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Investigating the Properties of Tympanostomus Fuscatus (Periwinkle) Shell Powder in High Temperature Oil and Gas Well Cementing Operations

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ABSTRACT

This study investigates the properties of Tympanostomus fuscatus (periwinkle) shell in HPHT oil and gas cementing operations. Tympanostomus fuscatus shell powder was tested in the laboratory for its potential use in well cementing operations. The shell was calcinated, pulverized and subjected to laboratory test following the API RP 10B for oilfield cement testing, with a cement slurry density of 15ppg at concentrations of 25%BWOC and 35%BWOC of periwinkle shell powder, with test temperatures of 2000C and 2500C. Characterization such as rheology, XRD, API fluid loss, compressive strength, equivalent circulating density was conducted on the sample. The results showed that the periwinkle shell contained Al_2O_3, CaO and SiO_2, which is the element predominant to prevent the strength retrogression of cement contraction. Tympanostomus fuscatus shell powder gave similar results with the silica flour based on its rheological properties, ECD, annular pressure loss. Tympanostomus fuscatus shell powder out performs silica flour based on the cement strength retrogression in all concentrations, temperatures and curing times. The Tympanostomus fuscatus shell powder is environmentally friendly as it naturally occurring and derived from edible substance. Tympanostomus fuscatus shell powder is a potential substitute for silica flour as additive and excellent properties for cement strength retrogression and cement contraction and showed no negative effect on the rheological properties of the cement slurry.

Keywords: High-Temperature; Cement slurry; Compressive strength; Tympanostomus fuscatus; Rheological Properties

Introduction

Oil well cement is a special type of cement known as Portland cement[1]. Cement is used in oil wells for a variety of reasons[2]. The main purpose of oil well cement is to provide a continuous impermeable hydraulic seal in the annulus which provides zone isolation in the wellbore thus excluding the migration of wellbore fluids (such as oil, water and gas) across zones. Furthermore, the hydraulic seal provides seal-off to loss circulation zones and also shuts off water production zones[3]. Aside from the sealing properties, oil well cement is used to provide structural integrity to the well and plug off the existing well in the case of abandonment during the drilling of directional wells. Cementing also protects the casing from collapse under pressure and against corrosion[4].

The design of cement slurries for a particular well is perhaps the most important aspect of the oil well-cementing process. In the design stage, accurate characterization of the rheology of the cement slurry is critical[5]. Many factors affect the rheology of cement slurries. They include the type of cement (this includes, the size and shape of the cement grains, its chemical composition and the relative distribution of its components at the surface of the slurry), the water/cement ratio, the chemical additives used (this includes the concentrations, quality and quantity of the additives), interaction between cement and chemical additives, the temperature and pressure, mixing and testing procedure and settling time[6].

Shahriar & Nehdi, noted the concentration of the chemical additives and the temperature and pressure of the well played the most profound roles in the rheology and mechanical properties of the cement slurry[6]. They further stated that chemical additives control the rheology of the cement slurry and its early mechanical properties. Cement slurries prepared with different additives types and concentrations using the same type of cement can exhibit large variations in flow and this variation becomes more profound when temperatures and pressures are elevated. Ma & Kawashima, observed that high temperature also reduces the thickening time of the cement thus making the cement sheath set quicker than normal[7]. Zhang, et al, reported that rheological properties of the cement slurry are affected by temperature, yield viscosity and plastic viscosity declines with an increase in high temperature[8]. They further noted that the bottom-hole circulating temperature (the temperature at which the cement slurry is pumped into the wellbore) decreases with an increase in pressure[9]. Therefore, the focus of this study is to investigate the properties of the of Tympanostomus Fuscatus (Periwinkle) shell powder in high pressure high temperature oil and gas well cementing operations.

Materials and Methods

Collection of the sample

The periwinkle shell which is used as the local material was sourced at Ihiagwa market, Owerri as showed in **(Figure 1)**. The periwinkle shell was obtained with its edible part excluded. The periwinkle shell was washed with distilled water removing extraneous particles that adhered to it. The washing was done using distilled water and then poured the periwinkle shell into it to ensure that the water covered the PSP well. The periwinkle shell was agitated to remove impurities. It was sundried and crushed into smaller particles and then sieve it to obtain the powdered form.

Preparation of the cement slurry with silica flour

Cement slurry was prepared with silica flour as cement retrogression additive by adding 25%, 30%, 35% and 40% concentrations (BWOC) as shown in **(Table 1)**.

Table 1: Cement Slurry Additives with Silica Flour.

Additives	Batch No.	Gms	Mils	Concentration	Function
G-CMT	601289	566.73	180.49	-	Cement
ASP-742	002/20WE27No-20	0.64	0.7	0.014gal/sk	Defoamer
WE-UDS	HC05DP22	4.53	2.87	0.8%BWOC	Dispersant
MD-21S	MM02K-01S398	3	2.44	0.5287%BWOC	Retarder
WFL05	2250560	19.69	17.58	0.35gal/sk	Fluid Loss Control
MICROBLOK	142017-000490	58.01	41.43	0.825gal/sk	Gas Check
WE-BON01	IITS101213RW	28.12	20.09	0.4gal/sk	Bonding Agent
WE-SF4	NIL20/06/2022	198.36	75.42	25%, 30%, 35%, 40%, BWOC	Strength Retrogression
FRESH WATER		258.98	258.98	5.157gal/sk	Mix Water
MIX FLUID REQUIREMENT		372.97	344.09	6.851gal/sk	Mix Fluid

Figure 1: Periwinkle shells (Tympanostomus Fuscatus).

Cement slurry with Periwinkle shell powder (PSP): Cement slurry was prepared with periwinkle shell powder as cement retrogression additive by adding 25%, 30% and 35% concentrations (BWOC). More so, different cement slurry formulations were prepared for PSP additive by adding respectively, the following concentrations of PSP to the cement slurry: 25%BWOC WE-PSP, 30%BWOC WE-PSP, 35%BWOC WE-SF and 40%BWOC WE-PSP. The cement slurry was then prepared by adding the cement additive mix into measured volume (250ml) of distilled water to form the test cement slurry as showed in **(Table 2)**.

Characterization of the periwinkle shell powder

The physical and compositional analyses of the PSP were done to determine the elemental and oxides characterization analyses of the PSP. Elemental and oxides characterization analysis of the periwinkle shells were carried out using X-ray diffraction (XRD) and X-ray fluorescence (XRF). The XRD measures the oxide characterization, while the XRF measured the elemental composition of the sample.

XRD procedure: X-ray diffraction provides detailed information on the chemical composition and physical properties of the test sample based on constructive interference of monochromatic X-rays on a crystalline sample. The XRD analysis was conducted by powering the XRD device and setting the voltage and current of the panel to 45kV and 40 mA, respectively. Furthermore, the temperature was set at 21 ±2°C. This was followed by switching the computer system on and double clicking the XRD software to initiate running. All the required settings of the power and temperature were double-checked to correspond to that of the XRD by clicking the settings dialogue. PSP sample was poured into the sample holder and then appropriately placed into the sample chamber column. The chamber door was then closed and was verified from the computer for appropriate closure. The measurement setting was then set for scan axis as Gonio. The start and end positions were set also including the angle and scan time. The scan was then commenced and ended at the required time and the results were saved to a file.

Table 2: Cement slurry additives with Periwinkle shells (Tympanostomus Fuscatus).

ADDITIVES	BATCH NO	GMS	MLS	CONC.	FUNCTION
G CMT	601289	566.73	180.49		Cement
ASP-742	002/20WE27No-20	0.64	0.7	0.014gal/sk	Defoamer
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MICROBLOK	142017-000490	58.01	41.43	0.825gal/sk	Gas Check
WE-BON01	IITS101213RW	28.12	20.09	0.4gal/sk	Bonding Agent
PSP	PSP20/06/2022			25%, 30%, 35%, 40%, BWOC	Strength Retrogression
FRESH WATER		258.98	258.98	5.157gal/sk	Mix Water
MIX FLUID REQUIREMENT		372.97	344.09	6.851gal/sk	Mix Fluid

XRF procedure: X-ray fluorescence provides information about the elemental composition of the crystalline sample. XRF determines the chemistry of the sample by measuring the fluorescent x-ray emitted from the sample when excited by an x-ray. The PSP sample was poured into the sample holder which was placed into the sample chamber column. The chamber was closed. The elemental compositions of the material were shown in a computer attached to the machine. Same procedures were followed for the synthetic sample.

Rheology test

The rheology test was done to determine the rheological properties of the cement slurry for the silica flour additive and for the periwinkle shell powder additive. The rheology test for all cement slurry composition was carried at a temperature of 250oF for different RPMs including 300RPM, 200RPM, 100RPM, 60RPM, 30RPM, 6RPM and 3RPM. The rheology test was conducted both for the cement slurry prepared with silica flour (SF) and with periwinkle shell powder (PSP) using Fann Model 35-viscometer.

API fluid loss test

The conditioned cement slurry was poured into a 250 ml measuring cylinder and allowed to stand for 2 hours. Free water started to come out of the mixture with time. After 2 hours the amount of free water deposited at the top of the cement slurry was decanted and measured. The results were taken and recorded. The procedure was repeated for all concentrations of silica flour and PSP cement slurry preparations.

Thickening time test

The thickening time relates to the pumpability of the cement. It refers to the duration that cement slurry remains in a fluid state to be capable of being pumped. After the thickening time, the consistency of the cement slurry becomes so high that it is considered unpumpable. The thickening time is determined using pressurized HPHT consistometer. For the thickening time test, the slurry container was filled with the test slurry and placed on the drive Table in the pressure vessel and then rotated. The potentiometer was secured and monitored while rotating to ensure consistency. The thickening time test was initiated by applying the initial pressure and starting the temperature ramp.

Compressive strength test

For the cement slurry compressive strength test, two-inch cube moulds were used. First, the moulds and the plate contact surface were thoroughly washed, cleaned and dried. It was then slightly coated with release agents. The prepared cement slurry was then mixed for about five minutes after which the cement slurry was poured into the molds to its fill and covered with the top plate. The cement mould was then inserted into the curing vessel and the temperature was set to desired temperature in the range 80±5 °F (26.7±2.8 °C).

Results of the characterization

The XRD and XRF (X-ray fluorescence) results is presented in **(Tables 3 and 4)**

Table 3: Elemental Composition of Periwinkle Shell Powder.

Element Number	Element Symbol	Element Name	Weight Concentration
20	Ca	Calcium	57
14	Si	Silicon	3.1
41	Nb	Niobium	0.013
26	Fe	Iron	3.71
19	K	Potassium	0.32
17	Cl	Chlorine	1.088
16	S	Sulphur	0.321
13	Al	Aluminium	1.75
8	O	Oxygen	30.0
6	C	Carbon	0.025
22	Ti	Titanium	0.251

(Table 3), it was observed that Ca and Si have the highest percentage weight concentration. PSP contains 57% by weight concentration Ca and 3% by weight concentration of Si. These two elements are predominant in Portland cement and are required for cement slurry strength retrogression.

(Table 4) showed the oxide analyses shows that periwinkle shell powder contains 80% of CaO%, 7% of SiO_2, 3.3% of

Al_2O_3 in the oxides composition as disclosed in table 4. The results showed that periwinkle shells contain mostly CaO, SiO_2 and Al_2O_3. CaO and Al_2O_3 prevents the contraction of cement sheath at high temperatures after setting. SiO_2 helps in cement compressive strength retrogression. Furthermore, SiO_2 and Al_2O_3 are nanoparticles helps to improve the fluid loss control during and after cementing operations.

Table 4: Oxides Composition of Periwinkle Shell Powder.

Oxide	Periwinkle Shell powder (%)
CuO	0.007
FeO_2	5.310
MnO	0.057
TiO_2	0.420
CaO	80.7
Al_2O_3	3.3
ZnO	0.04
SiO_2	6.7

Rheology test results

From **(Figure 2)**, the plastic viscosity for the additives decreased as additive concentration was increased from 25% BWOC to 30% BWOC for both the silica flour additive and the PSP additive. However, plastic viscosity remains almost constant when concentration was increased from 30% BWOC to 35% BWOC. It was also observed between the silica flour and PSP; the plastic viscosity of PSP was very much identical to that of silica flour at same concentrations for 30% and 35% BWOC considered. However, at 25% BWOC, silica flour showed 5% higher plastic viscosity than PSP. Higher plastic viscosity translates to higher resistance to flow. Thus, higher resistance to flow was observed at lower concentrations of silica flour and PSP additive concentrations in the cement slurry samples. At 25% BWOC, silica flour having slightly higher plastic viscosity than PSP would require thinner to work effectively as compared to PSP.

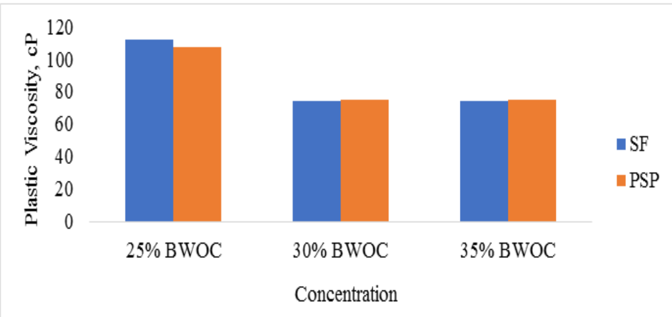

Figure 2: Plastic viscosity of various concentrations of Silica Flour and PSP.

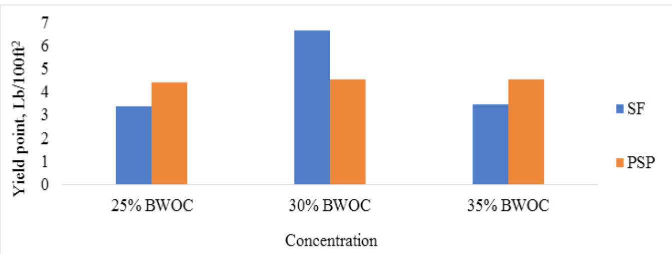

Figure 3: Yield point for silica flour and PSP cement slurry samples.

(Figure 3), it can be observed that the yield point of silica flour is not widely different from that of PSP, however, variations exist. For 25% BWOC and 35% BWOC, the yield point of PSP was observed to be higher than that of silica, while for 30% BWOC, the yield point of silica was higher than that of PSP. Thus, 25% and 35% BWOC samples required higher circulating pressures for the cement samples with PSP than silica flour while 30% BWOC required higher circulating pressures for silica flour than PSP.

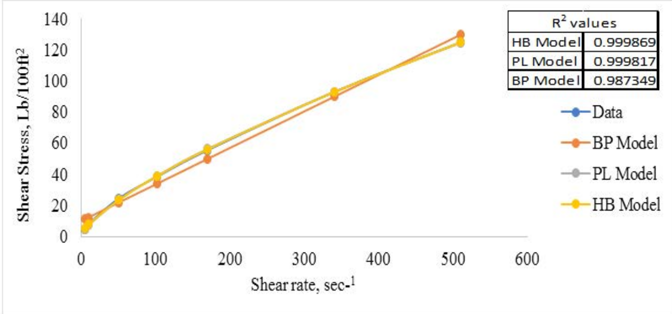

Figure 4: Curve fitting of rheological models to 25% BWOC Silica Flour.

(Figure 4) shows the curve fitting of common fluid rheological models to data from 25% BWOC Silica Flour cement sample. The best curve fit is represented as that which has the R2 value closes to unity. It can be observed that Herschel-Bulkley model (HB) with the highest R2 value of 0.999869 represents the best curve fit to the experimental data for 25% BWOC silica flour cement sample, while the Power Law and Bingham Plastic models have values of 0.999817 and 0.987349. With such a high R2 at 25% BWOC silica flour cement sample can adequately and correctly be represented by Herschel-Bulkley during cement design and analyses. Thus, the performance of the cement and the properties of the cement sample can be adequately and correctly determined using Herschel-Bulkley models.

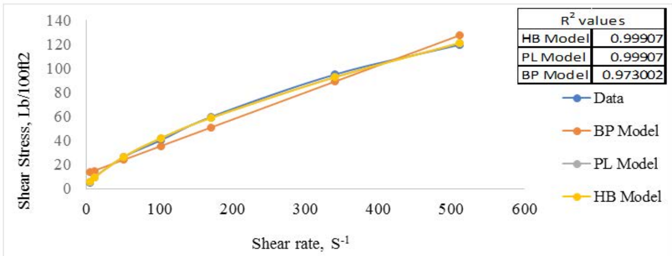

Figure 5: Curve fitting of rheological models to 25% BWOC Periwinkle Shell Powder.

(Figure 5) shows the curve fitting to rheological data for 25% BWOC Periwinkle Shell Powder cement sample. Bingham plastic, Power law and Hershel-Bulkey models were fitted to the data to determine the line of best fit by comparison of their respective R2 values. The R2 value of Hershel-Bulkley model and Power law model were the same (0.99907) and represents the highest R2 values closest to unity indicating that it has the best fit to the experimental data, while the Bingham Plastic value is 0.973002. This indicates that the actual yield stress for the data was zero since the Hershel-Bulkley curve fitting values was the same with that of Power law. The data can be conveniently represented with Power law model or Herschel-Bulkley model at zero yield stress.

(Figure 6), that the best curve fit to the experimental data was Herschel-Bulkley model with R2 value of 0.993866. This is followed by Bingham plastic model with R2 value of 0.992399. Power law model gives the least R2 value for the data of 0.984696. The result implies that Herschel-Bulkley model can conveniently model cement slurry prepared with 30% BWOC of Silica Flour with high accuracy.

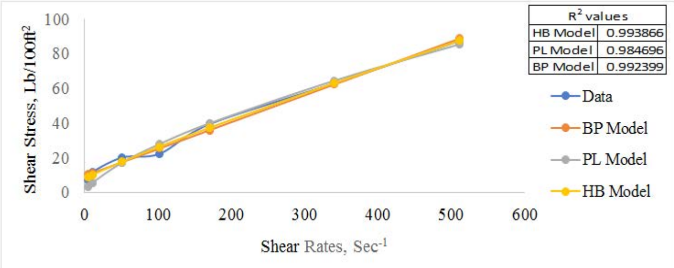

Figure 6: Curve fitting of rheological models to 30% BWOC Silica Flour.

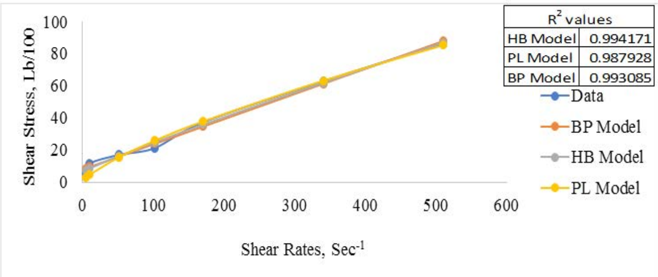

Figure 7: Curve fitting of rheological models to 30% BWOC Periwinkle Shell Powder.

(Figure 7), it can be observed that the best curve fit to the experimental data was Herschel-Bulkley model with R^2 value of 0.994171. This was followed by Bingham plastic model with R^2 value of 0.993085. Power law model gives the least R2 value for the data with a value of 0.987928. This implies that Herschel-Bulkey model had the least error and the highest curve fit accuracy. Thus, Herschel-Bulkley model can conveniently model cement slurry prepared with 30% BWOC of Periwinkle Shell Powder with high accuracy.

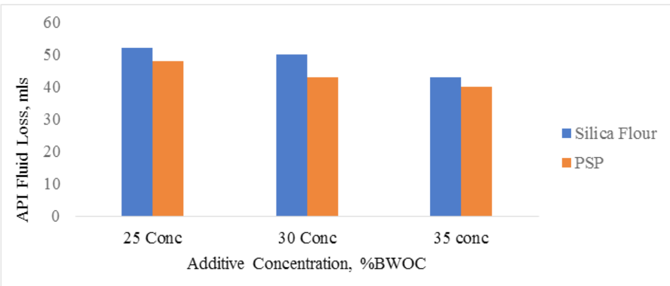

Figure 8: API fluid loss from cement samples.

(Figure 8) shows that the API fluid loss decreases with increase in concentration for both Silica Flour and Periwinkle Shell Powder cement additives respectively. The fluid loss was highest at 25% BWOC for both silica flour and PSP additives. For all concentrations, more fluid losses were observed from cement sample prepared with silica flour than PSP. This shows that PSP had better fluid loss control property than silica flour. Generally, both silica flour and PSP additives showed good fluid loss control in the cement slurry samples. For basic cementing operations, API stipulates that fluid loss should not be more than 50ml/30mins. All the cement samples met this criterion. However, in critical applications such as in severe HPHT environments, more fluid loss control is required to achieve less fluid loss, this would require the use of more fluid loss control agents. In this case, PSP offers better advantage to silica flour because of its better fluid loss control property. PSP is composed of nanoparticle such as SiO_2 and Al_2O_3 which improve the fluid loss control during and after cementing operations are required for critical cementing operations.

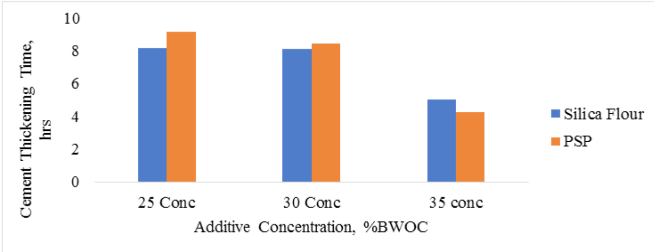

Figure 9: Thickening time of cement slurry samples.

It can be observed from **(Figure 9)**, that thickening time decreases with increase in the concentrations (%BWOC) for both silica flour and PSP cement slurry samples. It can also be observed that for 25% and 30% BWOC, PSP cement samples showed higher thickening time than silica flour cement samples, while for 35%BWOC, PSP showed lower thickening time than silica flour cement sample. Thickening time of cement slurry relates to the pumpability of the cement slurry. Excessive thickening time indicates that more dispersants is required to achieve improvements on the flow behaviour index to improve the pumpability and flowability of the cement slurry during applications in the field. The thickening time depends on the cement design and application. Higher thickening time is imperative in design of Lead cement slurries because of the comparatively higher slurry volume required to be placed in the annulus. Furthermore, temperature is a major factor of consideration for thickening time in HPHT. High temperature reduces the thickening time of cement slurries.

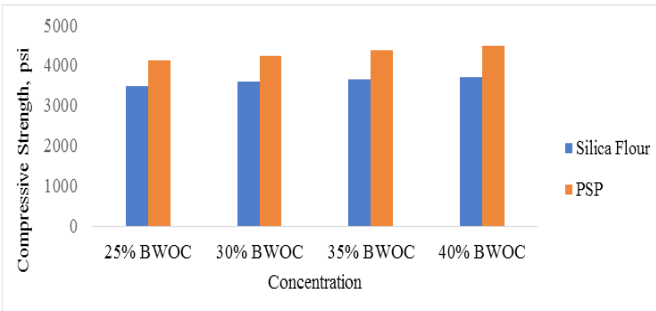

Figure 10: Comparison of compressive strengths of silica flour and PSP at 200oF after 30 days.

It can be observed that for all concentrations (%BWOC) considered as shown in **(Figure 10)**, cement slurry with PSP showed higher compressive strength than silica flour as additive after 30 days. The average percentage increase in compressive strength from the use of PSP in cement as additive over conventional silica flour is 19.16% (i.e. 4500psi for PSP and 3620psi for Silica Flour). This shows that after 30 days of conditioning, PSP shows higher compressive force (destructive) resistance than silica flour after cement setting.

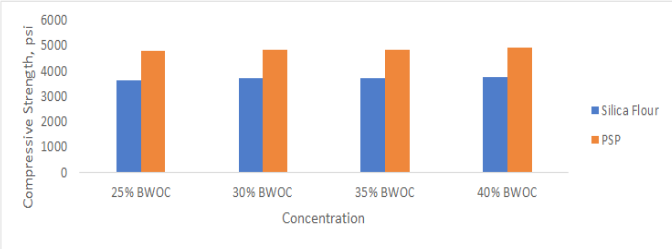

Figure 11: Comparison of compressive strengths of silica flour and PSP at 250oF after 24 hours.

From **(Figure 11)**, it can be observed that after curing at 250oF and conditioning of 24 hours, PSP showed higher compressive strength than silica flour when used as cement slurry retrogression additives in cement slurry preparation. The average percentage increase in compressive strength from the use of PSP in cement as additive over conventional silica flour was as high as 30.82% at 250oF and conditioning at 24 hours. This was about 10.56% higher compressive force than that observed at 200oF and 24 hours of conditioning implying that at higher temperature, the chemical constituents of PSP acquire more compressive strength thus improving cement bonding performance and compressive strength retrogression after set.

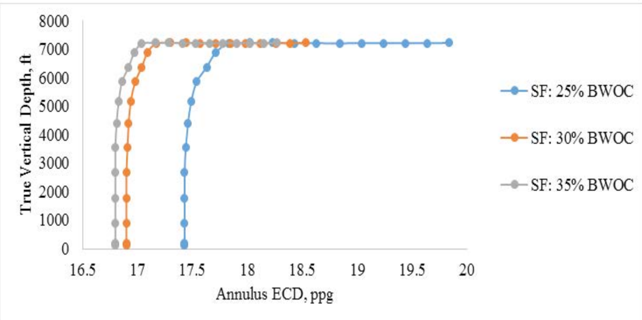

Figure 12: Effect of concentration of silica flour additive on annular ECD of cement slurry.

It is observed in **(Figure 12)** that for each concentration of silica flour additive in the cement slurry, the equivalent circulation density (ECD) maintained almost constant values from the surface up to around 2900ft TVD of the well. Slight increase was experienced from 2900 ft TVD until 7000 ft TVD. Above 7000 ft TVD, the ECD increased more significantly with depth. ECD is a function of the annular friction factor and pressure losses. Lower ECD values at higher silica flour concentrations implies that friction and pressure losses are minimized as concentrations of silica flour is increased. Furthermore, the marginal difference in the ECD decreases as concentrations of silica flour increases. For instance, the difference between the annular ECDs between 25% BWOC and 30% BWOC of silica flour is much higher than the difference in the annular ECD between 30% BWOC and 35% BWOC of silica flour. The average annular ECD difference between 25% BWOC, 30% BWOC of silica flour, 30% BWOC and 35% BWOC of silica flour cement additives in the cement slurry are 0.768 and 0.150, respectively.

(Figure 13) shows the effect of annular ECD with TVD for the annular flow of cement slurries formulated with varying concentrations of PSP additive. From Figure 13, it can be seen that for each concentration of PSP additive in the cement slurry, the equivalent circulation density (ECD) maintained almost constant values from the surface of the well up to around 2900ft TVD of the well. Slight increase was experienced from 2900 ft TVD till 7000 ft TVD. The observed increase of ECD with TVD is as expected because ECD theoretically increases with depth; as the fluid is pumped the pump pressure is slightly above the hydrostatic pressure. furthermore, from the chart it can be observed that the annular ECD increases with increasing concentration of PSP additive in the cement slurry formulation. 25% BWOC PSP additive has the highest annular ECD while 35% BWOC PSP showed least values of ECDs with depth. Analysis of the difference in ECD values with concentration of PSP shows that the difference in ECD values between 25% BWOC and 30% BWOC of PSP cement additive is 0.802, while the difference in ECD values between 30% BWOC and 35% BWOC of PSP cement additive is 0.174. Thus, at higher lower concentrations of PSP additive in the cement slurry, the ECD change is higher than at higher ECD concentrations. This implies that the change in annular ECD with PSP concentration decreases with increase in PSP concentration.

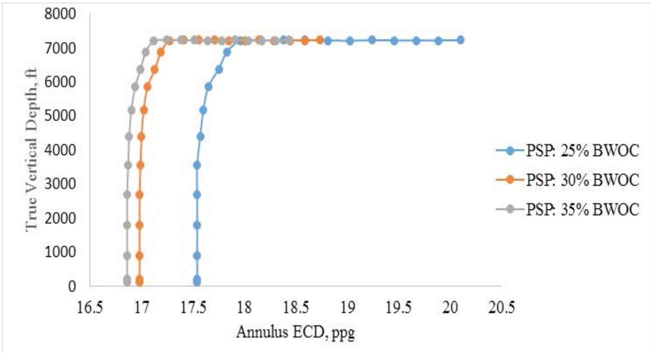

Figure 13: Effect of Concentration of PSP additive on annular ECD of cement slurry.

Conclusions

The following conclusions were drawn from the following:

- The annular equivalent circulation density was observed to increase with the true vertical depth of the well for cement slurries prepared with both silica flour and periwinkle shell powder (PSP)
- The equivalent circulation density of the cement slurry in the annulus was observed to decrease with increase in the concentration (BWOC) of both the silica flour additive and PSP in the cement slurry
- The annular ECD for PSP additive was observed to be slightly higher than that of silica flour additives during flow of cement in the annulus for all depth of the well, although the difference between the annulus ECDs of the two additives with depth are not very profound.
- The annular pressure loss was observed to increases with increase in pump rate and decreased with increase in the concentration (BWOC) of cement additives in the cement slurry for both silica flour and PSP additives.
- The annular pressure losses were observed to be higher for PSP additive than SF irrespective of pump rates and concentration (BWOC).
- The annular circulating pressures were observed to increase with increase in true vertical depth (TVD) of the well but decreased with increase in concentration BWOC of cement additive whether silica flour or PSP.
- The annular circulating pressures of PSP and silica flour

were observed to be very close irrespective of TVDs. However, PSP showed slightly higher values of annular circulating pressures than silica flour.

- Generally, the hydraulics performance of the cement slurry formulated with PSP was comparable to that of silica flour for all concentrations, pump rates and depth of the well.

Recommendations

The following recommendations have been made from this study:

- PSP has been recommended for use as cement strength retrogression additive for HPHT cement due to its enhanced performance at laboratory conditions
- There should be pilot field demonstration to determine the applicability and performance of PSP over silica at varying field conditions
- There should be measures provided by the government of Nigeria to encourage use of periwinkle shells powder for field applications through the local content act enforcement.

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Conflict of Interest

There is no conflict of interest regarding the publication of this manuscript.

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