CLAY-FREE AQUEOUS DRILLING FLUIDS

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INTRODUCTION

Historically, montmorillonitic clays have provided the essential rheological and filtration properties of drilling fluids; and because of their versatility, clay muds continue to this day to be used more frequently than any other type of mud. They are, however, inherently high-solids, high-viscosity muds. Even if they are initially formulated to have a low viscosity, their tendency to incorporate shales and clays encountered during drilling causes the viscosity to increase, often to undesirably high values. Unfortunately, the thinners used to combat these high viscosities increase the tendency of the drilled solids to disperse into the system, thereby creating a vicious circle. These high viscosities create handling problems; the concomitant high gel strengths increase the tendency to swab-in gas when pulling out of the hole, and cause pressure surges which may result in loss of circulation when running into the hole. But, worst of all, high-viscosity, high-solids muds are slow drilling muds, and consequently increase drilling costs.

Clay-free fluids were introduced to overcome these disadvantages. There are many different types but their essential features are that they contain no clay in their initial make-up, none is added during drilling, and they are treated either chemically or mechanically or both to reject virtually all drilled solids at the surface. For this reason, they are sometimes referred to as "closed circuit systems". In order to maximize drilling rate the solids content must be kept very low, and the viscosity no higher than that required to clean the hole. Furthermore, the agents used to provide filter loss properties, increase the viscosity or raise the density are those that will have minimum influence on drilling rate; for example, shear-thinning polymers are used to increase viscosity and soluble salts are used to increase density. Further advantages of the polymers are that they provide excellent rheological properties for cleaning the hole at relatively low pump pressure, and that some of them have the property of inhibiting caving shales.

True clay-free systems are not as versatile as clay muds and cannot be used in every well. For example, since they use soluble salts for weighting purposes, weights above 11.5 ppg cannot be obtained unless solids are added, which violates the low solids requirement. Similarly, it is difficult to drill through a thick section of montmorillonitic shale and maintain the low solids requirement. Also, the maximum permissible bottomhole temperature is 375°F.

This paper describes the principal types of clay-free fluids, the principles under which they operate and the conditions to which each type is best suited.

MUD PROPERTIES THAT INFLUENCE DRILLING RATE

Since the biggest advantage of clay-free drilling fluids is the faster drilling rates that may be achieved with them, it is well to discuss briefly the reasons why muds, in general, tend to reduce drilling rate. The first reason is the tendency for the mud to form a filter cake on the bottom of the hole, thus creating a pressure differential on the bottom of the hole that opposes the removal of the chips.[1,2,3] It has been shown, however, that the significant parameter in this action is not the API filter loss, which depends on the colloidal content of the mud, but the concentration of particles in the size range required to bridge the pores on the bottom of the hole, and thus initiate the formation of the filter cake.[4] The great majority of formations are bridged by particles ranging from 70 to 1 micron, which roughly corresponds to the size range of the inert solids present in all drilling muds. If the content of these solids is kept below about 2%, it is possible to have a mud that forms virtually no filter cake on the bottom of the hole, thus permitting a fast drilling rate, but that will still have a low API filter loss and form a normal filter cake on the sides of the hole.

The other property of a drilling mud that affects drilling rate is its viscosity.[5] The lower the viscosity, the quicker the chips are removed from under the bit and the faster the drilling rate. But it must be remembered that the viscosity of a mud changes with the rate of shear, and that shear rates under the bit are very high. Therefore, in comparing the influence of various muds on drilling rate their viscosities must be measured at high rates of shear, as may be done in a pipe or a capillary viscometer.

MINIMUM VISCOSITY CLAY-FREE FLUIDS

Minimum viscosity fluids may be defined as those whose viscosity is no higher than that of their base fluid, which may be water or brine. The simplest such fluid is water treated with minute amounts (0.0175-0.175 ppb) of an acrylamide copolymer. The polymer flocs out the clays and other fine solids, and if well-designed earthen settling pits are used, practically clear water is returned to the pump suction. The polymer provides only slight filter control, just enough to prevent massive losses to permeable formations. As one would expect, very fast drilling rates are obtained with this fluid; but it can be used only for drilling hard, massive, relatively impermeable formations.

Somewhat better filtration properties are obtained with milk emulsions, which in their purest form consist of about 5% diesel oil emulsified with an anionic emulsifier, usually a polyoxyethylene tall oil ester. The tendency of the oil to wet rock surfaces helps preserve the drill cuttings and promotes their separation in a cyclone. Lower filter losses at the expense of drilling rate may be obtained by adding small amounts of starch. Milk emulsions are used only in hard rock drilling.

Asphalt emulsions[4] provide fast drilling rates and low filter losses (around 5 cc API); they are made by emulsifying an asphalt-diesel oil mixture in water or brine (NaCl or $CaCl_2$). A strong oil-wetting agent is added to the oil phase, and a cationic emulsifier is added to the water phase, a combination which causes asphalt to be deposited on any solid surface that the emulsion contacts. This action flocculates the fine drilled solids and enables a very low solids content (around 1%) to be maintained without the aid of desilters. Drilling rates approaching those obtained with clear water have been obtained with asphalt emulsions, but they are expensive to use because of the need to be continually replacing the asphalt and surfactants.

VISCOUS FLUIDS

The minimum-viscosity fluids discussed above provide adequate hole cleaning provided that sufficient pump capacity is available and that the hole remains fairly close to gauge. There often are, however, conditions which necessitate the use of more viscous fluids, which inevitably entails some loss of drilling rate. This loss of drilling rate may be minimized if the required viscosity is obtained by the addition of a suitable polymer. The characteristics of such a polymer are:

1. It is adsorbed on shale surfaces, encapsulating the drill cuttings and thus inhibiting their dispersion into the system.
2. Its apparent viscosity in turbulent flow decreases sharply with increase in flow velocity. Therefore its viscosity under the bit is low relative to its viscosity in the annulus and so its effect on drilling rate is less than the effect of a clay mud of equal carrying capacity. Polymers also permit relatively high drilling rates because they give lower pressure drops in the drill pipe than do clay muds or even clear water, (since the viscosities of these fluids remain constant in turbulent flow)[7]. Therefore more hydraulic horsepower is available at the bit with the polymer fluids.
3. In laminar flow, the viscosities of clay and polymer muds both decrease with rate of shear but more so with polymer muds. Walker[8] has shown that the greater the variation of viscosity with rate of shear the better the carrying capacity for a given pressure drop in the annulus; but it should be noted that experiments by Sifferman et al[9] cast some doubt on this thesis. However, their experiments into this particular aspect of hole cleaning were too limited for any firm conclusions to be drawn.

In Table 1 the relevant rheological properties of various polymer suspensions are compared with those of water and of bentonite. The first column compares the pressure drops given by the fluids in turbulent flow at a constant rate in 2-in. tubing; all fluids, save water, having an apparent Fann viscosity of about 8 cp. Note the big difference between bentonite and the polymer fluids. The values shown were calculated from data obtained in a laboratory pipe viscometer.[7] The change of viscosity with rate of shear of the fluids in laminar flow may be judged from the YP/PV ratio, as suggested by Walker[8]. The higher this ratio the better; or alternatively from n′ in the last column, the lower this value the better. The exponent, n′, in the power law relates shearing stress to shear rate and was determined in a pipe viscometer[7] according to modified equations of Dodge and Metzner.[10] The exponent n′ so derived is to be preferred over n as derived from Fann multispeed readings, which is not a true constant with some fluids.[7]

It should be noted that the values of YP/PV and n′ given in Table 1 for bentonite are not typical of clay muds in the well. In practice, clay muds have a much higher solids content and they usually have been treated with thinners; consequently, their YP/PV ratios are considerably lower.

TABLE 1—COMPARISON OF FRICTION REDUCING AND RHEOLOGICAL PROPERTIES OF VARIOUS POLYMERS AND BENTONITE

All Suspensions Had a Fann Apparent Viscosity Approximately 8 cp

Expt. No.	Fluid	Press. drop in 10,000′ 2″Tbg @ 250 gpm psi	Fann Viscometer PV, cp	Fann Viscometer YP lb./100 ft²	Fann Viscometer YP/PV	Pipe Viscometer Exponent n′
1	Water	1278	1	0	0	1
2	21 ppb Wyoming bentonite	2981	6.5	5.5	0.85	0.69
3	1.2 Guar Gum	335	6	4	0.67	1.0
4	1 ppb hydroxyethyl cellulose (HEC)	384	6	3	0.5	0.85
5	1 ppb carboxymethyl cellulose (CMC)	432	6.5	1	0.15	0.95
6	1 ppb polysaccharide biopolymer	664	4	8.5	2.1	0.46
7	0.6 ppb 30% hydrolysed polyacrylamide	573	4.5	7	1.6	0.62
8	1.5 ppb polyacrylamide	897	6	4	0.67	0.82

FORMULATING CLAY-FREE DRILLING FLUIDS

The suspensions listed in Table 1 consisted of polymer and water in quite low concentrations in order to demonstrate their unusual properties. Such fluids would generally not be suitable for use in a drilling well; practical drilling fluids often require higher viscosities or densities, or better filtration control. The formulation of polymer drilling fluids to obtain the best compromise between the various requirements is discussed below.

The first consideration is the selection of the base polymer most suited to the anticipated hole conditions. If no specific problems are anticipated, then the polymer that will permit the fastest drilling rate should be selected. The pressure drops given in the first column of Table 1 provide a rough guide to this end. But in comparing the various polymers it is important to realize that the results depend on the size of pipe, the rate of circulation, and the concentration of the polymers. Therefore, prospective fluids should be tested in a pipe viscometer and the data converted to the specific well conditions.[7]

If difficulties in hole cleaning are anticipated, then a polymer which provides a high YP/PV ratio, or a low n′ exponent should be used. If the problem is more likely to be fill during trips, then a crosslinked polysaccharide, or a mixture of same with another polymer should be used. This is because the crosslinked polysaccharide is thixotropic; i.e., its gel strength increases with time of standing. But it should be remembered that high gel strengths increase the tendency to swab-in gas, and promote loss of circulation through pressure surges. Therefore the polysaccharide should be used in moderation.

When densities above 10 ppg are required, stabilized HEC or a polymer which is stable in concentrated $CaCl_2$ should be selected.

Unstable shales present a special problem. Some polymers have a marked stabilizing influence, though the mechanism is not well understood. It is definitely not due to filtration control since the stabilizing action diminishes when the filter loss is decreased. The stabilizing action depends on the salinity, the type of salt, and the type of shale as well as the type of polymer. The only way to determine the best formula is to run tests on samples of the shale in question in tests in which subsurface conditions can be simulated.[11] Good results have been obtained both in the laboratory and the field with partially substituted polyacrylamides and stabilized HEC.

Having decided on the best polymer to use, the next step is to make up a fluid which will have the necessary weight, rheological and filtration properties. It is obvious from what has been said already that additives such as bentonite or barite cannot be used for these purposes without destroying the fast drilling characteristic of clay-free fluids. Table 2 shows how the required properties are best achieved when stabilized HEC is used as the base polymer. The effect of the various modifications on drilling rate may be judged from the calculated pressure drops in 10,000 feet of 3-1/2 in., 11.2 lb/ft drill pipe.[7] Comparison of experiments 1 and 2 show how the filter loss may be sharply reduced with virtually no effect on the pressure drop. Experiments 2-7 compare the properties of weighted fluids. Note particularly the lower pressure drops given by the HEC-brine fluids; e.g., for 11 ppg fluids, HEC in $CaCl_2$—265 psi, $CaCl_2$ alone—705 psi, and bentonite plus barite—1730 psi. A comparison of experiments 8 and 9 shows that it is better to obtain higher viscosities by increasing the concentration of HEC (P.D. 165 psi) rather than by adding bentonite (P.D. 548 psi).

TABLE 2—PROPERTIES OF HEC CLAY-FREE DRILLING FLUIDS

Expt No.	Composition	Weight, ppg	API Filter Loss, cc	P.D., 10,000' 3 1/2x11-2 lb. DP	PV, cp	YP, $\frac{lb.}{100\ ft^2}$
1	1 ppb Stabilized HEC	8.3	55	135	6	3
2	6 ppb Stabilized HEC+lignosulphonate +ground carbonates	8.5	8.5	143	3	1
3	As for Expt. 2 but in Sat. NaCl	10.1	4.3	220	6	1.5
4	Sat. NaCl	10.0	--	635	2	--
5	As for Expt. 2 but in conc. $CaCl_2$	11.0	11.0	265	3.5	2.5
6	Conc. $CaCl_2$	11.0	--	706	4.5	--
7	21 ppb Bentonite + Barite	10.8	15	1730	10.5	9
8	2 ppb Stabilized HEC	8.3	17.8	165	13	15
9	1 ppb Stabilized HEC + 8 ppb Bentonite	8.5	130	548	8.5	8.5

MAINTENANCE OF CLAY-FREE SYSTEMS WHILE DRILLING

If efficient desilters are included in the mud circulating system, and close attention paid to their effective operation so that a true "closed circuit" is maintained, clay-free systems will require little treatment during drilling. If the inert solids content is allowed to rise above about 2% the drilling rate will fall off rapidly.

EFFECT ON PRODUCTIVITY IMPAIRMENT

Clay-free muds cause less productivity impairment than conventional muds because of their low solids content. If they are formulated with only acid or oil-soluble components, such impairment as they *do* cause can be rectified. This subject is beyond the scope of this paper but has been dealt with at length previously.[12]

CONCLUSIONS

Clay-free drilling fluids have the following advantages:

1. They permit fast drilling rates provided drilled solids are not allowed to accumulate in the fluid and no bentonite or barite is added during the course of drilling.
2. Their rheological properties are such that good hole cleaning can be obtained at relatively low pump pressures.
3. They can be formulated to stabilize caving shales.
4. They are not affected by formation salts.
5. They cause little or no productivity impairment.

The principal limitations to their use are:

1. Weights over 11.5 ppg can be obtained only by the addition of solids, with consequent decrease in drilling rate.
2. They cannot be used when bottomhole temperatures exceed 375°F.

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