DRILLING FLUID PROPERTIES & FUNCTIONS

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I. Introduction

The rotary or air method of drilling is distinguished by two factors; (1) the bit is rotated or hammered against the bottom of the hole, and (2) a fluid and/or air is circulated down the hollow drill string, through the bit, and up the annulus removing the cuttings. The most common, fastest, and effective type of drilling in unconsolidated permeable formations is the mud rotary system. In consolidated rock formations, down hole hammer drilling using air, mist, or foam is the most advantageous and effective type of drilling. This paper focuses on the role of the circulating fluids as they relate to drilling function and fluid properties. The properties of a drilling fluid useful in performance one function may be detrimental to another. A proper understanding of drilling fluid's role, be it bentonite, polymers, or chemicals added to make up water as treatments or drilling fluid enhancement materials are essential for efficient, productive, and safe drilling.

II. Functions of a Drilling Fluid

A. Cool and lubricate the bit and drill string.
B. Clean the bottom of the hole beneath the bit
C. Transport cuttings to the surface.
D. Suspend drill cuttings in the annulus when circulation is stopped.
E. Drop off the cuttings at the surface.
F. Support the walls of the borehole.
G. Control subsurface pressure.
H. Stabilize the borehole.

To achieve these functions, the following side effects must be minimized.

A. Damage to subsurface formation, especially those that may be productive.
B. Reduction of the penetration rate.
C. Swab and circulation pressure problems.
D. Loss of circulation.
E. Erosion of the borehole.
F. Swelling of the sidewalls of the borehole creating tight spots and/or hole swelling shut.
G. Sticking of the drill pipe against the walls of the hole.
H. Retention of undesirable solids in the drilling fluid.
I. Wear on the pump parts.

III. Characteristics of a Drilling Fluid

A. Lubricity
B. Velocity
C. Viscosity
D. Density
E. Gel Strength
F. Filtrate Control

IV. Relationships Between Characteristics and Functions

A. <u>Cool and Lubricate the Bit and Drill String</u>

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As the drill bit and drill string rotate in the borehole, they become hot due to friction. A liquid fluid will transfer heat from the bit and drill string, thereby cooling them. A drilling fluid that has slickness or lubricity will lubricate the drill bit and drill pipe, reducing heat-causing friction.

B. Clean Beneath the Drill Bit

During circulation, the drilling fluid is ejected through jets at high velocity. This hydraulic force strikes the bottom of the hole, blowing cuttings from beneath the bit and starting them up the annulus where the drilling fluid can then transport them to the surface. If the bottom of the hole is not cleaned of cuttings, the bit regrinds them, thus reducing the rate of penetration.

C. Transport, Suspend and Drop Off Cuttings

Once the cuttings are cleaned from the bottom of the hole, it is the drilling fluid's function to transport them to the surface. To accomplish this, the drilling fluid must have a high enough viscosity (thickness) to transport the cuttings at minimum velocity from the mud pump. In transporting cuttings, increased viscosity can accomplish this task at reduced velocity. At the same time, decreased viscosity will require an increase in velocity. A drilling fluid should be mixed to a minimum viscosity and pumped at a minimum velocity that will still allow cutting removal.

When drilling stops, for whatever reason, the drilling fluid must be able to suspend the cuttings, not allowing them to fall back down the annulus where they can collect around the drill bit. Once the cuttings reach the surface, they must be dropped off and not recalculate. If the cuttings are not dropped off, they will cause wear on the pump and increase pressure on the formation.

D. Support the Walls of the Hole

Lateral support of hole walls is removed as the bit drills a subsurface formation. Unless the drilling fluid prior to the casing being set replaces the support, the formation will collapse into the borehole. The mechanism, depending on the characteristics of the drilling fluid and the nature of the formation being drilled, prevents this from occurring.

If the formation is very firm and consolidated (granite is an extreme example), little support by the drilling fluid is required. If the formation is relatively firm and fairly consolidated (shale for example), sufficient support may be obtained solely from the density of the drilling fluid or drilling mud. If the formation is an unconsolidated permeable formation (sand, for example), the drilling fluid must have sufficient density (weight), and it must have the ability to form a thin deposition of particles (filter cake), on the walls of the borehole.

E. Control Pressure and Stabilize the Borehole

Two types of pressure are exerted on the borehole during drilling, formation pressure and hydrostatic pressure. Formation pressure can collapse the borehole if it is not overcome by hydrostatic pressure pushing back against the formation. Hydrostatic pressure is the weight or density of the volume of drilling fluid or mud pushing against the formation. In order to have hydrostatic pressure, the drilling fluid must push back against the formation with minimal penetration into the formation. In unconsolidated permeable formations, the hydrostatic pressure occurs when the weight of the fluid is in contact with the impermeable deposits (filter cake) placed on the sides of the borehole by the drilling fluid. The filter cake and the hydrostatic pressure thereby control the formation pressure, reduce fluid loss and prevent caving, resulting in hole stabilization.

V. Side Effects Minimized

A. Damage to Subsurface Formation

Almost any drilling fluid will alter the original characteristics of the formation it comes in contact with, although some formations are more sensitive than others and some fluids are more damaging. Damage to subsurface formations can take two forms; (1) reduced ability of a formation to produce water, and (2) reduced well bore stability. Damage to producing formations results from physical plugging by inert solids. The borehole can become unstable through chemical reactions (as in water-sensitive shale's), or through physical erosion. Particularly sensitive formations may require special treatment of the fluid, or even a special fluid.

B. Reduction of Penetration Rate

The most significant factor affecting penetration rate is the difference between the hydrostatic pressure of the drilling fluid and the formation pressure. Lower penetration rates are obtained if the density (weight) of the drilling fluid is much higher than the pressure gradient of the formation. To minimize hydrostatic pressure, the drilling fluid weight should be maintained at below 9 pounds per gallon of fluid. Excessive solid buildup and increased viscosity are factors that also lower penetration rates.

C. Swab and Circulation Pressure Problems

Swabbing (suction), and circulating pressure problems can be caused by a high viscosity, high solids content drilling fluid. A thick mud with high solids concentration reduces hydraulic energy available at the bit, increases pump wear, slows circulation, and can create a suction when the drill pipe is extracted or pulled from the borehole. To prevent these problems, viscosity and mud weight should be checked and maintained as follows:

* Mud weights less than 9 lbs./gal.
* Viscosity 32 to 36 as measured by a marsh funnel and cup.

D. Loss of Circulation

Loss of circulation is one of the most serious problems to overcome in drilling. Loss of circulation is partial or complete loss of the drilling fluid to the formation. Loss of circulation can occur due to naturally occurring fractures, crevices and channels. The driller has no control over these circumstances and must plug off the formation with a loss circulation material such as C/S Granular or Crumbles (bentonite). Loss circulation can also occur due to properties of the drilling fluid or mud. High viscosity, excessive density and high gel strengths can contribute to loss of circulation. To minimize this situation, frequent measurements of the drill mud should be taken. The density (weight) viscosity (thickness) and filtration (filter cake) should all be maintained at a minimum.

E. Erosion of the Borehole

Erosion of the borehole can occur when the drilling fluid is pumped at too great a velocity. Erosion can occur at the drill bit where the jetting action causes erosion. It can also occur as the fluid comes into contact with obstacles while it moves up the borehole at a rapid rate. As the fluid comes into contact with obstructions, it can begin to rotate causing a swirling effect that can erode the side of the hole. To minimize erosion, viscosity and velocity of the fluid should be minimized.

F. Swelling of the Side Walls and Sticking Pipe

If the borehole walls are not maintained, the fluid is allowed to continually penetrate the formation, and the hydration of native clays and shale are not minimized, the result will be tight spots and/or swelling shutting off the borehole. This is the result of a thick spongy filter cake or hydrated native clays. The result of either will be, in the worst case, stuck pipe. The simplest problem this causes is difficulty in coming out or going back into the borehole. It may necessitate redrilling through an already drilled formation. This reduces penetration rate and increases drilling time. To overcome this problem in unconsolidated formations, the use of a bentonite drilling mud (which seals off the formation with a thin impermeable filter cake) is advantageous. In swelling formations of native clay, the addition of polymers may be advantageous in that it coats the clays to prevent their swelling.

G. Retention of Undesirable Solids in the Drilling Fluid

There are two types of solids in a typical drilling mud. Functional or beneficial solids are, added to the make up water in order for the drilling mud to perform certain functions. Sodium bentonite is most commonly used.

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Objectionable solids are those that are picked up by the drilling mud as it circulates inside the borehole. Sand and other formation cuttings are examples of objectionable solids. Objectionable solids perform no function and have adverse effects on the drilling program and the drilling equipment. Objectionable solids increase both density and viscosity of the drilling mud. This makes the drilling mud more difficult to pump and requires greater velocity to move the mud. It increases pressure on the formation, resulting in a thicker filter cake, etc. Objectionable solids must be removed either chemically or mechanically from the drilling mud. Often, the addition of polymers to reduce gel strength of the drilling mud will aid in removal of cuttings. The best way to remove undesirable solids is to mechanically remove them through the use of a desander. If the solids are not removed, they will cause additional wear on the pump parts. By removing these solids, the maintenance on the mud pump and rebuilding of the mud pump will be minimized.

VI. Types of Drilling Fluids

A. Clay (bentonite)

B. Polymer

C. Foam

VII. Bentonite Clay

A. Advantages

i. High viscosity

ii. Low solids

iii. Suspends cuttings

iv. Fluid loss control

v. Stabilizes borehole

vi. Aids in prevention of lost circulation

B. Disadvantages

i. Retards settling of cuttings. The gel strength and viscosity properties of the bentonite clay allow for cutting suspension and removal. This advantage of bentonite clay becomes a disadvantage in the settling of small cuttings and sand at the surface.

ii. In highly swelling clays and shale's, the use of bentonite clay alone will not be sufficient to prevent hydration and swelling of the formation.

iii. Bentonite is sensitive to water contamination. Hard water and salt water have adverse effects on bentonite. Low pH and extremely high pH water will also affect the bentonite clay performance.

C. Overcoming Disadvantages

i. If the settling of cuttings becomes a problem in using bentonite clay, the addition of small amounts of polymers will aid in this application. Polymers increase the viscosity of a bentonite clay mud. At the same time, no additional solids are being added, and the gel strength characteristic of the bentonite clay is reduced. This allows for better cutting removal. The best method for removing cuttings is the use of a desander. The desander removes a greater percentage of sand and cuttings than the addition of polymers, and does not change the properties of the bentonite clay. The use of a desander will increase the life of the bentonite clay. It will also reduce maintenance and repair of the mud pump.

ii. In clay and shale drilling, it is most important to seal off this formation and to reduce hydration of the formation. Bentonite clay drilling mud cannot perform this function alone. Adding small amounts of polymer to the bentonite clay mud or switching to an all polymer drilling fluid system will

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offset this problem. Polymers coat the clay or shale preventing hydration. Always add polymers to hydrated bentonite not to the mix water. Adding polymers to the mix water will have the same effect on the bentonite as it will on the clay formation, and the bentonite clay will not hydrate.

iii. Bentonite clay's performance as the water in which it affects a drilling mud is mixed. The make up water is one of the main building blocks of the drilling mud. The pH, hardness, and salt content of the make up water determine the yield and performance of the bentonite clay.

a. The pH of the make up water should be within the alkaline range. On the pH scale, the acidity range is from less than 1 to just below 7. The alkalinity range is just above 7 to 14. A pH of 7 is considered neutral. The pH desired for mixing bentonite clay is between 8.5 and 10 on the pH scale. A pH of 9 is considered perfect. If the pH of the make up water is low, it will affect the hydration of the bentonite clay. The make up water should be treated with soda ash to raise pH. If the pH of the make up water exceeds 11 pH, flocculation of the bentonite clays can occur.

b. Hard water results in unsatisfactory performance of bentonite clay mud. Hard water contains dissolved calcium salts. Calcium salts impair the suspending and sealing properties of bentonite clay. Soda ash is used to treat hard water usually 1 to 2 pounds of soda ash will be sufficient treat for both high pH and hardness.

c. Salt has a most adverse effect on bentonite clay. Salt will affect the bentonite clay in the mix water and if it comes into contact with it during drilling. Salt adversely affects filtration, suspension, viscosity, and gel properties of bentonite clay. If the salt is in the make up water, the viscosity and gel development of the bentonite clay will be greatly reduced. Increased filtration and filter cake thickness will be accelerated. If the salt is encountered during drilling after freshwater hydration, the bentonite drilling mud will thicken. It will, over time, flocculate out the bentonite clay. There is no treatment for salt contamination. Bentonite clay should never be mixed in salt water. Find another water source for the mix water. If salt is encountered during drilling, the mud should be disposed of as it becomes contaminated, and fresh mud, made up in advance, should replace it. If the salt contamination within the formation is high or continuous, an alternate drilling fluid is advisable. VariFlo (guar gum) or Attapulgite clay mixed with Rel-Pac (dry polymer) are two alternatives that perform well in salt conditions. Note salt concentrations begin to adversely affect bentonite at 500 ppm. At 5000 ppm, bentonite should not be used.

VIII. Polymers

A. <u>Dry Polymers (Rel-Pac)</u>

Dry polymers such as Rel-Pac are non-toxic, non-fermenting organic polymers. There are many advantages to using a Rel-Pac type material in conjunction with a bentonite clay mud. Bentonite is very stable in the presence of Rel-Pac. Rel-Pac increases lubricity, decreases fluid loss, increases viscosity, and inhibits water sensitive shale and clay formations from hydrating. Dry polymers perform well in hard and salty water, and do not deteriorate with age. Dry polymers contain much higher active ingredients than liquid polymers.

B. <u>Natural Polymer (Guar Gum) - VariFlo</u>

Guar gum is natural occurring polymers in the form of a bean much like coffee beans. The product is finely ground and used as a drilling fluid or additive due to its viscosifying abilities. The product works well in fresh or salt water. The product is subject to biological degradation because it will support biological growth. Like all polymers, VariFlo (guar gum) is a poor filtrate control agent used alone. It also will not suspend cuttings when drilling stops. The product is sensitive to high temperatures and biological degradation. Mix waters should be low in temperature and free of enzymes and bacteria.

C. <u>Liquid Polymers (Insta Pac-425)</u>

Liquid polymers are polyacrylamide/polyacrylate emulsions kept in suspension with mineral oil. Because the polymer is a liquid, it is much faster mixing than dry polymers. Because of this it is the product of choice in the groundwater industry. Liquid polymers are high in viscosity buildings, but

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like all polymers, the product has poor filtration control when used alone. Liquid polymers work well in bentonite mud systems. They increase viscosity without increasing solids content of the mud. They increase lubricity and, working with bentonite, offer excellent fluid loss control. The liquid polymers are extremely sensitive to calcium and low pH water. The product is not as stable and has a much shorter shelf like than dry polymers. The primary function of Insta-Pac is as a clay shale formation hydration inhibitor. Secondary usage includes: use as a hydration inhibitor in mix water with granular bentonite for loss circulation material; use with bentonite clay as an aid to cuttings' removal; use as a low solid viscosifier with bentonite mud; and as an additive in foam drilling.

IX. Foam

When drilling in a consolidated formation, air drilling is typically used. The air drilling system increases cutting rates in rock by carrying the cuttings away from the drill bit and up the hole. The formation is naturally stable. Therefore, a drilling fluid systems objective is to maintain circulation, lower hydrostatic head, and remove cuttings using the lowest volume of water and compressed air. This is typically done using air, water, foam, and stiff foam, in that order, depending on the formations encountered, depth of hole, diameter of hole, and size of cuttings. When foams drilling, use 1 to 2 pints per 100 gallons of make up water. This should be added to the foam-mixing tank. The foam/water mixture is injected into the air stream from the compressor through the mixing nozzle. The resulting foam is piped through the parts in the bit where it expands and flows back up the hole to the surface bringing with it suspended cuttings.

If stiff foam is desired, the addition of Insta Pac- 425 in small quantities will help stiffen the foam. Insta-Pac 425 can also be used as a stiffing agent.

X. Chemicals

A. Sodium Carbonate ($NaCO_3$) soda ash is used to precipitate soluble calcium from water base mud's to control pH. When the soda ash enters hard water, it ionizes as Na^+ and CO_3= in the continuous phase. The carbonate ions combine with the calcium ions, forming calcium carbonate ($CaCO_3$), and inert precipitate. Treating hard water with soda ash prior to using the water to make a bentonite or polymer drilling fluid will result in a higher yield and more stable drilling fluid. Make up water should be treated with soda ash if 500-ppm calcium is present. Formula for soda ash addition is .001 x ppm Ca = lb. soda ash 42 gallons make up water. Excessive treatment with soda ash can cause high viscosity and gel strengths. If a mud has pH less than 11, soda ash additions will raise it.

B. Sodium Hydroxide (Caustic Soda)

A chemical primarily used to impart a higher pH. Caution is to be used when using caustic. It can cause severe burns and it is highly corrosive. To raise pH, use ¼ to 1-pound Caustic per 50 gallons of water. Product is not recommended for use by groundwater drillers.

C. Sodium Acid Pyrophosphate (SAPP)

SAPP has a 4.5 pH in 10% solution. It is used as a thinning agent, to disperse sticky clays and clean up and develop water-bearing formations. A very small amount of phosphate is required to thin clay-drilling fluids. Normally, ¼ to ½ pound per 50 gallons is adequate. To develop water well, use 4 to 10 pounds per 50 gallons of water, jetting and circulating product at the targeted water-bearing formation. The following phosphates can be used the same as SAPP:

* Sodium Hexametaphosphate - 6.8 pH
* Sodium Tetra phosphate - 8.0 pH

Care should be taken when using phosphate to develop water well. Development should start and be completed at the time the phosphate is introduced to the system. Introducing phosphate into a system and letting it sit for 6 to 12 hours prior to well development can damage water-bearing formation inhibiting proper well development.

D. Lime

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Lime (Ca[OH_2]) has the same detrimental effect as cement has on drilling mud. Lime increases viscosity, gel strength and fluid loss in the formation. The reaction is very severe. Lime hinders the ability to develop a water-bearing formation properly.

E. Borax (Sodium Borate)
Used as a viscosifier and gelling agent in conjunction with guar gum (VariFlo).

F. Chlorine (Sodium Hypo chlorite-Liquid or Dry)
Chlorine is primarily used to destroy bacteria once the well is completed. It is also used to destroy bacteria and enzymes in the mix water prior to using a guar gum (VariFlo) polymer.

XI. Mixing Drilling Mud

Attention should be given to the equipment used to mix drilling mud's and to the sequence of addition of the mud and any additives.

A. If the make up water requires treatment, always treat it prior to addition of the bentonite clay.

B. Use a jet hopper mixer to disperse the bentonite clay.

C. Bentonite clay (Super Gel-X) should be mixed slowly through the jet hopper at a rate of one 50 lb. bag every 10 to 20 minutes.

D. Volume of mud pit should be three times the volume of the proposed hole. Figuring volume of pit length (ft.) x width (ft.) x depth (ft.) x 7.5 = volume (gal).

E. The mud pit should be of such design that the drilling mud, during flow, changes direction and slows, allowing for cuttings to drop out.

F. The addition of viscosifying polymers should be made after the bentonite clay mud is thoroughly mixed in fresh water.

G. Viscosity and density tests should be run on the drilling mud following mixing. Periodic tests should be made during drilling and changes noted. Sand content tests should be run on the mud once drilling starts.

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