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A Comparative Study of the Rheological Properties and Stability of Local and Foreign Starch

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ABSTRACT

Nigeria is a country blessed with a vast variety of food items and cassava happens to be one of them. It is geographically widespread hence; it is very cheap. This research work revealed that cassava apart from consumption can also serve as an additive in cement slurry for well completion in oilfield operations after series of test was conducted in the laboratory on it. Tests such as rheology, free fluid, determination of slurry weights and stability at different temperatures ranging from 80°F to 190°F and concentrations was conducted using API procedure. The rheological properties, free fluid, slurry weights and stabilities at different temperatures and concentrations of starch were established and compared with the foreign sample and the results obtained proved that local cassava starch can be a substitute for foreign starch sample as it was seen to have similar rheological properties when compared with the foreign starch sample. The plastic viscosity and yield point values obtained from the rheological deductions for local starch compared favorably with the foreign starch. In terms of free fluid, zero free fluid is usually recommended for filed practice. Local cassava starch was seen to have 0 free fluid which means that this could be a substitute with the foreign starch. For the slurry weights, there were no significant difference between them. Therefore, from the research finding, locally produced starch especially POCEMA starch proved to have properties suitable for application in oil filed cementing operations as there was no significant difference between them when compared.

Keywords: Rheological Properties, Starch,

1 INTRODUCTION

Additives and Cement in Oil Field Application

Additives are basically substances which are added to slurry to improve their intended qualities [1]. During processes oil-well development, cementing characteristics are suitably modification to suit underground or in-situ conditions for optimal and intended performance. Cement slurry features are enhanced basically on their densities, flow-features (rheology) and stability. Several additives are already developed to improve or prolong efficacy of well-bore. Primary or main function of cementing is to create zonal and sectional isolation. There exists certain degree of improvement in well-qualities from re-engineering of real-time well conditions in-situ. Eric, B. et al (2016) stated that additives are substances which are usually introduced to cement slurry basically to enhance, adjust or modify them to intended or desired feature. Bett E. K. (2010) stated that cement additives are crucial and critical part of quality well design element and construction. Their roles are one, develop quality slurries, achieve successful positioning between casing and formation, fast compression capacity development and suitable and appreciable zone-based isolation through-out entire life involved well. Studies revealed that they one could modify cement time for setting under well conditions, monitor losses due to filtration of liquid from cement slurry when and after positioning, adequate cement shrinkage compensation during setting and hardening, enhance interfacial bond between cement and casing, and monitor influx and movement of formation fluids into cement designed column during setting.

Cement Additives

There are several known cement additives which were designed to allow for utilization of locally availed cement in several and various oil and gas well usage. Each form has several forms of additives which were designed to perform almost same function during design of cement slurry. But there are several additives under every main kind which are commonly utilized in design of cement slurry for O&G well cement activities. After normal drilling activities, depending on depth and casing design every well sections are isolated from each other. Zone based isolation retain reservoir conditions which are permeability for wellbore vicinity but importantly, zone-based isolation retain cement against unintended fluid movement from reservoir. Well cement is process of combining cement, water and additives, then flow this cement mix down hole via casing to required points in annular space between casing and formations surrounding wellbore. Thus, oil-well cement process is considered as among most crucial activities conducted in construction of wellbore [4]. High-quality cement [5] slurry is mostly needed so that oil production is cost-effectively and safely accomplished over entire lifetime of drilled well and to assure long-time durability of wellbore through providing high-quality casing [6]; [7]. Apart from remedy-based activities, poor cement quality equally causes many or problem in completion activities like loss of lives and facilities; example is loss encountered in global reserve in current Gulf of Mexico deep-water oil spill. Zone based isolation and poor hydraulic sealing between casing and cement and between cement and formations could trigger oil spills inhibiting well capacity to produce in their optimal and complete potential [8]. These additives are commonly introduced to cement formulations; to disband cement, modify setting time in dace of varying temperature and pressure in Oil-well, control filtration liquid losses from cement during and after positioning, compensate for shrinking of cement during setting and hardening, enhance interfacial bond between cement/casing, and regulate influx and movement of formation fluids into cement section during setting [9]. Selecting cement additives for cementing activities is major or integral section of well design, construction and integrity [10]. Cement performance is mostly ascertained through diagnosing certain measurable features like specific weight, time for thickening, compression strength, flow pattern or rheology, fluid loss, free fluid, stability, sedimentation, solid suspension, and time-based settling.

Cassava: Overview

Cassava (*Manihot esculenta, Crantz*) belongs to Euphobiaceae family. (Herman K, 2002) stated that it is second most abundant biomass uncovered in nature, following cellulose. In other parts cassava starch is called "tapioca" in Asia called "manioca" in Africa called "manioc", "yucca", or "mandioca" in South America. The work "cassava" is used to mean roots and "tapioca" is used in processed products like starch. Cassava is rooted crop planted in various regions of emerging nations. It is polymeric material and consist two key components; amylose and amylopectin. It composed of amylose, linear polymer that possess molecular weight that ranged from 100,000 to 500,000 and amylopectin which is branched polymer having molecular weight that ranged 1 to 2 million. It is long-chained non-ionic water soluble and alcoholic carbohydrate and consist of massive amount of glucose joined through glycosidic bonds, and it is readily hydrolysed by enzyme, metal, oxalic acid, and it is pseudo-plastic in liquid solutions. Brown, W. et al (2005) stated that starch contains 20 to 25 percent amylose and 75 to 80 percent amylopectin based on weight, cultivar-type could affect their biopolymer quality.

Cassava Starch as Additive in Oilfield Operations

Joel O. F. (2010) noticed and documented that starch polymers could be utilized to reduce hydro-filtration of every form of water utilized in disbanding drilling fluids and create protective colloids created when mixing; additionally, increasing drilling fluid viscosity. Also, Ademiluyi T. et al (2011) documented high amylose content and high capacity to absorb water in drilling fluid with high viscosity and low liquid loss. Although microbe attack was linked to challenges of using biopolymers for additives. The cassava starch performance as fluid loss minimizer and viscosity improver in drilling fluid were successful compared to imported starch [15] and [16]. The water-sellable amylose help starch to show fluid loss regulation features. Cassava starch is polysaccharide which was investigated and uncovered to show several features which possess potential for several uses. There are more than 40 cassava cultivars [17] and are categorized in two groups, bitter and sweet cassava (*Manihot palmata and Manihot aipi*) based on their cyanohydrins content [18]. Cassava possesses roughly 150 different species but their physical and chemical features like other natural material are affected by hereditary and location factors and processing method, storage period would equally affect cassava starch due to biodegradable [19]. For industrial reasons, bitter groups are usually planted and used because of high starch content. Sweet groups are preferred for food due to taste and dough creating capability. Cassava starch possesses several remarkable features which includes high viscosity, clarity and high freeze thaw stability which are benefits for industrial usage [20].

Rheology

Rheological features of cement are strongly impacted by several factors which includes water/ cement proportions, cement grain size and shape, chemical composition and relative distribution of components at grain surface, additive presence, interactions between cement and chemical mixtures, mixing procedures, time and temperature amongst others. (Shahriar and Nehdi, 2012); (Memon, K. R. et al, 2014) stated that flow behavior or rheological features of cement are complex and crucial to field performance of cement as concern flow and ability to work with. Although wells qualities are massively affected by mixture process and selected material, including water-to-cement proportions and temperature. Physical assessment of flow features of

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cement with additives developments are crucial tools in cementing work to understand suitably placing cement with no accidents. Because during well producing life, chances or possibilities of cement collapse exist due to uncertainty that occur during several well operations like well stimulation or pressure testing; communication test, cement squeeze work. These events create thermal and periodic stresses and trigger change or alteration on well profile [23]. The flow features of cement-based materials ascertain quality of hardened cement matrix and aid in predicting their end-use performance and physical features during and when processing. Furthermore, yield stress, seeming viscosity, malleable viscosity, and shear retreating or shear congealing behavior were noticed to massive part in understudying wellbore qualities. The yield stress showed minimum effort required for material to commence flowing. Threshold low compare to yield stress, cement slurries act like solid [24].

2 LITERATURE REVIEW

Additives are seen as "The Blood" in O&G well cementing activities and plays crucial part [12]. Several cement additives are already developed for use in Portland cement in different O&G activities. To design or formulate suitable cement slurry for particular cementing work, best additives are selected and correct quantity must be ascertained and introduced. Additives possess various functions and widely grouped based on performances like accelerator, extenders, retarders, fluid loss agents, and dispersants. These wider grouping of these additives possess different categories which are already designed to perform nearly the exact function when cement slurry are designs. So, there are certain additives under every main group which are commonly utilized in designing cement slurry for O&G well cement work. This research work reviews comparative works on local and imported starch as oil-well additives, giving emphasis to rheology, slurry weights and free fluid required during O&G well cement work [12].

Theoretical Background of polymers

"Polymer" as its name signifies is derived from Greek words, 'Poly' which means many and 'Mer' which means units. Simply "polymer" is long-chain molecule which is composed of massive number of repeated smaller and similar unit to form one structure. These structures are unit comprised of at least two molecules, combined to form one long chain. Due to large number of repeated units and having different behaviours, polymers are found naturally or created synthetically. Natural polymers derived from animal or plant is cellulose/starch, or rubber which is obtained from latex from rubber plant, hemp, shellac, amber, wool and silk. Synthesized polymers are man-made and some examples include fibre, PVC, synthetic plastic and nylon. Semi-synthetic polymers produced are created through modification of natural polymers in laboratory.

In oil-well cement works, polymers are not stable in cement slurry for elevated temperatures because of their different natural capability. Viscosity of polymers decrease at elevated temperature and in such case, they lose their intended features in cement work to heat. Excess amount of polymer could be utilized to elevate viscosity at elevated temperature but this equally elevates slurry viscosity at surface condition, and becomes risky [23].

Currently polysaccharides are amended with carbonates and some chemicals to elevate viscosity of polymer at elevated temperature which create value for oilfield cement work [23]. It is non-beneficial to introduce chemicals to polymers because such elevated cost of operation and it could equally affect cement features and other available additives. It is then crucial to use polymers like polymers POCEMA starch that elevates viscosity with elevated temperature with zero addition of chemicals.

Functions of Polymers

Polymers function as additives during drilling and cement operations and used in elevating viscosity of liquid phase and lowering filter permeability of drilling fluid or cement, thus reduces filtration rate. it is usually or commonly introduced in cement formulations; to disband cement, modify setting time in dace of varying temperature and pressure in Oil-well, control filtration liquid losses from cement during and after positioning, compensate for shrinking of cement during setting and hardening, enhance interfacial bond between cement/casing, and regulate influx and movement of formation fluids into cement section during setting [9]. Selecting cement additives for cementing activities is major or integral section of well design, construction and integrity.

Theoretical Background of Hydroxyethyl Cellulose

Hydroxyethyl Cellulose is named after two components which are cellulose and hydroxyethyl chains. Cellulose is non-ionic, soluble, long-chained molecule that consists of repeated anhydro-glucose units (Fig. 1). It is pseudo-plastic in liquid solutions and molecule is hydrolyzed easily in acid presence and widely utilized in oil-industry for cement slurry design. It minimizes hydraulic friction in slurry and reduces water loss to formation acting as free water and gas movement control agent when cementing. It could equally thicken, bind, suspend, form films, stabilize, emulsify and disperse it equally avail protective colloid. It could be utilized in preparing solutions with varying viscosities. It possesses massive tolerance for electrolytes. Hydroxyethyl Cellulose is cellulose where ethyl and hydroxyethyl radicals are attached to anhydro-glucose units through ether links. It is produced from cellulose through treatment with alkali, ethylene oxide, and ethyl chloride. It is hygroscopic, yellowish or grayish, odorless granules or powder having molecular weight of 250,000 and not soluble in boiled water and ethanol. This is utilized at

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temperatures close to 82 °C (180 °F) for fluid-loss control and utilized temperatures of nearly 110 °C (230 °F) Bottom Hole Circulation Temperature (BHCT), depending on co-additives employed and slurry viscosity 110 °C (230 °F) [2], HEC is not thermally stable.

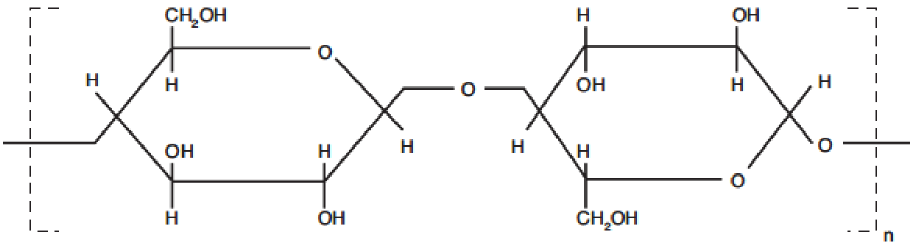

Figure 1: Structure of Hydroxyethyl Cellulose

Rheology of Oil Well Cement Slurries

In oil-well completions, immense understanding on rheological research as concern cement slurry is crucial as it is utilized in predicting stability of cement slurry for zone- based isolation in which cement slurry are pumped down several feet to earth seal some casing. Rheological theory for cement slurry exists between cement and water. Arnaud C. et al. (2019) stated that polymers possess strong impact on flow features of cement slurry and usually expected or supposed to play crucial part on suspension of particles in cement, cement homogeneity and control settling. The flow features of cement-based materials informs quality of hardened cement matrix and aid in predicting their final use performance and physical features when processing. To characterize flow feature cement slurry, flow parameters like yield stress, viscosity, shear retreating or shear congealing features are studied. Slurry is combination of cement and or with water and used in sealing annular space of formation. When slurry is positioned within permeable formation witnessing pressure, water seems to depart from slurry into permeable zone, particularly when pumping stops and slurry is static, but yet to set. If such fluid loss is uncontrolled in oil-well cement operations, rheology, particularly time for thicken and density will alter hence lead to failure of such cement jobs; design feature for slurries are appreciably affected by water content. Therefore, slurries which lose water could equally be subject to losing design feature [26].

Effect of Temperature on Rheological Properties of Cement Slurry

High temperature oil-wells are most trouble filled well especially during cement operation because of limitations on polymer additive to utilize. Polymers significantly utilized in such case are multi-operational additives to improve features of slurry as designed. During cement work on high temperature wells, polymer viscosity is noticed to reduce and not able to achieve needed and intended features for slurry as needed by API specifications. It is seen as main reason for fluid loss and gas movement when cementing thus, it needs polymers which are capable of enhancing viscosity at elevated temperatures. This work focuses on using starch polymers at high temperature that is able to increase viscosity at increased or elevated temperatures while comparing local and imported starches. Ravi and Sutton (1990) stated that there are fluid features which are appreciably affected by temperature like viscosity and yield. Temperature, pressure effects on flow features of slurries could be ignored (Ravi and Sutton, 1990). On another extreme if flow features are underestimated when temperatures is elevated, then design flow capacity would be overestimated. The aim of this current work is to effectively utilize starch mixtures to design slurries with satisfactory accepted features to overcome issues witnessed in oil-well cement operation like rapid workability losses, pumping issues, cement hydration acceleration, rapid evaporation of water and zone-based isolation, it was uncovered that flow feature of oil-well slurries with current starch are dependent on temperature, W/C ratio and percentage based on starch admixture amount used. impact of temperature and chemical mixtures appreciably affected on flow features of slurries at fixed conditions.

Free Fluid of Oil Well Cement Slurries

Due to complicated conditions downhole, numerous chemicals called additives are required in to design optimal cement to improve needed API features. Additive for liquid loss is required to avoid water movement to or from formation while additive for free water is main ingredient in slurry design to attain zero water at formation temperature [26].
Free water is water which is not needed during hydration process in slurry and occurs when cement flow paused; free water is seen on top of cement column. Slurry comprises cement and water in correct or right ratio or proportion. Fluid separation could occur at top of column or pockets in deviated wells. Such pockets result in leakage of annular gas and other issues associated to annular flow. It is easy to observe that huge quantity of water in deviated well could result in communication points on high side in wellbore. Also, it results in poor cement protection on casing and issues of corrosion with time creating holes in casing.

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Typically, operators give room for little amount of free water used in deep casing or liner work, especially in deviated-wells or where gas section exist. High free water presence is equally seen as indicator for unstable slurry having settling issues whose test is conducted at normal temperature and vertically or angle at downhole conditions. Normally one has free water at high temperatures. Keller, S. R. et al. (1987) confirmed that free water is crucial factor that is low after setting of cement. Yield point, viscosity, liquid loss, gel strength, and time-based settling features of slurry are crucial features as well.

3 MATERIALS AND METHODS

Research Activity

In other to achieve the aim of this research work, the formulated slurry underwent several phases such as design of cement slurry, determination of slurry weights, rheological and stability test at different temperatures and free fluid test. The local cassava starch and cement used for formulation of slurry were obtained from POCEMA laboratory while foreign starch (hydroxyethyl cellulose) and defoamer used were imported. The cement slurries were formulated at varied concentration with the local and imported starch (Tables 1 and 2).

Table 1: Materials used and their weights for the pilot test are as follows:

Additives	Weight (g)
Freshwater	345.21
Starch	Varied
Antifoam	0.63
Cement	773.69

Table 2: Weights of both local and foreign starch by percentage used based on available laboratory design:

Starch Quantity (%)	Weight (g)
0.1	0.77
0.2	1.55
0.3	2.32
0.5	3.85

METHOD

The different stages carried out on formulation of cement slurry; neat cement, cement slurries with local starch and foreign starch sample at varied concentrations as seen in Table 3.1 were prepared based on API standard and procedures. The neat cement (without additive) was taken to be the control (reference point) for the slurries with additives.

All the samples were measured out and weighed with the aid of an electronic weigh balance. For suitable cement slurry formulation (without additive), 773.69g of dry cement was poured out and weighed using electronic-weighing balance provided. 345.21g of water was measured and emptied into mixer cup. For mixing process to commence, mixer cup was installed to Hamilton beach multi mixer, turned on at speed of 4000±200 rpm. Antifoam of 0.63g was added into mixer cup to blend and avoid foaming tendency. Gradually, dry cement was added to this mixer which was then allowed to mix for homogeneity at speed of 12000±500 rpm for about 3 minutes. When cement slurries were set, it was further subjected to rheological, slurry weight, stability and free fluid tests to achieve research aims and objective.

Rheological Test

For rheology test, formulated slurry was poured in rheometer cup to ascertain its rheology. After slurry sample was prepared, the slurry was homogenized at rotation speed of 150 rpm for 20min in atmospheric consistometer. Its temperature was kept constant

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at this condition. The apparatus employed for this test is concentric cylinder commonly employed in oilfield (Fann VG 35A). After homogenization, slurry is position on this test vessel. Torque response for every rotation speed provided by this equipment (300, 200, 100, 6 and 3) rpm and result recorded. At every temperature, slurry was exposed to rheological test and at every rotation speed, dial reading was taken when rotation speed was stabilized.

Rheological values derived from viscometer and derivations such as plastic viscosity and yield point considered as main reason for ascertaining flow features were obtained as shown thus:

Derivation of Plastic Viscosity (PV) and Yield Point (YP)

Plastic viscosity (PV) and yield point (YP) of slurries were calculated using equations (1.1) and (1.2).

$$PV\ (cP) = (\theta_{300} - \theta_{100}) \times 1.5 \quad (1.1)$$

$$YP\ \left(\frac{Ib}{100ft^2}\right) = \theta_{300} - PV \quad (1.2)$$

Where θ = the dial reading

Free Fluid Test

The prepared cement slurry formulation was emptied into clean graduated 250ml cylinder and covered with foil paper to prevent evaporation and was kept aside to stand for 2 hours. Afterwards, volume of water which was settled on top was collected in conical flask and measured and from it, free fluid percentage is determined as shown below:

Calculation of free fluid percent

$$\%FF = \left\{\frac{VFF}{250ml}\right\} \times 100$$

Where:

FF = free fluid content of slurry (%)

VFF =free fluid volume (ml)

Slurry Weight Determination

The cement was emptied into API balance and adjusted to a balanced weight. Reading was taken at a balanced weight in pounds per gallon (ppg).

4 RESULTS AND DISCUSSION

Results

This chapter discusses extensively on the research test results regarding the comparison of the relationship of temperature on each of the different test. Series of tests were conducted to discover the rheological properties, free fluid, stabilities and slurry weights on the cement slurry formulation. The test results for the various cement slurries formulations at varied temperatures and concentrations are displayed below:

Table 3: **Rheological Properties of Neat Cement**

RPM	80°F	120°F	160°F	190°F
Ѳ300	123	120	119	175
Ѳ200	111	102	110	159
Ѳ100	92	87	92	126
Ѳ6	38	27	26	30
Ѳ3	21	17	18	25
PV (cP)	47	50	41	74
YP (lb/ 100ft²)	76	70	78	101

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Density (ppg)	15.0	-	-	-
Free fluid (ml)	0.6	-	-	-
Free fluid (%)	0.24	-	-	-

Table 4: Result of Cement Slurries with 0.1% of Additives

	0.1% POCEMA STARCH				**0.1% FOREIGN STARCH**			
RPM	**80°F**	**120°F**	**160°F**	**190°F**	**80°F**	**120°F**	**160°F**	**190°F**
ϴ300	134	134	137	138	150	147	149	146
ϴ200	124	122	123	123	134	130	132	131
ϴ100	109	108	110	111	115	112	114	112
ϴ6	38	38	34	32	37	36	26	28
ϴ3	23	22	23	26	22	19	19	16
PV (cP)	38	39	41	41	53	53	53	51
YP (lb/100ft^2)	96	95	96	97	97	94	96	95
Density (ppg)	15.1	-	-	-	15.1	-	-	-
Free fluid (ml)	0	-	-	-	0.51	-	-	-
Free fluid (%)	0	-	-	-	0.204	-	-	-

Table 5: Result of Cement Slurries with 0.2% of Additives

	0.2% POCEMA STARCH				**0.2% FOREIGN STARCH**			
RPM	**80°F**	**120°F**	**160°F**	**190°F**	**80°F**	**120°F**	**160°F**	**190°F**
ϴ300	113	122	126	126	126	162	155	148
ϴ200	104	110	110	112	152	144	140	136
ϴ100	84	91	98	96	131	125	121	120
ϴ6	29	26	27	26	43	35	30	29
ϴ3	20	20	18	17	26	27	24	25
PV (cP)	44	47	50	45	47	56	51	42
YP (lb/100ft^2)	69	75	76	81	115	106	104	106

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Density (ppg)	15.1	-	-	-	15.1	-	-	-
Free fluid (ml)	0	-	-	-	0.51	-	-	-
Free fluid (%)	0	-	-	-	0.204	-	-	-

Table 6: Result of Cement Slurries with 0.3% of Additives

	0.3% POCEMA STARCH				**0.3% FOREIGN STARCH**			
RPM	**80°F**	**120°F**	**160°F**	**190°F**	**80°F**	**120°F**	**160°F**	**190°F**
ϴ300	130	144	136	147	225	195	185	212
ϴ200	117	123	119	142	210	180	175	202
ϴ100	95	100	100	115	189	163	158	171
ϴ6	25	24	24	29	48	42	39	47
ϴ3	19	17	17	24	43	37	30	45
PV (cP)	53	54	54	48	54	48	41	62
YP (lb/100ft^2)	77	82	82	99	171	147	144	150
Density (ppg)	15.2	-	-	-	15.2	-	-	-
Free fluid (ml)	0	-	-	-	0.70	-	-	-
Free fluid (%)	0	-	-	-	0.28	-	-	-

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Table 7: **Result of Cement Slurries with 0.5% of Additives**

	0.5% POCEMA STARCH				0.5% FOREIGN STARCH			
RPM	**80°F**	**120°F**	**160°F**	**190°F**	**80°F**	**120°F**	**160°F**	**190°F**
Ɵ300	120	128	137	144	187	143	161	191
Ɵ200	112	114	121	128	162	130	144	176
Ɵ100	90	91	100	106	135	112	120	130
Ɵ6	28	27	26	26	38	33	33	39
Ɵ3	18	16	16	16	31	27	27	37
PV (cP)	47	56	56	54	78	47	62	92
YP (lb/100ft^2)	75	72	81	90	109	96	99	99
Density (ppg)	15.2	-	-	-	15.2	-	-	-
Free fluid (ml)	0	-	-	-	0.98	-	-	-
Free fluid (%)	0	-	-	-	0.392	-	-	-

Graphical Representation and Interpretation of Laboratory Test Results

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Shear Stress and Shear rate Graph

The result showing the relation between the shear stress and shear rate for different concentration of cement slurry is presented from Figure 2 to 6. Figure 2 shows the shear stress and shear strain relationship of the cement slurry when no additive was added. From Figure 2, it can be observed that the shear stress increased the shear rate also increased in a non-linear manner. The result from the shear stress and shear rate graph shows that cement slurries is not a Newtonian fluid and it is better defined with a Bingham plastic model or a power model.

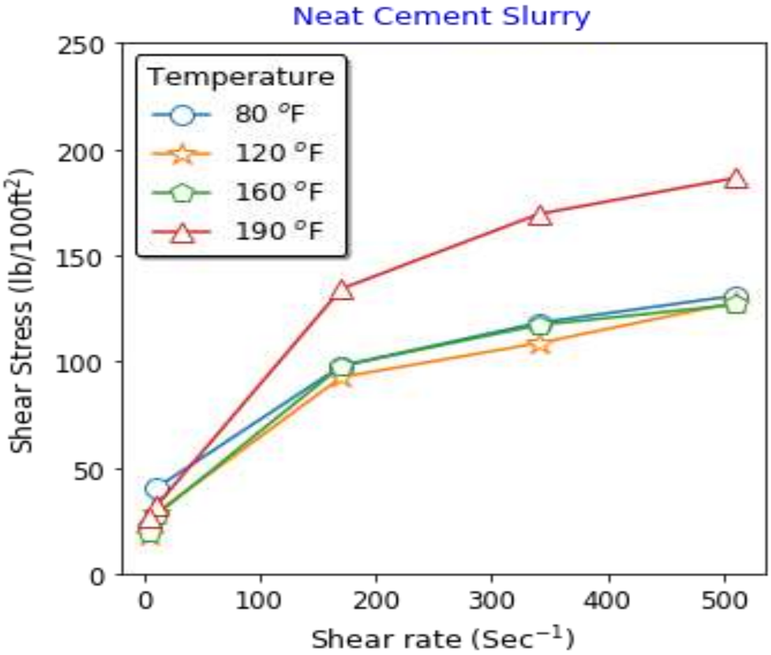

Figure 2: Graph of shear stress against shear rate for neat cement slurry at different temperature

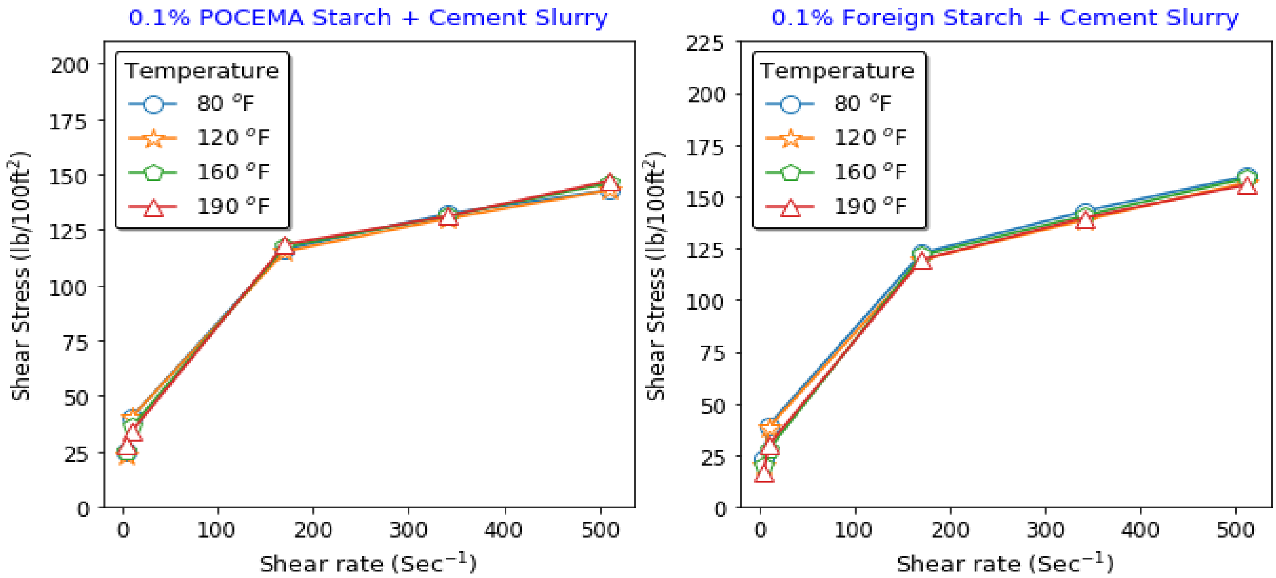

Figure 3: Graph of shear stress against shear rate for 0.1% starch with cement slurry at different temperature

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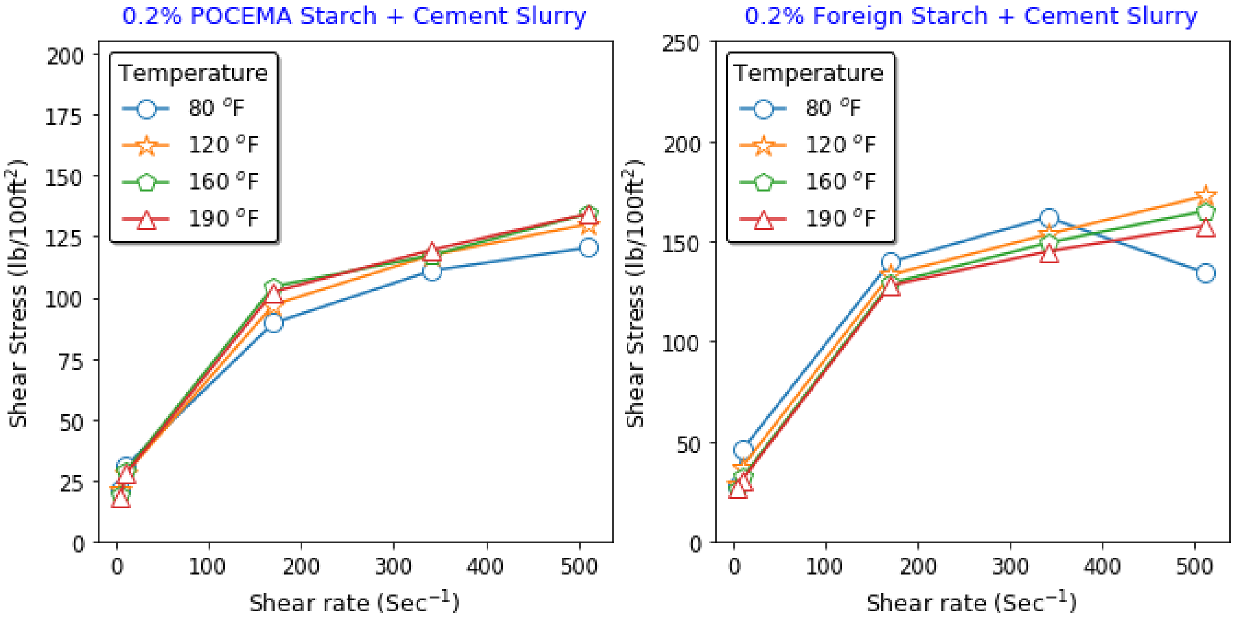

Figure 4: Graph of shear stress against shear rate for 0.2% starch with cement slurry at different temperature

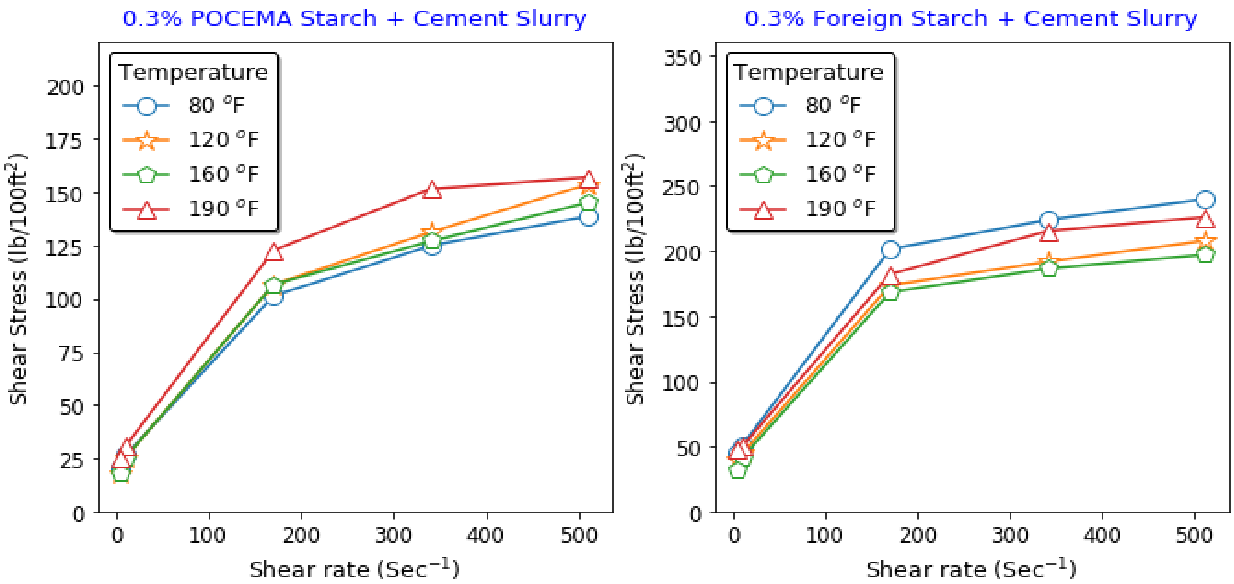

Figure 5: Graph of shear stress against shear rate for 0.3% starch with cement slurry at different temperature

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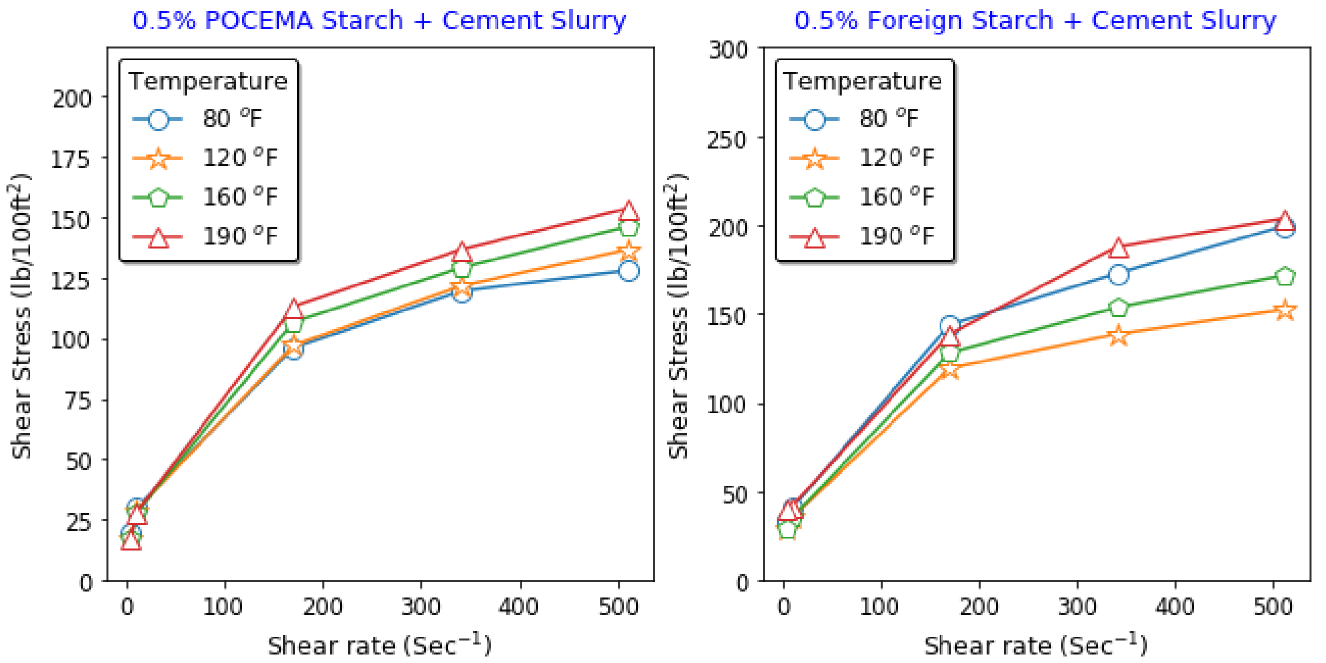

Figure 6: Graph of shear stress against shear rate for 0.5% starch with cement slurry at different temperature

Plastic Viscosity against Temperature

The effect of temperature on the plastic viscosity when starch is added to the cement slurry showed that as the temperature increases the plastic viscosity of the cement slurry tend to increase also. It was observed that when the starch concentration was 0.3% and 0.5%, the plastic viscosity first reduced till when the temperature was about 160°F and 120°F before starting to increase at higher temperature (Figs. 7 – 11).

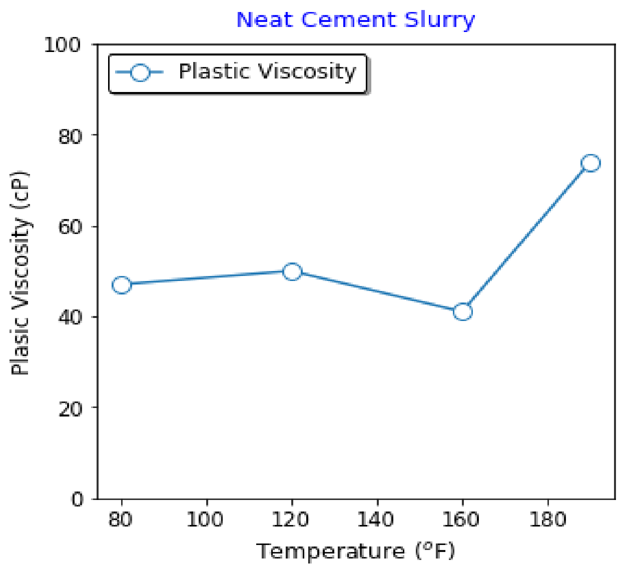

Figure 7: Graph of Plastic Viscosity against Temperature for neat cement slurry

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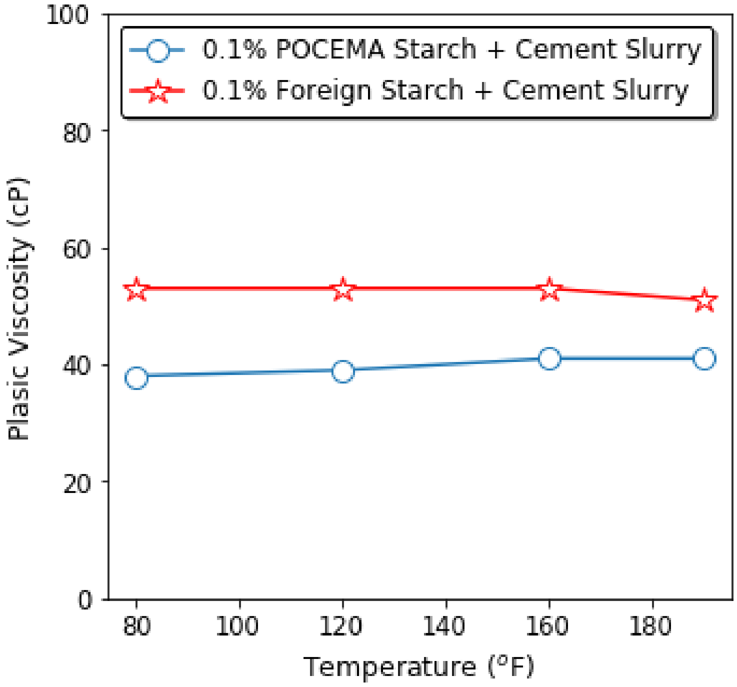

Figure 8: Comparism graph of Plastic Viscosity for POCEMA starch against Foreign Starch at 0.1% Starch Concentration with Cement slurry

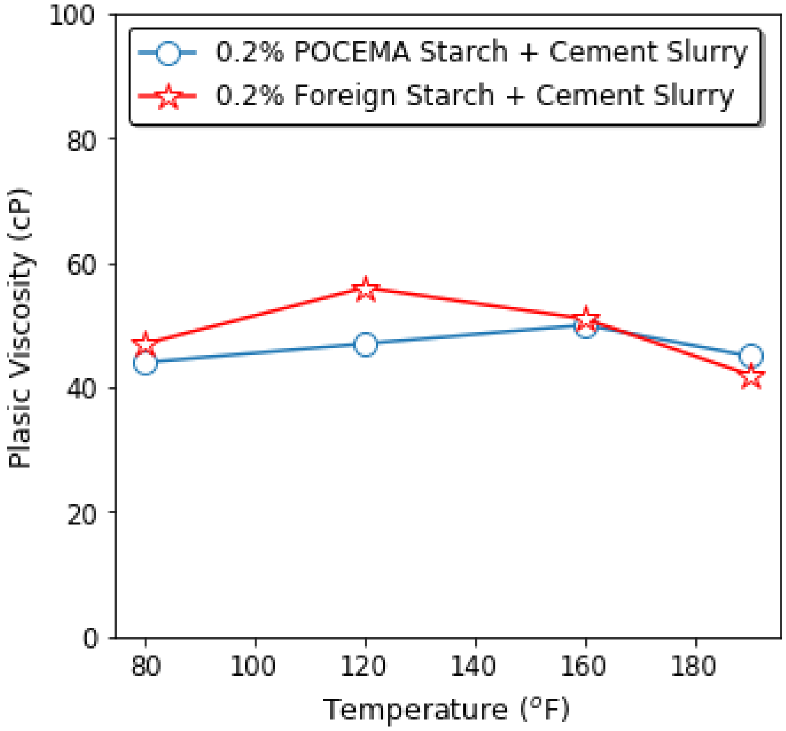

Figure 9: Comparism graph of Plastic Viscosity for POCEMA starch against Foreign Starch at 0.2% Starch Concentration with Cement slurry

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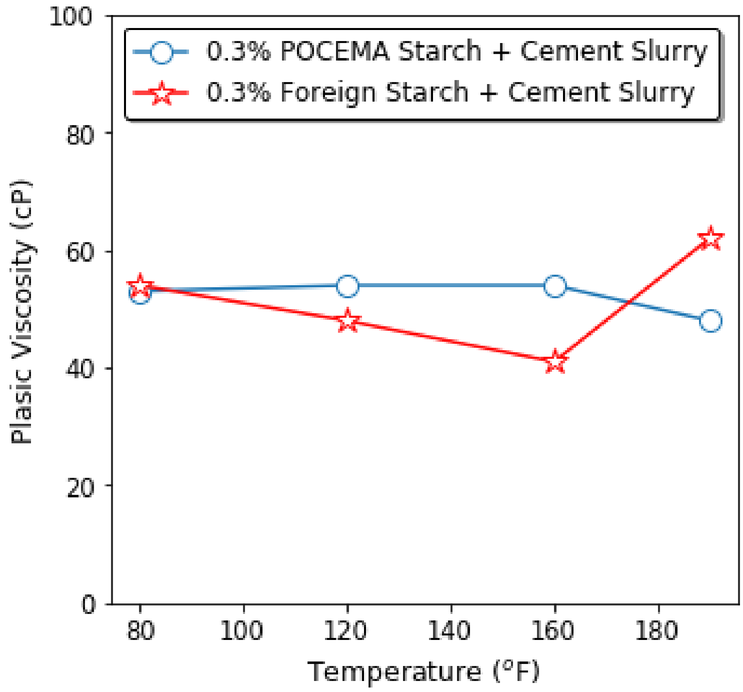

Figure 10: Comparism graph of Plastic Viscosity for POCEMA starch against Foreign Starch at 0.3% Starch Concentration with Cement slurry

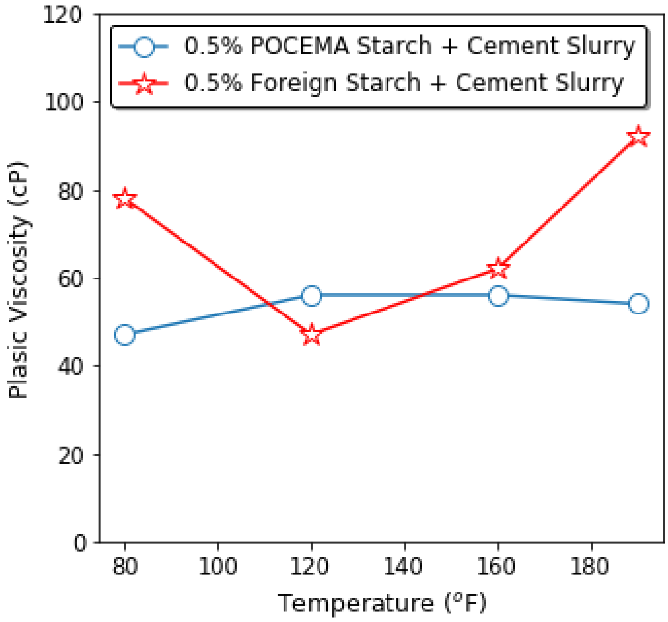

Figure 11: Comparism graph of Plastic Viscosity for POCEMA starch against Foreign Starch at 0.5% Starch Concentration with Cement slurry

The Effect of Starch Concentration on the Plastic Viscosity for POCEMA and Foreign Starch

The result of the effect on of starch concentration on cement slurry is presented in Figure 12. From Figure 12, it was observed that as the concentration of local starch increased the plastic viscosity of the cement slurry also increased. This was in line with literatures, as it is reported that fluid loss additive (starch) are intended to reduce the fluid loss and increase the viscosity of cement slurry. The foreign gave almost similar pattern but the pattern was not well defined.

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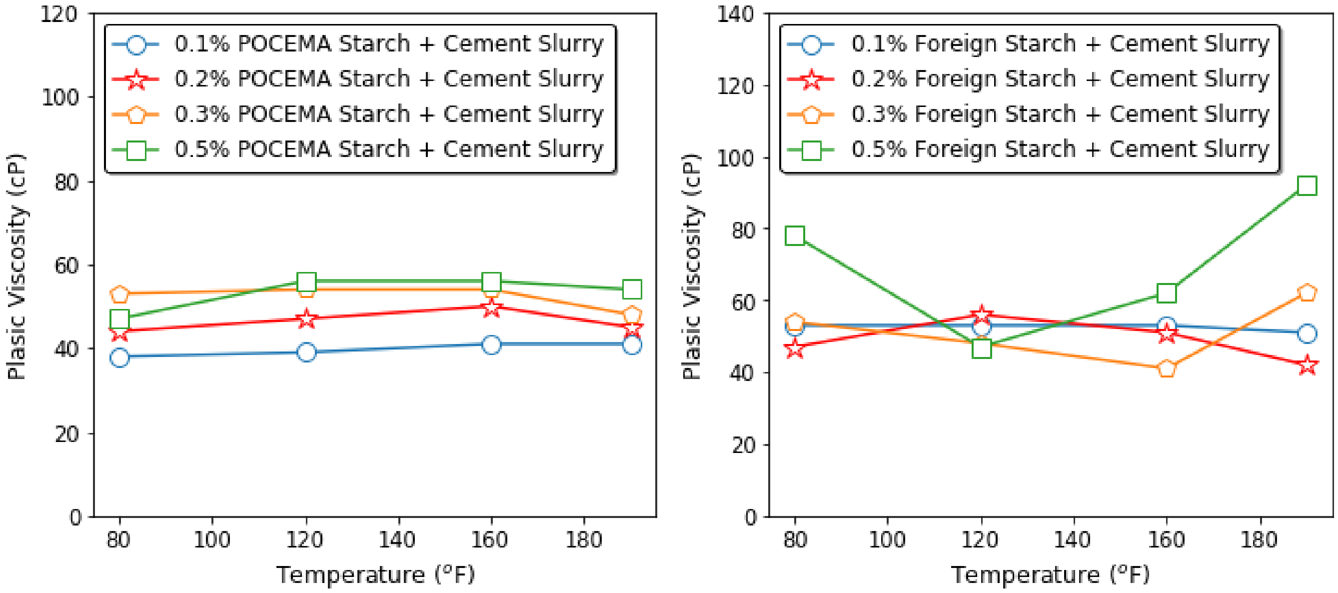

Figure 12: The effect of starch concentration on the plastic viscosity for POCEMA and Foreign Starch

Yield Point against Temperature

The result of the effect of temperature on the yield point of the cement slurry is presented from Figure 13 to figure 17. It was observed that the yield point of the cement slurry generally tends to increase with temperature increase for both when foreign and local starch was added to the cement slurry. The increase in the yield point was steeper in the local starch than the foreign starch. Ndubuisi (2020), in her study also reported similar finding for the effect of temperature on cement slurry when fluid loss additive is added to cement slurry.

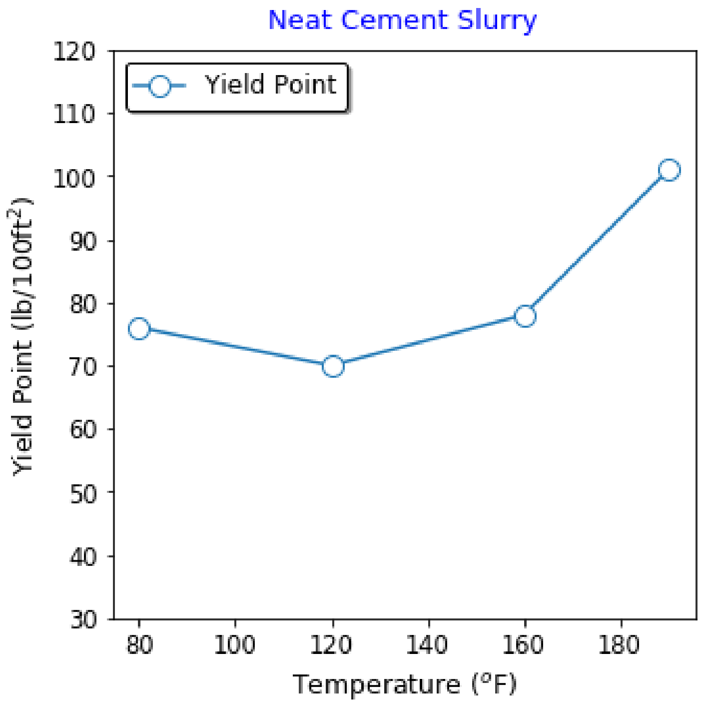

Figure 13: Graph of Yield Point against Temperature for neat cement slurry

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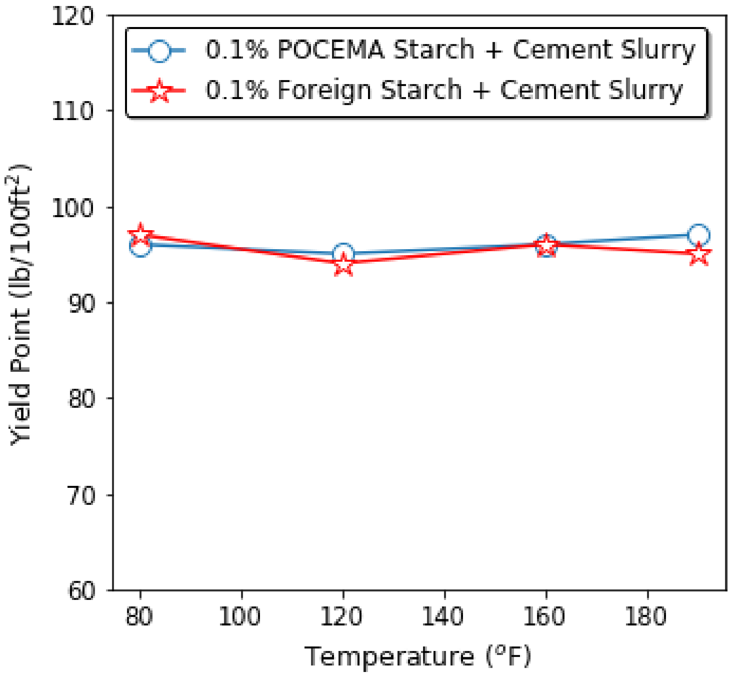

Figure 14: Comparism graph of Yield Point for POCEMA starch against Foreign Starch at 0.1% Starch Concentration with Cement slurry

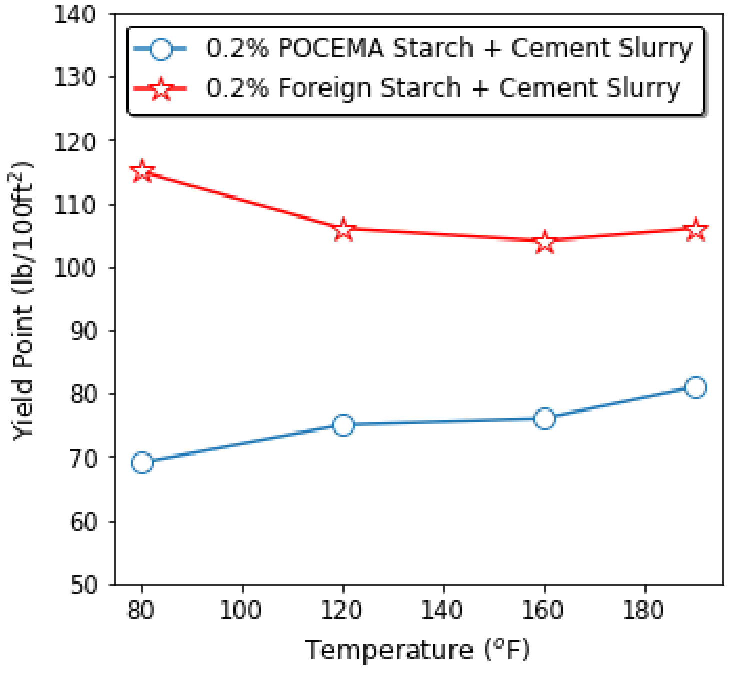

Figure 15: Comparism graph of Yield Point for POCEMA starch against Foreign Starch at 0.2% Starch Concentration with Cement slurry

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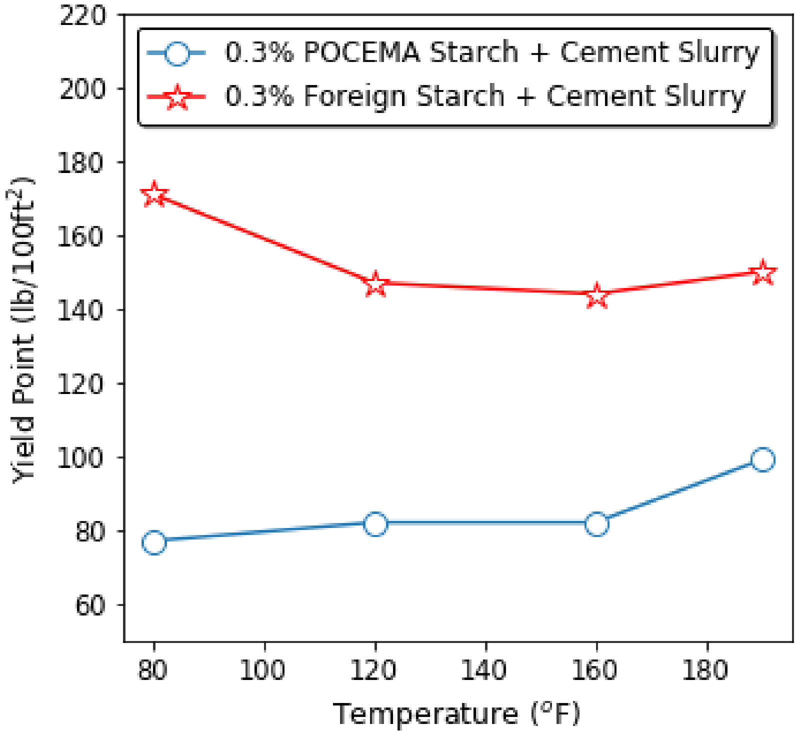

Figure 16: Comparism graph of Yield Point for POCEMA starch against Foreign Starch at 0.3% Starch Concentration with Cement slurry

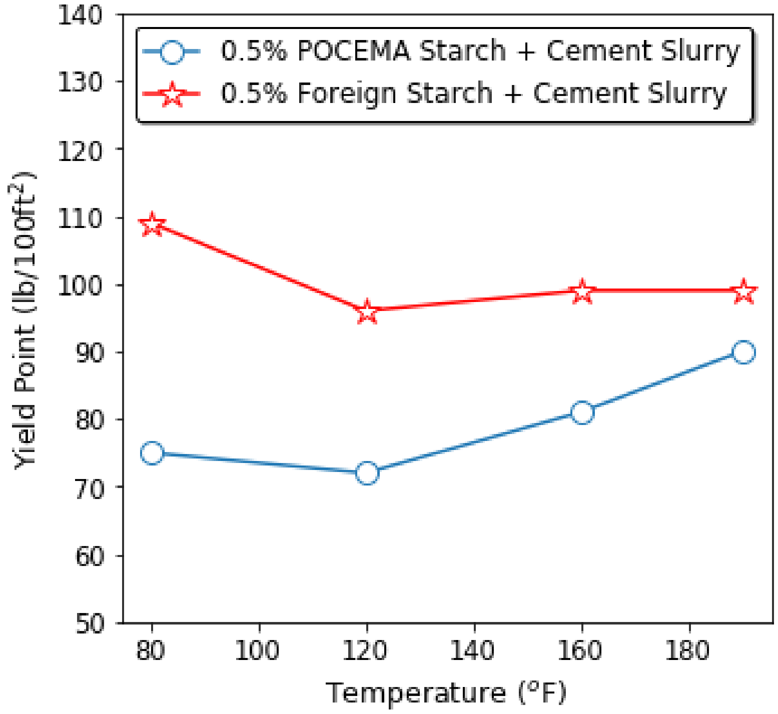

Figure 17: Comparison graph of Yield Point for POCEMA starch against Foreign Starch at 0.5% Starch Concentration with Cement slurry

The Effect of Starch Concentration on the Yield Point for POCEMA and Foreign Starch

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The effect of starch concentration on the cement slurry is presented in Figure 18. From Figure 18, it was observed that as the concentration of the local starch started to increase the yield point of the cement slurry started to reduce. For the foreign starch, the yield point was highest when the concentration of the starch was 0.3%, it was observed that the yield point was the lowest when the concentration of the starch was 0.1%

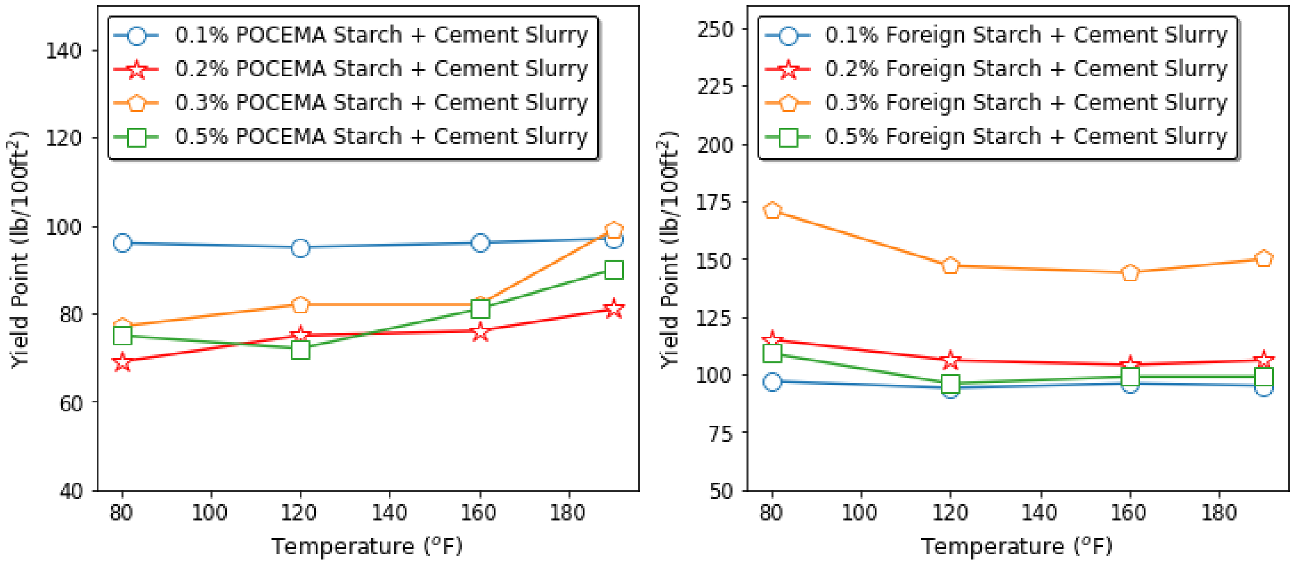

Figure 18: The effect of starch concentration on the yield point for POCEMA and Foreign Starch

Analysis of Variance

The result of the Analysis of Variance is presented in Table 8 to 10. The result of ANOVA for plastic viscosity and yield point for when starch concentration of 0.1% is added to the cement slurry is presented in Table 8. It can be observed that the neat cement slurry had a mean yield point of 81.25±13.66 lb/100ft^2, while cement slurry with 0.1% foreign starch concentration had mean yield point of 95.50±1.29 lb/100ft^2. The mean yield point was highest in the local starch with 0.1% concentration. This showed that the local starch tend to increase the plastic viscosity better than the foreign starch. The result from the ANOVA show that there was no significance difference between the foreign starch and the local starch.

The mean plastic viscosity for the neat cement slurry was 53.00±14.49cP, the mean plastic viscosity for cement slurry with 0.1% local starch was 39.75±1.50cP and the mean plastic viscosity for cement slurry with 0.1%foreign starch was 52.5±1.0cP. The foreign starch tends to give a higher plastic viscosity than the local starch. The result from ANOVA showed that there was no significance difference between the import starch and the local starch.

Table 8: ANOVA for Plastic Viscosity and Yield Point at 0.1% starch

Cement Slurry	Yield Point	Plastic Viscosity
Neat	81.25±13.60[a]	53.00±14.49[a]
Cement slurry + 0.1% POCEMA Starch	96.00±0.82[a]	39.75±1.50[a]
Cement slurry + 0.1% Foreign Starch	95.50±1.29[a]	52.5±1.0[a]

ANOVA for Plastic Viscosity and Yield Point at 0.2% starch

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The result of when 0.2% starch is added to the cement slurry is presented in Table 4.7. From Table 4.7, the mean yield point recorded in foreign starch was higher than the mean yield point recorded in the local starch. The result from the ANOVA showed that there was significance difference between the foreign starch and the local starch, as the foreign starch gave yield point of cement slurry that is significantly higher than the local starch. For the plastic viscosity for when 0.2% starch concentration was added to the cement slurry, there was no significance difference between the local and foreign starch.

Table 9: ANOVA for Plastic Viscosity and Yield Point at 0.2% starch

Cement Slurry	Yield Point	Plastic Viscosity
Neat	81.25 ± 13.60^{b}	53.00 ± 14.49^{a}
Cement slurry + 0.2% POCEMA Starch	75.25 ± 4.92^{b}	46.50 ± 2.65^{a}
Cement slurry + 0.2% Foreign Starch	107.75 ± 4.92^{a}	49.00 ± 5.94^{a}

ANOVA for Plastic Viscosity and Yield Point at 0.3% starch

Table 4.8 shows the result when 0.3% starch concentration was added to the cement slurry. From Table 4.8, the mean yield point for the foreign starch was higher than the mean yield point of the local starch. The result from the ANOVA showed that there was significance difference between the local starch and the foreign starch. The foreign starch tends to give yield point that is significantly higher than the local starch. For the plastic viscosity there was no significance difference between the local and foreign starch.

Table 10: ANOVA for Plastic Viscosity and Yield Point at 0.3% starch

Cement Slurry	Yield Point	Plastic Viscosity
Neat	81.25 ± 13.60^{b}	53.00 ± 14.49^{a}
Cement slurry + 0.3% POCEMA Starch	85.00 ± 9.63^{b}	52.25 ± 2.87^{a}
Cement slurry + 0.3% Foreign Starch	153.00 ± 12.25^{a}	51.25 ± 8.92^{a}

ANOVA for Plastic Viscosity and Yield Point at 0.5% starch

The result when 0.5% of starch concentration is added to the cement slurry is presented in Table 4.9. It can be observed that the mean yield point of the foreign starch was higher than that of the local starch. Result from the ANOVA showed that they were significant difference in the yield point between the foreign starch with cement slurry and the local starch with cement slurry. For the plastic viscosity, there was no significance difference between the foreign and local starch.

Table 11: ANOVA for Plastic Viscosity and Yield Point at 0.5% starch

Cement Slurry	Yield Point	Plastic Viscosity
Neat	81.25 ± 13.60^{b}	53.00 ± 14.49^{a}
Cement slurry + 0.5% POCEMA Starch	79.50 ± 7.94^{b}	53.25 ± 4.272^{a}
Cement slurry + 0.5% Foreign Starch	100.75 ± 5.68^{a}	69.75 ± 19.50^{a}

The result from the ANOVA showed that at lower concentration the local starch performed as well as the foreign starch but as the concentration increased beyond 0.1% of starch concentration the foreign starch was significantly different from the local starch.

5 DISCUSSION

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This segment discusses extensively on the outcome of the research finding of this project work.

Rheological Properties of Neat Cement at Varied Temperatures

Deductions made from Table 4.1 on the rheology of neat cement came up with the following observations. It was seen that the initial reading at ϴ300 rpm was 123 for 80°F, then there was an abrupt decrease of value with an increase in temperature from 120°F to 160°F. At 190°F, there was an increase in value. Similar trend followed for the rest of the RPM at ϴ200, ϴ100, ϴ6 and ϴ3. They followed the same trend with an initial increase in value then decrease at 120°F to 160°F temperature and then finally increase in value.

Effect of Temperature on Neat Cement Slurry

The rheology of neat cement was seen increasing with an increase in temperature. Perhaps this is as a result of fluid loss due to dehydration from the slurry as temperature increases. With increase in temperature, the cement slurry tends to lose its water of hydration which in turn leads to increase in viscosity. Therefore, we can say that the rheology of neat cement increased with an increase in temperature.

Effect of Free Fluid on Neat Cement Slurry

For neat cement slurry, there was observed to be free fluid reading of 0.6ml. This is as a result of no fluid loss additive was added to the slurry.

Effect of Yield Point (YP) and Plastic Viscosity (PV) on neat cement slurry.

The result of Plastic viscosity and Yield Point when derived from equation 3.0 and 3.1 were seen on Table 4.1 to increase as temperature increased.

Rheological Properties for POCEMA Starch and Foreign Starch Sample At 0.1% Concentration with Varied Temperatures

For local cassava starch;

At 0.1% concentration of local starch on Table 4.2, the trend seen here was an increase in the rheological properties with increase in temperature. From 80°F with 134 as the value recorded for ϴ300 as initial reading as temperature increased, the value increased progressively to 138 at 190°F. At ϴ200 reading, the initial value was 124 at 80°Fthen began a progressive decrease to 123 at 190°F. Same trend followed for the rest of the RPM reading. It can be deduced that there was instability for POCEMA starch as there was seen to be a continuous increase and decrease as temperature increased.

- For plastic viscosity and yield point of local starch, there was seen to be a progressive increase with increase in temperature.
- For free fluid of local starch, there was seen to be 0 free fluid.
- The density recoded was 15.1 ppg.

For foreign starch;

At 0.1% of concentration of foreign starch sample, it showed a trend of decrease in rheology with an increase in temperature. At ϴ300 rpm with temperature of 80°F, the initial reading was 150 rpm and then it gradually decreased to 146 at 190°F. Similar trend follows for ϴ200, ϴ100, ϴ6 and ϴ3 rpm. It is seen to begin with an initial high value then decreases with an increase in temperature.

- For plastic viscosity and yield point there was seen to be a decrease with increase in temperature. This is in line with the principle of rheology which says rheology of a given material decreases with an increase in temperature.
- The free fluid of foreign starch was recorded as 0.51ml and the percentage of free fluid was calculated as 0.204 at initial temperature.
- The slurry weight recorded was 15.1 ppg. This is to say there was no significant difference for slurry weights for both local and foreign starch.

Rheological Properties for POCEMA Starch and Foreign Starch At 0.2% Concentration with Varied Temperatures

For Local Starch;

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For local cassava starch at 80°F, there was an initial reading of 113 and then it progressively increased with an increasing temperature to 126. Same trend followed for ϴ200 to ϴ100 with a decreased value then progressively increase with an increase in temperature. ϴ6 and ϴ3 had initial increased reading then progressively decreased with increase in temperature.

- For plastic viscosity and yield point, there was seen to be an increase in rheology with increase in temperature.
- The slurry weight was recorded as 15.1 ppg.
- For free fluid, it was seen to be 0 free fluid

For Foreign Starch;

The initial reading was 126 at 80°F then at 120°F to 160°F there was a notable increase in value. At 190°F, 148 was recorded. Same trend followed with initial reading being the highest as it progressively decreases with an increase in temperature.

- For plastic viscosity and yield point, it was observed to be a decrease in the trend of rheology with an increased temperature.
- The slurry weight was recorded as 15.1 ppg.
- For free fluid, 0.51ml was recoded.

Rheological Properties of POCEMA starch and foreign starch sample at 0.3% Concentration of starch with Varied Temperatures

At 80°F the initial reading was recorded as 130 at ϴ300 but began an increase in value with an increase in temperature. At 190°F, the reading was 147. The trend followed for ϴ200, ϴ100, ϴ6 and ϴ3 showing an increase of rheology with increase in temperature.

- For plastic viscosity, there was an initial increase at room temperature of 80°F then increased furthermore with increasing temperature 120°F to 160°F. Then a decrease occurred at 190°F.
- For yield point, then value increased from 77 to 99 with an increasing temperature. The slurry weight was recorded to be 15.2 ppg.
- There was 0 free fluid observed.

For Foreign starch;

At initial reading 80°F, 225 was recorded but as temperature increased, there was a decrease in rheology with increase in temperature. Similar trend followed for ϴ200, ϴ100, ϴ6 until it came to ϴ3 where the initial value at 80°F was 43 then began to progressively decrease with increasing temperature. At 190°F the value increased to 45.

- For plastic viscosity, there was an initial reading of 54 which later decreased with increasing temperature then finally increased at 190°F.
- For yield point, there was a notable decrease with increase in temperature. We can say that there was a distortion in values.
- The slurry weight recorded was 15.2 ppg
- Free fluid recorded was 0.70ml

Rheological properties of POCEMA starch and foreign starch sample at 0.5% Concentration with Varied Temperatures

At ϴ300, the initial reading was 120 then it began to increase with increase in temperature. This followed for the corresponding dial readings with initial high values then begins to decrease with an increase in temperature. For dial reading of ϴ6 and ϴ3, it was observed that with increase in temperature, the value decreased.

- For plastic viscosity and yield point, the values tend to increase with increase in temperature.
- The slurry weight recorded was 15.2 ppg.
- There was 0 free fluid observed

For Foreign starch;

At ϴ300, ϴ200, ϴ6 and ϴ3, there was seen to be a notable increase as temperature increased. But for ϴ100, the reverse was the case. This is as a result of distortion in the value.

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- For plastic viscosity, it was seen to increase at initial reading followed by a decrease and then increase again with increasing temperature.
- For yield point, there was a decrease with an increasing temperature.
- The slurry weight was recorded as 15.2 ppg.
- 0.98ml was recorded as the value for free fluid.

Comparison of POCEMA Starch with Foreign Starch Sample from the Results Obtained

In terms of rheological properties;

Ordinarily, the rheology of any given material decreases with an increase in temperature. This was seen in the case of foreign starch whereas the local starch proved otherwise but for the rheology of plastic viscosity, since field practice indicates that the best cement slurry plastic viscosity should be less than 100 cp and all the values recorded for both local and foreign starch was less than 100 cp, hence, it implies that local cassava starch could be recommended as a viscosifier in cementing operations as high value of plastic viscosity will create problems in pumping down cement slurry.

For yield point, there was a corresponding increase in the yield points with increase in temperature for local cassava starch. This is to say that temperature affects the rheological properties of cement slurry which is in line with the postulations of historical literature which states that the higher the temperature, the greater the yield point of the cement slurry. This was seen to be the case of local cassava starch while the foreign starch proved otherwise.

In terms of slurry weights;

The densities of all the slurries were stable and not widely affected by concentration. The density of neat cement slurry which was the control for the local and foreign starch weighed 15.0 ppg. 0.1% and 0.2% concentration recorded 15.1 ppg while 0.3 and 0.5% recorded 15.2 ppg. Therefore, it is seen that the densities of the slurry weights increases uniformly with increase in the concentration of starch additives that is to say. Increase in the concentration of starch additive leads to an increase in the weight of cement slurry.

In terms of free fluid;

Zero free fluid is usually recommended for field practice in accordance with API – RP 10B – 2, 2009. Zero free fluid was observed for all the various concentrations of local cassava starch. This implies that local cassava starch has the capability of controlling free fluid in cement slurry. The foreign starch recorded free fluid.

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