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(57) Abrégé(suite)/Abstract(continued):
excavating the subterranean formation. A downhole motor is adapted for receiving electrical power from a cable extending into the subterranean formation. A downhole pump is powered by the motor and is configured for reverse circulating drilling fluid from the annular space surrounding the drill pipe to the interior space of the drill pipe. The drilling fluid is pumped upwards in the drill pipe by the downhole pump to carry excavated cuttings upwards through the interior space of the drill pipe.
Title: APPARATUS AND PROCESS FOR DRILLING A BOREHOLE IN A SUBTERRANEAN FORMATION

Abstract: An apparatus and process is disclosed for drilling a borehole into a subterranean formation with reverse circulation of drilling fluid. A tubular drill pipe extends into a subterranean formation. A bottom hole assembly connected to the drill pipe includes a drill bit for excavating the subterranean formation. A downhole motor is adapted for receiving electrical power from a cable extending into the subterranean formation. A downhole pump is powered by the motor and is configured for reverse circulating the drilling fluid from the annular space surrounding the drill pipe to the interior space of the drill pipe. The drilling fluid is pumped upwards in the drill pipe by the downhole pump to carry excavated cuttings upwards through the interior space of the drill pipe.
Declarations under Rule 4.17:

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

— as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))
APPARATUS AND PROCESS FOR DRILLING A BOREHOLE IN A SUBTERRANEAN FORMATION

CROSS REFERENCE TO RELATED APPLICATIONS

[001] This application claims priority to and relates to an earlier filed United States provisional application S.N. 61/556,986 which was filed in the United States Patent and Trademark Office on November 8, 2011.

FIELD OF THE INVENTION

[002] The field of the invention is directed to apparatus and processes for drilling a well by employing reverse circulation of drilling fluid.

BACKGROUND OF THE INVENTION

[003] When conducting drilling to construct deep wells, the pressure of drilling fluid or drilling mud that is pumped down from the surface and into the open hole of the formation may be quite high. It is usually advisable to maintain a fluid/mud weight above the formation pressure to prevent gas “kicks” or influxes from the wellbore. Furthermore, the friction pressure of pumping into a drill string may be quite substantial. Thus, pressure is required to be applied to cause the drilling fluid and cuttings to flow through the drill string, out into the open hole, and up the annulus at an adequate rate.

[004] Too much pressure applied in this process can cause other problems. That is, such fluid pressure applied at the surface also is applied to the open hole of the subterranean formation. High pressures applied to an open hole of a formation may cause the formation to fracture, with a subsequent sudden loss of drilling fluid into the formation. Such a sudden loss of drilling fluid into the formation may have severe consequences. In some instances, there is a very narrow “window” of pressure that may properly be applied in the drilling of a well without exerting too much or too little pressure. That is, excess applied pressure can fracture the formation. On the other hand, inadequate pressure may not properly carry the drilled cuttings up the annulus to the surface. Thus, a pressure “window” exists that engineers must observe in planning the pressure to exert while drilling a well.

[005] Sometimes, lost circulation materials or pills are applied into drilling fluid, and such materials travel out of the bit and adhere to the formation to prevent such fluid loss into the formation. But, such materials may damage the formation and reduce the ability of the
formation subsequently to produce oil and gas into the wellbore during production operations. Such damage to the formation is undesirable, and therefore the use of such materials is not always advisable.

[006] Operating within the mud weight “window” allows engineers to improve drilling efficiency and set casing at the best possible depth. If casing is set too shallow, well construction cost increases and well depth is limited. Sometimes, this may cause the production rate to be compromised. In other instances, the target formation may not be accessible. Techniques that widen or open the window to be employed are desirable.

[007] Conventional drilling employs rotary rock bits to compress the rock, causing the rock to fracture into cuttings. Pulsed power drilling, however, is a method of constructing a wellbore by applying voltage into the rock of a formation, which causes the rock to fail in tension rather than compression. High voltage pulses employed in pulsed power drilling may cause an electrical arc in the rock that causes the rock to break in an electro-crushing process. One illustration of such a drilling technique is described in U.S. Patent Publication No. US 2009/0050371 A1 to Moeny et al. (See “Moeny”). In such applications, drilling fluid flows down the drill string and out through passages in the bit near the electrodes and then up the outside of the drilling apparatus within the annulus to bring rock cuttings to the surface. (US 2009/0050371 A1, paragraph 0109).

[008] A technique or apparatus that is capable of reducing the risk of formation damage and allowing the use of a reduced bottom hole pressure in the drilling of deep wells would be very desirable. A drilling technique that is capable of allow cuttings to be brought to the surface using a reduced flow rate of flow of drilling fluid is highly desirable.

[009] The invention is directed to improved drilling apparatus and processes.

SUMMARY OF THE INVENTION

[010] An apparatus and process for drilling a borehole into a subterranean formation with reverse circulation of drilling fluid is provided. The apparatus employs a means to transfer a supply of electrical power downhole either from a cable running down the bottom hole assembly components or the use of “wired drill pipe” with the capability to conduct electrical energy downhole with electrical conductors incorporated into the drill pipe body. The apparatus comprises a tubular drill pipe extending into the subterranean formation, the drill pipe having an interior space and an annular space on the exterior of the drill pipe. A bottom
hole assembly is connected to the drill pipe, the bottom hole assembly comprising a bit to excavate the subterranean formation to form cuttings. A downhole motor is provided, the downhole motor being adapted for receiving electrical power from either the cable extending into the subterranean formation or the use of wired drill pipe supplying the electrical power. A downhole pump is powered by the motor, the downhole pump being configured for reverse circulating drilling fluid and cuttings upwards through the interior space of the drill pipe.

[0011] In one embodiment of the invention, the apparatus comprises a mechanism for removing excavated cuttings from the drilling fluid and then recirculating the drilling fluid downwards through the annular space on the exterior of the drill pipe. The bit may comprise a rotary rock bit. In other applications, the apparatus may have one or more electrodes configured for applying a pulsed voltage to excavate the formation with applied pulsed power. The downhole pump may be a positive displacement pump. In some applications, such as certain pulsed power bit applications, the bit may not rotate.

[0012] In some embodiments of the invention, the cross sectional area of the interior space of the drill pipe is less than the cross sectional area of the annular space, thereby minimizing the drilling fluid flow rate that is required to carry excavated cuttings upwards through the interior space of the drill pipe.

[0013] A downhole generator may be provided, in one embodiment of the invention, for applying pulsed power to the bit. The drilling fluid may comprise an electrically insulating formulation having a low level of electrical conductivity. In some applications, the drilling fluid comprises a carbon-based material.

[0014] A process is disclosed for drilling a borehole into a subterranean formation with reverse circulation of drilling fluid. The process comprises extending a tubular drill pipe into the subterranean formation, the drill pipe having an interior space and an annular space on the exterior of the drill pipe, the drill pipe having a proximal end near the top of the wellbore and a distal end with an attached bottom hole assembly. An electrical cable or wired drill pipe extends into the well to supply power to downhole apparatus. The bottom hole assembly may comprise a drilling bit. A pump and a motor are provided within the borehole, the pump being powered by the motor. The pump is in fluid communication with the interior of the drill pipe. It may be possible to circulate drilling fluid from the annular space to the interior space of the drill pipe. Drilling fluid with cuttings may be pumped upwards through the interior space of the drill pipe. In some embodiments of invention, excavated cuttings may be removed from the drilling fluid near the top of the wellbore and re-circulated.
downward through the annular space. A control system may be employed to regulate the pulse repetition rate of the electrodes.

**BRIEF DESCRIPTION OF THE FIGURES**

[0015] Figures are provided to illustrate specific embodiments of the invention, but the invention is not limited to only the embodiments illustrated in the Figures, but may extend to other variations that would be appreciated by a person of skill in the art of drilling.

[0016] **Fig. 1** illustrates a schematic of one embodiment of the invention that employs a pulsed power drilling bit;

**Fig. 1A** shows a perspective view of the pulsed power drilling bit employed in the apparatus of **Fig. 1**;

**Fig. 2** shows an alternate embodiment of the invention with a drilling apparatus that employs a rotary rock drill bit; and

**Fig. 2A** shows a more detailed view of the rotary rock drill bit.

**DETAILED DESCRIPTION OF THE INVENTION**

[0017] The present invention may employ pulsed power drilling apparatus or rotary rock drilling apparatus with reverse circulation drilling. Reverse circulation drilling refers to drilling wherein the drilling fluid is passed down the annulus to the outside of the drill string or drill pipe, and then circulated upwards through the drill pipe towards the upper end of the wellbore.

[0018] As used herein, "drilling" is defined as excavating or otherwise breaking and driving through a subterranean formation substrate. As used herein, "bit" and "drill bit" are defined as the working portion or end of a tool for providing cutting, drilling, boring, or breaking action on a substrate, such as rock. As used herein, the term "pulsed power" is that which results when electrical energy is stored (e.g., in a capacitor or inductor) and then released so that a pulse of current at high peak power is produced.

[0019] Referring to **Fig. 1**, a drilling apparatus 18 is disclosed for entry into a wellbore 19 of a subterranean formation 20. A tubular drill pipe 22 is provided with an interior space 24 inside the pipe, and an annular space 26 outside the drill pipe 22. A bottom hole assembly 28 is connected to the drill pipe 22 and is located, during drilling, at the lower portion of the wellbore 19. A bit 30 is configured to contact and break the rock of subterranean formation 20. **Fig. 1** shows a pulsed power bit 30, but other bits may be employed as further described
Drilling fluid is circulated in reverse flow direction, such that the fluid with cuttings flows along direction arrow 40, and then along direction arrow 32. Cuttings are dislodged by the bit 30 and transferred by way of drilling fluid along arrow 32 to upwards in the wellbore 19. A cable 36 is provided for providing a steady source of electricity to downhole motor 34, which drives downhole pump 38 to move the drilling fluid.

**Fig. 1A** shows a perspective view of the bit 30, which in the embodiment of Fig. 1A is a pulsed power bit 30. For drilling larger holes, a conical bit may be employed, especially if controlling the direction of the hole is a primary concern. Such a bit 30 may comprise one or more sets of electrodes for creating the electro-crushing arcs and may optionally comprise mechanical teeth to assist the electro-crushing process. One embodiment of the conical electro-crushing bit has a single set of electrodes arranged coaxially on the bit, as shown in **Fig. 2A**. In this embodiment, conical bit 30 comprises a center electrode 48, the surrounding electrode 44, the housing 42 and mechanical teeth 46 for drilling the rock. Either or both electrodes may be compressible. The surrounding electrode may have mechanical cutting teeth 50 incorporated into the surface to smooth over the rough rock texture produced by the electro-crushing process. In this particular embodiment of the invention, the inner portion of the hole is drilled by the electro-crushing portion (i.e., electrodes 48 and 44) of the bit 30, and the outer portion of the hole is drilled by mechanical teeth 46. This results in high drilling rates, because the mechanical teeth have good drilling efficiency at high velocity near the perimeter of the bit, but very low efficiency at low velocity near the center of the bit. The geometrical arrangement of the center electrode 48 to the ground ring electrode 44 is conical. It should be recognized that many types of pulsed power bit configurations could be employed in the practice of the invention, and the invention is not limited to only the configuration shown in **Fig. 1A**. U.S. Patent Publication No. US 2009/005031 A1 to Moeny et al. (See “Moeny”) describes various embodiments and technical specifications that may be employed in the application of pulsed power drilling, and is incorporated herein by reference. Further, other pulsed power drilling apparatus and techniques may be employed. Other embodiments of the invention may employ rotary rock bits that do not employ pulsed power, as further described herein in connection with **Figs 2 and 2A**.

**Fig. 2** shows an alternate embodiment of the invention of drilling apparatus 60 that employs a rotary rock bit to break the rock to form a borehole by compression upon the rock within subterranean formation 77. In this embodiment, a tubular drill pipe 52 comprises an interior space 72 and an annular space 70 on the exterior of the drill pipe 52. A power cable
extends into the wellbore 53 and supplied electrical power to downhole motor 56, which drives downhole pump 58, which transports drilling fluid. A bottom hole assembly 62 is positioned upon the end of drill pipe 52, and comprises a bit 64. In the embodiment of Fig. 2, the bit 64 is a rotary rock bit. A reverse circulation process is employed to circulate the drilling fluid along direction arrow 66 and then into the interior space 72 of the drill pipe 52. Drilling fluid picks up rock cuttings generated by bit 64 and transports them along direction arrow 68 and arrow 74 upwards in drill pipe 52 in a reverse circulation flow direction.

[0022] Fig. 2A illustrates rotary rock bit 64, which in this particular example is a tricone style bit 64. The bit 64 has teeth 76 for contact with rock of the subterranean formation 77.

[0023] As described previously, in the first illustrated embodiment of the present invention, as shown in Figs. 1 and 1A, a drill bit is provided upon which is disposed one or more sets of electrodes. In this particular embodiment, the electrodes are disposed so that a gap is formed between them and the electrodes are disposed on the drill bit so that they are oriented along a face of the drill bit. Electrodes between which an electrical current passes through a mineral substrate (e.g., rock) are not on opposite sides of the rock. Also, in this embodiment, it is not necessary that all electrodes touch the mineral substrate as the current is being applied.

[0024] The electrodes of the embodiments shown in Figs. 1-1A are disposed on a bit and arranged such that electro-crushing arcs are created in the rock. High voltage pulses are applied repetitively to the bit to create repetitive electro-crushing excavation events. Electro-crushing drilling can be accomplished, for example, with a flat-end cylindrical bit with one or more electrode sets. These electrodes can be arranged in a coaxial configuration, as one example.

[0025] The electrocrushing drilling process does not require rotation of the bit, but in some instances bit rotation may be desirable. The electro-crushing drilling process is capable of excavating the hole beyond the edges of the bit without the need of mechanical teeth. In addition, by arranging many electrode sets at the front of the bit and varying the pulse repetition rate or pulse energy to different electrode sets.

[0026] The invention may be provided in other arrangements not specifically shown or described in this specification but within the general spirit and scope of the invention.
CLAIMS

What we claim is:

1. An apparatus for drilling a borehole into a subterranean formation with reverse circulation of drilling fluid, the apparatus comprising:
   (a) a tubular drill pipe extending into the subterranean formation, the drill pipe having an interior space and an annular space on the exterior of the drill pipe;
   (b) a bottom hole assembly connected to the drill pipe, the bottom hole assembly comprising a bit to excavate the subterranean formation to form cuttings;
   (c) a downhole motor, the downhole motor being adapted for receiving electrical power from a cable extending into the subterranean formation; and
   (d) a downhole pump powered by the motor, the downhole pump being configured for reverse circulating drilling fluid and cuttings upwards through the interior space of the drill pipe.

2. The apparatus of claim 1 further comprising a mechanism for removing the excavated cuttings from the drilling fluid and recirculating the drilling fluid downwards through the annular space on the exterior of the drill pipe.

3. The apparatus of claim 1 wherein the bit comprises a rotary rock bit.

4. The apparatus of claim 1 wherein the bit comprises one or more electrodes configured for applying a pulsed voltage to excavate the formation with applied pulsed power.

5. The apparatus of claim 1 wherein the downhole pump is a positive displacement pump.

6. The apparatus of claim 1 wherein the bit does not rotate.

7. The apparatus of claim 1 wherein the cross sectional area of the interior space of the drill pipe is less than the cross sectional area of the annular space, thereby minimizing the drilling fluid flow rate that is required to carry excavated cuttings upwards through the interior space of the drill pipe.
8. The apparatus of claim 1 further comprising a downhole generator for applying pulsed power to the bit.

9. The apparatus of claim 1 wherein the drilling fluid comprises an electrically insulating formulation having a low level of electrical conductivity.

10. The apparatus of claim 9 wherein the drilling fluid comprises a carbon-based material.

11. A process for drilling a borehole into a subterranean formation with reverse circulation of drilling fluid, the process comprising the steps of:
   (a) extending a tubular drill pipe into the subterranean formation, the drill pipe having an interior space and an annular space on the exterior of the drill pipe, the drill pipe having a proximal end near the top of the wellbore and a distal end with an attached bottom hole assembly, the bottom hole assembly comprising a bit;
   (b) excavating the formation with the bit to form cuttings;
   (c) providing a pump and a motor in the borehole, the pump being powered by the motor, the pump being in fluid communication with the interior of the drill pipe;
   (d) circulating drilling fluid from the annular space to the interior space of the drill pipe; and
   (e) pumping drilling fluid with cuttings upwards through the interior space of the drill pipe.

12. The process of claim 11 further comprising the step of:
   (f) removing excavated cuttings from the drilling fluid near the top of the wellbore; and
   (g) recirculating the drilling fluid downward through the annular space.

13. The process of claim 11 wherein the bit comprises one or more electrodes, further wherein the excavating step (b) comprises applying a pulsed voltage to one or more electrodes to excavate the subterranean formation.

14. The process of claim 11 wherein the pump is a positive displacement pump.

15. The process of claim 11 wherein the bit is a rotary rock bit, the process comprising the additional step of rotating the rotary rock bit to excavate the formation.
16. The process of claim 11 wherein the cross sectional area of the interior space of the drill pipe is less than the cross sectional area of the annular space, thereby minimizing the drilling fluid flow rate required to carry excavated cuttings upwards through the interior space of the drill pipe.

17. The process of claim 13 further comprising a downhole generator for applying pulsed voltage to the bit.

18. The process of claim 13 wherein the drilling fluid comprises an electrically insulating formulation having a low level of electrical conductivity.

19. The process of claim 18 wherein the drilling fluid comprises a carbon-based material.

20. The process of claim 13 wherein a control system is employed to regulate the pulse repetition rate of the electrodes.