LABORATORY STUDY OF DRILLING FLUID ON HTHP WELLS

A thesis submitted to partial fulfillment of the requirements for the Degree of Master of Technology in Petroleum Exploration

By

J. SUDHARSAN

Under the guidance of

External Project Head

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DGM (Chem)

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Certificate

This is to certify that the work contained in the thesis titled "laboratory study of drilling fluid on HTHP wells" has been carried out by **Mr. J.SUDHARSAN** *under our supervision.*

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Declaration

"I hereby declare that this submission is my own work and that, to the best of knowledge and belief, it contains no material published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning except where due acknowledgement made in the text"

J.Sudharsan

R770213005

Bonafide Certificate

This is to certify that **Mr. J.Sudharsan**, student of University of Petroleum & Energy Studies, Dehradun pursuing **M.Tech in petroleum Exploration** has successfully completed dissertation project at Institute of Drilling Technology, ONGC Dehradun during December 2014 to May 2015.

The dissertation project report entitled **"LABORATORY STUDY OF DRILLING FLUID ON HTHP WELLS"** submitted by the student to the undersigned is an authentic record of his original work, which he has carried out under my supervision and guidance.

We wish him all the best in his future career.

Dr. Avinish Kumar
DGM (Chem)

Date: IDT,ONGC Dehradun

Abstract

Due to the growth of oil and gas demand, the petroleum sectors start to encounter the deeper formation which possess high temperature (more than 150 °C) high pressure (more than 10, 000 psia). Drilling HTHP wells are big challenging job where a specially designed formulation should be used because the normal drilling fluid starts to lose its rheological properties such as high flocculation, low yield point, excessive fluid loss, thicker mud cake which cause poor hole cleaning, stuck of drill pipe, bit balling etc., .

The study is based on both water based mud & oil based mud. In water based mud, main trouble is high fluid loss with higher yield point which means mud wont flow at dynamic condition. The thinner is used to reduce yield point to desired level. Polymeric additives (controlling other rheological factors also start to degrade above 200° C. Different composition of fluid loss additives and thinners are tried to maintain properties of mud in desired level. In oil based mud, the mud becomes thinner at HTHP conditions and yield point becomes very low.so the mud cannot transport drill cuttings to the surface. Controlling plastic viscosity is also another major concern.

The study deals with various fluid loss controllers, rheology modifiers can help to improve the rheology of mud upto 205 °C.

Acknowledgements

This industrial training report is a result of encouragement, guidance and effort on part of many. Here is a futile attempt to thank them all.

First and foremost, I would like to express my gratitude to our project head **Dr. Avinish Kumar,** DGM (Chem) IDT ONGC Dehradun, and my internal mentor **Dr. Pushpa Sharma,** Associate Professor who extended every possible facility for us and were the chief guiding force. I would also thankful to **Dr. Mandhira Agarwal**, Associate professor, **Dr. D.K. Guptha**, HOD, UPES for encouraging my academic carrier.

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CHAPTER 1 – NECESSITY OF DRILLING FLUID

1.1 Functions of drilling fluid:

1. Removal/transport of cuttings from the wellbore:

- If it is not happen, the cuttings make stuck of drill pipe.
- The carrying capacity of the mud directly depends on the properties of annular velocity, viscosity & density.
- The suspending of drill cutting capacity depends on gel strength/ thixotropic property of mud.
- The gel is formed while drilling is stopped/mud becomes static.
- The drill solids are removed by shale shakers or other mechanical devices. Although drill solids cannot be removed completely for recirculation, some chemicals are added to maintain the rheological properties of mud.
- Annular velocity should be higher than slip velocity. So the cuttings can be transported to the surface.

Transport velocity =

Annular velocity – slip velocity

2. Control the formation pressure:

- The hydrostatic pressure of mud column helps to restrict the formation fluid to the well bore.
- The hydrostatic pressure should not be too higher than formation pressure, otherwise it can cause the induced fracture and excess fluid loss.
- The mud invasion into the formation is called lost circulation.

Hydrostatic pressure should be:

$$P = 0.05*MW*TVD$$

Where,

P – the wellbore pressure/hydrostatic pressure in psi

MW – mud weight in ppg

TVD – total vertical depth in ft

3. Maintain wellbore stability:

- The borehole should be maintained as stable in unstable shales, over pressurized zone, highly permeable zone, lost circulation areas.
- Shale instability occurs due to following reasons majorly:
- The pressure difference between the BHP & pore pressure in the shales.
- Hydration of clay in the shale which is made by mud filtration.
- So in shale zones, non-water based mud is preferable.

4. Cool & lubricate the drill bit:

- When drilling enters into deep formation, the drill bit generates higher amount of heat along with formation (especially in PDC bits). If it is not cooled, the bottom hole assembly wears out completely.
- So the continuous circulation of the mud is needed to cool & lubricate the drill bit.

5. Transmit hydraulic energy to the drill bit:

- The mud pumps can supply the power more than 65% of drilling rate to the drill bit due to reducing frictional pressure at bottom of the well.

6. Seal the permeable formation:

- The mud solid started to deposit in the side of well bore with thin and low permeability. So the fractured/ permeable formation can be sealed.

7. Minimize the formation damage:

A specially designed mud formulation is used for avoiding formation damage such as

- Mud solids can react with formation and form matrix which will reduce the permeability.
- The formation swells itself because hydration of clays with mud.
- Mud filtration & formation fluid becomes incompatible.

- Emulsion maybe formed by formation fluids & mud filtrate.

8. The adequate formation evaluation:

- To evaluate the formation accurately is the success of drilling operation.
- During the drilling, the cuttings are collected by mud loggers which will be examined whether it has sign of hydrocarbon or not. It also helps to know the lithology, mineralogy of formation, ROP.

9. Controlling corrosion:

- Trapped oxygen/ mud aeration/foaming can corrode BHA very immediately in the short period of time.
- Corrosion leads to drill string failure. Chemical inhibitors/ scavengers are used to control it.
- Corrosion coupons are used to examine whether the amount of scavengers is sufficient.

Selection of the mud:

- It depends on well cost, environmental issues, ease availability of the products.

Relationship between properties & function:

- Mud should be maintained with all properties in the desired range, altering in one property should not affect other property /drilling/formation.
- For example, formation pressure is controlled by increasing mud density in the mud, by the time ECD should be considered for avoiding lost circulation.
- Increasing viscosity, can help effective hole cleaning, but it can lower hydraulic energy, decrease in ROP.
- So the selection of mud or changing rheological properties in the mud should be carefully done for a successful drilling operation.

1.2 Types of drilling fluid:

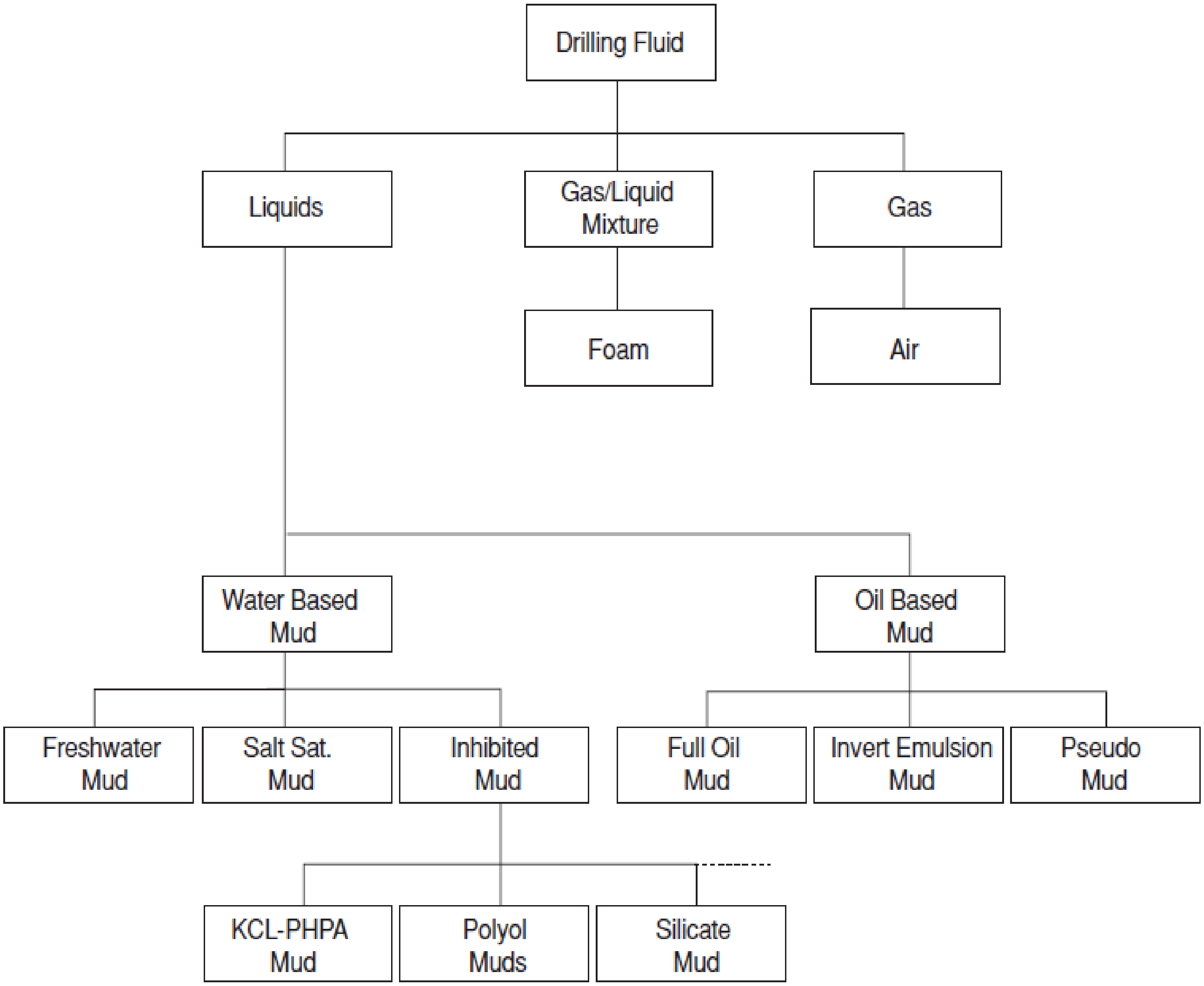

Figure 1 - Types of drilling fluid

<u>Dry air:</u>

- Where the fast drilling required, the subsurface should be dry, no water influx, hard.

<u>Mist:</u>

- Air with mud/ water is used as a source.
- The formation should be wet with small amount of water influx

Foam:

- It is composed of Foaming agent with water/air
- The formation should possess the stable rock.

Stable foam:

- Water containing polymer, air and or foaming agent, betonite are used.
- Low pressure condition, the large amount of waters, big cuttings are removed in lower annular velocity.
- Foaming agents give hole stability & salt acceptance.

Fresh water as mud:

- It used in the faster drilling operation against stable formation.
- It needs large amount of water & flocculants, its main advantage is easy disposal.

Salt water as mud:

- Sea water is used to reduce the freezing point of mud & increase in density.

Spud mud:

- Simple mud with only bentonite & water is inexpensive for shallow depth.

Salt water mud:

- Brine, polymers, starches are used to drill the rock salt, work over jobs.

Lime mud:

- Betonite, water, lime, chromo lingo sulfate are the additives.
- It tolerates from contamination, gives good well stability against shale zone.

Inhibited mud:

- Sometimes bentonite swells in sandstone if the mud is left in static condition for 24 hours.

- To control settling/filtrate, potassium chloride & PHPA, polyol, XC polymer is used.
- The mud is stable upto 150 °C.

Gypsum mud:

- Same composition of lime mud, gypsum is used instead of lime for simple maintenance.
- The mud stands upto 65 °C.

Oil based mud:

- Derivative oil from crude, emulsifiers, water, lime etc., is the additives.
- It is used in well completion; work over jobs, low pressure & shallow depth well.
- Brine is used for carrying drill cuttings, effective hole cleaning & to increase the density.

Invert mud:

- Mineral oil (because of environmental restrictions, diesel oil is not used now a days), emulsifiers, brine, clays, soaps are major contribution of mud.

CHAPTER 2 – HIGH TEMPERATURE & HIGH PRESSURE WELLS

2.1 HTHP wells:

- When depth increases, temperature starts increase is known as geothermal gradient which is mentioned by °F/100 ft due to the presence radiogenic heat and heat is transferred from lower crust and mantle.
- Geothermal gradient increases 0.44 °F/100 ft to 2.7 °F/100 ft from place to place.
- Geopressure gradient increases 0.45 psi/ft with the depth approximately.
- When temperature and pressure increase above 150 °C & 10,000 psia is called as HTHP wells.

2.2 HTHP challenges:

2.2.1 Unstable rheological properties of the mud in HTHP conditions:

- Increasing temperature decreases viscosity of the mud, increasing pressure increase the viscous, results increases the viscosity finally.

When temperature exceeds 94 °C, all hydroxides start to react with clay minerals which lead:

- The effect of thinner is consistently low for lower alkalinity of muds.
- When the temperature is crossed above 121 °C, bentonite suspension starts to flocculate the mud or increases the yield point where even thinnerss are also degradable at the same temperature.
- Thinner may reduce viscosity at the surface condition but which leads more viscosity at the down hole condition.
- Hydrated alumino silicates are formed for higher alkalinity of muds.
- The degree of dispersion, flocculation have been changed with increasing temperature due to the continuous exchange between any electrolyte and solubility of partially soluble salt in the mud.
- The thinner is not soluble in the mud whereas the pH is below than required level. It happens due to the reaction of clay minerals and caustic soda more and more in HTHP conditions.

- The behavior of calcium clay suspension is undesirable which leads more flocculation at high temperatures.

<u>Thermal degradation of water based mud at HTHP condition:</u>

- Plastic viscosity of the mud decreases with increasing temperature upto its thermal limit. After 149 °C PV increases gradually and mud becomes thicker.
- Gelation of mud is also increased. So there is possibility of loss of circulation.
- If mud becomes too thick, it cannot flow at dynamic condition. If mud is too thinner, leads poor hole cleaning and decreases other bottom hole functions.

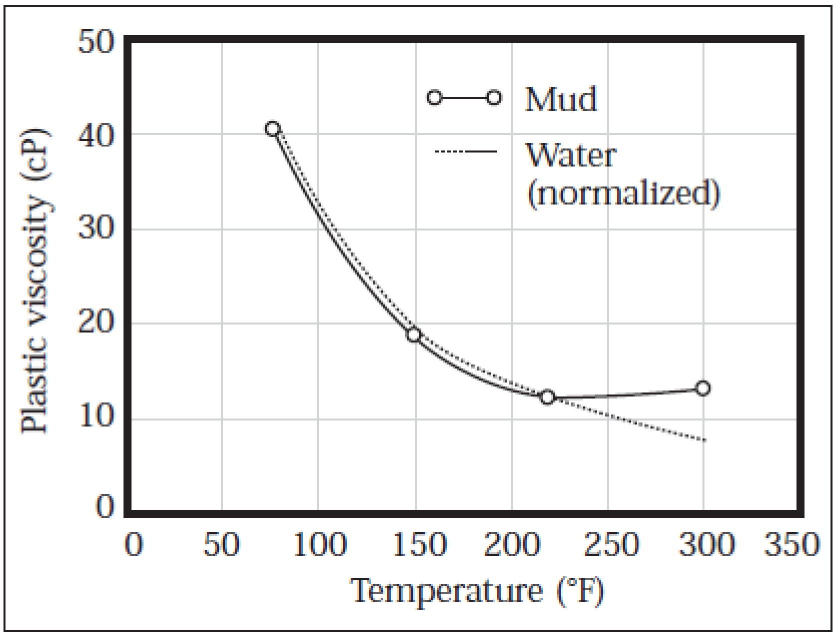

Figure 2 - plastic viscosity changes with temperature

- Down hole parameters such as Equivalent Circulating Density (ECD), hole cleaning, barite sag, surge/swab pressures during tripping, pump pressures and bit hydraulics are changed due to rheological properties get alteration.
- The ECD pressure is increased due to the smaller diameter of hole in deeper wells. So abnormal pressure is recognized which is controlled by higher density mud.
- Increasing weighting material makes more solid concentration which will affect thermal stability of the mud (even non-reactive solids).

- When higher mud pressure is exposed into the formation, there may be chance of differential sticking and high fluid loss.
- If fluid loss is higher whereas stuck pipe is the major problem.
- Contamination in the mud increases filtration and reduces thermal stability of mud.
- Mud gets more contaminated which cant be tolerable in deeper salt formation often encountered in HTHP condition. Mud starts to dilute from water and losses in density.
- Salt water mud can expand thermally in high temperature cause in reducing density & hydrostatic pressure.

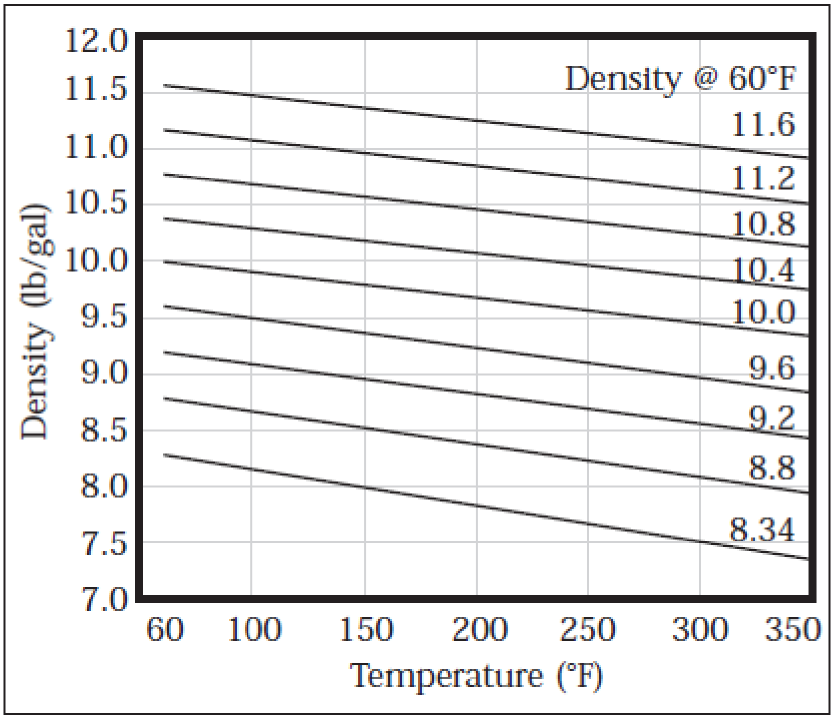

Figure 3 - Density changes with temperature

- Forming higher permeability thin cake strengthen well bore but may decrease the permeability of nearby well bore areas.
- Gel strength is increasing in HTHP conditions so hole cleaning will be very difficult.
- Mud starts to degrade from its original compsition such as solids, polymers and expansion of molecules will reduce the fluid flow at dynamic condition.

Thermal degradation of oil based mud at HTHP condition:

- Oil based mud becomes more thinner at HTHP, which will not carry drill cuttings may lead to loss of well control.

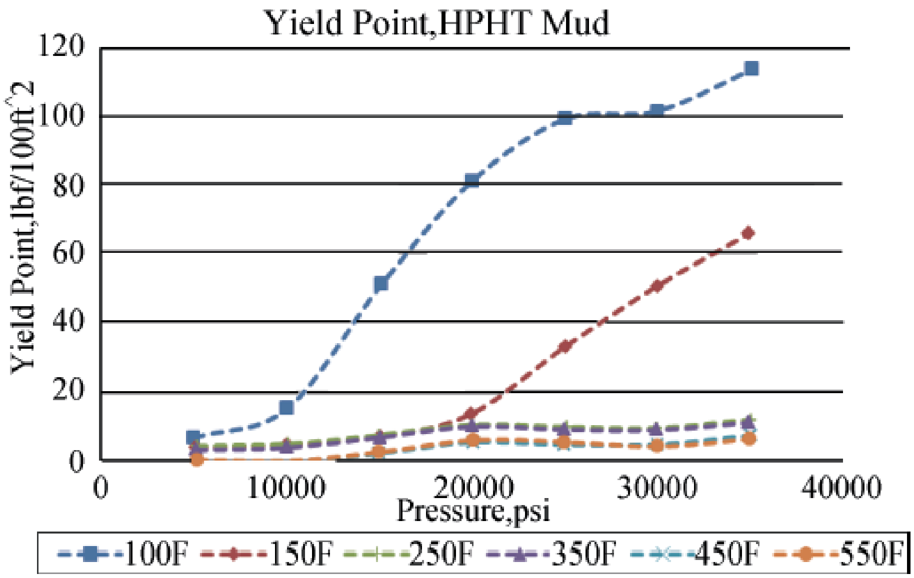

Figure 4 - yield point changes with temperature & pressure

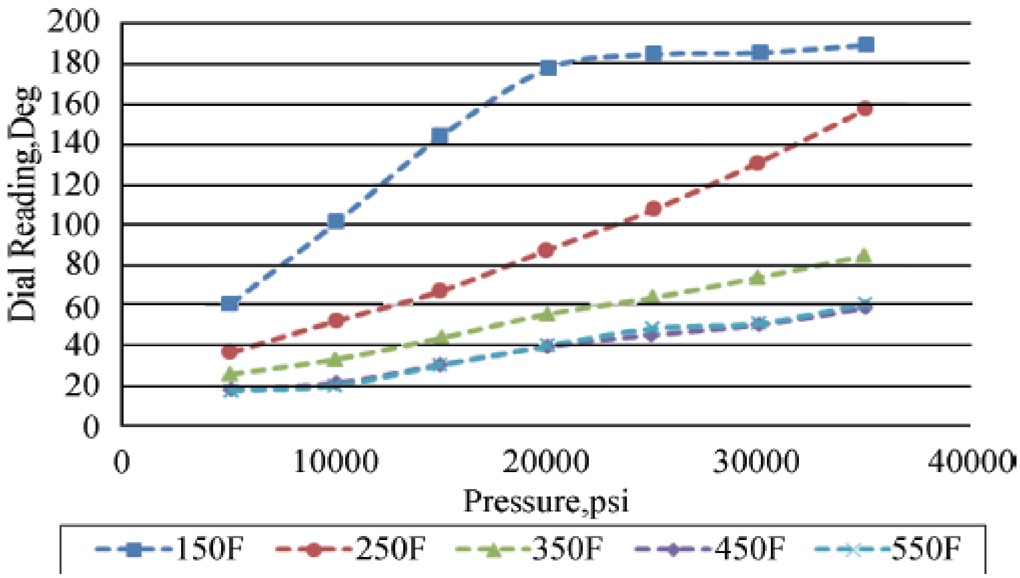

Figure 5 - - dial reading changes with temperature & pressure

- Barite is started to settle in bottom of the hole on HTHP conditions in oil based mud because mud becomes thinner and it can not retain the weighting agents.
- If solids are started to contaminate, brine clarity will be reduced and turbidity started to increase.
- If acid gas is entered, pH will be reduced.
- More salt blows decreasing in electrical stability & increasing chloride content in the mud.
- In reservoir zone, hydrocarbon also enters to well bore which which causes increase in O/W ratio,decrease in mud weight.
- In oil based mud, emulsion will be broken which may cause high water filteration, low electrical stability.
- If mud is contaminated with gypsum/anhydrate/cement,calcium concentration,pH are increased, spongy cake will be developed in the bore hole.

If mud losses its thermal stability, which causes:

- Breaking circulation becomes difficult.
- Running tools/logging to bottom is difficult.
- In oil based mud, due to evopration of water, water phase salinity and oil to water ratio is increeased. So the mud starts to loss its thermal stablility.

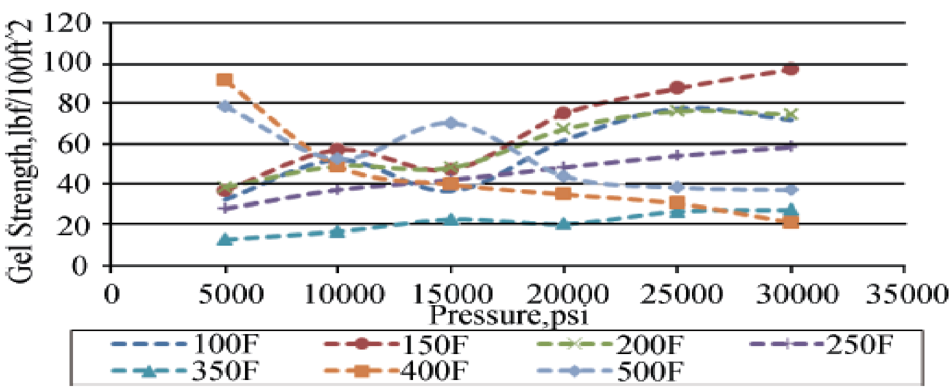

Figure 6 - Gel strngth changes with temperature & pressure

2.2.2 Drilling problems related to drilling fluid at HTHP condition:

The effect of drill cuttings

- At lower temperature, the higher volume of reactive drill cuttings can be controlled easily.
- But it is not possible in high temperature conditions, because mud starts to flocculate or gelation.
- The gel strength of amount of bentonite is discussed with increasing temperature in the graph.

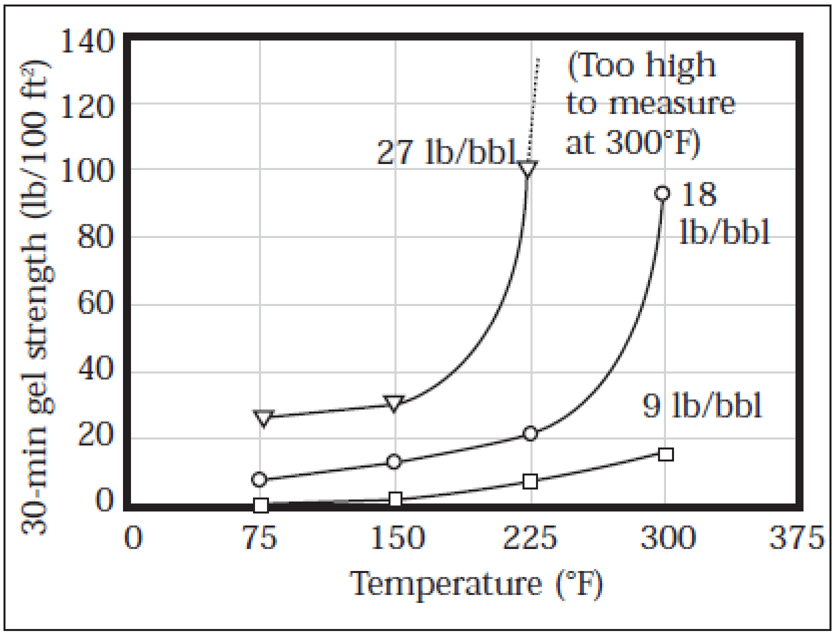

Figure 7 - 30 min gel strength changes with temperature

Higher density mud:

- When solid concentration is increased in the mud, the amount of available free liquid is decreased which helps to maintain higher PV and less reactive with other solids.
- But less free available liquid does not allow to solubilize other addives for working effectively.

Fluid loss or filteration:

- The mud should allow less fluid loss and seal the permeable formation with low permeable thinner mud cake.Once the fluid loss is high, the cake becomes thicker.

Problems of thicker mud cake:

- Borehole becomes tight condition causes more drag.
- The cantact area is increased between drill string and side borehole
- Surges and swabs are increased due to reduced annular clearance.
- Cementing is difficult due to insufficient movement of thicker mud cake.
- Casing installation becomes difficult.

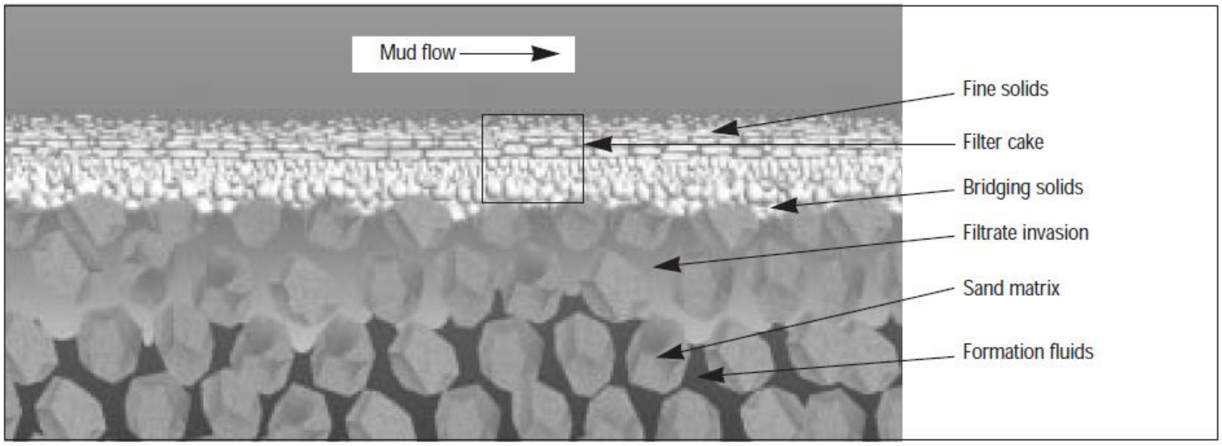

Figure 8 - A Thin, lower permeability mud filter cake

Problems of excessive fluid loss:

- Formation is damaging due to precipitation of mud such as change in wettability, permeability and formation plugging with fine solids, swelling of clays.
- Testing formation gives result of mud instead of formation fluids.
- It will also affect the electrical properties of logging, running and pulling tools.
- Invasion of fluid in reservoir keeps away hydrocarbon from wellbore. It is very difficult to evaluate the detection of hydrocarbon.

Differential sticking of pipe:

- The pipe will be stuck by differential pressure from an overbalanced mud column acts on drill pipe when thicker mud cake is formed.
- It is known as “wall sticking”.
- When the hydrostatic pressure is overbalanced against formation pressure, it will happen.
- Higher amount of drill solids & excessive fluid loss increase the thickness of mud cake.
- Thicker mud cake increases the contact area between drill string & annular space which leads wall sticking. So pulling drill string becomes challenging job.

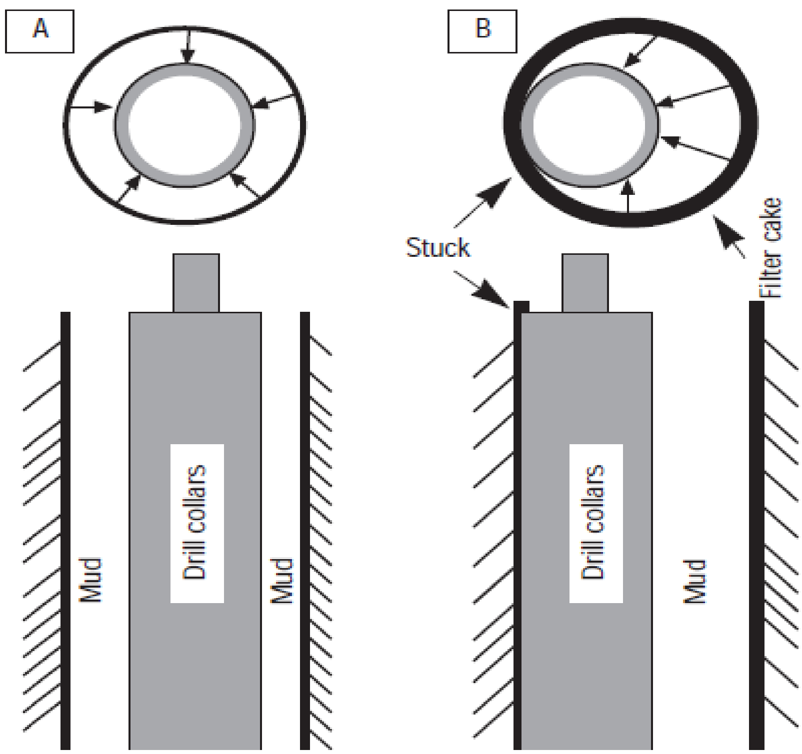

Figure 9 - Differential sticking

<u>Well bore stability at HTHP condition:</u>

- For deeper and high temperature formation, mineralogical properties are changed in the clay formation as the clay sediment holds plastic character and becomes more cemented which started to brittle the formation.
- Smectite clays in clay is more unstable chemically when temperature increases above 120 °C.
- Well bore stresses are developed due to difference between mud circulation between hotter and colder formation.
- Salt can flow under high pressure & above 107 °C which may cause closing the hole or tight hole or differential sticking.
- Soluble formations such as calcium carbonate, anhydrate, gypsum can easily react with water based mud and may cause formation swelling also leads poor hole cleaning.

<u>Corrosion:</u>

- Corrosion leads to drill string failure, drill pipe fallen on hole, etc.

- Oxygen, carbon di oxide, hydrogen sulfide are chemically reason for corrosion. They are pronounced as corrosive gases.
- When pressure increases, the solubility of oxygen & other corrosive gases also increase,
- Temperature plays twofold effect with corrosion.

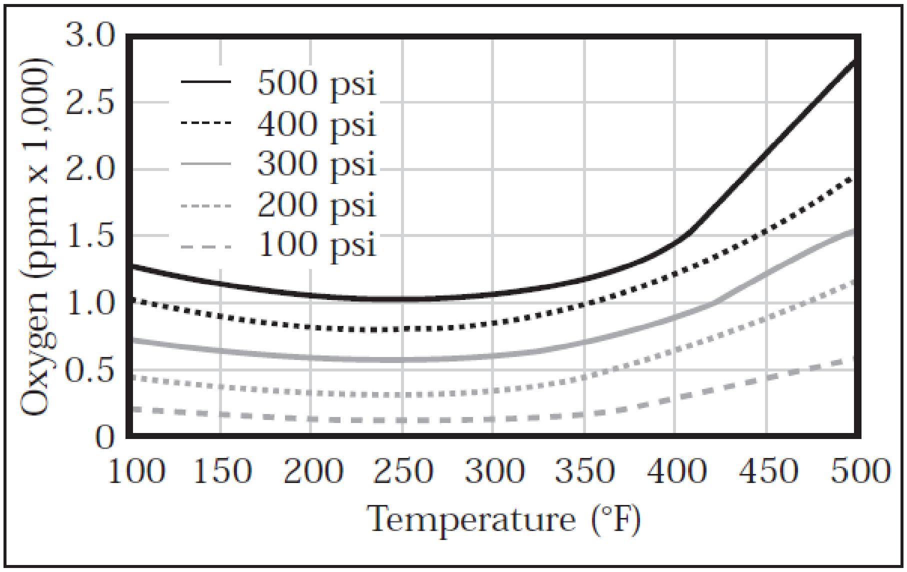

Figure 10 - solubility of oxygen changes temperature & pressure

- The corrosion rate increases with increasing temperature of 3% brine for oil based mud.

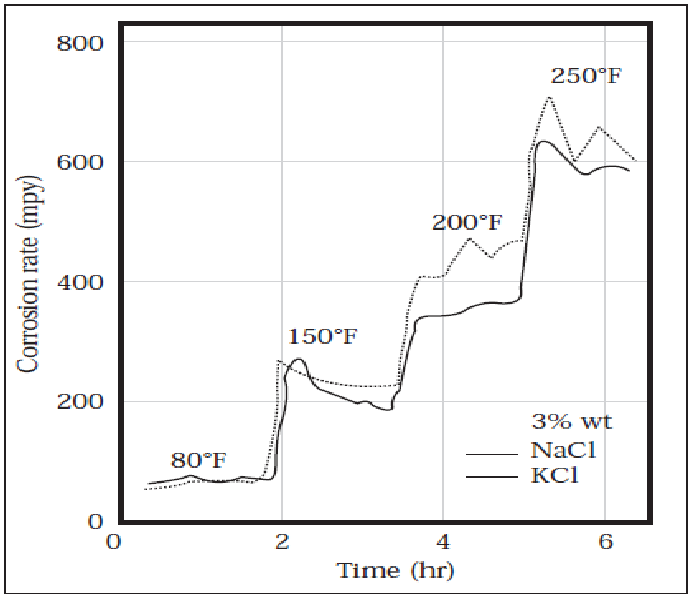

Figure 11 - The rate of corrosion changes temperature & pressure

CHAPTER 3 – DRILLING FLUID PREPRATION

3.1 Oil based mud composition:

1. Base liquid:

- The oil possesses kinematic viscosity and thermal/chemical stability.
- The density should work better in deep zone.
- Base oil (refined oil from crude oil)/ mineral oil can be used as base liquid.

2. Emulsifiers:

- It acts as surfactant to reduce the surface tension between oil and water.
- It stabilizes with partially soluble in water and oil form a coating around water droplets to keep them from coalescing.

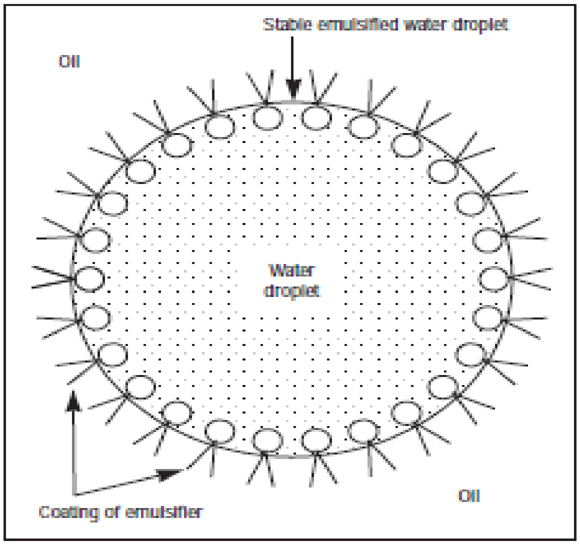

Figure 12 - Function of emulsifiers

3.Primary emulsifiers:

It reacts with lime and form as calcium soap which can act as emulsifier. It is used to keep the mud alkaline in all times.

4. Wetting agents/ secondary emulsifiers:

- It is a surface active agent which reduces the interfacial tension & contact angle between liquid and solid.so it can keep liquid to spread over solid surface.
- One end has soluble in continuous phase liquid & another end has strong affinity for solid surfaces.
- If solids are not wetted by continuous liquid phase, weighting material (drill solids, clays and barite) will aggregate and settle.

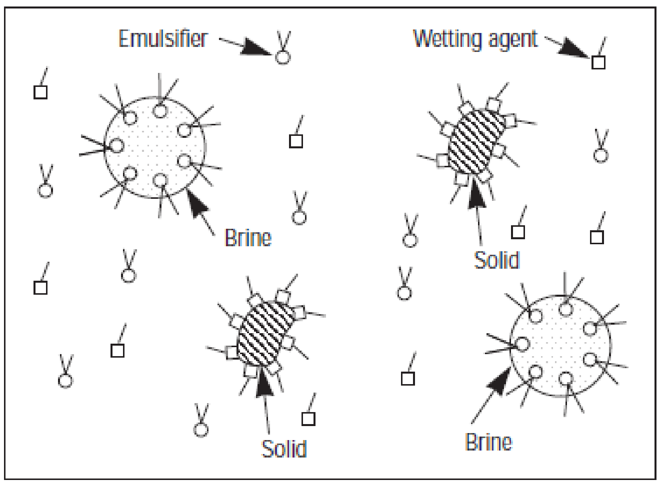

Figure 13 - Function of wetting agents

4. Weight material:

- Barite or hematite is the common mud density material.
- Sometimes calcium carbonate is also used for easy suspension than barite.

5. Filtration control additives:

- Oil based mud does not require any fluid loss additives upto 149 °C.
- Above this temperature, gilsonite or asphalt or amine treated lignite or polymers can be used.

6. clay:

- It helps to ciscosify the mud, carry weight materials and provide gel strength.

7. calcium chloride brine:

- It controls the salinity of formation and avoids osmasis process where the formation fluid can enter to bore hole (osmasis process: the fluid starts to flow from higher concentration to lower concentration through membrine.)

8. lime:

- It is added to react with calcium to maintain alkalinity and encounter corrsossive gases such as hydregen sulfide, carbon di oxide.
- It helps to enhance the function of emulsifier.

9.Calcium carbonate:

- It is used as weighting material as well as bridging material.
- Bridging particles are smaller particles than the formation pores. When the mud cake is forming, finer particles enter to formation deeper & deeper, bridged zone is created. Now liquid only can pass through that. Bridging material helps less damage formation.

10. Rheology modifier:

- This is used to enhance the low shear rheological properties. It helps to transport the drill cuttings & to prevent barite sag in deviated wells.

11.Oil/ water ratio:

- O/W should be maintained as low as possible which controls flow of the mud.

Pilot testing:

- 1 bbl = 42 US gallons = 350 pounds of water
- The unit is used to measure mud volume in the field. For testing purpose, this large amount of mud is very expensive & time consuming process.
- So the following units are used as lab bbl which will match to bbl unit.
- 1 lab bbl = 350 ml.
- For solid addives gram (g) is used as unit, for liquid specific gravity is used.

3.2 HTHP low toxic synthetic oil based mud formulation:

Formulation I based on Haliburton:

S.No	Function of the additive	Quantity per 1 lab bbl	Mixing time (min)
1	Base oil	130.77	-----
2	Emulsifier I	5.00	3
3	Emulsifier II	0.75	2
4	Alkalinty	5.0	5
5	Brine (distilled water) (Calcium chloride)	41.65 12.47	15
6	Viscosifier I	3.0	5
7	Organophillic clay	6.5	5
8	Viscosifier II	12.0	2
9	Fluid loss additive	4.0	3
10	Bridging agent	30.0	5
11	Rheology modifier	1.35	3
12	Weighting material	446.82	15
13	Wetting agent	1.0	2

Table 1 - Oil based mud formulation I

The mud is prepared with above specific time of each additive in silverson mixer at 6000 rpm.

Thermostability test:

The sample is hot rolled at 205 °C for 18 hours with 300 psia.

Results:

The rheology is tested at 65 ± 1 °C

S. No	Rheology	Value obtained
1	Mud weight	16.7 ppg
2	Plastic viscosity	67 cp
3	Yield point	22
4	Gel strength in 10 sec	08
5	Gel strength in 10 min	25
6	6 RPM	8
7	Electrical stability	537 V
8	HTHP fluid loss @ 160 °C	4.4 ml

Table 2 - results of Oil based mud formulation I

Formulation II based on KMC oil tools:

S.No	Function of additve	Quantity per 1 lab bbl in g	Mixing time (min)
1	Base oil	169.1	---
2	Primary emulsifier	4.0	3
3	Emulsifier II	0.5	4
4	Emulsifier III	0.5	3
5	Viscosifier I	7.5	5
6	Viscosifier II	1.75	5
7	Alkalinity	7.0	5
8	Fluid loss agent	1.25	4
9	Brine	72.66 22.55	15
10	Bridging agent	30	5
11	Rheology modifier	1.05	3
12	Weigting agent	103.28	15

Table 3 - Oil based mud formulation II

The mud is prepared with above specific time of each additive in silverson mixer at 6000 rpm.

Thermostability test:

The sample is hot rolled at 205 °C for 18 hours with 300 psia.

Results:

The rheology is tested at 50 ± 1 °C

S. No	Rheology	Value obtained
1	Mud weight	10.0 ppg
2	Plastic viscosity	26 cp
3	Yield point	21
4	Gel strength in 10 sec	10
5	Gel strength in 10 min	23
6	6 RPM	12
7	Electical stability	545
8	HTHP fluid loss @ 160 °C	3.0 ml

Table 4 - results of Oil based mud formulation II

Formulation III based on Baker hughes:

S.No	Function of additive	Quantity per 1 lab bbl in g	Mixing time (min)
1	Base oil	124.92	---
2	Primary emulsifier	19.0	5
3	Fluid loss controller I	4.0	5
4	Viscosifier I	0.70	3
5	Fluid loss controller II	1.25	5
6	Viscosifier II	0.70	5
7	Brine	38.41 13.61	15
8	Bridging agent	30.0	5
9	Weighting material	454.08	15

Table 5 - Oil based mud formulation III

The mud is prepared with above specific time of each additive in silverson mixer at 6000 rpm.

Thermostability test:

The sample is hot rolled at 205 °C for 18 hours with 300 psia.

Results:

The rheology is tested at 65 ± 1 °C

S. No	Rheology	Value obtained
1	Mud weight	16.7 ppg
2	Plastic viscosity	32 cp
3	Yield point	34
4	Gel strength in 10 sec	12
5	Gel strength in 10 min	23
6	6 RPM	9
7	Electical stability	560
8	HTHP fluid loss @ 160 °C	4.4 ml

Table 6 - Results of Oil based mud formulation III

3.3 Water based mud composition:

1. Bentonite:

- It gives viscosity and filtration control.

2. Pre hydrated bentonite gel:

- Bentonite 10% is added to water 90% stirred at maximum speed for 30 minutes. This mixture is aged at 90 °C for 24 hours.it becomes more viscous/ slurry.

3. Caustic soda:

- To maintain the alkalinity or to increase pH in the mud.

4. Shale stabilizer:

- To avoid swelling of mud in shake, the additive is added. It also contributes the fluid loss.

5. HTHP polymeric fluid loss additive:

- It is used to control the fluid loss & helps to improve the quality of mud cake.
- To inhibit the shale formation, improve the hole cleaning.

6. Thinner/ deflocculatant:

- To reduce viscous of the mud at HTHP conditions, thinner can deflocculate the mud and to keep low shear strength.

7. Scavengers:

- It is added for removing soluble oxygen from the drilling fluid. So corrosion can be controlled.

8. Soda ash:

- To remove the contamination solids/hardness from water.

3.4. HTHP water based mud formulation:

<u>Formulation I based on Haliburton:</u>

S.No	Function of additive	Quantity per 1 lab bbl in g	Mixing time (min)
1	Distilled water	337.12	---
2	Fluid loss controller	0.1	4
3	HTHP Fluid loss additive	1	3
4	Shale stabilizer	15	5
5	Viscosifier	113.97	5
6	Defloculatant	1.2	5
7	Wetting agent	2	3
8	Weighting material	442.05	5
9	Alkalinity	0.15	2
10	Corrosion controller	0.35	3

Table 7 - Water based mud formulation I

The mud is prepared with above specific time of each additive in Hamilton beach mixer at maximum speed.

<u>Thermostability test:</u>

The sample is hot rolled at 205 °C for 18 hours with 300 psia.

<u>Results:</u>

The rheology is tested at 65 ±1 °C

S. No	Rheology	Value obtained
1	Mud weight	16.7 ppg
2	Plastic viscosity	72 cp
3	Yield point	31
4	Gel strength in 10 sec	7
5	Gel strength in 10 min	13
6	pH	7.8
7	API fluid loss	3.8 ml
8	HTHP fluid loss @ 160 °C	14 ml

Table 8 - Result of Water based mud formulation I

Formulation II based on MI Swaco:

S.No	Function of the additive	Quantity per 1lab bbl in g	Mixing time (min)
1	Distilled water	213.53	-----
2	pH additive	0.25	2
3	Hardness remover	0.10	3
4	Viscosifier	5.0	5
5	Deflocculatant	3.0	5
6	Shale stabilizer	5.0	5
6	HTHP fluid loss additive	8.0	5
7	Bridging agent	30.0	5
8	Weighting material	426.32	5
9	HTHP deflocculatant	5.0	5
10	pH additive	1.0	2

Table 9 - Water based mud formulation II

The mud is prepared with above specific time of each additive in Hamilton beach mixer at maximum speed.

Thermostability test:

The sample is hot rolled at 205 °C for 18 hours with 300 psia.

Results:

The rheology is tested at 65 ± 1 °C

S. No	Rheology	Value obtained
1	Mud weight	16.6 ppg
2	Plastic viscosity	108 cp
3	Yield point	34
4	Gel strength in 10 sec	6
5	Gel strength in 10 min	17
6	pH	7.5
7	API fluid loss	3.0 ml
8	HTHP fluid loss @ 160 °C	14.6 ml

Table 10 – Results of formulation II

Formulation III based on MI Swaco:

S.No	Function of the additive	Quantity per 1lab bbl in g	Mixing time (min)
1	Distilled water	132.73	----
2	Viscosifier (prehydrated bentonite gel)	91.19	5
3	pH additive	0.25	3
4	Hardness remover	0.10	3
5	Deflocculatant	6.20	5
6	Shale stabilizer	12.0	5
7	HTHP fluid loss additive	2.5	5
8	Bridging agent	30.0	5
9	Weighting material	414.68	5
10	HTHP deflocculatant	12.0	5
11	pH additive	1.0	2
12	Oxygen scavenger	0.5	3

Table 11 - Water based mud formulation III

The mud is prepared with above specific time of each additive in Hamilton beach mixer at maximum speed.

Thermostability test:

The sample is hot rolled at 205° C for 18 hours with 300 psia.

Results:

The rheology is tested at 65 ± 1 °C

S. No	Rheology	Value obtained
1	Mud weight	16.6 ppg
2	Plastic viscosity	54 cp
3	Yield point	34
4	Gel strength in 10 sec	11
5	Gel strength in 10 min	34
6	pH	7.1
7	API fluid loss	4.2 ml
8	HTHP fluid loss @ 160 °C	14.8 ml

Table 12 – Results of formulation III

3.5 HTHP fluid loss additive quality assurance test for water based mud:

- For HTHP conditions, following composition is used for testing the quality of fluid loss additive in ONGC with its own specification.

1. Bentonite suspension: (4 – 5 cp)

- It gives generally viscosity, gel structure, fluid loss control and carrying weighting agent.
- But this Suspension is prepared with very lower viscosity because here it is used for carrying weighting agent only (barite). If it is too viscous, mud starts to flocculate at HTHP.

2. Weighting agent:

- Barite is used as mud weighting agent.
- Bentonite suspension is loaded with barite upto 2.05 (specific gravity) or 17 ppg because HTHP is deeper formation which needs higher density to control the formation pressure.

3. pH maintenance:

- It should be 10 – 10.5 by 10% NaOH
- If it is lower than mentioned range, thinners wont able to work because hydroxide ions starts to react with clay. So thinner may lose its thermal stability.
- At pH 10.5, calcium is nearly insoluble in the mud, so calcium hydroxide can encounter the corrosive gases such as carbon di oxide, hydrogen sulfide

4. Lignite powder:

It provides

- Filtration control, extension of thermal limitation for water based mud
- Reduce gel strength, viscosity at HTHP.
- Works in presence of large amount of contaminations.
- Improves quality of mud cake with lower permeability.
- Controls HTHP fluid loss
- Emulsifies oil & stabiles the mud.

5. Sulfonated asphalt:

- Improves lubricity which helps to reduce torque & drag of drill string.
- Helps to seal the low fractured/stressed shale formation.
- Helps to lower BHA temperature, improves corrosion inhibition.
- Reduces high temperature water loss
- Inhibits clay swelling & shale water wetting
- Controls HTHP fluid loss & improves mud cake quality.

6. Fluid loss control agent:

- It provides viscosifying mud, solids absorption and lower permeable mud cake.

7. Thinners:

It is used

- To reduce viscosity/thixotropic property of mud at HTHP condition.
- To reduce gel strength & assist in solid settling
- To disperse filter cake from drilling fluid.

Procedure:

S. No	Additives/composition	Range/quantity	Mixing time (min)
1	Bentonite suspension	4 – 5 cp	---
2	barite	2.05 (specific gravity)	---
3	pH	10 – 10.5	---
4	Lignite powder	1.5%	15
5	Sufonated asphalt	2%	30
6	Fluid loss additive	1.5%	30
7	thinner	0.5%	15

Table 13 - HTHP fluid loss additive thermostability test for water based mud

With above composition and procedure, mud can be prepared in heavy duty mixer with maximum speed.

Thermostability test:

The sample is hot rolled at 225 °C/200°C/ 175°C for 18 hours with 300 psia.

Fluid loss additives/thinners details		Polydrill/ Polythin (O BASF)			Flodrill ((SNF Floerger)		(United mud chem.pvt ltd		SHANGAI EVERBRIGHT	
S. No	additives/ hot roll temperature	225°C	200°C	175°C	225°C	200°C	225°C	200°C	225°C	200°C
1	Bentonite suspension(cp)	4 – 5	4 – 5	4 – 5	4 – 5	4 – 5	4 – 5	4 – 5	4 – 5	4 – 5
2	Loading Barite (sp.gr)	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05
3	pH by 1N NaoH	10 – 10.5	10 – 10.5	10 – 10.5	10 – 10.5	10 – 10.5	10 – 10.5	10 – 10.5	10 – 10.5	10 – 10.5
4	Lignite powder	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
5	Suphonated asphalt	2%	2%	2%	2%	2%	2%	2%	2%	2%
6	Fluid loss additive	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
7	thinner	0.5%	1.0%	1.0%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
8	Φ - 600	149	154	245	185	262	153	134	94	59
9	Φ - 300	129	124	215	107	154	91	77	57	34
10	YP	109	94	185	29	46	29	20	20	9
11	API fluid loss In ml	5.2	3.8	4.5	2.9	2.5	4.4	3.3	7	6.3
12	HTHP fluid loss In ml @ 160 °C	75*2= 150	13*2= 26	13*2= 26	16*2= 32	10*2= 20	23*2= 46	22*2= 44	90*2= 180	86*2= 172
13	Result as per ONGC spcif	Fail	Fail	Fail	Pass	may work	Fail	Fail	Fail	Fail

Table 14 - Different types of fluid loss additives for water based mud @ HTHP

- ONGC is following specific values for all rheological properties. After hot roll, if anyone of value of this property is changed from the given range, it is considered that mud is not stable thermally at testing hot roll oven temperature.

S.No	Rheology	Values for oil based mud	Values for water based mud	Values for HTHP fluid loss additive test
1	Yield point	>20	>20	20 – 45
2	Plastic viscosity in cp	ALAP	ALAP	ALAP
3	Gel strength in 10 sec	8 – 18	6 – 12	Not required
4	Gel strength in 10 min	10 – 25	10 – 25	Not required
5	6 RPM in cp	12 ± 4	8 ± 2	Not required
6	pH	Not required	Not required	Not required
7	Electrical stability in V	>450	-----	------
8	API fluid loss in ml	Not required	≤ 5	≤ 6
9	HTHP fluid loss in ml	< 5	< 15	≤ 30

ALAP: As Low As Possible.

Table 15 – Desired specification of rheology value after hot roll

3.6 Advantages/Disadvantages of oil & water based mud

<u>Limitation of oil based mud::</u>

- Oil based mud is quite expensive than water based mud. So it cannot be used for low number wells.
- Once lost circulation occurs, the formation will be damaged completely & controlling well becomes very difficult.
- The gas is readily soluble with oil which makes detection of gas kick will be very difficult.
- Gas influxes can reduce the viscosity of mud. it causes weighting material starts to settle in the well bore.
- The choice of oil based mud is not always environmental friendly with the local regulations. It pollutes ground water.
- Disposal of oil based mud along with drill cuttings is a major concern especially in the offshore drilling.
- Most of logging tools work effectively in water based mud environment.

- Oil based mud should not be preferred for exploratory/wildcat well. Because pressure of formation is unpredictable with available data.

Because of the following reasons the mud is very familiar with HTHP condition:

- It won't be contaminated with salt formation especially drilling against salt dome where as salt water mud is not more effective.
- Base oil gives lubricity, low torque & drag without adding any additive.
- Base oil is recyclable & it can be used n number of times.
- Oil based mud is stable 149 °C without any help of fluid loss additives.
- It always keeps mud density higher.
- Selection of oil based mud is technically supportive with drilling but not with environmentally.

Water based mud:

- It won't damage environment and formation and underground water.
- Disposal is simple & ecofriendly.
- The mud cost is cheaper than other muds.

But mud fails due to

- It is composed of many polymeric additives which starts to degrade at HTHP even may fail.
- There are more possibilities of bit balling in the well bore.
- Special additives/ extra additives are needed to gain the lubricity & to control the drag & torque.
- It needs separate additives for separate zones such as in shale zone, shale inhibitor or and shale stabilizer are required. The mud won't work continuously unless the salt level should be kept lower level.
- The function of all additives work only in their own desired pH level. So the regular monitoring of pH is needed or pH additive should be added to keep the function of additives.

- So the maintenance of water based mud is challenging job than oil based mud in HTHP condition.

Selection of HTHP fluid loss additive is based on

1. Whether it will work in presence of calcium or not.
2. Does it work in higher salt concentration or not.
3. Does it give unacceptable viscosity change or not.
4. Will it support to BHA with lower solids level (plastic viscosity).
5. Is it economically and environmentally acceptable or not.

CHAPTER 4 – EQUIPMENTS

4.1 Equipment for preparing drilling fluids:

1. Heavy duty mixer: it is used to prepare water based mud formulation which has high density/viscosity.

Figure 14 - Heavy duty mixer

2. Hamilton beach mixer: it is used to prepare water/oil based mud which has lower viscosity/density.

Figure 15 - Hamilton beach mixer

3. Silverson mixer: it is used only for oil based mud formulation for wide range of rpm to keep mud solids mixed properly.

Figure 16 - Silverson mixer

4.2 Equipments for testing HTHP mud:

4. Aging cell: to check thermal stability of the mud, this cell is used to pressurize (300 psi) the mud.so that mud can not leak during the hot roll.

Figure 17 - Aging cell

5. Roller oven

- To maintain the field temperature, the pressurized aging cell will be kept and rolled in the roller oven with required temperature for specific period of time.

Figure 18 - Roller oven

6. Electrical stability test:

- This test is for oil based mud to check the quality of emulsion and wetting agent of the mud after hot roll.

Figure 19 - ES tester

7. Viscometer: It is used to find out viscosity of the mud.

Figure 20 - Viscometer

Formulae:

- Apparent viscosity = Θ 600/2
- Plastic viscosity = Θ 600 – Θ 300
- Yield point = Θ 300 – PV

Gel strength:

- To check the suspension/carry capacity of the drill cuttings of mud. Generally known as thixotropic property.

In 10 sec:

- To determine shear stress at lower shear rate (3 rpm) after 10 seconds rest/static condition.

In 10 min:

- To determine shear stress at lower shear rate (3 rpm) after 10 min rest/static condition of the mud.

8. API filter press:

- It is the standard fluid loss test which is recommended by API.
- It is conducted at 24±2° C. and 100 psi for 30 minutes. The fluid loss is collected in the cylinder and reported in ml.
- Filter paper is used to filtrate the mud and check the quality of mud cake.
- This test gives idea about the loss will be minimum or not at this basic standard condition.

Figure 21 - API filter press

9. HTHP Fluid loss test:

- HTHP fluid loss is measured at 160° C. with 500 psia differential pressures as 600 psia in the top & 100 psia from the bottom side.
- The fluid loss will be collected by the cylinder for half an hour exactly from the above mentioned equipment.
- Filter paper is used to check the quality of mud cake.
- The result will be reported in ml (milliliter).

Figure 22 - HTHP filtration test

Safety precaution:

- The equipment is the most deadly dangerous with very high pressure and temperature even may burst and lives threaten losses.

The common mistake is,

- ***User tries to release the pin/ pressure without closing the stems of cell in both of the side top and bottom after the test.***

10. Mud balance:

- It is used to check the mud weight/ mud density with two units specific gravity in the upper side & ppg (pounds per gallon) in the lower side.

Figure 23 - Mud balance

11. lubricity tester/ film strength measurement:

Figure 24 - lubricity/ film strength tester

- The lubricity coefficient is measured by applying 150 inch pounds torque at 60 rpm.
- The final value is obtained from the monitor after 5 minutes.
- The film strength is measured by applying 300 inch pounds torque at 1000 rpm.
- The size of the Scrach in block holder is measured after 5 minutes run in extreme pressure test.

Conclusion

The prepared formulations in both oil and water based mud, can rid of the rheological problems upto 205 °C. Mainly high fluid loss is controlled and improved quality of the mud cake.It provides improved rheology of drilling fluids.It can enhance drilling efficiency in HTHP conditions.The formulation is friendly with environment (very low damage to environment).

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