

Aug. 23, 1966

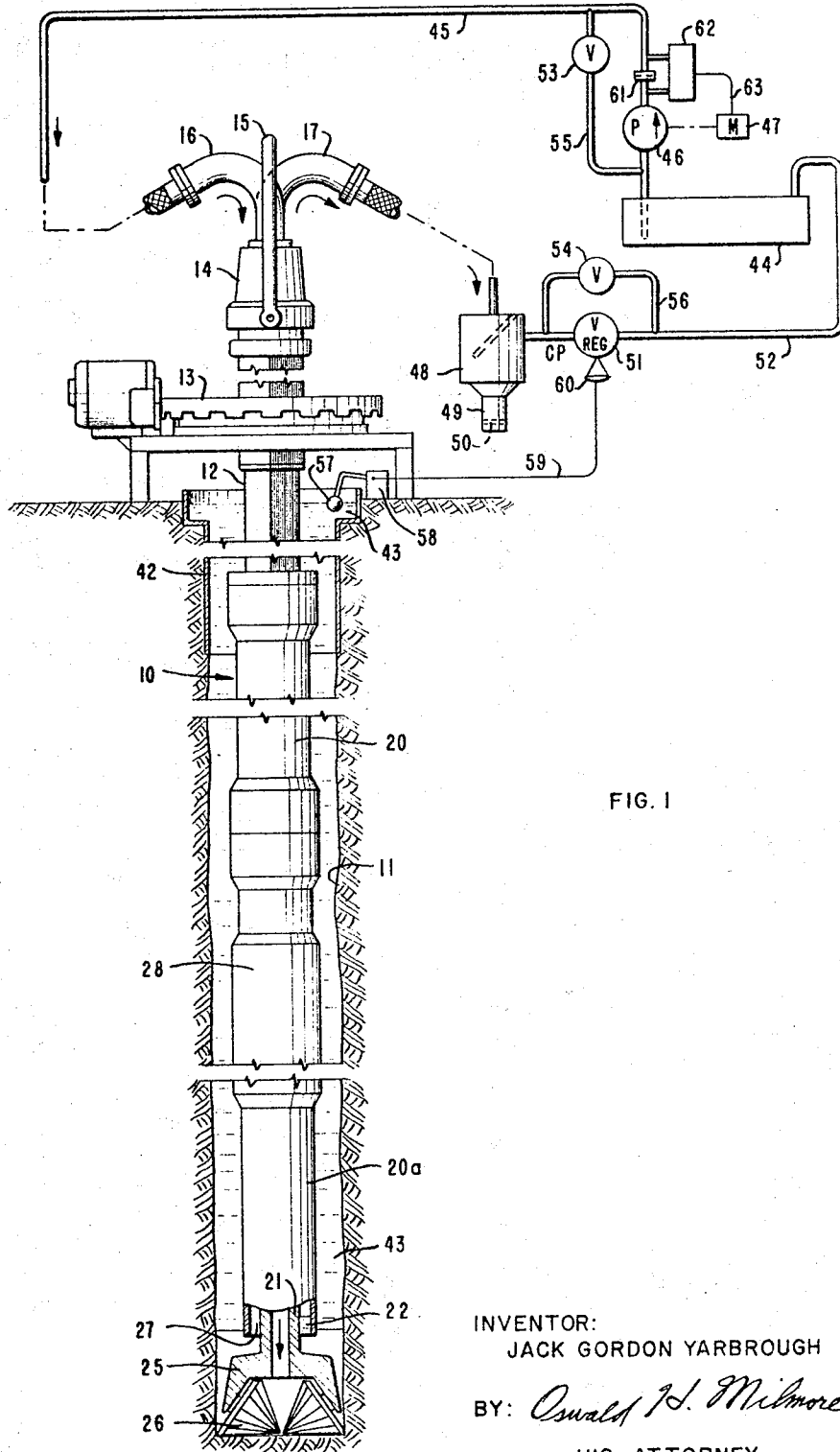
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3,268,017

DRILLING WITH TWO FLUIDS

Filed July 15, 1963

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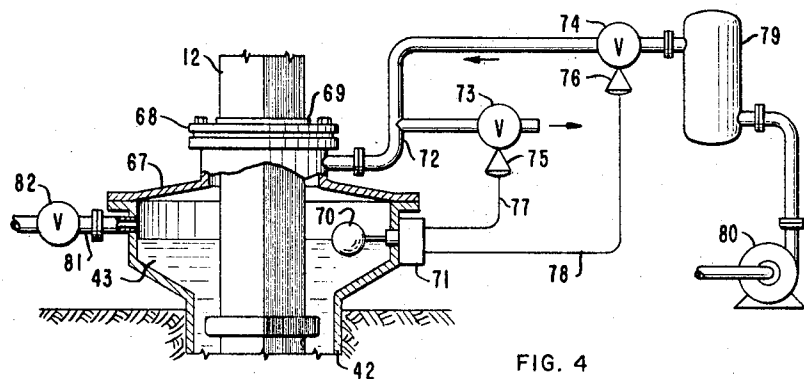


FIG. 4

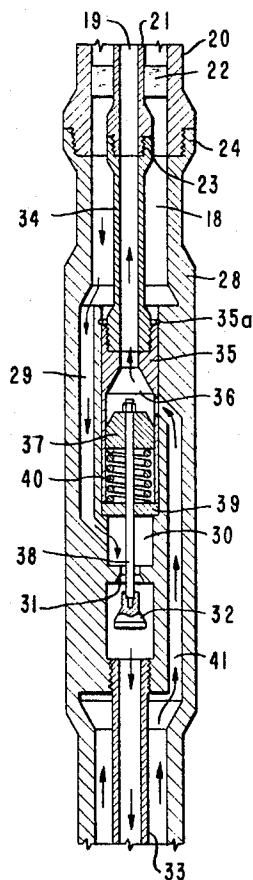


FIG. 2

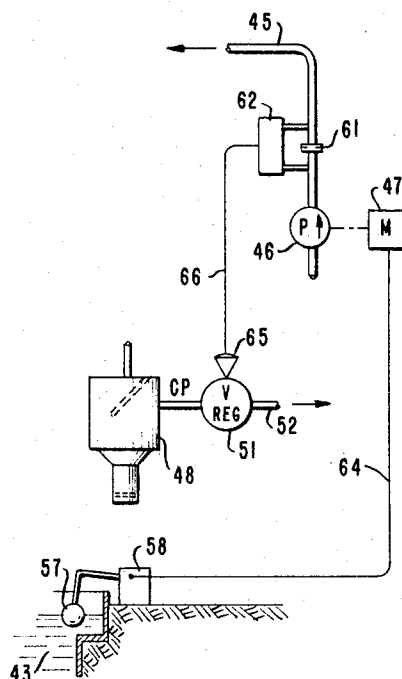


FIG. 3

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3,268,017

DRILLING WITH TWO FLUIDS

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9 Claims. (Cl. 175-25)

The invention relates to improved methods and apparatus for drilling boreholes in the earth using a fast-drilling fluid such as clear water together with a wall-coating liquid such as mud in contact with the borehole wall. More particularly, the invention relates to improvements in maintaining the wall-coating liquid in the borehole and keeping the two fluids substantially separated without the use of special packers.

The drilling of boreholes in the earth with a drill bit at the bottom of a drill string usually involves circulation of a drilling fluid for removing the cuttings, maintaining the hole stability and preventing damage to the formation, and for various other purposes. Accumulated information shows that the greatest drilling rates are usually attained with a clear, i.e., substantially solids-free, drilling fluid; gaseous drilling fluids, such as air, generally produce the highest rates, and progressively lower rates result with clear water, water carrying suspended matter, light muds, which are relatively free of suspended solids, and heavy muds, which have relatively high concentration of suspended solids. Increases in the pressure, hydrostatic or applied, in a solids-free drilling fluid do not significantly reduce the drilling rates that can be attained. Although there is considerable economic advantage in the higher drilling rates attained by the use of such clear drilling fluids, they cannot usually be used to maintain the integrity of the borehole and prevent damage to the formation. Also, there is often a high rate of loss of such drilling fluids by penetration into the formation.

It has been proposed, heretofore, to effect drilling with gaseous drilling fluids that provide a low bottom-hole pressure by maintaining a body of liquid of higher density and low filter-loss, such as mud, in contact with the borehole walls, outside of the drill string. (U.S. patent to Camp et al., No. 2,951,680, September 6, 1960.) A difficulty with the prior proposal is that of maintaining the column of high-density, low filter loss-liquid in position despite the low and variable pressures of the gaseous drilling fluid at the bottom of the borehole. This has heretofore made it necessary to provide a packer at the bottom of the liquid column in engagement with the borehole wall and to rotate the drill string within the packer, while further providing for progressive downward movement of the drill string (the drill collar being herein referred to as forming a part of the drill string) through the packer. Such a packer, apart from its complexity, had to be lowered periodically.

It is the object of this invention to provide an improved method and apparatus for maintaining a column of a wall-coating liquid of suitable characteristics and density in contact with the borehole wall while drilling with a low-solids, fast drilling fluid, particularly, clear water, wherein the column of wall-coating liquid is kept separated from the fast-drilling fluid and maintained at a pressure at least equalling the pressures of fluids in the formations being drilled, without the use of a packer at the bottom of the liquid column.

A further object is to provide a method and apparatus for controlling the pressure of the fast-drilling fluid at the bottom of the borehole, during the drilling with and circulation of the fast-drilling fluid, to balance the hydrostatic head of the column of wall-coating liquid. Ancillary thereto, it is an object to control the flow of the

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circulating fast-drilling fluid, in a manner affecting its bottom-hole pressure, in accordance with variations in the relation of the said pressure to the bottom-hole pressure of the column of wall-coating liquid by measuring changes in the height of the top of said liquid column and/or the pressure on said liquid column.

Another object is to provide means for maintaining the pressure of the fast-drilling fluid at the bottom of the borehole at a level to effect a balance of the hydrostatic head of the column of wall-coating liquid, when circulation is interrupted, e.g., while the top of the drill string is opened for the purpose of coupling on an additional length of drill string.

Additional objects will appear from the following description.

In summary, according to the invention a column of wall-coating liquid of suitable characteristics for protecting the borehole wall, e.g., mud or aqueous or petroleum-base suspension, is maintained adjacently to said wall as an annular column of liquid at pressures at least equaling the formation fluid pressures surrounding a dual drill string which carries a bit at the bottom, the bit is rotated at the bottom of the borehole while circulating a fast-drilling fluid, preferably clear water, but permissibly any substantially solids-free fluid, through one of the passages of the drill string and the bit and thence up, laden with cuttings, through the other passage, and the relation between pressure of the fast drilling fluid at the bottom of the borehole to the bottom-hole pressure of the column of wall-coating liquid, is controlled to make them equal. The said bottom-hole pressure is equal to the hydrostatic head of the said column, or exceeds the hydrostatic head when pressure is applied to the top of the column. The said bottom-hole pressure is preferably at least equal to the formation pressure at the bottom of the borehole.

According to another feature of the invention, the pressure of the last-drilling fluid at the bottom of the borehole is maintained, when circulation of said fluid is interrupted, by providing valves in both passages of the dual string and closing these valves when stopping the circulation; this traps a quantity of the fast-drilling fluid in the lower part of the borehole and retains it at the pressure of the bottom of the column of wall-coating liquid surrounding the drill string. The top of the dual drill string can then be opened to the atmosphere for any desired purpose, such as the addition of a length of drill pipe to the top for lengthening the drill string.

The pressure of the drilling fluid and/or pressure applied to the top of the column of wall-coating liquid may be controlled during circulation in accordance with the relation of the bottom-hole pressure of the column of wall-coating liquid to the pressure of the drilling fluid at the same point. This relation may be determined by measuring the height of and/or the pressure on the top of the said liquid column: thus, it is evident that when the hydrostatic head of a column of wall-coating liquid exposed at its surface to atmospheric pressure exceeds the bottom-hole pressure of the fast-drilling fluid, the height decreases, requiring an increase in said pressure of the drilling fluid; similarly, a rise in the height indicates a decrease in said hydrostatic head in relation to said pressure and calls for a reduction in said pressure. These relations hold also when the top of said column is subjected to a constant or to a variable superatmospheric pressure, which must be added to the above-mentioned hydrostatic head. In this case the pressures at the bottom of the hole can be brought into balance by varying the pressure applied to the top of the column of wall-coating liquid.

Control of fast-drilling fluid pressure in response to the determined relation just described may be effected, according to two alternative embodiments, (a) by varying

the amount of back-pressure applied in the outlet to the up-flow passage in the dual string or (b) by varying the rate at which the drilling fluid is circulated against a given back-pressure; in a third embodiment (c) the pressure balance is attained by varying the amount of pressure applied to the top of the column of wall-coating liquid.

In the first embodiment (a) it is possible to control the bottom-hole pressure of the fast-drilling fluid by pumping it at a rate which is substantially constant and varying the amount of throttling applied to the outlet of the up-flow passage in accordance with the determined relation described above.

In embodiment (b) a pump or compressor having a variable output rate is used. Some resistance to the flow of fast-drilling fluid in the up-flow passage is created by the entraining of earth solids and this flow resistance may optionally be increased to a selected amount by a throttling means. The bottom-hole pressure of the fast-drilling fluid is varied by varying the pumping rate in accordance with the determined relation described above.

In embodiment (c) the effective head of the column of wall-coating liquid is varied by varying the pressure applied, e.g., by a pump or compressor, to the top of the column, in accordance with the determined relation described above.

The invention is not, however, restricted to these exemplary, preferred modes of controlling the pressure balance between the fluids at the bottom of the borehole during circulation of the fast-drilling fluid.

The pressure of the fast-drilling fluid at the bottom of the borehole is maintained during interruption in circulation of the said fluid by any suitable valves which trap a quantity of the fluid, thereby maintaining the column of wall-coating liquid. Various arrangements and combination of valves may be used. In one specific embodiment the downflow passage has a check valve and the up-flow passage has a positively-actuated valve, such as a slave valve actuated by operation of the check valve to open and close therewith, or actuated by means responsive to the force of the drill bit against the borehole bottom to open when the weight of drill string rests on the bit and to open when the drill bit is retracted. Similarly, both valves may be actuated in response to the force of the drill bit on the borehole bottom.

The drilling fluid is preferably an aqueous liquid substantially free of suspended solids; however, clear liquids, such as liquefied hydrocarbons from C_5 - C_{12} , gasoline, kerosene and gas oil, as well as water, may be used and, with valves capable of withstanding the pressure differentials, the drilling fluid may be a gas or a mixture of liquid and gas where the gas is air or a non-oxidizing gas, such as nitrogen, or carbon dioxide, or natural gas which is inert with respect to the material encountered in the well.

The advantage of the invention is that the considerably higher bit penetration rates inherent in drilling with a low-solids content fluid are attained, the borehole is stabilized against damage or the influx of fluids contained in the earth formations, and loss of drilling fluid is greatly reduced; yet the complications of using a packer with means for rotating the drill string are avoided.

The invention will be further described with reference to the accompanying drawings forming a part of this specification and showing certain preferred embodiments, wherein:

FIGURE 1 is a vertical sectional view of a borehole, the parts being shown in elevation and some surface equipment being shown diagrammatically;

FIGURE 2 is an enlarged vertical sectional view through a part of the drill string, showing the valves therein;

FIGURE 3 is a fragmentary view of the surface equipment for circulating the drilling fluid, showing a modified control arrangement; and

FIGURE 4 is a fragmentary view of the surface equipment showing another modified control arrangement.

Referring to FIGURES 1 and 2, a dual drill string indicated generally at 10 extends into a borehole 11 and is connected at the top to a dual-passage kelly 12 which rises through a rotary table 13. The top of the kelly is secured to a swivel 14 which has a bail 15, the bail and top part of the swivel being rotatable with respect to the kelly. The swivel has an inlet pipe 16 and a discharge pipe 17 which are in communication, through separate passages through the swivel, respectively with an annular down-flow passage 18 and a central up-flow passage 19 in the dual drill string. The swivel may be of any suitable design, e.g., its passages may be concentric and formed as shown in the U.S. patent to Grable, No. 2,657,016, October 27, 1953.

The drill string comprises a plurality of terminally coupled dual drill pipes, each including, in the embodiment shown, an outer pipe 20 and a concentric inner pipe 21, maintained in spaced relation by radial spiders 22. The sections have threaded connections at 23 and 24. The lowermost section 20a, known as a drill collar, carries on the central pipe a drill bit of any desired type, e.g., including a holder 25 and toothed frusto-conical rollers 26. A turbo-drill could be substituted. The up-flow passage 27 between the concentric pipes communicates directly with the space adjacent to the bit and annular space of the borehole surrounding the drill collar.

Valve means for shutting off both passages are provided in the drill string, preferably in the lower part thereof, e.g., the drill collar 24 or a special valve section 28 above the drill collar. In the embodiment shown the section 28 is formed with passages which define, at the top, an outer down-flow passage 29 which leads into a central passage 30, the latter continuing through a transverse portion which forms a downwardly directed valve seat 31 for a check valve 32. The down-flow passage continues through a dependent, central, threadedly attached tube 33. At the top is a central up-flow tube 34 which is threaded at its bottom to a valve housing 35 which is secured by a snap ring 35a. The housing 35 provides a valve seat 36 for receiving a slave valve 37 which is fixed to a valve stem 38 to which the check valve 32 is fixed and which reciprocates in a partition wall 39. A compression spring 40 acts between the valve 37 and plate 39 to urge both valves to closed position. The valve housing communicates, through a lateral port, with an outer up-flow passage 41.

Although one specific valve arrangement was shown, for purposes of illustration, either or both valves can be actuated by other means, e.g., they can be normally opened and closed by the downward motion of a vertically reciprocable bit relative to the drill collar when the drill string is raised off the borehole bottom. Such a construction is shown, for example, in the copending application of W. E. Bingman, Ser. No. 295,095, filed July 15, 1963 and now abandoned.

The top of the borehole may have a casing 42 and the annulus surrounding the dual drill string contains a column of a suitable wall-coating liquid 43, such as mud, which preferably contains weighting materials and filter loss control agents for protecting the borehole wall. This column of liquid is preferably extended to a surface location and weighted to a density such that its hydrostatic head equals or slightly exceeds the pressures of the fluids in the earth formation enumerated by the borehole.

A fast-drilling fluid, such as clear water, is supplied to the inlet pipe 16 from a sump 44 via a pipe 45 and a pump or compressor 46, driven by a motor 47. The pump may, for example, be of a centrifugal or positive displacement type. The drilling fluid, laden with cuttings, is discharged from the pipe 17 to a separating tank 48 which may have a solids outlet 49, normally closed by a gate 50 so as to maintain the tank under pressure. Clean drilling fluid may be discharged through a pressure-regulating valve 51. When the fast-drilling fluid is a liquid it is preferably flowed via a pipe 52 to the sump 44 and

recirculated. This sump may be open or operated at superatmospheric pressure. Although the back-pressure valve 51 is shown downstream of the separating tank 48, this is not essential, and the coatings can be separated at atmospheric pressure.

Suitable venting means are provided to relieve the pressure of the drilling fluid prior to disconnecting the kelly. Especially when the drilling fluid is a liquid it is desirable to direct vented fluid into the sump 44. To this end there are vent valves 53 and 54, placed in ducts 55 and 56 interconnecting the pipe 45 and the outlet from the tank 48, respectively, to the sump.

According to one embodiment for determining the relation of the bottom pressure of said column of wall-coating liquid to the bottom-hole pressure of the circulating, fast-drilling fluid at the bottom of the borehole, there is provided a liquid-level measuring device, such as a float 57, movably mounted in a level-responsive controller 58. The latter emits a signal via a pneumatic or electrical control line 59 representing changes in the liquid level.

Control of the pressure at the inlet to the channel 27, i.e., in the part of the fast-drilling fluid which has a pressure equalling the bottom pressure of the wall-coating liquid is, in this embodiment, effected by controlling the back-pressure by means of the valve 51. To this end, this valve is provided with an operator 60 which decreases the back pressure when the level measured by the float 57 rises and increases the back pressure upon a fall in level. The action is as follows:

The drilling fluid is subject to two principal pressure changes, both of which change with the flow rates: ΔP_1 is the pressure change from the discharge of the pump 46 (source pressure P_s) to the outside of the bit 26 (bottom pressure P_b), and ΔP_2 is the pressure change from the outside of the bit to the inlet to the valve 51 (outlet pressure P_0). These changes are herein treated as pressure drops. However, in the preferred case wherein the drilling fluid is a liquid, the pressure change due to gravity exceeds the drop due to friction; and ΔP_1 is then a negative quantity. Thus $P_b = P_s - \Delta P_1 = P_0 + \Delta P_2$. It is desired that P_b be equal to the bottom pressure of the liquid in the annulus. Adjusting the valve 51 to increase P_0 , the back pressure, increases both P_b and P_s . An increase in P_s can, with many types of pumps and compressors, cause a decrease in the flow rate, thereby decreasing both ΔP_1 and ΔP_2 ; this makes it necessary often to increase P_0 by an amount greater than the desired increase in P_b .

According to an optional feature, the control characteristics may be determined by a pump 46 of a type, such as a positive displacement pump, which delivers drilling fluid at a substantially constant rate. Alternatively, a more or less constant delivery rate can be assured by providing a flow-measuring device, such as an orifice unit 61 in the pipe 45, determining the flow rate in a flow controller 62, and regulating the speed of the motor 47 through a control line 63.

In an alternative control arrangement, shown in FIGURE 3, the signal from the level-responsive controller 58 is transmitted via a line 64 to the motor 47, to vary the delivery rate of the pump. In this embodiment, a fall in the liquid level, calling for an increase in P_b , results in an increase in the speed of the motor 47, and of the source pressure P_s . When the back-pressure valve 51 is not provided with an operator, but is set for a constant back-pressure P_0 , this results in an increase in the circulation rate, whereby both ΔP_1 and ΔP_2 increase. It may be noted that, as an example of the setting of the valve 51, it may be at the extreme position of fully open, so that P_0 is atmospheric. It is, in general, desirable to make P_0 as low as possible. A positive back-pressure will often be required, particularly when drilling at shallow depths, especially when the drilling fluid is a gas and the compressor capacity is insufficient to attain the flow rates required to bring ΔP_2 to a sufficient value. However, the back pressure is not usually large, as when the higher density of

the wall-coating liquid more or less balances the friction in the drilling fluid per unit of depth.

According to an optional feature, the valve 51 is provided with an operator 65, and the flow rate through the pipe 45 is measured by any suitable device, such as the above-mentioned orifice device 61 and flow controller 62. Flow measurement is made in the conduit 45 for the purpose of operating on clean fluid. The valve 51 is controlled by the flow-controller 62 via a control line 66 so as to maintain the flow rate more or less constant. In this arrangement an increase in the motor speed not only increases the source pressure P_s but, by increasing the drilling fluid flow rate, causes the valve 51 to be adjusted to increase the back pressure P_0 . ΔP_1 and ΔP_2 then vary only by small amounts.

In the third embodiment shown in FIGURE 4, the top of the column of wall-coating liquid 43 is subjected to pressure by enclosing the top of the casing 42 by a cover fitting 67 having a removable annular plate 68. The latter carries, in sealed relation a rotatable sleeve 69 within which the kelly 12 can slide vertically in sealed relation. Within the sealed space is a level-sensing device 70, which operates from a level-responsive controller 71. The said space is further connected by a pipe 72 to a vent valve 73 and an inlet valve 74, these valves having operators 75 and 76 controlled by the controller 71 via control lines 77 and 78, respectively. The valve 74 is connected to a source of gas, e.g., air, under pressure, represented by a pressure tank 79 provided with a compressor 80. Make-up wall-coating liquid can be admitted through a pipe 81 and normally closed by a valve 82.

In operation, when the pressure of the fast-drilling fluid at the bottom of the borehole exceeds the bottom-hole pressure of the column of wall-coating liquid 43, the top level thereof rises. This causes the controller 71 to emit a signal through the line 78 to move the valve 74 to a more open position and admit more gas under pressure into the sealed space. This raises the pressure and depresses the column of liquid, until the level is re-established and the signal in the line 78 ceases. Conversely, a fall in the level causes the pressure to be reduced by venting gas through the valve 73 in response to a signal in the line 77.

It is evident that the controller 71 can be used in conjunction with the control systems of FIGURE 1 or 3, either in lieu of or together with the specific arrangement shown in FIGURE 4.

When it is desired to add a length of drill pipe, the motor 47 is stopped, and the vent valves 53 and 54 are opened. This causes the check valve 32 and slave valve 37 to close and traps drilling fluid below the valves. The kelly and drill string are raised by the bail 15, causing a slight drop in the column of wall-coating liquid. The kelly 12 is uncoupled from the uppermost section of drill string. A new section of dual drill pipe having been added and the kelly reconnected, the drill string is lowered, vent valves 53 and 54 are closed, and the motor 46 is started. This re-opens the valves 32 and 37. The bottom of the borehole is initially filled with liquid from the column 43, and this liquid is entrained by the circulating drilling fluid until the condition shown in FIGURE 1 is restored. It is, of course, necessary to add liquid to the column 43 during start-up and from time to time, both to replenish liquid which is lost into the formation and carried up with the drilling fluid, and to augment its supply as the depth of the borehole increases.

By way of a specific example, when drilling at a depth of 10,000 ft., using an annular column of liquid consisting of mud with density of 74 lbs. per cu. ft., the hydrostatic head of the wall-coating liquid is 5,130 p.s.i. During drilling, clear water is supplied at a source pressure P_s of 1,600 p.s.i. and the back-pressure P_0 is maintained at a value determined by the valve 51, e.g., about 20 p.s.i. ΔP_1 is then —2730 p.s.i. and ΔP_2 is 5,110 p.s.i. The pressure at the bottom of the downflow passage just above the

bit is about 5,330 p.s.i. When circulation is stopped and the valves 32 and 37 are closed, the pressures above these valves are atmospheric and the pressure within the bore, just above the bit, as well as outside the bit, is 5,130 p.s.i. When the drill string is raised the latter pressure falls by an amount equal to the head of the liquid for the distance that the bit is retracted.

I claim as my invention:

1. Method of extending the depth of a borehole in the earth by drilling which comprises the steps of:

- (a) rotating a drill bit in engagement with the bottom of said borehole at the end of a dual drill string having separate up-flow and down-flow passages,
- (b) establishing and maintaining an annular substantially stationary column of liquid that contains wall-coating material between the wall of the borehole and said dual drill string at a pressure at least sufficient to balance substantially the pressure of fluids in the earth formation encountered by the borehole, the bottom of said up-flow passage being in communication with the bottom of said liquid column and with the space at the bottom of the borehole adjoining the drill bit,
- (c) simultaneously with the rotation of said drill bit, flowing a substantially solids-free drilling fluid from a source at superatmospheric pressure downwards through said down-flow passage and the drill bit and thence, laden with formation cuttings, upward through said up-flow passage, and
- (d) controlling the pressure of the drilling fluid in said space to balance the bottom pressure of said column of liquid.

2. Method as defined in claim 1 wherein said pressure is controlled by steps including:

- (a) measuring the relation of the pressure of the drilling fluid at the bore hole bottom to the said bottom pressure of the column of liquid, and
- (b) regulating the flow rate of said drilling fluid in accordance with the measured relation.

3. Method as defined in claim 2 wherein said pressure relation is measured by measuring the level of the top of said column of liquid.

4. Method as defined in claim 1 wherein said pressure is controlled by steps including:

- (a) measuring the relation of the pressure of the drilling fluid at the borehole bottom to said bottom pressure of the column of liquid, and
- (b) regulating the back-pressure at the discharge of said up-flow passage in accordance with the measured pressure relation.

5. Method as defined in claim 4 wherein said pressure relation is measured by measuring the level of the top of said column of liquid.

6. Method as defined in claim 1 wherein said pressure is controlled by steps including:

- (a) measuring the relation of the pressure of the drilling fluid at the bottom to said bottom pressure of the column of liquid,
- (b) applying a controlled pressure to the top of said column of liquid, and

(c) varying the said controlled pressure in accordance with the measured pressure relation.

7. Method as defined in claim 6 wherein said pressure relation is measured by measuring the level of the top of said column of liquid.

8. Method as defined in claim 1 wherein said drilling fluid is a substantially clear water.

9. Method of extending the depth of a borehole in the earth by drilling which comprises the steps of:

- (a) rotating a drill bit in engagement with the bottom of said borehole at the end of a dual drill string having separate up-flow and down-flow passages,
- (b) establishing and maintaining an annular column of liquid between the wall of the borehole and said dual drill string at a pressure at least sufficient to balance substantially the pressure of fluids in the earth formation encountered by the borehole, the bottom of said up-flow passage being in communication with the bottom of said liquid column and with the space at the bottom of the borehole adjoining the drill bit,
- (c) simultaneously with the rotation of said drill bit, flowing a substantially solids-free drilling fluid from a source at superatmospheric pressure downwards through said down-flow passage and the drill bit and thence, laden with formation cuttings, upward through said up-flow passage,
- (d) controlling the pressure of the drilling fluid in said space to balance the bottom pressure of said column of liquid during said rotation of the bit; and
- (e) maintaining the pressure of the drilling fluid in said space sufficient to balance the bottom pressure of said column of liquid while increasing the length of the drill string by the steps of

- (1) closing both said passages in the drill string at a level below the top thereof to discontinue the flow of drilling fluid,
- (2) disconnecting the drill string from said source and opening the upper ends of said passages,
- (3) coupling an additional length of dual drill string to the top of the first-mentioned drill string, and
- (4) connecting said source to the top of the added length of drill string, re-opening said passages, and resuming the flow of drilling fluid.

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