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(54) Title: METHOD TO MEASURE AND PREDICT DOWNHOLE RHEOLOGICAL PROPERTIES

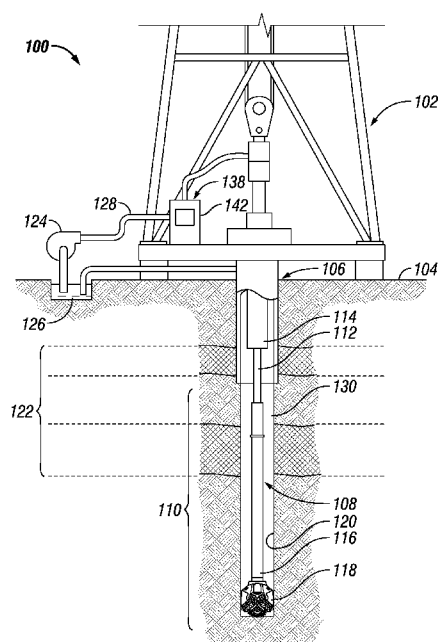


FIG. 1

(57) Abstract: Systems and methods of the disclosed embodiments include taking a first sample of a drilling fluid at a first time, measuring, with a rheometer, a first viscosity dial reading of the first sample, taking a second sample of a drilling fluid at a second time, measuring, with the rheometer, a second viscosity dial reading of the second sample, weighting the first dial reading and the second dial reading based on an elapsed time since the first time and an elapsed time since the second time, and calculating a shear stress vs. shear rate function of the drilling fluid for a plurality of temperatures and a plurality of pressures based on the weighted first viscosity dial reading and the weighted second viscosity dial reading.

METHOD TO MEASURE AND PREDICT DOWNHOLE RHEOLOGICAL PROPERTIES

Background

[0001] As a borehole is drilled into a production formation, drilling fluid is pumped down a borehole through a drill string to power the drill bit at a cutting end of the drill string. The drilling fluid then exits the drill bit to convey drill cuttings up and out of the borehole. As the drilling fluid flows up on the outside of the drill string, the pressure and chemical composition of the drilling fluid can interact with the formation. For example, over-pressurizing the drilling fluid can fracture the formation, and under-pressurizing can allow cave-in, among other potential interactions. Therefore, it is helpful to know the pressure at points along the length/depth of the borehole.

[0002] Collecting real-time pressure at all points along the borehole can be difficult due to the many moving parts and the constant lengthening of the borehole. Models may be used to predict the pressure in the borehole, but the models rely on a broad range of characteristics of the drilling fluid, such as rheological properties at a variety of temperatures and pressures, to achieve accurate results. Measuring all the characteristics at the various temperatures and pressures is impractical in real-time since the characteristics are changing constantly as additional drill cuttings are produced and mixed in to the drilling fluid.

Brief Description of the Drawings

[0003] FIG. 1 is a schematic and cross-sectional diagram of an embodiment of a drilling system using a well modeling system;

[0004] FIG. 2 is a list of possible temperatures and pressures that a well modeling system may select from to test and record the viscosity dial readings;

[0005] FIG. 3 is a list of data sets that were recorded by a well modeling system; and

[0006] FIG. 4 illustrates a shear stress vs. shear rate function for viscosity dial readings that is generated for the full range of pressures and temperatures.

Detailed Description

[0007] Turning now to the figures, FIG. 1 is a schematic and cross-sectional diagram of an embodiment of a drilling system 100 using a well modeling system 138. The drilling system 100 is for drilling a borehole 106 using a drilling fluid, and includes a drilling rig 102 located at the earth's surface 104 of the borehole 106. The drilling rig 102 provides support for a drill string 108. The drill string 108 conveys the drilling fluid from the surface 104 to a bottom-hole assembly 110 through a drill pipe 112. The bottom-hole assembly 110 has a drill collar 114, a downhole tool 116, and a drill bit 118. Other systems 100 may include additional or alternative components in the bottom-hole assembly 110.

[0008] The drilling system 100 pumps drilling fluid through the drill pipe 112 to power the downhole tool 116 and the drill bit 118. The drill collars 114 may be used to add weight to the drill bit 118 and stiffen the bottom-hole assembly 110. The downhole tool 116 may comprise any of a number of different types of tools including measurement-while-drilling (MWD) tools, logging-while-drilling (LWD) tools, pressure sensors, temperature sensors, and others. The bottom-hole assembly 110 creates and logs the borehole 106 by penetrating the surface 104 to access subsurface formations 122.

[0009] During drilling operations, a mud pump 124 pumps the drilling fluid (sometimes known as "drilling mud") from a mud pit 126 through a hose 128 into the drill pipe 112 and down to the drill bit 118. The drilling fluid flows out from the drill bit 118 and returns to the surface 104 through an annular area 130 between the drill pipe 112 and a side 120 of the borehole 106. The mud pump 124 can be controlled to influence the speed and effectiveness of the drill bit 118 pumping the drilling fluid fast enough to remove the cuttings that are drilled, cool the drill bit 118, and lubricate the drill string 112. Faster pumping increases the

effectiveness of transporting the cuttings, but the mud pump 124 will not pump as efficiently.

[0010] Generally, the drill bit 118 will drill faster with a higher pressure from the mud pump 124. The benefits of higher pressure can reach a limit, however, because the drilling fluid, among other things, exerts a pressure against the side 120 of the borehole 106. If the mud pump 124 pressurizes the drilling fluid too much, then the pressure against the side 120 can cause drilling fluid to penetrate into the subsurface formations 122. Furthermore, the drilling fluid can fracture or break down the side 120 and lose fluid to the formation. Too little pressure can also be a problem in the borehole 106, since fluid and gases from the formations 122 can come into the borehole 106 and expand to the surface 104. In summary, drilling with a pressure that is too high or too low can damage the subsurface formation 122, or otherwise decrease the fluid flow from the subsurface formation 122. Thus, it is useful to know the pressure at locations within the borehole 106.

[0011] The pressure of drilling fluid is easier to model when the fluid is stationary, since the density of the fluid is so highly determinative under those conditions. Unfortunately, during a drilling operation the drilling fluid is in constant motion. Despite being in constant motion, a well modeling system can determine the downhole pressures if values for rheological properties of the drilling fluid are accurately known and included in the models. Rheological properties for the drilling fluid can be measured at the surface, but these rheological properties change as the drilling fluid cycles through the borehole 106, the mud pit 126, the hose 128, and the drill pipe 112, etc. Drill cuttings that are not filtered out of the drilling fluid can change the chemical makeup and rheological properties of the drilling fluid. Furthermore, the formations 122 may include chemicals that dissolve into the drilling fluid and further change the makeup of the drilling fluid and how additional interactions with the formation

122 will influence the side 120. It is thus important to consistently update the rheological properties of the drilling fluid throughout the drilling process.

[0012] To monitor the rheological properties and model the pressure of the drilling fluid in the borehole 106, the system 100 includes a well modeling system 138. The well modeling system 138 receives information from a rheometer 142 that collects samples of the drilling fluid and measures a viscosity dial reading for each sample. The dial readings may be recorded at various shear rates and/or revolutions per minute, for example 2, 3, 4, 5, 6, or more different shear rates. The well modeling system 138 may have a processor and a memory for storing data and running instructions. To collect the samples, the rheometer 142 can be installed, as illustrated, in line with the hose 128. In other embodiments, the rheometer 142 may be located remotely from the drilling rig 102, and samples may be conveyed to this remote location periodically.

[0013] The rheometer 142 may include, for example, a rotating cylinder that imparts a rotational force on the drilling fluid and measures that force with a torsional bob. Other geometries and measurement techniques may be used to measure the viscosity dial reading for each sample. In the test of each sample, a temperature and pressure are selected (e.g., randomly, progressively) and the rheometer 142 monitors and keeps these selected parameters constant for the sample as a number of shear rates (e.g., the various rotational speeds of the rheometer 142) are tested. The viscosity dial readings for each shear rate are stored by the well modeling system 138, for example, in a computer memory for storing the viscosity dial readings.

[0014] A goal of the modeling is to be able to accurately model a complete picture of the pressure losses in the drilling fluid downhole. This complete picture is known as the equivalent circulating density (ECD) and can be dependent on the movement of the drilling fluid within the borehole. That is, if the drilling fluid were still, the pressure could be modeled and/or calculated more

simply using the density of the fluid. Since the drilling fluid constantly flows during the drilling process, however, the rheological properties must be accounted for in the model.

[0015] Rather than taking real time measurements for all temperatures and pressures that may be present in a borehole of a drilling operation, the system 100 periodically takes shear stress dial readings at a combination of temperature and pressure. The combination is based on selection criteria that has a high likelihood of representing a broad range of temperatures and pressures over the course of several measurement periods. For example, the combination may be randomly selected, or may be selected by systematically measuring from a low temperature/pressure, or vice versa. The shear stress dial readings are then ranked according to the relevance of each data set. For example, the shear stress dial readings may be ranked based on how recently they were taken. The system or method then scales a generalized rheology function of temperature and pressure with the time modified weighting. The scaled rheology function is used to model hydraulics for the borehole.

[0016] For example, after a set amount of time (e.g., 45 minutes, 1 hour, or more, or less), a new sample is collected and the rheometer 142 selects a new temperature and pressure to test the shear rates. The well modeling system may select the temperature and pressure randomly from a list and/or range of possible temperatures and pressures (see FIG. 2 and description below). The list and/or range of possible temperatures and pressures may be adjusted by the well modeling system 138 as the borehole 106 changes. For example, as the borehole 106 gets deeper the possible maximum pressures may get higher. Therefore, the maximum pressure in the list and/or range would increase. Furthermore, the list and/or range may be customized to each well based on geological characteristics that are already known about the formations 122. That is, for locations known to have particularly hot formations 122, a range for the temperatures of the borehole

being drilled there will include a higher maximum temperature than a range given for a borehole having cooler formations 122.

[0017] From the recorded viscosity dial readings, the well modeling system 138 uses a model (e.g., linear, non-Newtonian, Bingham, power law, Herschel-Bulkley) to scale a generalized rheology response to the range of pressures and temperatures that may be experienced within the borehole. The model may calculate rheological properties for the whole range of pressures and temperatures based on readings from just one combination of pressure and temperature. The model may be improved, however, by additional readings at other temperatures and pressures. For example, a first viscosity dial reading may be measured at the low end of the pressure range, and the low end of the temperature range. This first viscosity dial reading may be used to model the pressure and temperature at the high end of the pressure and temperature ranges. The model may be improved by taking an additional viscosity dial reading, and combining the generalized rheology response from both. The resulting response may be used to calculate the rheological parameters for the fluid at conditions experienced at particular locations downhole. This combination of generalized rheology responses may be done for any number of viscosity dial readings (e.g., 3, 4, 5, 6, 7, 8, or more viscosity dial readings).

[0018] Once the model is complete, the system 100 can change operational parameters to optimize drilling and keep the downhole pressure within a range. In operation, the system 100 manages the rate of the mud pump 124, the rotation of the drill string 112, and the mud density and viscosity. Changing the density and viscosity effects the relationship between movement of the fluid, and the pressure that it exerts on the formation. For example, the system 100 may include functionality to add a viscosifier if the drilling fluid is not viscous enough. If the drilling fluid is too viscous, a thinner may be added. The system 100 may add barite or other materials if the drilling fluid density is too low. Conversely, the

system 100 may dilute the fluid with a base fluid or centrifuge out some of the weighting material if the density is too high. These operational changes maintain the pressure, ECD, pore pressure within a production formation, and fracture gradient while maximizing the rate of penetration.

[0019] FIG. 2 is a list 200 of possible temperatures 202 and pressures 204 that a well modeling system (e.g., the well modeling system 138 of FIG. 1) may use to test and record the viscosity dial readings. The range of temperatures 202 and the range of pressures 204 may be customized to a borehole, and may change during the drilling operation as explained above. For example, the range of temperatures 202 may be between -18 degrees Celsius (0 degrees Fahrenheit) to 205 degrees Celsius (400 degrees Fahrenheit). In shallower boreholes, the max temperature may be 100 degrees Celsius (212 degrees Fahrenheit), increasing as the borehole is drilled deeper. The specific values within the range may differ by a set amount, or may be any values between the low end of the high end of the range. The range of pressures may include 0 Pascal (0 psi) to 1.7×10^8 Pascal (25,000 psi), or smaller ranges.

[0020] The well modeling system 138 may select the temperature 202 and pressure 204 independently, or the well modeling system may select the temperature 202 and the pressure 204 from sets 206 of temperature/pressure that are pre-determined combinations of temperature and pressure. In some instances, the well modeling system selects one temperature 202 and pressure 204, records the viscosity dial readings from a rheometer, and then randomly selects a new temperature 202 and pressure 204 after a given time period. The time period may range from a half an hour to several hours. Periodicity may depend on several factors including rate of expected change in the drilling fluid, speed of drilling, drilling equipment, weather, or other considerations. In other instances, the well modeling system may select one temperature 202 to be used for several viscosity dial readings in a row, randomly selecting a new pressure 204 after each given

time period. In still further instances, the well modeling system may select one pressure 204 for several viscosity dial readings in a row, randomly selecting a new temperature 202 after each given time period. The well modeling system may also systematically select the temperature 202 and pressure 204. For example, each new temperature 202 and/or pressure 204 is higher than the previous temperature 202 or pressure 204. After several iterations, a broad range of temperatures 202 and pressures 204 will have been selected, and the viscosity dial readings recorded at various shear rates and/or revolutions per minute.

[0021] FIG. 3 is a list 300 of example data sets 302-316 that were recorded by a well modeling system (e.g., the well modeling system 138 of FIG. 1). The list 300 includes the eight most recent sets 302-316 ordered according to when the set was recorded. Each set 302-316 in the list 300 includes viscosity dial readings 318 taken at six different shear rates (e.g., six different rotation speeds of the rheometer). The six shear rates will be common for each of the sets 302-316. In certain instances, the six shear rates will include: 1022, 511, 341, 170, 10.2, and 5.1 reciprocal seconds (1/s). In other instances, more shear rates may be tested, or fewer shear rates may be tested. As may be appreciated, the shear rates may include other values as well for testing the drilling fluid.

[0022] Each of the sets 302-316 is associated with a pressure value 322 and a temperature value 324. These values 322, 324 are selected by the well modeling system as described above. The viscosity dial readings 318 at one pressure value 322 and temperature value 324 may be used to create a generalized rheology response for all temperatures and all pressures using known techniques such as Herschel-Bulkley models.

[0023] To replicate and/or model as close as possible the real-time concurrent rheology tests at a full range of pressure values 322 and temperature values 324, each set 302-316 of viscosity dial readings 318 also includes a weighting value 326. The weighting value 326 for the latest set 302 illustrated in FIG. 3, for

example, is 0.50. The well modeling system uses this weighting value 320 in a modeling function to scale a generalized rheology response to pressure and temperature. The weighting value 326 is updated each time a new viscosity dial reading 318 is taken. The older viscosity dial readings 318 are weighted less, and the latest viscosity dial reading is given the highest weighting value 326. The scaling of the weighting values 326 may be based a variety of scaling functions, depending on the expected change in the drilling fluid. For example, the weighting values 326 may decrease according to a linear, parabolic, or exponential weighting function. Or, the eight most recent sets 302-316 may be given custom weighting values 326 based on the knowledge of an operator.

[0024] The generalized rheology response created from the latest set 302 is scaled according to the weighting value 326. That scaled rheology response from the latest set 302 is then combined with the rheology response from the second latest set 304 as it has been scaled by the weighting value 326 (i.e., 0.32). This scaling and combination is completed for each of the sets 302-316 until a shear stress vs. shear rate function for viscosity dial readings is generated for the full range of temperatures and pressures.

[0025] FIG. 4 illustrates a shear stress vs. shear rate function 400 for viscosity dial readings 402 that is generated for the full range of pressures 404 and temperatures 406. In the model 400, it is possible that only a few, or none of the values match the exact values that were measured by the well modeling system. Rather, the model 400 is a combination of all the sets (e.g., the sets 302-316 illustrated in FIG. 3), with the latest set (e.g., the latest set 302 from FIG. 3) having the most highly scaled values. This combination thus increases the accuracy of the model despite changing rheology in the drilling fluid, and, the inherent issues of modeling temperatures and pressures with only one reference point.

[0026] Once the model 400 is complete, a substantially real-time ECD can be determined for the length of the borehole. This information may be combined with information about formation downhole to control operating parameters of the drilling operation. For example, if the model 400 shows that a viscosity for conditions at a certain depth is increasing, and that depth has a formation with a low pressure threshold, then the drilling system may lower pressurization from the mud pump to protect the formation. If the viscosity decreases, then the pressure may be re-adjusted back up. Furthermore, the drilling system may also change the rotation speed of the drill string, and/or add additives to the drilling fluid to change the mud density or viscosity. The model 400 may also be updated whenever a new viscosity dial reading is measured.

CLAIMS

What is claimed is:

1. A method of drilling a borehole, comprising:
 - measuring, with a rheometer, a first viscosity dial reading of a first sample of a drilling fluid taken at a first time;
 - measuring, with the rheometer, a second viscosity dial reading of a second sample of a drilling fluid taken at a second time;
 - weighting the first dial reading and the second dial reading based on elapsed time since the first time and the second time;
 - calculating a shear stress vs. shear rate function of the drilling fluid for a plurality of expected borehole temperatures and a plurality of expected borehole pressures based on the weighted first viscosity dial reading and the weighted second viscosity dial reading; and
 - calculating an equivalent circulating density (ECD) at a location within the borehole based on the shear stress vs. shear rate function of the drilling fluid.
2. The method of claim 1, wherein the first viscosity dial reading is measured at a first temperature, and the second viscosity dial reading is measured at a second temperature that is different than the first temperature.
3. The method of claim 1, wherein the first viscosity dial reading is measured at a first temperature, the second viscosity dial reading is measured at a second temperature, and the first temperature and the second temperature are randomly selected from a range of possible temperatures, a list of possible temperatures, or a combination thereof.

4. The method of claim 3, comprising updating the range of possible temperatures, the list of possible temperatures, or both depending on changes to the borehole.
5. The method of claim 1, wherein the first viscosity dial reading is measured at a first pressure, and the second viscosity dial reading is measured at a second pressure that is different than the first pressure.
6. The method of claim 1, wherein the first viscosity dial reading is measured at a first pressure, the second viscosity dial reading is measured at a second pressure, and the first pressure and the second pressure are randomly selected from a range of possible pressures, a list of possible pressures, or a combination thereof.
7. The method of claim 3, comprising updating the range of possible pressures, the list of possible pressures, or both depending on changes to the borehole.
8. The method of claim 1, wherein the first viscosity dial reading comprises measuring a shear stress at a plurality of shear rates.
9. The method of claim 1, wherein the second time is weighted more than the first time.
10. The method of claim 1, comprising:
 - taking a third sample of a drilling fluid at a third time;
 - measuring, with the rheometer, a third viscosity dial reading of the third sample;
 - weighting the third dial reading on an elapsed time since the third time;
 - and

updating the shear stress vs. shear rate function of the drilling fluid for the plurality of temperatures and the plurality of pressures based on the weighted third viscosity dial reading.

11. The method of claim 10, wherein weighting the first dial reading, the second dial reading, and the third dial reading comprises weighting according to a linear, parabolic, or exponential weighting function.

12. The method of claim 1, comprising adjusting a drilling function based on the ECD, pore pressure within a production formation, and fracture gradient while maximizing the rate of penetration.

13. The method of claim 12, wherein the drilling function comprises a pressure of the drilling fluid provided by a mud pump, a density of the drilling fluid, a rotation speed of a drill string, or any combination thereof.

14. A system for drilling a borehole using a drilling fluid, comprising:
a rheometer configured to collect samples of the drilling fluid and measure a viscosity dial reading for each sample; and
a well modeling system comprising a processor configured to run instructions stored on a computer memory to:
store the viscosity dial readings of the samples;
weight the viscosity dial readings based on an elapsed time since the samples were collected; and
calculate an equivalent circulating density (ECD) of the drilling fluid for a plurality of temperatures and a plurality of pressures based on the weighted viscosity dial readings.

15. The system of claim 14, wherein the rheometer is configured to measure a first viscosity dial reading of a first sample at a first temperature, and to measure

a second viscosity dial reading of a second sample at a second temperature that is different than the first temperature.

16. The system of claim 14, wherein the rheometer is configured to measure a first viscosity dial reading of a first sample at a first pressure, and to measure a second viscosity dial reading of a second sample at a second pressure that is different than the first pressure.

17. The system of claim 14, wherein the rheometer is configured to measure the viscosity dial readings at a plurality of shear rates.

18. The system of claim 14, wherein the weighted viscosity dial readings comprise only the viscosity dial readings for the eight latest collected samples.

19. The system of claim 14, comprising a mud pump configured to adjust the pressure in the well based on the calculated ECD.

20. The system of claim 14, comprising a drill string configured to rotate while drilling the well, wherein the well modeling system is configured to change a speed of rotation of the drill string based on the calculated ECD to maximize the rate of penetration of the borehole.

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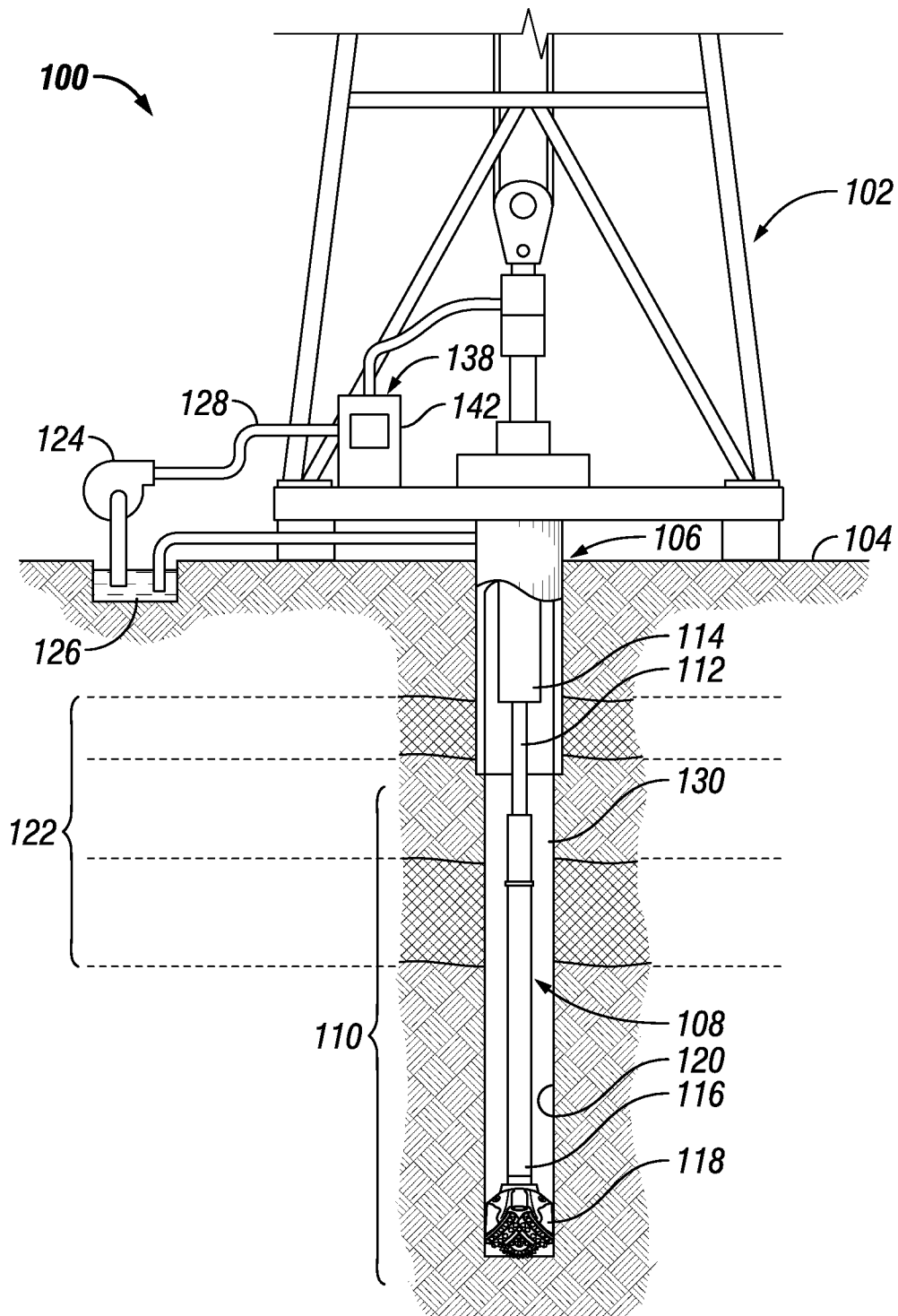


FIG. 1

2/3**200** 

202 TEMPERATURE	204 PRESSURE	206
TEMPERATURE 1	PRESSURE 1	SET 1
TEMPERATURE 2	PRESSURE 2	SET 2
TEMPERATURE 3	PRESSURE 3	SET 3
TEMPERATURE 4	PRESSURE 4	SET 4
TEMPERATURE 5	PRESSURE 5	SET 5
TEMPERATURE 6	PRESSURE 6	SET 6
TEMPERATURE 7	PRESSURE 7	SET 7
TEMPERATURE 8	PRESSURE 8	SET 8
TEMPERATURE 9	PRESSURE 9	SET 9
TEMPERATURE 10	PRESSURE 10	SET 10
TEMPERATURE 11	PRESSURE 11	SET 11
TEMPERATURE 12	PRESSURE 12	SET 12
TEMPERATURE 13	PRESSURE 13	SET 13
TEMPERATURE 14	PRESSURE 14	SET 14
TEMPERATURE 15	PRESSURE 15	SET 15

FIG. 2

6000	2000	12000	2000	6000	2000	12000	2000
350	250	120	200	250	300	120	200
41	40	108	44	49	34	104	42
26	23	58	25	28	20	56	24
21	18	41	19	22	16	40	18
16	13	24	13	15	12	23	12
8	5	5	4	5	5	5	4
7	4	4	3	4	5	4	3
0.50	0.32	0.20	0.13	0.08	0.05	0.03	0.02

[illegible]

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/029747**A. CLASSIFICATION OF SUBJECT MATTER****E21B 21/08(2006.01)i, E21B 47/06(2006.01)i, E21B 47/08(2006.01)i, E21B 47/12(2006.01)i**

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)

E21B 21/08; E21B 21/06; E21B 47/00; E21B 49/00; E21B 49/08; G01V 3/38; G05B 19/048; E21B 47/06; E21B 47/08; E21B 47/12

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: rheometer, viscosity dial reading, drilling fluid, weighting, elapsed time, equivalent circulating density

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013-0146357 A1 (LOVORN, JAMES R) 13 June 2013 paragraphs [0012], [0016], claims 3, 13, and figure 1	1-20
Y	US 2018-0195354 A1 (HALLIBURTON ENERGY SERVICES, INC.) 12 July 2018 paragraphs [0031]-[0032], [0036] and claim 5	1-20
A	US 2009-0282907 A1 (ZAZOVSKY et al.) 19 November 2009 claims 1-4	1-20
A	US 2016-0282503 A1 (HALLIBURTON ENERGY SERVICES, INC.) 29 September 2016 claims 1-4	1-20
A	WO 2018-076006 A1 (SCHLUMBERGER TECHNOLOGY CORPORATION et al.) 26 April 2018 paragraph [0076]	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

22 January 2020 (22.01.2020)

Date of mailing of the international search report

23 January 2020 (23.01.2020)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

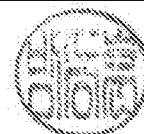


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INTERNATIONAL SEARCH REPORT

Information on patent family members

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PCT/US2019/029747

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013-0146357 A1	13/06/2013	AU 2011-293656 A1 AU 2011-293656 B2 BR 112013001174 A2 EP 2609282 A1 US 9279299 B2 WO 2012-027245 A1	24/01/2013 12/03/2015 31/05/2016 03/07/2013 08/03/2016 01/03/2012
US 2018-0195354 A1	12/07/2018	US 2017-0204688 A1 US 9938784 B2 WO 2017-011499 A1	20/07/2017 10/04/2018 19/01/2017
US 2009-0282907 A1	19/11/2009	US 2011-0320127 A1 US 8042387 B2 US 8429962 B2 WO 2009-139992 A2 WO 2009-139992 A3	29/12/2011 25/10/2011 30/04/2013 19/11/2009 18/03/2010
US 2016-0282503 A1	29/09/2016	EP 3058394 A1 MX 2016006305 A MX 358119 B US 9927551 B2 WO 2015-099779 A1	24/08/2016 26/07/2016 06/08/2018 27/03/2018 02/07/2015
WO 2018-076006 A1	26/04/2018	CN 110114552 A GB 2555137 A US 2019-0368336 A1	09/08/2019 25/04/2018 05/12/2019