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Experimental study of the influence of Potassium Chloride salt on the rheological properties of Carboxyl Methyl Cellulose (CMC) and Poly Anionic Cellulose – Regular (PAC-R) mud type at increasing temperature

Estudo experimental da influência do sal Cloreto de Potássio nas propriedades reológicas de Carboxil Metil Celulose (CMC) e Poli Celulose Aniônica – Regular (PAC-R) em temperatura crescente

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Resumo

A lama de perfuração é uma mistura de água e argila, materiais de pesagem e alguns produtos químicos que são chamados de aditivos para estabilizar a pressão do poço. Fluidos de perfuração afetam as operações de perfuração. O custo do fluido de perfuração tem sido um grande problema durante a operação e o efeito da salinidade nos aditivos também resultou em investigação para determinar se outros aditivos podem ser usados como substitutos dos usados predominantemente. Para tanto, este trabalho teve como objetivo determinar o efeito da salinidade nas propriedades reológicas de lamas do tipo preparadas com Carboxil-metilcelulose (CMC) e celulose polianiônica regular (PAC-R). A partir deste estudo, o efeito da salinidade mostra que, à medida que a salinidade da lama de perfuração aumenta, a eficácia do polímero diminui. Isso tem um efeito negativo nas propriedades reológicas da lama de perfuração. A viscosidade plástica diminui com o aumento da temperatura e o ponto de escoamento aumenta com o aumento da temperatura. Além disso, a propriedade tixotrópica (resistência do gel) das lamas PAC-R e CMC aumenta com a temperatura, mas diminui com a introdução de sal. Também pode ser deduzido que a capacidade de suspender cascalhos para lama KCl e CMC é única.

Palavras-chave: Propriedades reológicas. Carboxil-metilcelulose. Celulose polianiônica regular. lama de perfuração. Salinidade. Taxa de cisalhamento. Tensão de cisalhamento. Viscosidade.

Abstract

Drilling mud is a mixture of water and clay, weighing materials and few chemicals which is called additives to stabilize the wellbore pressure. Drilling fluids, affects drilling operations. The cost of drilling fluid has been a major issue during operation and the effect of salinity on the additives has also resulted into investigation of determine if other additives can be used as a substitute to the predominant used ones. To that effect, this work was focused to determine the effect of salinity on the rheological properties of mud type prepared with Carboxyl-methyl cellulose (CMC) and polyanionic cellulose-regular (PAC-R). From this study, salinity effect shows that as the salinity of drilling mud are increased, the effectiveness of the polymer decreases. This has a negative effect on the rheological properties of drilling mud. Plastic viscosity decreases with increasing temperature and yield point increases with increasing temperature. Also, the thixotropic property (gel strength) of both PAC-R and CMC muds increases with temperature but decreases on the introduction of salt. It can also be deduced that the ability to suspend cuttings for both KCl and CMC mud are unique.

Keywords: Rheological properties. Carboxyl-methyl cellulose. Polyanionic cellulose-regular. drilling mud. Salinity. Shear rate. Shear stress. Viscosity

Nomenclature

Symbol	**Description**	**Unit**
γ	Shear rate	sec^{-1}
θ	Dial reading	
τ	Shear Stress	$lbs/100ft^2$

Abbreviation

AV	Apparent Viscosity	cp
CMC	Carboxyl Methyl Cellulose (CMC)	
KCl	Potassium Chloride	
PAR-C	Poly Anionic Cellulose – Regular	
PV	Plastic Viscosity	cp
RPM	Revolution Per Minute	
YP	Yield Point	$Ibs/100ft^2$

1. Introduction

Drilling fluid or drilling mud is a mixture of water/oil and clay, weighing materials and few chemicals which called additives to stabilize the wellbore pressure. Prevention by the functions of the drilling fluid is formation damage, cool and lubricate the bits and drill string the fluid also aid cuttings removal and transport. Drilling fluid is a critical component in the rotary drilling process. One of the important means used in enhancing drilling operations is by the application of drilling mud (Bourgoyne *et al.*, 1991; Cheraghian and Afrand, 2021).

The drilling fluid could be used in the drilling operation to control formation pressure by sufficient drilling fluid weight and to remove drilling cuttings from the well bore (Abbas, 2021). Drilling fluids transport cuttings from the well bore as drilling progresses. The density of the suspending fluid has an associated buoyancy effect on the cuttings. An increase in density increases the capacity of the fluid to carry cuttings (Arthur *et al.*, 2009). The drilling fluid minimizes adverse effects on productive formations. The drilling fluid ensures maximum information from the well. The drilling fluid limits corrosion of the drill string, casing, and tubular tools. The drilling fluid minimizes environmental impact (Al-Hameedi *et al.*, 2019).

Rheology is a broad term that means the study of the deformation of materials, including flow. In oilfield terminology, the terms flow properties and viscosity are generally used to describe the behavior of drilling fluids in motion (Peysson 2004). The physical appearance of a high-viscosity drilling fluid may be described as "thick," and that of a low-viscosity fluid as "thin" (Williams and Bruce 1951). Simply put, the viscosity of a drilling fluid may be defined as its resistance to flow. The viscosity desired in a particular drilling fluid depends on several factors, including mud density, hole size, pump rate, drilling rate, pressure requirements, and hole conditions (Nasser *et al.*, 2013). The rheological properties, viscosity and gel strength of drilling fluids describe the ability of the fluid to transport cuttings while drilling and suspend them when circulation is interrupted (Agwu *et al.*, 2021). (Thorsrud *et al.*, 2000) stated that an understanding of the rheology is essential if the well site engineers of the drilling fluid is to cost effectively complement the objective of the well. There are various rheological properties of drilling fluid such as: fluid deformation, shear stress, shear rate, viscosity, gel strength, density, yield point (YP), filtration (Bayat *et al.*, 2018). Rheological properties are basis for all analysis of well bore hydraulics and to assess the functionality of the mud system (Mohamed *et al.*, 2021). It is critical to control and maintain rheological properties as a failure to do so can result in financial and loss of time, and in extreme cases, it could result in the abandonment of the well (Darley and Gray 1988).

The cost of the drilling fluid additives has been a major issue during drilling operation and the effect of salinity on these additives has also resulted into investigation to determine if other additives can be used as a substitute to the predominantly used ones. Practically using CMC to improve the rheological properties of drilling mud (water-based drilling mud) so that the drilling mud will perform all its required functions to avoid drilling operation problems such as inability to remove and transport drilled cuttings from the sub-surface to the surface and inability of the hydrostatic pressure of the drilling mud to balance the formation pressure. The main objectives of the study are to determine the effect of salinity on the rheological properties of CMC and PAC-R muds and to determine the effect of salinity on the thixotropic property (gel strength) of CMC and PAC-R muds.

Consequently, the drilling fluid affects the drilling operations. This research work would help the drilling fluid and its rheological properties as a necessity for drilling operations. To the drilling engineer, this study would guide on the importance of improving the rheological properties of drilling fluid using CMC and tend to reduce the industry spend (cost).

2. Methodology

This topic contains details of materials used, methods or procedures used to collect data, experimental design/layout, formulae, and statistical techniques employed in data analysis. The laboratory experiment was carried out in the Department of Petroleum Engineering, Federal University of Technology, Owerri (FUTO). All chemical materials used were sourced from the market, in Owerri, Imo state, Nigeria.

2.1 Materials

The materials used for the formulation of the drilling mud samples include the following:

(1) Freshwater
(2) Bentonite
(3) PAC-R
(4) Caboxymethyl cellulose (CMC)
(5) Potasium Chloride (3% concentration of KCl)

Equipment: The equipment used to carry out the experiment include (see Figure 1);

(1) Measuring cylinder

(2) Mud balance
(3) Agitator
(4) Thermometer
(5) Mud cups and laboratory barrels
(6) Variable speed rheometer (Model 800 Eight Speed Viscometer)
(7) Digital water bath

Figure 1- Equipment used for the experiment

2.2 Methods/Procedures

The procedures for conducting the rheological properties tests are described below;

(1) Fill the test cup to the marked line with the mud sample already blended or mixed after formulations are being made.
(2) Measure and record the temperature of the drilling mud sample (at room temperature).
(3) Unfasten the leg lock nut and lift the rheometer assembly
(4) Position the filled cup of drilling mud below the marked line on the rotor sleeve
(5) Fastened the leg lock nut
(6) Engage the speed shift lever to the agitating position (straight down)
(7) Rotate the crank clockwise direction for approximate 15 seconds.
(8) Thrust the speed shift lever up at the 600rpm position and rotate the crank clockwise direction until a slippage is felt, this indicates that you have reached 600rpm.
(9) Wait until the dial reading is stable before taking a reading (the 600rpm dial reading) and maintaining a stable head posture. this is the 600rpm dial reading.
(10) Shift the sleeve rotation and allow the dial reading to attain a stabilized value The dial reading for 300rpm was noted. These were repeated for 200rpm, 100rpm, 60rpm and 30rpm.
(11) After ten seconds, steadily turn the gel-strength knob clockwise once more while keeping an eye on the indicator dial. Record the peak reading as the dial peaks and then breaks back.
(12) Heat the same mud sample with a water bath to 60◦C
(13) Then repeat procedures 3 to 12 to acquire the new temperatures results.

3% concentration of potassium chloride was used for the experiment

Formulae and Statistical techniques employed

The Fann V-G meter speed, rpm is converted to shear rate γ, sec^{-1}, thus

$$1sec^{-1} = 1.703\ RPM \tag{1}$$

and the dial readings to shear stress (in $Ibs/100ft^2$) by multiplying by the conversion factor, 1.0678 as shown in Table 1.

Plastic Viscosity,
$PV = \theta 600 - \theta 300$, in cp (2)

Yield Point,
$YP = \theta 300 - PV$, in $Ibs/100ft^2$ (3)

Apparent Viscosity,
AV = 478.9 τ/γ, in cp (4)

Table 1- Mud samples composition

Sample	**Composition**			
	Freshwater (ml)	Bentonite (g)	PAC-R (g)	CMC (g)
1	350	10.5	1.5	1.5
2	350	10.5	1.5	1.5
3	350	10.5	1.5	1.5

3. Results and Discussion

3.1 CMC mud sample

As can be seen from Figure 2(a), at a fixed temperature, the dial reading increases with shear rate and at a fixed shear rate, the dial reading was found increasing with the temperature. Thus, improving the rheology of the mud. From Figure 2(b), it was observed that the dial reading increases with shear rate at dial speed ranging from 30 to 100 where a plateau high was observed at 100RPM, and then further decreasing from 100RPM to 200RPM before it finally increasing with the shear rate. This satisfies the pseudoplastic nature of drilling fluid. It was also revealed in Figure 2(b) that at each shear rate, the addition of 3% KCl salt to the CMC mud type causes the dial reading to decrease when the temperature was increased from 28°C to 60°C. In contrast to CMC mud type without a salt, dial reading reduces by 13% to 27% at a fixed temperature of 28°C. Meanwhile, at temperature of 60°C, about 37% to 78% reduction in the dial reading was reported.

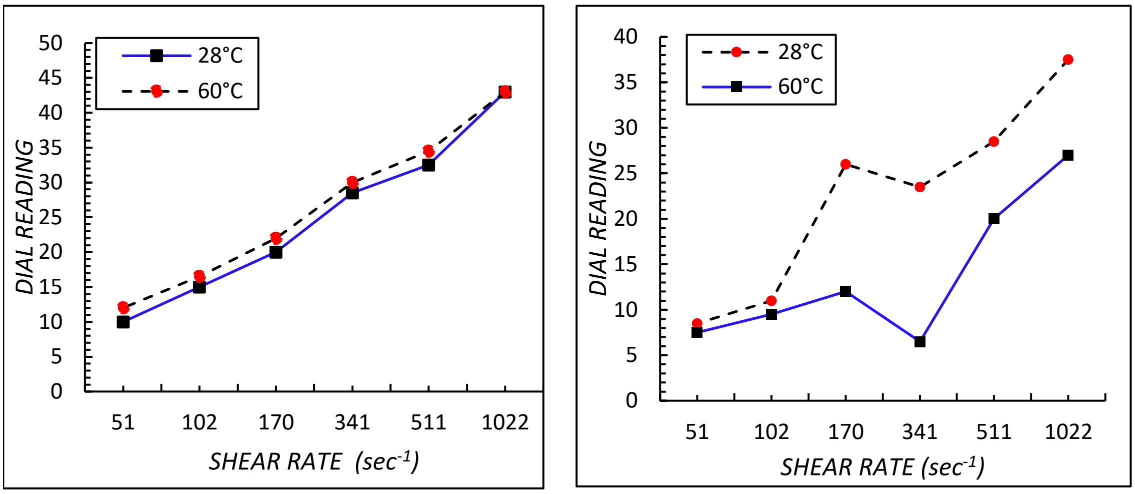


Figure 2- Plot of Dial Reading Against Shear Rate for drilling mud formulated with CMC (a) with no KCl salt (b) with KCl salt

From Figure 3(a), it was indicated that the shear stress relatively increases with the shear rate for both case of the temperature. However, it was observed that by increasing the temperature from 28°C to 60°C yields about 20% increment in the shear stress of the CMC mud type containing no salt. More so, no significant difference in shear stress was reported at shear rate of 1022sec-1. Figure 3(b) compares the shear stress with shear rate for CMC mud type containing KCl salt at temperature of 28°C and 60°C. For the case of temperature of 28°C, the shear stress uniformly rises with the shear rate. For the case of temperature of 60°C, a plateau was observed at shear rate of 170sec-1 before shear stress finally increases with the shear rate. Figure 4 shows the comparison of viscosity with the shear rate for CMC mud type with KCl salt and without KCl salt.

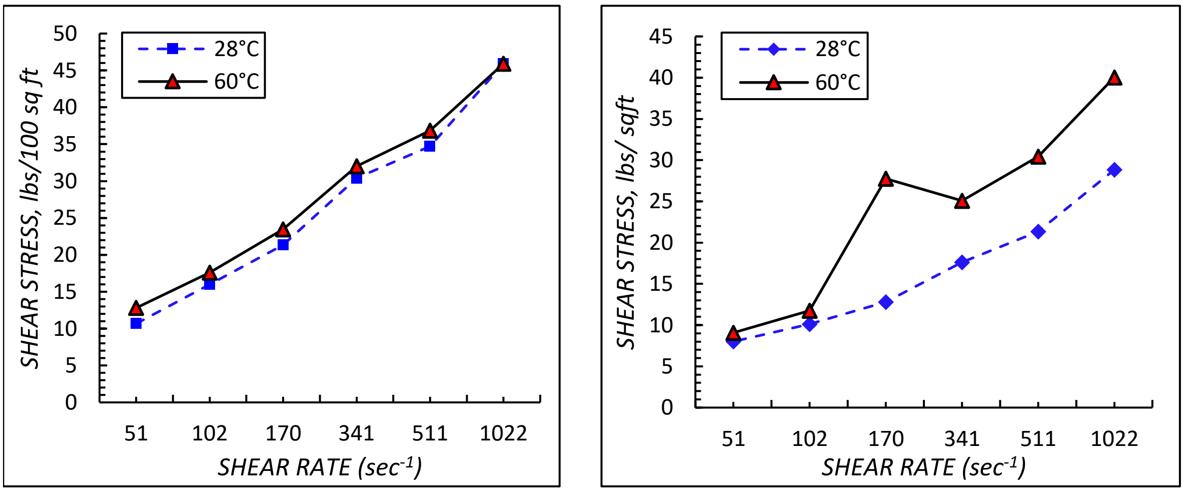


Figure 3-Plot of Shear stress against Shear rate for drilling mud sample formulated with CMC (a) with no KCl salt (b) with KCl salt

As can be seen from Figure 4(a), viscosity increases with temperature but decreases with increasing shear rate. From Figure 4(b), it was observed that suspension of KCl salt into CMC mud type caused reduction in the viscosity of the mud. At temperature of 28°C, about 25% to 43% reduction in the viscosity was reported, whereas, at temperature of 60°C, about 13% to 34% reduction in the viscosity was reported when the CMC mud type with salt was compared with mud without salt. This resulted from the fact that the entanglement of the fluid’s chain at low shear rate impeded shear flow and the viscosity was high. The shear-thinning behavior of the drilling fluids was seen, and pseudo-plastics are known to resist flow with decreasing rate of shear stress. From Table 2, it was observed that plastic viscosity decreases with increasing temperature but the trend changes on the addition of salt, but the salinity decreases the value. Also, yield point increases with increasing temperature but higher with a no salt sample. It thus means salinity decreases it value and the carrying capacity of the mud. Gel strength increases but value decreases with increasing salinity.

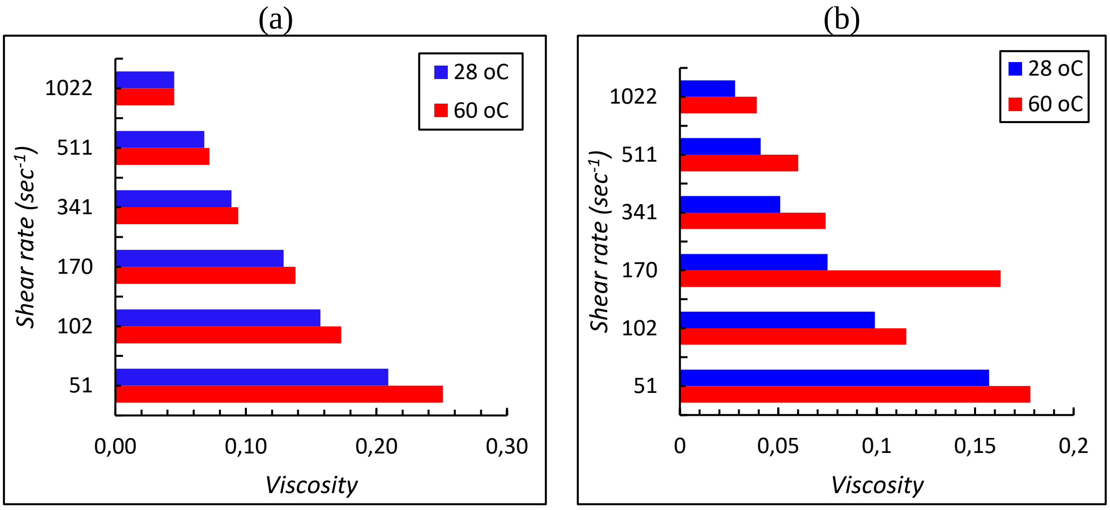


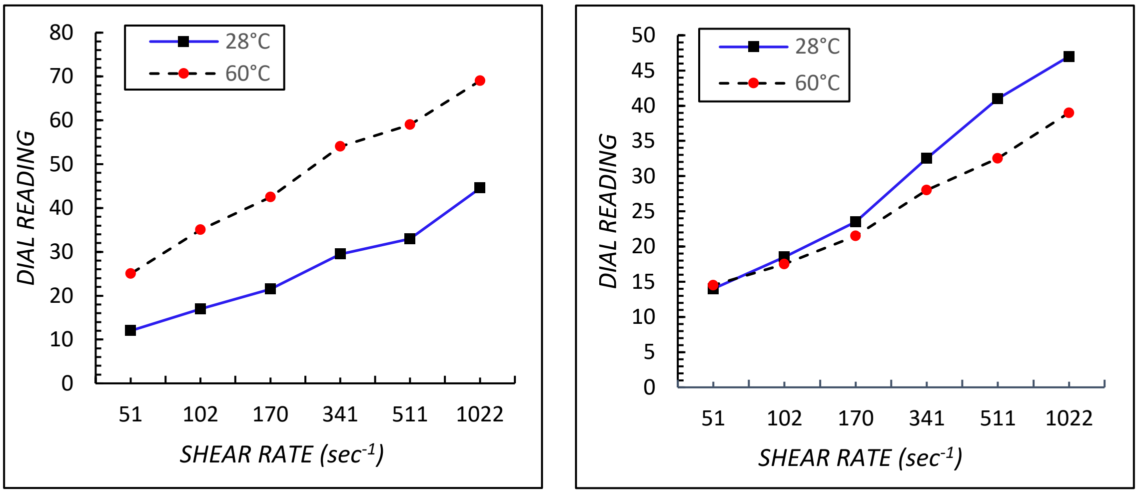
Figure 4-Plot of Shear stress against Viscosity for drilling mud formulated with CMC at temperature of 28°C and 60°C (a) with no *KCl* salt (b) with *KCl* salt

Table 2- Other rheological and thixotropic properties of CMC formulated Mud

TEMP (°C)	**CMC WITH NO SALT**			**CMC WITH *KCl* SALT**		
	Plastic Viscosity (cp)	Yield Point (lbs/100 sqft)	Gel Strength	Plastic Viscosity (cp)	Yield Point (lbs/100 sqft)	Gel Strength
28	10.5	22	3	7	13	2.5
60	8.5	26	4.5	9	19.5	4

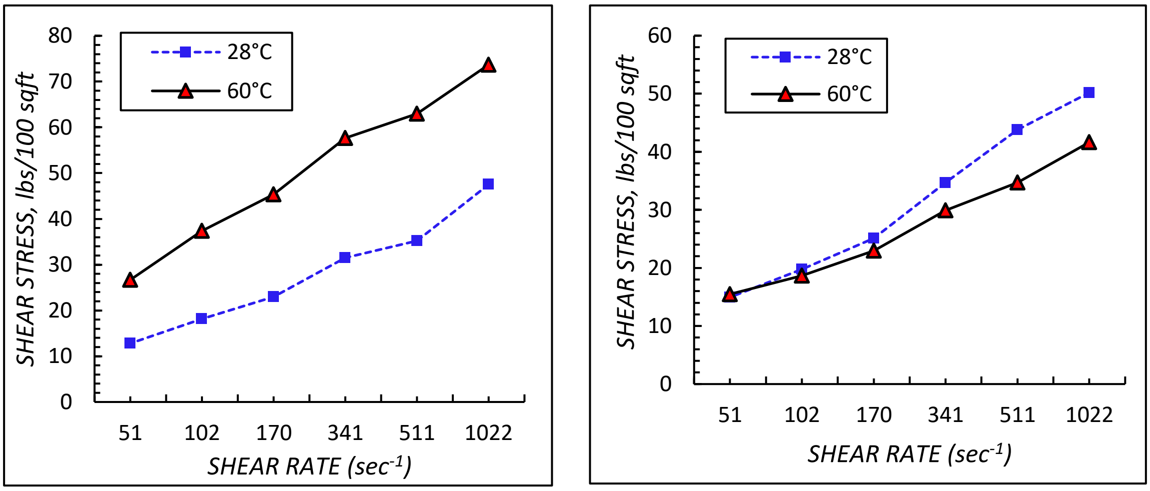
3.2 PAC-R mud sample

From Figure 5, it was observed that the dial reading followed the same trend as that of CMC but here higher values was noticed. When compared to CMC, about 3% to 20% increment in dial reading was observed in PAC-R at temperature of 28oC. Also, as in the case of the addition of salt, the high plateau was not observed in PAC-R. The dial reading increases at increasing ambient condition but decreases as temperature increases. At a temperature of 28oC, suspension of salt causes the dial reading in PAC-R to increase by 20% to 41% when compared to CMC. From Figure 6 and Figure 7, it was observed that shear stress-shear rate and viscosity-shear rate followed the similar trend but, in this case, higher values were obtained. From Table 3, the plastic viscosity decreases with increasing temperature but trend changes on the addition of KCl salt and it was observed that at ambient condition it has high values compared to CMC but value decreases as temperature increases. Thus, maintaining the stability of CMC at high temperature. Also, it was observed that the yield point increases with increasing temperature but trend changes on the addition of salt. It was also observed that the gel strength increases with temperature, but values are close to that of the sample containing KCl salt.


(a)

(b)

Figure 5. Plot of Dial reading against Shear Rate for drilling mud sample formulated with PAC-R (a) with no KCl salt (b) with KCl salt


(a)

(b)

Figure 6-Plot of Shear stress against Shear rate for drilling mud sample formulated with PAC-R (a) with no KCl salt (b) with KCl salt

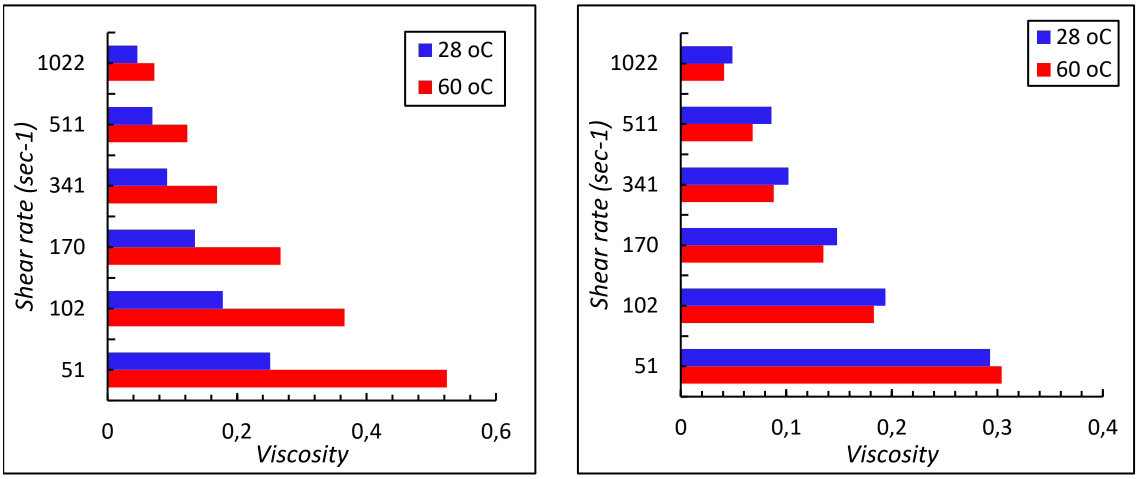

(a) (b)

Figure 7. Plot of Shear stress against Viscosity for drilling mud formulated with PAC-R at temperature of 28°C and 60°C (a) with no KCl salt (b) with KCl salt

Table 8- Other rheological and thixotropic properties of PAC-R formulated mud

TEMP (°C)	**PAC-R WITH NO SALT**			**PAC-R WITH *KCl* SALT**		
	Plastic Viscosity (cp)	Yield Point (lbs/100 sqft)	Gel Strength	Plastic Viscosity (cp)	Yield Point (lbs/100 sqft)	Gel Strength
28	11.5	21.5	3	6	35	2.5
60	10	49	4	6.5	26	4

4. Conclusion

From the result of the study, it can de deduced that salinity decreases the viscosity of the mud for both CMC and PAC-R formulated mud and, temperature increases the viscosity of the mud. It can also be deduced that PAC-R has a higher viscosity than CMC. Furthermore, salinity decreases the plastic viscosity and yield point of the mud and also as in viscosity, PAC-R has higher plastic viscosity and yield point compared to CMC. Also, temperature increases the plastic viscosity and decreases the yield point of both CMC and PAC-R formulated mud. Also, the thixotropic property (gel strength) of both PAC-R and CMC muds increases with temperature but decreases on the introduction of salt. It can also be deduced that the ability to suspend cuttings for both KCl and CMC mud are unique.

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