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EFFECT OF HEMATITE ON YIELD POINT OF WATER BASE MUD

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***Abstract**: The aim of any drilling operation is to provide a path way or conduit from surface to depth of interest which would later facilitate the production of the formation fluids. In order to achieve this, petroleum drilling engineers do incorporate the best of drilling practices in which drilling time is a critical factor. Drilling cost is directly proportional to time spent on drilling the well and as such any parameter that would drastically increase the drill cost is critically analyzed with the view of getting the optimum conditions for such parameter. Rate of penetration have been known to affect drill cost significantly. In order to optimized the rate of penetration and minimized torque during drilling, the hole must be adequately cleared of drill cuttings. The hole cleaning properties of the drilling fluid are essential to achieving the set objectives. Drilling fluids play important roles in any drilling operations. These roles are not limited to controlling formation pressures and lifting of drill cuttings to the surface but also as a means of providing hydraulic horsepower for downhole tools. Lifting and transporting of drill cuttings to the surface lies on, but not solely on the rheological properties of the drilling mud in used but also on the mud pump pressure exerted at the surface. The pump pressure which provides the circulating density of the mud is such that it is equivalent to the formation pressure. Above this pressure, the formation tends to fracture and formation fracturing is not a good development during any drilling operation. Hematite has been used as an additive to mitigate against formation pressures successfully, especially when combined with the conventional weighting agent such as barite, calcium carbonate, etc. Barite (with specific gravity between 4.2 – 4.8 g/cm^3) is the most popular of the weighting agents due to its ecofriendly nature. It has been used severally to control the mud weight of drilling mud during weighting up process. This weighting up process usually have significant effect on the equivalent circulating density (ECD) which in turn affect the cuttings removal process, hence poor hole cleaning and resultant increase in torque. Besides the increase in demand of barite and its global reserves reduction, there is need to look at other alternatives such as hematite, ilmenite, calcite, etc. Hematite with a specific gravity of 4.7 g/cm^3 is a good weighting agent in water base mud because it provides high value of mud density with low solid content when compared with equivalent volume of barite.*

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I. INTRODUCTION

Yield Point in mud engineering is the measure of the fluid's initial resistance to flow or the calculated value required to move the fluid in terms of shear stress. It can also be stated that the yield point is equivalent to the force of attraction between the particles of fluid colliding with one another. However; according to Bingham plastic model, the yield point is the value of shear stress when extrapolated to the zero value of shear rate on the y-axis. It is calculated from the 300-600 rounds per minute (rpm) viscometer dial readings by negating the plastic viscosity from the 300 rpm dial reading. Yield point gives an indication of the ability of the drilling mud to lift or remove the cuttings out of the annulus. A drilling fluid with higher yield point will carry cuttings better than that with lower yield point.

Mud is circulated in an instrument called Viscometer or Rheometer at different revolutions per minute and the values are obtained which are used in the calculation of yield point. The formula for the calculation of yield point are given as:

Yield Point (YP) = Reading at 300 rpm - Plastic Viscosity (PV)

And the value of Plastic Viscosity (PV) from the above equation can be calculated as:

Plastic Viscosity = Reading at 600 rpm - Reading at 300 rpm

SI unit used for the Yield Point (YP) is lb./100ft^2.

Factors Affecting Yield Point (YP) in Different Types of Drilling Mud

There is a direct relation between Yield Point (YP) and frictional pressure loss. The higher the value of Yield Point (YP), the higher would be the frictional pressure losses.

The following factors affect Yield Point (YP) in water base mud making its value increase:

- Higher Temperature**:** Measurements of Yield Point increases with increase in temperature showing that there is a direct relation between Yield Point and temperature in water-based muds.
- Contaminants: Because of the circulation of the drilling fluids in the wellbore and the influx of reservoir fluids into it there are many mud contaminants that includes in it. These contaminants effect the calculations of Yield Point making this an important factor to consider when dealing with the value of Yield Point. These contaminants might include carbon dioxide (CO_2), salt and anhydrite etc.
- Over Treatment**:** Many chemicals and mixtures are added in water-based muds for different reasons. Their quantities mixed in the mud if not managed properly might affect the values of Yield Point. These chemicals include lime or caustic soda.

Yield Point in Drilling Mud Applications

The Yield Point (YP) of the drilling mud has a very basic and important function while drilling. Some of its applications in the drilling operations of the oil and gas industry are as follows:

- Carrier of Drilled Cuttings: When the drilling bit at the end of the drill string cut through the formation it is very important to remove those cuttings from the face of the bit and avoid the accumulation of drilled cuttings in the borehole. Otherwise, the efficiency of the drilling is seriously threatened. Yield Point (YP) value demonstrates the ability of the drilling mud to carry back those drill bit cuttings to the surface.
- Equivalent Circulating Density (ECD): The equivalent circulating density typically increases with the increase in Yield Point value.
- Bore Cleaning: As explained earlier that is important to keep the bore hole clean for better penetration rate. So, the larger the diameter of borehole, the higher should be the Yield Point (YP) value of the drilling mud to support a better cleaning of the borehole.

The following factors affect Yield Point (YP) in oil base mud making its value increase:

- Drill Cuttings**:** Value of Yield Point (YP) increases with the increase in drilled cuttings from the formation. Cuttings that are circulated back to the surface when present in the oil-based mud effect the value of Yield Point (YP).
- Reaction of Lime (CaO) with the CO_2**:** Lime is often added in the oil-based mud which when chemically reacts with the CO_2 in the mud forms Calcium Carbonate ($CaCO_3$) that contribute towards the increment in the value of Yield Point (YP).
- Lower Temperature**:** On contrary to the water-based mud, it is the lower temperature that is affecting Yield Point (YP). Lower the temperature in oil-based mud higher will be the viscosity and more will be the value of Yield Point (YP).

Rheometer Test Method

A drilling fluid viscometer or rheometer is used for obtaining fluid rheology (apparent viscosity, plastic viscosity, yield point, and gel strength)). Several models are available, powered by a hand-crank or electric motor. The instrument comprises a solid pivoted cylindrical bob that is restrained by a torsion spring and connected to a torsion dial. The cylindrical bob sits inside a cylindrical outer sleeve that can be rotated at selected speeds, with a narrow annular clearance between the bob and the sleeve.

In the rheometer test method, the mud sample is placed in a heating cup to bring it to a designated temperature for measuring the rheology (usually 50°C or 120°F, but higher temperatures may be specified for high-temperature wells). The heating cup sits on the adjustable viscometer platform, which is raised until the cylindrical bob and rotating outer sleeve are immersed in the mud sample. Once the mud sample reaches the required temperature, the outer sleeve is rotated at selected speeds, and the resultant deflection of the cylindrical bob can be read off the torsion dial, high viscosity fluids producing larger deflections.

Basic viscometers only give 600, 300, and 3 rpm readings. Most drilling fluid viscometers give 600, 300, 200, 100, 6, and 3 rpm readings, while some also give 60 and 30 rpm readings. The apparent viscosity, plastic viscosity, and yield point can all be calculated from the 600 and 300 rpm readings, while the gel strength is given by the 3 rpm reading. Gel strengths are usually recorded after 10 seconds, 10 minutes, and occasionally 30 minutes. The correct procedure for the rheometer test method is as follows:

Drilling Fluid Viscometer

1. Fill the heating cup with the fluid sample and place on viscometer platform.
2. Adjust the viscometer platform until the fluid sample level reaches the circumferential groove marked on the rotating outer sleeve.
3. Rotate the outer sleeve to stir the fluid while the sample reaches the required temperature (usually 50°C or 120°F).
4. Once at the required temperature, select the 600 rpm gear and wait for a steady deflection before recording the 600 rpm dial reading.
5. With the motor still running, select the 300 rpm gear and wait for a steady deflection before recording the 300 rpm dial reading.
6. Repeat the procedure for all the other dial readings.
7. To measure the 10 second gel strength, stir the mud at 600 rpm for several seconds to breaks any gels, then select the low speed gear and switch off.
8. After 10 seconds, switch the viscometer back on at 3 rpm and record the maximum dial deflection before the gel breaks, which is the 10 second gel strength.
9. To measure the 10minute gel strength, stir the mud at 600 rpm for several seconds to breaks any gels, then select the low speed gear and switch off.
10. After 10 minutes, switch the viscometer back on at 3 rpm and record the maximum dial deflection before the gel breaks, which is the 10minute gel strength.
11. Repeat the procedure if the 30minute gel strength is also required.
12. The final step of rheometer test method is to wash the viscometer by carefully removing the rotating outer sleeve, which has a small slot that locks onto a pin. The cylindrical bob can then be wiped cleaned with a cloth or paper tissue, taking care not to bend the fragile assembly. The heating cup must be disconnected from the mains before cleaning.

Plastic Viscosity tends to increase while drilling due to the build-up of ultra-fine solids in the drilling fluid. Some drilled solids are too small to be removed by the Solids Control Equipment, so they remain in the drilling fluid and are gradually eroded into ultrafine particles, along with other fine particles that are designed to pass through the shale shaker screen (e.g. barite, calcium carbonate, etc.). The increase in solids results in an increase in friction between the solids, which increases the Plastic Viscosity of the drilling fluid.

In the Rheometer test method, yield Point helps to keep drilled solids and weighting materials (e.g. barite and calcium carbonate) in suspension. If the Yield Point is too low, then solids will gradually settle out when circulation is halted during a connection or while tripping pipe out of the hole. Solids could then build up in a deviated part of the hole, or collect around the BHA, with the potential for getting mechanically stuck in the hole. Solids falling out of suspension will also reduce the mud density in highly deviated sections, resulting in a reduction in hydrostatic pressure when it reaches the vertical part of the hole when circulation resumes, with the potential for a well control incident.

If the Yield Point is too high then circulating pressures and ECD in drilling will be high, with the potential for induced mud losses to the formation. Gel Strengths, which is a measure of the attractive forces between the particles when the drilling fluid is static, also need to be controlled. Progressive gels are another indication of high solids in the mud and will affect surge and swab pressures while tripping in or out of the hole. Higher gels will also require higher pump pressures to break circulation, which could increase the potential for induced mud losses to the formation.

Solids control is a constant problem, every day on every well. Generally, we can define solids control as controlling the quantity and quality of undesired cuttings in the drilling mud type since the increasing of these solids can generate negative effects both to the well and drilling. In addition, these solids will increase the total mud cost and further the cost of oil and gas wells. Therefore 30 bbls of solids must be removed by the solid control equipment every hour.

Based on the above, it is important to remove solids to allow efficient drilling to continue without increasing mud costs. However, it is also important to retain some particles in the mud (e.g., Barite, Bentonite, Hematite) since they are required to maintain the properties of the drilling fluids. If these desirable solids are removed, they must be replaced with more surface additions solids, thereby increasing the mud cost.

Solids in Drilling Mud Problem

Generally, mud additives (either OBM or WBM) and drilling cuttings are the major sources of solids. Formation cuttings are contaminants that degrade the performance of the drilling fluid. If we didn’t remove the cuttings, drill string & drilling bit rotation would grind them into smaller and smaller particles that become more difficult to withdraw from the drilling fluid. One of the primary uses for drilling fluid is to carry unwanted drilled solids from the borehole. These solids are contaminants and can lead to numerous operational problems if left in the mud.

Solids can be distinguished in two categories:

- Low Gravity Solids (LGS) with a specific gravity range of 2.3 to 2.8 S.G.
- High Gravity Solids (HGS) with S.G. of 4.2 or more.

Three options are available to maintain acceptable drilling fluid properties:

1. Firstly, by doing nothing and allowing the solids build up. When the mud no longer meets specifications, it is thrown away and a fresh drilling fluid is introduced.
2. Secondly, by diluting and rebuilding the drilling mud system to keep the mud properties within acceptable ranges while dumping excess fluids into the reserve pit.
3. Thirdly, by lower the drilling fluids’ solids content through solids removal to minimize the addition/dilution necessary to maintain acceptable properties.

Solid Control Benefits

Solids control is the most expensive part of the mud system since it operates continuously to remove unwanted solids. It is generally cheaper to use mechanical devices to reduce the solids content rather than treat the mud with chemicals once the solids have become incorporated into the drilling fluid. Solids which do not hydrate or react with other compounds within the mud are referred to as inert solids. These may include sand, silt, limestone, and barite. In addition, these solids are all considered undesirable except barite, because of the following reasons:

- Firstly, they increase frictional resistance without improving lifting capacity.
- Secondly, these solids will form a filter cake. This cake tends to be thick and permeable, leading to drilling problems. (stuck pipe, increased drag) and possible formation damage.
- Thirdly, solids also cause damage to the mud pumps, leading to higher maintenance costs.

Using solids removal to minimize addition/dilution volumes is usually the most effective and provides the following benefits:

- Increased penetration rates
- Reduced mud costs

- Lower water requirements
- Reduced torque and drag
- Less mixing problems
- Reduced system pressure losses
- Lower circulating density (ECD)
- Better cementing in drilling
- Reduced instances of lost circulation
- Reduced formation damage
- Less differential sticking
- Reduced environmental impact
- Less waste, lower disposal costs

The consequences of poor solids control:

- Stuck pipe
- Reduced Drilling rate
- Thick Filter cake
- Increased Drilling Fluid Dilution
- Increased Chemical consumption
- Increased Torque and Drag
- Formation Damage
- Problems with well Evaluation
- Poor cement jobs
- Increased surge/swab pressures (Swab and Surge In Drilling Definition & Calculations, ECD
- Increased equipment wear and tear, decreased bit life.

Methods of Solid Control While Drilling

For most practical purposes, oil and gas companies divide the mud solids into two groups according to their density:

- Low gravity solids (S.G.) = 2.5 – 3.0
- High gravity solids (S.G.) = 4.2 (barite).

Remember that drilling mud will contain different proportions of each solid (e.g., to maintain hydrostatic mud pressure, high-gravity solids are added, so that the mud should contain fewer low-gravity solids. Solids control in fluids containing barite (weighted muds) requires special procedures to ensure that there is no discarding for barite along with undesirable solids. Drilling Fluids containing low gravity solids only (unweighted muds) have a density of 8.5 – 12 ppg.

There are three basic methods used to control the solids content of a drilling fluid:

- Dilution
- Gravity Settling
- Mechanical Devices Screening.

II. RESULTS/ANALYSIS

Table 1: Mud Samples with Barite as Weighting Agent.

Mud Samples	Barite (%)	Mass of Barite (g)	Mass of Bentonite (g)	Mass of Water (ml)	Density of Mud Samples (ppg)
A	5	17.5	22.5	350	8.65

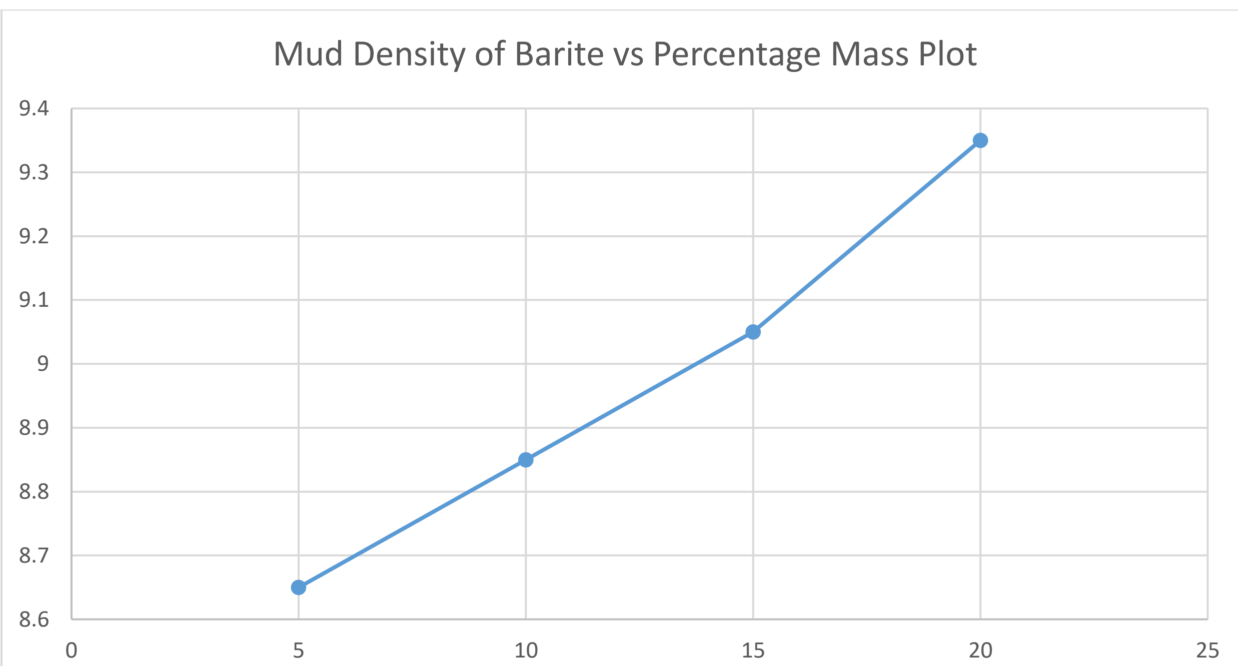
B	10	35.0	22.5	350	8.85
C	15	52.5	22.5	350	9.05
D	20	70.0	22.5	350	9.35

Table 2: Mud Samples with Hematite as Weighting Agent.

Mud Samples	Hematite (%)	Mass of Hematite (g)	Mass of Bentonite (g)	Mass of Water (ml)	Density of Mud Samples (ppg)
P	5	17.5	22.5	350	8.80
Q	10	35.0	22.5	350	9.35
R	15	52.5	22.5	350	9.90
S	20	70.0	22.5	350	10.65

Table 3: Compressed form of Mud Densities of table 1 and 2 above.

Mud Samples		Percentage Mass (%)	Mass of Additives (g)	Mass of Bentonite (g)	Mass of Water (ml)	Density of Mud Samples (ppg)	
Barite	Hematite					Barite	Hematite
A	P	5	17.5	22.5	350	8.65	8.80
B	Q	10	35.0	22.5	350	8.85	9.35
C	R	15	52.5	22.5	350	9.05	9.90
D	S	20	70.0	22.5	350	9.35	10.65



Fig; 1: A plot of Mud Density of Barite against Percentage Mass.

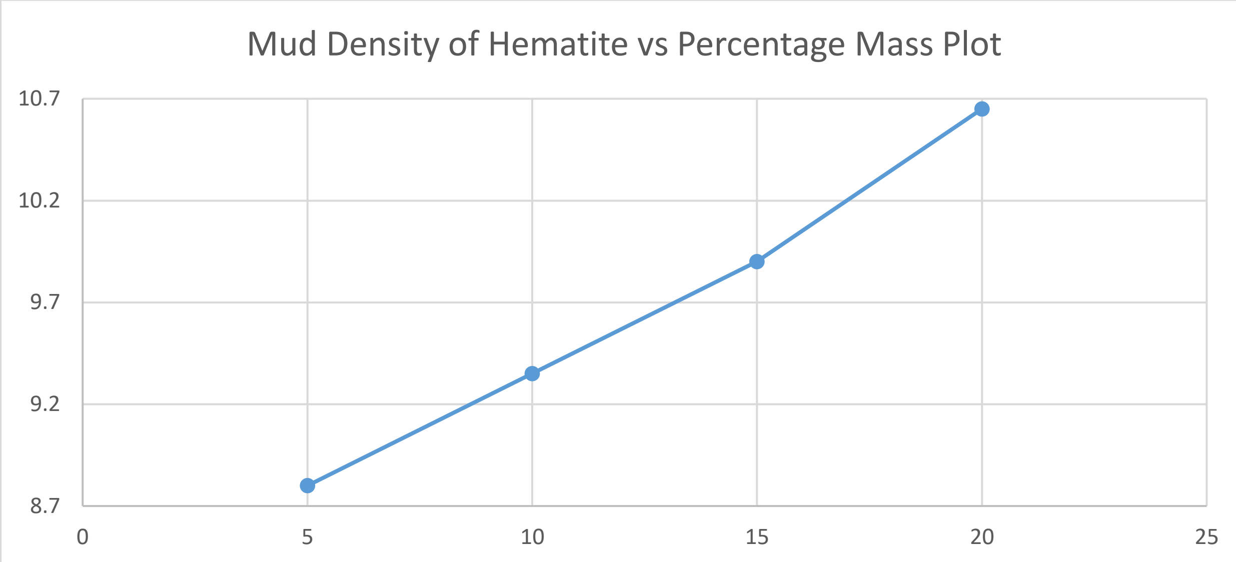


Fig: 2: A plot of Mud Density of Hematite against Percentage Mass.

A plot of the mud densities against percentage mass shows that the density of the formulated mud against the mass increases is directly related. However, hematite gives a higher value than barite.

Table 4: Yield Points of Barite and Hematite

Percentage Mass	5%	10%	15%	20%
Barite	25	29	35	41
Hematite	43	48	54	62

Table 5: Plastic Viscosities of Barite and Hematite

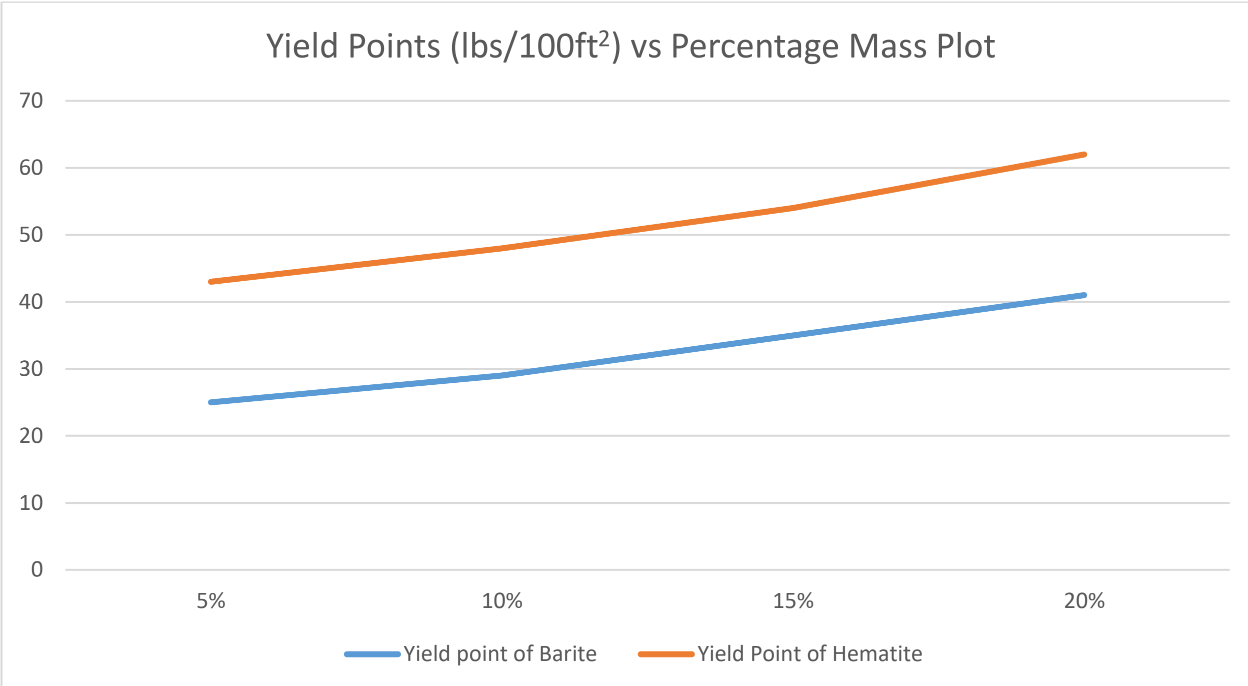
Percentage Mass	5%	10%	15%	20%
Barite	20	23	27	32
Hematite	22	28	32	39

Table 6: Gel Strengths of Barite and Hematite

Percentage Mass	5%	10%	15%	20%
Barite	7	8	10	13
Hematite	14	17	21	28

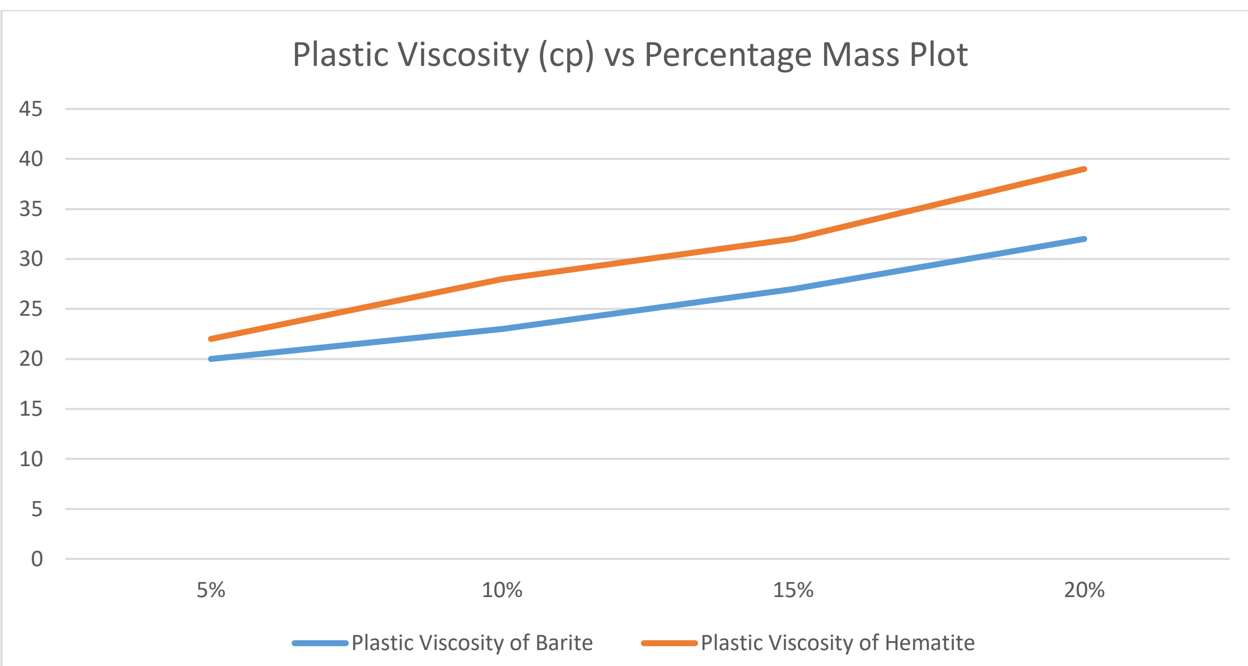
Table 7: Compressed form of selected rheological properties of tables 4, 5 and 6 above.

Percentage Mass (%)	Yield point (lbs/100ft^2)		Plastic Viscosity (cp)		Gel Strength (lbs/100ft^2)	
	Barite	Hematite	Barite	Hematite	Barite	Hematite
5	25	43	20	22	7	14
10	29	48	23	28	8	17
15	35	54	27	32	10	21
20	41	62	32	39	13	28



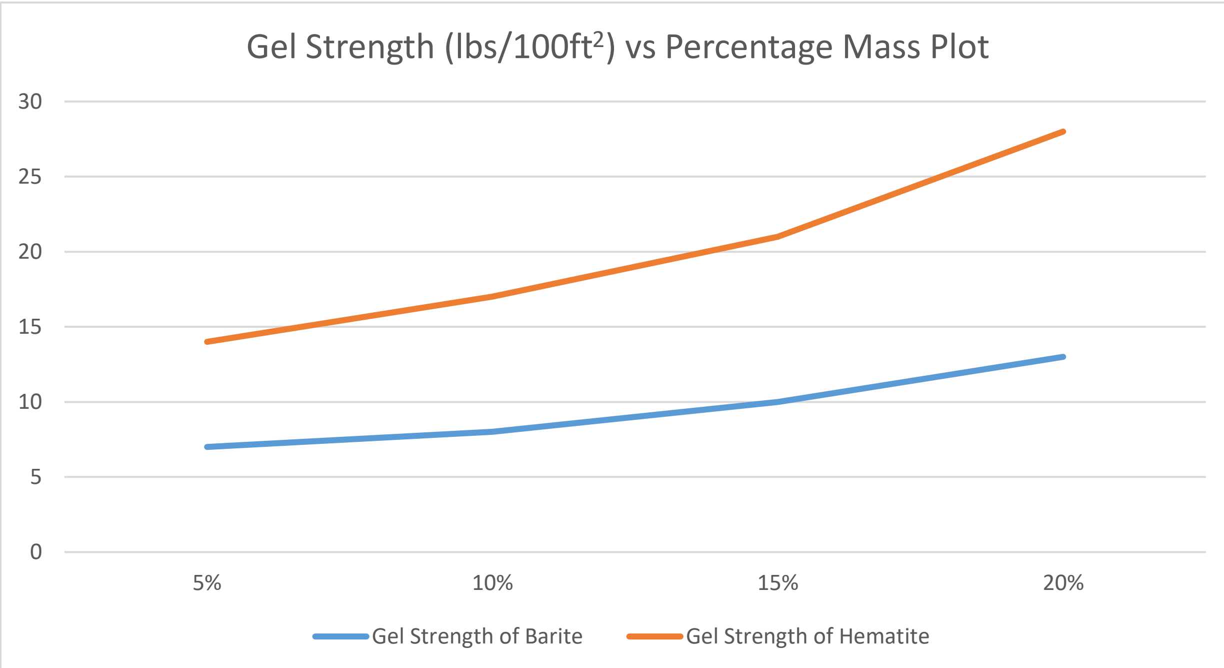
Fig; 3: A plot of Yield Points of Barite and Hematite against Percentage Mass.

From the plot of yield points of both barite and hematite at the various percentages by mass, it can be seen that the values are higher for hematite than barite, though both shows direct linear relationships with both variables. As the quantities of the additives increases, the values of the yield point increases also, with hematite having the greater increase.



Fig; 4: A plot of Plastic Viscosities of Barite and Hematite against Percentage Mass.

Figure 4 also shows the effect of hematite on the PV of the formulated drilling muds. The figure shows that an increase in hematite causes an increase in PV. The PV of hematite is higher than the mud additives.



Fig; 5: A plot of Gel Strengths of Barite and Hematite against Percentage Mass.

The gel strengths of both barite and hematite are within the standard range of values. High gel strengths have been known to increase equivalent circulating density, thereby causing fracturing of the formation and subsequent loss of mud and pressures. Conversely, lower gel strength also leads to barite sag, a phenomenon where the mud is unable to suspend barite. This will likely cause varying values of mud densities within a mud column.

Rheologically, hematite performed better at 15 to 20 percent by mass than barite at the same concentration, with less solid content.

III. CONCLUSION

The rheological properties of any drilling mud depends on the constituents' additives and its amount. Weighting materials like barite, calcium carbonate, hematite, etc. can alter the rheological properties of drilling mud significantly. To achieve desirable mud properties with barite or hematite as weighting agent, the concentrations of the additive must be considered. Hematite performs relatively better than barite in terms of mud density, plastic viscosity, gel strength and yield point at the same concentrations with less solid content, a factor desirable in mud formulation. However, in order to maintain the values of these rheological properties of the mud with desirable mud density, barite must be introduced in calculated concentrations. Above 20%, hematite may likely cause a spike in the values of the measured parameters and that would be investigated in later studies.

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