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Investigating the Effects of Contaminants on the performance of Oil Based Invert Emulsion Drilling Fluid

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Abstract

Drilling fluid optimization is the main focus while drilling, this entails ensuring the fluid is at its right condition downhole at all time during drilling operation. The composition, including all additives added to the fluid must key into achieving the foremost goal of fluid optimization. Maintaining the integrity of drilling fluids downhole has become herculean especially at HTHP conditions. The possibility of fluid contamination at such prevalent downhole condition poses another major challenge to the fate of the drilling fluid.

This work was undertaken to investigate the effect of clay and sea water (containing calcium and magnesium ions) contaminations on the rheology of the oil based invert emulsion fluid. Barite (Ba_2SO_4) was used as the weighting agent; the based fluid used for the oil based invert emulsion system was EDC-99, a specialized kind different from the conventional diesel oil. The fluid were analysed before and after aging using, rheometer, filtration and emulsion stability tests.

From the experimental result, it was discovered that addition of contaminants lowered the electrical stability of the invert emulsion fluid. Fluid loss, Plastic viscosity, yield point and gel strength increased in the presence of contaminants. Only the plastic viscosity of the invert emulsion fluid was slightly out of API range for each set of contaminations, but this is still within the tolerance limit of an invert emulsion fluid with a S.G less than 1.6[1][1]. Fluid Rheology stabilization after HT aging indicate the suitability of the fluid to be employed for downhole HTHP drilling that may take longer time.

Introduction

Over the last decade, exploratory drilling has been on the increase with focus shifting to the offshore where there are vast amount of potentials. Wells being drilled at such locations worldwide are high temperature and high pressure wells, with harsh downhole conditions. Drilling under this conditions have posed several challenges to the drilling operations in totality, and drilling companies are daily seeking out ways to overcome numerous of these challenges. Example of these challenges is the initial discovery of the inability of water based fluids to drill at HTHP condition; this led to the development of the water based fluid by adding polymers. However, over the years it has been discovered that in lieu of the water based fluid, as temperature increases downhole while

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[1] Taugbol, K, Gurnar, F Prebersen, O.I, Kaare, S, Omland, T.H, Svela, P.E, Breivik, D.H. 2005. Development and field testing of a unique high temperature and high pressure(HTHP) Oil based drilling fluid with minimum rheological properties and maximum sag stability. Paper SPE- 96285 presented at the Offshore Europe, Aberdeen, 6-9 September,2005

drilling, oil based fluid can be used as a preferred substitute. The use of the oil based mud has also found its own limitation as environmental pollution control becomes a factor to reckon with. Most regions in North America and Europe where offshore exploration is on the increase have strict environmental law against pollution enforced by agencies to protect the aquatic habitat of the region. In such regions, high temperature and high pressure drilling are not carried out with conventional oil based mud. This has led to the modification of the oil based invert emulsion drilling fluid by using specialized synthetic base fluid as the continuous phase instead of the conventional diesel oil.

Oil muds have shown special economic advantage when used for troublesome shales, slim hole drilling, corrosion control, workover fluids, difficult directional wells, drilling and coring, sensitive coring, production zones and deep hot wells. Environmental concerns during the 1980s led to the use of mineral oils, highly refined oils with less toxicity and more acceptable than diesel. Mineral oil contains lower concentration of aromatic compounds than diesel. Minerals oil are non polar and non aqueous liquid, and will not conduct electricity nor dissolve ionic compounds such as salts or anhydrite, they are used for based fluid in invert emulsion mud systems.

A typical example is the base fluid used for this invert system, EDC-99 which is a trademark name by Mi Swaco. The choice of which base oil to be employed is a matter of selecting a formulation that will provide a balance between environmental acceptability, waste disposal cost, performance and availability.

Generally oil or synthetic based invert emulsion drilling fluid show superior temperature stability when compared to water based drilling fluid. Oil based invert emulsion drilling fluid also exhibit a lower coefficient of friction and provide a thinner filter cake making them the right choice to be applied for these extreme conditions.

Basics of Invert Emulsion Fluid

Invert emulsion drilling fluids are mixture of two immiscible liquids: oil (or synthetic) and water. They may contain 50%, less or more water. This water is broken down into small droplet and dispersed in the external non aqueous phase. The droplets are kept in the oil by surfactants that act between the two phases. These surfactants sometimes are emulsifiers which reduces the surface tension between the water droplet and the oil (or synthetic). A typical emulsifier for invert emulsion drilling fluids belong to a class of chemicals characterized by functional groups that can confer bipolarity, such as fatty acids, fatty alcohols and amines. Calcium chloride is added to increase the emulsified water phase salinity to provide inhibition of shales and reactive solids. Alternative to calcium chloride, include; sodium chloride, potassium chloride, organic non-chloride salts and other water soluble liquids.

Fluid Contaminations

Drilling fluids are growingly faced with several challenges as a result of improvement in sophisticated drilling operations[2]. Over the years the inability to adequately meet these challenges has resulted in numerous drilling problems and setbacks during drilling operations. Fluid contaminations constitute the major problem in drilling fluids during drilling operations, these contamination challenges has resulted into wellbore instability[3], wellbore position error[4], loss of time during drilling operations[5] amidst others.

[2] E. Stamatakis, S. Young, G. De Stefano, MI- Swaco. Meeting the Ultra deep HTHP Fluid Challenge. SPE paper-153709. Presented at the SPE Oil and gas India conference and Exhibition held in Mumbai, India, 29-30 March 2012

[3] Peng Chunyao, MOE Key Laboratory of Petroleum Engineering, China Univ. of Petroleum; Feng Wenqiang, Yan Xiaolin, Greatwall Drilling Company Ltd; Yan Jienian, SPE, China Univ. of Petroleum; Luo Xiangdong, Oilchemleader Science &Technic Development Co. Ltd. Offshore Benign Water-Based Drilling Fluid Can Prevent Hard Brittle Shale Hydration and Maintain Borehole Stability. IADC/ SPE paper- 114649 presented at the 2008, IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition.

Aside from the well known salt water and rock salt contaminations[6], other major source of contamination is the sea water (containing magnesium and calcium ion) and clay particles. Magnesium ions and calcium ions both present in seawater are detrimental to water base muds. Since magnesium hydroxide ($Mg(OH)_2$) and calcium hydroxide ($Ca(OH)_2$) are relatively insoluble at higher pH, caustic should be used to remove magnesium and suppress the solubility of calcium.

Caustic soda is used to reduce the magnesium and calcium in seawater by first precipitating magnesium as $Mg(OH)_2$, and then increasing pH to suppress the solubility of calcium and precipitate lime. If lime is used in seawater it, too, will remove magnesium, but the resulting calcium levels will be very high and are undesirable. Gulf of Mexico seawater requires 1.5 to 2 lb/bbl caustic soda (4.3 to 5.7 kg/m^3) to precipitate all magnesium. In seawater, the preferred treatment for magnesium removal is caustic, while the preferred treatment for calcium removal is soda ash.

Contamination with clay particles can occur during drilling and depend on formation composition. The bentonitic clay colloids like sodium or calcium montmorillonite are made of individual thin flat sheet in layers. One of the flat surfaces has positive ions like Na^+ and Ca^+ while the surface of the facing plate is negatively charged[7]. This result in a weak interaction binding the clay platelets together[8], calcium montmorillonite has calcium ions at the interfoliaceous cations and thus the degree of ionization is less. Thus calcium montmorillonite clay particles due to lower degree of ionization and hydration will be more unstable as colloidal solution. This may lead to a greater instability in the clay suspension and cause flocculation. To curtail this flocculation dispersants are employed.

The rheology of drilling fluid is typically characterized with the parameters of yield point, plastic viscosity, and low shear rate yield point. The yield point, which is the second component of resistance to flow in a drilling fluid, is a measure of the electrochemical forces in the fluid which determines the hole cleaning ability of the drilling fluid, the PV is the resistance to flow of the drilling fluid caused by mechanical friction, it is related to the type and concentration of the solids in the drilling fluid. The LSYP is related to the sag character of the fluid. A desirable drilling fluid has a low PV but good low shear viscosity (LSYP 7-15 lb/100ft^2)[9 10 11]) and a good yield point within API recommended range. The ability of the mud to suspend barite is more dependent on the gel strength, low shear viscosity and the thixotropy of the fluid. Both the gel strength and the yield point are a measure of the attractive forces in the fluid system, while the gel strength measures the static attractive forces the yield point

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[5] Yan Ye, China University of Petroleum, and An WenHua, Wang ShuQi, and Luo FaQian, Petrochina Tarim Oil-field Company. Drilling Fluid Challenge During The Ultra-deep HT/HP/HS Drilling in The Mountainous Area, Tarim Basin. SPE paper-131533 Presented at the International Oil and Gas Conference and Exhibition in China, 8-10 June 2010, Beijing, China.

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[7] Benchabanae A., Bekkour K, 2006, Effects of Anionic Additives on the Rheological behaviour of Aqueous Calcium Montmorillonite Suspensions, Rheologica Acta, 45, 425- 434.

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measures the dynamic attractive forces. Initial gel strength above 5lb/100ft^2 is usually required to suspend weighting materials.

Through numerous researches it has even been found out that low shear viscosity values (6 and 3-RPM) have greater impact on hole cleaning than yield point. A high LSYP under HTHP conditions demonstrate improved sag resistance[3] and cutting carrying capacity[12 13].

Recent experimental research to investigate contamination effect on water based drilling fluids at HTHP was carried out in 2011[2]. They tested the effect of cements, rock salt and clay on water based drilling fluids of high specific gravity using manganese tetroxide (Mn_3O_4) as weighting agent, they also tested over 100 dispersants and they discovered two environmentally friendly dispersants that will still perform effectively under such downhole condition. However the scope of their work was limited to water based fluids as they majorly considered wells in the North Sea where environmental regulation is of paramount importance prohibiting usage of oil based fluids.

Earlier, the effects of synthetic oil based drilling fluid internal water phase composition on barite sag was carried out in 2006[14]. Several salts were tested including $CaCl_2$ when employed as internal brine phase components, from the result they discovered that the salt content of the brine phase can result into mud sagging. However they did not consider influence of other salts asides the one making up the brine phase which can contaminate the fluid during drilling operation.

Experimental procedure

The fluid prepared were analysed based on their rheology, stability and fluid loss (shown in Table2 page 8)

Drilling Fluid Rheology

Drilling fluid Rheological measurement was done by using a Fann viscometer 35A at 50^{o}C, (120°F), and also at 180°F, after increasing the temperature in the heating jacket of the viscosimeter. The YP was obtained from the Bingham plastic model when extrapolated to zero. The PV represents the viscosity of the fluid when extrapolated to the infinite shear rate. Both YP and PV are calculated using 300 revolutions per minute (rpm) and 600 rpm shear rate readings.

PV= 600 rpm reading – 300 rpm reading

YP= 300 rpm reading – PV

LSYP= [2 *(3 rpm reading)] - (6rpm reading)]

Aging experiment was done on the drilling fluid, at 350°F for a total of 16 hours. Static aging was employed with aging cell at angle of 45°. Four different fluids samples were aged:

- Blank sample
- Blank sample + sea water
- Blank sample + clay
- Blank sample + sea water + clay

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Samples were put in an aging oven in a static position resting at an angle to prevent overturning of mud inside the aging cup. High pressure/ high temperature filtration test was performed using the HP/HT filter press, this was conducted at a temperature of 350°F and a pressure of 500psi, the cartridge used contained CO_2 , fluid loss were measured as a function of time.

Emulsion Stability Test

The electrical stability is a function of the emulsion stability. It is an indication of how well the water is emulsified in the oil or synthetic phase. Oil and synthetic fluids do not conduct electricity. In the electrical stability test, the voltage (electrical potential) is increased across electrodes on a fixed- width probe until the emulsified water droplets connect (i.e. coalesce) to form a continuous bridge or circuit. The stronger the emulsion the higher the required voltage to break down the emulsion completing the electrical circuit to conduct electricity.

Materials

For the oil based invert emulsion system, several materials were put in place to make up the composition of the fluid used.

Oil based fluid preparation

- EDC-99- Based fluid for the oil based system
- Calcium chloride $CaCl_2$- with a specific gravity of 1.68, was used as a salt, in the water making up the internal brine phase of the synthetic fluid system.
- Sure Mul
- Sure Wet-wetting agent
- VG plus- Organophilic clay viscosifier
- Versagel HT
- Ecotrol RD- HTHP fluid loss controller
- Lime- Alkalinity Control
- Water-Discontinuous phase of the invert emulsion
- Barite- weighting agent for fluid,
- Sea water 35ml, with a specific gravity of 0.86
- 10% weight of clay
-

Oil based fluid preparation procedure

- Measure the base oil fluid and add VG plus, Versagel HT, and Lime in the right quantity simultaneously
- Leave to stir for 15mins
- Add Suremul and Surewet in their required proportion
- Allow to stir for 10 minutes
- Measure the required quantity of water, dissolve Calcium chloride in the water, and then add to the mixture.
- Allow to agitate for another 15 minutes and
- Add Ecotrol
- Measure the quantity of barite to be used and the add to the mixture after 5minutes
- Allow to stir for 7minutes

The oil to water ratio relate only to the liquid portion of the mud and is not affected by the solid content. The oil-to-water-ratio relates the oil and water fraction to the total liquid fraction.

$$\text{Oil to water ratio} = \frac{\textbf{vol \% oil}}{(\textbf{vol \% oil+vol \% water})}$$

Equation 1

Results and Discussions
From the experimental set up and procedure, after testing the overall effects of contaminant on the fluids prepared, the following observations were noticed.

For the oil based mud system (invert), drilling fluid rheology was both measured at 120°F and 180°F to check the variation in rheological properties before and after heat aging.10% weight of clay and 10% sea water (containing magnesium salt) was used as contaminant.

Table 3 shows the result of the fluid rheology without contaminant, the graphical a comparative graphical analysis of viscosity changes was plotted in Fig 1&2 respectively. Fig 1 shows the result for the oil based invert emulsion fluid system before heat aging; result revealed that rheology decreased with temperature increase for the fluid sample while Fig.2. shows the result for the oil based system after heat aging; generally the fluid rheology decrease slightly after the aging process. The plastic viscosity and yield point are well within the API recommended range. The LSYP is within the recommended range showing lower tendency for sagging in the drilling fluid before and after heat aging.

Table 4 shows the fluid rheology with sea water as contaminant, a comparative graphical analysis of viscosity changes was plotted in Fig 3&4 respectively. Fig.3. shows the result of the oil based invert emulsion fluid before aging water, result reveal a pronounced increase in the rheology of the fluid at 120°F as compared to when there was no contaminant (Fig 2and3) there was a slight decrease at 180°F with a moderate gel strength, yield point. The plastic viscosity before heat aging in this case went beyond the recommended value, this is due to the high insoluble Ca+ and Mg+ inherent in the sea water contaminants, causing a reasonable degree of flocculation in the fluid sample. This invariably makes the sample unsuitable. Fig.4. shows the result of the oil based IEF after heat aging at 350°F, the rheology was taken at 120°F and 180°F, there was a decrease in PV, YP, and LSYP as compared to before the aging process.

Table 5 shows the fluid rheology with clay as contaminant, a comparative graphical analysis of viscosity changes was plotted in Fig 5&6 respectively. Fig.5. shows the result of the oil based invert emulsion fluid before heat aging, result reveal a general increase in fluid rheology as compared with the blank sample with the exceptions of gel strength, and yield points which increased as a result of temperature increase. At 180^0F for the blank sample, the drilling fluid becomes unsuitable since API specification for yield point has been exceeded.

The LSYP also increased greatly showing less propensity for sag. Fig.6. shows the result of the oil based fluid after heat aging at 350°F when rheological properties were fully developed, the rheology of the fluid was greatly increased in the blank sample (both plastic viscosity, average viscosity, gel strength and yield point). The high increase in gel strength for the blank sample at both 120°F and 180°F, after aging at 350°F was due to the significant flocculation of particles in the drilling fluid after exposure to HP/HT conditions during the 16hours of aging. A well of this type will require a moderately high pumping pressure for resuming drilling fluid circulation after long trips or halts in drilling.

Table 6 shows the fluid rheology with both sea water and clay as contaminant, a comparative graphical analysis of viscosity changes was plotted in Fig 7&8 respectively Fig.7. shows the result of the oil based invert emulsion fluid before aging, result revealed an increase in drilling fluid rheology at 120°F for both samples, plastic viscosity extended out of the API range for the blank sample at 120°F, which in turn reduced when heated to 180°F.

Fig.8. Shows the result of the oil based system after heat aging with both sea water and clay as contaminant. The rheology for both blank and dispersant sample decreased at 120°F and even more at 180°F as compared to that before aging.

The cumulative effect of clay and the calcium, magnesium ions in sea water was pronounced. The swelling, dispersion characteristics in clay coupled with ionic segregation as a result of sea water resulted in a reasonable degree of dispersion within the mud increasing the yield point for the samples after aging for 16hours under high temperature.

Fig 9 shows the emulsion stability result for the oil invert emulsion based fluid. The emulsion stability of the fluid decreased as contaminants were added both before and after heat aging at 350°F. It was also observed that after aging the sample with both clay and sea water contaminant had the lowest emulsion stability. Due to the cumulative presence of Ca ions and Mg ions contaminants in the fluid, the conductivity of the water phase in the external oil phase increases. This will cause a decrease in electrical stability of the fluid. From the figure, it was also evident that electrical stability increases after aging process, this is due to the fact that any temporal instability caused initially in the fluid if given time, the water phase will restabilize slowly, making it to be dispersed in the invert fluid causing an increase in electrical stability.

In Table 7 page 10, the fluid loss experiment revealed an increase in the fluid loss as contaminants were added with the highest fluid loss recorded when both clay and sea water were used as contaminant. The high fluid loss was due to the presence of calcium and magnesium ions in the fluid causing high degree of flocculation.

Conclusion

From the experiment the following deductions can be made:

- Fluid Rheology decreases with increasing temperature.
- The initial low viscosity of the invert emulsion fluid reflects its ability to reduce frictional pressure loss.
- Clay contamination increases the gel strength and LSYP of fluid as compared to only sea water as contaminants decreasing the tendency for sagging of weighting material to occur. This suggests the usage of clay as rheology modifiers for an invert emulsion based fluid system.
- Mud electrical stability decreases in the presence of contaminations which indicate the partial emulsification of water in the oil phase.
- The plastic viscosity of the invert emulsion fluid was slightly out of API recommended range for each set of contaminations before heat aging, however the invert emulsion fluid can still tolerate and withstand such level of contaminantion. Nevertheless if threatening to the fluid, pretreatment is adviced.
- Fluid rheology stabilization after heat aging reveals the suitability of the oil based invert emulsion fluids for downhole HTHP drilling that may take longer time.

Recommendation

- A viscometer sag shoe test is also recommended to further quantify the extent of flocculation that might occur when the invert emulsion system is employed under these harsh downhole conditions.
- The Experimental Scope tested clay as a contaminant, however results proved that it can provide sag stability and better hole cleaning for laminar flow, to verify and solidify these claims effects of other types of clays on invert emulsion based systems need to be experimentally tested.

- Based on the experimental scope, $CaCl_2$ was employed as internal brine phase for the water, its influence on contamination results obtained cannot be ascertained, so further work should be done employing other internal brine phase in the water to check what correlation exist between them and the results of contaminations.

Acknowledgement

Special thanks to MI Swaco Nigeria for funding the project. We are also grateful to all who contributed in the experiment.

Acronyms

WBS- Water based System
OBS- Oil based System
IEBS- Invert Emulsion based system
YP- Yield point
PV- Plastic Viscosity
API- American Petroleum Institute
HTHP- High Temperature High Pressure.
LSYP- Low Shear Yield Point
IEF- Invert Emulsion Fluid
$CaCl_2$- Calcium Chloride

Experimental results

Table 1: Recommended Values of the Rheological properties for the Drilling fluids [1]

Property	Unit	Recommended Values
Plastic Viscosity	cp	8 – 35
Yield point	$lb/100ft^2$	Min= 5 Max = YP< 3× PV
10 min. Gel strength	$lb/100ft^2$	2 - 35

1. Amosa, M.K, Mohammed,I.A., Yaro, S.A., Arinkoola, A.O. Azeez, G.O. 2010. Comparative analysis of the efficacies of ferrous gluconate and synthetic magnetite and sulphide scavengers in oil and gas drilling operations Nafta Journal Croatian Scientific Journal 61(3): 117-122

Table 2: Formulation of oil based invert emulsion drilling fluids with S.G of 1.56	
Components	**Amount(g)**
EDC-99	167.3
Calcium chloride $CaCl_2$	21.40
Sure Mul	5.96
Sure wet	1.0
VG plus	1.75
Versagel HT	5.26
Ecotrol RD	1.75
Lime	5.96
Water	51.21
Barite	280.96
Clay	10%wt
Sea water	10%wt

Table 3: Rheology of oil based invert emulsion drilling fluid with S.G of 1.56 without contaminants				
Speed(rpm)	Before heat aging		After heat aging at 350°F	
	120°F	180°F	120°F	180°F
600	82	66	81	58
300	50	40	49	37
200	40	30	37	28
100	25	20	25	18
6	5	6	8	6
3	4	5	6.5	5
Gel 10 sec	3	5	7	5
Gel 10min	6	6	9	8
PV	32	26	32	21
AV	41	33	47.5	29
YP	18	14	17	16
LSYP	3	4	5	4
EMS	631		789	

Table 4: Rheology of oil based invert emulsion drilling fluid S.G of 1.56 with Sea water as contaminant

Speed(rpm)	Before heat aging		After heat aging at 350°F	
	120°F	180°F	120°F	180°F
600	108	80	82	59
300	71	54	50	38
200	56	42	38	29
100	40	26	26	20
6	13	11	9	7
3	11	9	8	6
Gel 10 sec	11	7	7	6
Gel 10min	13	11	9	7
PV	37	26	32	21
AV	54	40	41	29.5
YP	34	28	18	17
LSYP	8	7	7	5
EMS	462		443	

Table 5: Rheology of the oil based invert emulsion drilling fluid S.G of 1.56 With Clay as contaminant				
Speed(rpm)	Before heat aging		After heat aging at 350°F	
	120°F	180°F	120°F	180°F
600	110	96	139	136
300	79	85	103	110
200	62	68	68	94
100	44	59	59	75
6	16	29	32	64
3	14	23	23	31
Gel10 sec	17	23	24	23
Gel10min	19	25	29	30
PV	31	11	36	26
AV	55	48	69.5	68
YP	48	74	67	84
LSYP	12	14	14	-3
EMS	468		548	

Table 6: Rheology of the oil based invert emulsion drilling fluid S.G of 1.56 with Sea Water and Clay as contaminant				
Speed(rpm)	Before heat aging		After heat aging at 350°F	
	120°F	180°F	120°F	180°F
600	112	72	85	59
300	74	54	50	32
200	57	34	37	23
100	38	20	23	15
6	12	5	6	4
3	7	4	4	3
Gel10sec	6	4	5	3
Gel 10min	11	7	5	3.5
PV	38	18	35	17
AV	56	36	42.5	29.5
YP	36	36	15	15
LSYP	2	3	2	2
EMS	471		276	

Table 7: Fluid loss of oil based invert emulsion drilling fluid at 350°F and 500psi for the various samples	
	ml
Blank	3.7
Blank + sea water	4.4
Blank + clay	3.9
Blank + sea water + clay	4.6

Keys:

- AV-Average Viscosity (cp)
- PV-Plastic Viscosity (cp)
- YP-Yield Point (lb/100ft^2)
- Ty-Shear stress
- SG-Specific gravity
- Gel strength (lb/100ft^2)
- LSYP- Low Shear Yield Point
- HTHP- High Temperature High Pressure

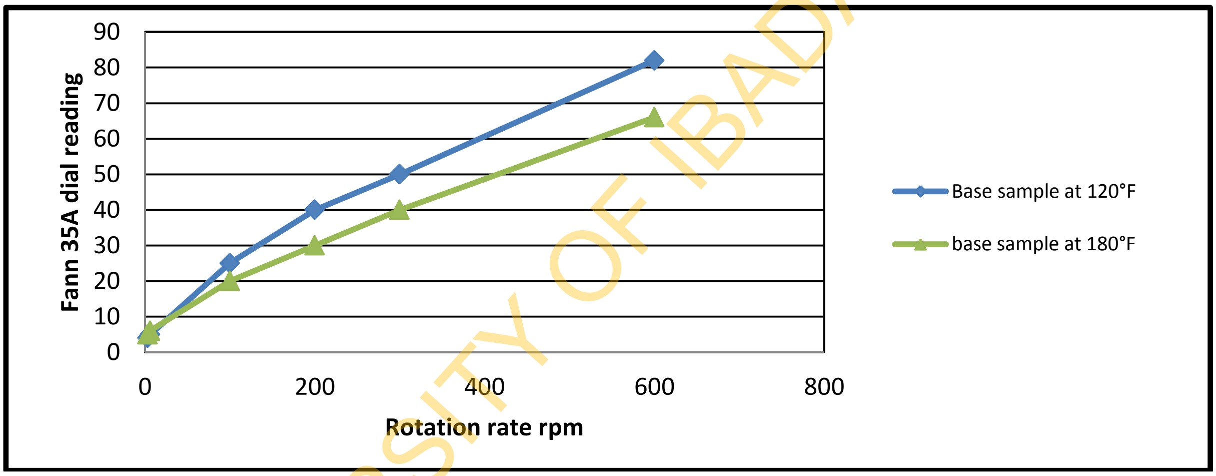

Fig.1: Fann 35A reading of Oil based invert emulsion drilling fluid before heat aging without contaminant.

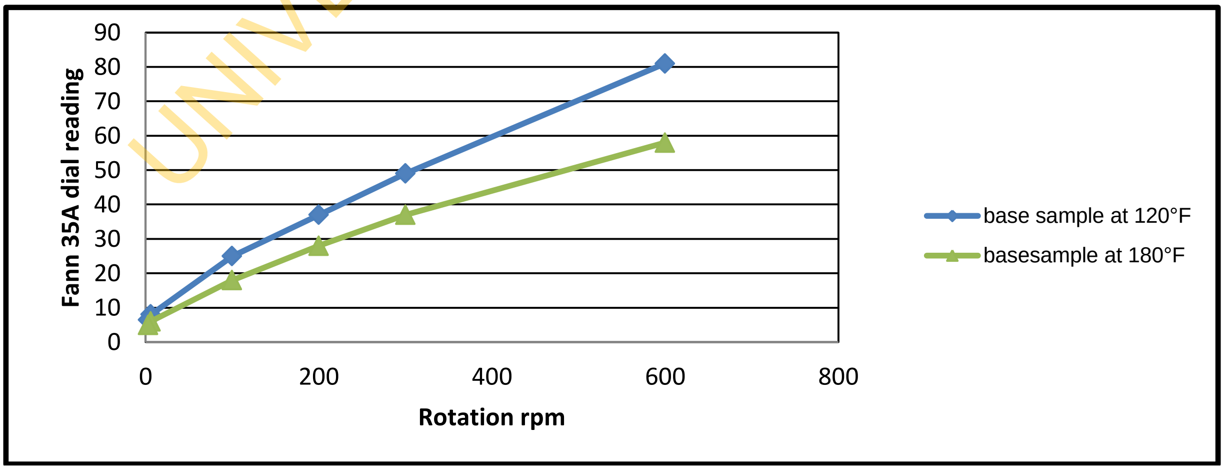

Fig. 2: Fann 35A reading of Oil based invert emulsion drilling fluid after heat aging without contaminant.

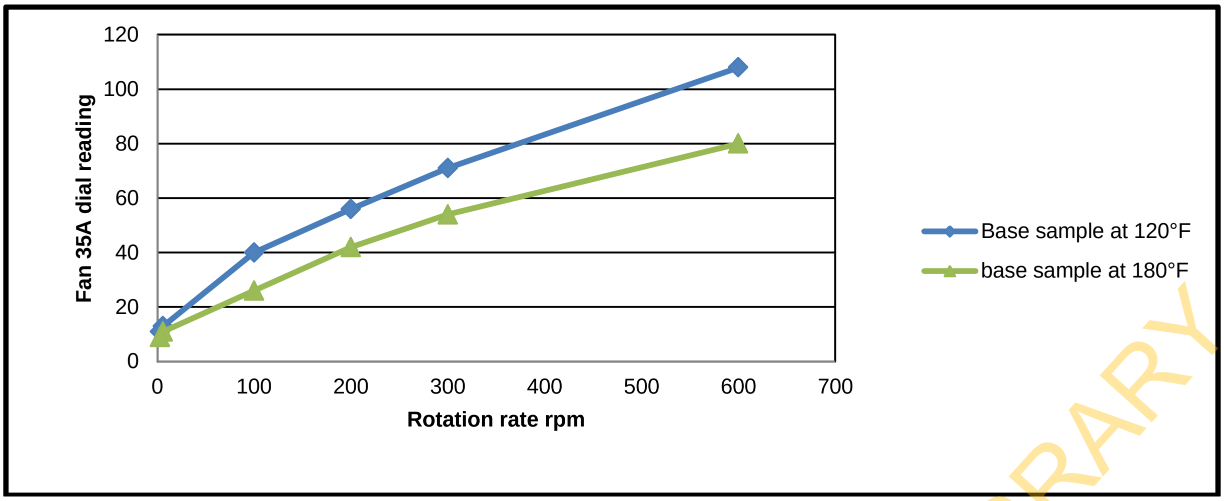

Fig.3: Fann 35A reading of Oil based invert emulsion drilling fluid before heat aging with sea water as contaminant.

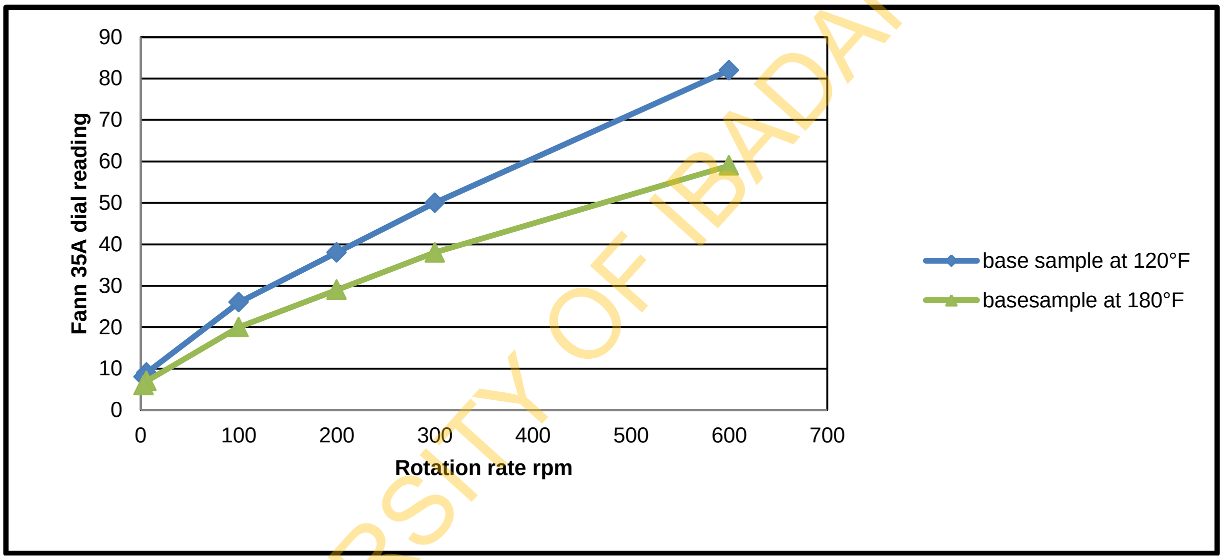

Fig.4: Fann 35A reading of Oil based invert emulsion drilling fluid at both temperature after heat aging with sea water as contaminant

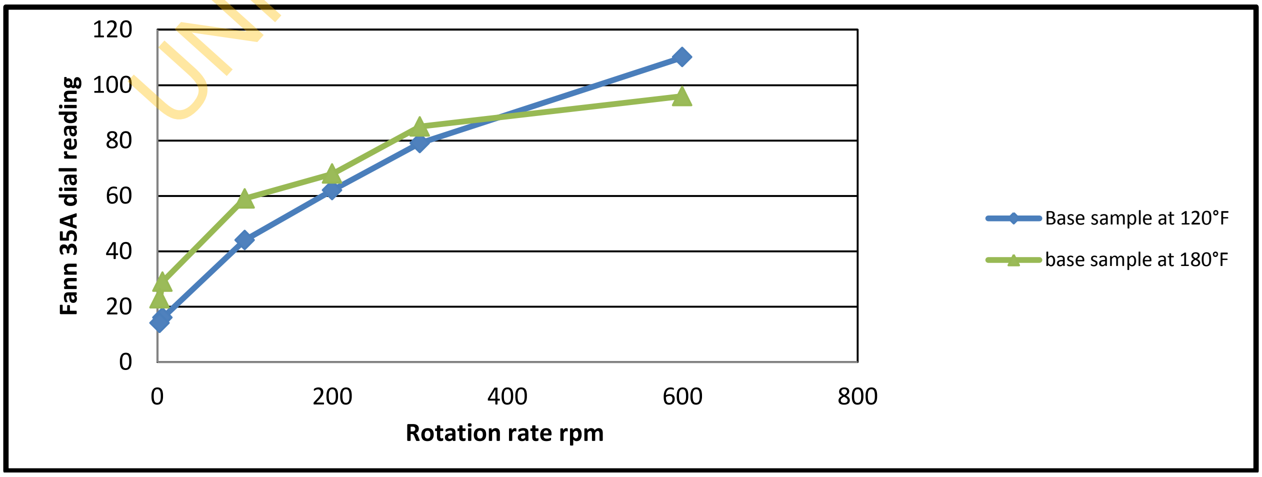

Fig.5: Fann 35A reading of Oil based invert emulsion drilling fluid before heat aging with clay as contaminant

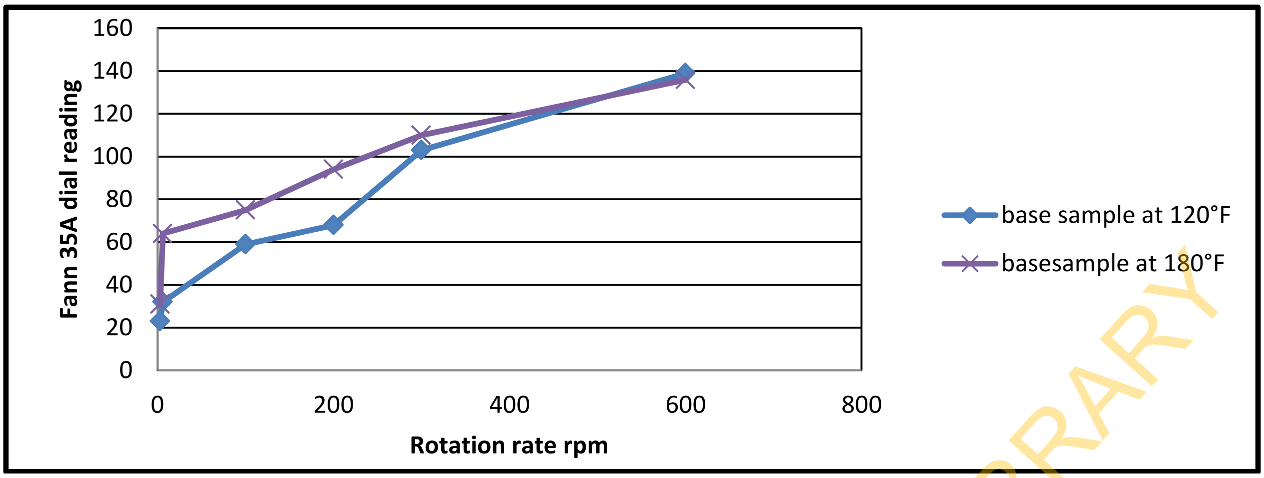

Fig.6: Fann 35A reading of Oil based invert emulsion drilling fluid after heat aging with clay as contaminant. Aging done at 350°F

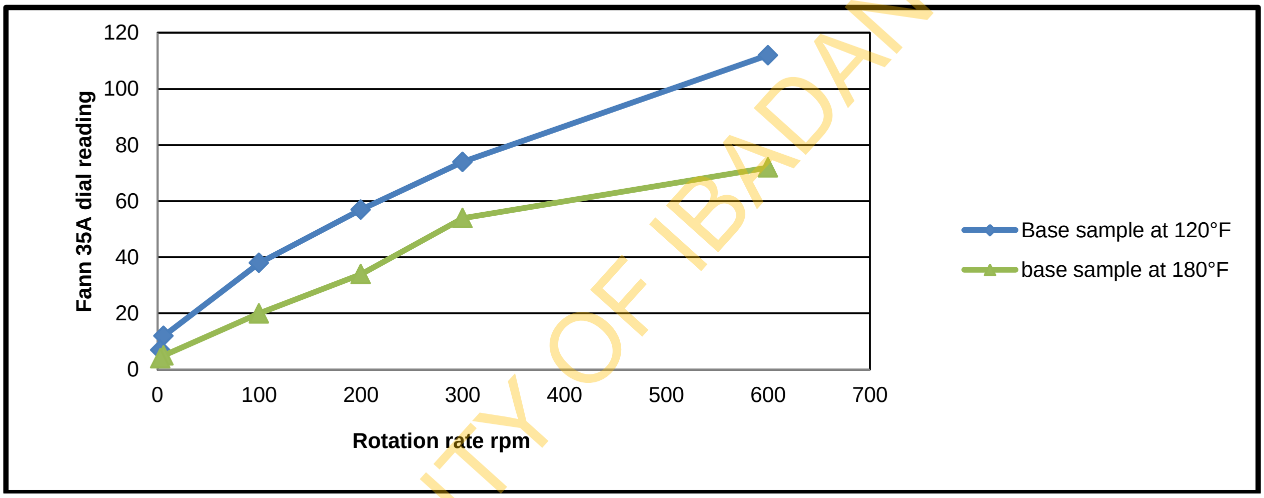

Fig.7: Fann 35A reading of Oil based invert emulsion drilling fluid after heat aging with both clay and sea water as contaminant.

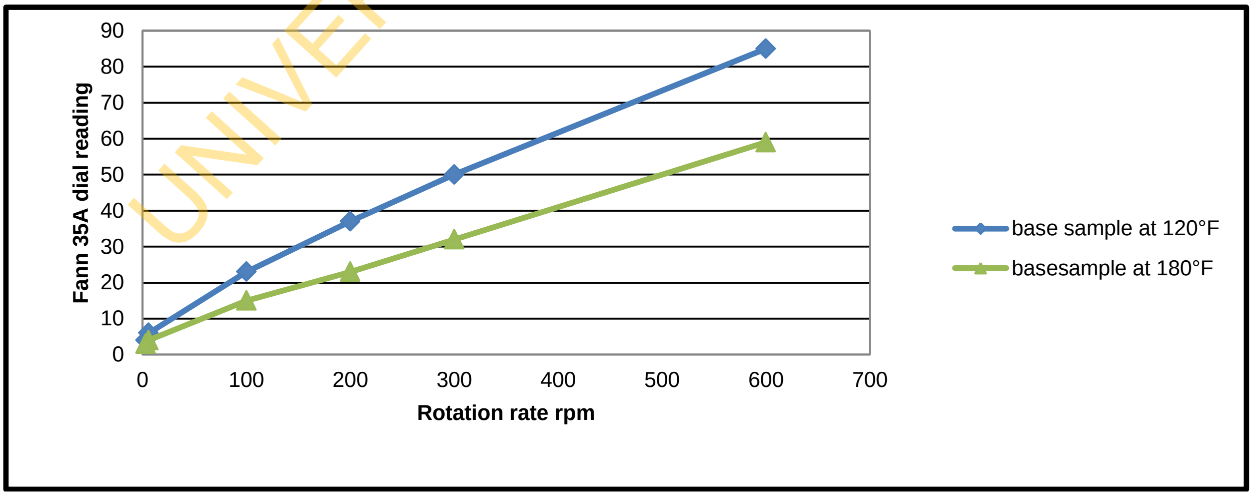

Fig.8: Fann 35A reading of Oil based invert emulsion drilling fluid after heat aging with both clay and sea water as contaminant. Aging was done at 350°F

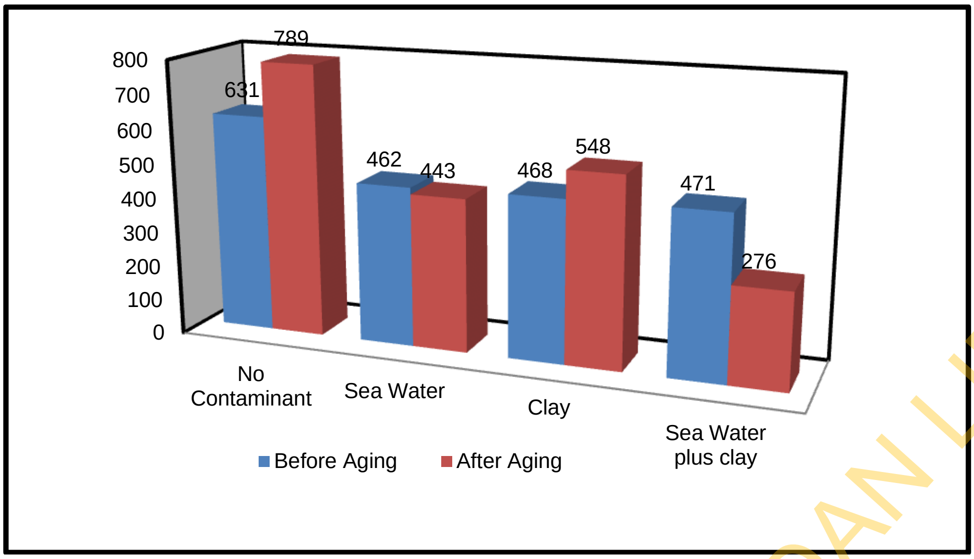

Fig.9: Emulsion stability results for the oil based invert emulsion fluid system