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METHOD FOR DRILLING WELLS WITH A GAS

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ABSTRACT OF THE DISCLOSURE

Migration of earth fluids to a borehole, particularly in connection with air or gas drilling, is prevented by producing an oil-water emulsion around the borehole. The emulsion is formed without agitation by injecting a nonionic surfactant solution into the formation, the solvent being either oil or water. Preferably, the solution penetrates the formation to a depth of one inch for every 100 p.s.i. of formation pressure. The nonionic surfactant must have a cloud point temperature above the formation temperature.

Cross reference to related applications

This application is a continuation-in-part of our U.S. patent application 321,357, filed Nov. 4, 1963, for "Method for Drilling Wells with a Gas," now abandoned.

Background of the invention

This invention relates to an improved method of blocking the migration of earth fluids to a borehole. More particularly the invention is directed to drilling boreholes in the earth following the rotary drilling technique, wherein a gas rather than a liquid is circulated to carry earth cuttings to the surface, and to sealing off water-bearing formations encountered while so drilling with a gas.

There are a number of circumstances when it is desired to prevent migration of earth fluids to a borehole. For example, where a gas, such as air or natural gas, may be used as the circulating fluid in place of more conventional liquid drilling fluids, water-bearing earth formations are often encountered while drilling and the influx of formation water can seriously interfere with drilling operations and substantially detract from the advantages associated with gas drilling. The bit cuttings become dispersed by hydration and mechanical action to form a viscous mud in the bottom of the well to prevent removal of cuttings from the hole. Furthermore, if the influx of water into the borehole is sufficiently great, the hydrostatic head may build up to a point where air circulation is prevented. As a result, the use of gas as a circulating medium may have to be discontinued and the operation converted to the use of liquid drilling fluids.

A number of techniques for decreasing intrusion of fluids into boreholes have been suggested. For example, it has been proposed to inject thermosetting plastics or viscous oils into the portion of the formation immediately around the wellbore to block off water-bearing sands from the borehole. For a number of reasons, these techniques have not been particularly effective. In the first place, usually it is quite difficult to inject the relatively viscous fluids into the formations. Usually, water-bearing sands have limited permeability and tend to fracture when the high pressures necessary to inject viscous fluids thereinto are employed. Manifestly, when the formation is fractured the whole system for preventing migration of water into the borehole is rendered more or less inoperative because there are produced very large openings by virtue of which water can flow quite easily into the wellbore.

Summary of the invention

In accordance with the teachings of one aspect of the present invention, a viscous emulsion is formed in situ around the wellbore in the earth formation from which fluids are being produced into the wellbore. The emulsion comprises water, oil, and a hydrophilic surface-active agent, which emulsion has a viscosity of at least 100 centipoises. When connate water is being produced, the emulsion may be formed by mixing oil and a nonionic hydrophilic surfactant having a cloud point temperature above the temperature of, and preferably from 0 to 60° F. above the temperature of, the water-bearing earth formation, and having a salinity tolerance up to 100,000 parts per million chloride. The mixture is injected into the water-bearing earth formation over the length thereof traversed by the wellbore to penetrate the formation around the wellbore at least one inch for each 100 pounds of formation pressure. (Preferably, the injection pressure is maintained for a period sufficiently long to allow the viscous emulsion to develop a gel structure, usually about two hours, to prevent the emulsion from being forced back into the wellbore.)

Description of the preferred embodiments

When water influx into a borehole commences, the drilling crew often will notice a diminshed return of dust and cuttings at the blowline or exhaust pipe from the borehole annulus. Not infrequently, however, dust and dry cuttings may be produced through the blowline even though a water-bearing formation is being drilled. Usually, this is the result of erosion and abrasion caused by the drill string and by the air itself as the drill string rubs against dry, up-hole formations. More often, the operators will notice a large increase in circulation pressure resulting from wet cuttings that ball up at the bit and bridge in the wellbore. Furthermore, any accumulation of water in the borehole increases circulation pressure because of its hydrostatic head. Under any circumstances, the operator should drill as far as possible into the water-bearing formation so that as much of the formation as possible may be sealed off by the technique of the present invention.

When it has been decided to make an effort to seal off the formation, drilling is stopped and the lower end of the borehole is sealed off. This may be done by expanding a packer connected to the lower end of the drill stem, such as is often used for drill stem testing. If an entire section of a water-bearing formation has been penetrated by the drill bit, it may be necessary to use straddle packers to seal off the formation. Either before or after the lower end of the borehole is sealed off, the temperature of the water-producing earth formation is determined by any of a number of conventional techniques.

At the earth's surface, a mixture of an oil solvent and a nonionic surfactant agent is prepared. The oil may be diesel oil, kerosene, crude oil, condensate, crude residuum, refinery waste, or any other oil with a gravity of 40° API or less. The oil should have a viscosity of less than 100 centipoises at the temperature of the formation being treated. The nonionic surfactant may be: an alkyl aryl polyethylene oxide, such as nonyl phenol ethylene oxide (8–40 mols of ethylene oxide) and octyl phenol ethylene oxide (8–40 mols ethylene oxide); fatty acid esters of sorbitan such as sorbitan monolaurate, sorbitan monopalminate, sorbitan monostearate, sorbitan tristearate, sorbitan monooleate, sorbitan trioleate, and sorbitan sesquioleate; polyethylene sorbitan fatty acid esters such as the substituted sorbitans listed above with polyoxyethylene substitution; ethylene diamine (1 N, 2 N) dipolyoxyethylene, or dipolyoxyethylene with the oxyethylene substituted in any of several manners, such as ethylene diamine with amine hydrogens fully substituted by polyethylene and polypropylene oxides; ethylene oxide-propylene oxide copolymers; and polyoxyethylene esters of fatty acids, such as polyoxyethylene stearate, polyoxyethylene palminate, polyoxyethylene oxypropylene stearate. The specific surfactant selected must have a cloud point temperature above the temperature of the water-producing earth formation to be selaed off, and preferably from 0 to 60° F. above the temperature of the formation. Most desirably, the cloud point temperature is at least 40° F. above the formation temperature. The preferred surfactants for use with the invention are alkyl aryl polyethylene oxides having ethylene oxide chains of from 10 to 13 mols.

The amount of the nonionic surfactant incorporated in the treating oil may vary between 4% and 10% by volume of surfactant in the oil. Preferably, between 4% and 6% by volume of surfactant is incorporated in the oil.

As much as possible of the water in the packed-off section of the borehole is removed, preferably by injecting the surfactant-free oil spearhead mentioned below down the drill pipe and out the bottom to displace the water just prior to setting the packer. Preferably, the surfactant-free spearhead should be displaced above the packer so that only oil-surfactant solution can enter the formation, as will be described. Where this technique cannot be followed, other techniques may be used to remove the water, as by swabbing or pumping when pumping equipment is available and the water is replaced with the solution formed as described above. A wire line swab usually will be found to be a convenient means for removing the water. Bailing may be resorted to if necessary.

A surfactant-free oil spearhead and then the solution of surfactant and oil solvent are pumped down the borehole into the formation surrounding the packed-off section of the borehole. It is important to determine the pressure of the water in the formation. This may be done by increasing the pressure of the fluid column in the drill pipe until a point is reached at which the water in the formation and the surfactant are in balance. At this point, with no water leaving the formation and fluid from the drill pipe entering the formation, the pressure exerted on the fluid in the drill pipe should be noted and will be equal to the water pressure in the formation.

The pressure of the fluid in the drill pipe is thereupon increased and the oil spearhead followed by the surfactant-oil solution is forced into the formation until the surfactant-oil solution has penetrated to a depth of at least one inch for every 100 pounds of formation water pressure. Preferably, the surfactant-oil solution is pumped into the formation to a depth at least 50% greater than the depth as determined above. This will insure that an effective water block is obtained.

After the surfactant-oil solution has been pumped back into the formation to the desired depth, pressure is maintained for a period of at least two hours to prevent the mixture from being forced back into the well-bore. In due course an emulsion will be formed that is sufficiently viscous to resist the pressure of the resident water in the formation. In spite of the fact that a relatively small amount of mechanical agitation is available to aid in

emulsifying the fluids, it will be found that an emulsion is formed quite readily that is effective to block the flow of water out of the formation. Furthermore, the emulsion has excellent time stability and will not tend to de-emulsify until long after drilling operations have ceased and completion operations have been carried out.

As indicated above, the surfactant used should have a cloud point temperature at least equal to the temperature of the earth formation to be treated, and preferably should be somewhat greater than the formation temperature. The upper limit of cloud point temperature is determined by the dispersibility of the surfactant in oil. In other words, a surfact having an extremely high cloud point temperature can be used if it is sufficiently dissolved in the oil solvent.

In the above discussion, it was assumed that water was the undesirable liquid being produced into a borehole. As is known, on occasion oil may be so produced, but in a quantity insufficient to justify a completion. In such a circumstance it may be necessary to stop oil flow into the borehole if drilling is to continue without the use of drilling liquids. In this circumstance, water may be used as the solvent for the surfactant and the resulting solution may be injected into the formation to form the desired emulsion in situ. Furthermore, when air is the drilling fluid, the production of natural gas into the borehole may produce an explosive mixture. Either oil or water is initially forced into the formation, and a solution formed as described above using the other liquid (i.e., water or oil) as the solvent is subsequently injected to form the desired emulsion. The invention is also useful to prevent water coning by producing an emulsion in situ by injecting an oil-surfactant solution into the earth at a level near the upper level of the water-producing zone to place a barrier between the connate water and the borehole for a substantial distance around the borehole. Preferably, the zone of reduced permeability is formed in the water-oil transition zone of the reservoir around the wellbore.

To illustrate the efficacy of the invention, laboratory tests of the method were conducted in unconsolidated sand packs one inch in diameter and four inches long containing Clemtex #5 sand with a permeability to water of three to four darcys when fully saturated. Permeability was measured at 100% salt water saturation before an oil solution of surfactant was pumped through the sand. Less than a pore volume of the oil solution plugged or radically reduced permeability of the sand in most of the tests. Flow was then reversed and permeability to water was measured again and a percent reduction in permeability was recorded. Reverse permeability was measured at a differential pressure greater than that required to place the emulsifying materials, usually about twice as great, and in all instances not less than 100 p.s.i. was placed across the four-inch sand column.

Tables I and II list typical results of these tests. Anionic 4 is an anionic agent, sodium tetradecyl sulfate; Pluronic L–81 is a nonionic agent, polyoxyethylene polyoxypropylene polymer; NPX is a nonionic agent, nonyl phenol 10.5 ethylene oxide; and Corban 207 is a proprietary surfactant.

TABLE I

Test No.	Sand Pack Temp., ° F.	Treatment	Remarks	Reverse K_{sw}, Percent
1	75	25 cc. S.W. (10% Orzan P)+25 cc. Diesel	SandPlugged During Treatment	10.0
2	75	25 cc. Diesel (4% Anionic 4)	No Plugging	
3	75	25 cc. Diesel (4% Pluronic L–81)	do	
4	75	25 cc. Diesel (4% AL Stearate)	Sand Plugged During Treatment	3.0
5	75	25 cc. Diesel (4% Nonionic NPX)	K Reduced During Treatment	11.3
6	75	25 cc. Diesel (10% Nonionic NPX)	Sand Plugged During Treatment	0.0
7	125	25 cc. Diesel (4% AL Stearate)	do	29.0
8	125	25 cc. Diesel (10% Corban 207)	K Reduced During Treatment	1.3
9	125 125	25 cc. 50% NaOH 50 cc. Diesel (10% AL Stearate)	K Reduced During Treatment	0.8
10	160	100 cc. Diesel (1%jNH^4 Oleate, 4% Corban 207).	No Plugging	
11	160	100 cc. Diesel (2% AL Isopropoxide, 3% Corban 207).	do	
12	160	100 cc. Diesel (2% AL Stearate, 5% Corban 207).	Sand Plugged During Treatment	0.04

TABLE II

Test No.	Solution		Temp., ° F.	Final Permeability to Salt Water, Percent of Original
	Surfactant	Percent		
13	AN-7	10	75	0.0
14		5	75	4.2
15		10	160	21.4
16	AN-7+NPX	10	75	5.6
17	AN-7+Span 80	10	75	18.0
18	NP-14	10	75	20.8
19	TMN	10	75	8.1
20	Span 85	10	75	12.7
21	NP-27	10	75	1.2
22		5	75	2.9
23	Hyamine 1622	10	75	20.0
24	Hyamine 10-X	10	75	0.0
25		5	75	0.0
26		3	75	1.4
27		10	120	18.7
28		5	120	15.7
29		10	160	20.4
30	NP-27+Hyamine 10-X	10	75	1.9
31	NPX	10	120	1.1
32		5	120	0.5
33		3	120	3.5
34		10	160	19.2
35	NPX+Hyamine 10-X	10	120	1.1
36		5	120	5.7
37	TP-9	10	120	27.8
38	NP-33	10	160	7.5
39	NP-35	10	160	0.7
40		5	160	0.1
41		3	160	0.2

Tests 1 through 6 of Table I were for the purpose of determining which of the various types of surfactants held promise for the purpose of reducing permeability. The tests indicated that nonionics and aluminum stearate held greatest promise. However, the tests were conducted at a temperature of 75° F., which is seldom found in reservoirs. Test 4 was repeated at the elevated temperature of 125° F. as Test 7, and the aluminum stearate was found to be ineffective at practical restrvoir temperatures. Adding of sodium hydroxide and increasing the concentration of aluminum stearate to 10 percent (a prohibitively high concentration) increased its effectiveness at the temperature of 125° F., as illustrated by Test 9. The combination of 2 percent aluminum stearate and 5 percent Corban 207, a proprietary corrosion inhibitor, was effective at a temperature as high as 160° F., as indicated by Test 12.

Tests 13 through 41 of Table II constitute a systematic evaluation of various anionic, nonionic, and cationic surfactants. These tests were performed by adding the surfactants to diesel oil in concentrations of 10, 5, and 3 percent, respectively, and testing them at increasingly higher temperatures to find the concentrations of surfactant most effective at various temperatures. 50 cc. of solution was injected into the sand core in each test. Tests 13, 14, and 15 show that anionic 7 is effective at 10 percent concentration at 75° but that at 5 percent it starts to lose its effectiveness. When the temperature is increased to 160°, even a concentration of 10 percent is ineffective. Inasmuch as 75° is not a realistic reservoir temperature, AN-7 is shown to be ineffective as a surfactant for the purposes of this invention.

Tests 16 and 17 show that mixtures of the anionic surfactant AN-7 with nonionics and cationics are also ineffective. NP-14, a nonionic with a very low cloud point, is shown in Test 18 to be ineffective even at the very low temperature. The same holds for the proprietary nonionic surfactant TMN and the proprietary nonionic surfactant Span 85. The results with NP-27, a nonionic having low cloud point temperature, in Tests 21 and 22 indicate moderate effectiveness at 10 percent concentration at the low temperature and decreasing effectiveness as the concentration goes down at the same temperature. In Test 23, Hyamine 1622, a cationic surfactant, showed little effectiveness even at room temperature. Hyamine 10-X, a nonionic surfactant having a cloud point in the vicinity of 90° F., shows effectiveness in 10 and 5 percent concentrations at room temperature; at 3 percent concentration, it begins to lose its effectiveness. At increased temperatures, it becomes ineffective even at a concentration of 10 percent. The combination of NP-27 and Hyamine 10-X at room temperature appears to have about the same effectiveness as NP-27 alone at the same temperature. NPX, a nonionic surfactant with slightly higher cloud point than NP-27 shows effectiveness in the 10 and 5 percent concentrations at 120°, as shown in Tests 31 and 32, and decreasing effectiveness at 3 percent concentration. In 10 percent concentration at 160° F., NPX is ineffective. NPX in combination with Hyamine 10-X is moderately effective at 120°; at concentration of 5 percent, it begins to lose its effectiveness. The low cloud point TP-9 is shown in Test 37 to be ineffective at low temperatures and is similar to TMN (Test 19). Tests 38, 39, 40, and 41 show the effect of cloud point on temperature performance of the surfactants. NP-33 is shown to be relatively ineffective in 10 percent concentration at 160°, whereas NP-35, with a higher cloud point, is effective in all concentrations at 160°.

It is readily apparent that the invention provides an inexpensive, effective means for preventing the flow of undesired earth fluids into boreholes. The low viscosity of the injection fluid mitigates against fracturing of the formation. When the invention is used during drilling operations, the invention is particularly advantageous in that a relatively short amount of time is required for carrying out the treatment so that drilling need be interrupted only for a very short time interval.

Although there has been shown and described what at present is considered to be the preferred embodiment of the present invention, other modifications will be apparent to those skilled in the art which do not depart from the scope of the broadest aspects of the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In the rotary drilling of boreholes wherein gas is used as a circulating fluid to carry drilled material from the bottom of the borehole to the earth's surface, the improved method of sealing off a water-bearing formation encountered during drilling operations which comprises:

injecting into the water-bearing formation an oil solution of a nonionic hydrophilic surface active agent having a cloud point temperature above the temperature of the water-bearing formation, and having a salinity tolerance up to 100,000 parts per million of chloride; and

reacting said oil solution with the formation water to form a viscous emulsion.

2. The method of claim **1** wherein the cloud point temperature of the surface active agent is at least 40° F., above formation temperature.

3. The method of claim **1** wherein said agent is injected into the earth formation by isolating a portion of the wellbore adjacent the earth formation,

removing water from the isolated portion of the wellbore, and

replacing said water with the oil solution of a hydrophilic surface active agent having a cloud point temperature above the temperature of the water producing formation, and having a salinity tolerance up to 100,000 parts per million of chloride.

4. The method of claim **3** wherein said agent is selected from the group consisting of alkyl aryl polyethylene oxides, fatty acid esters of sorbitan, polyethylene sorbitan fatty acid esters, ethylene diamine (1 N, 2 N) dipolyoxyethylene, ethylene oxide-propylene oxide copolymers, and polyoxyethylene esters of fatty acids.

5. The method of claim **4** wherein the oil solution is forced into the water producing formation to a distance from the wellbore of at least one inch for every 100 p.s.i. of hydrostatic pressure in the water producing formation.

6. The method of claim **3** wherein the surface active agent is an alkyl aryl polyethylene oxide having ethylene oxide chains of from 10 to 13 mols.

References Cited

UNITED STATES PATENTS

2,164,459	7/1939	Kennedy	166—30
2,377,529	6/1945	Stephenson	166—42
2,801,931	8/1957	Morgan et al.	166—31 X
2,851,105	9/1958	Garst	166—42
2,874,779	2/1959	Johnson	166—42
2,882,973	4/1959	Doscher et al.	166—42
3,065,791	11/1962	Bearden et al.	166—42 X
3,149,684	9/1964	Eckel et al.	166—29 X

OTHER REFERENCES

Moilliet, J. L., et al., Surface Activity. London, Spon Ltd., 2d ed., 1961, pp. 348 and 479.

Water Barrier Boosts Output, in Oil & Gas Journal, Nov. 4, 1957, p. 96.

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