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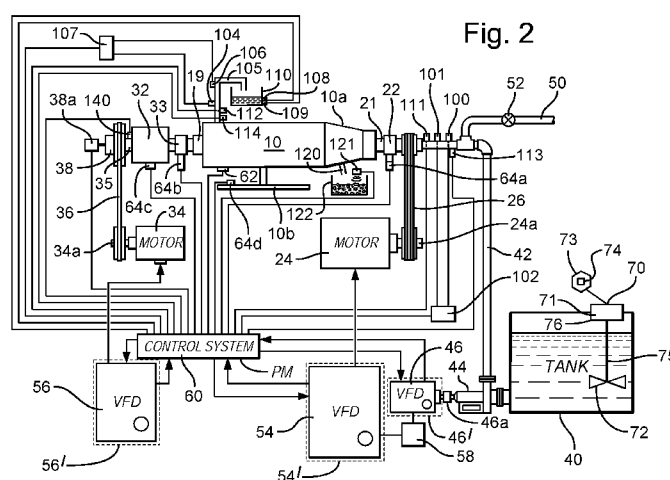
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(54) Title: A CENTRIFUGE AND A CONTROL SYSTEM THEREFOR



(57) Abstract: A drilling mud system for separating solids from solids laden drilling mud, the system comprising a centrifuge (10) having a bowl (12) and a conveyor (18), an inlet (18a) for solids laden drilling mud to be introduced to the bowl (12), a solids discharge outlet (12c) and a drilling mud discharge outlet (19'), a bowl drive (24) for driving the bowl (12) and a conveyor drive (34) for driving the conveyor (18), the system further comprising at least one sensor and a control system (PM) measuring centrifuge performance with said at least one sensor, said control system (PM) storing an algorithm for determining optimum performance and said control system (PM): making a small evolutionary operation parameter change in a first direction; checking if the small evolutionary operation parameter change is within constraints; re-measure centrifuge performance, whereupon if the centrifuge performance improves, for making a further small evolutionary operation parameter change in said first direction and if the performance does not improve for making a small evolutionary operation parameter change in a second direction.



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A CENTRIFUGE AND A CONTROL SYSTEM THEREFOR

The invention relates to a centrifuge and a drilling mud system for separating solids from solids laden drilling mud.

5 In the drilling of a borehole in the construction of an oil or gas well, a drill bit is arranged on the end of a drill string, which is rotated to bore the borehole through a formation. A drilling fluid known as "drilling mud" is pumped through the drill string to the drill bit
10 to lubricate the drill bit. The drilling mud is also used to carry the cuttings produced by the drill bit and other solids to the surface through an annulus formed between the drill string and the borehole. The density of the drilling mud is closely controlled to inhibit the
15 borehole from collapse and to ensure that drilling is carried out optimally. The density of the drilling mud affects the rate of penetration of the drill bit. By adjusting the density of the drilling mud, the rate of penetration changes at the possible detriment of
20 collapsing the borehole. The drilling mud may also carry commercial solids i.e. any purposely added solids, such as lost circulation materials for sealing porous sections of the borehole. The acidity of the drilling mud may also be adjusted according to the type of formation strata
25 being drilled through. It is not uncommon to have 30 to 100 m³ of drilling fluid in circulation in a borehole. The drilling mud contains *inter alia* expensive synthetic oil-based lubricants and it is normal therefore to recover and re-use the used drilling mud, but this
30 requires *inter alia* the solids to be removed from the drilling mud. This is achieved by processing the drilling mud. The first part of the process is to separate large solids and lost circulation material from the solids

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laden drilling mud. This is at least partly achieved with one or more a vibratory separators, such as those shale shakers disclosed in US 5,265,730, WO 96/33792 and WO 98/16328. The shale shakers may be cascaded in series of stages, such as three stages: a scalping deck having a large mesh screen suitable for removing colloidal material such as clumps of clay and large solids; a primary deck having fine mesh screen for removing large particles (but smaller than the colloidal material) which may include lost circulation material; and a secondary deck a fine screen to remove small particles, mainly drill cuttings. The decks may be arranged in a single basket or in separate baskets and vibrated with a vibratory mechanism.

Further processing equipment such as a centrifuge may be used to further clean the drilling mud of smaller solids. The centrifuge may be used to remove large and medium size solids, although is particularly suitable for removing small, heavy particles such as "barites". A portion of thickening agents commonly referred to as "bentonites" may also be separated from drilling fluid during the operation of the centrifuge. These particles are generally too small for a screen in a shale shaker to remove. The resultant drilling mud is returned to the active mud system of the drilling rig.

A mud engineer will analyse the resultant drilling mud and *inter alia*: dilute the drilling mud if it is too viscous; add more bentonites if the drilling mud is not viscous enough; and add more barites if the drilling mud is not dense enough for recirculation.

It should also be noted that a centrifuge may be used without or ahead of the shale shakers or directly after only one or two stage of screening. Furthermore,

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the centrifuge may be used to clean drilling mud or other fluids on a rig which are not being continuously circulated in the well.

Centrifuges are typically used in any one of three
5 modes of operation:

1. low gravity solids (LGS) removal, in water based mud (WBM) while meeting environmental discharge criteria, and in oil based mud (OBM/NAF) while meeting environmental discharge criteria
- 10 2. barite separation, which sometimes requires two centrifuges; and
3. dewatering, simply discharging as many solids as possible

Low Gravity Solids (LGS) is a type of solid found in
15 a drilling fluid having a lower density than the barite or hematite that is used to weight up a drilling fluid. LGS include drilled solids plus any added thickening agent such as bentonite clay. The mud engineer calculates the concentration of these and other types of solids on
20 the basis of mud weight, retort analysis, chloride titrations and other information. Solids are reported as lbm/bbl or vol.%. Water is 1.0, barite 4.20, and hematite 5.505 g/cm³. LGS are normally assumed to have a density of 2.60 g/cm³.

25 Typically, Low Speed Decanting is used for Barite removal. Separating factor 500-700, 4-7 micro-metre particle size. Barite is a dense mineral comprising barium sulfate [BaSO₄]. Commonly used as a weighting agent for all types of drilling fluids, barites are mined
30 in many areas worldwide and shipped as ore to grinding plants in strategic locations, where API specifies grinding to a particle size of 3 to 74 microns. Pure barium sulphate has a specific gravity of 4.50 g/cm³, but

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drilling-grade barite is expected to have a specific gravity of at least 4.20 g/cm³ to meet API specifications. Contaminants in barite, such as cement, siderite, pyrrhotite, gypsum and anhydrite, can cause
5 problems in certain mud systems and should be evaluated in any quality assurance program for drilling-mud additives.

Typically, Medium Speed Decanting is used with a separating factor 800 for 5-7 micrometre separation.

10 High Speed Decanter Separating factor 1200-2100 rpm for 2-5 micrometre separation.

The present invention may be used in any of these modes of operation or for any other form of separation stage.

15 The inventors have noted that use of the centrifuge is not optimised. The centrifuge is adjusted manually to achieve desired results, which produces inconsistent results. The inventors noted that the centrifuge may be operated to produce drilling mud which does not need to
20 be adjusted or only minimally for re-circulation. The inventors also observed that the price of clean drilling mud, bentonite and barites and the cost of processing used drilling mud vary, making it economically desirable to use the centrifuge in different ways according to
25 these costs. Thus optimum performance of the centrifuge may vary according to these costs.

In accordance with the present invention, there is provided a drilling mud system for separating solids from solids laden drilling mud, the system comprising a
30 centrifuge having a bowl and a conveyor, an inlet for solids laden drilling mud to be introduced to the bowl, a solids discharge outlet and a drilling mud discharge outlet, a bowl drive for driving the bowl and a conveyor

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drive for driving the conveyor, the system further comprising at least one sensor and a control system measuring centrifuge performance with the at least one sensor, the control system storing an algorithm for
5 determining optimum performance and the control system: making a small evolutionary operation parameter change in a first direction; checking if the small evolutionary operation parameter change is within constraints; re-measure centrifuge performance, whereupon if the
10 centrifuge performance improves, for making a further small evolutionary operation parameter change in the first direction and if the performance does not improve for making a small evolutionary operation parameter change in a second direction. Centrifuge performance
15 improves if the small change moves performance of the centrifuge towards optimum performance.

Preferably, the optimum performance is assessed by economic benefit. It is thus wasteful to separate and discard desirable solids, such as barites and thickening
20 agents such as bentonite, if they are need in the recirculated fluids. It is wasteful if the solids laden drilling mud is over separated, producing: solids which are too dry; and stripping out thickening agents such as bentonite which may want to be re-used in the drilling
25 mud, as well as other desirable solids such as barite. Conversely, the solids exiting the centrifuge should not be too oily, as they may not fulfil environmental restrictions nor be able to be used in secondary industries, such as in road or housing construction. Each
30 way of use or disposal has an economic value. The inventors have noted that these values can be input into an algorithm in a control system of a centrifuge and used to automatically operate the centrifuge to gain best

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economic advantage for the operator, whilst fulfilling its legislative and environmental obligations. It is thus more cost effective to sometimes over separate or under-separate, depending on economic conditions.

5 Preferably, the solids laden drilling mud contains a base drilling mud, desirable solids and thickening agent, the algorithm comprises:

$$E = D - B - F - b, \text{ where}$$

10 E = the net economic benefit (\$) from operating the centrifuge

D = the cost of the liquid that would otherwise have to be used to dilute the used solids laden drilling mud if the centrifuge wasn't operating to remove the fine drilled solids

15 B = cost of desirable solids [barite] that is lost via the centrifuge solids discharge

F = cost of the drilling mud that is lost via the centrifuge solids discharge

20 b = cost of the thickening agent [bentonite gel] that is lost via the centrifuge solids discharge

Advantageously, the operational cost of the drilling mud system minimised by the algorithm comprising the sum of the following costs of:

a. mud dilution

25 b. chemical additives that must be replaced because the centrifuge discarded all or a portion of them
The chemical additives may be barite, chlorides, well bore stability materials, lost circulation material (LCM), etc.

30 Preferably, the operational cost of the mud system are minimised by the algorithm comprising the sum of the following costs of mud dilution by maximizing the Low Gravity Solids removal rate while still meeting

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environmental discharge requirements

Advantageously, the algorithm further comprises further comprises a factor from a table for maintenance costs running the centrifuge at a set condition and
5 minimizing the maintenance costs, the table stored in the control system.

Preferably, the parameter is at least one of: bowl speed by the control system controlling the bowl drive; and conveyor speed by the control system controlling the
10 conveyor drive.

Advantageously, the drilling mud system further comprises a feed pump, and the parameter is slurry feed rate, the control system controlling the feed pump.

Preferably, the drilling mud system further
15 comprises an adjustable gate and a gate actuator for moving the adjustable gate, and the parameter is pond depth, the control system controlling the gate actuator to control pond depth.

Preferably, the sensor comprises a feed slurry
20 density sensor apparatus for measuring the density of the feed slurry to be processed by the centrifuge, preferably using differential pressure measurement along a part of the feed pipe.

Advantageously, the sensor comprises a liquid
25 density sensor apparatus for measuring the density of the liquid processed by the centrifuge. Preferably, using differential pressure measurement along a part of the liquid discharge pipe.

Preferably, the sensor comprises feed slurry
30 viscosity sensor. Preferably, the feed slurry viscosity sensor is located at an input to centrifuge, liquid output from centrifuge and the tank that the centrifuge is discharging into receiving the solids.

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Advantageously, the sensor comprises a feed slurry mass flow rate sensor. Most advantageously, a Coriolis mass flow meter is used, preferably in feed pipe.

Preferably, the sensor comprises a liquid mass flow rate sensor. Advantageously, a Coriolis mass flow meter is used preferably in the discharge pipe.

Advantageously, the sensor comprises a feed slurry volumetric flow rate sensor. Preferably, the sensor comprises a liquid volumetric flow rate sensor.

Preferably, the sensor comprises a moisture meter to measure the moisture content of the solids discharged from the centrifuge.

Advantageously, the sensor comprises temperature sensor at at least one of the following locations: rotating assembly bearings; gearbox; VFD control cabinet; ambient air; motor windings of bowl and conveyor drives; feed slurry at the inlet.

Preferably, the sensor comprises vibration frequency and amplitude sensors located at at least one of the following: rotating assembly bearings; an equipment skid on which the centrifuge is arranged; and gearbox. Preferably, vibration frequency and amplitude sensors comprise one accelerometer, orthogonal pairs or orthogonal triple accelerometers to accurately measure vibrations in one or more planes.

Preferably, the sensor comprises a bowl rotational speed sensor and a conveyor rotational speed sensor for the conveyor. Advantageously, drilling mud system comprises a gearbox and the sensor comprises an input torque sensor and output torque sensor.

Advantageously, the sensor comprises a pond depth sensor to measure the depth of the feed slurry in the bowl of the centrifuge. The pond depth sensor may be a

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position sensor on a gate valve

Preferably, the constraints comprise a maximum allowable % moisture on solids. Advantageously, % moisture on solids is estimated from a dampness sensor reading using a sensor such as an NIR device, but may also be a sensor for measuring % moisture on cuttings or manually analysed and resultant data input to the control system. Preferably, if the maximum allowable % moisture on solids is breached, the control system reduces the feed pump speed in order to reduce the solids load in the bowl. Advantageously, if the maximum allowable % moisture on solids is breached, the control system reduces the differential speed between the conveyor and bowl. Preferably, if the maximum allowable % moisture on solids is breached, the control system controls gate actuator to increase the pond depth of the solids laden drilling mud in the bowl. The moisture on/in the solids is typically a mixture of water and oil. If the moisture is below a predetermined threshold, the solids can be regarded as having a negligible amount of oil thereon. The predetermined threshold may be set in a local environmental standards document or a condition set by the customer. Alternatively, the oil content can be measured using an analysis technique, either in a lab or on site and thus the % moisture criteria above may be replaced with % oil.

Preferably the drilling mud system further comprises the step of obtaining a torque on bowl drive and torque on conveyor drive, the constraints comprise a maximum allowable torque on bowl drive and a maximum torque on conveyor drive. Advantageously, if the torque is too high, then the centrifuge control system adjusts the feed pump speed in order to reduce the solids load in the

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bowl. Preferably, if the torque is too high, then the centrifuge control system increases the differential speed between the conveyor and bowl by increasing the conveyor drive motor speed. The torque on the bowl and
5 conveyor can be obtained from the VFD or a separate torque sensor.

Advantageously, the constraints comprise a maximum allowable barite loss rate. Preferably, if the barite loss rate is too high, then the control system reduces
10 the feed pump speed in order to reduce the amount of barite processed by the centrifuge.

Preferably, the second direction is an opposite direction. Advantageously, at least one of the bowl drive and conveyor drive comprise a variable frequency drive.
15 Advantageously, the bowl drive and conveyor drive are two separate drives or may be one drive with a speed changer, such as a gearbox therebetween to vary speeds applied to each of the bowl and conveyor. Preferably, the inlet to the comprises a feed tube.

20 The present invention also provides a method of operating a centrifuge comprising a bowl and a conveyor, an inlet for solids laden drilling mud to be introduced to the bowl, a solids discharge outlet and a drilling mud discharge outlet, a bowl drive for driving the bowl and a
25 conveyor drive for driving the conveyor, at least one sensor and a control system the method comprising the steps of the control system measuring centrifuge performance with the at least one sensor, the control system storing an algorithm for determining optimum
30 performance and the control system: making a small evolutionary operation parameter change in a first direction; checking if the small evolutionary operation parameter change is within constraints; re-measuring

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centrifuge performance, whereupon if the centrifuge performance improves, making a further small evolutionary operation parameter change in the first direction and if the performance does not improve making a small
5 evolutionary operation parameter change in a second direction.

The present invention also provides an apparatus for separating solids from solids laden drilling mud, the apparatus comprising a centrifuge having a bowl and a
10 conveyor, an inlet for solids laden drilling mud to be introduced to the bowl, a solids discharge outlet and a drilling mud discharge outlet, a bowl drive for driving the bowl and a conveyor drive for driving the conveyor, the apparatus further comprising at least one sensor and
15 a control system comprising a memory for storing an algorithm for determining optimum performance and storing instructions for carrying out the method of the invention. The present invention also provides a control system storing an algorithm for determining optimum
20 performance and for executing instructions in accordance with the method of the invention.

In accordance with another aspect of the invention, there is provided a centrifuge having a bowl for retaining a pond of solids laden drilling mud and a
25 conveyor, an inlet for solids laden drilling mud to be introduced to the bowl, a solids discharge outlet and a drilling mud discharge outlet, a bowl drive for driving the bowl and a conveyor drive for driving the conveyor, the system further comprising at least one sensor and a
30 control system wherein the drilling mud discharge outlet further comprises an adjustable gate and a gate actuator for moving the adjustable gate, the gate maintaining the pond of solids laden drilling mud, the control system

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controlling the gate actuator to control depth of the
pond of solids laden drilling mud. Other preferable and
advantageous features of this centrifuge are set out in
any of the preferable and advantageous features set out
5 above and the below description.

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For a better understanding of the present invention, reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is a sectional view of a part of the
5 centrifuge shown in Figure 2;

Figure 2 is a schematic view of a drilling mud system in accordance with the present invention including a centrifuge;

Figure 3 is a schematic diagram showing options for
10 location of a control system for the centrifuge;

Figure 4 is a perspective view of a part of the centrifuge shown in Figure 1;

Figure 5 is a schematic view of part of an automatic weir of the centrifuge shown in Figure 1;

Figure 6 is a schematic view of part of an
15 alternative automatic weir to the automatic weir shown in Figure 5; and

Figure 7 is a flow diagram setting out steps in a method in accordance with the present invention.

20 Figures 1 shows a centrifuge 10 in accordance with the present invention. The centrifuge 10 has a bowl 12, supported for rotation about its longitudinal axis. The bowl 12 is in the form of a hollow solid walled cylinder of circular cross-section preferably having a first bowl
25 portion 12' having an internal diameter which reduces in a tapering fashion towards a distal end 12a and a second bowl portion 12'' having a substantially constant internal diameter from the first bowl portion 12' to a proximal end 12d. The bowl 12 has an opening at each of the distal
30 and proximal ends 12a and 12d, the distal end 12a having a drive flange 14 fitted into the opening which is connected to a drive shaft 21 for rotating the bowl 12. The drive flange 14 has a longitudinal passage which receives a feed tube 16 for introducing a feed slurry,
35 such as solids laden drilling mud, into the interior of

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the bowl 12.

A hollow flanged shaft 19 is disposed in the opening in the proximal end 12d of the bowl 12 and preferably fixed thereto with a plurality of bolts 8 (shown in Figure 4). The hollow flanged shaft 19 receives a drive shaft 20 of an external planetary gear box 32 for rotating a screw conveyor 18 in the same direction as the bowl 12 at a selected speed, which may be at a different speed from the bowl 12.

The screw conveyor 18 is arranged within the bowl 12 in a coaxial relationship thereto and is supported for rotation within the bowl 12 between a distal hollow stub axel 14a of the drive flange 14 and a distal hollow stub extending from flanged shaft 20. The screw conveyor 18 has a hollow solid walled cylindrical body 17 of circular cross-section, a first part 17a of which has a tapering external diameter and a second part 17b which has a constant diameter. The screw conveyor 18 has a flight 13 of substantially constant pitch, although as an alternative may be a variable pitch (not shown). As an alternative, a further flight may be provided for a double-start flight (not shown). Annular depth of the flight 13 is preferably substantially constant along second part 17b of the screw cylindrical body 17, advantageously reducing in a tapering fashion in a linear taper or alternatively, non-linear taper (not shown), towards and along first part 17a. Openings (not shown) are formed in the cylindrical body 17 of the screw conveyor 18 in the region identified by reference numeral 15.

The solids laden drilling fluid flows from an inlet 18a of the feed tube 16 so that the centrifugal forces generated by the rotating bowl 12 move the slurry radially outwardly through the openings in region 15 in the solid walled cylindrical body 17 and into an annular

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space 13' between the solid walled cylindrical body 17 and the bowl 12. The liquid portion of the slurry forms a pond 11 and is displaced to the proximal end 12d of the bowl 12. Entrained solid particles 11a in the slurry settle towards the inner surface 12''' of the bowl 12 due to the G forces generated, and are scraped and displaced by the screw conveyor 18 back towards the distal end 12a of the bowl 12 for discharge through a solids discharge outlet(s) which may be a plurality of solids discharge ports 12c formed through the wall of the bowl 12 near its end 12a. The solids discharge ports 12c are arranged closer to the centreline of the bowl than the pond depth, thus only the solids are displaced through the discharge ports 12c with very little or no drilling mud. A cowling 10a (shown in Figure 2) is provided about the bowl 12 to collect and direct the solids to a discharge pipe 120 into a discharge system, such as a skip, trough or solids conveying apparatus.

A liquid discharge outlet is provided in the bowl 12, which liquid discharge outlet may comprise liquid discharge ports 19' provided in flange 19'' of hollow flanged shaft 19. The flange 19'' is bolted to the bowl 12 with bolts 8 (shown in Figure 4). The liquid discharge ports 19', preferably five ports, but may be any suitable number such as one to twenty, are spaced in a concentric circle about the flange 19'', each spaced from the inner surface 12''' of the bowl 12 at an equal distance. Thus the liquid discharge ports 19' act as weirs, controlling the depth of the pond 11.

The liquid discharge ports 19' are shown in more detail in Figure 4 and an alternative embodiment in Figure 5. The liquid discharge ports 19' each comprise a circular hole 20' in the flange 19'', although the hole 20' may be of any shape, such as a polygon, oval and may take the form of a slot. The hole 20' is approximately

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five to ten centimetres in diameter. A disc gate 20a is pinned to the flange 19" with a pin 20b. The pin 20b is rigidly fixed to the flange and may be welded thereto. The pin 20b may be placed at or close to a point on the same radius as the centre of the hole 20', the radius taken from the centre of the flanged shaft 19. The disc gate 20a is movable about the pin 20b. A toothed cog 27 engages with a splined opening 25 in the disc gate 20a about the pin 20b. A drive shaft 23 of a control motor 29 is rotationally fixed to the toothed cog 22. The disc gate 20a has a circular opening 20c therein, although the opening 20c may be of any shape such as a polygon or oval and may take the form of a slot. Upon activation of the control motor 29, the drive shaft 23 rotates rotating the disc gate 20a about the fixed pin 20b. The disc gate 20a is movable about the fixed pin 20b to vary the effective weir height. The control motor 29 moves disc gate 20a in small increments or linearly in response to commands from a control system PM.

The disc gate 20a may alternatively be solid, the outer perimeter of the disc gate 20a used for the weir and thus controlling pond depth.

Another alternative automatic weir is shown in Figure 6. The disc gate 20a takes the form of a radially slideable gate 20a' arranged in a track 25'. The gate 20a' is slideable over the hole 20' with a linear actuator motor 29'. Activation of the linear motor 29' thus controls the position of the gate 20a' over the hole 20' by extending and retracting an arm 23' fixed to the gate 20a'. An end 31 of the gate 20a' acts as the weir and its position and thus weir height controlled by the linear actuator motor 29'. The linear actuator motor 29' is controlled by control system PM.

The centrifuge as shown in Figures 1 and 2 is enclosed in a cowl 10a in a conventional manner to

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collect and divert the flow of separated liquid into a fluid discharge pipe 105 and to collect and divert the solids into a solids discharge pipe 120.

As shown in Figure 2, a drive shaft 21 forms an extension of, or is connected to, the drive flange 14 and is supported by a bearing 22. A variable speed AC main bowl drive motor 24 has an output shaft 24a which is connected to the drive shaft 21 by a drive belt 26 and therefore rotates the bowl 12 of the centrifuge at a predetermined operational speed. The flanged shaft 19 extends from the interior of the conveyor 18 to a planetary gear box 32 and is supported by a bearing 33. A variable speed AC back conveyor drive motor 34 has an output shaft 34a which is connected to a sun wheel 35 by a drive belt 36 and the sun wheel is connected to the input of the gear box 32. The conveyor drive motor 34 rotates the screw conveyor 18 of the centrifuge through the planetary gear box 32 which functions to establish a differential speed of the conveyor 18 with respect to the bowl 12. A coupling 38 is provided on the shaft of the sun wheel 35, and a limit switch 38a is connected to the coupling which functions in a conventional manner to shut off the centrifuge when excessive torque is applied to the gearbox 32.

For receiving and containing the feed slurry being processed, there is a tank 40 and a conduit 42 connected to an outlet opening formed in the lower portion of the tank to the feed tube 16. An internal passage through the shaft 21 receives the conduit 42 and enables the feed slurry to pass through the conduit and the feed tube 16 and into the conveyor 18.

The slurry is pumped from the tank 40 by a powered pump 44 which is connected to the conduit 42 and is preferably driven by a motor and most preferably having driven by a variable frequency drive unit 46, which pumps

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the slurry through the conduit 42 and the feed tube 16, and into the centrifuge. Optionally, a control valve 52 disposed in the conduit 50 controls flow through the conduit. Two variable frequency ("VFD") drives 54 and 56
5 are respectively connected to the motors 24 and 34 for driving the motors at variable frequencies and at variable voltages. The drive unit 46 may also be a variable frequency drive. Preferably, the VFDs 46, 54 and 56 are connected to and controlled by the control system
10 PM. Optionally, the VFD 54 is also electrically connected to the input of a magnetic starter 58, the output of which is connected to the drive unit 46. The VFD 54 supplies a control signal to the starter 58 for starting and stopping the drive unit 46, and therefore the feed
15 pump 44.

The control system PM may be a computer provided which contains computer programs stored on a computer readable media, such as a ROM, RAM, in the computer itself containing instructions for controlling the
20 operation of the drilling mud system: the centrifuge 10 and preferably the feed pump 44. To this end, the control system PM has several input terminals two of which are respectively connected to the VFDs 54 and 56 for receiving data from the VFDs, and two output terminals
25 for respectively sending control signals to the VFDs. The control system PM thus responds to the input signals received and controls the VFDs 54 and 56 in a manner so that the drive units can continuously control the system and vary the frequency and the voltage applied to the
30 respective AC motors 24 and 34, to continuously vary the rotation and the torque applied to the drive shaft 21 and to the sun wheel 35, respectively.

The control system may be a Programmable Logic Controller having readable media containing instructions
35 for controlling the operation. Alternatively, the control

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system may be a single board computer. Alternatively, the control system PM may comprise a dumb terminal DT having access, wired or wireless to an intranet I via a network connection NE or internet on which the instructions for controlling the operation are stored and/or executed. The sensors of the type set out herein may transmit their data through a wire back to bus connection of the dumb terminal DT from which the data is collected and passed through a network connection or wirelessly to the internet. Thus the instructions for controlling the operation may be in a cloud PM'. An HMI apparatus (human-machine interface, e.g. the touch screen system) 54d provides a visual display of the system operation and a tactile means of control 54d for the control system. The HMI apparatus 54d is shown in Figure 3 as part of or attached to a laptop computer CP, but may be arranged as part of dumb terminal DT on a skid 10b of the centrifuge and/or in a control room of a drilling rig and/or a remote control room RS distant from said drilling rig. The instructions for controlling the operation may alternatively be in a computer readable media PM'' in the laptop CP. The centrifuge 10 could also be remotely monitored. This could be done by apps on a portable device such as a smart phone with different user profiles for technicians, customers, etc.

The control system PM has another input terminal connected to the drive unit 46 with a motor 46a for receiving data from the drive unit 46. Another output terminal of the control system PM is connected to the drive unit 46 for sending control signals to the drive unit 46. The control system PM thus responds to the input signals received from at least one the VFDs 54 and 56 and can send corresponding signals to the drive unit 46 to for varying the operation of the feed pump 44. Another input terminal of the control system PM is connected to

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the limit switch 38a which provides a signal in response to excessive torque being applied to the gear box 32.

Mounted on the outer surface of the bowl 12 is a vibration sensor 62, such as an accelerometer which is connected to the control system PM, and responds to excessive vibrations of the centrifuge for generating an output signal that causes the control system to send signals to the VFDs 54 and 56 to turn off the motors 24 and 34, respectively and therefore shut down or slow down the centrifuge.

Near the bearings 22 and 33 are connected a pair of accelerometer sets 64a, 64b, 64c and 64d each set advantageously including two accelerometers for respectively measuring certain operational characteristics, particularly, but not exclusively, at high frequencies of the drive shafts 21 and 20 and their associated bearings, gearbox 32 and equipment skid 10b on which the centrifuge 10 sits. The accelerometer sets 64a, 64b, 64c and 64d are connected to the control system PM for passing their respective output signals to the control system PM for processing. The accelerometer sets 64a, 64b, 64c and 64d can be of the type disclosed in U.S. Patent No. 4,626,754, the disclosure of which is hereby incorporated by reference.

Each accelerometer set preferably includes two or more accelerometers having orthogonal axes that are placed on the frames of the bearings 22 and 33 for detecting vibrations caused by the rotating bowl 12 and screw conveyor 18, as well as the drive shaft 21 and the sun wheel 35. The accelerometer signals provided by the accelerometers of each set 64a, 64b, 64c and 64d are passed to the control system PM where a computer program contained therein analyzes the signals for the presence of specific predetermined frequency signatures corresponding to particular components and their status,

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which could include a potentially malfunctioning condition. The computer program is designed to provide instructions to produce an output in response to any of these frequency signatures being detected. The
5 accelerometer signals are analysed by the control system PM and upon using the evolutionary operation parameter change method as set out below, if the accelerometer signals pass a predetermined threshold, are regarded as constraints on the system and the control system may
10 regard any change in the parameter as a performance not improved status. The back current to the drive units 24 and 34, are proportional to the loading of the bowl 12 and the conveyor, respectively, the values of which is fed back to the control system PM.

15 The control system PM has conventional devices including, but not limited to, programmable media, computer(s), processor(s), memory, mass storage device(s), video display(s), input device(s), audible signal(s), and/or programmable logic controller(s),
20 access to storage on the internet and cloud, such that any computer program used by the control system PM may be stored and/or run on in the cloud. Optionally, e.g. in field applications, a generator is provided which generates electrical power and passes it to a breaker box
25 which distributes the power to the VFDs 54, 56, and 46. Optionally, the VFD 54 (and any VFD of the system 10 and any VFD disclosed herein) can have a manual potentiometer apparatus 54a for manually controlling a motor; a display or window in a display 54b for displaying *inter alia*
30 torque; a display or window 54c in a display 54c for displaying rpm/speed display apparatus 54c; and/or an HMI apparatus (human-machine interface, e.g. the touch screen system) 54d which provides a visual display of the system operation and a tactile means of control.

35 In use, the storage tank 40 receives the slurry,

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(which, in one particular aspect, is a mixture of drilling fluid and drilled cuttings). The control system 60 sends an appropriate signal, via the VFD 54, to the starter 58 which functions to start the VFD 46 and activate the pump 44. The slurry is pumped through the conduit 42 and into the interior of the bowl 12 under the control of the control system 60. The bowl drive motor 24 is activated and controlled by the VFD 54 to rotate the drive shaft 21, and therefore the bowl 12, at a predetermined speed. The conveyor drive motor 34 is also activated and driven by the VFD 56 to rotate the sun wheel 35, and therefore the screw conveyor 18, through the planetary gear box 32, in the same direction as the bowl 12 and at a different speed. As a result of the rotation of the bowl 12, the centrifugal force thus produced forces the slurry radially outwardly so that it passes through the inlet 18a in the conveyor and into the annular space between the conveyor and the bowl 12. The drilling fluid portion of the slurry is displaced to the end 12b of the bowl 12 for discharge from the weirs 19a in the flanged shaft 19. The entrained solid particles (drilled cuttings) in the slurry settle towards the inner surface of the bowl 12 due to the G forces generated, and are scraped and displaced by the screw conveyor 18 back towards the end 12a of the bowl for discharge through the discharge ports 12c.

The control system PM receives signals from the VFD 46 or flow meter 113 corresponding to the pumping rate of the feed pump 44, and signals from the VFDs 54 and 56 corresponding to torque and speed of the motors 24 and 34, respectively. The control system PM contains instructions which enables it to process the above data and control the VFDs. The control system PM controls the VFDs 54 and 56 to vary the frequency and voltage applied to the motors 24 and 34, as needed to control and/or

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continuously vary the rotational speed of, and the torque applied to, the drive shaft 21 and the sun wheel 35, to maintain predetermined optimum operating conditions. The control system PM also monitors the torque applied to the sun wheel 35 from data received from the VFD 56 and maintains the torque at a desired level. In the event one of the inputs to the control system PM changes, the system contains instructions to enable it to change one or more of its output signals to the VFDs 54 and 56 and/or the VFD 46, to change their operation accordingly. The accelerometer sets 64a, 64b, 64c and 64d respond to changes in rotational speed of the drive shaft 21 and the sun wheel 35, and therefore the bowl 12 and the conveyor 18, in terms of frequency, as well as changes in the drive current to the motors 24 and 34 in terms of amplitude which corresponds to load. In the event the centrifuge becomes jammed for whatever reason the control system PM will receive corresponding input signals from the VFDs 54 and/or 56 and will send a signal to the starter 58 to turn off the feed pump 44 and thus cease the flow of the feed slurry to the centrifuge.

The control system PM of the invention attempts to optimize performance of the centrifuge. The optimization requires an "optimal" operation. The definition of "optimal" operation is programmed into the control system and is preferably either of the following algorithms:

1. Maximize the economic benefit of the centrifuge by maximizing the equation: $E = D - B - F - b$, where
E = the net economic benefit (\$) from operating the centrifuge
D = the cost of the base fluid that would otherwise have to be used to dilute the used drilling mud if the

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centrifuge wasn't operating to remove the fine drilled solids. The % drilled solids in the mud should be kept below a certain threshold or problems such as slow drilling and stuck pipe can occur.

5 B = cost of the barite that is lost via the centrifuge solids discharge

F = cost of the base fluid that is lost via the centrifuge solids discharge

10 b = cost of the bentonite gel (thickening agent) that is lost via the centrifuge solids discharge

2. Minimize the operational cost of the mud system based on the sum of the following costs

15 a. mud dilution (new mud that has to be added to the working volume to reduce the percentage of solids in the mud)

20 b. chemical additives that must be replaced because the centrifuge discarded some of them (barite, chlorides, well bore stability materials, lost circulation material (LCM), etc.

25 3. ignore the loss of chemical additives and just minimize the mud dilution costs by maximizing the LGS removal rate while still meeting environmental discharge requirements

4. achieve either of the two above objectives while minimizing maintenance costs

30 The parameters in a centrifuge in accordance with the present invention comprise:

1. bowl speed (directly affects acceleration or g-

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force)

2. conveyor speed (differential - relative difference in speed between the bowl and conveyor)
- 5 3. slurry feed rate
4. pond depth

Bowl speed is varied by the control system PM by signalling the VFD 54 controlling the bowl drive motor
10 24.

Conveyor speed is varied by the control system PM by signalling the VFD 56 controlling the conveyor drive motor 34.

15

Slurry feed rate is varied by the control system PM by signalling the VFD 46 controlling the slurry feed pump 44.

20 Pond depth is varied by the control system PM by signalling the control motor 29 or linear motor 29'.

The parameters are adjusted to achieve the optimum as established by one of the two above equations using an
25 "evolutionary operation" approach. A flow diagram showing steps in the operation in accordance with the present invention is shown in Figure 7. This entails using a set of operating parameters as a starting point, for example, the rotational speed of bowl 12, the rotational speed of
30 conveyor 18 and speed of feed pump 44 are initially set at the speeds used in the centrifuge's last use. The control system PM calculates the value of an optimization algorithm, such as the algorithm above. The control

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system PM measures the performance using at least one sensor. If the performance is not optimal, as defined by the algorithm, then the control system will select a parameter to change, for example, one of the rotational
5 speed of bowl 12, the rotational speed of conveyor 18 and speed of feed pump 44. The control system checks that making a small change to the selected operational parameter is within constraints. For example, if the bearings 33 are not able to cope with the small increase
10 in speed of the conveyor 18, then the control system would not increase the speed of the conveyor 18 and move on to making a small change in another parameter, such as the bowl speed 12, which again would be checked to be within constraints. The small change to the parameter
15 would then be made by the control system PM. The control system then monitors the performance for improvement toward optimum performance. If the performance improves, then this new set of operating parameters would become the new starting point. If not, then the parameter that
20 was changed would be changed by a small amount in a different, preferably opposite direction and the performance measured again. By automatically repeating this process over and over with every parameter, the centrifuge is made to continually seek out optimal
25 performance. Preferably, each change is made every fifteen minutes, although it is envisaged that a change made every two minutes, five minutes, twenty minutes or thirty minutes or any other reasonable time interval is feasible, preferably allowing at least a portion of the
30 feed slurry separation to be separated by the centrifuge 10 under the new changed parameter before the process is repeated. The time interval is preferably programmed into control system PM so that the process is repeated

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automatically.

When the control system PM checks that making a small change to the selected operational parameter is within constraints and if the parameter would not be within constraints, then another parameter is picked by the control system. This is preferably defined by a predetermined list programmed into the control system PM of parameters and the control system moves on to the next parameter in the predetermined list.

The parameters are constrained by the following constraints:

1. Maximum allowable % moisture on cuttings (as determined by regional regulations or customer preference). If the % moisture on cuttings discharged from the centrifuge is too high, then the centrifuge control system PM adjusts any or all of the following parameters:

a. reduce the feed pump 44 speed in order to reduce the solids load in the bowl 12

b. reduce the differential speed between the conveyor 18 and bowl 12 preferably, by reducing the conveyor drive motor 34 speed in order to increase the retention time of the solids in the bowl 12

c. reduce the pond depth of the feed slurry 11 in the bowl 12 by activating gate position motor 29, 29' to retract the gate 20a,20a' to allow more fluid to be returned to the active mud system

2. Maximum allowable torque on conveyor drive motor 34 or bowl drive motor 24. If the torque is too high, then the centrifuge control system PM adjusts any or all of the following parameters:

a. reduce the feed pump 44 speed in order to

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reduce the solids load in the bowl 12;

- b. increase the differential speed between the conveyor 18 and bowl 12 by increasing the conveyor drive motor 24 speed to push the solids out faster and therefore have a shallower solids bed dragging against the conveyor 18;

3. maximum allowable barite loss rate (determined by the customer's barite loss tolerance). If the barite loss rate is too high, then the centrifuge computer would adjust any or all of the following parameters:

- a. reduce the feed pump 44 speed in order to reduce the amount of barite processed by the centrifuge.

The following data may be obtained for use in the control system PM. At least one, preferably several and most preferably all of the following will be required and measured values sent to the control system. The data includes feed slurry data, flow rate data, retrieved solids data, retrieved fluid data and centrifuge apparatus data. Preferably, the data is retrieved in real time, taken every few minutes, although certain of the data may take a relatively long time to obtain, taken every few hours.

25

1. Liquid density measured preferably at at least one of the following:

- a. of the feed slurry at the input to centrifuge 10, preferably using differential pressure measurement along a part of the feed pipe. First and second pressure sensors 100,101 are located along the feed pipe 42, spaced a few metres apart. The differential pressure readings taken from the pressure sensors 100, 101 sent

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back to a measurement system 102, such as a computer, which may be a part of the control system PM or separate. The measurement system 102 calculates the pressure differential and density of the slurry can thus be
5 derived. Other factors may also be measured to obtain the density of the feed slurry.

b. separated liquid output from centrifuge 10 in the liquid discharge pipe 105. The method set out above may be used in a liquid discharge pipe, using a first and
10 second pressure sensors 104, 106 located along the discharge pipe 105, spaced a few metres apart. The differential pressure readings taken from the pressure sensors 104, 106 sent back to a measurement system 107, such as a computer, which may be a part of the control
15 system PM or separate. The measurement system 107 calculates the pressure differential and density of the slurry can thus be derived. Other factors may also be measured to obtain the density of the feed slurry.

c. the holding tank into which the centrifuge 10
20 discharges. Preferably the liquid is put into a holding tank 110 of an active mud system of a rig, the measurement advantageously made in the holding tank, preferably using first and second vertically spaced pressure sensors 108, 109 differential pressure is
25 measured in the tank in a similar method to that stated above to calculate density.

The density of the solids output may also be obtained using a solids density sensor or by weighing the tank 122 into which the solids are discharged, sensing a
30 volume and calculating the density therefrom.

2. Feed slurry viscosity may be sampled and measured manually with a Marsh Funnel or by a viscosity sensor and

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the measured result sent to the control system. The feed slurry viscosity is measured preferably at at least one of the following:

- a. input to centrifuge
- 5 b. liquid output from centrifuge
- c. the tank that the centrifuge is discharging into

3. Flow rate, i) mass flow rate and/or ii) volume flow rate preferably of the feed slurry flow rate in feed pipe 42 and advantageously separated liquid flow rate in discharge pipe 105.

i) Mass flow rate is measured using a Coriolis mass flow meter 111, 112. Each Coriolis mass flow meter 111, 112 preferably uses an inlet and an outlet arm which vibrate in synchronous when there is no flow of slurry feed/liquid, but vibrate out of synchronous when there is a flow of slurry feed/liquid. This phase shift in vibration produces a signal indicative of mass flow through the pipe. Each coriolis meter is in communication with the control system.

ii) Volumetric flow rate is measured with an ultrasonic flow meter or paddle wheel 113, 114, which are in communication with the control system.

25

4. low gravity drilled solids content of feed slurry % by volume and mass [feed slurry data] measured using a low gravity drilled solids sensor or sampled and analysed manually at preferably the slurry feed input to centrifuge 10 and/or advantageously the output from centrifuge 10.

30

5. low gravity commercial solids content of feed slurry

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% by volume and mass, measured using a low gravity commercial solids sensor or sampled and analysed manually at preferably the slurry feed input to centrifuge 10 and/or advantageously the output from centrifuge 10

5

6. high gravity commercial solids content % by volume and mass, measured using a high gravity commercial solids sensor or sampled and analysed manually at at preferably the slurry feed input to centrifuge 10 and/or
10 advantageously the output from centrifuge 10.

7. % of oil or water on the discharged cuttings by wet or dry calculation measured using a near infrared (NIR) moisture meter 121 at solids output from centrifuge. The
15 solids are discharged through a discharge pipe 120 into a solids collection box 122 or hopper of a solids conveying system. An NIR moisture meter 121 measures the moisture content of the solids and sends a signal representative of the moisture content reading back to the control
20 system PM.

8. Salt content by volume and mass, measured using a salt content sensor or sampled and analysed manually at preferably the input to centrifuge 10 and advantageously,
25 the liquid output from centrifuge 10.

9. Particle size analysis, measured using a particle size sensor or sampled and analysed manually at preferably the slurry feed input to centrifuge and
30 advantageously the liquid output from centrifuge 10.

10. Temperature, measured using a thermometer or other temperature sensor preferably at at least one of the

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following:

- a. rotating assembly bearings
 - b. gearbox
 - c. VFD control cabinet
 - 5 d. ambient air
 - e. motor windings
 - f. drilling mud input to centrifuge
11. Vibration frequency and amplitude, measured using an
10 accelerometer 64a, 64b, 64c, 64d or other suitable device
preferably at at least one of the following:
- a. rotating assembly bearings 22, 33
 - b. equipment skid 10a
 - c. gearbox 32
- 15 12. Rotational speed of the bowl 12 and conveyor 18
measured using a bowl rotational speed sensor 135 for the
bowl 12 a conveyor rotational speed sensor 130 for the
conveyor 18.
- 20 13. Torque at gearbox input and gearbox output measured
using an input torque sensor 140 and output torque sensor
145.
- 25 14. The level of the slurry fluid 11 in the bowl 12,
known as pond depth measured preferably using an
ultrasonic distance measuring sensor 150. The ultrasonic
distance measuring sensor 150 is arranged outside of the
bowl 12 aimed at the fluid level in the bowl 12 through
30 the holes 20' in flange 19" of the flanged shaft 19
forming the end plate of the bowl 12. Alternatively or
additionally, the position of the adjustable gate 20a,
20a' is sensed with sensor 155, 155' from which the pond

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depth can be calculated, as the end of the gate 20c, 31.
The measurements are sent to the control system PM.

Each of the sensors is preferably controlled by the control system. The control system takes readings from
5 each sensor at predetermined time intervals or continuously. The predetermined time intervals may be at regular time intervals or irregular time intervals. If any of the data is obtained from a manual analysis, the obtained figure may be input to the control system PM.
10 Preferably, the time intervals are such that up-to-date readings can be made from the small change made. The small incremental changes are most preferably made every fifteen minutes and thus readings are preferably taken immediately before the next change is made, for example
15 between ten and fifteen minutes after the change such that the control system can accurately determine if an improvement has been made towards optimum performance to establish in which direction a further change should be made.

20

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CLAIMS

1. A drilling mud system for separating solids from solids laden drilling mud, the system comprising a centrifuge (10) having a bowl (12) and a conveyor (18),
5 an inlet (18a) for solids laden drilling mud to be introduced to the bowl (12), a solids discharge outlet (12c) and a drilling mud discharge outlet (19'), a bowl drive (24) for driving the bowl (12) and a conveyor drive (34) for driving the conveyor (18), the system further
10 comprising at least one sensor and a control system (PM) measuring centrifuge performance with said at least one sensor, said control system (PM) storing an algorithm for determining optimum performance and said control system (PM):
- 15 making a small evolutionary operation parameter change in a first direction;
checking if the small evolutionary operation parameter change is within constraints;
re-measure centrifuge performance, whereupon if the
20 centrifuge performance improves, for making a further small evolutionary operation parameter change in said first direction and if the performance does not improve for making a small evolutionary operation parameter change in a second direction.
- 25 2. A drilling mud system as claimed in Claim 1, wherein the optimum performance is assessed by economic benefit.
3. A drilling mud system as claimed in Claim 1 or 2, wherein said solids laden drilling mud contains a base drilling mud, desirable solids and thickening agent, said
30 algorithm comprises:
- $$E = D - B - F - b, \text{ where}$$

E = the net economic benefit (\$) from operating the centrifuge

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D = the cost of the liquid that would otherwise have to be used to dilute the used solids laden drilling mud if the centrifuge wasn't operating to remove the fine low gravity solids

5 B = cost of desirable solids that is lost via the centrifuge solids discharge

F = cost of the drilling mud that is lost via the centrifuge solids discharge

10 b = cost of the thickening agent that is lost via the centrifuge solids discharge

4. A drilling mud system as claimed in Claim 1 or 2, the operational cost of the drilling mud system minimised by the algorithm comprising the sum of the following costs of:

15 a. mud dilution

b. chemical additives that must be replaced because the centrifuge discarded all or a portion of them.

20 5. A drilling mud system as claimed in Claim 1 or 2, wherein the operational cost of the mud system are minimised by the algorithm comprising the sum of the following costs of:

25 a. mud dilution by maximizing the Low Gravity Solids removal rate while still meeting environmental discharge requirements

6. A drilling mud system as claimed in any of Claims 2 to 5, wherein the algorithm further comprises further comprises a factor from a table for maintenance costs running the centrifuge at a set condition and minimizing said maintenance costs, the table stored in said control system (PM).

30 7. A drilling mud system as claimed in any preceding claim, wherein said parameter is at least one of: bowl

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speed, the control system (PM) controlling the bowl drive (24); and conveyor speed, the control system (PM) controlling the conveyor drive (34).

8. A drilling mud system as claimed in any preceding
5 claim, wherein said system further comprises a feed pump (44), and said parameter is slurry feed rate, the control system controlling the feed pump (44).

9. A drilling mud system as claimed in any preceding
10 claim, wherein said system further comprises an adjustable gate (20a,20a') and a gate actuator (29,29') for moving said adjustable gate (20a,20a'), and said parameter is pond depth, the control system controlling the gate actuator (29,29').

10. A drilling mud system as claimed in any preceding
15 claim, wherein said sensor comprises a feed slurry density sensor apparatus (100,101) for measuring the density of the feed slurry to be processed by the centrifuge.

11. A drilling mud system as claimed in any preceding
20 claim, wherein said sensor comprises a liquid density sensor apparatus (103,104) for measuring the density of the liquid processed by the centrifuge.

12. A drilling mud system as claimed in any preceding
25 claim, wherein said sensor comprises feed slurry viscosity sensor.

13. A drilling mud system as claimed in any preceding
claim, wherein said sensor comprises a feed slurry mass flow rate sensor (111)

14. A drilling mud system as claimed in any preceding
30 claim, wherein said sensor comprises a liquid mass flow rate sensor (112).

15. A drilling mud system as claimed in any preceding
claim, wherein said sensor comprises a feed slurry

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volumetric flow rate sensor (113).

16. A drilling mud system as claimed in any preceding claim, wherein said sensor comprises a liquid volumetric flow rate sensor (114).

5 17. A drilling mud system as claimed in any preceding claim, wherein said sensor comprises a moisture meter (121) to measure the moisture content of the solids discharged from the centrifuge (10).

10 18. A drilling mud system as claimed in any preceding claim, wherein said sensor comprises temperature sensor at at least one of the following locations: rotating assembly bearings (22,33); gearbox (32); VFD control cabinet (46',54',56'); ambient air; motor windings of bowl and conveyor drives (24,34); feed slurry (11) at
15 said inlet (18a).

19. A drilling mud system as claimed in any preceding claim, wherein said sensor comprises vibration frequency and amplitude sensors (64a,64b,64c,64d) located at at least one of the following: rotating assembly bearings
20 (22,33); an equipment skid 10a on which said centrifuge (10) is arranged; and gearbox (32).

20. A drilling mud system as claimed in any preceding claim, wherein said sensor comprises a bowl rotational speed sensor (135) and a conveyor rotational speed sensor
25 (130) for the conveyor 18.

21. A drilling mud system as claimed in any preceding claim, wherein said system comprises a gearbox (32) and said sensor comprises an input torque sensor (140) and output torque sensor (145).

30 22. A drilling mud system as claimed in any preceding claim, wherein said sensor comprises pond depth sensor to measure the depth of the feed slurry in the bowl (12) of the centrifuge.

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23. A drilling mud system as claimed in any preceding claim, wherein said constraints comprise a maximum allowable % moisture on solids.

24. A drilling mud system as claimed in Claim 8 and 23,
5 wherein if the maximum allowable % moisture on solids is breached, said control system (PM) reduces the feed pump (44) speed in order to reduce the solids load in the bowl (12).

25. A drilling mud system as claimed in Claim 23,
10 wherein if the maximum allowable % moisture on solids is breached, said control system (PM) reduces the differential speed between the conveyor (18) and bowl (12).

26. A drilling mud system as claimed in Claim 9 and 23,
15 wherein if the maximum allowable % moisture on solids is breached, said control system (PM) controls gate actuator (29,29') to increase the pond depth of the solids laden drilling mud (11) in the bowl (12).

27. A drilling mud system as claimed in any preceding
20 claim, further comprising the step of obtaining a torque on bowl drive (24) and torque on conveyor drive (34), said constraints comprise a maximum allowable torque on bowl drive (24) and a maximum torque on conveyor drive (34).

28. A drilling mud system as claimed in Claim 8 and 27,
25 wherein if said torque is too high, then the centrifuge control system (PM) adjusts the feed pump (44) speed in order to reduce the solids load in the bowl (12).

29. A drilling mud system as claimed in Claim 27,
30 wherein if said torque is too high, then the centrifuge control system (PM) increases the differential speed between the conveyor (18) and bowl (12) by increasing the conveyor drive motor (24) speed.

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30. A drilling mud system as claimed in Claim 2, wherein said constraints comprise a maximum allowable barite loss rate

31. A drilling mud system as claimed in Claim 8 and 30,
5 wherein if the barite loss rate is too high, then the control system (PM) reduces the feed pump (44) speed in order to reduce the amount of barite processed by the centrifuge (10).

32. A drilling mud system as claimed in any preceding
10 claim, wherein the second direction is an opposite direction.

33. A drilling mud system as claimed in any preceding claim, wherein at least one of the bowl drive (24) and conveyor drive (34) comprise a variable frequency drive
15 (54,56).

34. A drilling mud system as claimed in any preceding claim wherein the inlet (18a) for solids laden drilling mud to be introduced to the bowl (12) comprises a feed tube (16).

20 35. A method of operating a centrifuge comprising a bowl (12) and a conveyor (18), an inlet (18a) for solids laden drilling mud to be introduced to the bowl (12), a solids discharge outlet (12c) and a drilling mud discharge outlet (19'), a bowl drive (24) for driving the bowl (12)
25 and a conveyor drive (34) for driving the conveyor (18), at least one sensor and a control system (PM) the method comprising the steps of the control system (PM) measuring centrifuge performance with said at least one sensor, said control system (PM) storing an algorithm for
30 determining optimum performance and said control system (PM):

making a small evolutionary operation parameter change in a first direction;

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checking if the small evolutionary operation parameter change is within constraints;

re-measuring centrifuge performance, whereupon if the centrifuge performance improves, making a further
5 small evolutionary operation parameter change in said first direction and if the performance does not improve making a small evolutionary operation parameter change in a second direction.

36. An apparatus for separating solids from solids laden
10 drilling mud, the apparatus comprising a centrifuge (10) having a bowl (12) and a conveyor (18), an inlet (18a) for solids laden drilling mud to be introduced to the bowl (12), a solids discharge outlet (12c) and a drilling mud discharge outlet (19'), a bowl drive (24) for driving
15 the bowl (12) and a conveyor drive (34) for driving the conveyor (18), the apparatus further comprising at least one sensor and a control system (PM) comprising a memory for storing an algorithm for determining optimum performance and storing instructions for carrying out the
20 method as claimed in Claim 34.

37. A control system for a centrifuge comprising a computer readable media comprising instructions for carrying out the method as claimed in Claim 35.

38. A centrifuge having a bowl (12) for retaining a pond
25 of solids laden drilling mud and a conveyor (18), an inlet (18a) for solids laden drilling mud to be introduced to the bowl (12), a solids discharge outlet (12c) and a drilling mud discharge outlet (19'), a bowl drive (24) for driving the bowl (12) and a conveyor drive
30 (34) for driving the conveyor (18), the system further comprising at least one sensor and a control system (PM) wherein said drilling mud discharge outlet (19') further comprises an adjustable gate (20a,20a') and a gate

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actuator (29,29') for moving said adjustable gate (20a,20a'), said gate maintaining said pond of solids laden drilling mud, the control system controlling the gate actuator (29,29') to control depth of said pond of
5 solids laden drilling mud.

* * *

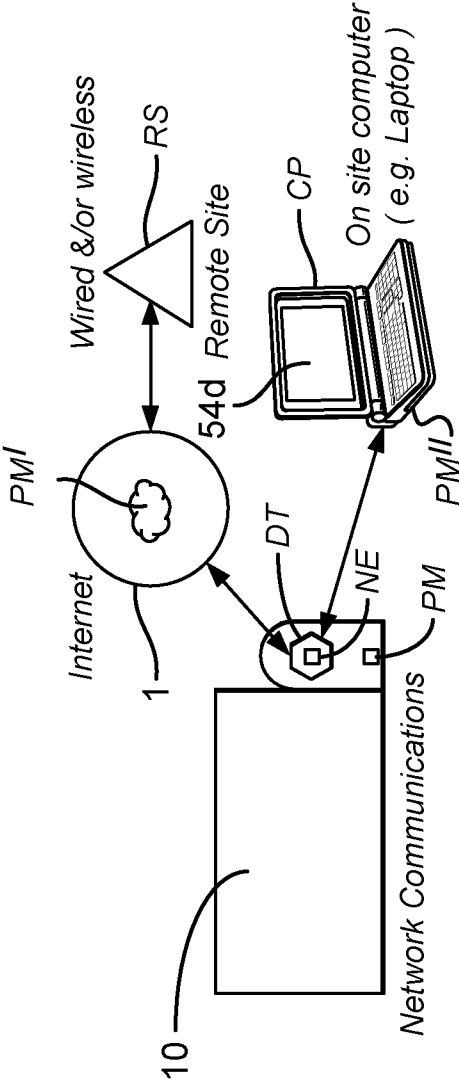
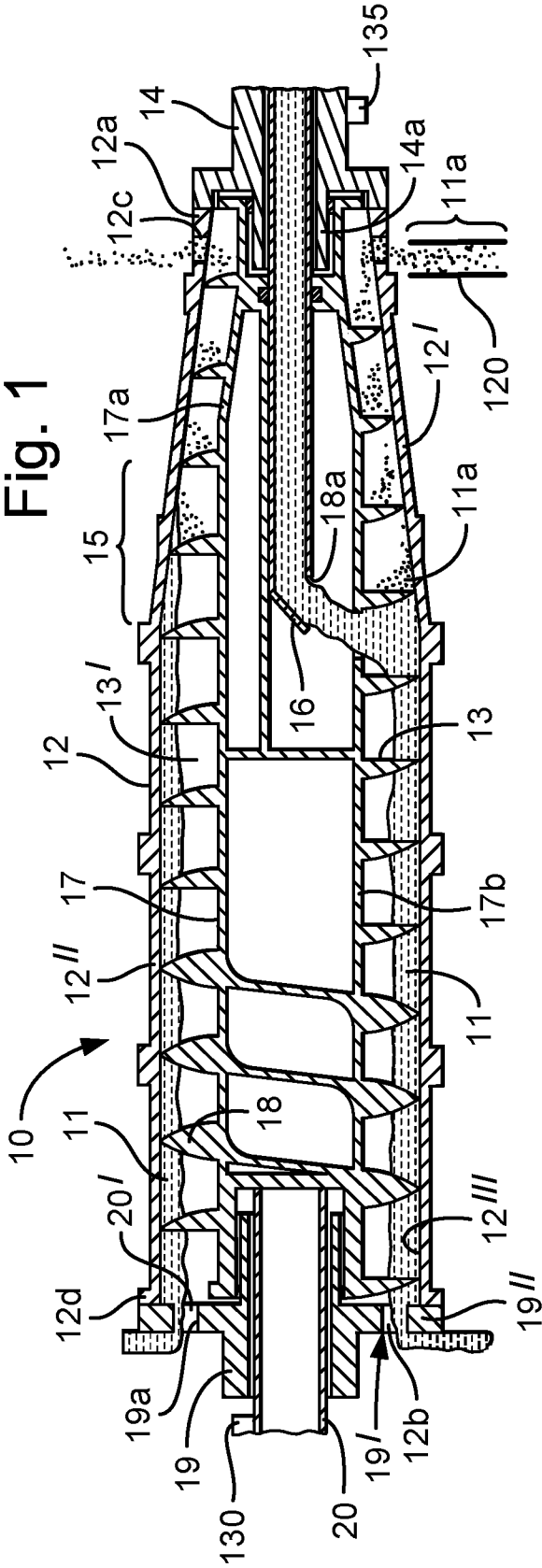
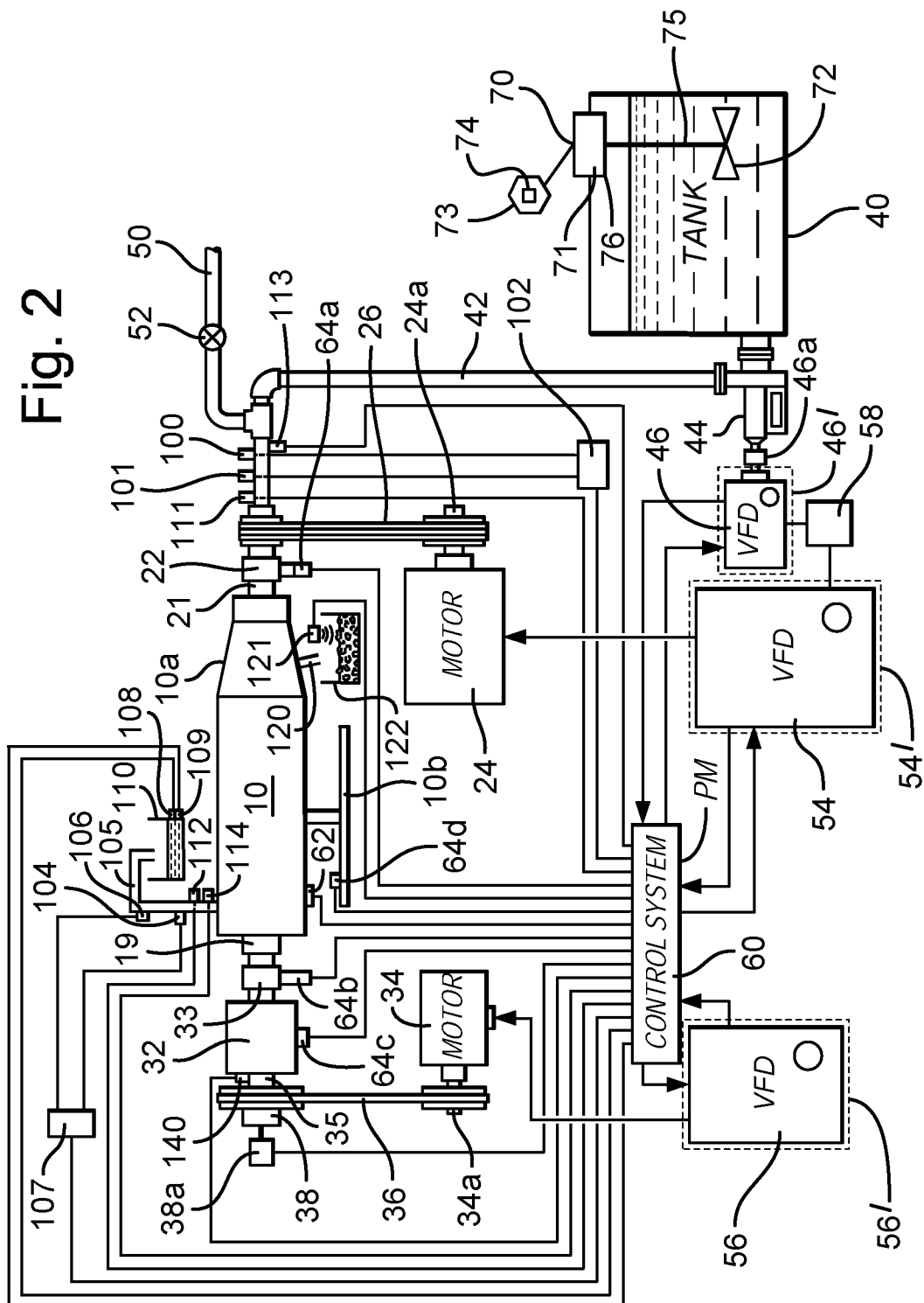


Fig. 2



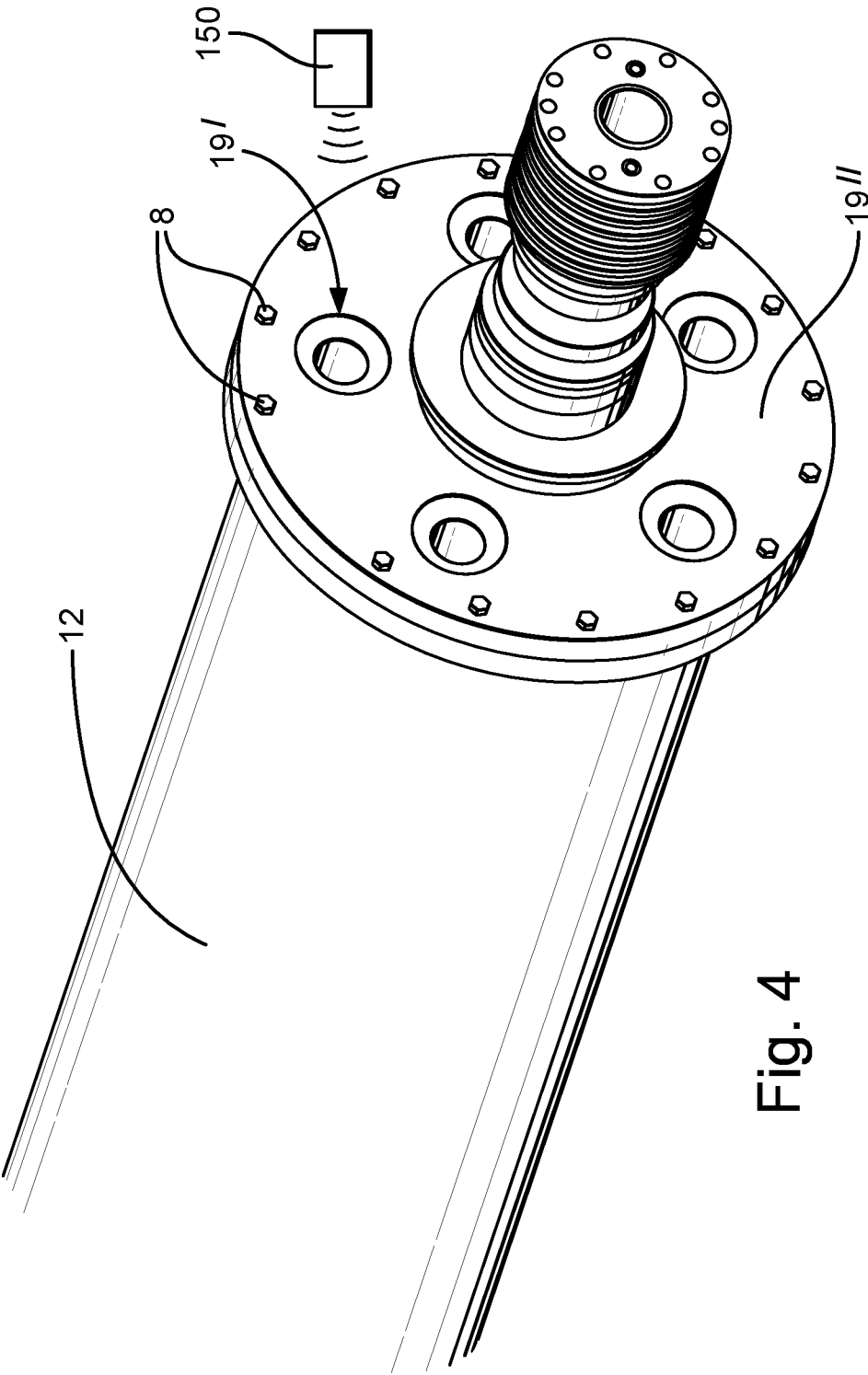
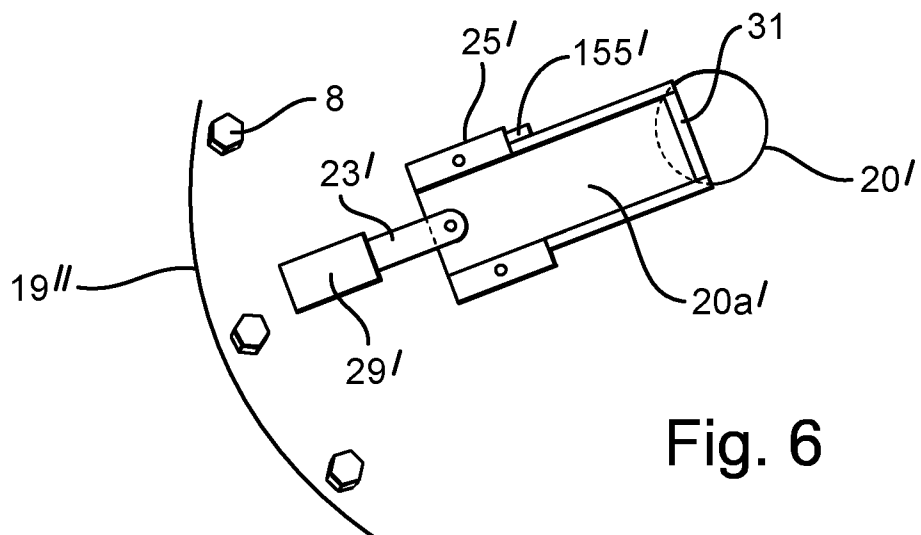
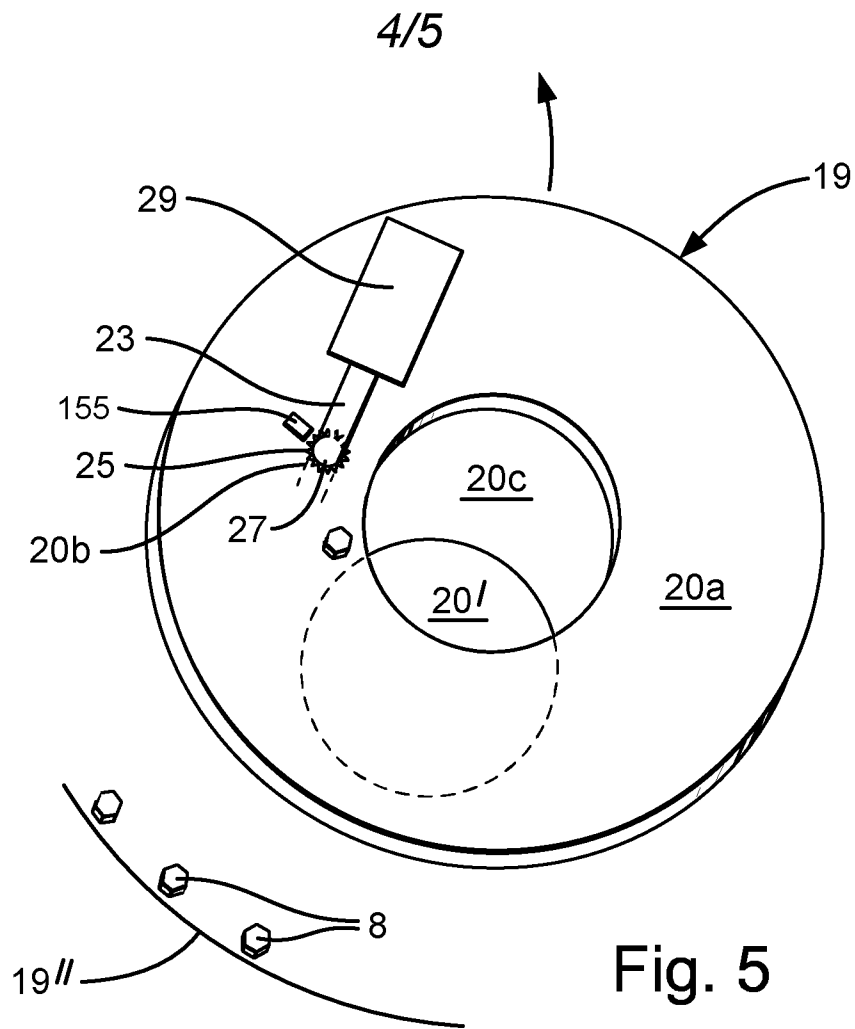
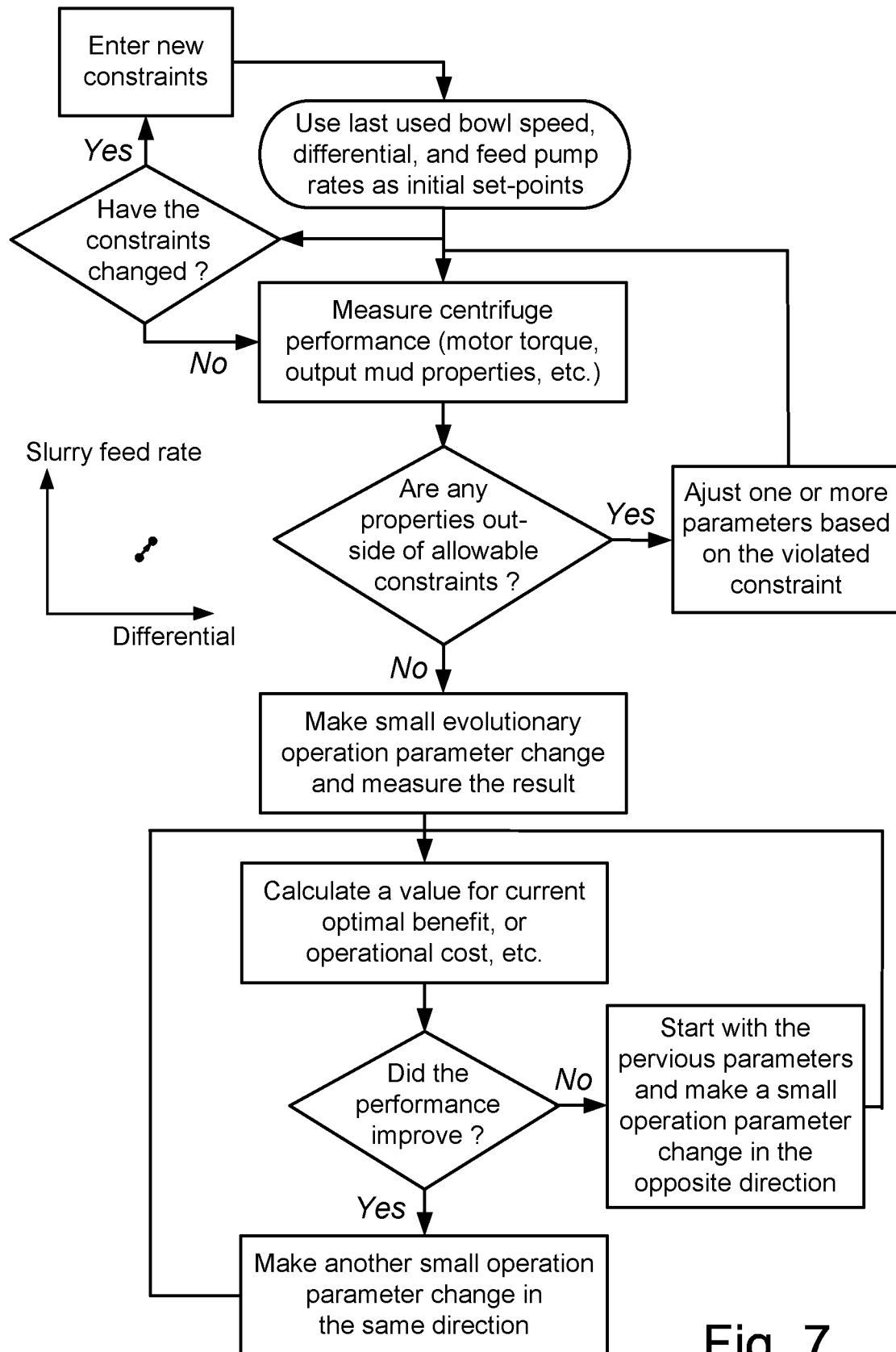


Fig. 4



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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2014/051222

A. CLASSIFICATION OF SUBJECT MATTER

INV. B04B1/20 B04B11/02 B04B13/00 E21B21/06
ADD.

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)

B04B E21B

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97/20634 A1 (BAKER HUGHES INC [US]) 12 June 1997 (1997-06-12) the whole document -----	1,7-29, 32-38



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

17 July 2014

Date of mailing of the international search report

28/07/2014

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Authorized officer

Leitner, Josef

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2014/051222

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 2-6, 30, 31
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 2-6, 30, 31

The claims 2 - 6 and 30, 31 do not meet the requirements of Article 6 PCT because the matter for which protection is sought is not clearly defined. The claims attempt to define the subject-matter in terms of the result to be achieved, which merely amounts to a statement of the underlying problem, without providing the technical features necessary for achieving this result. The functional statements do not enable the skilled person to determine which technical features are necessary to perform the stated function. The features in the apparatus claims 2 - 6 and 30,31 relate to a method rather than clearly defining the apparatus in terms of its technical features. The intended limitations are therefore not clear from this claim, contrary to the requirements of Article 6 PCT. Furthermore, these claims, together with the description, do not disclose the invention in a manner sufficiently clear and complete to be carried out by a person skilled in the art.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2014/051222

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9720634	A1	12-06-1997	AU 7706696 A 27-06-1997
		DE 69618989 D1 14-03-2002	
		DE 69618989 T2 26-09-2002	
		DK 0868215 T3 06-05-2002	
		EP 0868215 A1 07-10-1998	
		US 5948271 A 07-09-1999	
		US 6143183 A 07-11-2000	
		WO 9720634 A1 12-06-1997	
