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AIR DRILLING METHOD WITH FORMATION WATER SEAL-OFF

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No Drawing. Filed Nov. 28, 1961, Ser. No. 155,894
18 Claims. (Cl. 175-71)

This invention is concerned with an improved method of drilling earth boreholes by rotary drilling wherein a gas rather than a liquid is employed as the circulation medium for carrying particles of dislodged earth to the surface. More specifically, the invention is concerned with sealing off formation water encountered while air drilling. The term "air drilling" as used herein refers generically to the use of any suitable gas as a circulation fluid, although air or natural gas is usually employed. The advantages of air drilling, compared with the more conventional use of liquid drilling fluids, include a higher penetration rate, longer bit life, and a cleaner borehole. A borehole uncontaminated by drilling muds is desirable because it facilitates the detection of oil-bearing formations and also improves the productivity of a completed well.

A major problem, however, which detracts somewhat from the above advantages is the influx of formation water encountered while drilling. The water causes a conglomeration of bit cuttings which interferes both with the action of the drill bit and with the circulation of air within the borehole. Moreover, if excessive amounts of water invade the borehole, the hydrostatic head may become great enough to prevent air circulation and thereby force an abandonment of air drilling and a conversion to liquid drilling fluids. In accordance with this invention, when formation water is encountered during rotary air drilling the circulation of air is interrupted and, with continued drilling, a liquid is circulated which is capable of sealing off the water-bearing formation. Once the water-bearing formation has been sealed, the excess sealing liquid is removed from the borehole and normal air drilling, with its resultant benefits, is resumed.

The sealing liquid circulated after interruption of air drilling must be a high density fluid such its hydrostatic head exerted against the borehole wall is greater than the formation pressure, whereby the liquid is driven into the pores of the formation. Also, the liquid must have an adequate viscosity in order to lift bit cuttings out of the hole. Third, the liquid must be characterized by a high filter loss so that it readily penetrates a porous formation. Fourth, the liquid must react within the aquifer to form a solid barrier capable of withstanding back-pressures upon resumed air drilling, and thereby stop water invasion into the borehole.

Examples of salts, which in aqueous solution form liquids that meet the specifications named are: (1) Sodium silicate which has a specific gravity of 2.6 in the pure state or in a 35% aqueous solution for example weighs 12.45 pounds per gallon. It reacts with calcium salts in the connate water to form a solid precipitate which seals off the formation; (2) Trisodium phosphate, (3) Sodium carbonate; (4) Sodium arsenate; and (5) Sodium sulfate. Other alkali metals, or ammonium ions, may be substituted for sodium. These examples are not intended to fix the scope of the invention. That is, any soluble salt, the anion of which forms an insoluble precipitate with the cations of dissolved salts in the formation water, is suitable.

The formation waters encountered normally contain substantial quantities of dissolved salts. These salts include alkaline-earth metal salts as well as salts of iron, copper and aluminum, each of which is capable of form-

ing a suitable precipitate with silicate, carbonate, arsenate, or phosphate ions. However, it is contemplated that when a formation water tests unusually low in ions capable of forming such a precipitate, a step of circulating one or more of these ions into the wellbore will precede the circulation of the sealing fluid.

Trisodium phosphate forms a 10% solution (saturated) in water at 20° C. which weighs 9.23 lbs./gallon. It reacts with salts in the formation water to form alkaline-earth metal phosphates, as well as iron, copper and aluminum phosphates, all of which are sufficiently insoluble in water to seal off the pores of the water-bearing formation.

Sodium carbonate forms an 18% solution in water at 20° C. which weighs 9.92 lbs./gallon. The alkaline-earth carbonates and the carbonates of iron and copper which form within the aquifer are all sufficiently insoluble to seal off the formation.

Sodium sulfate heptahydrate forms a 30% solution (based on anhydrous form) at 20° C. which weighs 10.8 pounds per gallon. Although copper, iron, and aluminum sulfates are soluble, calcium sulfate is sufficiently insoluble; adequate plugging therefore results.

Sodium orthoarsenate dodecahydrate forms a 28% solution at 17° C., weighing 9.67 pounds per gallon. The alkaline-earth arsenates and the arsenates of aluminum, copper and iron are each sufficiently insoluble to cause the desired plugging.

Prior art methods of formation water shut-off have required first of all that the air drilling be continued, at reduced efficiency, in traversing the water sand, with the probability that air-drilling may have to be abandoned altogether. Next, with a loss of valuable drilling time, the point of water entry must be determined by careful logging techniques. The sealing equipment such as drill pipe straddle packers must be carefully placed to isolate the interval of water influx, followed by the injection of sealant chemicals. The method of this invention eliminates the need for a careful determination of exactly where the water influx is located, and eliminates the need for packing equipment and procedures, because the entire borehole is filled with the sealing liquid whereby any porous, water-bearing formation is invaded and sealed. Most important, however, practically no drilling time is lost, since the sealing liquid also serves as a temporary drilling fluid.

Sodium silicate, or water glass, is the preferred species of sealing material. It is a relatively complex inorganic substance, available in various grades analyzing from $\text{Na}_2\text{O} \cdot 2\text{SiO}_2$ to $\text{Na}_2\text{O} \cdot 4\text{SiO}_2$. A less common form is sodium metasilicate, Na_2SiO_3 . Any of the various forms, including mixtures thereof, is suitable for the purposes of the invention. A specific example is a 37.3% aqueous solution, marketed by Diamond Alkali Company of Cleveland, Ohio as "Grade 33," having a density of 40° Baumé and analyzing $\text{Na}_2\text{O} : 3.3\text{SiO}_2$.

The first step of the invention is the interruption of gas circulation upon encountering formation water. Accordingly, the operator must be able to recognize the symptoms of water influx into the borehole. One such indication is a diminished return of dust and cuttings at the "blowline" or exhaust pipe. The change may be gradual or abrupt, depending primarily upon the rate of water influx. It is possible, however, that a return of dust and dry cuttings may persist even though a wet formation is being drilled. This is due to erosion and abrasion from dry uphole sections, caused by the drill string and by the air stream itself. A simple test for a water formation is to hold some dry object in the path of the blowline return, and to notice any accumulation of moisture or wet dust.

Another, more serious indication of having drilled into

water is the circulation pressure. Wet cuttings ball up at the bit, and also bridge in the wellbore, causing an increased and erratic circulation pressure. Any accumulation of water in the borehole also increases circulation pressure because of its hydrostatic head.

The second step of the invention is to establish circulation of the sealing liquid, for example aqueous sodium silicate. The changeover from air circulation to sealing liquid is normally accomplished without interrupting drilling, since the sealing liquid also serves as a drilling fluid. If, however, the water influx has caused drilling to be interrupted, it is resumed at this time. As drilling proceeds deeper into the water-bearing interval, the wall of the borehole is automatically sealed. That is, the column of silicate solution exerts a sufficient hydrostatic head at the bottom of the hole to force its way into the pores of the water-bearing formation, where it reacts with dissolved salts in the formation water to form an insoluble silicate, for example calcium silicate, which precipitates and thereby seals off the formation.

In the event that the formation water is known to contain an unusually low concentration of precipitate-forming metallic ions, or if the salt content thereof is unknown, and if analysis is inconvenient, a preliminary circulation of a salt solution is employed to ensure a subsequent formation of the sealing precipitate. For example, an aqueous solution containing from 0.1% by weight of calcium chloride up to saturation (42% at 20° C.) is suitable, with 0.2% to 20% being preferred. A 20% solution of calcium chloride weighs 9.82 pounds per gallon at 20° C., and is also suitable as a temporary drilling fluid. The lower concentrations are adequate from the standpoint of ultimately forming an effective seal; but the higher concentrations are sometimes necessary, to provide a static head great enough to cause flow into the aquifer. Any water-soluble salt may be substituted for calcium chloride, provided the metallic ion thereof is capable of forming an insoluble precipitate with the anion of the salt chosen for the sealing solution.

With continued drilling, the salt solution is circulated until substantially complete penetration of the well bore through the water-bearing formation is attained, as indicated by examination of the cuttings. The salt solution is then followed immediately by the silicate solution, which replaces it in the hole as mentioned above. Drilling is then continued with the circulation of silicate solution for a period of time sufficient to permit substantial plugging to occur, whereupon the excess sealing liquid is blown from the hole, and normal air drilling is resumed.

The salt solution containing precipitate-forming metallic ions may be circulated either before or after the sealing solution. If, for example, in drilling through a water-bearing formation using aqueous sodium silicate as drilling fluid, an inadequate seal is obtained because of a low salt content in the formation water, then a seal may nevertheless be obtained by subsequently filling the borehole with the calcium chloride solution, or other insoluble silicate-forming salt. In displacing one solution from the wellbore with the other solution, it is desirable of course to avoid any mixing of the two within the hole. Accordingly, the solutions are spaced from each other by interposing a slug of inert liquid, for example fresh water, during the displacement circulation.

It is a common practice in connection with air drilling to keep a supply of ordinary drilling mud at the drilling site, as a precautionary measure, for use in the event that circumstances should force an abandonment of air drilling. One reason for this is the need for pressure control if a high pressure formation is encountered. Since the sealing liquid of the invention is also suitable for pressure control, such mud reserves are no longer essential.

The sealing liquids of the invention are readily distinguished from ordinary aqueous drilling muds, by a comparison of filtration loss. Using the standard A.P.I. filter test, a mud is considered unsuitable, even for shallow

drilling, if it has a filter loss of more than 30 cc. of filtrate in 30 minutes. For medium-depth drilling (5,000 to 7,000 ft.) filter loss should be only 10 cc. or less in 30 minutes, and for deeper wells the maximum permissible filter loss is still less. By contrast, the sealing liquids of the invention must have a high filter loss, preferably in excess of 35 cc. in 30 minutes. Incidentally, of course, some of the sealing liquid will enter porous intervals other than water-bearing intervals, but this is not considered disadvantageous, since these sections of the wall are thereby consolidated and stabilized against erosion and abrasion.

Throughout the several steps of the invention, essentially no drilling time is lost. Lost drilling time, if any, occurs at the very onset of difficulties from having encountered a wet formation, and even this lost time can usually be avoided by an alert recognition that water has been encountered, followed by immediate use of the method disclosed herein.

An additional advantage of the method disclosed is that no need arises to isolate that portion of the borehole responsible for water influx, as is necessary in prior art methods of sealing off formation water. This means, first of all, that time need not be wasted in determining the exact depth of the water influx, and moreover, that packer equipment and methods are unnecessary. Also, in many boreholes, packing cannot be satisfactorily accomplished, where the borehole wall will not support packers.

A further advantage of the invention, compared with certain prior art methods of sealing off formation water, is that an inadvertent formation of the sealing precipitate in the drill pipe, or in the annulus surrounding the drill pipe, does not plug the pipe or cause it to become stuck in the borehole. That is, the strength of the precipitate is adequate to form a stable plug in the capillaries of an earth formation, but not of sufficient strength to plug the drill pipe or freeze it within the borehole.

The sealing liquids of the invention are not seriously contaminated by circulation into the wellbore. Accordingly, the excess solution removed from the hole after sealing one water-bearing formation is conveniently stored in tanks or pits, and is recirculated to seal the next aquifer encountered.

The method of the invention may of course be repeated upon encountering one or more additional water-bearing formations as drilling progresses. Moreover, it sometimes happens that a first water-bearing interval does not produce enough water to force interruption of air drilling since moderate amounts of water can be lifted from the borehole, and cuttings dispersed therein by the use of foaming agents and surfactants. Then, as drilling progresses, one or more additional points of water influx causes a cumulative flow greater than can be tolerated. In such instances, the invention permits a sealing-off of all such water-bearing intervals, with a single period of sealing liquid circulation. About 2 barrels per hour of water influx is the maximum rate which can be tolerated with continued air circulation.

As an illustration of the disclosed sealing method, the following experiment was carried out. A Torpedo sandstone core was subjected to a permeability test, by flowing therethrough an aqueous salt solution of the following analysis:

	P.p.m.
NaCl -----	26,000
CaCl ₂ -----	2,700
MgCl ₂ -----	830

While the core was saturated with the salt solution, a sodium silicate solution was forced into the core at 100 p.s.i.g. The silicate was "Grade 33" of the Diamond Alkali Company, as mentioned above. Then, the core was again tested for permeability, by backflowing the above salt solution therethrough. Permeability before plugging was 760 millidarcies; after plugging it was 24 millidarcies. This is a 97% reduction in permeability.

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While various embodiments of the invention have been specifically described, it is obvious that further modifications will occur to those skilled in the art. Accordingly, it is intended to include all such modifications within the scope of the following claims. For example, it is considered to be a desirable advantage that the invention permits uninterrupted drilling throughout the seal-off procedure; but it is nevertheless within the scope of the invention merely to fill the borehole with the sealing liquid and allow it to stand therein without continued drilling, once an aquifer is penetrated.

What is claimed is:

1. In the rotary drilling of earth boreholes, the improved method of operation which comprises advancing a rotary cutting tool into the formation to form granular cuttings at the bottom of the bore, conducting a high velocity continuous stream of a gas downwardly through the bore to the bottom thereof and thence again to the surface of the earth whereby cuttings are entrained in said gas stream, interrupting the flow of said gas upon encountering formation water, substituting as said circulation fluid a liquid capable of selectively sealing off said water formation while continuing said drilling, interrupting the flow of said sealing liquid upon completing the penetration of said water-bearing formation, then resuming the circulation of said gaseous fluid and continuing said drilling.

2. The method as defined by claim 1 wherein said sealing liquid comprises sodium silicate in aqueous solution.

3. In the rotary drilling of earth boreholes wherein a gas is used as a circulating fluid for carrying drilled material from the borehole and wherein a water-bearing formation is encountered, the improved method of sealing off said water-bearing formation which comprises interrupting the flow of said gaseous circulating fluid and substituting therefor a liquid circulating fluid capable of selectively sealing off said water-bearing formation, continuing said drilling throughout said water-bearing formation until the formation is sealed and thereafter resuming the circulation of said gaseous fluid.

4. A method as defined by claim 3 wherein said sealing liquid comprises an aqueous solution of sodium silicate.

5. In the rotary drilling of earth boreholes wherein a gas is used as the circulating fluid for carrying drilled material from the borehole, the improved method of operation upon encountering a water-bearing formation which comprises interrupting the circulation of said gas, substituting therefor an aqueous solution of an alkaline-earth metal salt while continuing said drilling throughout said water-bearing formation, then replacing said salt solution with a liquid capable of reacting with said salt to form a water-insoluble precipitate thereby sealing off said water-bearing formation while continuing said drilling, and thereafter resuming the circulation of said gaseous circulation fluid.

6. In the rotary drilling of earth boreholes wherein a gas is used as the circulating fluid for carrying drilled material from the borehole, the improved method of operation upon encountering a water-bearing formation which comprises interrupting the circulation of said gas when the rate of water influx exceeds two barrels per hour, replacing said gas with an aqueous solution of a salt having a precipitate-forming anion, continuing said drilling throughout said water-bearing formation, then replacing said salt solution with an aqueous solution of a salt having a cation capable of forming a precipitate with said anion, continuing said drilling until said water-bearing formation is sealed, and then resuming the circulation of said gas.

7. A method as defined by claim 6 wherein said precipitate-forming anion is selected from the group consisting of silicate, phosphate, carbonate, arsenate and sulfate, and said cation is derived from a metal selected

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from the group consisting of alkaline-earth metals, iron, copper, and aluminum.

8. In the rotary drilling of earth boreholes wherein a gas is used as the circulating fluid for carrying drilled material from the borehole, the improved method of operation upon encountering a water-bearing formation which comprises interrupting the circulation of said gas when the rate of water influx exceeds two barrels per hour, replacing said gas with an aqueous solution of a salt having a precipitate-forming cation, continuing said drilling throughout said water-bearing formation, then replacing said salt solution with an aqueous solution of a salt having an anion capable of forming a precipitate with said cation, continuing said drilling until said water-bearing formation is sealed, and then resuming the circulation of said gas.

9. A method as defined by claim 8 wherein said precipitate-forming anion is selected from the group consisting of silicate, phosphate, carbonate, arsenate and sulfate, and said cation is derived from a metal selected from the group consisting of alkaline-earth metals, iron, copper, and aluminum.

10. In the rotary drilling of earth boreholes wherein a gas is used as the circulating fluid for carrying drilled material from the borehole, the improved method of operation upon encountering a water-bearing formation which comprises interrupting the circulation of said gas when the rate of water influx exceeds two barrels per hour, substituting therefor an aqueous solution of an alkaline-earth metal salt while continuing said drilling throughout said water-bearing formation, then replacing said salt solution with a liquid comprising a water-soluble silicate salt, thereby forming a water-insoluble alkaline earth silicate to seal off said water-bearing formation while continuing said drilling, and thereafter resuming the circulation of said gaseous circulation fluid.

11. In the rotary drilling of earth boreholes wherein a gas is used as a circulating fluid for carrying drilled material from the borehole and wherein a salt water-bearing formation is encountered, the improved method of sealing off said water-bearing formation which comprises interrupting the flow of said gaseous circulating fluid and substituting therefor a liquid circulating fluid comprising a salt capable of sealing off said water-bearing formation by reacting with the salts of the formation water, continuing said drilling throughout said water-bearing formation until the formation is sealed and thereafter resuming the circulation of said gaseous fluid.

12. A method as defined by claim 11 wherein said sealing liquid comprises an aqueous solution of sodium silicate.

13. A method as defined by claim 11 wherein said sealing liquid comprises an aqueous solution of sodium phosphate.

14. A method as defined by claim 11 wherein said sealing liquid comprises an aqueous solution of sodium carbonate.

15. A method as defined by claim 11 wherein said sealing liquid comprises an aqueous solution of sodium sulfate.

16. A method as defined by claim 11 wherein said sealing liquid comprises an aqueous solution of sodium arsenate.

17. In the rotary drilling of earth boreholes wherein a gas is used as the circulating fluid for carrying drilled material from the borehole, the improved method of operation upon encountering a water-bearing formation which comprises interrupting the circulation of said gas when the rate of water influx exceeds about two barrels per hour, replacing said gas with an aqueous solution of a salt having a precipitate-forming cation, continuing said drilling throughout said water-bearing formation, removing the excess of said salt solution from the borehole, then filling said borehole with an aqueous solution of a salt having an anion capable of forming a precipitate

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with said cation, removing the excess of said last-named solution and then resuming said drilling with the circulation of a gas.

18. In the rotary drilling of earth boreholes wherein a gas is used as the circulating fluid for carrying drilled material from the borehole, the improved method of operation upon encountering a water-bearing formation which comprises interrupting the circulation of said gas when the rate of water influx exceeds about two barrels per hour, replacing said gas with an aqueous solution of a salt having a precipitate-forming anion, continuing said drilling throughout said water-bearing formation, removing the excess of said salt solution from the borehole, then filling said borehole with an aqueous solution of a salt having a cation capable of forming a precipitate

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with said anion, removing the excess of said last-named solution and then resuming said drilling with the circulation of a gas.

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