Effect of Salinity (KCl) on Rheological Properties and Rate of Penetration of Treated Bentonite and Ca^{2+} Based Polymer Drilling Mud

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Abstract: **The objective of this study was to evaluate the effect of salinity (KCl) on rheological properties and rate of penetration of treated bentonite mud and Ca^{2+} based polymer mud. A laboratory prepared treated bentonite and Ca^{2+} based polymer mud acquired from the field were used. The salinity of the mud was increased from 0 – 15% by adding KCl, and the fluid loss properties were tested both at LP/LT for both mud and at HP/HT dynamic conditions for the Ca^{2+} based polymer mud. It was observed that there was a general increase in the mud weight and gel-strength when concentration of KCl was increased. Plastic viscosity, yield point and apparent viscosity of Ca^{2+} polymer mud reduced as the salinity was increased. For the treated bentonite mud there was a reduction of plastic viscosity, yield point and apparent viscosity from 0 -2% and an increase from 5% - 10%. Also, the fluid loss to the formation increased and the quality of the filter cake formed reduced as the salinity was increased for all conditions tested. Results showed an increase in ROP as the plastic viscosity reduces and vice versa.**

Keywords: **Bentonite, Polymer, Rate of Penetration, Rheology, Salinity**

I. INTRODUCTION

Petroleum being among the world's most essential natural resources since coal was driven away from the world market due to its environmental problems. Petroleum has been the most significant and most traded commodity in the international trade (Ichenwo and Okotie, 2015). Although there have been alternates and now researchers are still finding an environmentally friendly fuel that will be less costive and profitable to use, petroleum remains the world's primary source of energy for both industrial and domestic application. However, drilling for oil and gas comes with its enormous disadvantages. Despite these challenges, wells are still being drilled globally. Drilling fluids like the "bathing shampoos" used by humans help to transport cuttings to surface, prevent well-control issues, preserve wellbore stability, minimise formation effects, cooling, and lubrication of the drill string, gives vital information about the well drilled and minimise danger to crew, the environment, and drilling rig. Hence, properly formulating and predicting the behaviour of a drilling fluid remains a core aspect of the drilling operations. Whilst drilling, drilling fluids encounter some contaminates such as drilled solids and salts. These contaminates change the rheological properties and drilling parameters of the mud. Also, drilling fluids have experienced a high reduction in viscosity which reduced its cutting carrying abilities when it encountered formation brine (Das *et al.,* 2014). There are different types of drilling fluids used in the oil and gas industry. Among these are the oil base mud and water base mud. Water base mud, which has water as its primary phase and can be prepared using fresh water or saltwater depending on the location and its compatibility with the formation been drilled. When these salts are added to slurry, the hydration and dispersion tendency is not promoted but rather enhances the flocculation tendency of the particles and reduce the quality of the filter cake formed (Rugang, 2014). Salinity reduces the viscosity of the water base mud (Amani *et al.*, 2016), but this consequence lies largely on the polymers used (Das *et al*., 2014). Ofei and Bendary (2016), in their research to investigate the effect of potassium formate in combination with synthetic polymers made the assertion that the rheological properties of water base mud may exhibit a fluctuational trend based on the concentration of potassium formate and types of polymers used in the mud formulation. KCl gained international recognition in 1960 when mud containing potassium ion improved hole stability by impairing the swelling of clay better as compared to the commonly used calcium or potassium cations to suppress clay inflammation or swelling. Potassium ions has significantly reduced hole enlargement in the shale section a result of its inhibitive properties (Joel *et al.,* 2012). Since then, the use of KCl as an additive in water base mud to reduce shale swelling has been on a rise till date. In broad prospective, shale or clay swelling ability has been reduced by increasing salt content in drilling fluids and vice versa (Ichenwo and Okotie, 2015; Awele, 2014). However, it is clear from literature that due to ability of KCl to help suppress clay swelling, little has been done to assess its effect on ROP and rheological properties of water base mud. Hence, the study seeks to evaluate the effect of salinity (KCl) on rheological properties and ROP of Water Base Mud formulations.

II. MATERIALS AND EXPERIMENTAL METHODS

A. Sample Collection and Preparation

The drilling muds used in this study are Ca^{2+} based polymer mud collected from the field and a laboratory prepared treated bentonite mud. The water base mud was prepared in accordance with American National Standards Institute/American Petroleum Institute (ANSI/API) specifications. The standard bentonite drilling mud is described in the API 13A page 15. The standard temperature is 27± ^{0}C and 22.5 g/350 cm^3 distilled water. Normally the bentonite is 3-8 % by mass. It consists of 90 percent montmorillonite and 10 percent other minerals, mostly feldspar. The montmorillonite is a crystalline, three phase hydrosilicate. It absorbs five times its own mass and swells about 15 times. In the study, the water base mud was prepared using bentonite and distilled water, Caustic Soda, Lime, Polythin, Polypac, Polydrill, Duo-vis and Barites being the additives and salt was added in time steps to increase its salinity. The Hamilton beach multi-mixture was used in mixing the mud. The mud was prepared by weighing 285 grams of the bentonite using a triple beam balance. The measured sample was transferred into cup containing 4 litres of distilled water to allow for its mixing. 16 grams of polydrill was then added to ensure fluid loss control at HPHT, 3 grams of Duo-Vis for rheology, 11.4 grams of Polypac -R for general fluid loss control, 12 grams of Polythin as a thinner, 11 grams of caustic soda to increase and maintain pH and alkalinity, 5.7 grams of lime for pH buffer and 411 grams of barites to achieve the desired weight. The mixture was vigorously agitated with the multimixer for 10-15 minutes to produce a homogeneous mixture after each additive was added. The mud sample was then aged for 24 hours to allow for adequate hydration after which the properties under investigation was measured. 500 ml of the prepared mud was measured and saturated with the salt before every test was conducted. Table 1 depicts the properties of the mud received from the field.

Table 1. Properties of Ca^{2+} Based Polymer Mud

Product Name	**Function**	**Concentration (m. ton)**
Avadeter	Mud detergent	0.600
Avage OCMA	Viscosity improver	2.250
Avacid 50	Liquid biocide	0.500
AVATENSIO LT	Low-toxicity pipe-freeing agent	0.560
AVACARB (Calcium Carbonate)	Weighting material	17.000
Barite	Mud weight adjustment	4.500
Citric Acid	Reduce the level of hydrogen (ph) in drilling mud	0.375
Caustic Soda	To increase and maintain ph and alkalinity	0.525
Gypsum	Inhibit swelling of clay	3.450
Ecollube	Torque and friction reducing lubricant	1.360
Granular MC	Help retard the loss of mud into fractures or highly permeable formations	0.500
Incorr	Corrosion inhibitors	0.200
Intasol FMC	Lost circulation material	5.000
Policell RG	Filtrate reducers	0.575
Policell SL	Shale-control agents	2.000
STEARALL LQD	Defoamer compound for dispersed muds x	0.170
Visco XC84 (Pure xanthan gum polymer)	Shale-control agents	0.450
Deoxy Deha	Oxygen remover (corrosion inhibitor)	0.500
KCL	Shale inhibitor / encapsulator	3.000

The Salinity of both lab and field mud was increased by adding KCL in steps after each measurement. The salts were added from (0-15) % in 5 % step increase. However, a further (1 and 2) % salinity increase test was conducted using the treated bentonite mud to confirm a trend which was observed during the test.

B. Rheological Measurements

The rheological properties of the fluid samples used in this study were measured using Fann 35A Viscometer. Its calibration by industrial experts is in revolutions per minute (RPM). It measures mud viscosity by use of a coaxial cylinder. A cylinder and a bob assembly are immersed into a sample of mud and the cylinder is rotated with an electric motor. As the cylinder rotates through the mud, a torque arising from the viscous drag of the fluid is exerted on the bob. The torque is balanced by helical spring and the deflection, which is dependent on the mud viscosity, is indicated on a dial. The Fann viscometer with 6 speeds is designed for field and lab use and turns at 600 RPM, 300 RPM, 200 RPM, 100 RPM, 6 RPM and at 3 RPM. The readings obtained by the dial determines the rheological properties although sometimes come computations are needed (Anon., 2018). The properties of interest in this study includes gel strength, plastic viscosity, yield point and apparent viscosity and were computed using Equations 1, 2 and 3.

Plastic viscosity PV (μ_p) = $\theta_{600} - \theta_{300}$ (1)

Where

θ_{600} = 600 rpm dial reading.

θ_{300} = 300 rpm dial reading.

Yield Point YP (τy) = θ 300 - μp (2)

Where μp= Plastic Viscosity.

Apparent viscosity $\mu_a = \frac{\theta\ 600}{2}$ (3)

Where: μ_a= Apparent Viscosity.

C. Filtration and Mud Cake Measurements

Fluid loss is the measurement of filtrate passing from a drilling mud into a porous permeable formation. A good drilling mud should form a thin filter cake on the sides of the wel1bore to prevent excessive fluids loss into the formation. Low fluid loss is a characteristic of good drilling fluids and vital to the integrity of the wellbore (Broni-Bediako *et al.*, 2019). Filtration is done by measuring the amount of filtrate that will pass through filter paper in 30 minutes under given pressure and temperature condition using a standard size cell. Filtration of the mud was determined at high pressure and high temperature dynamic conditions for the Ca^{2+} base mud using the OFITE HPHT dynamic filter press and at low pressure and low temperature static conditions for both mud using Baroid multiple unit filter press. After each measurement, the thickness of the cake formed was measured. The dynamic HTHP filtration was determined using Equation 4.

Dynamic HTHP Filtration (mL) = 2 × (mL)   (4)

III. RESULTS AND DISCUSSION

A. Density Test

The starting point of pressure control is the control of mud density. To effectively predict and control pressure during drilling operations, operators monitor closing the exact mud weight need to balance the formation pressure because it is the basis upon which all pressure control predictions are based. For proper estimation of the weight of the mud column, the density of the mud should be known (Annis and Smith, 1974). For easier wellbore cleaning and faster cuttings uplift, drilling muds should have higher weights than cuttings being made whilst drilling (Nwaiche, 2015). Hence, a general analysis can be made that if the weight of the mud surpasses the formation and does not fracture it, it can cause other adverse effects, like reducing rate penetration. Table 2 shows the density results for treated bentonite and Ca^{2+} based polymer mud. From Table 2, the increase in the salinity of the mud increased the density of both muds under investigation. However, the percentage increase in density from salinity levels of 0 to 15% for the Ca^{2+} based polymer mud is 8.66 % and that for the treated bentonite mud is 8.33%. This means the density increase of Ca^{2+} is 0.33 % more than the treated bentonite mud. Hence, it is of prime importance for drillers to thoroughly check the density of mud when adding salt to avoid any unexpected density increase that may cause an adverse effect on the borehole being drilled. The increase in mud density because of increase in salinity confirms research done by Amani *et al*., (2016) on salinity effects on the viscosity of water-based drilling mud at high pressures and high temperatures. To Amani *et al*., (2016), when they increased the salinity of the mud by adding NaCl and $CaCl_2$, the density of the mud was observed to increase. Moore (2016) also made same assertion in his drilling mud paper that he transferred to SPE in 2016. Again, Das *et al.* (2014), stated in his research on effect of salt concentration on base-gel viscosity of different polymers used in stimulation fluid systems that salt is added to drilling fluid at different concentrations to increase the mud weight. Hence, the trend in mud weight increase observed in this study is in support of the works published by other authors.

Table 2: Density Test Values for the Ca^{2+} Based Polymer and Treated Bentonite Mud

Salt Content (%)	Mud Density (Kg/m^3)	
	Ca^{2+} Based Polymer Mud	Treated Bentonite Mud
0	1160	1100.0
5	1210	1115.0
10	1240	1150.0
15	1270	1200.00

B. Rheological Properties

By going accordingly to the API specifications (1998), the basic rheological properties such as Apparent Viscosity (AV), Plastic Viscosity (PV), Yield Point (YP) and Gel Strength of the Ca^{2+} based polymer mud and treated bentonite mud were determined by using the Fann Viscometer. A Ca^{2+} Based Polymer and treated bentonite mud should have its properties as specified in Table 3 according to API Specification 13A – 8.1.2 (Anon, 2010).

Table 3: API Physical Specifications for Treated Bentonite Mud and Ca^{2+} Based Polymer

Treated Bentonite Mud	Standard	Ca^{2+} polymer-based mud)	Standard
Suspension Properties:		Suspension Properties:	
Viscometer dial reading at 600 r/min	Minimum 30	Moisture content	Maximum 10 %
Yield point/plastic viscosity ratio	Maximum 6	Apparent viscosity	Minimum 50 cP
Filtrate volume, millilitres	Maximum 15.0	API filtrate volume	Maximum 23 ml

(Source: Anon, 2010)

1)Treated Bentonite Mud: Data obtained from test on treated bentonite had a viscometer dial reading at 600 r/min of 45 cP, 41.5 cP, 38 cP, 45.5 cP, 49 cP and 55 cP respectively as the salinity levels were increased from 0 %, 1 %, 2 %, 5 %, 10 % and 15 %. As observed from the data, the 1% and 2% test became possible when the readings deviated from the trend during the experiment. Hence, further test was conducted to confirm the trend. However, the readings at 600 r/min for all the salinity levels conforms to the API specification of a minimum of 30 cP. Yield point and plastic viscosity ratio was 1.2 maximum for various salinity levels which falls within the API range of a maximum 6 as shown in Table 3.

Table 4: Rheological Results obtained with Treated Bentonite Mud

Rheological Properties	Treated Bentonite Mud					
	% Concentration of Salt (KCl)					
	0	**1**	**2**	**5**	**10**	**15**
Plastic Viscosity (cP)	15	13.5	12	14.5	16	18
Apparent Viscosity(cP)	22.5	20.8	19	22.8	24.5	27.5
Yield Point ($lbf/100ft^2$)	15	14.5	14	16.5	17	19
Yield point and plastic viscosity ratio	1	1.07	1.17	1.14	1.06	1.06

From Table 4, the plastics viscosity of the treated bentonite mud started reducing as the salinity levels where increased from 0 - 2 % and increased from 5 % to 15 % respectively. Similar behaviour was observed for the yield point and apparent viscosity. However, gel strength levels were seen to increase as the salinity levels were increased and no fluctuational trend was observed as seen with the other rheological properties concerning the test conducted with the treated bentonite mud. This fluctuational trend observed agrees with research conducted by (Olphen, 1963) on the effect of NaCl on rheology of clay suspensions. It also agrees to an assertion made by Ofei and Bendary (2016) in their research on formulating water base muds for high temperature wellbores using potassium formate brine and synthetic polymers. Ofei and Bendary (2016) found out that some of the mud they formulated with synthetic polymer and potassium formate brine caused an increase in plastic viscosity whilst some concentration also caused a reduction in plastic viscosity. However, the reasons for the reduction were not well explained in their research. Olphen (1963) also made the revelation that adding a small amount of NaCl, suspensions start from a flocculation state, Bingham yield stress reaches a minimum, and thus suspension deflocculates. Upon further addition of NaCl, Bingham yield stress increased again which means the solution flocculates again.

Luckham and Rossi (1999), also in their review summarised the same assertion made by Olphen (1963) indicated the fluctuations observed with the use of bentonite may be due to charged particles of the clay platelets which they assumed that the edges were positively charged whilst the faces were negatively charged. In addition, both authors agreed that the internal mutual flocculation was so because of the initial edge to face bonding due to the opposite attractive forces. Further elaboration on their stand, they attributed the deflocculating to excess salt added which compressed the double clay layers thereby reducing the attractive forces between the edge to edge. This resulted in the breaking down of the bond and reducing the rheological properties as well. However, further compression of the double layers by increasing the salt concentration restores the edge-to-face attraction, which is now greater than the face-to-face repulsion causing the rheological properties to increase again. At extremely high salt levels, there is a face-to-face bonding again reducing the links between the cay structure and causing thicker particles formations. Oort (2003), also made similar observations in his research concerning the physical and chemical stability of shales. He deliberated that the success of K^+ ions in reducing the pressure of swelling clays is attributed to its low ion repulsion because of its small hydration in water. At low concentration of salt, the swelling tendency of clay was suppressed but the clay was seen to increase in swelling at high concentrations. He went on to say that the addition of more salt resulted in further ion repulsion as a result of the excess hydrated ions introduced into the clay inter layers. The initial small concentration of the potassium salt resulted in a reduction in clay swelling due to K^+ ions substituting the more hydrated ions at the clay surface. But the swelling of clay increased upon more addition of salt because an excessive hydrated ions increase in the clay layers resulting in further spacing. The ions were both positively and negatively charged. But it is worth knowing that in his experiment, the interplatelet clay spacings were filled with only saline water. From these prior studies, it is then evident that addition of salt (KCl) influences the rheological parameters of bentonite dispersions. But the fluctuation trend observed in this study with different polymers has not been given much attention. Recent authors have all reported a decrease in the rheological properties (Uti and Joel, 2013) and K^+ containing clays show a lower tendency to swell than Na+. That is why KCl has gained international recognition as the most effective in reducing clay swelling (Hensen and Smit, 2002).

2) Ca^{2+} Polymer-Based Mud: Table 5 shows the rheological results obtained with Ca^{2+} polymer-based drilling mud. From Table 5, the viscometer dial readings for Ca^{2+} polymer-based drilling mud were observed to reduce upon the addition of the KCl from 0-15 % in 5 % step increased. Yield point, plastic viscosity and gel strength was also observed to reduce. In increasing the salinity by 5 % in step, there was an average reduction in plastic viscosity by 2%, yield point by 2.5 % and apparent viscosity by 2.2 %. This means whilst increasing the salt content, the mud will exhibit initial resistance to flow. This trend confirms a lot of work done by different Authors. Sami (2016) made similar assertion by saying he observed a decrease in yield point, viscosity, and gel strength of his sample due to an increase in magnesium salt concentration also confirmed by (Hosseini *et al*., 2017; Uti and Joel., 2012; Joel *et al*., 2012). Most authors confirmed a reduction in the properties highlighted above although the salts used vary from author to author.

Table 5 Rheological Results obtained with Ca^{2+} Polymer Based Mud

Rheological Properties	**Ca^{2+} Polymer Based Mud**			
	% Concentration of Salt (KCl)			
	0	5	10	15
Plastic Viscosity (cP)	33	32.5	31.5	31
Apparent Viscosity(cP)	50.3	49.5	48	47
Yield Point (lbf/100ft²)	34.5	34	33	32
10 Seconds Gel (lbf/100ft²)	7	6.5	6	5.5
10 Minutes Gel (lbf/100ft²)	8.5	17	20	22

C. Shear Stress and Shear Rate

It was evident that both the drilling mud used with and without salt followed the yield pseudoplastic model which was conceived by Herschel-Bulkley model. This trend agrees to earlier research by Hassiba and Amani (2013) to investigate the salinity effect on the rheological properties of water-based mud under elevated pressure and temperature conditions. Their plot fitted well to Herschel and Bulkley model of both NaCl and KCl used in their experimentation.

3) Shear Stress and Shear Rate for Ca^{2+} Based Polymer Mud: Fig.1 shows that for all mud samples measured, an increase in shear rate causes a corresponding increase in shear stress. However, for a given shear rate, an increase in salinity causes a reduction in shear stress.

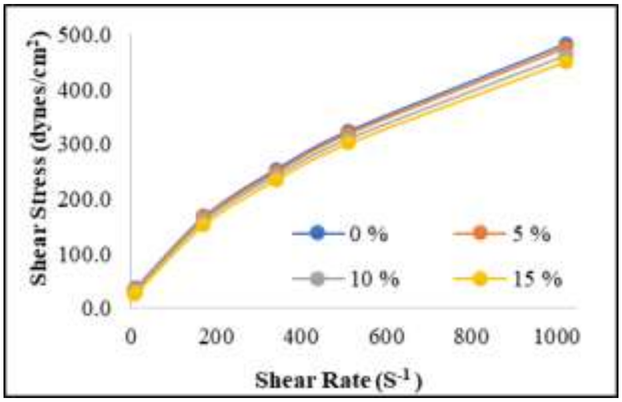

Fig. 1 Shear Stress and Shear Rate plot for Ca^{2+} Based Polymer Mud

4) Shear Stress and Shear Rate for Treated Bentonite Mud: Fig. 2 shows the shear stress and shear rate for the treated bentonite mud.

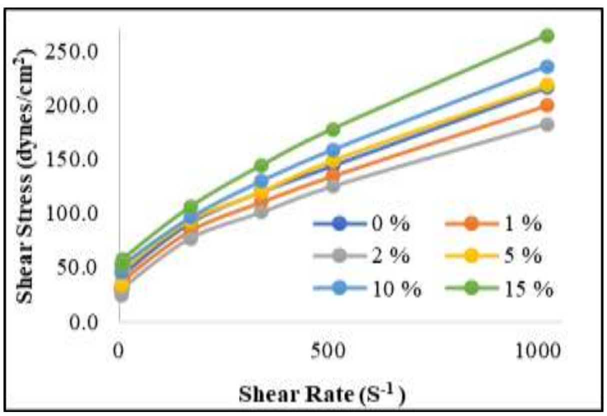

Fig. 2 Shear Stress and Shear Rate Plot for Treated Bentonite Mud

From Fig. 2, it can be deduced that for all the mud samples measured, an increase in shear rate caused a corresponding increase in shear stress. However, for a given shear rate, an increase in salinity level from 0 - 2 % caused a reduction in shear stress whilst an increase from 5 % - 15 % caused an increase in shear stress.

D. Filtration Test

1) Treated Bentonite Mud: API fluid loss test was carried out using a filtration apparatus (Filter Press) and according to the specifications of API, a good bentonite drilling fluid should have a fluid loss of a maximum of 15 ml after 30 minutes filtration test which was demonstrated after the filtration loss test. The treated bentonite mud had a fluid loss of 7 ml after 30 minutes of test whilst fluid loss started increasing at each level of salt added till it became unacceptable according to API standards form 10 % - 15 %. The volumes recorded for 10 % and 15 % were 17.9 ml and 22 ml as depicted on Fig. 3. This result confirms the work done by Neshat *et al.*, (2014), on experimental investigation of the effects of a plant-based additive on the rheological properties of bentonite mud contaminated by salt. They demonstrated that the addition of KCl caused the filtration volume to increase by 132% as compared to the original mud.

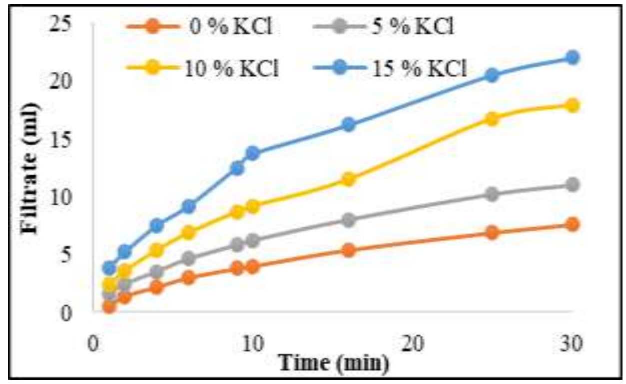

Fig. 3 Effects of Salinity on Filtration Loss of the Treated Bentonite Mud

As the filtrate volume increased, the thickness and quality of the filter cake formed was greatly affected (Figs. 4a, b, c and d). The filter cake thickness measured for 0 and 5 % salinity level was 0.5 mm and 0.75 mm which compares very well to API standard of 0.8 mm. However, the thickness formed for the 10 % and 15 % were 4 mm and 5 mm which were far greater than the API standard. The filter cakes formed was very thick and soft. Hence, although is true KCl reduced shale swelling, its concentration in a mud should be controlled as poor filter cake can cause differential pipe sticking as well as increased fluid loss to the formation.

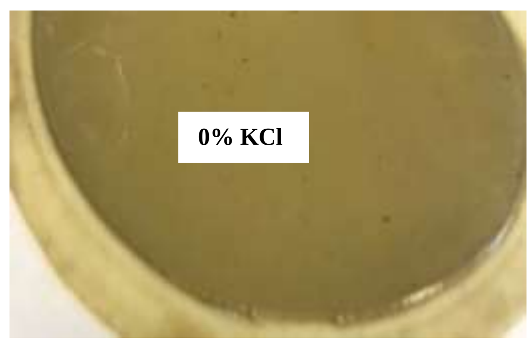

Fig. 4a Filter Cake from Treated Bentonite Mud with 0% KCl under LT/LP

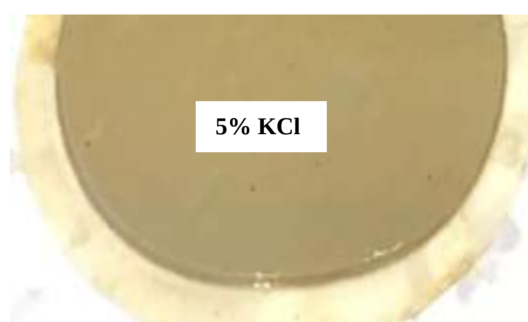

Fig. 4b Filter Cake from Treated Bentonite Mud with 5% KCl under LT/LP

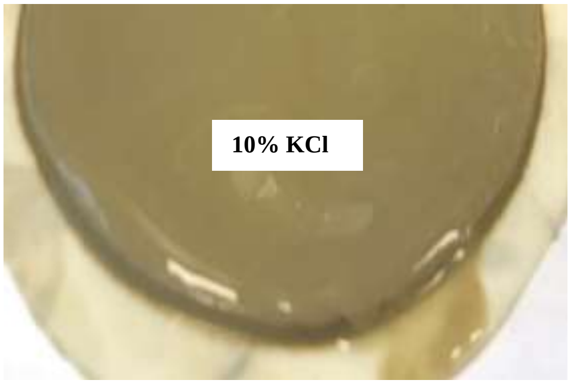

Fig. 4c Filter Cake from Treated Bentonite Mud with 10% KCl under LT/LP

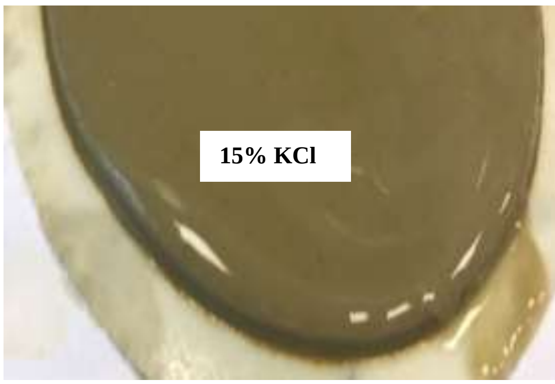

Fig. 4d Filter Cake formed for the Treated Bentonite Mud under LT/LP

For the case of the Ca^{2+} based polymer, two filtration tests were performed on the samples. A low pressure and low temperature filtration test and a high pressure and high temperature dynamic filtration test. All test results reveal that the filtration volume increased as the salinity of the mud increased as depicted on Figs. 5 and 6. Also, the quality of the filter cakes formed when the salinity levels were gradually increased was poor as compared to the samples without salt. The thickness of the filter cake measured at ambient condition and pressure of 100 psi were seen to increase from 1.5 mm, 1.8 mm, 2 mm and 2.5 mm as the salt content was increased from 0-15 % respectively. Also, the filter cake when touched felt soft as the salinity was increased. The same effect was seen when the mud was tested at HPHT dynamic conditions.

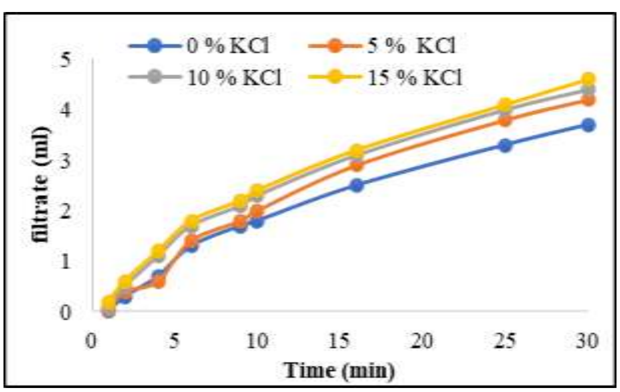

Fig. 5 Salinity Effect on Filtration Loss of Ca2+ Polymer Base Mud at LP/LT

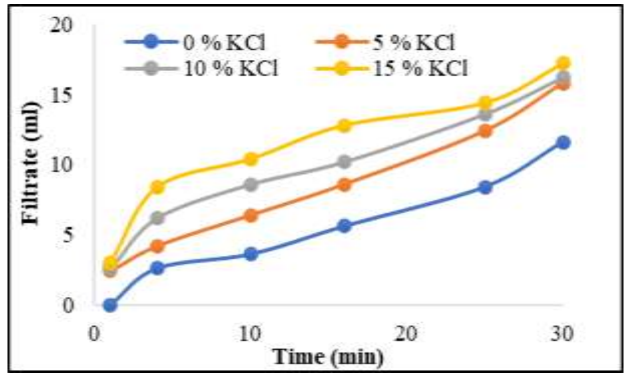

Fig. 6 Salinity Effect on Filtration Loss of Ca2+ Polymer base Mud at HPHT Dynamic Conditions.

E. Rate of Penetration

To appreciate the effect of salinity on rate of penetration. The modelled equation by Beck *et al.*, (1995) of Equation 4 was used. This equation relates plastics viscosity to rate of penetration. The main parameters affecting rate of penetration, such as hole size, weight-on-bit, rotary speed, bit type, formation type, bit hydraulic energy, and basic mud type were all optimized prior to data-collection and were kept constant throughout the data collection process. In this research, all the assumptions used by Beck *et al.*, (1995) holds, except that the mud type used in this research was assumed to be same as that used to drill side-track wells drilled in Prudhoe Bay Alaska (Beck *et al.*, 1995). This assumption was made so that their correlation can be applied without ambiguity.

$$\frac{RoP_2}{RoP_1} = 10^{0.0124(PV_1 - PV_2)} \quad (4)$$

Fig.7 is a plot showing how ROP varies with salt content. The results obtained as depicted by Fig. 7, confirms to the same assertion made by Beck *et al.*, (1995) that an increased in plastics viscosity will cause a decrease in rate of penetrations when other parameters affecting rate of penetration are kept constant. The fluctuation trend observed in the case of the treated bentonite mud was due to the same trend observed during the plastic viscosity determination.

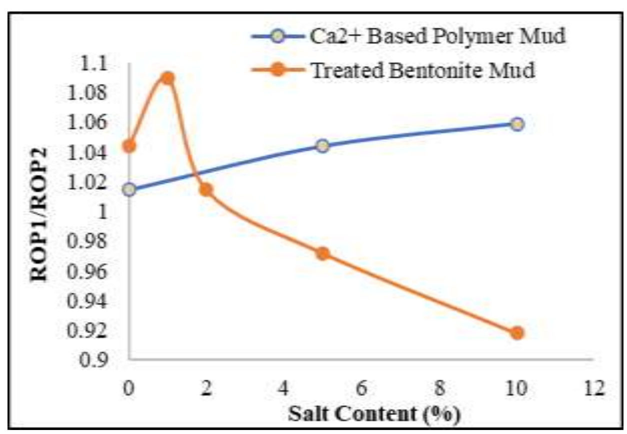

Fig. 7 Plot showing how ROP Varies with Salt Content

IV. CONCLUSIONS AND RECOMMENDATIONS

From the study, the following conclusions have been drawn:

a. KCl may cause some water base muds to be unstable at higher concentrations.
b. The use of KCl in mud formulation will increase the amount of fluid loss to formation.
c. The addition of KCl to a drilling mud will have an influence on ROP because it will alter the plastic viscosity of the mud.
d. Drilling mud with or without KCl assumed the Herschel Bulkley (yield Power law) model.

It is recommended that:

a. The concentration of KCl to be used in drilling mud formulation should be tailored to suite the type of mud that will be used to drill the formation.
b. Fluid loss additives should be added to the mud to control the amount of fluid loss due to the addition of KCl.

REFERENCES

[1] Amani, M., Khorasani, H. M. and Ghamary, M. H. (2016), "Effect of Salinity on the Viscosity of Water Based Drilling Fluids at Elevated Pressures and Temperatures", Qatar Foundation Annual Research Conference Proceedings, EEPP2318.
[2] Annis, M. R. and Smith, M. V, (1974), Drilling Fluids Technology. Exxon Company Publication, U.S.A. pp. 6-20.
[3] Anon. (2018). Drilling Engineering Laboratory Handbook, Unpublished, Miskolc University, Hungary, pp. 5.
[4] Anon. (2010), API Specification 13A, American Petroleum Institute, 18th Edition, USA, pp. 11 - 12.
[5] Awele, N. (2014). "Investigation of Additives on Drilling Mud Performance", Master Thesis Report, Chemical Engineering Department, Aalborg University Esbjerg, pp 6-18.
[6] Beck, F. E., Powell, J. W., and Zamora, M. (1995). "The Effect of Rheology on Rate of Penetration", Society of Petroleum Engineers, doi:10.2118/29368-MS.
[7] Broni-Bediako, B. and Amorin, R. (2019), "Experimental Study on the Effects of Cement Contamination in a Water Based Mud", Advances in Geo-Energy Research, Vol. 3, No. 3, pp. 314-319.
[8] Das, P., Konale, S., and Kothamasu, R. (2014) "Effect of Salt Concentration on Basegel Viscosity of Different Polymers used in Stimulation Fluid Systems", Society of Petroleum Engineers.
[9] Hassiba, K. J. and Amani, M. (2013), "The Effect of Salinity on the Rheological Properties of Water Based Mud under High Pressures and High Temperatures for Drilling Offshore and Deep Wells", Earth Science Research, Vol. 2.
[10] Hensen, E. J. M. and Smit, B. (2002), "Why Clays Swell", Journal of Physical Chemistry B, Vol. 106, No. 49, pp. 12664-12667.
[11] Hosseini, E., Mozafari, H. R., Hojjatoleslamy, M. and Rousta, E. (2017), "Influence of Temperature, pH and Salts on Rheological Properties of Bitter Almond Gum", Food Science and Technology.
[12] Ichenwo, J. L. and Okotie, S. (2015), "Experimental Investigation on the Effect of KCL and Bentonite on Shale Stability", International Journal of Current Engineering and Technology, Vol.5, No.1, pp. 959 - 965.
[13] Iledare, O. O. and Pulsipher, A. (1999)," The State of the Global E&P Industry: Is the World Running Out of Oil?", Society of Petroleum Engineers.
[14] Joel, O. F., Durueke, U. J. and Nwokoye, C. U. (2012), "Effect of KCL on Rheological Properties of Shale Contaminated Water-Based MUD(WBM)", Global Journal of Researches in Engineering, Volume 12, Issue 1.
[15] Luckham, F. P. and Rossi, S. (1999), The Colloidal and Rheological Properties of Bentonite Suspensions, Advances in Colloid and Interface Science", Vol. 82, Issues 1–3, pp. 43-92.
[16] Moore, P. L. (2006), "Drilling Muds" Society of Petroleum Engineers, DPM Chapter 5.
[17] Neshat, J., Hosseini, E., Moradi, P. and Moradi, F. (2014), "Experimental Investigation of the Effects of a Plant Based Additive on the Rheological Properties of Bentonite Mud Contaminated by Salt", American Journal of Oil and Chemical Technologies, Volume 2, Issue 5.
[18] Nwaiche, J. (2015), "Selection and Application of Drilling Fluids", https://www.researchgate.net/publication/275334398, Accessed: March 27, 2018.
[19] Ofei, T. N. and Al Bendary, R. M. (2016), "Formulating Water-Based Muds for High Temperature Wellbores Using Potassium Formate Brine and Synthetic Polymers: A Design of Experiment Approach", Society of Petroleum Engineers.
[20] Olphen, H. V. (1963), "Internal Mutual flocculation in clay Suspensions", journal of Colloid Science, 19, pp. 313-322.
[21] Oort, V. E. (2003)," On the Physical and Chemical Stability of Shales", Journal of Petroleum Science and Engineering, 38, pp. `213-235.
[22] Rugang, Y., Guancheng, J., Longyun, Y., Wei, L., and Tianqing, D. (2014), "The Effect of Inorganic Salt on the Structure of Filter Cake of Water Based Drilling Fluid", SOCAR Proceedings, pp 30-38.
[23] Sami, N. A. (2016), "Effect of Magnesium Salt Contamination on the Behaviour of Drilling Fluids", Egyptian Journal of Petroleum, Volume 25, Issue 4, pp 453- 458.
[24] Uti, L. O. and Joel, O. (2013)," Comparative Study of Different Salts on Hydration of Bentonite", Annual SPE International Technical Conference and Exhibition, Lagos-Nigeria. 10.2118/167583-MS.