Drilling fluids & Maintenance equipment

Functions of drilling fluid

- Cool and lubricate the bit and drill string
- Clean the bit and bottom-hole
- Suspend solids and transport cuttings and sloughing to the surface
- Stabilize wellbore and control subsurface pressure

(Borehole instability is natural function of unequal mechanical stresses, physio-chemical interactions, pressure created when supporting material & surface exposed in the process of drilling a well. Drilling fluid must overcome both the tendency for the hole to collapse from mechanical failure or from chemical interaction of the formation with the drilling fluid)

- Assist with gathering subsurface geological data and formation evaluation

(Last two mentioned function should be given priority in designing drilling fluid and controlling its properties. Once drilling fluid has been selected, the properties required to accomplish the first three functions then can be estimated by hydraulic optimization process.)

Drilling fluid properties

Standards for testing:

API RP 13-B1 (Routine testing of water based drilling fluid)

API RP 13B-2 (Field testing of oil based drilling fluids)

Field determined properties:

Mud weight

The mud weight is density of fluid measured in terms of mass of a unit volume of the drilling fluid.
Usually low mud weights are desirable for achieving optimum penetration rates and minimizing the chances of loss circulation. However in practice, mud weights in excess of two and half-times the density of oil may be require to control the formation fluid influx and to control sloughing of troublesome formations.

Mud weight is measured by the conventional mud balance or pressurized mud balance. Pressurized mud balance can be useful to determine the density of the gas cut mud.

\[
P (\text{psi}) = 0.052 \times \text{density of mud (ppg)} \times \text{True vertical depth (ft)}
\]

**Equivalent circulating density**

Pressure exerted of mud in static condition is always less than the pressure applied in dynamic condition. This additional pressure is due to friction between mud and the system (annulus). This pressure acts in the opposite direction of the motion of the mud.

The pressure at the standpipe gauge is algebraic sum of frictional pressure losses that occurs in the circulating system. These pressure losses occur in:
- Surface equipment
- Inside string (drill string)
- Drill collars
- Bit nozzles and downhole tools
- Annulus

\[
P_{loss} = P_{sur.eq} + P_{dp} + P_{dc} + P_{bit} + P_{annulus}
\]

*Out of the total system friction pressure loss, only the loss in annulus contributes directly to the bottomhole pressure (causes increase in BHP)*

\[
ECD = \text{Phydrostatic} + \text{Pannular loss}
\]

Or in terms of mud weight,

\[
ECD \text{ (ppg)} = \text{OMW}(\text{ppg}) + \left(\frac{P_{annulus}}{0.052 \times TVD}\right)
\]
Viscosity

Viscosity is the property of fluid that causes resistance to flow. Drilling fluid viscosity is measured by funnel viscosity or fan VG viscometer. Funnel viscosity of the given mud system is one point determination of mud consistency and cannot be correlated with measured rheological properties. Therefore, a mud system solely should not be treated on the basis of funnel viscosity.

‘The settling velocity of particle is directly proportional to the viscosity of the fluid’. In order to transport the solid vertically, the upward velocity of particle must be greater than the settling velocity of the particle. By stoke’s law,

\[ u = \frac{(D^2) \ast (\rho_s - \rho_f) \ast g}{18 \ast \mu \ast 10^8} \]

Where
- \( u \)= velocity (cm/sec)
- \( \rho_s \)= density of solid (gm/cm3)
- \( \rho_f \)= density of fluid (gm/cm3)
- \( g \)= gravity
- \( \mu \)= viscosity (poise)
- \( D \)= diameter of sphere (microns)

Viscous behavior of drilling fluid:
Relation between force required for fluid to flow (shear stress) and the rate at which force is applied (shear rate) is given by newton’s law. According to Newton’s law,

**Shear stress \( \propto \) shear rate**

**Shear rate (Y):** It is defined as the velocity gradient across adjacent fluid layers while in laminar flow.

**Shear rate (\( \tau \)):** force per unit area to initiate a velocity gradient or to start the motion.

Newton’s law of viscous resistance
**shear stress** = \( \mu \times \text{shear rate} \)

The proportionality constant is the true viscosity of Newtonian fluids.

**Drilling fluid models**

**Bingham plastic model:**

Bingham plastic is a viscoplastic material that behaves as rigid body at low stresses but flows as viscous fluid at high stresses.

To describe the viscous behavior of clay based drilling fluid.

\[ \tau = \tau_0 + \mu p \times \gamma \]

Y-intercept on graph is defined as dynamic yield point. Yield point is minimum value of stress required to initiate the flow of the fluid. The slope of the straight line is defined as plastic viscosity.

Determination of rheological properties for viscometer readings:

Plastic viscosity: The difference between dial reading at \( \Theta 600 \) and \( \Theta 300 \).
\[ PV = \theta_{600} - \theta_{300} \]

\[ YP = \theta_{300} - PV \]

(Change in funnel viscosity such as increase in 1 or 2 seconds per hour or per circulation, indicate that there may unacceptable solid build up or continuous chemical contamination. Abrupt increases in funnel viscosity would indicate a drastic change of basic flow properties possible due to large scale contamination).

**Plastic viscosity**

The plastic viscosity is resistance to fluid flow caused by mechanical friction within the fluid. This mechanical friction is due to the interaction of solid particles in mud, the interaction of solid and liquid particles and deformation of liquid particles under shear stress.

Plastic viscosity should be taken as quantitative indicator of the total solid content.

**Yield point**

Yield value is interpreted as the component of the resistance to shear due to build up of structure in a fluid caused by electrochemical forces within the mud under initial flowing conditions. The electrochemical forces arise from the charges on the surface of reactive particles, the charges on the sub micron sized particles and presence of electrolytes in the water phase.

Yield value is mud property that must be controlled within a specified range according to hole conditions and mud system in use. In addition to solid control, maintaining yield value within specified limits require proper chemical treatments.

In well dispersed clay based mud system, yield value can be lowered by chemical deflocculation and mechanical removal of solid. Addition of chemical dispersant (lignite and lignosulphate) treat the effects of solid build up by altering the surface charges of the reactive particles. To increase yield value, additions of bentonite or a viscosifying polymer such as xanthan gum or polysaccharides.
In non-dispersed clay base system, the key to maintaining a stable yield value is to avoid over treatment of the mud system with bentonite and viscosifying polymers & to avoid an accumulation of drilled solids.

**Types of fluid**

<table>
<thead>
<tr>
<th>Newtonian fluid</th>
<th>Water, glycerin, diesel oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Newtonian fluid (Time independent)</td>
<td></td>
</tr>
<tr>
<td>Bingham plastic</td>
<td>Grease, ketchup</td>
</tr>
<tr>
<td>Pseudo plastic</td>
<td>Polymer solutions, water-based fluid</td>
</tr>
<tr>
<td>Dilatants</td>
<td>Starch, mica fish solutions</td>
</tr>
<tr>
<td>Non-Newtonian (Time dependant)</td>
<td></td>
</tr>
<tr>
<td>Thixotropic</td>
<td>Drilling muds</td>
</tr>
<tr>
<td>Rheopectic</td>
<td>Grease, gypsum</td>
</tr>
<tr>
<td>Viscoelastic</td>
<td>Drilling fluids, long chain polymers</td>
</tr>
</tbody>
</table>

**Viscoelastic fluids**

Viscoelastic fluids are those with viscous properties but also exhibits a certain degree of elasticity of the shape. Viscoelastic polymers used in drilling fluids tend to straighten and elongate when subjected to extremely high shear stress but revert back to their coiled chain links when shear rate has decreased to nominal levels. Viscoelastic mud behavior causes thinning of the mud while going through the bit and reduces the friction losses. In annulus, under low shear rates, the polymers revert back to their characteristics shape, thickening the mud and provide better cuttings capacity.

**Power law model**

Power law model parameters can be calculated between any two shear rates representative of the annular region, it will provide much greater accuracy in predicting drilling fluid’s performance.
\[ \tau = K \gamma^n \]

Where
\( \tau \) = shear stress
\( K \) = consistency index
\( \gamma \) = shear rate
\( n \) = power law index

**Herschel-Bulkley model**

\[ \tau = \tau_0 + K \gamma^n \]

**Optimum drilling fluid viscosity**

Desired viscous properties of drilling fluid:
- It should be shear thinning to impart optimum hydraulic horsepower at bit
- It should have sufficient viscosity in annulus for sufficient hole cleaning. It should have sufficient gelation characteristics to suspend cuttings and weight material when motionless.

**Gel strength**

Gel strength are measure of the attractive forces within the drilling fluid under static conditions and by convention are measured after 10 sec and 10 minutes. These attractive forces differ from yield value in that they are time dependant and disrupted after flow initiated.

In most unweight water-base system 10 sec/10 min gel strength of 2/4 ln /100 ft² are sufficient to suspend cuttings. In weighted system, a 10 sec gel strength of at least 2lb/100 ft² will be required to suspend most of the barite. In such systems, it would be preferable to have 10 sec gel strength in range of 3-5lb/ 100 ft² and 10 minute gel strength of 5-10 lb/100 ft².

**Filtrate loss**

- Spurt loss- loss of fluid to the formation before building of mud cake (filter medium)
- Filtrate loss- loss fluid to the formation after building of mud cake
- Fluid loss- loss of complete fluid to the formation
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Effect on filtrate loss</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Increase</td>
<td>With temperature filtrate loss increases, as viscosity is reduced. Fluid is easily movable at elevated temperatures.</td>
</tr>
<tr>
<td>Particle type and size</td>
<td>Can’t define</td>
<td>High permeable mud cakes because more filtrate loss than low permeable mud cakes. Permeability of mud cakes depend on particle size and its distribution.</td>
</tr>
<tr>
<td>Time</td>
<td>Increases</td>
<td>$Q = c \sqrt{T} + \text{spurt loss volume}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spurt loss-volume of filtrate at zero time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volume of filtrate depends on square root of time. Filtrate will be doubles if time is quadrupled.</td>
</tr>
<tr>
<td>Pressure</td>
<td>Can’t define</td>
<td>Highly compressible filter cake gets compacted as differential pressure increases. Ultimate reduction in permeability reduces filtrate losses.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turbulent flow cause higher fluid loss due to scouring</td>
</tr>
<tr>
<td>Flow profile</td>
<td>Depends on type of profile</td>
<td>effect of filter cake and turbulence is associated with high pressure which with reduced filter cake forces more filtrate into formation</td>
</tr>
</tbody>
</table>

**Method of obtaining spurt loss and ultimate loss**

Classic loss = $2 \times (30 \text{ min} - 7.5 \text{ min})$

Spurt loss = $30 \text{ min} - \text{classic loss}$

Ultimate loss = $\{(\text{classic loss}) \times (\text{Total time/30})^{1/2}\} + \text{spurt loss}$

**Controlling filtrate loss**

Controlling filtrate loss is very important. Too low filtrate loss is detrimental to penetration rates or too high filtrate loss could be harmful to borehole stability and water sensitive formations. The most desirable properties are high spurt loss and low ultimate filtrate loss.

API low temperature filtrate loss test, the low ultimate filtrate loss as measured by 30 min API low temperature test should be rarely less than 10 cm$^3$. In HPHT conditions, 20 cm$^3$ filtrate in full 30 min test at 300F and 500 psi is generally sufficient to avoid most of the hole problems.

Bentonite is most basic loss control agent. Polymers used as filtrate loss control agent mainly by tying up clay particles and bridging the gaps between the platelets.

**Solid content**

All main mud properties such density, viscosity and filtrate loss are depends on type and amount of solid in suspension. The essential solid are added to the drilling systems at the surface in controlled amounts. While undesirable solids are get added to system. Those solids are generated by the bit and retained mud. These solids adversely affect the primary mud properties.

Results of solid content can be useful to identify dissolved & undissolved solid, active and inert solids and low & high gravity solids.

Fields measurement of solid includes total solid contents, sand content and bentonite content.
**Sand content** is defined as volume percent of particles that are retained on 200 mesh size screen. Sand content sample is taken at the flowline. Sand content in pit sample indicates the efficiency of solid removal system. It is expected that sand content in pit sample should be negligible.

If sand particles are being carried into suction pit, first step should be taken to check the shaker screen for holes, to dump or jet sand trap and bottoms of settling pits and check other solid control equipment for any malfunction.

**Methylene blue test**

MBT is use to determine amount of reactive bentonitic type solid in drilling fluid and it's based on cation exchange capacity of solid particles. Organic material present in the sample is oxidized with hydrogen peroxide, a measured quantity of methylene blue dye is added and stirred vigorously. The gets absorbed on active particles. When these particles gets saturated with adsorbed dye, the unabsorbed dye appears and denotes the end point.

Possible errors in measurement includes presence of air bubble in mud sample, making sure after each incremental addition of dye is contacting all particles in flask (obtained by vigorous shaking of the flask) and end point is overshot by carelessness.

MBT values can be utilized in two ways. It gives direct measure of equivalent bentonite content and to evaluate each type of solid present in drilling fluid in conjunction with retort data, mud weight and filtrate analysis.

MBT gives total bentonite content (added at surface and added while drilling) in ppb bentonite equivalent.

**Calculating types and amount of solid**

**Total low gravity solids**

The amount of accumulate drilled solid can be obtained by subtracting MBT value from total low density solid content.
\[ D (\text{Actual drilled solid ppb}) = \frac{(S - MBT)}{\left(1 - \left(\frac{MBC}{100}\right)\right)} \]

MBC= activity of formation in lbs (derived from methylene blue analysis of drill cuttings)

S=total low gravity solid content (ppb)

MBT= methylene blue test results in mud (ppb)

D=total drilled solid in mud (ppb)

\[ A (\text{active drilled solids}) = D \times \left(\frac{MBC}{100}\right) \]

For optimum performance and in order to maintain stable properties and avoid hole problems, \((D*S/B)\) should be less than 3 to 1 in unweight systems and preferable no more than 2 to 1. In weighted solids systems, the ratio should not exceed 2 to 1.

**Chemical analysis of drilling mud**

<table>
<thead>
<tr>
<th>Property</th>
<th>Additives</th>
<th>Method</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Acid materials- salts calcium chloride, calcium sulfate, SAPP sodium bisuphite Alkaline additives- salts sodium carbonate &amp; sodium bicarbonate</td>
<td>pHydration paper ColorHast sticks Glass electrode pH meters pH indicator solutions</td>
<td>Drilling fluid should be maintained at 7 and above Drilling fluid must be basic due to corrosive effects of acid and chemistry of clays</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>If filtrate sample has Pf or Pm value greater</td>
<td>Pf Pm Mf</td>
<td>Phenolphthalein is pink at pH&gt;8.3 and is colorless</td>
</tr>
</tbody>
</table>
than zero, then pH of sample cannot be less than 8.3
These values are use to estimate concentrations of hydroxyl, carbonate, bicarbonate and carbonate ion sin filtrate

<table>
<thead>
<tr>
<th>Relation b/n Pf and Mf</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>P=0</td>
<td>Alkalinity due to bicarbonate ion</td>
</tr>
<tr>
<td>P=M</td>
<td>Alkalinity due to hydroxyl ion</td>
</tr>
<tr>
<td>2P&gt;M</td>
<td>Alkalinity due to mixture of carbonate and hydroxyl</td>
</tr>
<tr>
<td>2P=M</td>
<td>Alkalinity is all carbonate ions</td>
</tr>
</tbody>
</table>

Clay chemistry

Clay can be chemically classified as ‘Aluminum silicate’. The selection of drilling fluid should be related to possible reactions between rock and drilling fluid as these reactions can and do influence stability of the borehole.

Both cations and anions are absorbed on the platelet edges. When clay platelets are broken, unbalanced group of charges are created at the edge. In aqueous suspensions, both sets of ions may exchange with ions in bulk solution. Some of newly exposed groups have the structure of silica (a weak acid) and some have structure of alumina or magnesia (a weak base). Therefore charge on the edge will vary according to the pH of the solution.
Thus at the low pH values, the broken edges are more positive and at high pH are more negative. This is the reason for maintaining pH values of drilling fluid on alkaline side to ensure that the clay particles in the mud are only negatively charged. If all the clay particles are negatively charged, the electrostatic interactions due to charge difference are minimized.

<table>
<thead>
<tr>
<th>Type of clay</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bentonite (sodium montmorillonite)</td>
<td>Montmorillonite is three layer and expandable clay.</td>
</tr>
<tr>
<td><strong>STRUCTURE OF MONTMORILLONITE</strong></td>
<td><img src="image" alt="Montmorillonite Structure" /></td>
</tr>
<tr>
<td></td>
<td>When sufficient water penetrates between crystalline sheets, the base exchange cations will begin to separate from silica surface. The degree of separation is more for sodium and less for calcium.</td>
</tr>
<tr>
<td></td>
<td>In tetrahedral sheet, aluminum sometimes partially replaced by silicon.</td>
</tr>
<tr>
<td></td>
<td>In the octahedral sheets, there can be replacement of aluminum by magnesium, iron, zinc, lithium, potassium or other ions. The relatively smaller size of ions permits them to take a place of silica or aluminum.</td>
</tr>
<tr>
<td></td>
<td>In many minerals, generally ion of low positive charge is replaced by the larger one. It leads to deficit of positive charge thus an excess negative charge on clay surface.</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>Two layer clay lattices. Kaolinite is composed of one silica tetrahedral sheet and one alumina octahedral sheet.</td>
</tr>
</tbody>
</table>
Illite

Illite is non-expanding three layer clays that are distinguished from montmorillonite primarily by absence of interlayer swelling upon contact with water.

One of the four silicon atoms in the tetrahedral sheet is substituted for one aluminum atom and the positive charge deficit is satisfied by one potassium ion on the unit layer surface.

Chlorite

Three layer sheet
<table>
<thead>
<tr>
<th></th>
<th>Replacement of magnesium by aluminum in the magnesium hydroxide sheet, the sheet has net positive charge.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attapulgite</strong></td>
<td>Use to viscosify salt water based drilling fluid.</td>
</tr>
</tbody>
</table>