sensor. The antenna transmits the pressure data recorded by the sensing element 32 to an antenna outside the formation located on tool placed down the wellbore. The power supply for electronics platform 33 is provided by embedded batteries or directly by antenna 34. To supply power via the antenna 34, the power is transferred from the tool antenna towards antenna 34 by electro-magnetic coupling between the two antennae. Rechargeable batteries can be used and recharged from the tool antenna. Energy harvesting techniques can also be used to collect energy available at the reservoir level. Vibrations induced by the downhole flow can be collected by electro-acoustic sensors and converted to electrical energy to supply the sensor electronics or recharge the battery cells. Further details of suitable sensors can be found in WO2006/005555.

[0033] With reference to Figure 4 each sensor 41 aligns with an antenna 42 of the array. The sensors 41 are inserted into the formation 44 through the casing 45 of the wellbore 46. The spacing of the sensors 41 is recorded during their insertion into the formation 44. The sensors 41 are installed in a hole through the casing so that the sensor extends between the inside and outside of the casing 45, with the sensing elements in the formation 44 surrounding the well and the communication antenna of the sensor able to communicate with the antennas in the well. An array of antennas 42 and its associated interrogating tool 47 are mounted on the outside of the drillstring 48 of the DST tool. The antennas 42 are positioned along the drillstring 48 so that their spacing is equal to the spacing between each sensor 41. The distance between each antenna 42 can be adjusted with pipes of various lengths. The drillstring 48 is inserted down into the wellbore 46 until the array of antennas 42 is proximate to the sensor 41. When the antennas 42 are aligned with their respective sensor 41, antenna coupling 49 occurs between the antenna 42 of the array located on the drillstring 48 and the antenna of the sensor 41. The sensors 41 may comprise a radioactive marker, such as a gamma ray pip-tag that allows their location in the wellbore to be sensed by the DST tool.

[0034] Data is transmitted from the antenna in the sensor 41 to its corresponding antenna 42 mounted on the outside of the drillstring 48 of the DST tool by wireless communication such as by electro-magnetic coupling or acoustic transmission. The interrogating tool 47 scans the array of antennas 42 and all the data acquired by each antenna 42 is transferred to the interrogating tool 47. This allows the data to be sent up-hole for surface recording and further analysis.

Example

[0035] A vertical test well penetrating a three layer formation as shown in Figure 5 is constructed and pressure measurements are taken using the apparatus and method of the invention.

[0036] The welltest consists of flowing layer 3 at 2000 bl/d for 24 hours followed by 48 hours of build up. The pressure response is recorded at the wellbore by gauge 53 and within the formation layers 1 and 2 by monitoring gauges 51 and 52 respectively.

[0037] An analytic model is built to have the characteristics shown in Table 1.

Table 1 - Forward model values of test well

Layer #	Thickness (ft)	k_h (mD)	k_z (mD)	Skin
1	35	70	10	-
2	20	35	4	-
3	50	150	20	0.5

[0038] The model is first run in a forward mode to simulate the pressure responses in the well bore and at the two monitoring gauges. The results are shown in Figure 6.

[0039] A non-linear regression routine is used to match the pressures transient that are previously established and to recover the individual layer permeabilities along the horizontal and vertical directions (k_h , k_z). The results are shown in Table 2.

Table 2 - Inverted values (in italics)

Layer #	Thickness (ft)	k_h (mD)	k_z (mD)	Skin
1	35	72	9	-
2	20	38	4	-
3	50	148	20	0.44

[0040] The results obtained with regards to horizontal and vertical permeabilities and skin values compare well (within 10%) with the forward model values of Table 1.

Claims

1. An apparatus for characterising the permeability of a formation surrounding a wellbore, comprising:
 - a drillstem test (DST) tool comprising, a packer for isolating a zone of the wellbore, a valve for controlling fluid into and out of the zone via the drill string of the tool and, a pressure gauge for detecting the pressure in the zone;
 - wherein the apparatus further comprises an array of at least two antennas arranged on the tool above the packer such that when in use each antenna of the array aligns with a corresponding pressure sensor placed in the formation to obtain pressure measurements and therefore allow horizontal and vertical permeability to be determined.
2. An apparatus according to claim 1 wherein the distance between each individual antenna of the array is determined by the placement of the sensors in the formation.
3. An apparatus according to any of claims 1 or 2 which further comprises an interrogating tool that can scan the array of antenna to commute the information to the surface.
4. An apparatus according to any of claims 1, 2, or 3, wherein the array of antenna is mounted on the outside of the DST tool.
5. An apparatus according to any of claims 1-4, wherein the antennas can transmit and receive information from the sensors by wireless communication and transfer power to the sensors.
6. An apparatus according to claim 5, wherein the wireless communication and power transfer is based on electromagnetic coupling or acoustic transmission.
7. A sensor system for characterising the permeability of a formation surrounding a wellbore in two dimensions, comprising:
 - at least two sensors in the formation surrounding the wellbore; and an apparatus comprising, a DST tool comprising, a packer for isolating a zone of the wellbore, a pressure gauge for recording the pressure in the zone, and a valve for controlling fluid into and out of the zone via the drillstring of the tool, and an array of at least two antennas arranged on the tool above the packer such that each antenna of the array aligns with a corresponding pressure sensor in the formation.
8. A method for characterising the permeability of a formation surrounding a wellbore, comprising:
 - inserting sensors into the formation surrounding the wellbore at various depths;
 - inserting an apparatus as claimed in any of claims 1-6 in the wellbore; isolating a zone of the wellbore;
 - changing the pressure in the zone by altering flow through the valve; measuring the pressure of the formation at the location of each sensor and transmitting the data obtained to the array of antenna;

measuring the pressure in the zone with the pressure gauge; and
determining the horizontal and vertical permeability of the formation using the pressure measurements obtained.

5 **9.** A method according to claim 8 comprising recording the spacing between the sensors as the sensors are inserted into the formation.

10 **10.** A method according to any of claims 8 or 9, comprising positioning the antennas along the DST tool so that the spacing between the antennas is equal to the spacing between the sensors in the formation, before inserting the DST tool down the wellbore.

15 **11.** A method according to any of claims 8, 9, or 10, comprising scanning the array of antennas with an interrogating tool to power the sensors and transfer the information from the antennas to the tool.

20 **12.** A method according to claim 11 comprising sending the information from the interrogating tool up-hole for surface recording and further analysis.

25 **13.** A method according to any of claims 8-12, when transmitting the data between the sensors and antenna is done by wireless mode.

30 **14.** A method according to any one of claims 8-13 when performed using the system according to claim 7.

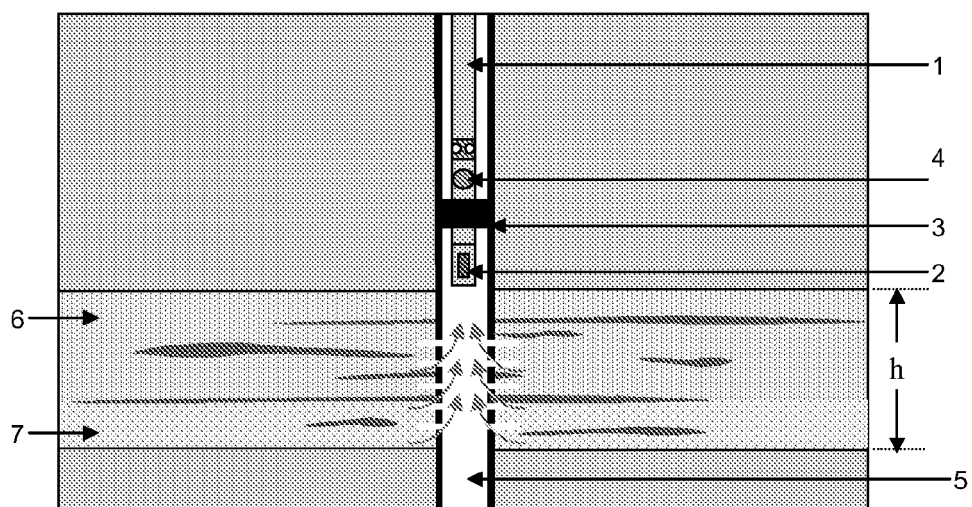


Figure 1

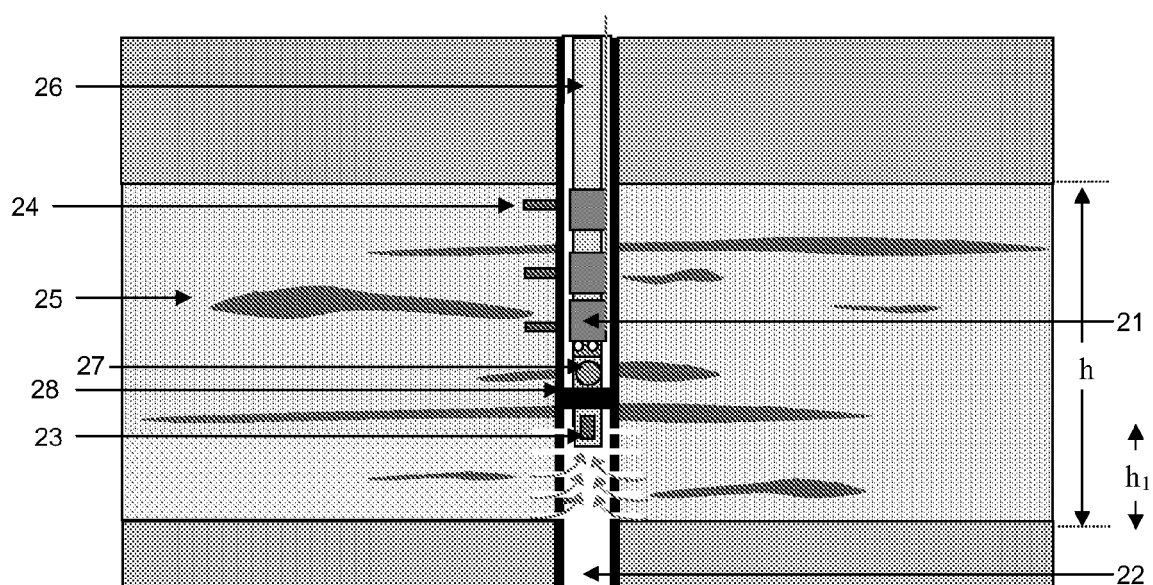


Figure 2

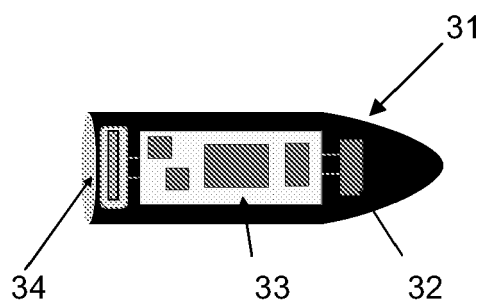


Figure 3

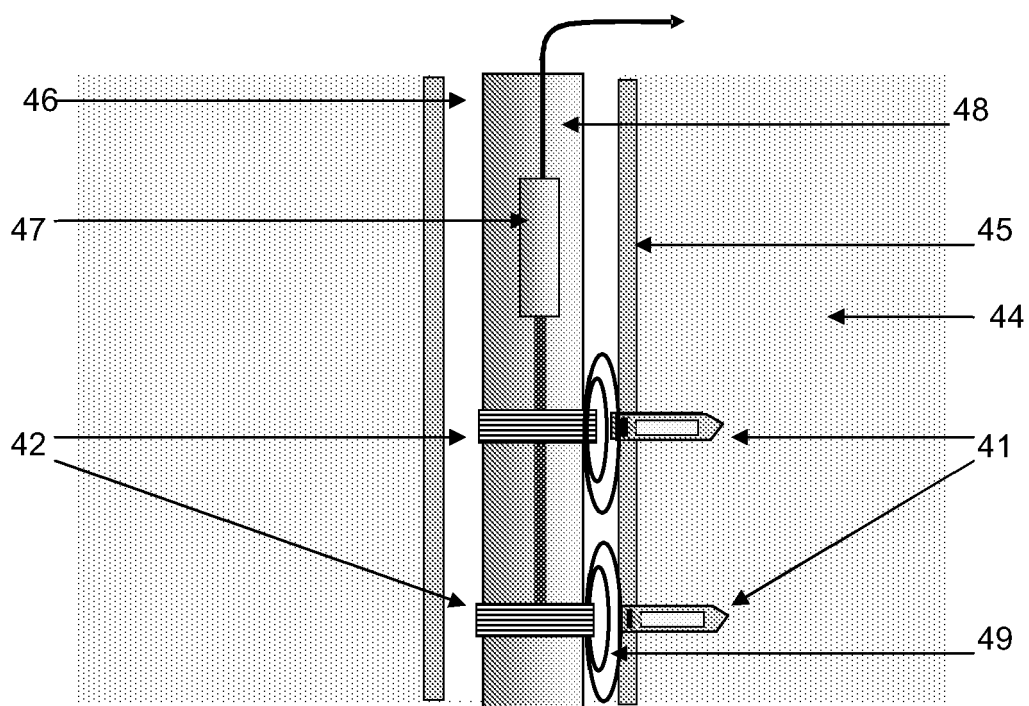


Figure 4

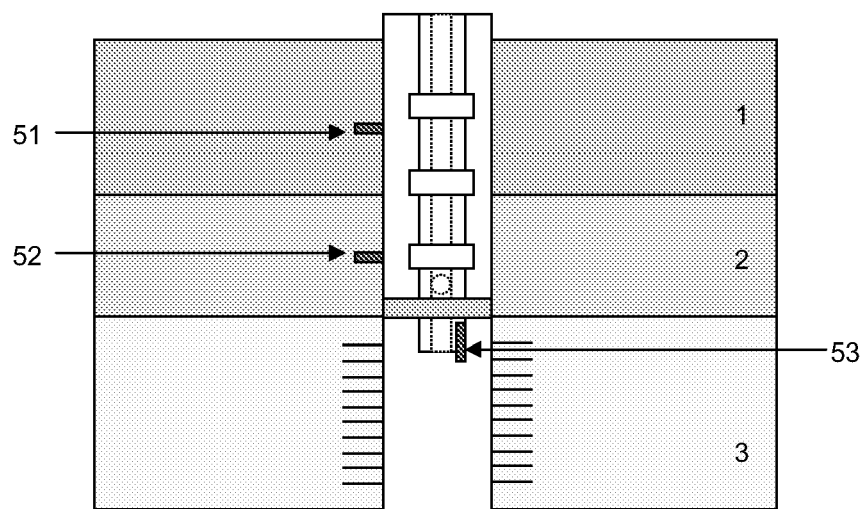


Figure 5

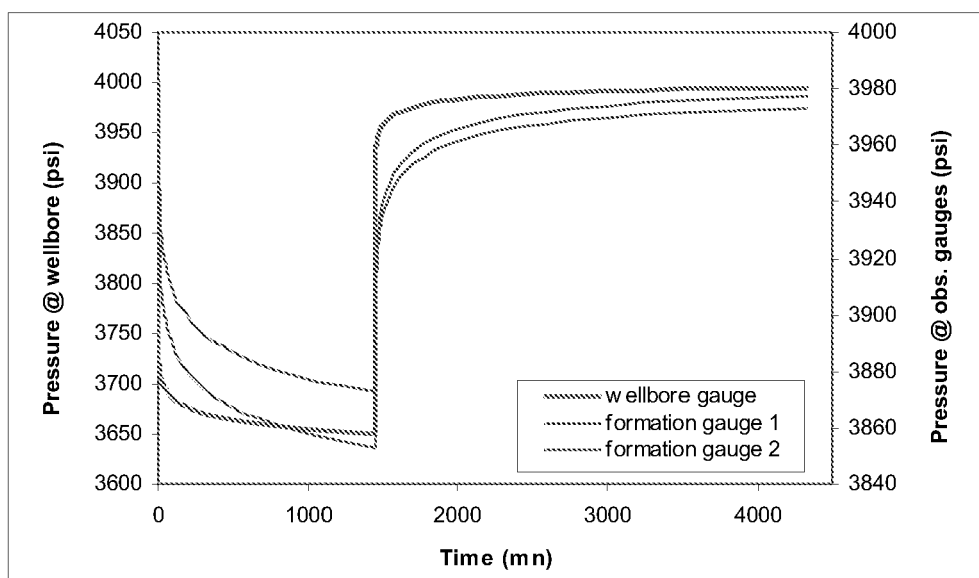


Figure 6



European Patent
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Application Number
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Place of search The Hague		Date of completion of the search 25 April 2007	Examiner Schouten, Adri
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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