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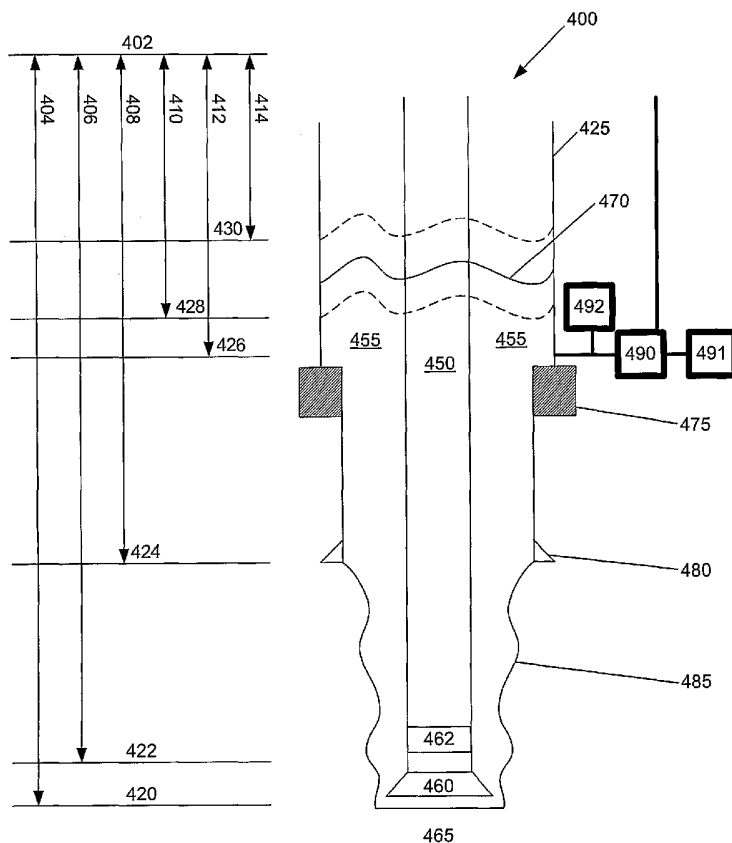
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[Continued on next page]

(54) Title: SYSTEMS AND METHODS FOR MANAGING DOWNHOLE PRESSURE

(57) Abstract: A system comprising a drilling vessel, a riser connected to the drilling vessel, a drillstring within the riser, the drillstring extending into a borehole, a drill bit connectable to the drillstring, a pump system comprising an inlet in the riser and an outlet to the drilling vessel, and a pump controller adapted to control a pressure within the riser and the borehole by raising or lowering a fluid level within the riser.





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SYSTEMS AND METHODS FOR MANAGING DOWNHOLE PRESSURE

Field of Invention

There are disclosed systems and methods for managing downhole
5 pressure.

Background

A typical riser system normally consists of one or more fluid-conducting
conduits that extend from the water surface to a structure (e.g., wellhead) on the
bottom of a water body. For example, in the drilling of a submerged well, a drilling
10 riser usually consists of a main conduit through which the drill string is lowered and
through which the drilling mud is circulated from the lower end of the drill string
back to the surface. In addition to the main conduit, it is conventional to provide
auxiliary conduits, e.g., choke and kill lines, etc., which extend parallel to and are
carried by the main conduit.

15 When drilling into a subsea formation, frequent and multiple casing strings
may be needed in order to isolate the formation sections that have lower strength
from the hydraulic pressure exerted by the drilling fluid. In addition to the static
hydraulic pressure acting on the formation from a standing column of fluid in the
well bore there are also the dynamic pressures created when circulating fluid
20 through the drill bit. These dynamic pressures acting on the bottom of the hole are
created when drill fluid is pumped through the drill bit and up the annulus between
the drill string and formation. The magnitude of these forces may depend on
several factors such as the rheology of the fluid, the velocity of the fluid being
pumped up the annulus, drilling speed and the characteristics of the well
25 bore/hole. This pressure seen by the formation in the bottom of the hole caused
by the drilling process may be referred to as Equivalent Circulating Density (ECD).

In drilling operations in offshore deepwater wells, the bottom of the well may
observe the combined hydrostatic pressure exerted by the column of fluid from the
drilling vessel to the bottom of the well, plus the additional pressures due to
30 circulation.

In some drilling operations there are a minimum of two potential barriers in
the well. The primary barrier may be the drilling fluid in the borehole with sufficient

density to control the formation pressure, also in the event that the drilling riser is disconnected from the wellhead. The second barrier may be a blowout preventer (BOP), which is closed in case the primary barrier is lost.

As the drilling fluid must have a specific gravity such that the fluid remaining in the well still is heavy enough to control the formation when the drilling marine riser is disconnected, this may create a problem when drilling in deep waters. The marine riser may be full of heavy mud when connected to a sub sea blowout preventer, causing a higher bottom-hole pressure than required for formation control. This results in the need to set frequent casings in the upper part of the hole since the formation cannot support the higher mudweight from the surface, for example because the pressure would otherwise exceed the fracture pressure.

In order to be able to drill wells with a higher density drilling fluid, multiple casings may be installed in the borehole for isolation of weak formation zones.

The consequences of multiple casing strings may be that each new casing string reduces the borehole diameter. Hence the top section must be large in order to drill the well to its planned depth. This also means that slimhole or slender wells are difficult to construct with present methods in deeper waters. One prior solution is a dual gradient system, in which liquids with different densities will be present in the borehole and riser, thus being able to drill longer sections without having to set a new casing.

U.S. Patent Number 4,063,602 discloses an improved method and apparatus for offshore drilling which is particularly useful for drilling in deep water from a floating surface vessel. Drilling fluid is introduced into a drill string extending from the vessel into a wellbore in the floor of the body of water. In order to maintain a controlled hydrostatic pressure within the riser, drilling fluids are diverted from the lower end of the riser and are either discharged into the body of water or pumped to the surface through a return conduit adjacent the riser. United

U.S. Published Patent Application Number 2004/0238177 discloses an arrangement and a method to control and regulate the bottom hole pressure in a well during subsea drilling at deep waters. The method involves adjustment of a liquid/gas interface level in a drilling riser up or down. The arrangement comprises a high pressure drilling riser and a surface BOP at the upper end of the drilling

riser. The surface BOP has a gas bleeding outlet. The riser also comprises a BOP, with a by-pass line. The drilling riser has an outlet at a depth below the water surface, and the outlet is connected to a pumping system with a flow return conduit running back to a drilling vessel/platform. United States Published Patent
5 Application Number 2004/0238177 is herein incorporated by reference in its entirety.

There is a need in the art for improved systems and methods for controlling downhole pressure.

10 There is another need in the art for more efficient systems and methods for controlling downhole pressure.

These and other needs of the present disclosure will become apparent to those of skill in the art upon review of this specification, including its drawings and claims.

Summary of the Invention

15 One aspect of the disclosed invention provides a system comprising a drilling vessel, a riser connected to the drilling vessel, a drillstring within the riser, the drillstring extending into a borehole, a drill bit connectable to the drillstring, a pump system comprising an inlet in the riser and an outlet to the drilling vessel, and a pump controller adapted to control a pressure within the riser and the
20 borehole by raising or lowering a fluid level within the riser.

Another aspect of the disclosed invention provides a method of controlling borehole pressure comprising installing a riser from a drilling vessel to a subsea blow out preventer or a wellhead, installing a pump system and a pump controller, the pump system comprising an inlet in the riser and an outlet to the drilling vessel,
25 and selectively pumping fluid from within the riser to the drilling vessel, to control a fluid level within the riser, and to control a pressure level within the borehole.

Advantages of the invention include one or more of the following:

Improved systems and methods for controlling downhole pressure;
more efficient systems and methods for controlling downhole pressure;
30 improved systems and methods for drilling which require fewer casing strings;
improved systems and methods for kick detection;

improved systems and methods for kick remediation; and/or
improved systems and methods for maintaining downhole pressure at a
desired value.

Brief Description of the Drawings

- 5 Figure 1 illustrates an offshore system.
 Figure 2 illustrates details of an offshore system.
 Figure 3 illustrates details of an offshore system.
 Figure 4 illustrates details of an offshore system.
 Figure 5 illustrates details of an offshore system.

10 Detailed Description of the Invention

 In one embodiment of the invention, there is provided a system comprising
a drilling vessel, a riser connected to the drilling vessel, a drillstring within the riser,
the drillstring extending into a borehole, a drill bit connectable to the drillstring, a
pump system comprising an inlet in the riser and an outlet to the drilling vessel,
15 and a pump controller adapted to control a pressure within the riser and the
borehole by raising or lowering a fluid level within the riser. In some embodiments,
the system also includes a subsea blow out preventer connected to the riser. In
some embodiments, the system also includes at least one string of casing
connected to the subsea blow out preventer, the casing within the borehole. In
20 some embodiments, the drilling vessel is floating. In some embodiments, the
system also includes a liquid level and/or pressure sensor connected to the pump
control system.

 In one embodiment of the invention, there is provided a method of
controlling borehole pressure comprising installing a riser from a drilling vessel to a
25 subsea blow out preventer or a wellhead, installing a pump system and a pump
controller, the pump system comprising an inlet in the riser and an outlet to the
drilling vessel, and selectively pumping fluid from within the riser to the drilling
vessel, to control a fluid level within the riser, and to control a pressure level within
the borehole. In some embodiments, the method also includes pumping fluid from
30 within the riser to lower the pressure level within the borehole. In some
embodiments, the method also includes monitoring the fluid level within the riser
and/or the pressure within the borehole. In some embodiments, the method also

includes stopping pumping as needed to raise the pressure level within the borehole.

Referring now to Figure 1, there is illustrated offshore system 100. System 100 includes platform or other type of drilling vessel 110 with facilities 105 on top. Platform 110 is in a body of water having water surface 115 and sea bottom 135. Buoyancy device or structure 120 keeps platform 110 from sinking. Riser 125 connects platform 110 with well 140. Mooring lines 130 anchor platform 110 to the bottom of the body of water 135. Alternatively, platform 110 may be kept on station above well 140 with a dynamic positioning system that may be used with or without mooring lines 130. Drill string 150 is fed through riser 125. Annular space 155 is defined around drill string 150. Drill bit 160 is mounted at the end of drill string 150, adapted to drill into formation 165. A subsurface blow-out preventer may be provided between riser 125 and casing.

In operation, drilling mud may be pumped down drill string 150 to lubricate drill bit 160 and to carry pieces of formation 165 that are removed by drill bit 160. Drilling mud may then be returned through annulus 155. If the drilling mud in annulus 155 has a high pressure, casing strings may be installed in formation 165, so that the formation is not fractured.

Referring now to Figure 2, in some embodiments of the invention, offshore system 100 is illustrated. Riser 125 is connected to subsea blow out preventer (BOP) 175. Drill string 150 is fed through riser 125. Annular space 155 is about drill string 150. Drill bit 160 is mounted at the end of drill string 150, in order to drill into formation 165. Casing 180 is connected to BOP 175 to contain pressure within the annular space. Beneath casing 180 is open hole 185, which was created by drill bit 160. Pump 190 has an inlet in riser above BOP 175, to maintain fluid level 170 at a desired height.

In operation, pump 190 may be used to maintain fluid level 170 at a desired height in order to control downhole pressure, with the use of control system 192. One suitable control system is disclosed in U.S. Patent Number 6,904,981, assigned to Shell Oil Company, and herein incorporated by reference in its entirety.

Downhole pressure may be maintained at a level between pore pressure and fracture pressure. An over balanced situation may be maintained, where the fluid pressure exceeds the formation pore pressure for reasons of pressure control and hole stability. However, pressures in excess of the formation fracture pressure will result in the fluid pressurizing the formation walls to the extent that small cracks or fractures will open in the borehole wall and the fluid pressure overcomes the formation pressure with significant fluid invasion. Fluid invasion can result in reduced permeability, adversely affecting formation production. The annular pressure generated by the fluid and its additives may be maintained between the pore pressure and the fracture pressure.

Control system 192 may receive data from various sources and continuously calculate the correct downhole pressure set-point based on the input parameters. The input parameters may include a level gauge in the riser 125 and/or a pressure gauge in the riser 125, casing 180, and/or open hole 185; well and casing string geometry; drill bit nozzle diameters; well trajectory; temperature profile of the fluid in the annulus and the fluid composition; flow rate data provided by downhole and/or return flow meters; the drill string rate of penetration (ROP) or velocity; the drill string rotational speed; the bit depth; and/or the well depth.

Control system 192 attempts to calculate the pressure in the annulus over its full well bore length utilizing various models designed for various formation and fluid parameters. The pressure in the well bore is a function not only of the pressure or weight of the fluid column in the well, but may also include the pressures caused by drilling operations, including fluid displacement by the drill string, frictional losses returning up the annulus, and other factors. In order to calculate the pressure within the well, control system 192 may consider the well as a finite number of segments, each assigned to a segment of well bore length. In each of the segments the dynamic pressure and the fluid weight may be calculated and used to determine the pressure differential for the segment. The segments may then be summed and the pressure differential for the entire well profile may be determined.

The controller 192 may be adapted to calculate a desired downhole pressure based on a level gauge or pressure input, and to activate the pump 190

when the downhole pressure is too high, and/or deactivate the pump 190 when the pressure is too low. In operation, if the downhole pressure as calculated by control system 192 is too high, control system 192 will turn on or increase the flow through pump 190 to lower fluid level 170 and lower the downhole pressure. Alternatively, 5 if the downhole pressure as calculated by control system 192 is too low, control system 192 will turn off or decrease the flow through pump 190 to raise fluid level 170 and raise the downhole pressure.

In some embodiments of the invention, riser 125 and/or casing 180 may have an outside diameter of about 5 to about 100 cm. In some embodiments of 10 the invention, riser 125 and/or casing 180 may have an outside diameter of about 10 to about 50 cm. In some embodiments of the invention, riser 125 and/or casing 180 may have a outside diameter of about 20 to about 30 cm.

In some embodiments of the invention, riser 125 and/or casing 180 may have a wall thickness of about 0.1 to about 5 cm. In some embodiments of the 15 invention, riser 125 and/or casing 180 may have a wall thickness of about 0.2 to about 3 cm. In some embodiments of the invention, riser 125 and/or casing 180 may have a wall thickness of about 0.5 to about 2 cm.

In some embodiments of the invention, a drilling riser system so arranged that the pressure in the bottom of an underwater borehole can be controlled so 20 that the hydrostatic pressure inside the riser is equal to or below the formation strength of the weakest section of the borehole. In some embodiments of the invention, a drilling riser system so arranged that the pressure in the bottom of an underwater borehole can be controlled so that the hydrostatic pressure inside the riser is equal to or above the pore pressure of the highest pressure section of the 25 borehole.

In some embodiments of the invention, the ECD effect can be neutralized so that subsequent sections can be drilled deeper, making it possible to drill the well with fewer casings.

In some embodiments of the invention, there is an outlet on the riser 125 30 below the surface of the water 115 that is connected to a pump system 190 that will be able to regulate the liquid level 170 inside the drilling riser 125 to a depth below sea level. In this way it will be possible to pump drilling fluid (mud) through

the drill string 150 and up the annulus 155 between the riser 125 and the drill string 150 together with formation cuttings without fracturing or losing returns caused by a weak formations.

5 In some embodiments of the invention, there is provided methods and arrangements whereby the fluid-level 170 in the riser 125 can be dropped below sea level 115 and adjusted so that the hydraulic pressure in the bottom of the hole can be controlled by measuring and adjusting the liquid level 170 in the riser 125 in accordance with the dynamic drilling process requirements. Due to the dynamic nature of the drilling process the liquid level 170 will not remain steady at a
10 determined level but may constantly be varied and adjusted by the pumping control system 192. A pressure control system may be provided to control the speed of the pump 190 and actively manipulate the level 170 in the riser 125 so that the pressure in the bottom of the well is controlled as required by the drilling process. With the methods described it is possible to regulate the pressure in the
15 bottom of the well without changing the density of the drilling fluid.

In some embodiments of the invention, varying the fluid height can also be used to increase the bottom-hole pressure instead of increasing the mud density.

In some embodiments of the invention, as drilling takes place deeper in the formation 165 the pore pressure may vary. In conventional drilling operation the
20 drilling mud density may have to be adjusted. This can be time-consuming and expensive since additives have to be added and/or discharged.

In some embodiments of the invention, riser 125 has a lower outlet between the sea level 115 and ocean floor 135 with valves that will divert the fluid in the riser 125 into pump system 190 which will pump the fluid and solids back up to the
25 surface 115.

The formation portions being removed by the drill bit 160 may be pumped up to surface by the pump system 190.

In some embodiments of the invention, an arrangement may be used when drilling oil and gas wells from offshore structures that float on the surface of the
30 water in depths from about 250 to about 3000 meters above the seabed.

The bottom of the well may observe the combined hydrostatic pressure exerted by the column of fluid from the drilling vessel to the bottom of the well, plus

the additional pressures due to circulation. The riser 125 that connects the subsea BOP 175 with the drilling vessel 110 contains this drilling fluid. The bottom-hole pressure to overcome the formation pressure is regulated by increasing or decreasing the density of the drilling fluids and/or adjusting fluid level 170.

5 In some embodiments of the invention, high pressure is high enough to contain the pressures from the subsurface formations, for example, 3000 psi (200 bars) or higher. Low pressure is not high enough to contain the pressure from the formation, for example less than 3000 psi (200 bars), such as the subsea hydrostatic pressure encountered at the sea floor. In some embodiments, high
10 pressure means able to withstand the maximum pore pressure encountered in the formation 165. In some embodiments, casing 180, BOP 175, drill bit 160, and/or drill string 150 are adapted to withstand high pressure. In some embodiments, riser 125, and/or pump 190 are only adapted to withstand low pressure.

Referring now to Figure 3, in some embodiments of the invention, offshore
15 system 200 is illustrated. Riser 225 is connected to subsea blow out preventer (BOP) 275. Drill string 250 is fed through riser 225. Annular space 255 is about drill string 250. Drill bit 260 is mounted at the end of drill string 250, in order to drill into formation 265. Casing 280 is connected to BOP 275 to contain pressure within the annular space 255. Beneath casing 280 is open hole 285, which was
20 created by drill bit 260. Pump 290 has an inlet in riser above BOP 275, to maintain fluid level 270 at a desired height. Pump 290 may be used to pump fluid and cuttings to shaker 298. Shaker 298 may be used to separate cuttings from fluid, and fluid returned to mud pit 296. Mud pump 288 may be used to pump fluid from mud pit 296 to drill string 250. Valves 294 and 292 may be opened to provide a
25 gravity feed path from mud pit 296 to the annular space.

In operation, pump 290 may be used to maintain fluid level 270 at a desired height in order to control downhole pressure, with the use of control system 291.

System 200 may also be used for early detection of a major well event, such as a fluid influx. Under present methods, in the event of a large formation
30 fluid influx, such as a gas kick, the only option is to close the BOP's to effectively to shut in the well, relieve pressure through the choke and kill manifold, and weight up the drilling fluid to provide additional annular pressure. This technique requires

time to bring the well under control. Utilizing the present system 200, a small formation fluid influx can be detected, by monitoring and comparing the speed of both mud pump 288 and subsea pump 290 using control system 291. For example, if the speed of subsea pump 290 has to be increased by control system 291 to maintain the desired fluid level 270, but there is no corresponding change in the speed of mud pump 288, then the control system 291 would signal that a small formation fluid influx had occurred. In this event, valves 294 and 292 may be opened to quickly raise fluid level 270 within the annular space, and to increase the downhole pressure sufficiently to stop any further influx.

In some embodiments, valve 294 may be a flow control valve, where the fill rate is controlled by valve 294 being partially open or closed. In some embodiments, valves 294 and 292 may be opened to quickly raise fluid level 270 when pump 288 is shut down, and the downhole pressure needs to be quickly recovered.

Referring now to Figure 4, in some embodiments of the invention, offshore system 300 is illustrated. Riser 325 is connected to subsea blow out preventer (BOP) 375. Drill string 350 is fed through riser 325. Annular space 355 is about drill string 350. Drill bit 360 is mounted at the end of drill string 350, in order to drill into formation 365. Casing 380 is connected to BOP 375 to contain pressure within the annular space. Beneath casing 380 is open hole 385, which was created by drill bit 360. Pump 390 has an inlet in riser above BOP 375, to maintain fluid level 370 at a desired height. Pump 390 may be used to pump fluid and cuttings to shaker 398. Shaker 398 may be used to separate cuttings from fluid, and fluid returned to mud pit 396. Mud pump 388 may be used to pump fluid from mud pit 396 to drill string 350. Riser boost pump 394 may be used to provide a feed path from mud pit 396 to the annular space through an inlet into riser 325 located above BOP 375 and below inlet to pump 390.

In operation, pump 390 may be used to maintain fluid level 370 at a desired height in order to control downhole pressure, with the use of control system 391.

System 300 may also be used for early detection of and/or to control a major well event, such as a fluid influx. Utilizing the present system 300, when a formation fluid influx is detected, riser boost pump 394 may be used to quickly

raise fluid level 370 within the annular space, and to increase the downhole pressure.

In some embodiments, riser boost pump 394 may have a speed control, where the fill rate is controlled by the speed of riser boost pump 394. In some
5 embodiments, riser boost pump 394 may be used to quickly raise fluid level 370 when pump 388 is shut down, and the downhole pressure needs to be quickly recovered.

Referring now to Figure 5, in some embodiments of the invention, offshore
system 400 is illustrated. Riser 425 is connected to subsea blow out preventer
10 (BOP) 475. Drill string 450 is fed through riser 425. Annular space 455 is about drill string 450. Drill bit 460 is mounted at the end of drill string 450, in order to drill into formation 465. Casing 480 is connected to BOP 475 to contain pressure within the annular space. Beneath casing 480 is open hole 485, which was created by drill bit 460. Pump 490 has an inlet in riser above BOP 475, to maintain
15 fluid level 470 at a desired height. Pump 490 may be used to pump fluid and cuttings to a shaker or a mud pit. Pressure gauge 492 may be used to provide a real time pressure measurement at pump inlet level 426 in annulus. Measurement while drilling system 462 may be provided above drill bit to measure pressure and other measurements by mud telemetry, wire, fiber, cable, radio frequency, or
20 electromagnetic signal to control system 491 and/or surface.

In operation, pump 490 may be used to maintain fluid level 470 at a desired height in order to control downhole pressure, with the use of control system 491.

Reference level 402, for example sea level, drill floor or similar, is provided. Hole depth 420, control depth 422, shoe depth 424, pump inlet level 426, fluid
25 level 470, adjusted fluid level 428, and adjusted fluid level 430 are also provided. Distance 404 is from reference level 402 to hole depth 420. Distance 406 is from reference level 402 to control depth 422. Distance 408 is from reference level 402 to shoe depth 424. Distance 410 is from reference level 402 to adjusted fluid level 428. Distance 412 is from reference level 402 to pump inlet level 426. Distance
30 414 is from reference level 402 to adjusted fluid level 430.

Pressure gauge 492 may be used to provide a real time pressure measurement at pump inlet level 426 in annulus. A hydraulic model may be used

to calculate pressure level at any other level in annulus, for example levels 430, 428, 470, 424, 422, and/or 420. The model includes a static portion (P_s) where the pressure increases as a linear function of the depth of the borehole according to the simple formula:

5 $P_s = \rho(\Delta H)$ (equation 1)

Where P is the pressure, ρ is the fluid density, ΔH is the total vertical depth from pump inlet level 426 to the desired level, for example control depth 422.

The model also includes a dynamic portion (P_d) which can be calculated as a sum of the drill cuttings related increase in density and friction pressure along the return pressure length from the desired level to pump inlet level 426, and is a function of the drilling rate of penetration (ROP), pipe geometry, flow rate, and viscosity, as is known in the art. The total pressure difference can be calculated by summing the static portion (P_s) and the dynamic portion (P_d):

$\Delta P = P_s + P_d$ (equation 2)

15 Measurement while drilling system 462 may be used to provide a feedback loop to control system 491 to modify the hydraulic model as needed to accurately calculate the pressure at any level in the annulus.

To maintain a downhole pressure at control depth 422 within the range of pore pressure and fracture pressure:

- 20 (1) the annulus pressure at pump inlet level 426 can be measured by pressure gauge 492;
- (2) the annulus pressure at control depth 422 can be calculated with the hydraulic model by control system 491 with an input of annulus pressure at pump inlet level 426;
- 25 (3) if the annulus pressure at control depth 422 is too high, control system 491 will increase the pump flow to lower fluid level 470 to adjusted fluid level 428; or
- (4) if the annulus pressure at control depth 422 is too low, control system 491 will decrease the pump flow to raise fluid level 470 to adjusted fluid level 430;
- 30 (5) repeat steps 1-4 until drilling process is complete.

Example

At control depth 422 the pore pressure is 30 MPa and the fracture pressure is 50 MPa. The target pressure is set at 40 MPa for control depth 422. The hydraulic model provides a pressure difference of 30 MPa between control depth 422 and pump inlet level 426, so the target pressure at pressure gauge 492 is 10 MPa. When the measured pressure at pressure gauge 492 exceeds 10 MPa, the pump speed is increased to lower the annulus fluid level and the downhole pressure. When the measured pressure at pressure gauge 492 is less than 10 MPa, the pump speed is decreased to raise the annulus fluid level and the downhole pressure.

Those of skill in the art will appreciate that many modifications and variations are possible in terms of the disclosed embodiments, configurations, materials and methods without departing from their spirit and scope. Accordingly, the scope of the claims appended hereafter and their functional equivalents should not be limited by particular embodiments described and illustrated herein, as these are merely exemplary in nature.

C L A I M S

1. A system, comprising:
5 a drilling vessel;
a riser connected to the drilling vessel;
a drillstring within the riser, the drillstring extending into a borehole;
a drill bit connectable to the drillstring;
a pump system comprising an inlet in the riser and an outlet to the drilling
10 vessel; and
a pump controller adapted to control a pressure within the riser and the
borehole by raising or lowering a fluid level within the riser.
2. The system of claim 1, further comprising a subsea blow out preventer
15 connected to the riser.
3. The system of claim 2, further comprising at least one string of casing
connected to the subsea blow out preventer, the casing within the borehole.
- 20 4. The system of one or more of claims 1-3, wherein the drilling vessel is
floating.
5. The system of one or more of claims 1-4, further comprising a liquid level
and/or pressure sensor connected to the pump control system.
25
6. A method of controlling borehole pressure comprising:
installing a riser from a drilling vessel to a subsea blow out preventer or a
wellhead;
installing a pump system and a pump controller, the pump system
30 comprising an inlet in the riser and an outlet to the drilling vessel; and
selectively pumping fluid from within the riser to the drilling vessel, to control
a fluid level within the riser, and to control a pressure level within the borehole.

7. The method of claim 6, further comprising pumping fluid from within the riser to lower the pressure level within the borehole.

5 8. The method of one or more of claims 6 and 7, further comprising monitoring the fluid level within the riser and/or the pressure within the borehole.

9. The method of one or more of claims 6-8, further comprising stopping pumping as needed to raise the pressure level within the borehole.

10

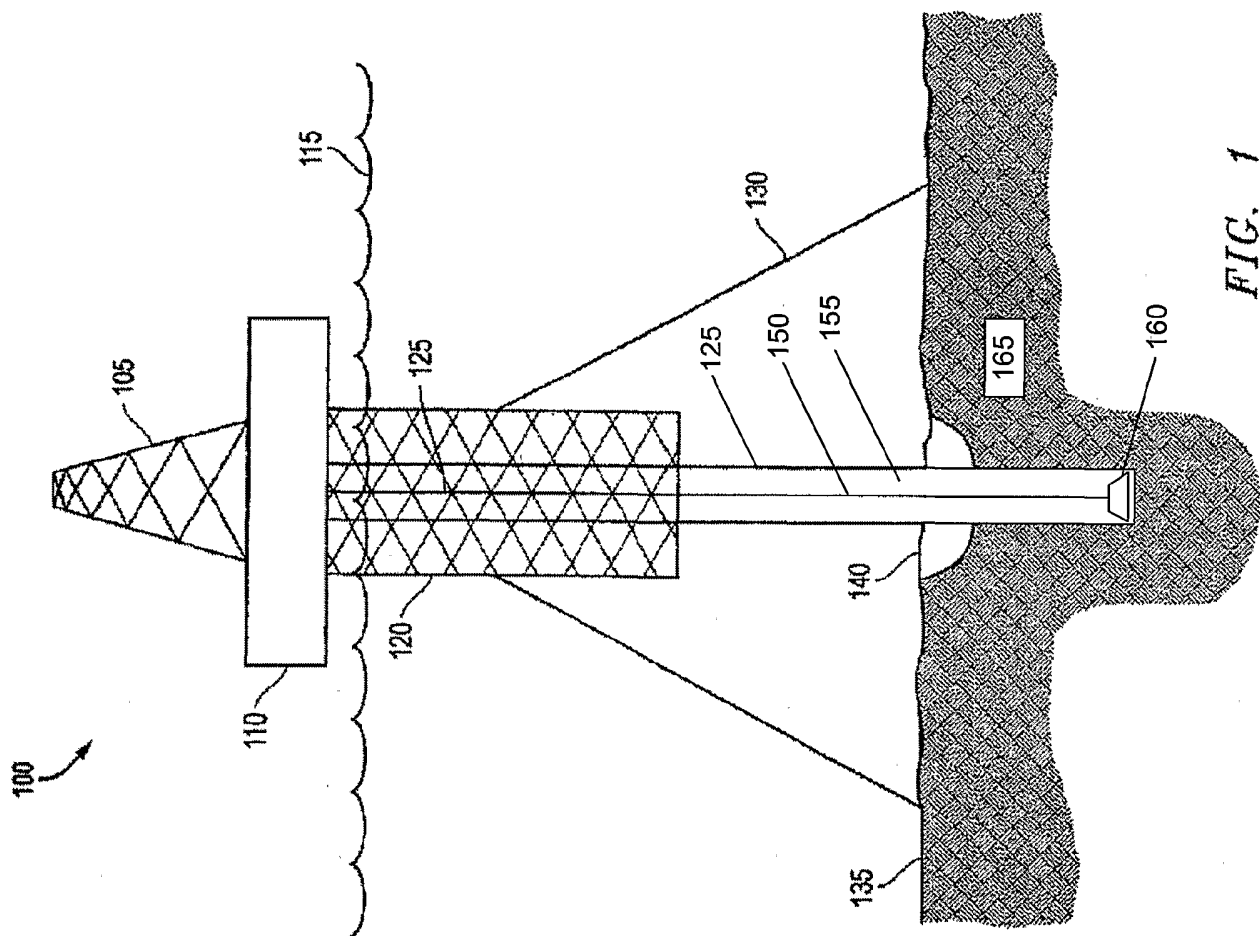


FIG. 1

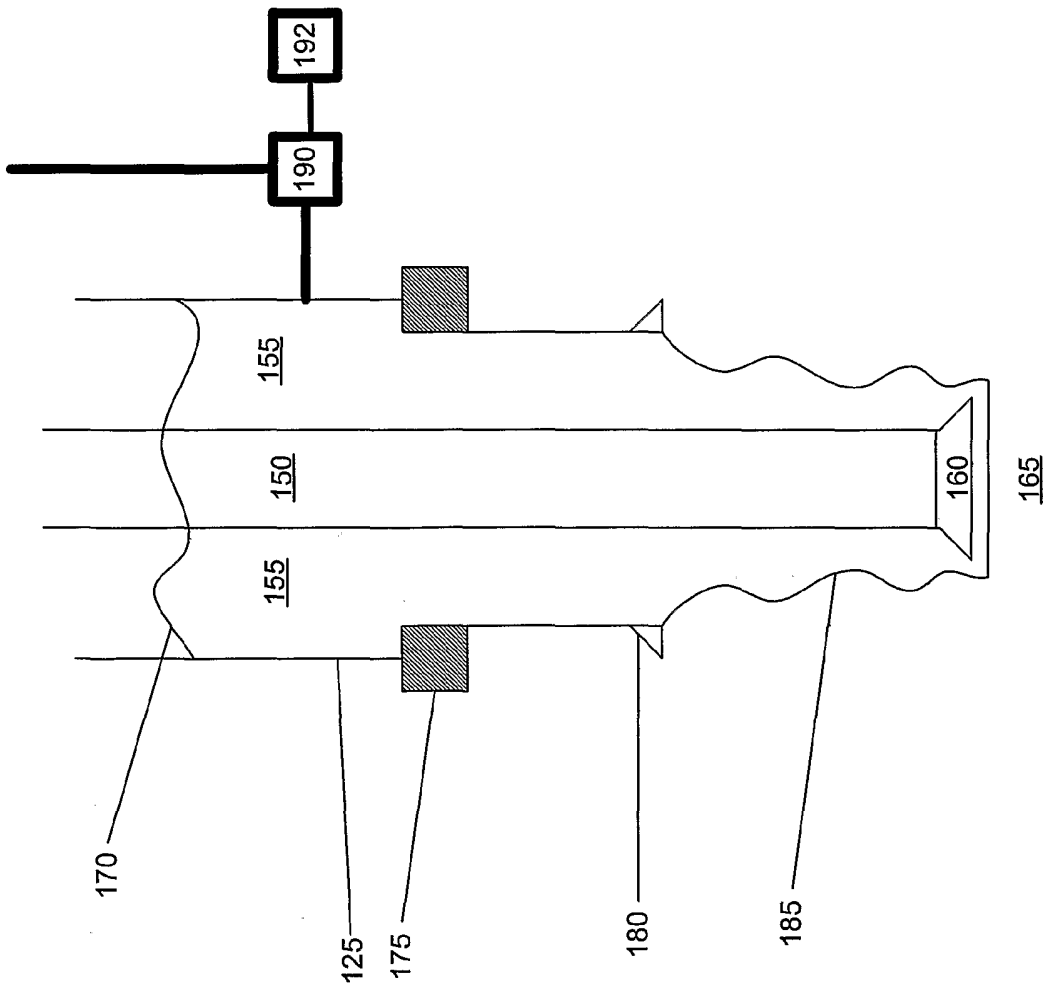


Figure 2

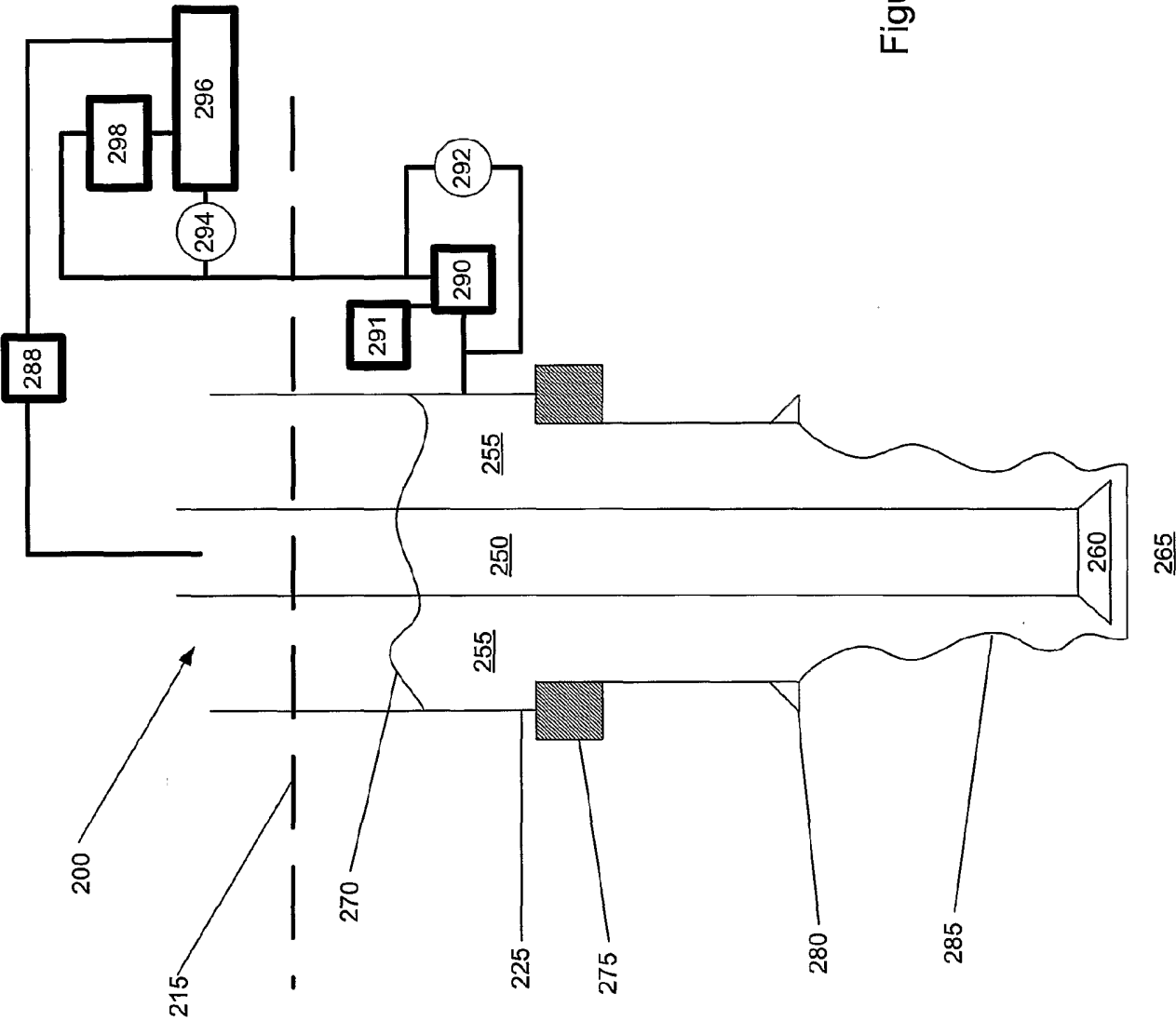


Figure 3

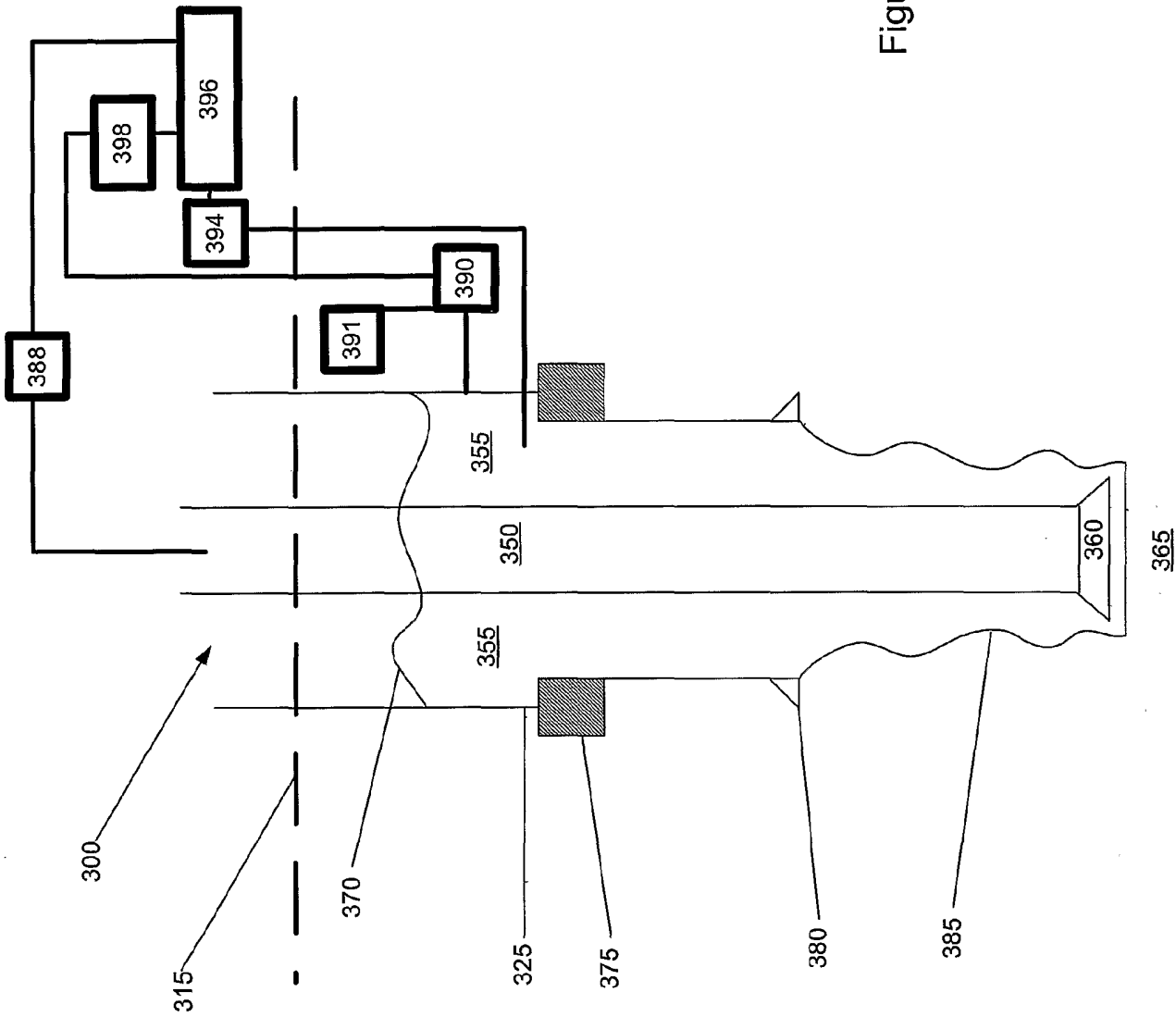


Figure 4

