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Performance Evaluation of *Tympanostomus fuscatus* (Periwinkle) Shell Powder as Alternative to Silica Flour in High Temperature Well Cementing Operation

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Abstract

The effect of high temperature on cement slurry is a problem in the oil and gas drilling industry. Over the years, silica flour was used to prevent the strength of cement that results from high temperature effect. But the silica flour is imported and not environmentally friendly. Hence, the need for local material that can serve as alternative becomes imperative. Periwinkle shell (Tympanostomus fuscatus) was tested in the laboratory to determine its potential use in place of the synthetic silica flour. The shell was pulverised, calcinated, and subjected to laboratory test following the requirement API RP 10B for cement testing. Cement slurry density of 15 ppg at 25, 30 and 35% BWOC concentrations of periwinkle shell powder, and temperature range of 200 and 250°C were conducted. Rheology test, API fluid loss, compressive strength, equivalent circulating density, and annular pressure loss were examined for its suitability to be used as an additive in cement slurry. The results showed that Periwinkle shell powder gave similar results with the silica flour based on its rheological properties, Equivalent Circulating Density (ECD), and annular pressure loss. In addition, periwinkle shell powder outperformed silica flour in all concentrations, temperatures and curing times. The results of this study showed that periwinkle shell powder is a potential alternative for silica flour as an additive for cement strength retrogression for cement slurry.

Keywords: Periwinkle shell powder, high temperature, rheology, compressive strength

INTRODUCTION

Cementing operations have gradually evolved from conventional cementing operations to high-pressure high-temperature cementing [1]. This comes with the increased drilling of deep and ultra-deep wells [2]. The gradual depletion of shallow oil and gas resources, the hope of sustaining the global petroleum supply lies in unconventional deep and ultra-deep reservoirs. Statistics have revealed that more than 40% of the world's remaining oil and gas resources reside in reservoir formations that are below 5000 m deep [3]. High temperature and high pressures are prevalent in deep and ultra-deep formations as temperature and pressure increase with depth [4]. Recent technological advancement in drilling has enabled the assessment of these resources by drilling long-distance extended reach and other maximum reservoir contact (MRC) wells. With the high temperature and high pressure of these wells, the design and performance of cement slurries during cementing operations are significantly affected [5]. This is because the physical and chemical properties of oil-well cement considerably change when exposed to high temperatures and high

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pressures. Thus, careful design is of vital importance when preparing oil-well cement slurries targeted for high pressure high temperature (HPHT) applications [6].

Yetunde and Ogbonna reported that another effect of HPHT wells is seen in the equivalent circulating density (ECD) [7]. As the depth of the hole increases, increased hydrostatic head increases the equivalent circulating density due to higher compression, however, high temperature causes a decrease in the ECD due to thermal expansion. Frigaard and Pelipenko noted that high temperature and pressure also affect the casing walls, resulting in uneven expansion and contraction in the formation of cracks in the set cement [8]. Cracks in cement are highly undesirable as they compromise cement integrity and may jeopardize the well's longevity.

Experimental findings by Haichuan *et al*. observed that, the cement slurry had relatively temperature-stable rheological properties and shows very little thermal thinning between 20 and 120°C [9]. In addition, the thermally stable-viscosity cement slurry had good stability and a performance that can meet the demands of well cementing as shown in Figure 1.

Frittella *et al.* noted that the effects of pressure can be felt in the well, drilling fluid, and cement slurry [10]. Accurate pressure prediction helps in mud and cement slurry design to effectively balance the hydrostatic pressures during drilling, cementing, or tripping. Inaccurate pressure prediction may result in casing collapse and consequently the occurrence of kicks. Guo *et al.* reported that weighting agents help to achieve minimum overbalance by increasing the weight of cement slurries, but, they however reduce the pumpability of the cement slurry, thereby creating increasing the development of premature compressive strength [11].

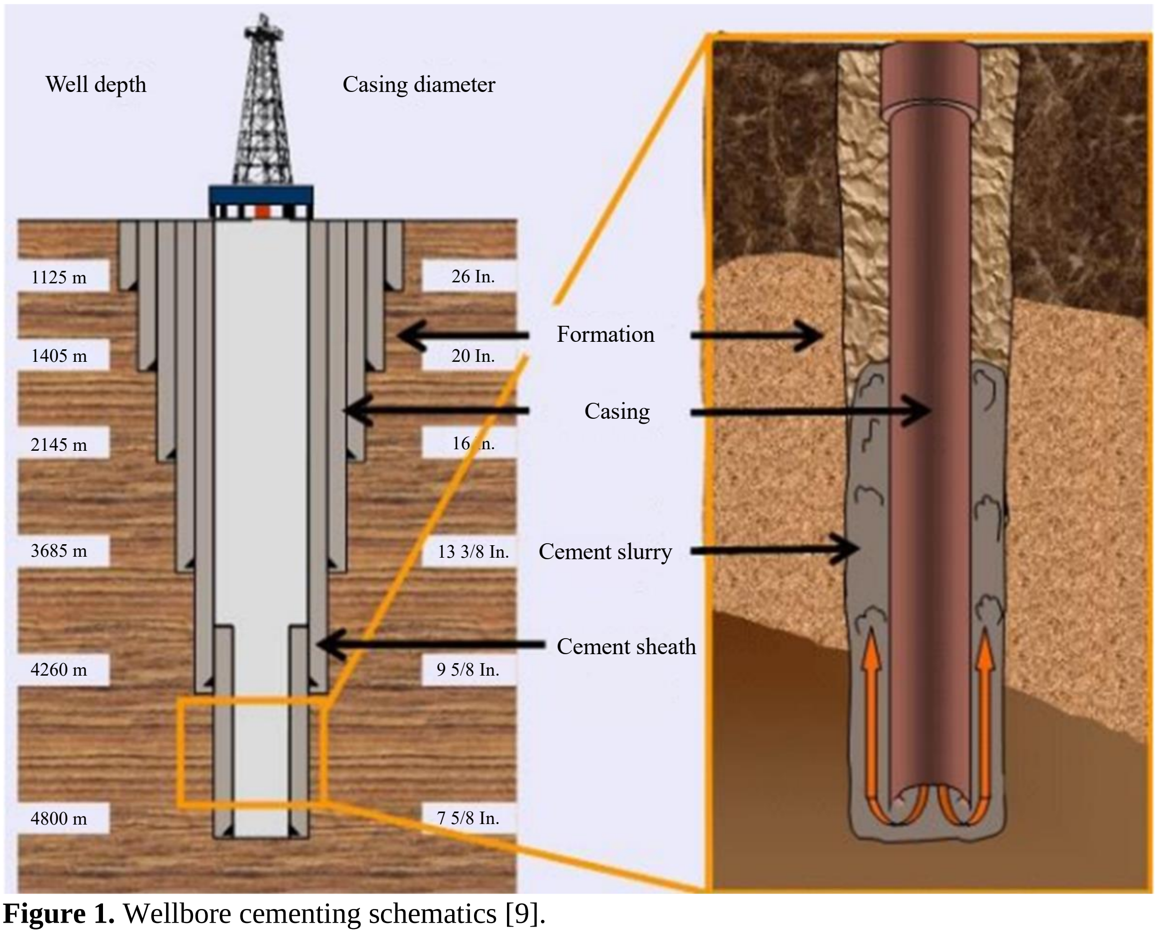

Figure 1. Wellbore cementing schematics [9].

The study of Haichuan *et al.* noted that cement slurries with rheological properties unaffected by temperature, sought to determine a solution for the problematic effect of temperature change on the variation of the rheological properties [12]. Cement slurry with temperature-insensitive viscosity was being prepared by adding a type of thermo-sensitive viscosity controller (TVC). Liu *et al.* observed that the consequences of high pressures and high temperatures on cementing operations include the total collapse of the wellbore when cement slurry was designed without proper prediction of reservoir pressure and temperature which can result to possible formation of cracks in the cement sheath which forms a pathway for gas migration from the reservoir to the surface leading to a compromise in the integrity of the cement sheath which may rise to a kick or blowout if not properly controlled [13]. Therefore, this study evaluates the performance of *Tympanostomus fuscatus* (Periwinkle) shell powder as alternative to synthetic Portland cement for high pressure high temperature well cementing operation.

MATERIALS AND METHODS

The materials used in this study include; Dyckerhoff G cement, ASP-742, WE-UDS, MD-21S, WFL05, MICROBLOK, WE-BON01, periwinkle shells, and fresh water. In addition, the apparatus used in the study are HPHT consistometer, compressive strength tester, HPHT fluid loss tester, mould, variable speed viscometer, electronic weighing device, variable speed mixer, atmospheric pressure consistometer, measuring cylinder, spatula and stop watch.

Methods

Sample preparation

The periwinkle shell was used as a local material and obtained from New market, Owerri. It was washed with distilled water to remove bacteria. Using thongs, the periwinkle shell was agitated and picked up from the water and placed in a glass ware. After washing the sample, it was sundried to remove impurity. The sample was crushed using hammer into smaller particles. Figure 2 shows the local material used for the study.

Preparation of the Cement slurry with Silica Flour

Cement slurry was prepared using silica flour as cement retrogression additive by adding 25, 30, 35 and 40% concentrations (BWOC). Table 1 shows the cement slurry formulation while Table 2 shows the test conditions.

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 250°F for different rpms including 300, 200, 100, 60, 30, 6 and 3 rpm.

Figure 2. Periwinkle shells.

Table 1. Cement slurry additives with silica flour.

Additives	**Batch no.**	**gm**	**Mls**	**Conc.**	**Function**
G CMT	601289	566.73	180.49		Cement
ASP-742	002/20WE27No-20	0.64	0.7	0.014 gal/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	0.35 gal/sk	Fluid loss control
MICROBLOK	142017-000490	58.01	41.43	0.825 gal/sk	Gas check
WE-BON01	IITS101213RW	28.12	20.09	0.4 gal/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	5.157 gal/sk	Mix water
Mix Fluid Requirement		372.97	344.09	6.851 gal/sk	Mix fluid

Table 2. Test conditions.

Parameter	**Value**
True vertical depth	14,700 ft
RAMP time	55 min
API schedule	9.33 M
Ambient temperature	80°F
Temp grad	1.3°F/100 ft
Slurry density	15.8 ppg
BHST	250°F
BHCT	250°F
Initial pressure	1864 psi
Final pressure	12689 psi
Cement blend	Dyckerhoff-G
Consistometer	PCON-004

API Fluid Loss Test

The API fluid loss test in cement slurry test analyses is to determine the amount of free water that comes out of the cement slurry. First the test slurry after its preparation was stirred appropriately to homogeneity and consistency, and then conditioned for 20 min in the atmospheric consistometer. The conditioned cement slurry was poured into a 250 ml measuring cylinder and allowed to stand for 2 h. Free water started to come out of the mixture with time. After 2 h, the amount of free water deposited at the top of the cement slurry was decanted and measured.

Compressive Strength Test

The prepared cement slurry was then mixed for about 5 min after which the cement slurry was poured into the moulds 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). This setup was then heated and pressured according to the test schedule. The moulds and plate contact surfaces were cleaned and dried and lightly coated with release agents. After 5 min of the last slurry mixing, the moulds used to hold the cement slurry were filled and covered with the top plate. The cement mould was placed in a curing vessel at the desired test temperature 80±5°F (26.7±2.8°C).

Frictional Pressure Loss

Frictional pressure loss equations differ based on the rheological model. Herschel Bulkley (HB) model gives a better accurate description of cement slurries. Thus, the frictional pressure loss for Herschel Bulkley model is given below for concentric annuli.

The Reynolds number Equation for Herschel Bulkley fluid in the annulus is given as:

$$Re_{AL} = \frac{12^{(1-n)}\rho v^{(2-n)}(D_a - d_a)^n}{k\left(\frac{2n+1}{3n}\right)^n + \left(\frac{2n+1}{n+1}\right)\left(\frac{D_a - d_a}{12v}\right)^n \tau_0} \quad (1)$$

Where, Re_{AL} is the Reynolds number for HB fluid flow in the annulus; n is the Herschel Bulkley exponent; k is the consistency factor, (Pas^n); τ_0 is the fluid shear force; ρ is the density of the fluid, (kg/m^3); υ is the average velocity of the fluid, (m/s); da is the inner diameter of the annulus, (m); Da is the outer diameter of the annulus, (m). Flow patterns for determination of Reynolds number can be divided into laminar, transitional and turbulent flow regimes.

For laminar flow:

$$Re_{AL} \leq Re_{AL1}$$

For transitional flow:

$$Re_{AL1} < Re_{AL} < Re_{AL2}$$

For turbulent flow:

$$Re_{AL} \geq Re_{AL2}$$

Where,

$$Re_{AL1} = 3250 - 1150n \quad (2)$$

$$Re_{AL2} = 4150 - 1150n \quad (3)$$

For laminar flow of HB fluid in the annulus, the frictional coefficient is given as:

$$f_a = \frac{24}{Re_{AL}} \quad (4)$$

For turbulent flow of HB fluid in the annulus, the frictional coefficient is given as:

$$\frac{1}{\sqrt{f_{tu}}} = \frac{4}{n^{0.75}} \log\left[Re_{AL} f_{tu}{}^{(1-n/2)}\right] - \frac{4}{n^{1.2}} \quad (5)$$

For transitional flow of HB fluid in the annulus, the frictional coefficient is given as:

$$f_{tr} = f_{lc} + \frac{(Re - Re_{LC})(f_{tc} - f_{lc})}{Re_{TC}} \quad (6)$$

Where, fa is the frictional coefficient of laminar flow in the annulus; f_{tu} is the frictional coefficient of turbulent flow; f_{tr} is the frictional coefficient of transition flow; f_{lc} is the frictional coefficient of turbulent flow at critical Reynolds number; f_{lc} is the frictional coefficient of laminar flow at critical Reynolds number; Re is the Reynolds number; Re_{LC} is the laminar critical Reynolds number; Re_{LC} is the turbulent critical Reynolds number.

The frictional pressure drop is thus given by:

$$\Delta P = \frac{2\rho v^2 f_a L}{(D_a - d_a)} \quad (7)$$

Where, ΔP is the frictional pressure loss in Pa; L is the depth of the wellbore section in m.

RESULTS AND DISCUSSION

Figure 3 shows that the plastic viscosity remains almost constant when concentration was increased from 25 to 35% BWOC. It was observed that at 25% BWOC, silica flour showed 5% higher plastic viscosity than PSP. Higher plastic viscosity translates to higher resistance to flow. Also, higher resistance to flow was noted at lower concentrations of silica flour and PSP additive concentrations in the cement slurry samples.

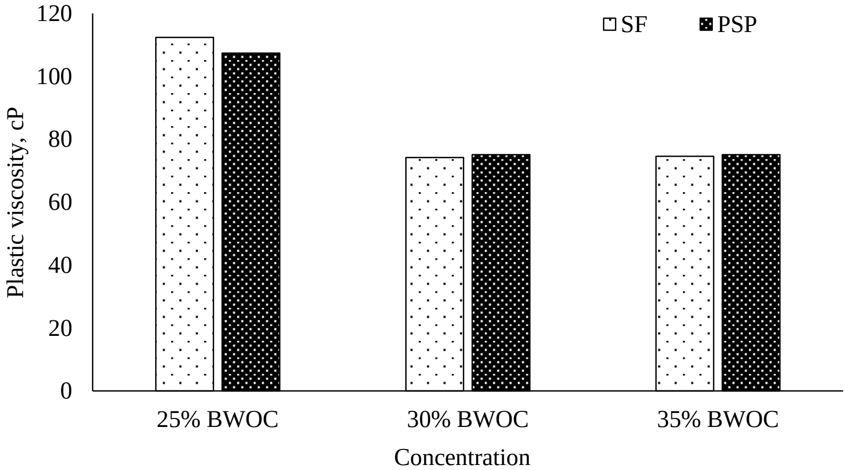

Figure 3. Plastic viscosity of various concentrations of Silica Flour and PSP.

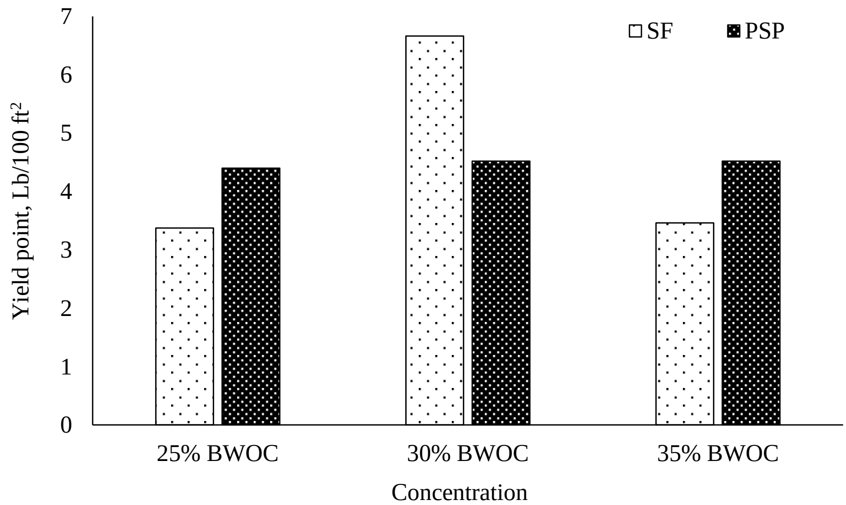

Figure 4. Yield point for silica flour and PSP cement slurry samples.

Figure 4 shows that the yield point of silica flour is not widely different from that of Periwinkle Shells Powder (PSP), for the 25 and 35% BWOC, the yield point of PSP was noted to be higher than that of silica, and however, for the 30% BWOC, the yield point of silica was higher than that of PSP. This suggest that the BWOC samples required higher circulating pressures for the cement samples with PSP than silica flour and 30% BWOC could require higher circulating pressures for silica flour than PSP.

As shown in Figure 5, the Bingham plastic, Hershel-Bulkey models and Power law models were fitted to the data to determine the line of best fit by comparison of their respective R^2 values. The R^2 value of Hershel-Bulkley model and Power law model were the same (0.99907) and represents the highest R^2 values closest to unity indicating that it has the best fit to the experimental data, but the Bingham Plastic value was 0.973002. This result indicates that the actual yield stress for the data was zero since the Hershel-Bulkley curve fitting value was the same with that of Power law.

Figure 6 shows that the API fluid loss decreases with increase in concentration for both Silica Flour and Periwinkle Shell Powder cement additives respectively. The API fluid loss from the Silica Flour cement additives are 52, 50 and 43 ml; however, for the Periwinkle Shell Powder are 48, 43 and 40 ml for concentrations of 25, 30 and 35% BWOC respectively. It was observed that more fluid losses were observed from the cement sample prepared with silica flour than PSP. This showed that the local material Periwinkle Shell Powder (PSP) had better fluid loss control property than silica flour.

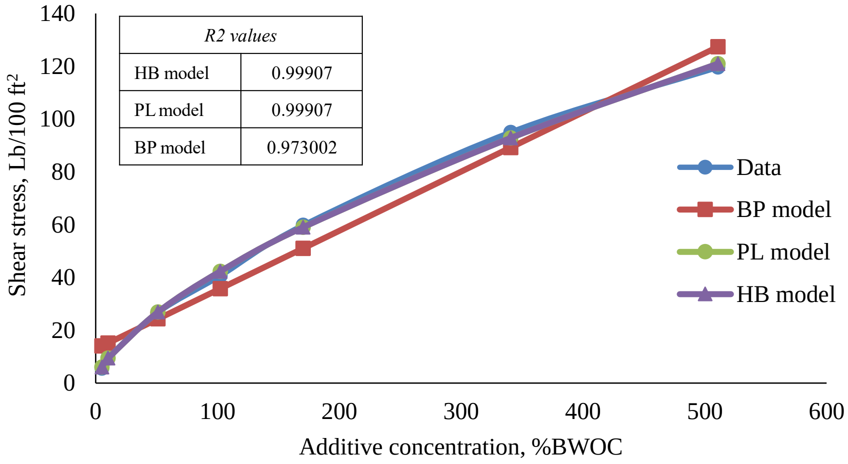

Figure 5. Curve fitting of rheological models to 25% BWOC Periwinkle Shell Powder.

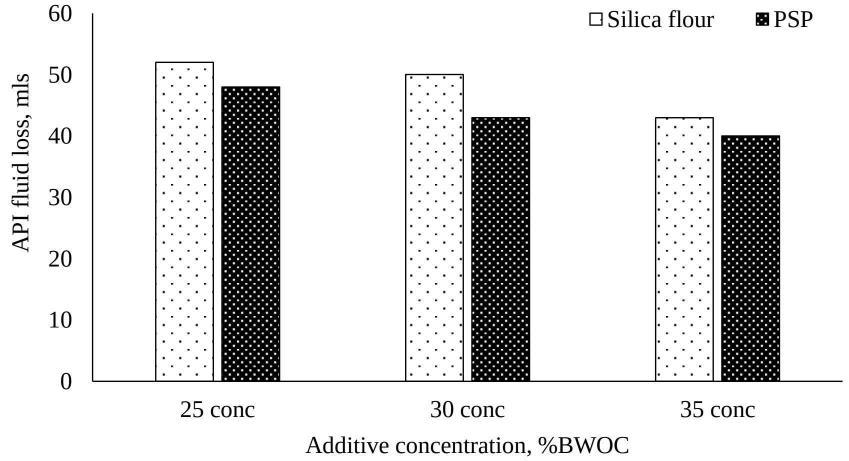

Figure 6. API fluid loss from cement samples.

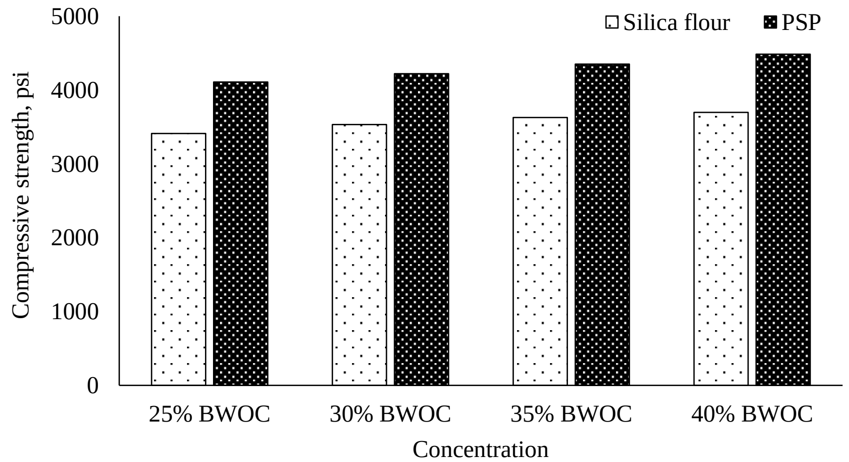

Figure 7. Comparison of compressive strengths of silica flour and PSP at 200°F after 24 h.

Figure 7 shows that the cement slurry using PSP as an additive exhibits higher compressive strength when compared to silica flour at temperature of 200°F and time of 24 h. It was observed that the average percentage increase in compressive strength using the local materials PSP in cement as additive over conventional silica flour was 20.26% and PSP showed higher compressive force resistance than silica flour after cement setting because of the presence of CaO, SiO_2 and Al_2O_3 oxides.

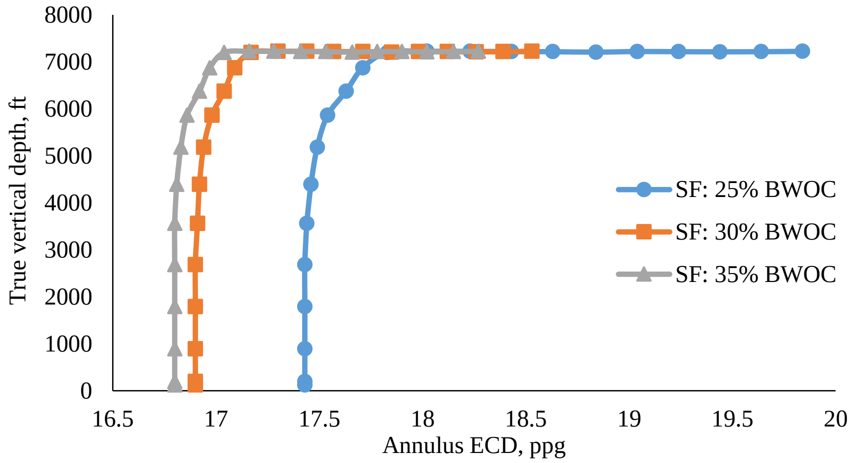

Figure 8. Effect of concentration of silica flour additive on annular ECD of cement slurry.

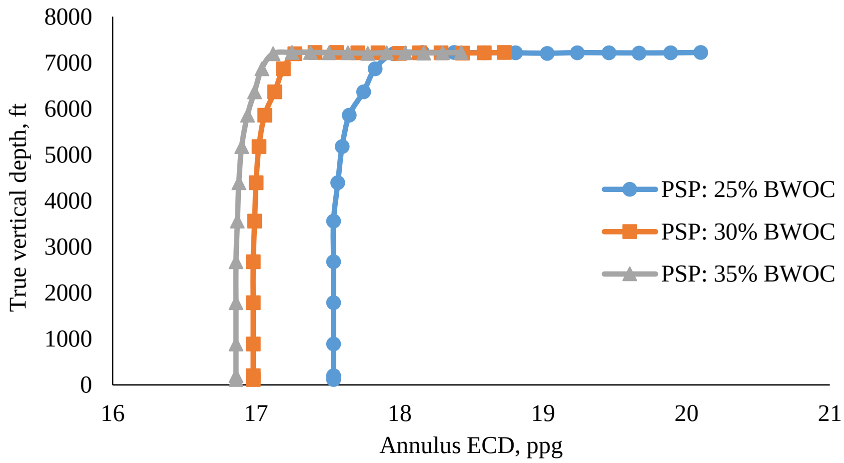

Figure 9. Effect of concentration of PSP additive on annular ECD of cement slurry.

Figure 8 shows that for every concentration of silica flour additive in the cement slurry, the equivalent circulation density (ECD) maintained almost constant values from the surface up to around 2900 ft TVD of the well. The slight increase from 2900 to 7000 ft TVD is a function of the annular friction factor and pressure losses. In addition, lower ECD values at higher silica flour concentrations suggest that friction and pressure losses are minimised as concentrations of silica flour was increased. The difference between the annular ECDs between 25 and 30% BWOC of silica flour was much higher than the difference in the annular ECD between 30 and 35% BWOC of silica flour.

Figure 9 shows the effect of annular ECD with TVD for the annular flow of cement slurries formulated with varying concentrations of PSP additive. From Figure 9, 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 2900 ft TVD of the well. Slight increase was experienced from 2900 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 and 30% BWOC of PSP cement additive is 0.802, while the difference in ECD values between 30 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.

In Figure 10, we observe that the annular ECD for PSP was slightly higher than the SF cement additives during flow of cement in the annulus, the annular ECD values for PSP and SF were observed to be 18.43 and 18.27 ppg, respectively, with a difference of 0.16 ppg.

Figure 11 shows that the annular pressure loss increases with increase in pump rate of cement and decrease with increase in PSP additive concentration (BWOC). It was observed that between 25 and 30% BWOC was 567.6 psi, but between 30 and 35% BWOC, the difference in annular pressure loss was 115.8 psi which indicate that pressure loss could be minimised by increasing the concentration (BWOC) of PSP.

Figure 12 shows that the difference in annular pressure loss between PSP and SF at 600 GPM was 71.67 psi. This result suggests that using PSP additive in the cement requires higher pump pressures than SF additive due to higher annular pressure losses during cementing operation with PSP cement slurry.

Figure 13 shows that the annular circulating pressures increase with increase in true vertical depth of the well. It was observed that the circulating pressures decreases with increase in the concentration BWOC of silica flour. The results indicate that the well (target depth) in the annulus, the annular circulating pressure of the cement slurry were 7,111, 6,796 and 6,690 psi for 25, 30 and 35% BWOC respectively.

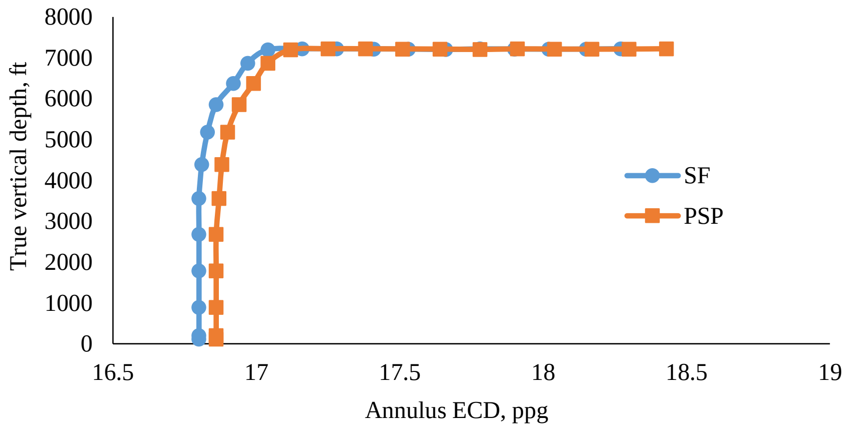

Figure 10. Annular ECDs for SF and PSP cement additives at 35% BWOC concentration.

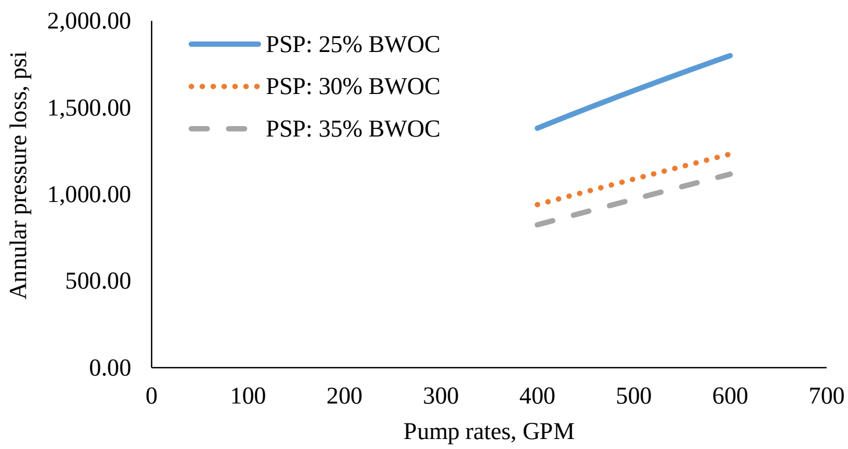

Figure 11. Effect of PSP additive concentration annular pressure loss.

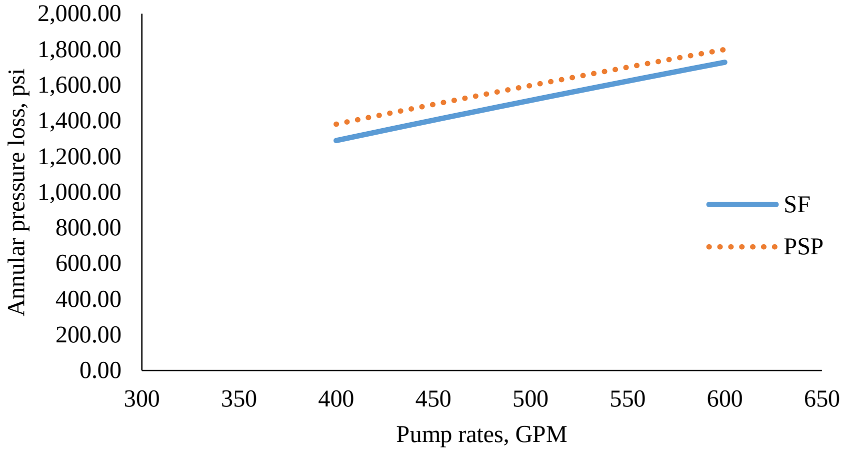

Figure 12. Annular pressure losses for SF and PSP cement additives at 25% BWOC concentration.

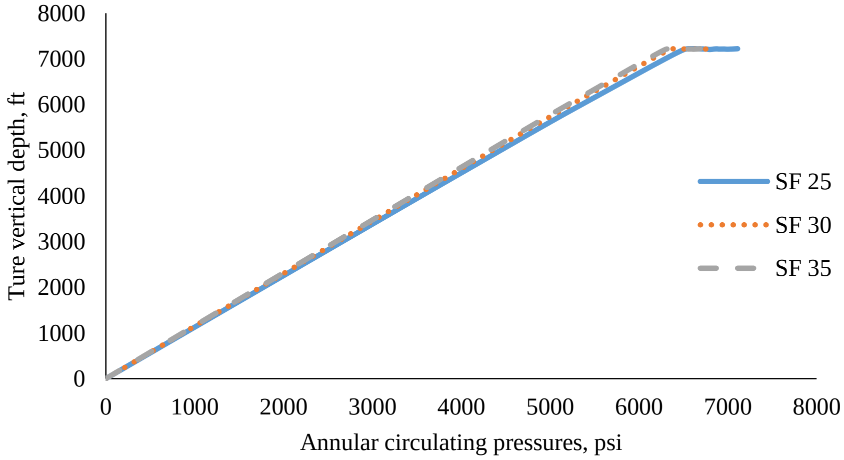

Figure 13. Annular circulating pressures versus TVD at various concentrations BWOC of silica flour additive.

CONCLUSION

The following conclusions can be drawn from the study:

1. The equivalent circulation density (ECD) of the cement slurry in the annulus was noted to decrease with the increase in the concentration (BWOC) for both the Periwinkle shells powder (PSP) and silica flour additive in the cement slurry.
2. The equivalent circulation density ECD for PSP additive was noted to be bit higher than that of silica flour additives during flow of cement in the annulus for all depths of the well, although the difference between the annulus ECDs of the two additives with depth are not very profound.
3. 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.
4. The annular pressure losses were observed to be higher for PSP additive than SF irrespective of pump rates and concentration (BWOC).

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Conflict of Interest

There is no conflict of interest regarding the manuscript.

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