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- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

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Declarations under Rule 4.17:

— of inventorship (Rule 4.17(iv))

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- (54) Title: MUD LIFT DRILLING SYSTEM USING EJECTOR ASSEMBLY IN MUD RETURN LINE

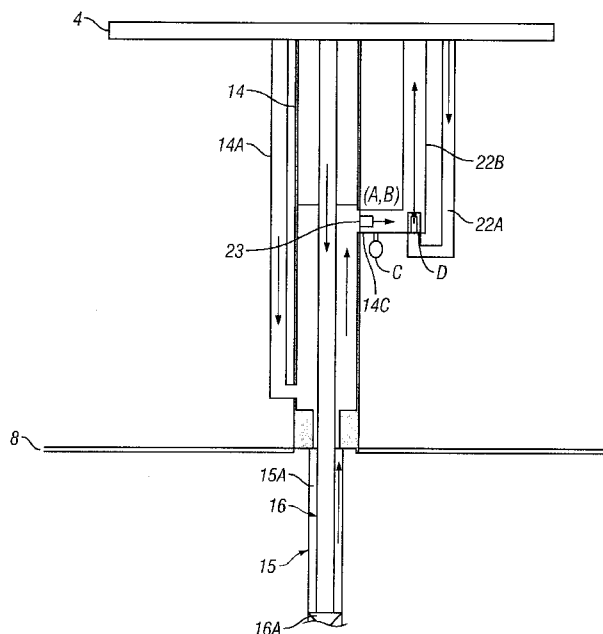


FIG. 2

(57) Abstract: A method is described for controlling pressure in a wellbore drilled below the bottom of a body of water wherein the wellbore has a fluid outlet in communication with a working fluid inlet of an ejector assembly to return drilling fluid to a drilling platform on the water surface. The method includes pumping drilling fluid into a drill string extending from the drilling platform into the wellbore and at least one of, (i) introducing fluid into a power fluid inlet of the ejector assembly at a rate selected to remove fluid from the wellbore fluid outlet at a selected rate and (ii) operating a controllable flow restriction in a flow path from the wellbore fluid outlet to the working fluid inlet of the ejector assembly, in order to maintain a selected wellbore pressure.

MUD LIFT DRILLING SYSTEM USING EJECTOR ASSEMBLY IN MUD RETURN LINE

Background

- [0001]** This disclosure is related to the field of controlled pressure drilling and “dual gradient” drilling. More particularly the disclosure relates to apparatus and methods for controlled pressure and/or dual gradient drilling that use ejector assemblies.
- [0002]** International Application Publication No. WO 2013/0177331 describes a managed pressure drilling system using a pump in a drilling fluid return line. The pump may be used to maintain a selected fluid level in a drilling riser disposed above a top of a subsea wellbore, wherein the riser extends from a subsea wellhead at the water bottom to a drilling platform above the water surface. By suitable operation of the pump, the fluid level may be maintained at a selected elevation at or below the water surface so that a pressure in the wellbore may be maintained at or below the hydrostatic pressure of the fluid column in the riser were it to extend from the bottom of the wellbore to the surface. In the case the fluid level elevation in the riser is maintained below the surface, the pressure elevation gradient of the fluid in the riser may be different than the fluid pressure elevation gradient of fluid (“mud”) pumped into a drill string used to drill the wellbore below the water bottom. In other implementations, a riser may be omitted, and drilling fluid being discharged from the wellbore may be returned to the surface by a separate return line having a pump therein.
- [0003]** The system shown in the ‘331 publication cited above is illustrative of “mud lift” drilling systems known in the art. Referring to FIG. 1, when a wellbore is drilled from a bottom supported drilling platform or a floating drilling platform (“drilling rig”) 1 disposed above the surface of a body of water, a conductor is first driven into the water bottom or seabed. When drilling a wellbore 15 from a drilling rig 1, drilling fluid may be pumped using a mud pump 26, through an interior conduit in a drill string 16 suspended by a kelly or top drive, down to a drilling tool, which may terminate in a drill bit (not shown) that cuts through the sub-bottom formations to lengthen the wellbore 15. The

drilling fluid serves several purposes, some of which are to transport drill cuttings out of the borehole, and to maintain fluid pressure in the wellbore 15 to prevent collapse of the wellbore 15 and prevent entry of fluids into the wellbore 15 from exposed formations. Efficient transport of drill cuttings requires that the drilling fluid is relatively viscous. The drilling fluid flows back through an annulus 30 between the wellbore wall, a liner or casing 14 and the drill string 16, and up to the drilling rig 1, where the drilling fluid may be treated in devices 24 for such purposes and conditioned before being pumped back down into the wellbore 15. In some cases, the combined pressure of pumping and the selected density of the drilling fluid will result in a head of pressure and/or pressure gradient in the wellbore annulus 30 that is undesirable.

[0004] By coupling a subsea mud lift pump 20 to the liner 14 near the seabed (or to the wellhead when drilling, e.g., from a floating drilling platform), the returning drilling fluid can be pumped out of the annulus 30 and up to the drilling rig 1 to reduce the fluid pressure in the annulus 30. In some implementations, the annular volume above the wellbore may include a riser that may be partially or completely filled with drilling fluid and/or with a different riser fluid. The density of the riser fluid, if used, may be less than that of the drilling fluid. It is also possible to drill such wellbores without a riser by using a rotating control head or rotating diverter coupled to the top of the wellbore (i.e., the wellhead) to seal against the drill string 16.

[0005] The drilling fluid pressure existing at the level of the water bottom may be controlled from the drilling rig 1 by selecting the inlet pressure to the subsea mud lift pump 20. In riser-type drilling systems as shown in FIG. 1, the height H_1 of the column of drilling fluid above the water bottom depends on the selected inlet pressure of the subsea mud lift pump 20, the density of the drilling fluid, the density of the riser fluid and the relative vertical elevation levels of each such fluid in the riser. The inlet pressure of the subsea mud lift pump 20 is equal to: $P = (H_1 \gamma_b) + (H_2 \gamma_s)$ in which γ_b represents the density of the drilling fluid, H_1 represents the height of the drilling fluid column above the pump inlet point, H_2 represents the height of the column of riser fluid, and γ_s represent the density of the riser fluid.

[0006] H_1 and H_2 together make up the length of the riser section from the water bottom 8 and in some examples may extend upward to the deck 4 of the drilling rig 1. Filling the riser 12 at least in part with a riser fluid allows continuous flow quantity control of the fluid flowing into and out of the wellbore 15. Thus, it is relatively easy to detect a phenomenon, such as, for example, drilling fluid flowing out of the wellbore 15 into an exposed formation (“lost circulation”). It is furthermore possible to maintain a substantially constant drilling fluid pressure at the level of the water bottom when the drilling fluid density changes. Choosing a different inlet pressure to the subsea mud lift pump will cause the heights H_1 and H_2 to change according to the new selected subsea mud lift pump 20 inlet pressure. If so desired, the outlet 17 from the annulus 30 to the subsea mud lift pump 20 can be arranged at a level below the water bottom, by coupling a first pump pipe (not shown in FIG. 1) to the annulus at a level below the water bottom. In order to prevent the drilling fluid pressure from exceeding an acceptable level (e.g., in the case of a pipe “trip”), the riser 12 be provided with a dump valve. A dump valve of this type can be set to open at a particular pressure for outflow of drilling fluid to the body of water. Other examples may omit a dump valve.

[0007] As explained above, using a riser to exert part of the hydrostatic pressure on the wellbore annulus is optional, and in other implementations the riser may be omitted. Such implementations may use a rotating control head or other rotatable sealing device (not shown) to seal the annular space above the top of the wellbore 15 while enabling rotation and axial motion of the drill string 16.

[0008] In FIG. 1, reference number 1 denotes the drilling rig comprising a support structure 2, a deck 4 and a derrick 6. The support structure 2 is placed on the water bottom 8 and projects above the surface 10 of the sea. As explained above the deck may also be supported by a floating platform (not shown). A riser section 12 of a liner 14 extends from the water bottom 8 or a subsea wellhead (not shown) up to the deck 4, while the liner 14 runs further down into the wellbore 15. The riser section 12 is provided with required well head valves (not shown). The drill string 16 projects from the deck 4 and down through the liner 14. A first pump pipe 17 may be coupled to the riser section 12 near the water bottom 8 via a valve 18 and the opposite end portion of the pump pipe 17

is coupled to the intake of the subsea mud lift pump 20. In the present example the subsea mud lift pump may be placed near the water bottom 8. A second pump pipe 22 runs from the pump 20 up to a collection tank 24 for drilling fluid on the deck 4. A tank 26A for a riser fluid communicates with the riser section 12 via a connecting pipe 28 at the deck 4. The connecting pipe 28 may have a volume meter (not shown). Preferably, the density of the riser fluid is less than that of the drilling fluid, as explained above. The power supply for the subsea mud lift pump 20 is typically provided by an electrical cable (not shown) from the drilling rig 1, and the pressure at the inlet to the subsea mud lift pump 20 is selected from the drilling rig 1. The drilling fluid is pumped down through the drill string 16 in a manner that is known in the art, and returns to the deck 4 via an annulus 30 between the liner 14 and the drill string 16. When the subsea mud lift pump 20 is started, the drilling fluid is returned from the annulus 30 via the subsea mud lift pump 20 to the collection tank 24 on the deck 4.

[0009] While the embodiment shown in FIG. 1 has the subsea mud lift pump 20 disposed near or on the water bottom 8, it should be understood that the subsea mud lift pump may be placed at any intermediate position along the return line 22. Thus, the depth of the subsea mud lift pump 20 in the body of water is not a limitation on the scope of the present invention.

[0010] The volume of fluid flowing into and out of the tank 26 is typically monitored, making it possible to determine, e.g., whether drilling fluid is being lost into an exposed formation (i.e., one not sealed by the liner 14), or whether gas or liquid is flowing from an exposed formation and into the wellbore 15 and fluid circulation system.

Brief Description of the Drawings

[0011] FIG. 1 shows an example mud lift or dual gradient drilling system known in the art.

[0012] FIG. 2 shows an example ejector assembly mud lift drilling system.

[0013] FIG. 3 shows example embodiments of pump connections that may be used in various embodiments.

- [0014] FIG. 4 shows an example ejector assembly in more detail.
- [0015] FIG. 5 shows another embodiment wherein an annular seal is used to seal an annular space between the drill string and the riser.
- [0016] FIG. 6 shows an example of a retrievable ejector disposed in a fluid return line.

Detailed Description

- [0017] As explained in the Background section herein, most lifting devices that perform the function of the subsea mud lift pump (20 shown in FIG. 1) are either constant lift/constant head pumps in the form of a centrifugal pump or are positive displacement pumps operated by hydraulic pressure or an electric motor. An example mud lift device will now be described with reference to FIGS. 2 and 3 that may be directly driven by a power fluid and which has no moving parts. Certain components of the drilling system shown in FIG. 1 have been omitted from FIGS. 2 and 3 for the sake of clarity.
- [0018] In some embodiments, a drilling riser 14 may extend from a wellhead BOPE located on the bottom 8 of a body of water and may extend to a drilling platform 4 at the water surface as explained with reference to FIG. 1. A drill string 16 may have drilling tools at a bottom end thereof of types known in the art, generally terminated by a drill bit 16A which may be rotated by means not shown to extend the length of a wellbore 15. Drilling fluid may be pumped into an interior of the drill string 16 by a pump (26 in FIG. 3). During drilling, the drilling fluid may leave the wellbore 15 and enter the base of the riser 14. A fluid outlet 14C may be provided in the riser 14 at a selected depth above the wellhead BOPE and below the drilling platform 4. A jet assembly or ejector assembly D may be included in a drilling fluid return path extending from the fluid outlet 14C to the base of a fluid return line 22B. The fluid return line 22B may extend to the drilling platform 4. In some embodiments such as shown in FIG. 2, the fluid return 22B line may extend substantially vertically to the drilling platform 4 to enable retrieval and replacement of the ejector assembly D using, for example wireline or slickline if required. The structure of the fluid return line 22B in other embodiments may be other than vertical or substantially vertical. A power fluid line 22A may extend from the

drilling platform 4 to a power fluid inlet of the ejector assembly D. Power fluid, which may be the same fluid as the drilling fluid, may be pumped into the power fluid line 22A from a separate pump on the drilling platform (see 26B in FIG. 3) or may have some of the discharged fluid from the drilling fluid pump (see 26 in FIG. 3) diverted into the power fluid line 22A.

[0019] In the present example embodiment, a pressure sensor C may be in pressure communication with the interior of the drilling riser 14 at a selected position. The pressure sensor C may be in signal communication with a pump controller (not shown separately) which may selectively operate the power fluid pump (26B in FIG. 3) or a diverter valve (not shown) to selectively divert an amount of flow from the drilling fluid pump (26 in FIG. 3). In either of the foregoing example embodiments, a rate of flow of power fluid into the power fluid inlet of the ejector assembly D may be controlled so that a selected pressure in the drilling riser 14 is measured by the pressure sensor C. By such control over the pressure measured by the pressure sensor C and with knowledge of the hydrostatic and hydrodynamic properties of the drilling fluid, a selected pressure gradient may be maintained within the drilling riser 14 and the wellbore 15 outside the drill string 16. In some embodiments, a variable flow restriction such as a controllable orifice choke 23 or similar controllable flow restrictor may be used at any selected position in the flow path between the wellbore fluid outlet and the working fluid inlet of the ejector assembly D so that the ejector assembly D may be operated at a substantially constant power fluid flow rate and fluid level in the riser 14 and resulting wellbore pressure may be controlled by controlling the controllable orifice choke 23.

[0020] In some embodiments, a booster line 14A may be included alongside the drilling riser 14 for injecting fluid when required, for example, such as when necessary to circulate out a fluid that may enter the wellbore 15 from a sub-bottom formation.

[0021] In other implementations, the riser 14 may be omitted, and drilling fluid being discharged from the wellbore 15 may be returned to the surface by a separate return line having an ejector assembly therein. Such return line may be hydraulically connected to the wellbore below the wellhead (BOPE in FIG. 2) or above the wellhead. In such

implementations, the power fluid line (22A in FIG. 2) may extend to the depth at which the ejector assembly D is disposed. In embodiments that do not use a riser, an annular space between the drill string and the wellbore (15A in FIG. 2) may be hydraulically closed using a sealing element such as a rotating control head, rotating blowout preventer or rotating diverter. Other “riserless” embodiments may simply have the annular space (15A in FIG. 2) open at an upper end thereof.

[0022] FIG. 3 shows one example implementation in which a separate drilling fluid pump 26, power fluid pump 26B and booster line pump 26C may be disposed on the drilling platform 4. All three separate pumps 26, 26B, 26C may withdraw drilling fluid from the tank 26A. In other embodiments, each pump 26, 26B, 26C may have a separate fluid supply tank.

[0023] An example ejector assembly D is shown in more detail in FIG. 4. The ejector assembly D may include a diffuser comprising a converging inlet diffuser D3 and a diverging outlet diffuser D4. An outlet of the outlet diffuser D4 may be coupled to the fluid return line (22B in FIG. 2). A working fluid inlet D1 to the ejector assembly D may be in fluid communication with the wellbore fluid outlet (e.g., riser outlet 14C in FIG. 2). Power or motive fluid pumped through the power fluid line 22A may enter the ejector assembly D through a power fluid inlet. The power fluid is discharged in the interior of the ejector assembly D upstream of the converging diffuser D3 through a nozzle D2. The nozzle D2 serves to increase velocity of the power fluid so as to reduce fluid pressure at the working fluid inlet D1. A combination of the power fluid and the working fluid, e.g., the drilling fluid, maybe returned to the drilling platform (4 in FIG. 2) through the fluid return line (22B in FIG. 2).

[0024] Another embodiment shown in FIG. 5 may include a seal 16A disposed in the annular space between the interior of the riser 14 and the exterior of the drill string 16. In some embodiments, the seal 16A may be a rotatable seal such as a rotating control head, rotating diverter or rotating control device of any type known in the art. In the embodiment shown in FIG. 5, the seal 16A may generally be disposed axially above the position of the fluid outlet 14C. In some embodiments, the seal 16A may be disposed

proximate the drilling platform 4. The exact position of the seal 16A is not intended to limit the scope of the present disclosure. In embodiments such as shown in FIG. 5, a rate of pumping fluid into the power fluid injection line 22A may be selected to provide a selected fluid pressure at the riser outlet 14C independently of fluid pressure in the riser 16 above the seal 16A.

[0025] FIG. 6 shows an example of an ejector D that may be replaced without the need to disconnect any components of the power fluid injection line (22A in FIG. 5) or the fluid return line (22B in FIG. 5). The ejector D may include a latch 52 of types well known in the art for mating with corresponding locking features 52A in the interior of the fluid return line 22B. For example, the locking features may comprise collets or tangs that may be radially compressed when upward force is applied to a fishing neck 50, such as by using an “overshot” coupled to the end of a wireline, slickline, spoolable tube or other conveyance mechanism known in the art. A seal 54 may be disposed on the exterior of the ejector D to prevent movement of fluid between the exterior of the ejector D and the interior of the fluid return line 22B. The riser outlet 14C may be in fluid connection with the interior of the fluid return line 22B such that irrespective of the rotational orientation of the ejector D, the working fluid inlet (D1 in FIG. 4) is in fluid communication with the riser outlet 14C. Fluid from the power fluid injection line (22A in FIG. 5) may enter the ejector D from the bottom thereof as shown in FIG. 6. If during operation of a system using an ejector D such as shown in FIG. 6, the ejector becomes worn or damaged, or if the fluid transport properties of the ejector D require changing the ejector, the fluid return line 22B may be opened from the surface, and an overshot (not shown in the Figures) may be lowered into the fluid return line 22B such as by extending a wireline, slickline, coiled tubing or semi-stiff spoolable rod into the fluid return line 22B. After latching onto the fishing neck 50, the entire ejector D may be removed from the fluid return line 22B and a replacement ejector may be inserted therein by lowering the replacement ejector into the fluid return line 22B and allowing the latching mechanism 52 to engage the locking features 52A therein.

[0026] A mud lift drilling system and method according to the present disclosure may provide the capability of controlling wellbore pressure without the need for a pump

having moving parts disposed below the surface of a body of water. Embodiments of an ejector assembly according to the present disclosure may be replaceable by a wireline or slickline operation, or using a coiled tubing or semi-stiff spoolable intervention rod thus simplifying ejector assembly replacement if and when needed. A semi-stiff, spoolable intervention rod and deployments is available from Ziebel, AS, Stavanger, Norway under the registered trademark Z-LINE.

[0027] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

What is claimed is:

1. A method for controlling pressure in a wellbore drilled below the bottom of a body of water, the wellbore having a fluid outlet in fluid communication with a working fluid inlet of an ejector assembly to return drilling fluid to a drilling platform on the water surface, the method comprising:
pumping drilling fluid into a drill string extending from the drilling platform into the wellbore; and
at least one of, (i) introducing fluid into a power fluid inlet of the ejector assembly at a rate selected to remove fluid from the wellbore at a selected rate and (ii) operating a controllable flow restriction in a fluid path from the wellbore to the working fluid inlet of the ejector assembly, to maintain a selected wellbore pressure.
2. The method of claim 1 wherein the maintaining the selected wellbore pressure comprises maintaining a fluid level in a riser extending from a wellhead disposed on the bottom of the body of water to a drilling platform above the water surface.
3. The method of claim 1 further comprising removing the ejector assembly from a fluid return line extending from the drilling platform using at least one of a wireline, slickline, coiled tubing and a semi-stiff spoolable intervention rod extended into the fluid return line.
4. The method of claim 1 further comprising sealing an annular space between the drill string and an interior of a drilling riser extending from a wellhead proximate the bottom of the body of water to proximate the drilling platform.
5. A wellbore drilling system comprising:
a drill string extending into the wellbore from a drilling platform at a surface of a body of water;
a fluid pump coupled to an interior passage in the drill string;

- a fluid outlet connected to the wellbore, the fluid outlet in fluid communication with a working fluid inlet of an ejector assembly, an outlet of the ejector assembly in fluid communication with a fluid return line extending to the drilling platform;
- a pressure sensor in pressure communication with an interior of the wellbore; and
- means for pumping a power fluid into an inlet therefor in the ejector assembly, the means for pumping controllable in response to signals from the pressure sensor to enable maintaining a selected wellbore pressure.
6. The wellbore drilling system of claim 5 further comprising a variable flow restriction between the fluid outlet and the ejector assembly.
 7. The wellbore drilling system of claim 5 further comprising a riser extending from the bottom of the body of water to the drilling platform and wherein the pressure sensor is in fluid communication with an interior of the riser.
 8. The wellbore drilling system of claim 5 wherein the fluid return line is substantially vertical and the ejector assembly is disposed in the fluid return line such that the ejector assembly is removable from the fluid return line by at least one of a wireline, slickline, coiled tubing and a semi-stiff spoolable intervention rod extended into the fluid return line.
 9. The wellbore drilling system of claim 5 further comprising a seal disposed in an annular space between the drill string and an interior of a drilling riser extending from a wellhead proximate a bottom of a body of water to proximate the drilling platform.

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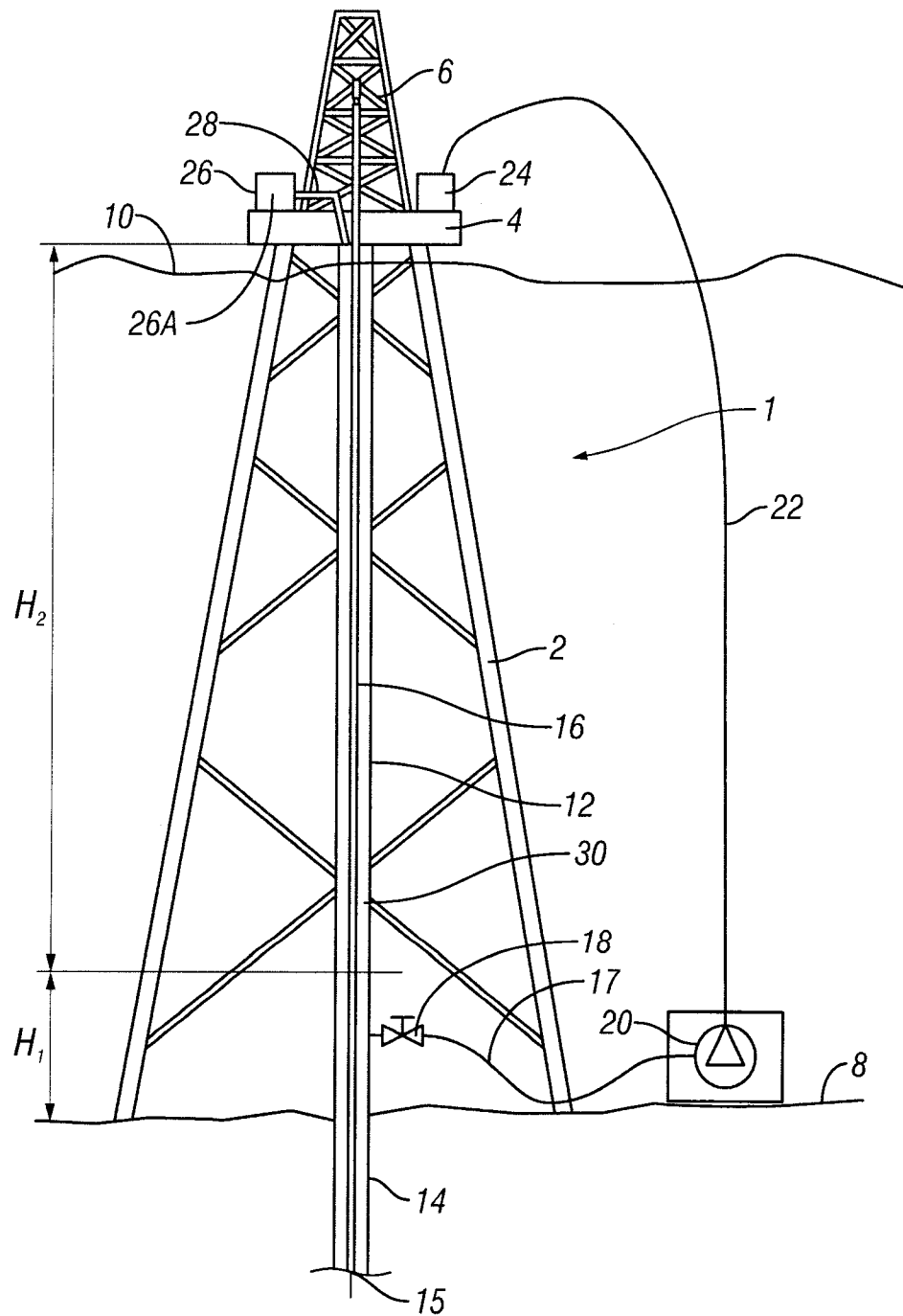


FIG. 1
(Prior Art)

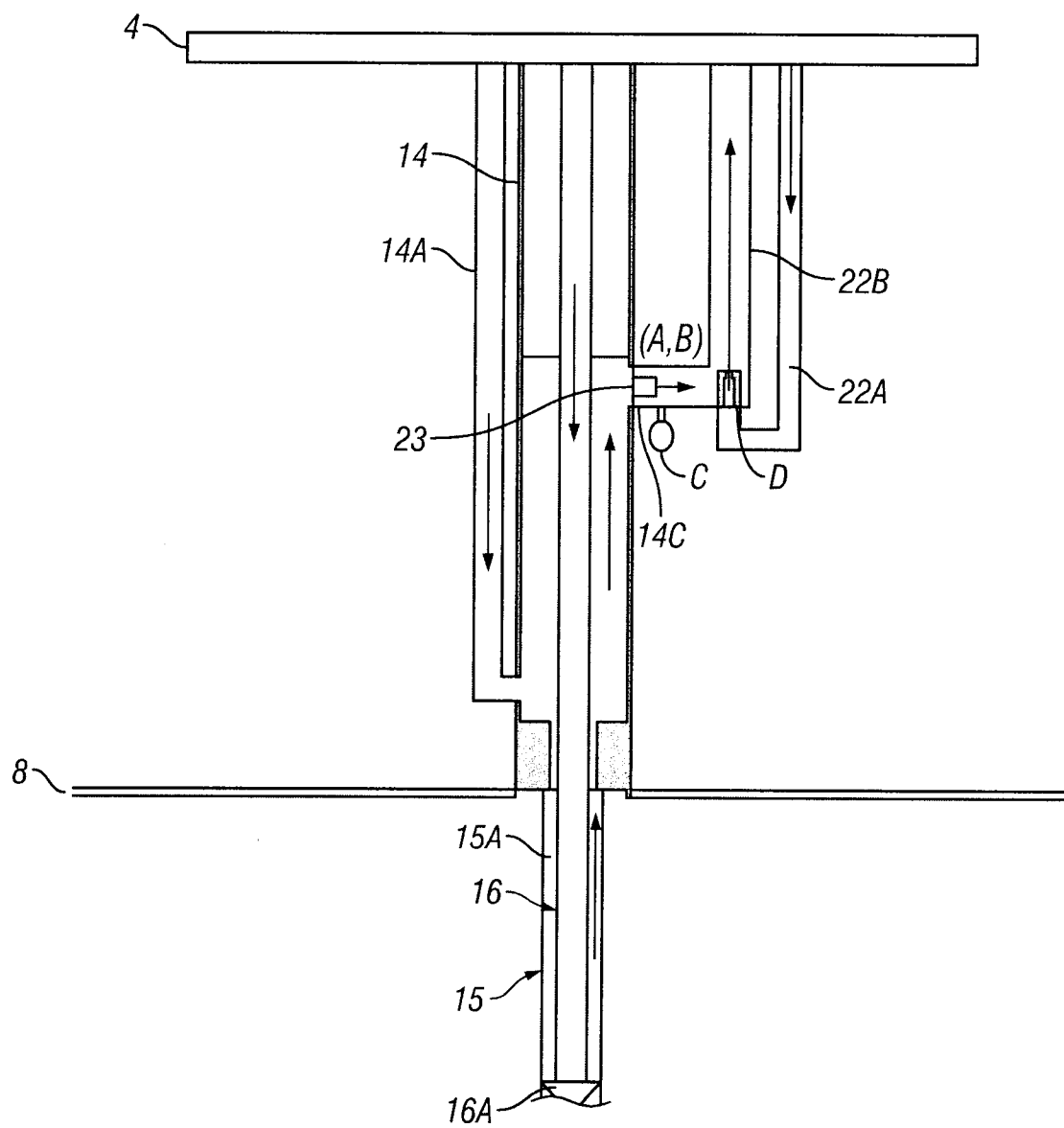


FIG. 2

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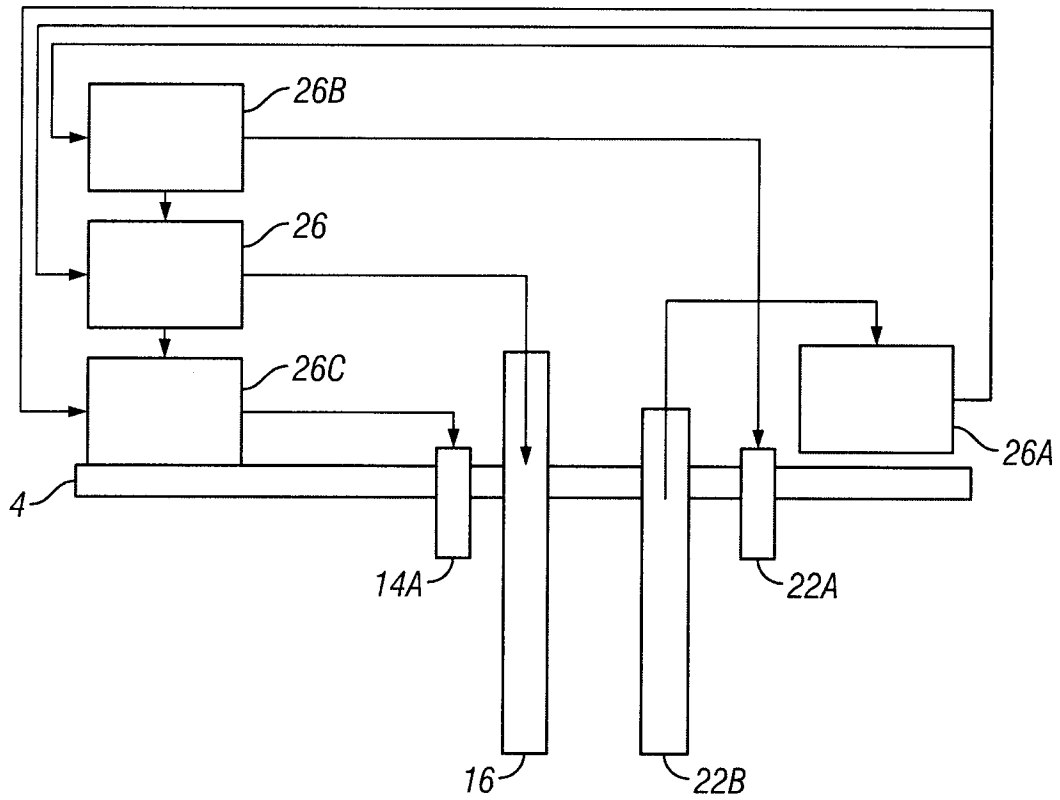


FIG. 3

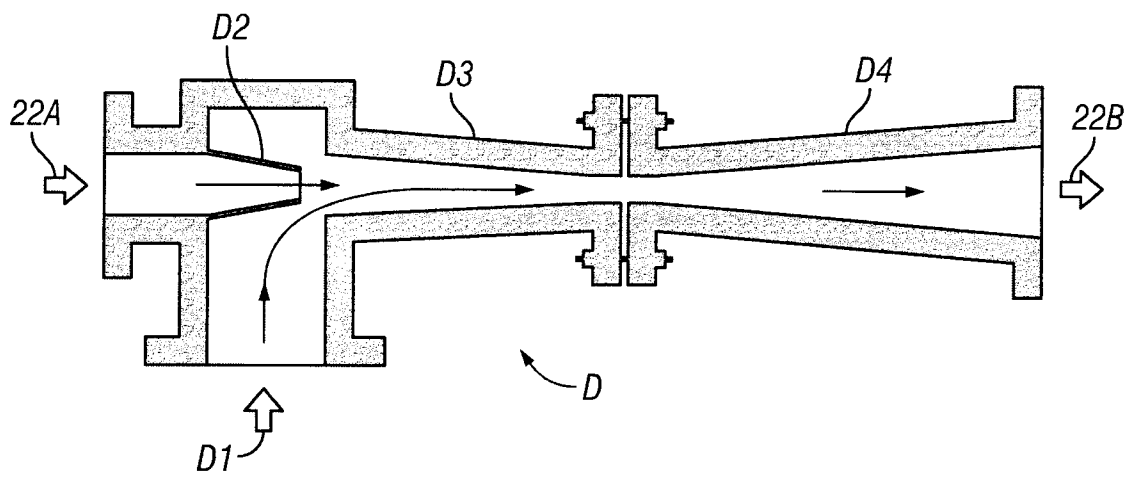


FIG. 4

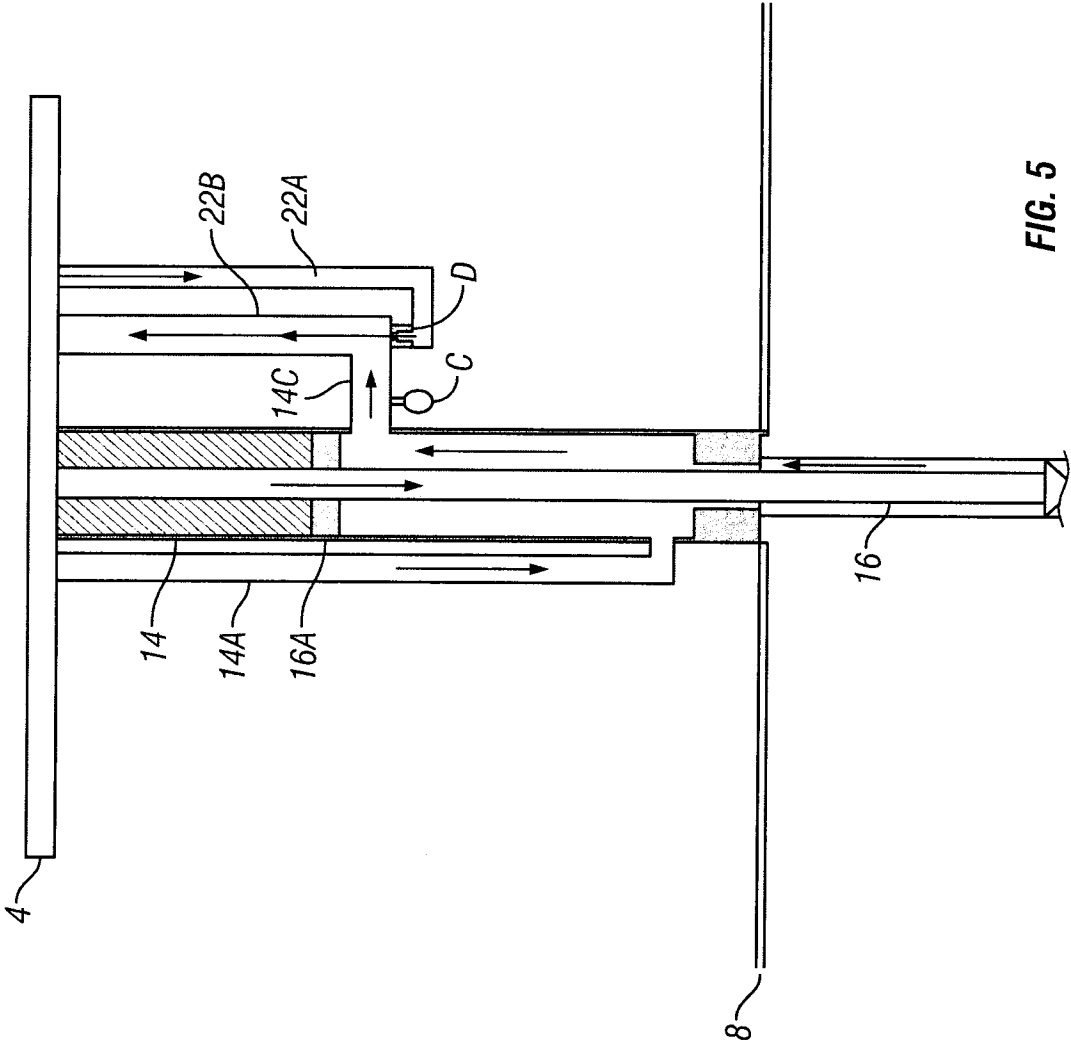


FIG. 5

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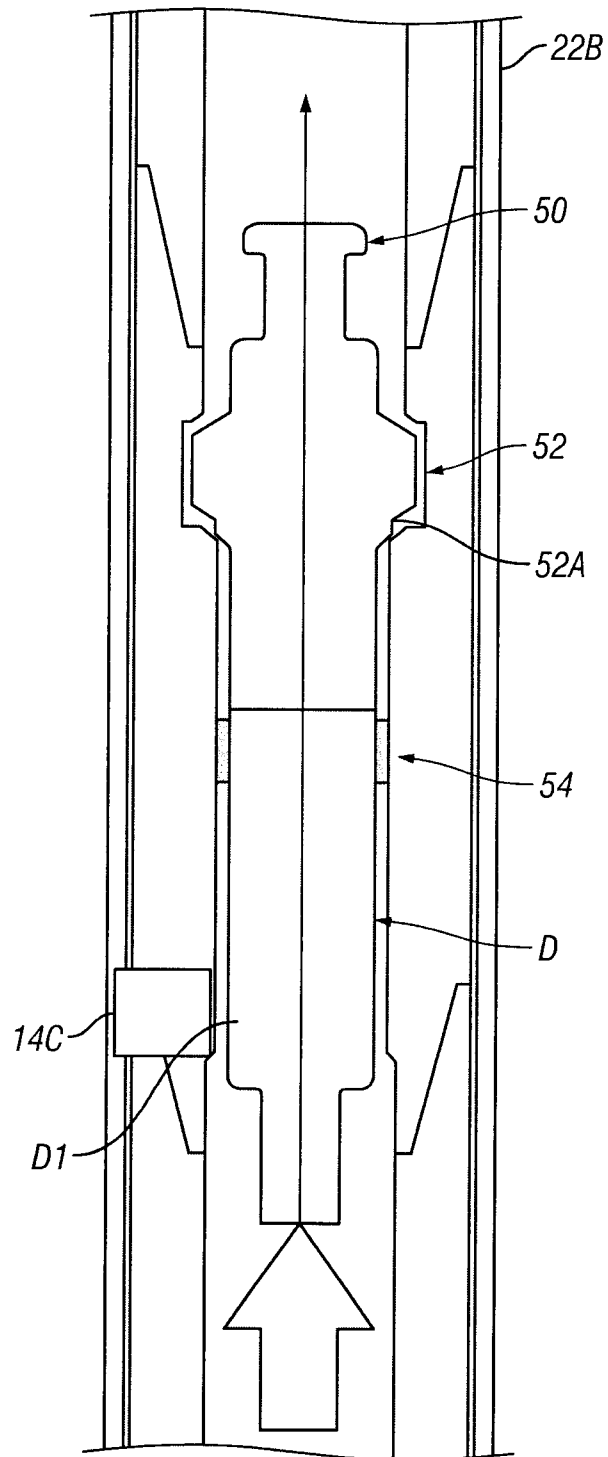


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2015/000317A. CLASSIFICATION OF SUBJECT MATTER
IPC: **E21B 21/08** (2006.01)

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)
IPC: **E21B 21/08** (2006.01)

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Questel-Orbit, Canadian Patent Database

Keywords : Drilling, wellbore, ejector, pressure control, jet assembly, injector, mud lift, gradient, diffuser, nozzle, choke, latch, lock, collet, tangs

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US6,530,437B2 (MAURER, W.C. et al.) 11 March 2003 (11-03-2003) *Abstract; Figs. 1, 6, 8; Cols. 6-8*	1 2, 4-7, 9
Y	CA2871620A1 (REITSMA, D.G. et al) 31 October 2013 (31-10-2013) *Same Inventor* *Abstract; Figs.1 and 2; Para[0023]*	2, 4-7, 9
A	WO2013/115651A2 (REE, S. et al.) 08 August 2013 (08-08-2013) *Abstract*	1, 5
A	US2013/0192841A1 (FEASEY, G.F. et al.) 01 August 2013 (01-08-2013) *Abstract*	1, 5
A	US8,403,059B2 (HUGHES, W.J. et al.) 26 March 2013 (26-03-2013) *Abstract*	1, 5

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* "A" "E" "L" "O" "P"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance earlier application or patent but published on or after the international filing date 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) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	"T" "X" "Y" "&"	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 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 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
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Date of the actual completion of the international search
29 June 2015 (29-06-2015)Date of mailing of the international search report
30 July 2015 (30-07-2015)Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 001-819-953-2476

Authorized officer

William Tse (819) 934-6355

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2015/000317

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US2014/0102789A1 (SPRINGETT, F.B. et al.) 17 April 2014 (17-04-2014) *Abstract*	1, 5
A	US3,815,673A (BRUCE, G.H. et al.) 11 June 1974 (11-06-1974) *Abstract*	1, 5
A	US2012/0055678A1 (HUMPHREYS, G.) 08 March 2012 (08-03-2012) *Abstract*	1, 5
A	US2013/0032396A1 (STAVE, R.S.) 07 February 2013 (07-02-2013) *Abstract*	1, 5

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CA2015/000317

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