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Temperature Effects on the Overall Performance of Polymers in the Light-weight Cement Slurry

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Abstract

In drilling operations, the condition of the fluid downhole during circulation is very important because the alteration of the properties of the fluid could lead to a serious drilling and completion problem. Temperature is one of the key parameters to be considered during drilling operations, because it has the capacity to completely change the characteristics of the fluid system. Therefore, the choice of additives for the formulation of fluid systems is very important. The additives must be able to impact the desired properties to withstand the hole conditions expectations and meet up with the job expectation. In this study, three admixtures, namely; sodium silicate, gypsum and polyanionic cellulose R (PAC R) were selected. They were added to the cement slurries in two different concentrations (1.5% and 3.0% by weight of cement) with slurry weight of 12.5ppg. A neat sample was prepared to act as a control. The rheological properties, such as, plastic viscosity, yield point, shear stress-shear rate relationship and free fluid of the fluids were evaluated at 80℉, 120℉, 140℉ and 160℉. The rheological properties such as gel strengths at 10 sec and 10 min, plastic viscosity, yield point, shear stress-shear rate and free fluid determined. The results showed that all the fluids showed shear-thinning characteristics at the tested temperatures. The sodium silicate, gypsum and PAC-R showed good thermal stability and ability to suspend solid particles. The fluids stability increases with increase in concentration of the sodium silicate and gypsum. The PAC-R fluid was not mixable at 3%. The gypsum and the sodium silicate thin down with increase in temperature but still showed adequate suspension capability to be used as cement extender.

Keywords: *Temperature, polymer, PAC-R, sodium silicate, gypsum, yield point, drilling fluids, thermal stability*

1.0 Introduction

Low temperatures have an impact on the setting time in shallow wells, which has made it difficult for the oil and gas sector to get enough cement slurries behind the casing (Velayati et al., 2015). These problems have significantly increased the cost of the drilling process, since they make it impossible to guarantee zonal isolation when the mechanical strength of the slurries is impaired (Jueun et al., 2018; Sheng et al., 2019). Making suitable cement slurry that is compatible with underground formations at a low temperature is one of the most crucial elements of a successful cementing operation (Yuhuan et al., 2018; Jiankun et al., 2021; Stephen and Salaheldin, 2020). For a considerable amount of time, the largest issue in oilfields has been the lack of a suitable cement casing during cold weather. According to a 2019 study by Suhua et al., there is renewed interest in developing various cement compositions to attain early compressive strengths in these situations. In general, lightweight cements (LWCs) don't work well in cold weather (Yanfei et al. 2015). Low temperatures considerably slow down cement set, as is well known in the drilling business (Aldridge, 1982). One important chemical reaction that takes place at lower temperatures is cement hydration, which slows down molecular movement and decreases the pace of reaction or hydration. Lightweight slurries exacerbate this problem by having slower reaction rates and less reactive cement available for hydration per unit of water. Reduced-density cement compositions with high hydration rates, enhanced compressive strength, and reduced permeability upon setting are consequently still required for cementing pipe in wellbores in low-temperature settings. The potential phase composition, that is, the relative distribution of the main clinker phases is the main chemical factor used to classify Portland cement. It was created to encourage performance consistency among cement manufacturers by the American Petroleum Institute (API) and the American Society for Testing and Materials (Munib et al., 2020). Six classes, A through H, comprise the specifications of the 24th edition of API standard 10 A, Portland well cement (i.e., A, B, C, D, G, and H). According to Nelson and Guillot, the C_3A (tricalcium aluminate) content in these classes exhibits different levels of sulfate resistance in cement, including ordinary (O), moderate sulphate resistance (MSR), and high sulphate resistance (HSR). To accelerate the setting of slurries in low-temperature conditions, a variety of additives can be used to impact the required properties to accelerate the setting of cement and shorten the wait on cement (WOC) time. Portland cements often need to have their properties altered to meet the demands of a particular well application. These modifications are achieved by including materials referred to as additives, which effectively alter the hydration chemistry. Many different chemicals can be used to efficiently alter the properties of Portland-cement slurries. The cement slurry that is deemed beneficial will be the primary gainer when these chemicals are used separately. They will also exhibit at least one secondary characteristic that has the potential to enhance or detract from the cement slurry's performance characteristics. The influence of the additives can be minimized or amplified by changing the additive or adding more additives. For most downhole requirements, more than one additive is needed. This trade-off among additives forms the basis of cement-slurry design. It is challenging to describe these additives' interactions and reactions with cement chemically. It is really known how these additions will physically affect the slurry's performance metrics. The rheology, fluid loss, free fluid, slurry stability, thickening time, and compressive strength of slurry are all measured. Cement manufactured in compliance with the American Petroleum Institute's (API) criteria for temperature and depth is sold in the majority of oil-producing regions of the world. Any properly produced Portland cement that is consistent from batch to batch can be utilized at temperatures up to 570°F. For example, when the appropriate additives are added, Class H cement has been regularly used down to 20,000 feet. In addition to cement, other factors like as the appropriate Bottom Hole Circulating Temperature (BHCT) should be considered while generating cement slurry to meet well specifications. When making cement slurry, the designer must consider more than just temperature; permeability and water-sensitive formations must also be taken into mind. Slurry should be specifically designed for its intended function and possess the necessary properties to allow installation in a reasonable length of time.

2.0 Materials and Method

Sodium silicate, gypsum and PAC-R were used as extenders to formulate 12.5ppg cement slurry blended with sea water.

2.2 Methodology

Preparation of Cement Slurry

For the experiments, three extenders such as powder sodium silicate, gypsum, and Polyanionic Cellulose R were employed. As indicated in Table 1 cement slurry densities (12.5 ppg) were created with a sample concentration of 0 %, 1.5 %, and 3.0 % by weight of cement. After weighing components using an electronic balance, they were evenly combined and transferred to the mixing fluids. A 1.2 L capacity standard CTC constant electric stirrer was utilized to create a uniform mixture. In accordance with API RP10-2B procedure (API Edition, 2009), the mixer motor was turned on and maintained at (4000±200 rpm). Before adding cement, water and fluid additives were thoroughly dispersed by stirring them at a speed faster than rotation. In less than 15 seconds, the cement and solid additives were combined and added consistently. Following the incorporation of all dry ingredients into the mixture, the mixing speed was elevated to 12,000±500 rpm for duration of 35 seconds. The temperature of the water and the dry ingredients (cement and solid additives) were maintained at 23±1.10C prior to mixing. The extenders were the polyanionic cellulose R, gypsum, and sodium silicate, and the slurry design employed Class G cement. Antifoam (FP-30 L) was added to the cement slurry in order to reduce interfacial tension and prevent air entrainment. Rheological experiments, including fluid loss, free fluid, compressive strength, and rapid gelation tests, were performed on the cement slurries.

An atmospheric consistometer can be used to determine how long it will take for low-temperature cement systems to thicken. Slurries are usually conditioned prior to rheology, fluid-loss, or free-fluid testing. The slurry's consistency is expressed in Bearden units (Bc).

Table 1: Design of Cement Slurry Recipe with Sodium silicate/ Polyanionic Cellulose R/Gypsum

Additives	**Laboratory Quantities for 600ml API @ % Bwoc**					
	Volume (ml)			**Weight (g)**		
Sodium silicate/ Polyanionic Cellulose R/Gypsum	0 %	1.5 %	3.0 %	0 %	1.5 %	3.0 %
	-			-	6.25	12.35
Cement				422.21	416.89	411.70
Seawater	463.94	463.05	462.18			
Antifoam	1.85	1.85	1.83			

2.3 Rheological Properties Test

The measurements of rheology were performed using API RP 10B-2/ISO 10426-2 as a basis. Following preparation, the cement slurry was placed in the cup of the viscometer and sheared in the Fann direct-indicating viscometer. The torque response was recorded for each rotational speed that the apparatus could produce, which was 300, 200, 100, 6, and 3 rpm, or 511, 340, 171, and 10 s-1, in that order. When the speed of rotation stabilized at each rotation speed, the revolution per minute (rpm) reading was recorded. Cement slurries were conditioned using an atmospheric pressure consistometer (Model 1200) at a rotating speed of 150 rpm for 20 minutes in order to achieve test temperatures. A rheological test was conducted on cement slurry at each temperature, and dial readings were taken at each rotation speed once the speed of rotation stabilized.

Below are several calculations derived from test results and rheological parameters collected from the viscometer. For measuring viscosity and doing calculations, the American Petroleum Institute requirements (API RP 13B-1/ISO 10414-1, 2016) served as the reference. Features and specifications of the Model 35 Fann direct-indicating viscometer include a stainless-steel sample cup, B1 bob, F1 torsion spring, and the standard R1 rotor sleeve. The constant values utilized in the computations adhere to the R1-B1-F1 standard.

Using equations (1) and (2), the viscometer data are translated to oilfield units to give values for shear stress and shear rate.

Calculation of shear stress and shear rate:

For (R1-B1-F1):

Shear stress (lb/100ft^2) = 1.065 x 1^{o} Fann (1)

Shear rate (sec^{-1}) = 1.7023 x rpm, N (2)

N = Rate of revolution of the outer cylinder, rpm

θ= Fann viscosity reading

Viscosity was obtained by using equations (3a), (3b) or (3c) and conversion factors are listed in Table 2.

$$\mu = \frac{k_1 k_2}{k_3}(100)\frac{\theta}{N} \quad (3.3a)$$

$$\mu = kf\frac{\theta}{N} \quad (3.3b)$$

$$\mu = \frac{\tau}{\gamma}(100) \quad (3.3c)$$

where:

μ = Viscosity in centipoise, (cP)

N = Rate of revolution of the outer cylinder, rpm

θ= Fann viscosity reading

τ = Shear Stress, dynes/cm^2, which is calculated as $k_1k_2\theta$

γ = Shear Rate, sec^{-1}, which is calculated as k_3N

K = Overall instrument constant (dyne-sec/cm^2) or (rpm/degree deflection)

f = Torsion Spring Factor

1 poise = 100cP

Table 2: Constant for viscosity calculations

Constant	Rotor-Bob Combinations R1B1
Overall Instrumental Constant, k standard F1 Torsion spring,	300
Torsion Constant, k_1 (dyne/cm/degree deflection) for F1	386
Shear stress constant for effective bob surface, k_2 (cm^{-3})	0.01323
Shear rate constant, k_3 (sec^{-1} per rpm)	1.7023
Torsion spring factor	1

Calculation of plastic viscosity (PV) and yield point (YP):

Plastic viscosity (PV) and yield point (YP) of the cement slurries were calculated using equations (4) and (5).

$$PV\ (cP) = (\theta_{300} - \theta_{100}) \times 1.5 \qquad (4)$$

$$YP\ \left(\frac{lb}{100ft^2}\right) = \theta_{300} - PV \qquad (5)$$

Where θ = the dial reading

Gel strength at 10 seconds and gel strength at 10 minutes were obtained from the viscometer immediately after the desired time, at the first deflection. This is by the American Petroleum Institute Specification procedure (API RP 13B-1/ISO 10414-1, 2016).

2.3.2 Free Fluid/Free Water Test

Following sample preparation, the cement slurries were homogenized in an atmospheric pressure consistometer for 20 minutes at a rotational speed of 150 rpm. They were then stirred and conditioned at test temperatures ranging from 80 °F (29 °C) in order to determine the free-fluid content. The atmospheric consistometer is a revolving cylindrical slurry container in a liquid bath with temperature control that is fitted with a paddle assembly that is virtually stationary. In addition to rotating the slurry container at a pace of 150 revolutions per minute, the atmospheric consistometer was able to maintain the temperature under test conditions. ± 15 revolutions per minute.

(2.5 r/s±0.25 r/s) while the slurry is being stirred and allowed to condition. All components of the slurry container exposed to the slurry, including the paddle, are made of materials resistant to corrosion. A thermometer or thermocouple with a digital indicator that is accurate to ±1.7 C (±3 F) was used to measure the bath's temperature. A 250cc slurry was utilised for the free fluid test. In order to evaluate the water separation through the slurry, a two-hour test period was started when the conditioned slurry was poured into 250 cc glass graduated cylinder as shown in Table 3.2 under nearly vibration-free circumstances and maintained at an inclination of 45 degrees in accordance with API RP 10B-2 / ISO 10426-2. To stop evaporation, the graduated cylinder was wrapped in plastic film. After two hours, the total water segregation was noted.

Calculation of free fluid percent;

$$\%FF = (\text{volume of decanted fluid} / 250\text{ml}) \times 100 \qquad (6)$$

3.0 Results

3.1 Rheological Properties of Cement Slurries Formulated with Different Concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R)

This section has results of the rheological properties of three extenders. The rheological tests of the formulated cement slurries of sodium silicate, gypsum, and polyanionic cellulose HV (PAC R) at concentrations 1.5 % and 3.0 of temperatures (80 ^{o}F – 160 ^{o}F) are presented in Figure 1 - 3

3.1.1 Effect of Temperature on Shear stress and Shear rate Relationship at different concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R) Cement Slurries

Effect of temperature of shear stress and stress rate relationship of neat, sodium silicate, gypsum, and polyanionic cellulose HV (PAC R) cement slurries were presented in Figures 1 - 6

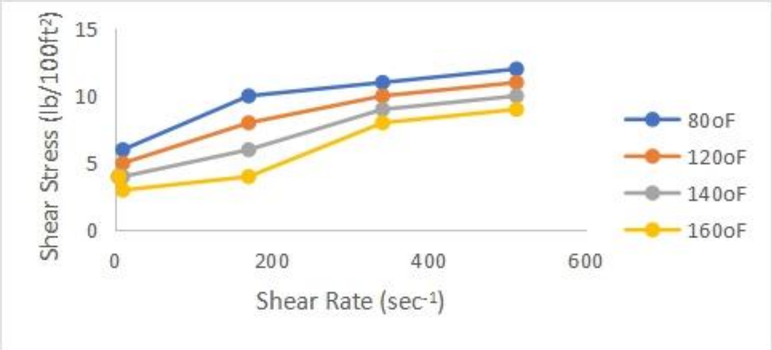

Figure 1: Shear Stress ($lb/100ft^2$) vs Shear Rate (sec^{-1}) of

Neat cement slurry of 12.5ppg at different temperatures

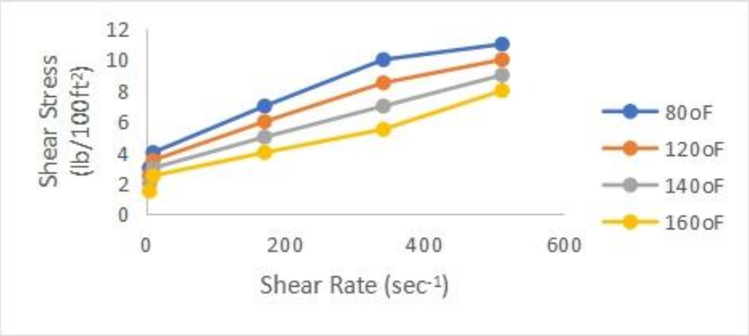

Figure 2: Shear Stress (*lb/100ft*^{2}) vs Shear Rate (*sec*$^{-1}$) of

1.5% Sodium Silicate cement slurry of 12.5ppg at different temperatures

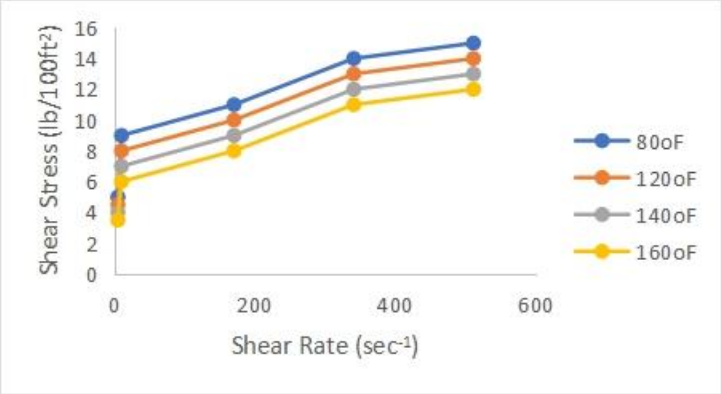

Figure 3: Shear Stress (*lb/100ft*^{2}) vs Shear Rate (*sec*$^{-1}$) of

3.0% Sodium Silicate cement slurry of 12.5ppg at different temperatures

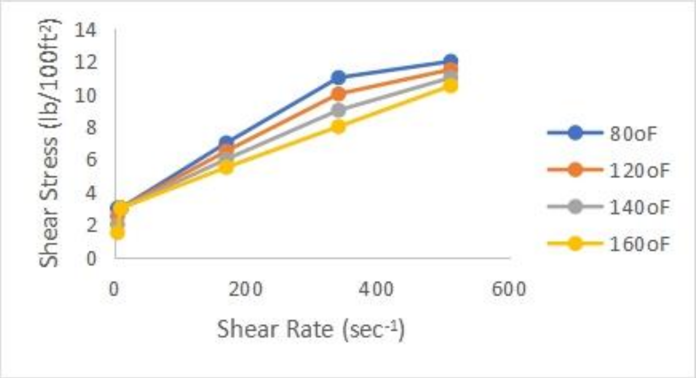

Figure 4: Shear Stress (*lb/100ft*^{2}) vs Shear Rate (*sec*$^{-1}$) of

1.5% Gypsum cement slurry of 12.5ppg at different temperatures

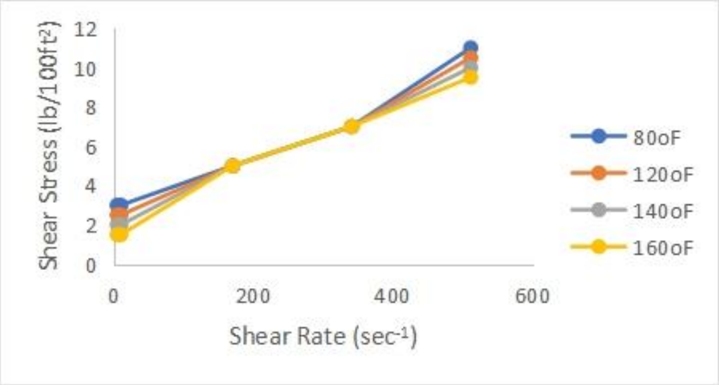

Figure 5: Shear Stress (*lb/100ft*^{2}) vs Shear Rate (*sec*$^{-1}$) of

3.0 % Gypsum Cement Slurry of 12.5ppg at different temperatures

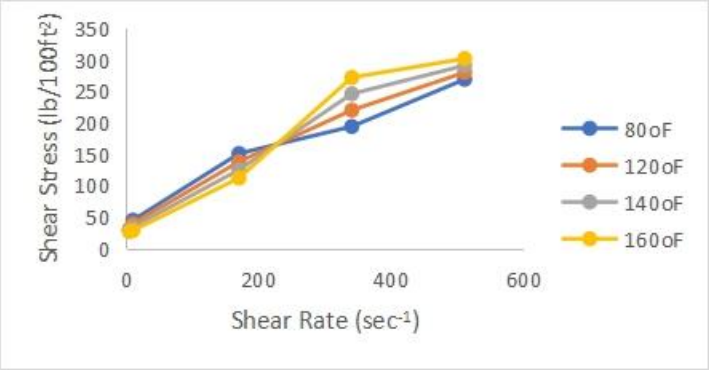

Figure 6: Shear Stress ($lb/100ft^2$) vs Shear Rate (sec^{-1}) of

1.5 % Polyanionic Cellulose R cement slurry of 12.5ppg at different temperatures

3.2 Effect of Temperature on Plastic Viscosity at different concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R) Cement Slurries

Effect of temperature on plastic viscosity of neat, sodium silicate, gypsum, and polyanionic cellulose HV (PAC R) cement slurries were presented in Figures 7 to 12.

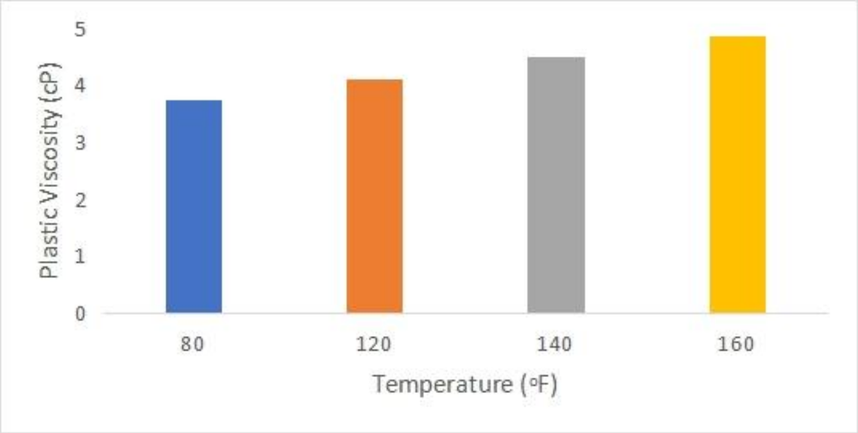

Figure 7: Plastic Viscosity (cP) vs Temperature (^oF) of

Neat cement slurry of 12.5ppg

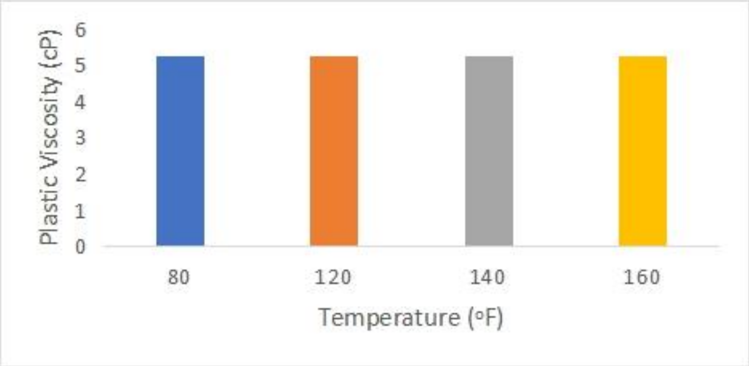

Figure 8: Plastic Viscosity (*cP*) vs Temperature (*^oF*) of

1.5% Sodium Silicate cement slurry of 12.5ppg

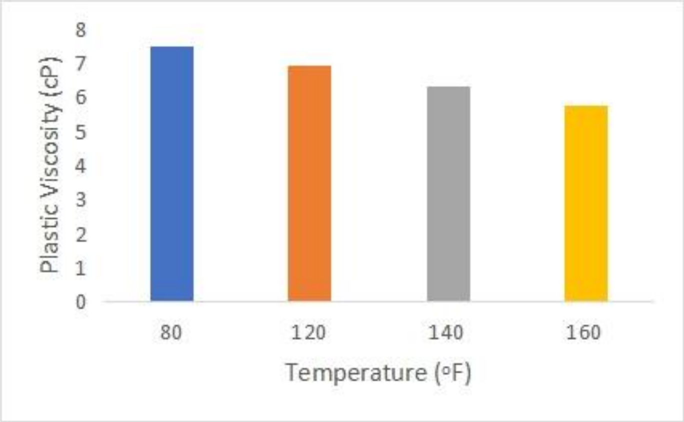

Figure 9: Plastic Viscosity (*cP*) vs Temperature (*^oF*) of

3.0% Sodium Silicate cement slurry of 12.5ppg

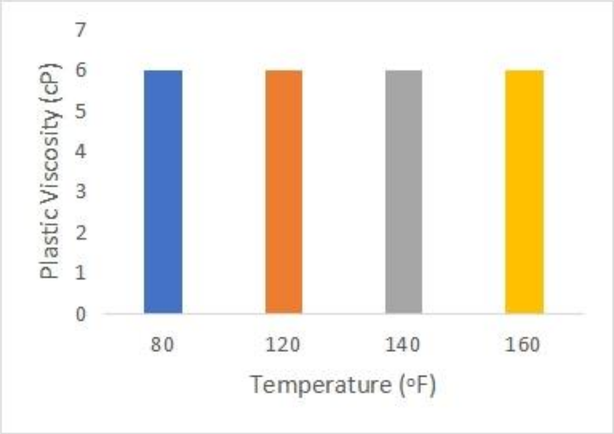

Figure 10: Plastic Viscosity (*cP*) vs Temperature (*^{o}F*) of

1.5% Gypsum cement slurry of 12.5ppg

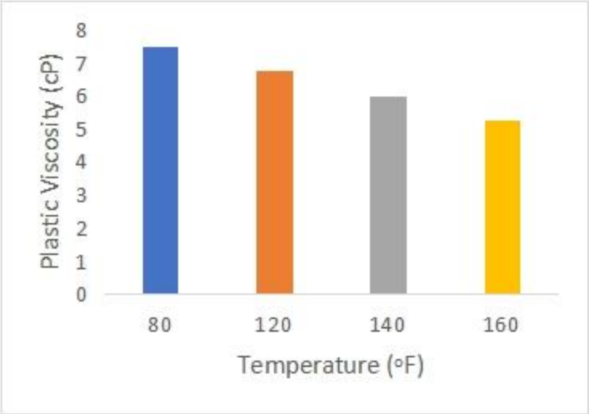

Figure 11: Plastic Viscosity (*cP*) vs Temperature (*^{o}F*) of

3.0% Gypsum cement slurry of 12.5ppg

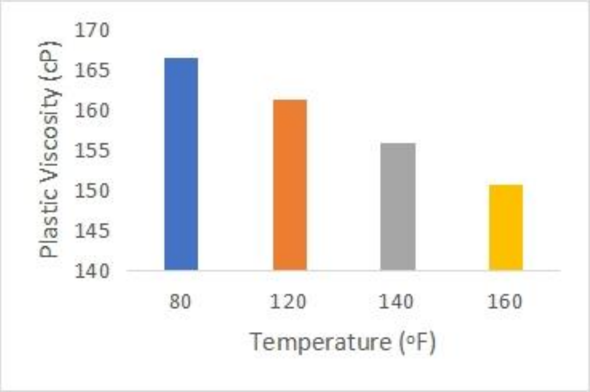

Figure 12: Plastic Viscosity (cP) vs Temperature (^oF) of

1.5% Polyanionic Cellulose R cement slurry of 12.5pp

3.3 Effect of Temperature on Yield Point at different concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R) Cement Slurries

Effect of temperature on plastic viscosity of neat, sodium silicate, gypsum, and polyanionic cellulose HV (PAC R) cement slurries were presented in Figures 13 to 18.

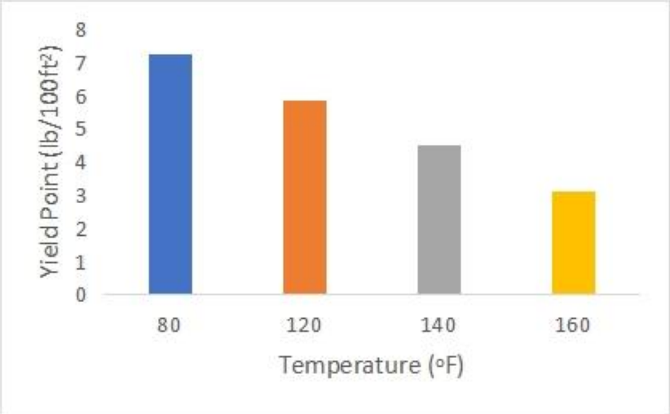

Figure 13: Yield Point ($lb/100ft^2$) vs Temperature (^oF) of

Neat cement slurry of 12.5ppg

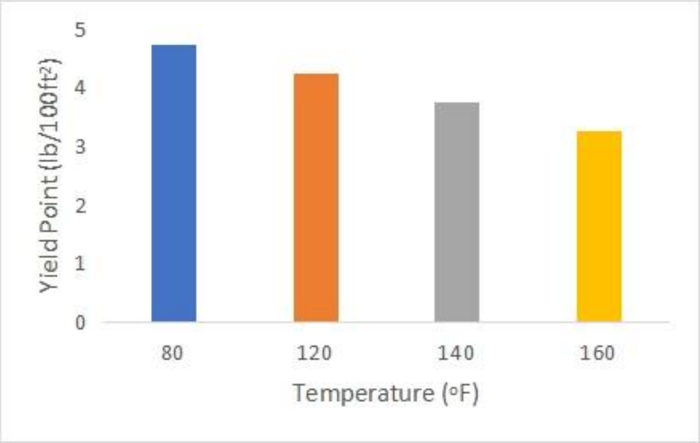

Figure 14: Yield Point (*lb/100ft*^{2}) vs Temperature (*°F*) of

1.5% Sodium Silicate cement slurry of 12.5ppg

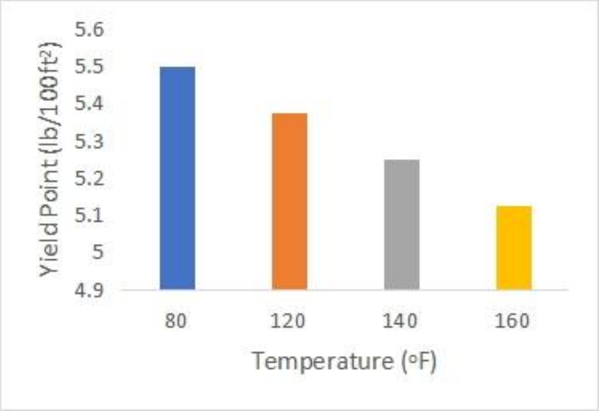

Figure 15: Yield Point (*lb/100ft*^{2}) vs Temperature (*°F*) of

3.0% Sodium Silicate cement slurry of 12.5ppg

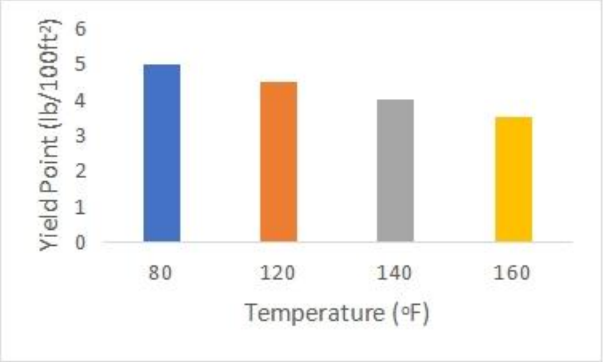

Figure 16: Yield Point (*lb/100ft*^{2}) vs Temperature (*ºF*) of

1.5% Gypsum cement slurry of 12.5ppg

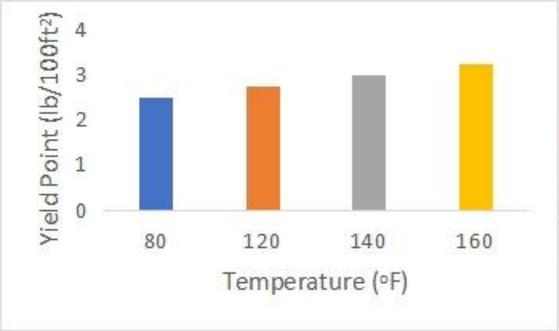

Figure 17: Yield Point (*lb/100ft*^{2}) vs Temperature (*ºF*) of

3.0% Gypsum cement slurry of 12.5ppg

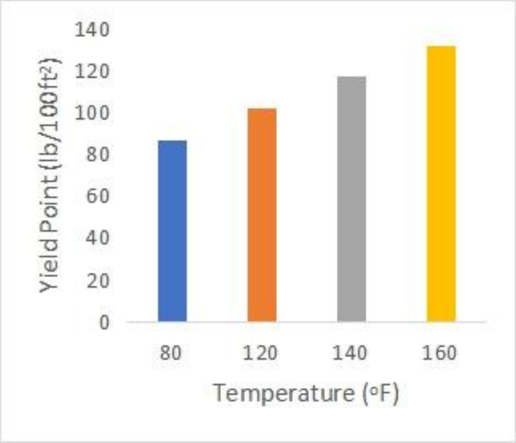

Figure 4.18: Yield Point (*lb/100ft*^{2}) vs Temperature (*ºF*) of

1.5% Polyanionic Cellulose R cement slurry of 12.5ppg

3.4 Effect of Temperature on 10 secs/mins Gel Strength at different concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R) Cement Slurries

Effect of temperature on gel strength of neat, sodium silicate, gypsum, and polyanionic cellulose HV (PAC R) cement slurries were presented in Figures 19 to 30

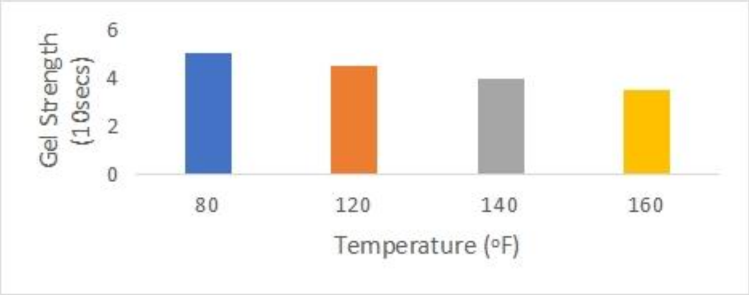

Figure 19: Gel Strength (*10secs*) vs Temperature (*^oF*) of

Neat Cement slurry of 12.5ppg

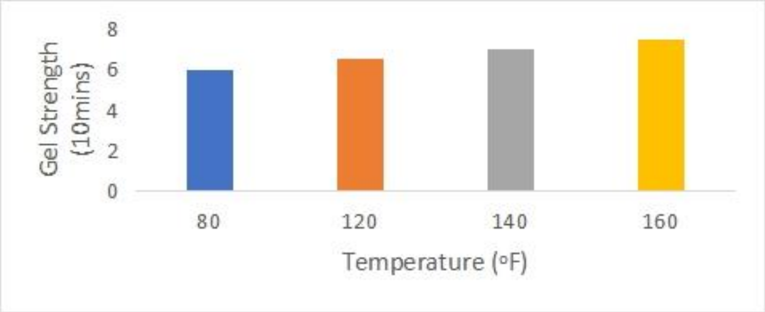

Figure 20: Gel Strength (*10mins*) vs

Temperature (*^oF*) of Neat cement slurry of 12.5ppg

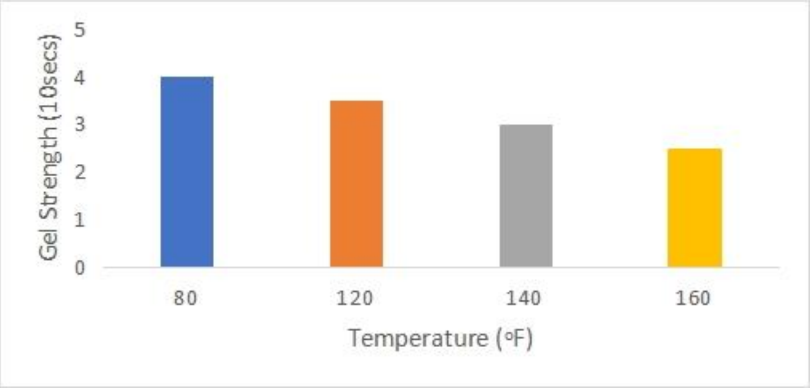

Figure.21: Gel Strength (*10secs*) vs Temperature (°*F*) of

1.5% Sodium Silicate cement slurry of 12.5ppg

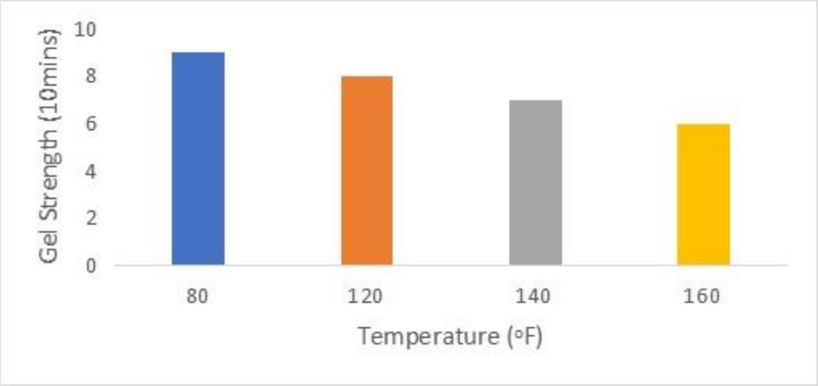

Figure 22: Gel Strength (*10mins*) vs Temperature (°*F*) of

1.5% Sodium Silicate cement slurry of 12.5ppg

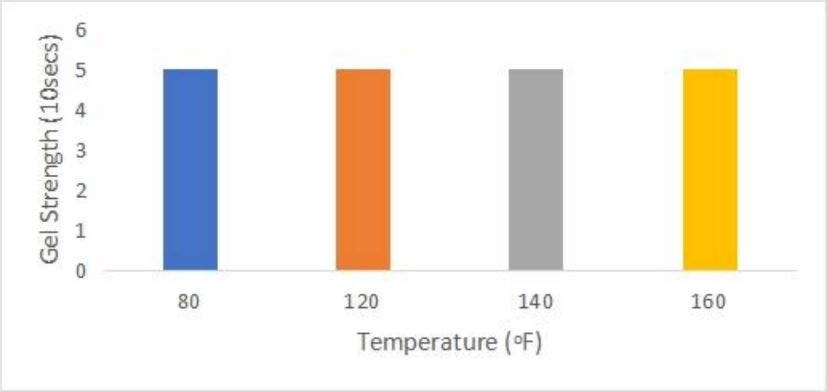

Figure 23: Gel Strength (*10secs*) vs Temperature (*ºF*) of

3.0% Sodium Silicate cement slurry of 12.5ppg

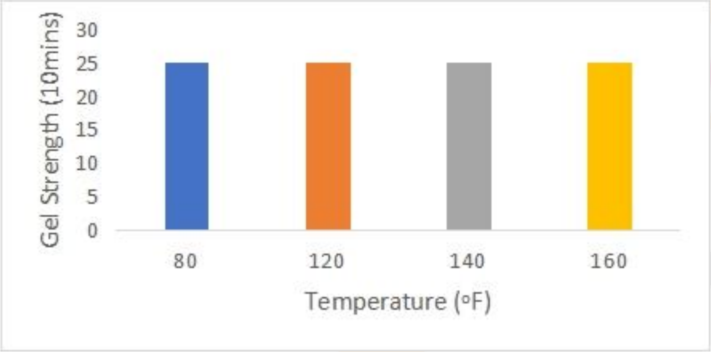

Figure .24: Gel Strength (*10mins*) vs Temperature (*ºF*) of

3.0% Sodium Silicate cement slurry of 12.5ppg

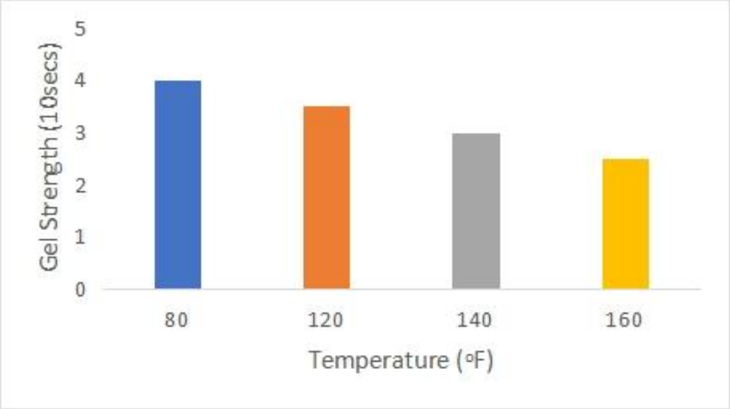

Figure 25: Gel Strength (*10secs*) vs Temperature (*ºF*) of

1.5% Gypsum cement slurry of 12.5ppg

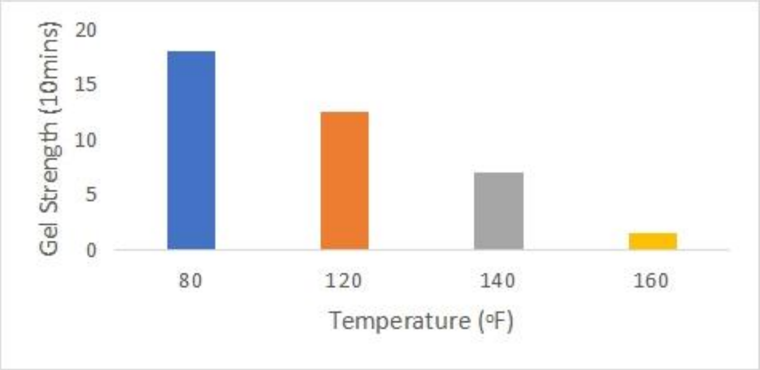

Figure 26: Gel Strength (*10mins*) vs Temperature (*ºF*) of

1.5% Gypsum cement slurry of 12.5ppg

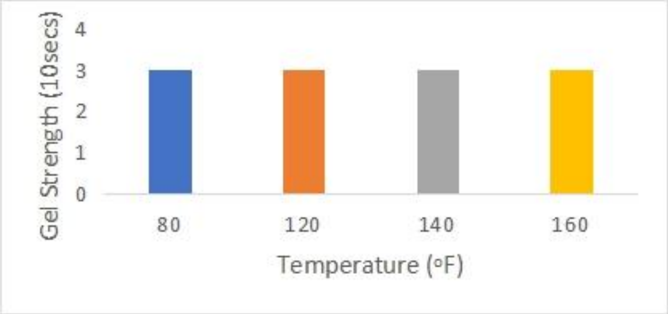

Figure 27: Gel Strength (*10secs*) vs Temperature (*ºF*) of

3.0% Gypsum cement slurry of 12.5ppg

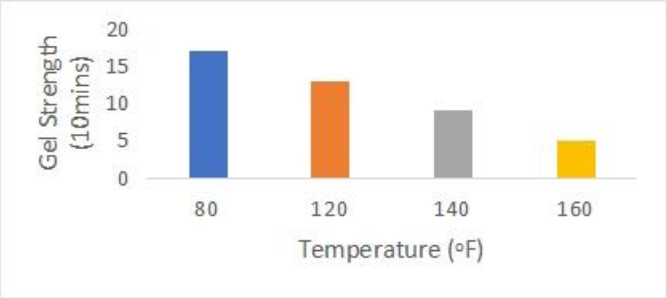

Figure 28: Gel Strength (*10mins*) vs Temperature (*°F*) of

3.0% Gypsum cement slurry of 12.5ppg

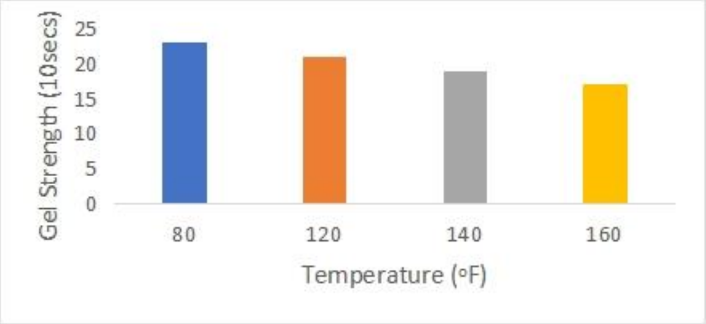

Figure 29: Gel Strength (*10secs*) vs Temperature (*°F*) of

1.5% Polyanionic Cellulose R cement slurry of 12.5ppg

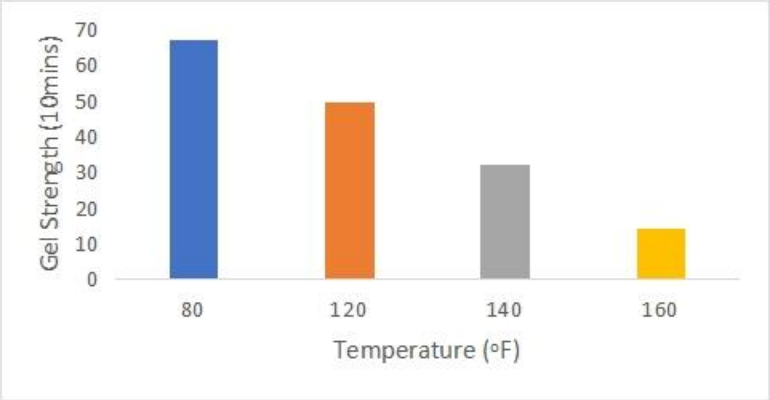

Figure 30: Gel Strength (*10mins*) vs Temperature (*°F*) of

1.5% Polyanionic Cellulose R cement slurry of 12.5ppg

3.5 Free Fluid of Cement Slurries Formulated with Different Concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R)

Table 1 has the results of free fluid of neat, sodium silicate, gypsum, and polyanionic cellulose HV (PAC R) cement slurries at 1.5 % and 3.0 % respectively

Table 1: Free Fluid of Sodium Silicate, Gypsum, and Polyanionic Cellulose R

Free Fluid	**Neat**		**Percentage of Sodium Silicate (% bwoc)**		**Percentage of Gypsum (% bwoc)**		**Percentage of Polyanionic Cellulose R (% bwoc)**	
	mls(÷ 250)	%	mls (÷ 250)	%	mls (÷ 250)	%	mls (÷ 250)	%
0 %	14	5.6	-	-	-	-	-	-
1.5 %	-	-	6	2.4	4.2	1.68	0	0
3.0 %	-	-	4	1.6	2.8	1.12	-	-

4.0 Discussion

4.1 Effect of Temperature on Shear stress and Shear rate Relationship at different concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R) Cement Slurries

The relationship between the shear stress and shear rate is very important as it is used to establish the viscosity of the cement slurries. Normally, as the shear rate increases the shear stress increases. Shear thinning occurs when the apparent viscosity drops as the shear rate increases, or when the shear stress curve's slope falls as the shear rate flow increases. Shear thickening occurs when the cement slurry's viscosity rises in proportion to the shear rate. From the results obtained for different extenders, it was observed that the viscosity of the cement slurry at the temperature of 80°F was a way higher than the viscosities at 120°F, 140°F and 160°F (Figure1). This result implied that the cement slurry sample without the extender (Neat slurry) was only stable in terms of viscosity at the lowest temperature, but higher temperature values, cement became unstable. In figures 2 and 3 the viscosities of the cement slurry prepared with 1.5% sodium silicate and 3% sodium silicate were highest at 80°F (Room temperature), but showed decreased viscosity values as the temperatures increased. These results indicated a level of thermal instability at higher temperature. 1.5% gypsum showed the same results as the viscosity was highest at 80°F, declined greatly at the temperature values of 120°F, 140°F and 160°F (Figure 4). However, the result in figure 4.5 showed that increase in temperature did not have impact on the viscosity of the cement slurry when the concentration of gypsum was increased to 3% (Figure 5). The viscosities at different temperatures – 80. 120, 140 and 160 were the same. The concentration affected the viscosity of the cement slurries. 1.5 % Polyanionic Cellulose R (PAC-R) showed a similar result at concentration of 1.5%, the viscosities of the cement slurries did not change considerable in which there was a lapping of the curve (Figure 6). Therefore, the gypsum at 3% concentration and PAC-R at 1.5% showed thermal stability at higher temperature. Shear thinning was the same rate as the temperature increased from 80°F - 160°F. Both PAC-R did well as they did not alter the properties of the cement slurries at higher temperatures.

4.2 Effect of Temperature on Yield Point at different concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R) Cement Slurries

Yield point is the property of the cement slurry that show how long it takes cement slurry to flowing after it has been left in a stationary condition. It is the obtained from the straight line matched with the flow curve of the plot of shear stress against share strain. It is an important rheological property as it indicates the shear stress that is required to result in shear thinning which will consequently lead to flow. In the result obtained so far showed that the yield point (YP) of the neat slurry decrease exponentially as the temperature of the sample increased from 80°F - 160°F (Figure 13) because the increase in the temperature brought about shear thinning. The yield point was observed to reduce slightly as the temperature increase when 1.5% of sodium silicate was added (Figure 14) which implies that the addition of the extender did not impact greatly on the YP. In figure 15, the cement slurry was prepared using 3% of sodium silicate and the result showed that there was a sharp reduction in the YP as the temperature increased from 80°F - 160°F, which was contrary to the result of 1.5% dosage of the additive (sodium silicate). The discrepancy in the results could be traced to the effect of dosage on the extending property of sodium silicate. Also, the result of the YP of cement slurry treated with 1.5% gypsum showed that the there was a light reduction in the YP as the temperature elevated from 80°F - 160°F (Figure 16), showing that the impact of gypsum powder was not much on the YP of the cement slurry. The 3% concentration of gypsum powder showed a reversal effect on YP. As the temperature increased, there was a slight increase in the YP (Figure 17). The increased in the YP as the temperature increased could be as a result of the higher dosage. This reversal behaviour could affect the performance of the cement slurries. 1.5% Polyanionic Cellulose R cement slurry had its YP increasing as the temperature increased which was a non-thixotropic behaviour which indicates that the material tightened at high temperatures with higher shear, a behavior that has already been seen in other places (Eirich, 1960). In the normal condition, as the temperature increases, there will be an increase in hydration, making the admixture to be dispersed enough to enable an increase in thixotropy, high concentration would mean that the amount soluble admixture in slurry will exceed the hydration rate causing stiffening (ie increase in YP), thereby decreasing the thixotropy of the cement slurry as the temperature peaks. This was similar to the findings from previous studies using ordinary Portland cement (Al-Martini, 2008; Nehdi and Al-Martini, 2007).

4.3 Effect of Temperature on Plastic Viscosity at different concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R) Cement Slurries

Plastic viscosity is one of the rheological properties of cement slurries that is very vital in its performance during cementing operations. The rheological properties of cement-based materials determine the quality of the hardened cementitious matrix and help to predict its end-use performance and its physical properties during and after processing. The results of the experimental work showed increasing plastic viscosities as the temperature increased from 80°F - 160°F. Normally, if the viscosity is increasing with increasing temperature, the condition is termed shear thickening. So, there was observable shear thickening as the temperature increase for a fresh sample ie without any extender (Figure 7). The 1.5% of sodium silicate was added, and the admixture showed no significant increase in the plastic viscosity as the temperature increased from 80°F - 160°F displaying Newtonian fluid behaviour. When 3% of sodium silicate was added to the sample, the plastic viscosity was seen to decrease as the temperature increased as shown in Figures 8 and 9, indicating shear thinning (dispersion characteristics) ie shear thinning, which is typical non-Newtonian fluid. Also, the addition of 1.5% of gypsum showed no significant change in the plastic viscosity (Figure 10). There was neither thinning nor thickening, as it is common among Newtonian fluids while the 3% of gypsum showed a reversal behaviour. The plastic viscosity of the sample decreased proportionately with increasing temperature (Figure 11). This result was similar to the result obtainhed for 3% of sodium silicate (Figure 9). However, (Polyanionic Cellulose R) Pack R showed shear thinning as the temperature increased from 80 – 160. The plastic viscosity decreased sharply as the temperature increased (Figure 12). The cement slurry treated with Pack R showed non-Newtonian fluid behaviour.

4.4 Effect of Temperature on 10 secs/mins Gel Strength at different concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R) Cement Slurries

Gel strength as an important rheological of oil-field fluid was studies when different admixtures were added to the cement slurries. Neat cement slurry showed that the gel strength at 10sec decreased as the temperature increased from 80°F – 160°F (Figure 19). The increase in temperature brought about a decrease in the gelation of cement slurry. However, a reversal behaviour was noticed of the gel strength at 10 minutes as the temperature increased from 80 – 160 (Figure 20), increasing the slurry gelation. The gel strength values at 10 sec and 10 min showed a similar result. As the temperature increased, the gel strengths at 10 sec and 10 min reduced when the doge of sodium silicate was 1.5 % (Figures 21 and 22) while 3% dosage of sodium silicate showed that an increase in brought about no change in the gel strengths at 10 sec and 10 min (Figures 23 and 24). The change in the concentration of the admixture could have been responsible for the discrepancy in the behaviour of the cement slurries. In figure 25, there was a decrease in the gel strength of the cement slurry treated with 1.5% of gypsum but the drop in the gel value at 10 min was sharp as the temperature increased. In fact, the gel strength at 10 min was near zero at 160°F (Figure 26), indicating a possible of having zero gelation if the there was any further increase in temperature. At 3% concentration of gypsum, the gel strength at 10 sec remained even as the temperature increased (Figure 27) but the reverse was the case when the gel strength was taken at 10 min, in that the gel began to increase as the temperature was increasing (Figure 28). 1.5% Polyanionic Cellulose R (Pack R) showed a slight decrease in the gel strength at 10 sec as the temperature increased (Figure 29), but the gel strength at 10 min experienced a sharp reduction as the temperature increased (Figure 30), nearing zero. Further increase in the temperature could lead to completion zero gelation.

4.5 Free Fluid of Cement Slurries Formulated with Different Concentrations of Sodium Silicate, Gypsum, and Polyanionic cellulose HV (PAC R)

Free fluid (FF) is the amount of fluid ie water that separates from cement slurries at a stationary phase. It is used to determine the fluid loss and hydration properties of cement slurries. In table 4.1, the concentrations of the admixtures – sodium silicate, gypsum and Pack R in the cement slurries show that variation in the amount of water separated from the cement at a settled condition. The result of neat cement slurry showed that there was free fluid of 14 ml (5.6%) while 1.5% sodium silicate cement produced 6ml (2.4%) while 3% sodium silicate cement produced 4ml (1.6%). So, as the concentration of the admixture (Sodium silicate) increased, the amount of free fluid decreased (Table 1). 1.5% gypsum cement showed that the produced water was 4.2ml (1.68%) while 3% gypsum cement produced 2.8ml (1.12%), indicating that an increase in the concentration of the admixture brought about a decrease in the amount of separated from the cement slurries at a static condition. 1.5% Polyanionic Cellulose cement had no free water (Table 1). The result obtained from the cement slurry treated with Pack R (Polyanionic Cellulose R) indicated that it has the ability to induce 100% hydration in the cement slurry ensuring that there is homogeneity of the entire cement system. Both sodium silicate and gypsum did well, but their abilities to reduce free fluid formation depend on the concentration.

Conclusions

From the discussion of the result obtained, the conclusions were as follows:

a) PAC-R at 1.5% and gypsum at 3% concentration both demonstrated thermal stability at higher temperatures. The rate of shear thinning increased with temperature from 80°C to 160°C. Since they didn't change the cement slurries' characteristics at higher temperatures.

b) The yield points of the cement slurries treated with sodium silicate and gypsum showed dependence on the percentage concentration, which means that the dosage these admixtures determines whether the yield point/stress of the cement slurries will decrease or increase at high temperature values.
c) In terms of yield point, sodium silicate and gypsum showed thixotropic behaviour at 3.0% and 1.5% respectively while 1.5% of-PAC-R showed non-thixotropic characteristic.
d) The effects of temperature on the plastic viscosities of the cement samples were altered due to the concentrations of the admixture.
e) Sodium silicate and gypsum can be used as cement extenders at optimum concentrations.

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Conflict of Interest

This is no conflict of interest

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