(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
18 October 2018 (18.10.2018)

(10) **International Publication Number**
WO 2018/190821 A1

(51) **International Patent Classification:**
E21B 49/08 (2006.01) *E21B 47/06* (2006.01) *E21B 21/01* (2006.01)

(21) **International Application Number:** PCT/US2017/027138

(22) **International Filing Date:** 12 April 2017 (12.04.2017)

(25) **Filing Language:** English

(26) **Publication Language:** English

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,

(54) **Title:** USING THE SPECIFIC HEAT CAPACITY OF A DRILLING FLUID TO DETERMINE OTHER PROPERTIES THEREOF

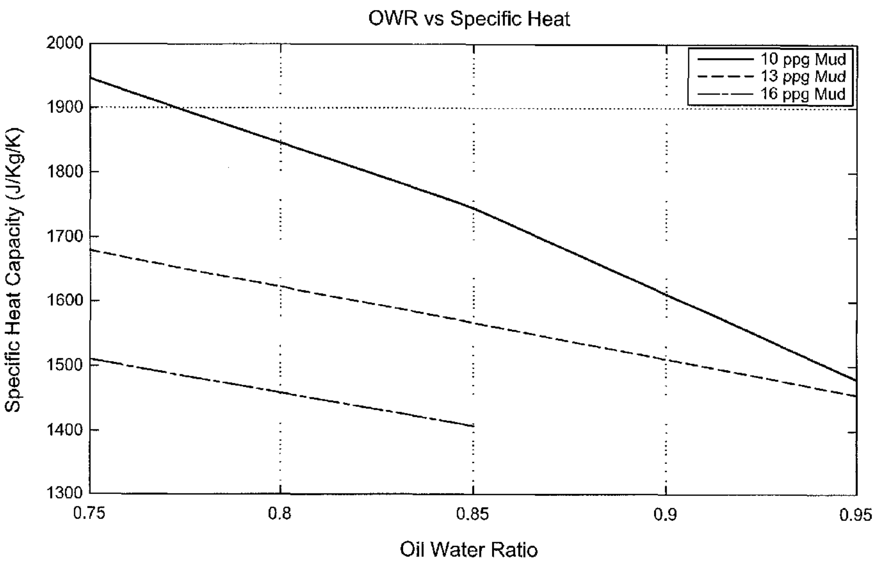

FIG. 1

(57) **Abstract:** A method of monitoring and controlling one or more properties of a drilling fluid used in drilling a well is provided. The method comprises circulating the drilling fluid through the wellbore, measuring the specific heat capacity of the drilling fluid, and determining the value of an additional property of the drilling fluid based at least in part on the measured specific heat capacity of the drilling fluid. For example, the additional property of the drilling fluid can be the oil-to-water ratio of the drilling fluid. As another example, the additional property of the drilling fluid can be average specific gravity of the solids in the drilling fluid.

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MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

USING THE SPECIFIC HEAT CAPACITY OF A DRILLING FLUID TO DETERMINE OTHER PROPERTIES THEREOF

BACKGROUND

[0001] As a well is being drilled, a drilling fluid is continuously circulated from the surface, through the wellbore and back to the surface in order to carry out various functions. For example, the drilling fluid, also referred to as drilling mud, functions to remove cuttings from the borehole, control formation pressure, and cool, lubricate and support the drill bit. Typically, the drilling fluid is pumped down the borehole through the interior of the drill string, out through nozzles in the end of the drill bit, and then back to the surface through the annulus between the drill string and the wall of the borehole. On the surface, the drilling fluid is circulated through a series of shaker screens and other types of equipment to reclaim it and make it suitable for continued circulation through the wellbore.

[0002] Due to reactions with the drill cuttings, fluid leak-off into the formation and other factors, the nature of the drilling fluid can change as the drilling fluid is circulated through the wellbore. As a result, the composition and other properties of the drilling fluid must be carefully monitored and controlled as the drilling process is carried out.

[0003] Many drilling parameters, such as the measured depth, string rotary speed, weight on the bit, downhole torque, surface torque, surface pressure, downhole pressure, drill bit orientation and bit deflection can be measured and adjusted in real-time (that is continuously) or at least on a frequent basis as the drilling process is carried out. However, some properties of the drilling fluid, such as the ratio of oil-to-water in the drilling fluid and the average specific gravity of the solids in the drilling fluid, cannot be easily measured and adjusted in real time or even on a frequent basis.

[0004] For example, in order to ascertain the oil-to-water ratio of the drilling fluid and the average specific gravity of the solids in the drilling fluid, a drilling fluid engineer or mud engineer (hereafter a "mud engineer") must directly measure such properties. A typical on-site mud engineer has numerous other responsibilities in his or her daily routine and usually only measures the oil-to-water ratio of the drilling fluid and/or average specific gravity of the solids in the drilling fluid every few hours. Even if the mud engineer has the ability to carry out more frequent measurements of these properties, the current methods of taking the measurements are complex and time consuming. For example, it can take as much as an hour or more for a mud engineer to directly measure the oil-to-water ratio of the drilling fluid and the average specific gravity of solids in the drilling fluid. Depending on the nature of the rock formations being penetrated by the drill bit, the expected types of hydrocarbons (for example, oil and/or gas) associated therewith and other factors, such a time frame may not be sufficient in all cases.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The drawings included with this application illustrate certain aspects of the embodiments described herein. However, the drawings should not be viewed as exclusive embodiments. The subject matter disclosed herein is capable of considerable modifications, alterations, combinations, and equivalents in form and function, as will be evident to those skilled in the art with the benefit of this disclosure.

[0006] FIG. 1 is a graph illustrating an example of a representation depicting the correlation between the specific heat capacity of a drilling fluid and the oil-to-water ratio of the drilling fluid.

[0007] FIG. 2 is a graph illustrating an example representation depicting the correlation between the specific heat capacity of a drilling fluid and the average specific gravity of solids in the drilling fluid.

[0008] FIG. 3 is a diagram illustrating an example of a wellbore drilling system that may be used in accordance with certain embodiments of the present disclosure.

[0009] FIG. 4 is a diagram illustrating an example of a wellbore drilling system wherein the fluid processing unit is located in the mud retention pit in accordance with the present disclosure.

[0010] FIG. 5 is a diagram illustrating an example of a wellbore drilling system wherein the fluid processing unit is downstream of the mixing hopper in accordance with the present disclosure.

[0011] FIG. 6 is an enlarged view of a portion of the fluid processing unit specifically related to the method disclosed herein.

DETAILED DESCRIPTION

[0012] The present application may be understood more readily by reference to this detailed description as well as to the examples included herein. For simplicity and clarity of illustration, where appropriate, reference numerals may be repeated among the different figures to indicate corresponding or analogous elements. In addition, numerous specific details are set forth in order to provide a thorough understanding of the disclosed subject matter. However, it will be understood by those of ordinary skill in the art that the subject matter described herein can be practiced without these specific details. In other instances, methods, procedures and components have not been described in detail so as not to obscure the related relevant feature being described. Also, the description is not to be considered as limiting the scope of the subject matter described herein. The drawings are not necessarily to scale and the proportions of certain parts may have been exaggerated to better illustrate details and features of the present application.

[0013] In accordance with this disclosure, a method of monitoring and controlling one or more properties of a drilling fluid used in drilling a well is provided. For example, in one embodiment, the method is a method of monitoring and controlling the oil-to-water ratio of a drilling fluid used in drilling a well. In another embodiment, the method is a method of monitoring and controlling the average specific gravity of the solids in a drilling fluid used in drilling a well. As used herein and in the appended claims, the term “drilling fluid” and the term “drilling mud” are used interchangeably and mean the same thing.

[0014] As used herein and in the appended claims, drilling a well means a drilling a wellbore from the surface to a point below the surface. The wellbore can penetrate one or more subterranean formations that contain, for example, water and/or hydrocarbons such as oil and gas. The drilling fluid can be any type of drilling fluid useful in drilling a well. For example, the drilling fluid can be an emulsion having a water continuous phase and an oil discontinuous phase, or an inverse emulsion having an oil continuous phase and a water discontinuous phase.

[0015] The disclosed method comprises:

circulating the drilling fluid through the wellbore;

after circulating the drilling fluid through the wellbore, measuring the specific heat capacity of the drilling fluid; and

determining the value of an additional property of the drilling fluid based at least in part on the measured specific heat capacity of the drilling fluid.

[0016] The drilling fluid is circulated from the surface, through the wellbore, and back to the surface. Typically, the drilling fluid is pumped down the borehole through the interior of the drill string, out through nozzles in the end of the drill bit, and then back to the surface through the annulus between the drill string and the borehole wall (that is, the inside surface of the borehole). For example, in drilling an oil and gas well, the drilling fluid is typically also circulated through various types of equipment in order to reclaim the drilling fluid and make it suitable for continued circulation through the wellbore.

[0017] For example, as shown by FIGS. 3, 4 and 5, which are further described below, the drilling fluid can be circulated through the wellbore and a fluid processing unit. The fluid processing unit can be located on the surface adjacent to the wellbore. For example, the drilling fluid can be circulated through the wellbore, the fluid processing unit and a mud retention pit that is also located on the surface adjacent to the wellbore. The fluid processing unit can be located upstream of the retention pit, or in the mud retention pit. As another example, the drilling fluid can be circulated through the wellbore, the fluid processing unit, the mud retention pit, and a mixer also located on the surface adjacent to the wellbore. The mixer can be located downstream of the mud retention pit, and the fluid processing unit can be located downstream of the mixer.

[0018] As used herein and in the appended claims, measuring the specific heat capacity of the drilling fluid "after" circulating the drilling fluid through the wellbore means measuring the specific heat capacity of a portion of the drilling fluid after that portion has circulated, at least to an extent, through the wellbore. For example, the specific heat capacity of a portion of the drilling fluid can be measured on the surface after that portion of the drilling fluid has been circulated from the surface, through the wellbore, and back to the surface. For example, the specific heat capacity of a circulated portion of the drilling fluid can be measured while the remaining drilling fluid continues to circulate through the wellbore.

[0019] The specific heat capacity of the circulated drilling fluid can be measured quickly and accurately. For example, the fluid processing unit can comprise a specific heat capacity sensor such as a specific heat capacity probe, and a computer associated with the specific heat capacity sensor. As used herein and in the appended claims, a "computer" means a computer or other device that includes a central processing unit and has one or more computer programs associated therewith.

[0020] For example, as the drilling fluid is circulated through the fluid processing unit, the specific heat capacity of the drilling fluid can be measured by the specific heat capacity probe or other sensor, and a signal comprising the value of the specific heat capacity of the drilling fluid can be sent to the computer for further processing. For example, the specific heat capacity can be measured at two or more fluid pressures, and the additional property of the drilling fluid can be determined based at least in part on the measured specific heat capacity at each fluid pressure. For example, the specific heat capacity of the drilling fluid can be measured at a temperature that is above or below ambient temperature. For example, the specific heat capacity of the drilling fluid can be measured at a temperature that is above ambient temperature. For example, the specific heat capacity of the drilling fluid can be measured at a temperature that is below ambient temperature.

[0021] For example, the specific heat capacities of the water and oil phases of the drilling fluid are dependent on pressure and temperature. At increased fluid pressure, the fluids portion of the drilling fluid contents tend to compress which causes the specific heat capacities of the water and oil phases of the drilling fluid to change. At increased pressure, the concentrations of the fluid portion of drilling fluid will also shrink compared to the entire drilling fluid.

[0022] It has been shown that the oil in the drilling fluid will typically compress more than the water in the drilling fluid and that the density of the solids in the drilling fluid will usually remain constant. This changes the fractional concentrations of the individual components (for example, oil, water, and solids) with respect to the total fluid. With the changes in concentrations of the individual components, the specific heat capacity of the fluid will change, which makes it possible to back calculate the concentrations of the respective components in view of the changes in the concentrations of each component. When the temperature of the fluid changes, the respective components (for example, oil, water, and solids) will also have a change in specific heat capacity. However, the changes in specific heat capacity due to temperature changes are different for each component. If the specific heat capacity is measured at enough temperatures, it is possible to back calculate the fractional concentrations of the individual components.

[0023] Specific heat capacity is a measure of the amount of heat required to raise the temperature of a mass by one degree. The total specific heat capacity of a drilling fluid is dependent upon the specific heat capacities of the components that create the drilling fluid. As used herein and in the appended claims, the term “specific heat” and the term “specific heat capacity” are used interchangeably and mean the same thing.

[0024] For example, the table below shows the specific heat capacities of the most common elements inside an inverse emulsion drilling fluid.

Component	Specific Heat (kJ/kg K)
Water	4.19
Oil	1.5 - 2.2
Barite	0.46
Low Gravity Solids (LGS)	0.5-1.0

As shown, the liquids have a higher specific heat than the solids. The liquids also make up most of the fluid compared to the solids.

[0025] A common method of determining the specific heat capacity of a drilling fluid utilizes the weighted average of specific heat capacities of the individual components of the drilling fluid. Specifically, the weighted average of each individual component is added together to get the total specific heat capacity of the drilling fluid. This can be seen in the equation (1) below where h_{total} is the specific heat capacity of the drilling fluid, h_n is the specific heat capacity of an individual component and φ_n is the fraction of the component of the total (by mass or volume).

$$h_{total} = \sum_{n=1}(h_n * \varphi_n) \quad (1)$$

[0026] An additional equation that may be used to determine the specific heat capacity of a drilling fluid is to use the known or measured concentrations and corresponding specific heat capacities of the individual components of the drilling fluid. This can be seen in Equation (2) below, where φ_O is the oil concentration, h_o is the specific heat capacity of oil, φ_B is the water or brine concentration, h_B is the specific heat capacity of the water or brine, h_{LGS} is the low gravity solids ("LGS") specific heat capacity, φ_{LGS} is the LGS concentration, h_{HGS} is the high gravity solids ("HGS") or weighting agents specific heat capacity, and φ_{HGS} is the HGS or weighting agents concentration.

$$h_{mud} = \varphi_O * h_O + \varphi_B * h_B + \varphi_{LGS} * h_{LGS} + \varphi_{HGS} * h_{HGS} \quad (2)$$

[0027] For example, the concentrations of the individual components of the drilling fluid can be determined through a number of methods of measuring or otherwise determining the same. For example, the individual concentrations can be determined by way of a mud balance and retort, which are commonly done by a mud engineer. For example, the specific heat capacities of the individual components can be determined by measuring them individually and having their values stored in a database or like data storage element that can be recalled at any time. The specific heat capacities of the individual components and the known or measured concentrations of the individual components may then be used to determine the total specific heat capacity of the drilling fluid. This can be easily done to predict the specific heat of the mud or other drilling fluid in the field if the mud engineer does not have a specific heat sensor or probe on hand, which in turn can help predict how the drilling fluid will operate downhole.

[0028] Alternatively, the total specific heat capacity of the drilling fluid can be measured using a specific heat capacity sensor, including, without limitation, a commercially available specific heat capacity probe. The specific heat capacity sensor may be any type of specific heat capacity sensor useful for measuring the specific heat capacity of a fluid. Such a sensor measures the specific heat of the entire drilling fluid and not the individual components.

[0029] The value of an additional property of the drilling fluid can also be quickly and accurately determined in accordance with the disclosed method by, for example, indirectly determining the value based on the measured specific heat capacity of the drilling fluid. For example, the disclosed method can further comprise providing a representation including multiple potential values of the additional property of the drilling fluid, each potential value corresponding to a predetermined specific heat capacity. The additional property of the drilling fluid can then be determined by comparing the measured specific heat capacity of the drilling fluid to the predetermined specific heat capacities of the representation and selecting the potential value of the additional property that corresponds to the predetermined specific heat capacity that most closely matches the measured specific heat capacity of the drilling fluid.

[0030] For example, this approach can be used to determine the degree to which a drilling fluid has become contaminated. For example, the initial drilling fluid specific heat can be measured before any contamination occurs. As drilling commences, contamination of the drilling fluid with low gravity solids can occur. At this point the specific heat of the drilling fluid can be measured again. Contamination that has occurred can be quantified by using Equation (3) below, where $\varphi_{contaminate}$ is the contaminate concentration, $h_{contaminate}$ is the contaminate specific heat, h_{mud} is the post-contamination measured specific heat of the drilling fluid, and $h_{initial}$ is the initial specific heat of the drilling fluid.

$$h_{mud} = \varphi_{contaminate} * h_{contaminate} + (1-\varphi_{contaminate}) * h_{initial} \quad (3)$$

[0031] As used herein and in the appended claims, the term "representation" refers to a graph, table, electronic database, or other printed or electronic compilation of data that includes multiple potential values of the additional property of the drilling fluid with each potential value corresponding to a predetermined specific heat capacity, and that: (a) allows the measured specific heat capacity of the drilling fluid to be compared to the predetermined specific heat capacities in the representation; and (b) allows the potential value of the additional property that corresponds to the predetermined specific heat capacity that most closely matches the measured specific heat capacity of the drilling fluid to be selected. For example, the representation can be an electronic database that includes multiple potential values of the additional property of the drilling fluid, with each potential value corresponding to a predetermined specific heat capacity, and that is capable of being manipulated by a computer program and computer to compare the measured specific heat capacity of the drilling fluid to the predetermined specific heat capacities in the database and select the potential value of the additional property that corresponds to the predetermined specific heat capacity that most closely matches the measured specific heat capacity of the drilling fluid.

[0032] For example, in one embodiment, the value of the additional property of the drilling fluid that is determined in accordance with the disclosed method is the oil-to-water ratio of the drilling fluid. The oil-to-water ratio of a drilling fluid is the ratio of the volume percent of oil to the volume percent of water in the drilling fluid. In another embodiment, the value of the additional property of the drilling fluid that is determined in accordance with the disclosed method is the average specific gravity of the solids in the drilling fluid. The average specific gravity of the drilling fluid is the average of the ratio of the density of each solid in the drilling fluid (for example, a weighting agent and the drilled solid) to the density of water.

[0033] For example, if the representation is a graph or table, the measured specific heat capacity of the drilling fluid can be compared to the predetermined specific heat capacities of the representation, and the potential value of the additional property that corresponds to the predetermined specific heat capacity that most closely matches the measured specific heat capacity of the drilling fluid can be manually selected by an operator. For example, a graph plotting potential values of the oil-to-water ratio of the drilling fluid against predetermined specific heat capacities of the drilling fluid (at three different solids concentrations) is shown by FIG. 1. In using the graph of FIG. 1, the operator can merely find the predetermined specific heat capacity on the y axis of the graph that matches the measured specific heat capacity, and then find the corresponding oil-to-water ratio on the x axis of the graph. A similar graph plotting potential values of the average specific gravity of the solids in the drilling fluid against predetermined specific heat capacities of the drilling fluid (at two different solids concentrations) is shown by FIG. 2. The graph of FIG. 2 can be used in the same way that the graph of FIG. 1 is used.

[0034] On the other hand, if the representation is an electronic database associated with a computer, the measured specific heat capacity of the drilling fluid can be compared to the predetermined specific heat capacities of the representation, and the potential value of the additional property that corresponds to the predetermined specific heat capacity that most closely matches the measured specific heat capacity of the drilling fluid can be selected automatically by the computer.

[0035] If desired, the values of multiple properties of the drilling fluid can be determined based at least in part on the measured specific heat capacity of the drilling fluid. For example, the value of a first additional property of the drilling fluid and the value of a second additional property of the drilling fluid can be determined based at least in part on the measured specific heat capacity of the drilling fluid. For example, the method can further comprise providing a separate representation for each of the first and second additional properties, each representation including multiple potential values of the corresponding additional property of the drilling fluid, and each potential value corresponding to a predetermined specific heat capacity of the additional property of the drilling fluid. Each of the first and second additional properties of the drilling fluid can then be determined by comparing the measured specific heat capacity of the drilling fluid to the predetermined specific heat capacities of the corresponding representation and selecting the potential value of the additional property that corresponds to the predetermined specific heat capacity that most closely matches the measured specific heat capacity of the drilling fluid. For example, the first additional property of the drilling fluid can be the oil-to-water ratio of the drilling fluid, and the second additional property of the drilling fluid can be the average specific gravity of the solids in the drilling fluid.

[0036] If desired, specific heat measurements can be combined with other measurements such as density or even specific heat at a different pressure, and the concentrations of the individual components can be determined. For example, this approach can be used to achieve a more accurate and precise measurement than can be achieved by referencing tables and plots or by focusing on one contaminating component.

[0037] For example, in oil-based muds, there are four major components (high gravity solids (HGS), low gravity solids (LGS), oil, and water). In water-based muds, there are three major components (HGS, LGS, and water), meaning there are either three or four unknowns (the concentrations of the components). A system of equations can be created and solved to find out the concentration of each individual component. For example, Equations (4), (5) and (6) below can be used in connection with a water-based mud with a specific heat measurement being complemented by a density measurement:

$$h_{mud} = \varphi_B * h_B + \varphi_{LGS} * h_{LGS} + \varphi_{HGS} * h_{HGS} \text{ (Specific Heat)} \quad (4);$$

$$\rho_{mud} = \varphi_B * \rho_B + \varphi_{LGS} * \rho_{LGS} + \varphi_{HGS} * \rho_{HGS} \text{ (Density)} \quad (5); \text{ and}$$

$$1 = \varphi_B + \varphi_{LGS} + \varphi_{HGS} \text{ (The sum of the components equal the whole)} \quad (6),$$

where h_{mud} is the specific heat capacity of the drilling fluid, φ_B is the water or brine concentration, h_B is the specific heat capacity of the water or brine, φ_{LGS} is the low gravity solids concentration, h_{LGS} is the low gravity solids specific heat capacity, φ_{HGS} is the high gravity solids concentration, h_{HGS} is the high gravity solids specific heat capacity, ρ_{mud} is the density of the drilling fluid, ρ_B is the density of the water or brine, and ρ_{LGS} is the density of the low gravity solids. The density measurement could be replaced by any other measurement and even using a specific heat measurement at a different temperature or pressure as this would change the relative specific heats and volume fractions as discussed earlier.

[0038] The disclosed method can further comprise adjusting at least one property of the drilling fluid in response to the determined additional property or properties of the drilling fluid. For example, characteristics of the drilling fluid and/or the composition of the drilling fluid can be altered based on the oil-to-water ratio and/or the average specific gravity of the solids as needed to improve the performance of the drilling fluid and the efficiency of the drilling operation. Continuously monitoring the oil-to-water ratio and/or the average specific gravity of the solids in the drilling fluid helps maintain optimal fluid properties. The oil-to-water ratio of the drilling fluid and/or the average specific gravity of the solids in the drilling fluid are required inputs for many mud prediction models and software applications and help the mud engineer provide an optimal fluids solution.

[0039] For example, based on the determined oil-to-water ratio of the drilling fluid, it may be determined that more water needs to be added to the drilling fluid to improve the rheology of the fluid and reduce the overall cost of the fluid. Based on the determined average specific gravity of the solids in the drilling fluid, it may be determined that the amount of low gravity solids in the drilling fluid needs to be reduced in order to improve the drill rate, put less stress on the drill bit and eliminate other problems that slow down or otherwise hinder the drilling process. For example, if the average specific gravity of the solids is too low, the mud engineer can request that adjustments be made to the solids control equipment, or can dilute the mud to adjust the properties of the fluid to get the properties back within desired specifications.

[0040] For example, one or more of the oil-to-water ratio of the drilling fluid, the composition of the drilling fluid, the solids content of the drilling fluid, and the average specific gravity of the solids in the drilling fluid can be adjusted based on the oil-to-water ratio of the drilling fluid and/or the average specific gravity of the solids in the drilling fluid. For example, if both the oil-to-water ratio of the drilling fluid and the average specific gravity of the solids in the drilling fluid are determined, at least one property of the drilling fluid can be adjusted in response to both the determined oil-to-water ratio of the drilling fluid and the average specific gravity of the solids in the drilling fluid. The adjustment(s) to the property or properties of the drilling fluid in response to the determined additional property or properties of the drilling fluid can be made manually by the operator or automatically, for example, by the central processing unit in the fluid processing unit.

[0041] Referring now to FIG. 3, an exemplary wellbore drilling assembly 100 that may be used in association with the disclosed method is illustrated and generally designated by the reference numeral 100. It should be noted that while wellbore drilling assembly 100 is depicted in FIG. 3 as a land-based drilling assembly, those skilled in the art will readily recognize that the principles described herein are equally applicable to subsea drilling operations that employ floating or sea-based platforms and rigs, without departing from the scope of the disclosure.

[0042] As illustrated, the drilling assembly 100 may include a drilling platform 102 that supports a derrick 104 having a traveling block 106 for raising and lowering a drill string 108. The drill string 108 may include, but is not limited to, drill pipe and coiled tubing, as generally known to those skilled in the art. A kelly 110 supports the drill string 108 as it is lowered through a rotary table 112. A drill bit 114 is attached to the distal end of the drill string 108 and is driven either by a downhole motor and/or via rotation of the drill string 108 from the well surface. As the bit 114 rotates, it creates a borehole 116 that penetrates various subterranean formations 118.

[0043] A pump 120 (for example, a mud pump) circulates a drilling fluid 122 through a feed pipe 124 and to the kelly 110, which conveys the drilling fluid 122 downhole through the interior of the drill string 108 and through one or more orifices in the drill bit 114. The drilling fluid 122 is then circulated back to the surface via an annulus 126 defined between the drill string 108 and the walls of the borehole 116. At the surface, the recirculated or spent drilling fluid 122 exits the annulus 126 and may be conveyed to a fluid processing unit 128 via an interconnecting flow line 130. If necessary or desired, more than one fluid processing unit can be used. After passing through the fluid processing unit 128, a "cleaned" drilling fluid 122 is deposited into a nearby retention pit 132 (also referred to as a mud pit).

[0044] One or more chemicals, fluids and/or additives (for example, weighting agents and fluid loss control additives) may be added to the drilling fluid 122 via a mixing hopper 134 communicably coupled to or otherwise in fluid communication with the retention pit 132. The mixing hopper 134 may include, but is not limited to, mixers and related mixing equipment known to those skilled in the art. In other embodiments, however, one or more chemicals, fluids and/or additives may be added to the drilling fluid 122 at any other location in the drilling assembly 100. In at least one embodiment, for example, there could be more than one retention pit 132, such as multiple retention pits 132 in series. Moreover, the retention pit 132 may be representative of one or more fluid storage facilities and/or units where the disclosed chemicals, fluids and/or additives may be stored, reconditioned, and/or regulated until added to the drilling fluid 122.

[0045] For example, when used in association with the method disclosed herein, the drilling assembly 100 can be used to drill a wellbore penetrating a subterranean formation while circulating a drilling fluid 122 through the wellbore. The method disclosed herein may further include measuring the specific heat capacity of the drilling fluid 122 and then determining one or more additional properties of the drilling fluid 122 including the oil-to-water ratio of the drilling fluid and/or the average specific gravity of the solids in the drilling fluid.

[0046] While illustrated in FIG. 3 as being arranged on the surface at the outlet of the borehole 116 via the annulus 126 and upstream from the mud retention pit 132, the fluid processing unit 128 may be arranged at other locations in the drilling assembly 100 to facilitate its proper function, without departing from the scope of the disclosure. For example, FIG. 4 is the same as FIG. 3, except it depicts the fluid processing unit 128 as being located in the mud retention pit 132. For example, FIG. 5 is the same as FIGS. 3 and 4, except it depicts the fluid processing unit 128 as being located downstream of the mixing hopper 134.

[0047] Referring to FIG. 6, a portion of the fluid processing unit 128 that specifically relates to the method disclosed herein will be described in more detail. The fluid processing unit 128 may also include other equipment (not shown) such as one or more shakers (for example, shale shakers), centrifuges, hydrocyclones, separators (including magnetic and electrical separators), desilters, desanders, filters (for example, diatomaceous earth filters), heat exchangers and other types of fluid reclamation equipment. In addition, the fluid processing unit 128 may include one or more sensors and one or more gauges, pumps, compressors, and the like used, for example, to store, monitor, regulate, and/or recondition any exemplary chemicals, fluids and additives disclosed herein. Multiple fluid processing units containing some or all of the above equipment can be used.

[0048] As shown by FIG. 6, the portion of the fluid processing unit 128 that specifically relates to the method disclosed herein can include a specific heat capacity sensor ("SHCS") 136 and a computer and central processing unit ("CPU") 138. For example, the specific heat capacity sensor 136 measures the specific heat capacity of the drilling fluid 122. For example, the specific heat capacity sensor 136 may be a commercially available specific heat capacity probe.

[0049] The CPU 138 is communicably coupled to the SHCS 136 and receives a signal comprising the specific heat capacity of the drilling fluid from the SHCS 136 for further processing. The CPU 138 may be configured to execute one or more sequences of instructions, programming stances, or code stored on a non-transitory, computer-readable medium. For example, the CPU 138 can include an electronic database and computer program that allows it to import the specific heat capacity measured by the SHCS 136 into a representation as described above, compare the measured specific heat capacity to the predetermined specific heat capacities of the representation, and select the potential value of the additional property that corresponds to the predetermined specific heat capacity that most closely matches the measured specific heat capacity of the drilling fluid. The CPU can also adjust one or more properties of the drilling fluid based at least in part on the determined additional property or properties of the drilling fluid 122.

[0050] The fluid processing unit 128 may be configured to extract a sample from the drilling fluid 122 and measure the sample's specific heat capacity. For example, the specific heat capacity measurement can be made at an elevated or reduced temperature, elevated fluid pressure, or both. Therefore, the fluid processing unit 128 can be a container that can be heated, pressurized or both for performing the specific heat capacity measurement of the drilling fluid 122.

[0051] The CPU 138 may be, for example, a general purpose microprocessor, a microcontroller, a digital signal processor, an application specific integrated circuit, a field programmable gate array, a programmable logic device, a controller, a state machine, a gated logic, discrete hardware components, an artificial neural network, or any like suitable entity that may perform calculations or other manipulations of measurements and/or data. In some embodiments, the CPU 138 may further include elements such as, for example, a memory (*e.g.*, random access memory (RAM)), flash memory, read only memory (ROM), programmable read only memory (PROM), erasable programmable read only memory (EPROM)), registers, hard disks, removable disks, CD-ROMS, DVDs, or any other like suitable storage device or medium.

[0052] As used herein, a machine-readable medium will refer to any medium that directly or indirectly provides instructions to CPU 138 for execution. A machine-readable medium may take on many forms including, for example, non-volatile media, volatile media, and transmission media. Non-volatile media may include, for example, optical and magnetic disks. Volatile media may include, for example, dynamic memory. Transmission media may include, for example, coaxial cables, wire, fiber optics, and wires that form a bus. Common forms of machine-readable media may include, for example, floppy disks, flexible disks, hard disks, magnetic tapes, other like magnetic media, CD-ROMs, DVDs, other like optical media, punch cards, paper tapes and like physical media with patterned holes, RAM, ROM, PROM, EPROM and flash EPROM.

[0053] For example, the CPU 138 may be configured to perform or reference mathematical calculations, lookup tables, and offset well data comparisons that are stored on the CPU 138 to derive the oil-to-water ratio, the average specific gravity of the solids, or both. In some instances, the CPU 138 may output a numerical value, graph, or the like indicative of one or more properties of the drilling fluid 122, including, without limitation, the oil-to-water ratio of the drilling fluid and/or the average specific gravity of the solids in the drilling fluid. In some instances, the CPU 138 may adjust or suggest an adjustment to the drilling fluid 122 composition (*e.g.*, adding additional weighting agent), the drilling operation parameters (*e.g.*, increasing or decreasing the rate of penetration and weight on bit), or both based on the derived one or more properties of the drilling fluid 122, including, without limitation, the oil-to-water ratio, the derived average specific gravity of the solids, or both.

[0054] Thus, the method disclosed herein utilizes the specific heat capacity of a circulated drilling fluid to quickly and easily determine additional properties of the drilling fluid such as the oil-to-water ratio of the drilling fluid and average specific gravity of the solids in the drilling fluid. For example, the disclosed method can be carried out continuously, in real time, or at least periodically on a frequent basis (for example, every half hour as the drilling process is carried out). For example, the specific heat capacity can be measured and the additional property or properties of the drilling fluid can be determined in 5 or 10 minutes. The specific heat capacity of the circulated drilling fluid can be measured as the drilling fluid is coming out of the wellbore or being put back in the wellbore.

[0055] Any exemplary chemicals, fluids and additives disclosed herein may directly or indirectly affect one or more components or pieces of equipment associated with the preparation, delivery, recapture, recycling, reuse, and/or disposal of any disclosed chemicals, fluids and additives. For example, any disclosed chemicals, fluids and additives may directly or indirectly affect one or more components or pieces of equipment associated with the exemplary wellbore drilling assembly 100.

[0056] For example, any disclosed chemicals, fluids and additives may directly or indirectly affect the fluid processing unit(s) 128 which may include, but is not limited to, one or more shakers (for example, shale shakers), centrifuges, hydrocyclones, separators (including magnetic and electrical separators), desilters, desanders, filters (for example, diatomaceous earth filters), heat exchangers and other types of fluid reclamation equipment. In addition to one or more specific heat capacity sensors, as discussed above, the fluid processing unit(s) 128 may further include one or more other sensors and one or more gauges, pumps, compressors, and the like used, for example, to store, monitor, regulate, and/or recondition any exemplary chemicals, fluids and additives disclosed herein.

[0057] Any disclosed chemicals, fluids and additives may directly or indirectly affect the pump 120, which representatively includes any conduits, pipelines, trucks, tubulars, and/or pipes used to fluidically convey the chemicals, fluids and additives downhole, any pumps, compressors, or motors (*e.g.*, topside or downhole) used to drive the chemicals, fluids and additives into motion, any valves or related joints used to regulate the pressure or flow rate of the chemicals, fluids and additives, and any sensors (*i.e.*, pressure, temperature, flow rate, etc.), gauges, and/or combinations thereof, and the like. The disclosed chemicals, fluids and additives may also directly or indirectly affect the mixing hopper(s) 134 and the retention pit(s) 132 and their assorted variations.

[0058] Any disclosed chemicals, fluids and additives may also directly or indirectly affect the various downhole equipment and tools that may come into contact with the chemicals, fluids and additives such as, but not limited to, the drill string 108, any floats, drill collars, mud motors, downhole motors and/or pumps associated with the drill string 108, and any MWD/LWD tools and related telemetry equipment, sensors or distributed sensors associated with the drill string 108. Any disclosed chemicals, fluids and additives may also directly or indirectly affect any downhole heat exchangers, valves and corresponding actuation devices, tool seals, packers and other wellbore isolation devices or components, and the like associated with the wellbore 116. Any disclosed chemicals, fluids and additives may also directly or indirectly affect the drill bit 114, which may include, but is not limited to, roller cone bits, PDC bits, natural diamond bits, any hole openers, reamers, coring bits, etc.

[0059] While not specifically illustrated herein, any disclosed chemicals, fluids and additives may also directly or indirectly affect any transport or delivery equipment used to convey the chemicals, fluids and additives to the drilling assembly 100 such as, for example, any transport vessels, conduits, pipelines, trucks, tubulars, and/or pipes used to fluidically move the chemicals, fluids and additives from one location to another, any pumps, compressors, or motors used to drive the chemicals, fluids and additives into motion, any valves or related joints used to regulate the pressure or flow rate of the chemicals, fluids and additives, and any sensors (*i.e.*, pressure and temperature), gauges, and/or combinations thereof, and the like.

[0060] Therefore, the present methods are well adapted to attain the ends and advantages mentioned, as well as those that are inherent therein. The particular examples disclosed above are illustrative only, as the present methods may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular illustrative examples disclosed above may be altered or modified, and all such variations are considered within the scope and spirit of the present methods. While methods are described in terms of "comprising," "containing," "having," or "including" various components or steps, the methods may also, in some examples, "consist essentially of" or "consist of" the various components and steps. Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee.

[0061] What is claimed is:

1. A method of monitoring and controlling one or more properties of a drilling fluid used in drilling a well, comprising:

circulating the drilling fluid through the wellbore;

after circulating the drilling fluid through the wellbore, measuring the specific heat capacity of the drilling fluid; and

determining the value of an additional property of the drilling fluid based at least in part on the measured specific heat capacity of the drilling fluid.

2. The method of claim 1, wherein said drilling fluid is circulated through the wellbore and a fluid processing unit.

3. The method of claim 2, wherein said fluid processing unit is located on the surface adjacent to said wellbore.

4. The method of claim 3, wherein said drilling fluid is circulated through the wellbore, said fluid processing unit and a mud retention pit that is also located on the surface adjacent to said wellbore, and wherein said fluid processing unit is located upstream of said mud retention pit.

5. The method of claim 3, wherein said drilling fluid is circulated through the wellbore, said fluid processing unit and a mud retention pit also located on the surface adjacent to the wellbore, and wherein said fluid processing unit is located in said mud retention pit.

6. The method of claim 3, wherein said drilling fluid is circulated through the wellbore, said fluid processing unit, a mud retention pit also located on the surface adjacent to the wellbore, and a mixer also located on the surface adjacent to said wellbore and located downstream of said mud retention pit, and wherein said fluid processing unit is located downstream of said mixer.

7. The method of claim 1, wherein the specific heat capacity of the drilling fluid is measured at two or more fluid pressures, and wherein said additional property of the drilling fluid is determined based at least in part on said measured specific heat capacity at each fluid pressure.

8. The method of claim 1, wherein the specific heat capacity of the drilling fluid is measured at a temperature that is above or below ambient temperature.

9. The method of claim 1, further comprising providing a representation including multiple potential values of said additional property of the drilling fluid, each potential value corresponding to a predetermined specific heat capacity of the drilling fluid, and wherein said additional property of the drilling fluid is determined by comparing said measured specific heat capacity of the drilling fluid to the predetermined specific heat capacities of said representation and selecting the potential value of the additional property that corresponds to the predetermined specific heat capacity that most closely matches said measured specific heat capacity of the drilling fluid.

10. The method of claim 1, wherein said value of the additional property of the drilling fluid that is determined is the oil-to-water ratio of the drilling fluid.

11. The method of claim 1, wherein said value of the additional property of the drilling fluid that is determined is the average specific gravity of the solids in the drilling fluid.

12. The method of claim 1, wherein the value of a first additional property of the drilling fluid and the value of a second additional property of the drilling fluid are determined based at least in part on the measured specific heat capacity of the drilling fluid.

13. The method of claim 12, further comprising providing a separate representation for each of said first and second additional properties, each representation including multiple potential values of the corresponding additional property of the drilling fluid, each potential value corresponding to a predetermined specific heat capacity of said additional property of the drilling fluid, and wherein each of said first and second additional properties of the drilling fluid are determined by comparing said measured specific heat capacity of the drilling fluid to the predetermined specific heat capacities of the corresponding representation and selecting the potential value of the additional property that corresponds to the predetermined specific heat capacity that most closely matches the measured specific heat capacity of the drilling fluid.

14. The method of claim 13, wherein said first additional property of the drilling fluid is the oil-to-water ratio of the drilling fluid, and the second additional property of the drilling fluid is the average specific gravity of the solids in the drilling fluid.

15. The method of claim 1, further comprising adjusting at least one property of the drilling fluid in response to said determined additional property of the drilling fluid.

16. The method of claim 15, further comprising adjusting one or more of the oil-to-water ratio of the drilling fluid, the composition of the drilling fluid, the solids content of the

drilling fluid, and the average specific gravity of the solids in the drilling fluid in response to said determined additional property of the drilling fluid.

17. The method of claim 14, further comprising adjusting at least one property of the drilling fluid in response to the determined oil-to-water ratio of the drilling fluid and the determined average specific gravity of the solids in the drilling fluid.

18. The method of claim 2, wherein said fluid processing unit comprises:

a specific heat capacity sensor; and

a computer associated with said specific heat capacity sensor.

19. A method of monitoring and controlling the oil-to-water ratio of a drilling fluid used in drilling a well, comprising:

circulating the drilling fluid through the wellbore;

after circulating the drilling fluid through the wellbore, measuring the specific heat capacity of the drilling fluid;

providing a representation including multiple potential values of the oil-to-water ratio of the drilling fluid, each potential value corresponding to a predetermined specific heat capacity of the drilling fluid;

determining the oil-to-water ratio of the drilling fluid based at least in part on the measured specific heat capacity of the drilling fluid by comparing said measured specific heat capacity of the drilling fluid to the predetermined specific heat capacities of said representation and selecting the oil-to-water ratio that corresponds to the predetermined specific heat capacity that most closely matches said measured specific heat capacity of the drilling fluid; and

adjusting at least one property of the drilling fluid in response to the determined additional property of the drilling fluid.

20. A method of monitoring and controlling the average specific gravity of the solids in a drilling fluid used in drilling a well, comprising:

circulating the drilling fluid through the wellbore;

after circulating the drilling fluid through the wellbore, measuring the specific heat capacity of the drilling fluid;

providing a representation including multiple potential values of the of the drilling fluid, each potential value corresponding to a predetermined specific heat capacity of the drilling fluid;

determining the average specific gravity of the solids in the drilling fluid based at least in part on the measured specific heat capacity of the drilling fluid by comparing said measured specific heat capacity of the drilling fluid to the predetermined specific heat capacities of said representation and selecting the oil-to-water ratio that corresponds to the predetermined specific heat capacity that most closely matches said measured specific heat capacity of the drilling fluid; and

adjusting at least one property of the drilling fluid in response to the determined additional property of the drilling fluid.

21. The method of claim 20, wherein the drilling fluid is circulated through the wellbore using pumping equipment.

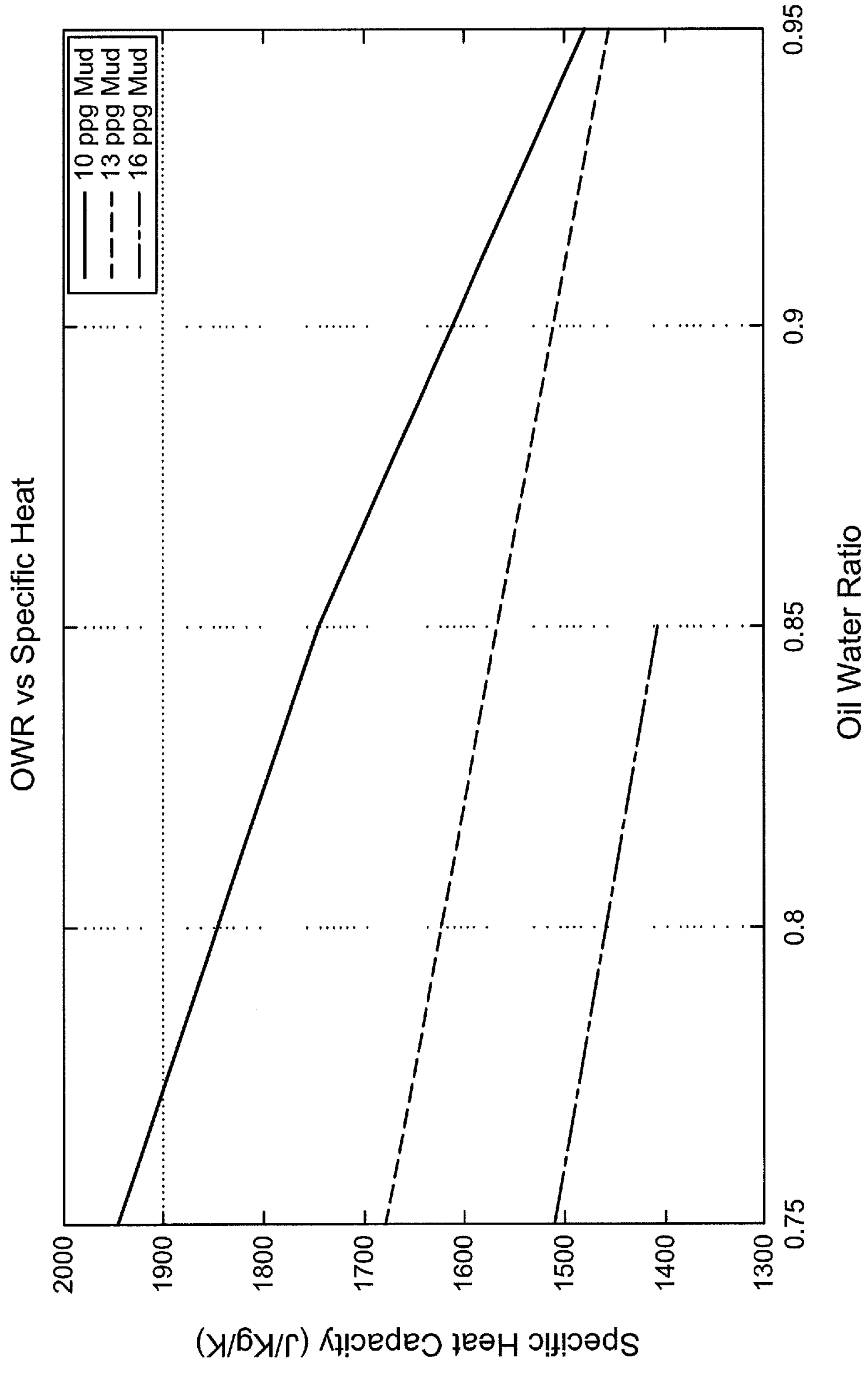
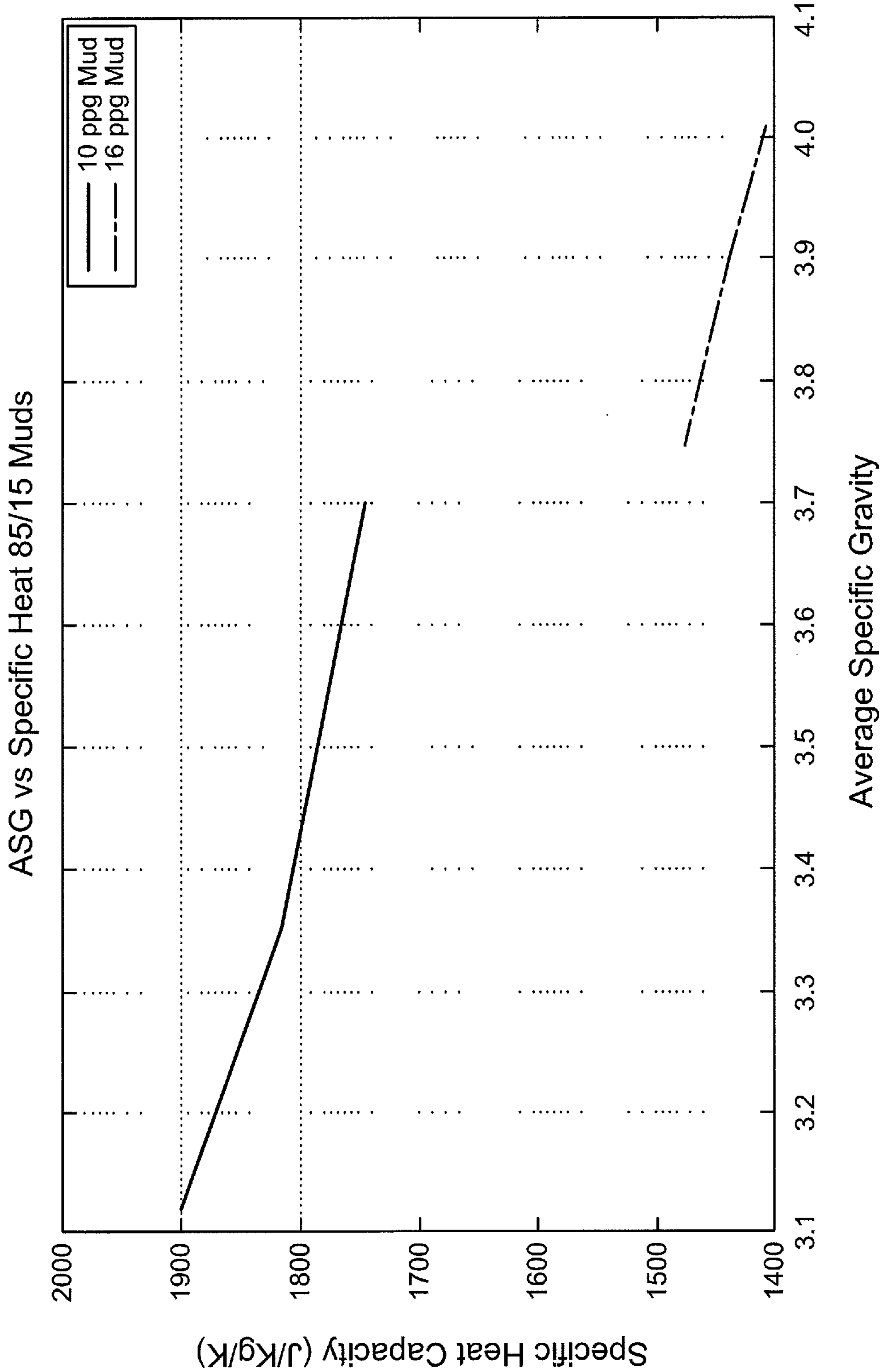

OWR vs Specific Heat
10 ppg Mud
13 ppg Mud
16 ppg Mud
Specific Heat Capacity (J/Kg/K)
2000
1900
1800
1700
1600
1500
1400
1300
Oil Water Ratio
0.75
0.8
0.85
0.9
0.95

FIG. 1



ASG vs Specific Heat 85/15 Muds
10 ppg Mud
16 ppg Mud
Specific Heat Capacity (J/Kg/K)
2000
1900
1800
1700
1600
1500
1400
Average Specific Gravity
3.1
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3.7
3.8
3.9
4.0
4.1

FIG. 2

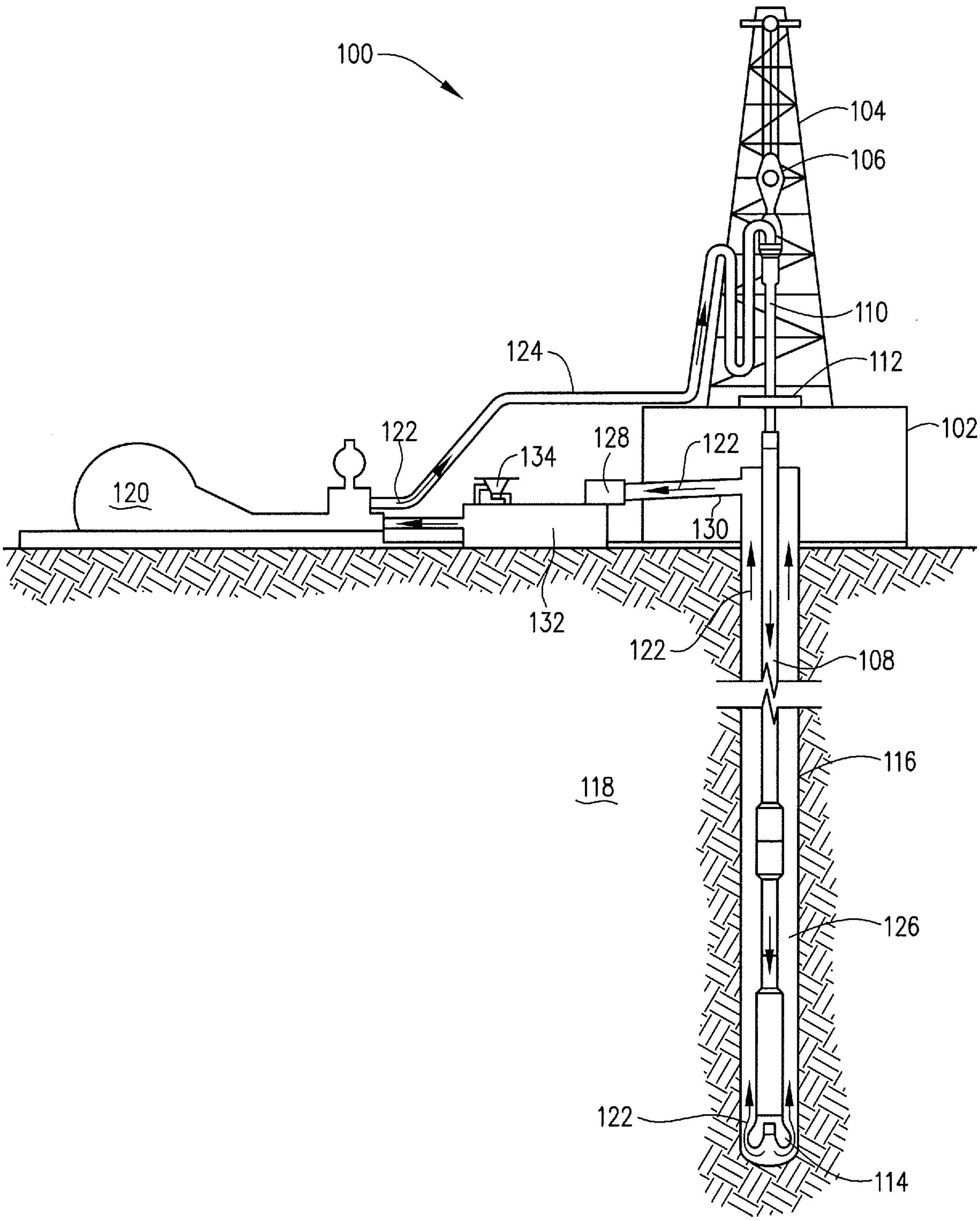
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FIG. 3

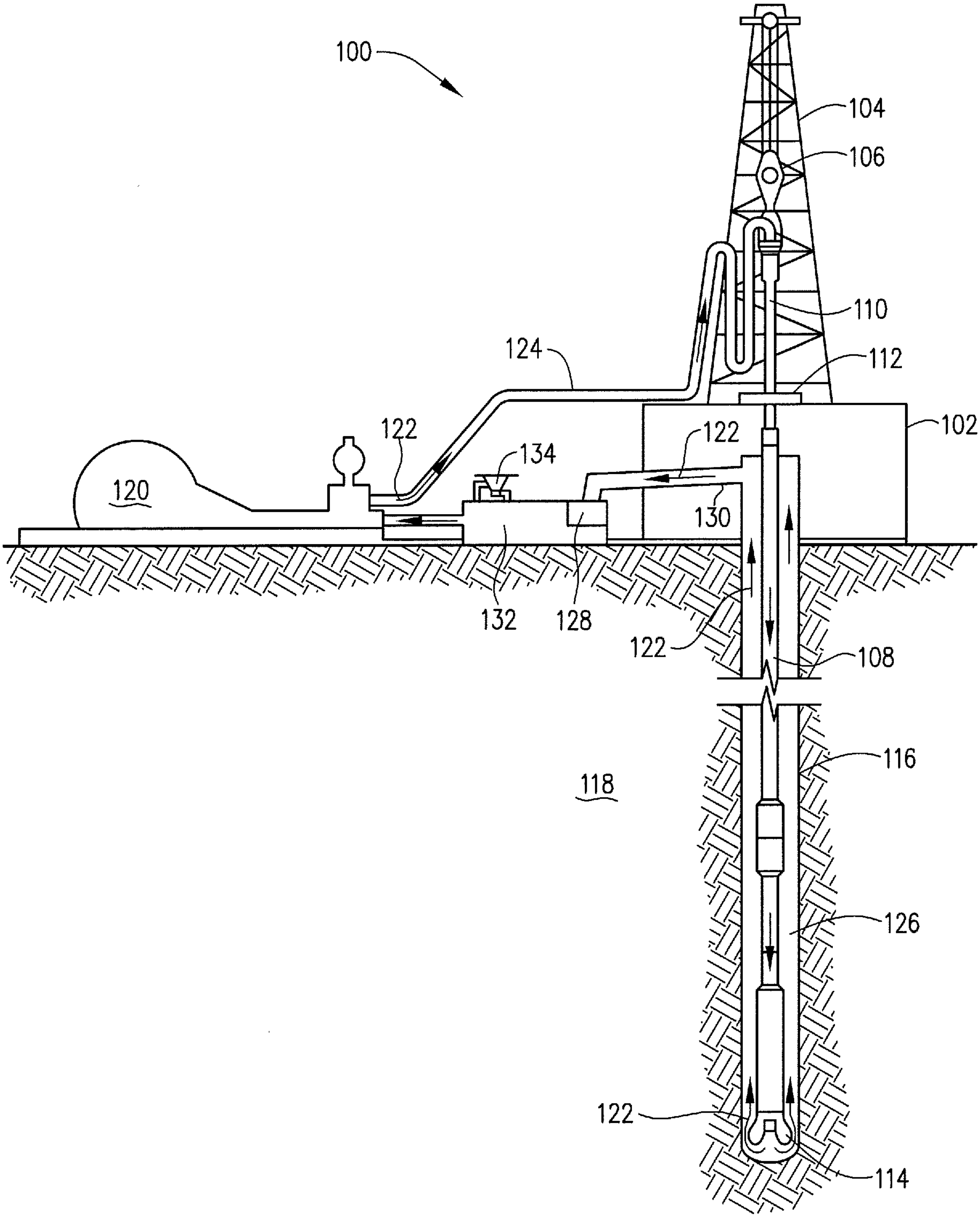
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FIG-4

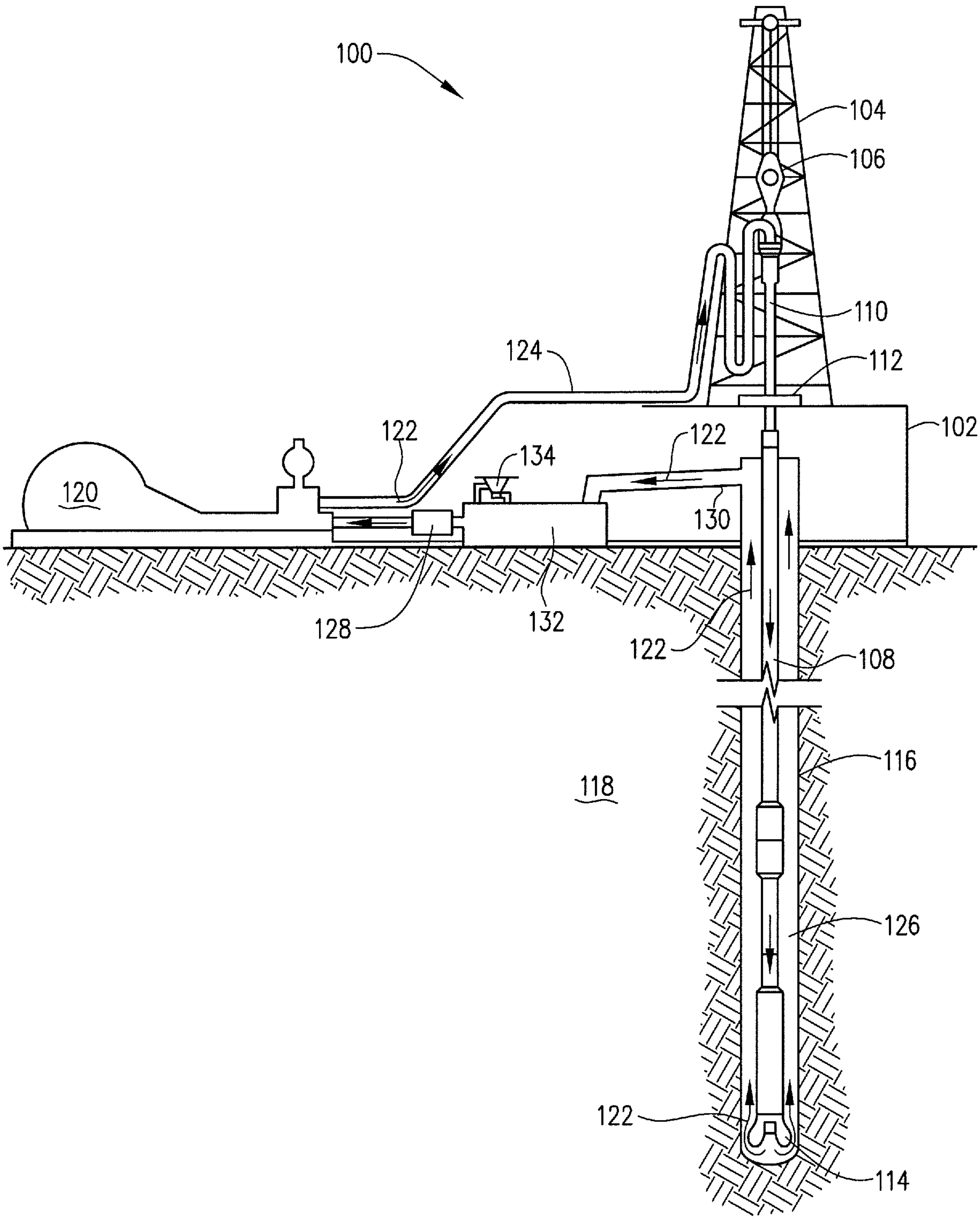

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FIG-5

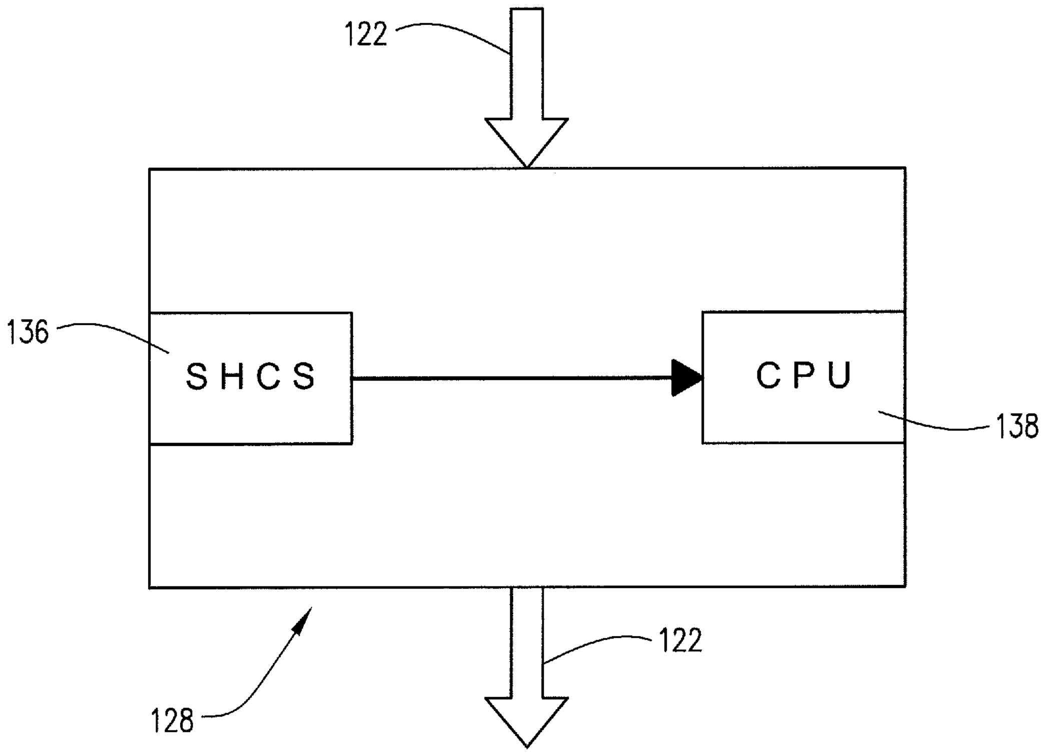

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/027138

A. CLASSIFICATION OF SUBJECT MATTER

E21B 49/08(2006.01)i, E21B 21/01(2006.01)i, E21B 47/06(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 49/08; B07B 1/28; E21B 21/01; E21B 47/06; E21B 36/04; G01V 9/00; B07B 1/46; E21B 21/06

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: monitor, specific heat capacity, fluid, oil to water ratio, average specific gravity

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 9518434 B1 (DRILL COOL SYSTEMS, INC.) 13 December 2016 See column 4, lines 32-62; column 6, line 23 - column 8, line 29; claim 18; and figure 1.	1-8,10-12,15-16,18
A		9,13-14,17,19-21
Y	US 2015-0007984 A1 (HALLIBURTON ENERGY SERVICES, INC.) 08 January 2015 See paragraphs [0052]-[0059]; and figure 7.	1-8,10-12,15-16,18
A	US 2016-0259084 A1 (HALLIBURTON ENERGY SERVICES, INC.) 08 September 2016 See paragraphs [0035]-[0037]; and figures 1, 9.	1-21
A	WO 2015-200886 A1 (M-I L.L.C.) 30 December 2015 See paragraphs [0027]-[0032]; and figures 1-2.	1-21
A	WO 2017-011505 A1 (HALLIBURTON ENERGY SERVICES, INC.) 19 January 2017 See paragraphs [0009]-[0014]; claims 1-3, 11-13, 19-20; and figure 1.	1-21

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 February 2018 (13.02.2018)	**13 February 2018 (13.02.2018)**

Name and mailing address of the ISA/KR
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Korean Intellectual Property Office
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/027138

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 9518434 B1	13/12/2016	None	
US 2015-0007984 A1	08/01/2015	AU 2012-396812 A1	21/05/2015
		AU 2012-396812 B2	04/08/2016
		CA 2892884 A1	19/06/2014
		EP 2836679 A1	18/02/2015
		EP 2836679 A4	27/04/2016
		MX 2015006787 A	06/08/2015
		US 9175546 B2	03/11/2015
		WO 2014-092679 A1	19/06/2014
US 2016-0259084 A1	08/09/2016	EP 3055503 A1	17/08/2016
		MX 2016010458 A	17/10/2016
		US 9791595 B2	17/10/2017
		WO 2015-137917 A1	17/09/2015
WO 2015-200886 A1	30/12/2015	GB 2543179 A	12/04/2017
		NO 20161872 A1	24/11/2016
		US 2015-0377020 A1	31/12/2015
WO 2017-011505 A1	19/01/2017	US 2017-0204689 A1	20/07/2017