DRILLING PROCESS USING A SHALE PROTECTING POLYMER DRILLING FLUID SYSTEM

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United States Patents

References Cited
UNITED STATES PATENTS

2,165,824 7/1939 Vietti et al. 252/8.5

3,323,603 6/1967 Lummus et al. 252/8.5
3,360,461 12/1967 Anderson et al. 252/8.5
3,558,545 1/1971 Lummus 252/8.5

FOREIGN PATENTS OR APPLICATIONS
6,414,645 6/1965 Netherlands 252/8.5

Primary Examiner—Stephen J. Novosad
Attorney—Harold L. Denkler and H. W. Coryell

Abstract

The cost of drilling a water sensitive shale is reduced by first enhancing drilling rate by circulating a clear drilling fluid, then avoiding borehole instability due to shale-water interaction by circulating an aqueous solution of partially hydrolyzed polyacrylamide and alkali metal halide, and avoiding borehole instability due to mechanical incompetence of earth formations by circulating a suspension of pre-hydrated bentonite in the said solution to enhance the borehole cleaning while continuing the shale stabilization.

7 Claims, No Drawings
DRILLING PROCESS USING A SHALE PROTECTING POLYMER DRILLING FLUID SYSTEM

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

This application is a continuation-in-part of application Ser. No. 50,990, filed June 29, 1970, now abandoned, and application Ser. No. 50,991, filed June 29, 1970, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to a method of drilling water sensitive shales. More particularly, it relates to reducing the cost of such an operation by utilizing a sequence of relatively low cost drilling fluids that cooperate to avoid borehole problems due to either shale instability or mechanical instability while maintaining a relatively high drilling rate.

The history of drilling water sensitive shales with conventional water-based drilling fluids has been plagued by borehole instability problems related to the welling and sloughing of shales due to their interaction with water. Such problems include stuck drill pipe, time lost in redrilling shale that has sloughed into the borehole, difficulty in running casing, and the like. Heretofore an avoidance of such problems required a use of dense viscous aqueous drilling fluids or the use of oil-base drilling fluids. However, such solutions are relatively expensive due to slow drilling rates and/or high drilling mud costs.

A primary object of the present invention is to reduce the cost of drilling water sensitive shales by reducing the drilling time without increasing the cost of the drilling fluid. A series of mutually compatible and/or inter-convertible drilling fluids are used in a sequence that first maximizes the drilling rate and later, substantially as required by the earth formations being encountered, provides shale stabilization and enhanced cleaning.

SUMMARY OF THE INVENTION

This invention relates to drilling a borehole that encounters a water sensitive shale and is drilled by operating a drilling means while circulating a drilling fluid. Initially the rate of drilling is enhanced by circulating a relatively low density, fast drilling, substantially clear fluid. When the encountering of borehole instability due to water destabilization of water sensitive shale is at least imminent, a shale stabilization while drilling is effected by circulating a shale-stabilizing aqueous solution containing both a partially hydrolyzed polyacrylamide (which is from about 20 to 40 percent hydrolyzed, has a molecular weight above about 1 million, and is present in an amount at least sufficient to satisfy the minimum adsorption requirement of the shale) and an alkali metal halide (which is present in an amount at least sufficient to enhance the adsorption of the polymer on the shale). When the encountering of borehole instability due to sloughing of mechanically incompetent earth formations is at least imminent, the rate of borehole cleaning is enhanced by suspending a drilling fluid niscosifier such as prehydrated bentonite in said aqueous solution (with the amount of prehydrated Bentonite being sufficient to enhance the solids lifting capacity of the fluid) and circulating said suspension while maintaining the fluid loss of the circulating sus-

dension at a level sufficient to facilitate said shale stabilization by polymer adsorption.

As used herein the terms "a borehole instability due to water destabilization of water sensitive shale is at least imminent" refers to a situation in which a water sensitive shale has been or is about to be contacted by an aqueous fluid. That aqueous fluid may be a circulating air or gas drilling fluid containing water from a water-producing formation, a mist or foam drilling fluid, an aqueous drilling fluid, or the like. Similarly, "a borehole mechanical instability due to sloughing of mechanically incompetent earth formations is at least imminent" when the borehole has penetrated or is about to penetrate a mechanically incompetent zone such as a rumbled zone, a highly fractured zone, an unconsolidated sand or gravel, or the like. As known to those skilled in the art, the times when such events are about to occur are often known or are readily determinable from subterranean geological information (in the light of the rate of the borehole advance) and/or previous experience with wells drilled in similar regions. In addition, the encountering of such borehole instabilities are readily detectable from the behavior of the drill string and/or drilling fluid and/or rate of borehole advance, or the like signs and symptoms that are commonly looked for during the drilling of a well.

DESCRIPTION OF THE INVENTION

The shale destabilizing interaction of water and water-sensitive shale involves a long known and troublesome problem. It is known to be more complicated than the result of a single type of phenomena. Osmosis and osmotic pressure forces tend to induce transfer of water from a water-containing drilling fluid to the layers or interstices within the shale. Osmosis is known to be involved but to be less than a total explanation. For example in a U.S. Pat. No. 2,165,824 filed over 30 years ago, Garrison pointed out that such an interaction involves more than osmosis and, accordingly, a use of salts that provide a high osmotic pressure, i.e., an "inhibited" aqueous drilling fluid, will not prevent either the heaving or dispersing of the shale. That patent suggests using a relatively concentrated aqueous solution of an alkali metal silicate. But, such a solution is disadvantageously expensive to maintain as a circulating drilling fluid.

One aspect of the interaction between water and a water-sensitive clayey or shaly earth formation causes a dispersion of colloidal sized particles of clay in a circulating aqueous drilling fluid. Such a dispersion tends to increase the viscosity and density of the drilling fluid. It causes a problem of drilling fluid maintenance that may be expensive even in the drilling of clayey earth formations which are not sufficiently active to create a borehole instability problem. Numerous prior patents have described combinations of carboxyl group containing polymeric materials that are designed to handle such clay dispersion problems. They relate to clear or low solids drilling fluids or clay-containing drilling muds in which the types and amounts of the polymeric materials are adapted to effect a beneficiation or dispersion of the viscosity-adjusting bentonite type clays while tending to flocculate and enhance the removal of other clays, such as those encountered in drilling operations. As known to those skilled in the art such clay beneficiating and flocculating aqueous polymer systems are not suited for drilling in water sensitive
shales and are generally no more effective than a simple aqueous clay mud with respect to stabilizing a borehole in a water sensitive shale. Such aqueous polymer systems are described in U.S. Pat. Nos. 2,775,557; 3,070,543; 3,081,260; 3,323,603; 3,358,545; 3,511,799; etc.

A “cohered inhibited mud system” that is an aqueous fluid for drilling a water sensitive shale has been described by R. L. Sperry, in Netherlands Pat. No. 6,414,645. In that system a carboxyl group-containing polymeric material and a water-soluble inorganic salt are dissolved in water in a ratio of polymer to salt that ranges from about one to 25 to three to one with the stipulation that no more than about 6 pounds per barrel (ppb) of the inorganic salt be present in the solution. The patent teaches that the specified proportions of the polymer and salt are critical and should be adapted to cause the surfaces of clay particles to be slightly swollen, without being dispersed in the water, so that the swelling action seals the clay against further water intake or interaction.

The present invention is at least in part based on a discovery that, contra to such prior teachings, in a low cost aqueous drilling fluid that is readily convertible from a fast drilling clear fluid to a solids-suspending mud when enhanced cleaning is needed, a stabilization of a water sensitive shale is advantageously effected by an aqueous solution that contains only a relatively small amount of polymer in the presence of a relatively large amount of salt. In such a solution the polymer must be a polyacrylamide of the specified degree of hydrolysis and molecular weight while the salt is either a sodium or potassium halide, and is preferably the latter. The shale stabilizing mechanism of this solution appears to be distinctly different from that described in the Netherlands patent. The shale stabilization requires at least about seven pounds per barrel of the salt — and is better when more than 10 pounds per barrel are present.

Fast drilling clear fluids suitable for use in the present invention can vary in type of fluid phase as well as in composition as long as the fluids are adapted to enhance the rate of drilling within at least an upper portion of a borehole. Such a fluid can be an essentially gaseous fluid such as air, nitrogen, hydrocarbon gases, flue gases or the like, an aqueous liquid containing essentially gaseous fluid such as mist or foam or the like, or a substantially clear aqueous liquid such as water, brine, or the like, or a solution of partially hydrolyzed polyacrylamide and an alkali metal halide in proportions that are effective or ineffective for shale stabilization, or the like, as long as the fluid has a density and viscosity at least substantially as low as those of water. Such a fast drilling fluid is preferably a relatively low cost fluid such as air or brine.

Partially hydrolyzed polyacrylamides suitable for use in the present invention can comprise such polymers formed by polymerizing and subsequently hydrolyzing acrylamide (or a lower homolog of acrylamide) or copolymerizing acrylamide with an acrylate, or the like. The molecular weight of the polyacrylamide should be at least greater than about one million and is preferably greater than about three million. The range of hydrolysis (and/or the proportion of the amide groups of the polyacrylamide that are carboxyl groups or have been hydrolyzed to form carboxyl groups) should be from about 20 to 50 percent and extents of hydrolysis of from about 30 to 40 percent are particularly suitable. Examples of such polymers that are commercially available include Separan AP-273 (30 percent hydrolyzed molecular weight greater than three million, Dow Chemical Co.), Separan AP-30 (30 percent hydrolyzed, molecular weight greater than two million, Dow Chemical Co.), Pusher 500 (40 percent hydrolyzed, molecular weight 3.4 million, Dow Chemical Co.), Pusher 700 (40 percent hydrolyzed, molecular weight about seven million, Dow Chemical Co.), Pusher 1000 (40 percent hydrolyzed, molecular weight about seven million, Dow Chemical Co.), RC-326 (20-30 percent hydrolyzed, molecular weight greater than 12 million, American Cynamide), RC-334 (greater than 30 percent hydrolyzed, molecular weight greater than 12 million, American Cynamide), RC-304 A (30 percent hydrolyzed, molecular weight 10 million, Cynamide of Canada), Percol 155 (30 percent hydrolyzed, molecular weight 12-15 million, Allied Colloids), Percol 156 (40 percent hydrolyzed, molecular weight 12-14 million, Allied Colloids), etc. As known to those skilled in the art such polymers are usually marketed in form of their sodium salts. As used herein (in reference to the weights or concentrations by weight of such polymers) the amounts of such polymers refer to amounts of the sodium salt or the equivalent amount of polymer that is needed to form the sodium salt. If desirable, the present solutions can be made by dissolving the carboxylic acid forms of the polymers in an aqueous liquid and converting them to the salts in solution.

Aqueous liquids suitable for use in the present invention can comprise water or substantially any aqueous solution that is free of interferring solutes. Examples of suitable aqueous liquids include natural waters or brines or sea waters and/or waters softened or otherwise treated by means of ion exchange resins, flocculating agents, etc. comprising aqueous solutions that are free of significant proportions of solutes that cause chemical changes in polyacrylamide polymer molecules, e.g., degredation, cross-linking, etc. or compete with polyacrylamide polymer molecules for adsorption sites on clay particles (e.g., solutes such as chromium or the like polymer reaction catalytic materials, carbonate, phosphate, sulfide or the like anions that compete for adsorption sites, etc.). Relatively soft sodium or preferably potassium brines are particularly suitable.

Shale stabilizing aqueous solutions of partially hydrolyzed polyacrylamides and alkali metal salts used in the present invention are relatively low cost solutions adapted for use as drilling fluids that stabilize the shale while the maximizing drilling rate and/or borehole cleaning effects. The shale protection appears to be the result of polymer adsorption at specific critical sites on the shale. The critical sites appear to be the positively charged edges of the packets of clay platelets. On them the adsorption of the specified polymer molecules sufficiently reduces the inhibition of water between the clay platelets to prevent the shale destabilization. In addition to containing at least enough polymer to satisfy those adsorption sites, the solution should contain at least enough alkali metal halide salt to enhance the rate of polymer adsorption on the clay. In addition the solution preferably has an alkaline pH in a range that tends to enhance the thermal stability of the polymer. It is also important that such a solution be free of interfer-
ring solutes that tend to cause chemical changes in the polymer molecules or to compete with them for adsorption of the critical adsorption sites of the clay. In general, suitable concentrations range from about 0.2 to 0.75 ppb of polymer (preferably 0.3 to 0.6), from about seven to 70 ppb of salt (preferably from about 10 to 35) in water solution having a pH of from about nine to 11 (preferably from 9.5 to 10). Such solutions should be kept substantially free of polymer stability and/or adsorption-interfering solutes that tend to cause chemical changes in the polymer or compete with the polymer molecules for adsorption sites on clay. Where such solutions are gelled (by a suspension of prehydrated bentonite) in order to increase their hole-cleaning capabilities, they should contain from about six to 20 ppb prehydrated bentonite (preferably from about 10 to 20 ppb) and be maintained as moderately high filter loss muds having an API 30 minute filter loss of from about eight to 30 ml.

Field tests have indicated that as clear drilling fluids, the above solutions provide the advantages of clear water drilling without the attendant hole instability problems that result from using fresh water in watersensitive shales. Penetration rate improvements in the order of 50 to 100 percent compared with the gelled muds (i.e., approaching clear water drilling rates) have been experienced. In field preparations of such solutions, it is advantageous to use about ¾ to ¾ pound per barrel Separan AP-273 (or equivalent polymer) partially hydrolyzed polyacrylamide, about 10 to 11 pounds per barrel muriate of potash (potassium chloride) and enough sodium hydroxide or metasilicate to provide a pH from about 9.5 to 10. It is advantageous to mix the muriate of potash first and then the Separan. Mixing the Separan in fresh water tends to produce high fluid viscosities that are difficult to handle and can result in the plugging of the hoppers, pumps, etc. “Gunning,” the mixing tanks during the mixing period is advantageous. Such an aqueous solution can be circulated and maintained as a substantially clear drilling fluid by simply using no desierter and allowing all solids to settle in tanks or preferably in a reserve pit through which the solution is circulated.

Test Examples 1-11 (Table 1) on Effects of: Percent Hydrolysis, Molecular Weight, and Salt Concentration

In the test examples described herein, various properties of fluids were measured by means of the triaxial shale shaker tester described in Journal of Petroleum Technology, Volume 21, pages 883-892, July 1969. This tester simulates field conditions in the behavior of cylindrical shaped specimens (about 2 inches in order diameter and 1 inch high) which are placed in a rubber jacket. Isotropic loading is obtained by applying approximately equal vertical and radial pressures simultaneously and/or independently. Fluids being tested are circulated through a hole drilled in such specimens in a manner permitting a filtrate penetration of the specimens. The specimens may be natural cores or shales that were reconstituted by compacting drill cuttings or fragments, or the like.

Table 1 shows of circulating the specified aqueous polymer and salt solutions through Atoka shale specimens under equivalent conditions of temperature, isostatic loading, etc. Tests 1, 3 and 7 compared the extent of shale protection by substantially equivalent polymers having extends of hydrolysis of, respectively, less than one, five and 30 percent — and show that the less hydrolyzed polymers were less than 10 percent as effective. Tests 4 and 9 and tests 10 and 11 indicate that molecular weight increases (of from two million to three million and from 3.4 million to seven million) provide significant increases in the extent of protection. As known to those skilled in the art, when a solution of polymer is circulated through a drilling assembly, the polymer is subjected to relatively severe shearing forces which tend to degrade its molecules from high molecular weights to lower molecular weights. Such a degradation is reflected by Test 9 in which the fresh polymer provided 4,885 minutes of stabilization but a retesting of a previously used sample (on a fresh shale specimen) provided only 540 minutes of protection, due to the degradation of the polymer. Tests 4 and 5 show protection effects of salt concentrations of zero and one percent and are comparable with tests 6, 7 and 8 in which the salt concentrations were two, three and 25 percent. The relative effectiveness indicates that substantially no shale protection is provided by salt concentrations of less than about two percent (about 7 ppb). In addition, tests 6, 7 and 8 show that the effectiveness of the shale protection with increase in salt concentration peaks within the range between two and 25 percent with the amount of protection provided by about three percent being substantially twice that provide by amounts near the upper and lower ends of the range.

Table 1

<table>
<thead>
<tr>
<th>Test</th>
<th>Polymer*</th>
<th>Molecular Weight</th>
<th>Degree Hydrolysis %</th>
<th>NaCl Conc. %</th>
<th>Triaxial Test Time, Minutes</th>
<th>Shale Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Separan</td>
<td>MGL</td>
<td>2×10⁷</td>
<td>&lt;1</td>
<td>3</td>
<td>227*</td>
<td>42*</td>
</tr>
<tr>
<td>2 Separan</td>
<td>NP-10</td>
<td>1×10⁸</td>
<td>5</td>
<td>3</td>
<td>273*</td>
<td>264*</td>
</tr>
<tr>
<td>3 Separan</td>
<td>NP-20</td>
<td>2×10⁸</td>
<td>5</td>
<td>3</td>
<td>243*</td>
<td></td>
</tr>
<tr>
<td>4 Separan</td>
<td>AP-30</td>
<td>2×10⁸</td>
<td>30</td>
<td>0</td>
<td>818</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>1</td>
<td>555</td>
<td>438</td>
</tr>
<tr>
<td>6</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>2</td>
<td>1440+</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>3</td>
<td>3722</td>
<td>372</td>
</tr>
<tr>
<td>8</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>25</td>
<td>1440+</td>
<td></td>
</tr>
<tr>
<td>9 Separan</td>
<td>AP-273</td>
<td>3×10⁷</td>
<td>30</td>
<td>3</td>
<td>4885</td>
<td></td>
</tr>
<tr>
<td>10 Pusher</td>
<td>500</td>
<td>3.4×10⁷</td>
<td>40-45</td>
<td>3</td>
<td>3732</td>
<td>746</td>
</tr>
<tr>
<td>11 Pusher</td>
<td>700</td>
<td>7×10⁷</td>
<td>40-45</td>
<td>3</td>
<td>4652</td>
<td>457</td>
</tr>
</tbody>
</table>

*Polymer concentration = 0.5 lb/bbl except for triaxial test on Separans MGL, NP-10, and NP-20 which were at 1.5 lb/bbl.

Test Examples 12-24 (Table 2) on Effects of Actual or potential Contaminants

Test 12 and 13 show that although numerous anionic polymer solutes tend to be precipitated by calcium ions, such ions (in normally encountered proportions) do not reduce the effectiveness of the shale protection of the present aqueous solutions. Tests 14-17 show that carbonate ions do, however, interfere with the shale protection. Tests 18 and 19 show a similar interference by sulfide and phosphate ions. Such interfering ions
are adapted to compete with the partially hydrolyzed polyacrylamide anions for the positively charged adhesion sites on the edges of the packets of clay platelets. Tests 20–22 show the interfering effects of a relatively high pH due to uncured (green) cement or excess metal hydroxide. Other tests have indicated that at a pH of 10 a fluid of the type used in test 22 will protect such a shale for more than 24 hours. Tests 23 and 24 show the interfering effects which are caused by chromate ions (relative to solutions which, free of the chromate ions, are adapted to provide a stabilization for more than 24 hours). Although such chromate ions are commonly used as corrosion inhibitors and are indicated to be suitable or even advantageous in various prior formulations of polymers and salts, in the present solutions, such ions accelerate the degradation of the high molecular weight partially hydrolyzed polyacrylamide polymer molecules to molecules too small to affect the shale protection.

**TABLE 2**

[Effect of contaminants on 3,500 psi, Triaxial Tester results of 3% KCI–0.5 p.p.b. Separan AP–273 polymer drilling fluid]

<table>
<thead>
<tr>
<th>Test</th>
<th>Shale</th>
<th>Contaminant, conc., percent wt.</th>
<th>Initial pH</th>
<th>Initial viscosity, cP</th>
<th>Triaxial tester,erosion, percent</th>
<th>Erosion, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.</td>
<td>A</td>
<td>CaCO₃ (in 10% KCl brine)</td>
<td>8.7</td>
<td>3.3</td>
<td>1,140+</td>
<td>9.2</td>
</tr>
<tr>
<td>13.</td>
<td>A</td>
<td>CaCO₃, 1.0</td>
<td>9.7</td>
<td>5.0</td>
<td>1,105+</td>
<td>6.8</td>
</tr>
<tr>
<td>14.</td>
<td>A</td>
<td>Na₂CO₃ (soda ash), 0.0%</td>
<td>9.0</td>
<td>3.7</td>
<td>567</td>
<td>0.4</td>
</tr>
<tr>
<td>15.</td>
<td>A</td>
<td>Na₂CO₃ (soda ash), 0.1%</td>
<td>10.0</td>
<td>5.8</td>
<td>464</td>
<td>7.4</td>
</tr>
<tr>
<td>16.</td>
<td>A</td>
<td>Na₂CO₃ (soda ash), 0.2%</td>
<td>10.2</td>
<td>5.5</td>
<td>279</td>
<td>5.4</td>
</tr>
<tr>
<td>17.</td>
<td>A</td>
<td>Na₂CO₃ (soda ash), 0.2%</td>
<td>10.2</td>
<td>5.8</td>
<td>279</td>
<td>5.4</td>
</tr>
<tr>
<td>18.</td>
<td>A</td>
<td>Na₂CO₃, 0.2%</td>
<td>10.2</td>
<td>5.8</td>
<td>675</td>
<td>12.9</td>
</tr>
<tr>
<td>19.</td>
<td>A</td>
<td>Na₂SO₄, 0.24%</td>
<td>11.5</td>
<td>5.6</td>
<td>275</td>
<td>8.5</td>
</tr>
<tr>
<td>20.</td>
<td>A</td>
<td>NaPO₄, H₂O, 0.28%</td>
<td>10.7</td>
<td>5.8</td>
<td>277</td>
<td>8.6</td>
</tr>
<tr>
<td>21.</td>
<td>A</td>
<td>Type I cement (uncured), 2.0%</td>
<td>11.8</td>
<td>5.6</td>
<td>366</td>
<td>16.6</td>
</tr>
<tr>
<td>22.</td>
<td>A</td>
<td>Type I cement (uncured), 2.0%</td>
<td>11.8</td>
<td>5.6</td>
<td>336</td>
<td>16.6</td>
</tr>
<tr>
<td>23.</td>
<td>A</td>
<td>NaOH</td>
<td>11.9</td>
<td>6.8</td>
<td>295</td>
<td>17.5</td>
</tr>
<tr>
<td>24.</td>
<td>A</td>
<td>Na₂CO₃, H₂O, 0.28%</td>
<td>9.7</td>
<td>1.7</td>
<td>10</td>
<td>10.3</td>
</tr>
</tbody>
</table>

* A = Houston Area, State Track 929; B = Oklahoma Aiken.
* Percent weight sample eroded by flowing fluid.
* (%) indicates no failure at test termination.
* Fluid pH adjusted to pH = 10 with NaOH then heated to 325 °F. (16 hr. warm up), 8 hrs. 325 °F., 18 hr. cool down.

**TABLE 3**

[Test Conditions: 1–2 inch diam. x 1 inch shale specimens reconstituted with 3% NaCl brine at 10,000 psi; 2–Specimen isostatically stressed as shown below; 3–Test fluid circulated through 1-inch axial borehole in specimen at 590°F (315 °C) for 24 hrs.

<table>
<thead>
<tr>
<th>Test</th>
<th>Shale</th>
<th>Sample depth (in.)</th>
<th>Percent clay</th>
<th>Distilled water dispersion *</th>
<th>Swelling percent limited</th>
<th>Test stress (psi.)</th>
<th>Conventional muds b)</th>
<th>Separan AP–273 polymer fluid c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.</td>
<td>Aoka, Arkansas Basin</td>
<td>9,410</td>
<td>69</td>
<td>3</td>
<td>980</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>26.</td>
<td>Aoka, Arkansas Basin</td>
<td>9,410</td>
<td>69</td>
<td>3</td>
<td>980</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>27.</td>
<td>Tongue river, Wyoming</td>
<td>76</td>
<td>11</td>
<td>20</td>
<td>964</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>28.</td>
<td>Houston area, State Track 929</td>
<td>13,500+</td>
<td>59</td>
<td>38</td>
<td>964</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>29.</td>
<td>Aoka, Arkansas Basin</td>
<td>9,410</td>
<td>69</td>
<td>3</td>
<td>980</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>30.</td>
<td>Aoka, Arkansas Basin</td>
<td>9,410</td>
<td>69</td>
<td>3</td>
<td>980</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>31.</td>
<td>Smithwick, Wash Texas</td>
<td>13,500+</td>
<td>59</td>
<td>38</td>
<td>964</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>32.</td>
<td>Smithwick, Wash Texas</td>
<td>13,500+</td>
<td>59</td>
<td>38</td>
<td>964</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>33.</td>
<td>Canadian shale</td>
<td>9,410 (3,820)</td>
<td>90</td>
<td>10</td>
<td>964</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>34.</td>
<td>Canadian shale</td>
<td>9,410 (3,820)</td>
<td>90</td>
<td>10</td>
<td>964</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>35.</td>
<td>Canadian shale</td>
<td>9,410 (3,820)</td>
<td>90</td>
<td>10</td>
<td>964</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>36.</td>
<td>Canadian shale</td>
<td>9,410 (3,820)</td>
<td>90</td>
<td>10</td>
<td>964</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
<tr>
<td>37.</td>
<td>Pachuta creek, Mississippi midway</td>
<td>2,200</td>
<td>45</td>
<td>50</td>
<td>964</td>
<td>2,900</td>
<td>6</td>
<td>1.9</td>
</tr>
</tbody>
</table>

* Weight distilled water included when dry clay.
* See Table 3A for Mud A, B, C, and polymer fluid properties.
* 3% KCl: 0.6% Biocide, Separan AP–273 unless otherwise indicated.
* 3% KCl: 0.6% Biocide, Separan AP–273 unless otherwise indicated.
* (-) indicates no failure at test termination.
* 1% KCl: 0.6% Biocide, AP–273.
* Fresh water.
3,738,437

### TABLE 3A

**TEST FLUID PROPERTIES**

<table>
<thead>
<tr>
<th>MUD A</th>
<th>Composition</th>
<th>Fresh water</th>
<th>20 ppb Milgel</th>
<th>10 ppb Unical</th>
<th>4 ppb Ligeo</th>
<th>Systeric to pH = 8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight</td>
<td>8.85 lb/gal.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rheology (72°F)</td>
<td>PV = 16</td>
<td>Gw = 1</td>
<td>YP = 4</td>
<td>Gu = 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>API Filter Loss</td>
<td>4.5 ml</td>
<td>Marsh Funnel = 42 Seconds</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MUD B</th>
<th>Composition</th>
<th>Fresh water</th>
<th>3 ppb Aquagel</th>
<th>7 ppb Xact Clay</th>
<th>0.75 ppb XC</th>
<th>0.5 ppb Impermix</th>
<th>Preservative</th>
<th>Weight</th>
<th>Rheology (72°F)</th>
<th>PV 2 18</th>
<th>YP = 24</th>
<th>Gw = 5</th>
<th>YP = 4</th>
<th>Gu = 10</th>
<th>pH = 8.0</th>
<th>Marsh Funnel = 48 seconds</th>
<th>API Filter Loss</th>
<th>8.0 ml</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>MUD C</th>
<th>Composition</th>
<th>Native Fresh Water Mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>9.1 lb/gal.</td>
<td></td>
</tr>
<tr>
<td>Rheology (72°F)</td>
<td>PV = 4</td>
<td>Gw = 2</td>
</tr>
<tr>
<td>API Filter Loss</td>
<td>31.8 ml</td>
<td></td>
</tr>
</tbody>
</table>

**PRESENT INVENTION FLUID REFERRED TO IN TABLE 3 AS KCl-SEPARAN AP-273**

**FLUID**

- **Composition**: 0.5 ppb Separan AP-273 in 3% weight potassium chloride brine.
- **Viscosity**: 2-3 cp (72°F)
- **Weight**: 8.5 lb/gal.
- **API Filter Loss**: High

Some of the more active shales can be protected at high stress levels by increasing the KCl concentration. As shown in Test 39, the Lower Cretaceous shale from the Pachuta Creek field failed in 66 and 292 minutes when tested at 3,500 psi stress with native field mud and three percent KCl polymer fluid. By increasing the KCl concentration to 10 percent (Test 40) the Lower Cretaceous was protected at 2,500 psi for 24 hours without sample failure.

Alkaline metal silicates can be used in the aqueous drilling fluids of the present invention to inhibit or prevent corrosion and/or to maintain the pH of the solution within the range of 9-12. In such a use a small amount of alkaline metal silicate and/or hydroxide can be added to the drilling fluid (such as sodium and/or potassium silicates and/or hydroxides). Potassium silicate or mixtures of potassium silicate and sodium hydroxide are preferred and the preferred and the amount used should be such as to maintain the pH of the total drilling fluid composition in the range of 9-12, preferably between 9.5 and 11.5. By the addition of 0.05-0.1 percent volume of 40% Be’ sodium silicate liquid or 0.05-0.1 percent weight metaphosphate granules and maintaining the pH between 9.5 and 10.0 with additional NaOH to a shale stabilizing drilling fluid of the present invention (such as a aqueous KCl-Separan AP-273 solution) corrosion can be effectively controlled or eliminated. It is additionally advantageous to use metasilicate when such a shale stabilizing solution is used for clear fluid drilling since the metasilicate tends to aid in the flocculation and settling of solids. However the silicate should not be used in waters, containing more than about 100 parts per million calcium ion since the silicate will be precipitated as an insoluble calcium silicate.

The suspension of pre-hydrated bentonite in the aqueous solution of polymer salt is used when additional hole cleaning capacity is required. Field tests have indicated that in many drilling situations from about 4-6 pounds per barrel of prehydrated bentonite can readily be suspended in such a solution to provide a stable mud system, particularly if an additional ¼ per barrel of the polymer is added to compensate for the polymer adsorption by the bentonite. In such a mud the rheological properties tend to increase with increasing concentrations of salt until amounts in the order of 70 pounds per barrel are reached at which time the rheological properties tend to decrease with increasing concentration of salt.

In general, the rheological properties of the present drilling fluid system can be varied from a clear fast drilling system to a gelled system with excellent hole cleaning properties. The viscosity of the system can be adjusted by dilution with fresh water or by the addition of pre-hydrated bentonite or viscosifiers such as the Kelzan XC polymer. Filter loss control to within 8 cc’s is achieved, for example, by addition of Drispac. Solids control is achieved by means of fluorocarbons in the clear fluid system and by the use of dilution/shakes/desilters in the gelled system. When the pre-hydrated bentonite is included, the API 30 minute filter loss is preferably maintained at from about 8 to 30 cc’s. The filter loss should be low enough to avoid a buildup of thick filter cakes along highly permeable earth formations that could cause tight hole problems. On the other hand, it should be high enough to avoid a reduction in the shale stabilizing effect of the polymer deposition from the aqueous solution filtrate.

Drilling mud thinners and filter loss additives can be used where desirable. Particularly suitable thinners are lignosulfates and particularly suitable filter loss additives are Drispac (polyanionic cellulosic, Drilling Specialties Co.) and OC-Polymers (Xanthan biopolymer, to ½ pound per barrel of either is generally sufficient. The filter loss agent should be utilized with caution to avoid reducing the API 30 minute filter loss to below about 8 ml. In order to obtain the present effective shale stabilization, the polymer must be a polycrystalline that has shale protection properties and sufficient proportions of the polymer must be available to the shale to effect that protection. If the filter loss control is such that the mud provides a filter cake that is too tight, the amount of polymer that is available to the shale surfaces behind the filter cake may be decreased beyond the minimum required to stabilize the shale.

Weighting materials can be used in the polymer muds of the present invention. Such materials can be conventional weighting materials such as barite, iron oxides, etc. It has been found that samples weighted to values in the order of 13.8 pounds per gallon maintain good...
rheological properties and shale protection. Since the partially hydrolyzed polyacrylamides such as Separan AP-273 is adsorbed on barite at the rate of about 0.03 pounds of polymer per 100 pounds of barite, an additional proportion of polymer (such as an additional 0.03 pound per 100 pounds of barite) should be added to compensate.

The equipment utilized in drilling with the present clear fluid and subsequently bentonite-containing mud can be generally conventional equipment. As known to those skilled in the art, the bentonite is preferably prehydrated at the well site shortly before use and the prehydration system should be designed to prevent salt contamination from the main mud system. The use of a separate circulation system is advantageous and the prehydrating or preyielding tank can be independent or one compartment of a suction tank.

Field Tests (Examples 42–44)

The present polymer muds have a good tolerance for normally encountered drilling fluid contaminants and anhydrite stringers have been drilled during field tests without any detrimental effects other than the decrease in mud rheological properties that would be expected by those skilled in the art. More than 400 parts per million calcium ion has been found to cause the mud viscosity and yield to be decreased, however the changes were corrected by simply adding additional bentonite. Alternatively the calcium ions can be removed by adding barium carbonate or sodium carbonate if care is used with the latter to prevent the addition of an excess of the carbonate ions.

In the following field tests, clear drilling fluid aqueous solutions of from about 0.3 to 0.6 pounds per barrel Separan AP-273, from about 10.5 to 35 pounds per barrel potassium chloride, and sufficient sodium hydroxide to maintain a pH of from 9.5 to 10 were used. And, such solution were converted to polymer muds by addition of from about 10 to 20 pounds per barrel prehydrated bentonite to the aqueous solutions. The maintenance of the polymer muds included adjustments of clay content or filter loss material as required to maintain and API 30 minute filter loss of from about 8 to 30 ml.

Test example 42 was conducted in a borehole in which the upper portion was gas-drilled, from an intermediate casing at about 3,600 feet to a depth of 6,000 feet, at which depth it became necessary to mud-up the hole due to sloughing and otherwise generally bad hole conditions. The dry gas-drilled hole was mud-up with the above polymer mud with no problems. About 48 hours after the mud-up, earth formation cavities having diameters of from about ¼ to ¾ inch were filtered out of the returning mud stream by the shale shaker. This occurred for a period of about 10 to 12 hours after which little if any caving was apparent. The drilling with the polymer mud proceeded without incident to a depth of 10,263 feet at which point 7 ¼ intermediate casing was run. The casing was cemented and the bonding provided an excellent cement bond log. The polymer mud weight was controlled at between 8.8 and 8.9 pounds per gallon by using only the shale shakers and the desilts to control the amount of suspended clay. While the mud viscosities were being maintained in the range of 100 to 150 seconds per quart, a fine screen high speed shaker was used. The viscosity control was achieved by simply adding pre-hydrated bentonite or diluting with water as required. Sour gas was encountered after round tripping the drill string from a depth of 7,100 feet. The mud blackened but no observable viscosity effects could be noted.

Test example 43 was conducted in an area in which severe hole instability problems had been previously experienced at depths below 9,000 feet when drilled with conventional fresh water mud systems. No instability problems were encountered with the test well drilled with the present shale stabilizing polymer mud from near surface to a total depth of 15,522 feet. Mud on bottom and bridges were rarely encountered. In one instance two cores and a drill stem test were run back-to-back with no need for a cleanout trip between the operations. It was found however that at least three percent (10.5 pounds per barrel) potassium chloride was required in order to maintain shale stability. Disipac was utilized as a filter loss control agent to maintain an API 30 minute filter loss of about 8–10 ml. A layer of anhydrite was drilled and the drilling of it caused a slow decrease in the viscosity of the mud (although it contained from about 10 to 11 pounds per barrel of bentonite). A remedial increasing of the bentonite content (to from about 13 to 15 pounds per barrel) increased yield point and gel strength dramatically, and required an addition of lignosulfate to reduce the gel strength. The anhydrite contamination had very little effect on water loss control, causing only an increase from about 7.5 cc to 10 cc in 30 minute API filter loss. Addition of 0.1 pound per barrel Disipac reduced the water loss to the original level. In this well the mud was weighted to 10.5 pounds per gallon by the addition of barite with no problems and no appreciable effect on viscosity.

Test example 44 was conducted in an area in which deviation and hole sloughing problems have been considered to be severe enough to make it unfeasible to use a clear water drilling fluid, due to subsequent hole problems. However, in view of the cost savings obtainable and the proven capability of the present system to alleviate hole enlargements problems (by means of the high hole-cleaning capacity of the gelled polymer system), the top section of the test borehole was drilled with a clear potassium chloride brine containing only a flocculant. At a depth of about 2,000 feet, mirror hole-cleaning difficulties were corrected by simply increasing the pump rate to provide an increased annular velocity. Such a clear fluid, fast drilling, procedure as successful to a depth of 7,258 feet at which depth the accumulation of excessive fill on bottom necessitated mudding up. By that time the drilling fluid pumping rate had been increased to a maximum of 600 gallons per minute in a 5 inch drill pipe in a 8 inch borehole to provide an annular velocity of above 284 feet per minute. The borehole was then mudded-up with the present polymer system and was drilled on to an intermediate casing depth with no problems. The test provided a very substantial saving in cost.

What is claimed is:

1. A process for drilling a borehole that encounters a water-sensitive shale, with the borehole being drilled by operating a drilling means and circulating a drilling fluid, which process comprises:

   initially enhancing the rate of circulating the drilling fluid a relative low density, fast drilling, substantially clear fluid;

   when the encountering of borehole instability due to the interaction of the water and water-sensitive
shale is at least imminent, circulating as the drilling fluid an aqueous solution that (a) contains a partially hydrolyzed polyacrylamide which is about 20 to 50 percent hydrolyzed, has a molecular weight of more than about one million, and is present in an amount at least sufficient to satisfy the minimum adsorption requirements of the shale, and (b) contains an amount of alkali metal halide which is at least sufficient to enhance the adsorption of polymer on the shale, with said aqueous solution being circulated so that the shale is contacted by the solution and stabilized by the adsorption of the polymer; and

when the encountering of mechanical borehole instability due to a sloughing of mechanically incompetent earth formations is at least imminent, suspending prehydrated bentonite in said aqueous solution in an amount that provides a suspension having both a relatively high solids-lifting capacity and a filter loss that is high enough to permit said shale stabilization, and circulating the suspension so that the earth formation solids are removed by the circulating suspension while said shale stabilization is continuing.

2. The process of claim 1 in which said aqueous solution contains from about 0.2 to 0.75 ppb of the polymer and from about 7–7 ppb of the halide, and said suspension contains from about 6–20 ppb of the bentonite and has an API 30 minute filter loss of from about 8–30 ml.

3. The process of claim 1 in which said initially circulated clear fluid is a gas.

4. The process of claim 1 in which said initially circulated fluid is brine.

5. The process of claim 1 in which said initially circulated fluid is said shale-stabilizing aqueous solution of polymer and salt.

6. The process of claim 1 in which said initially circulated fast drilling fluid is gas and said subsequent circulations of (a) a shale-stabilizing aqueous solution of polymer and salt and (b) a suspension of prehydrated bentonite in that solution are effected substantially simultaneously by a circulation of said suspension.

7. A process for drilling a borehole that encounters a water-sensitive shale, with the borehole being drilled by operating a drilling means and circulating a drilling fluid, which process comprises:

initially enhancing the rate of drilling by circulating as the drilling fluid a relatively low density, fast drilling, substantially clear fluid;

when the encountering of borehole instability due to the interaction of water and water-sensitive shale is at least imminent, circulating as the drilling fluid an aqueous solution that (a) contains a partially hydrolyzed polyacrylamide which is about 20 to 50 percent hydrolyzed, has a molecular weight of more than about 1 million, and is present in an amount at least sufficient to satisfy the minimum adsorption requirements of the shale and (b) contains an amount of alkali metal halide which is at least sufficient to enhance the adsorption of polymer on the shale, with said aqueous solution being circulated so that the shale is contacted by the solution and stabilized by the adsorption of the polymer; and

when the encountering of mechanical borehole instability due to a sloughing of mechanically incompetent earth formations is at least imminent, suspending a drilling fluid viscosifier in said aqueous solution in an amount that provides a suspension having both a relatively high solids-lifting capacity and a filter loss that is high enough to permit said shale stabilization, and circulating the suspension so that the earth formation solids are removed by the circulating suspension while said shale stabilization is continuing.

* * * * *
CERTIFICATE OF CORRECTION

United States Patent Office

Patent No. 3,738,437 Dated June 12, 1973

Inventor(s) RONALD F. SCHOEPERMAN

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In claim 2, line 3, "7-7 ppb of the halide" should read: -- 7-70 ppb of the halide --.

Signed and sealed this 27th day of November 1973.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

RENE D. TEGTMeyer
Acting Commissioner of Patents
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