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Investigation of Hydraulics Performance of Periwinkle Shell Powder for HPHT Cementing Operations in the Niger Delta

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Abstract

This study investigates the hydraulic performance of cement slurry samples enhanced with periwinkle shell powder (PSP). Preparation of cement slurries with varying concentrations were carried out as per the American Petroleum Institute standard. Concentrations of 25%, 30%, 35% and 40% By Weight of Cement (BWOC) were considered. WellPlan software was used. The impact of additive concentration on Equivalent Circulation Density (ECD), annular pressure loss, and annular circulating pressures were examined. Results revealed that ECD increases with well depth but decreases with additive concentration. Silica flour and Periwinkle Shell Powder (PSP) exhibit comparable ECD trends, with PSP exhibiting slightly higher values. Annular pressure losses increased with pump rate and diminish with increased additive concentration for both PSP and silica flour. PSP consistently demonstrates higher pressure losses compared to silica flour. Circulating pressures also increase with well depth but decrease with higher additive concentration. PSP exhibits slightly higher circulating pressures than silica flour across different depths. It was observed that PSP-enhanced cement slurries offer comparable hydraulic performance to silica flour, with marginal differences in ECD, pressure loss, and circulating pressures. The potential of periwinkle shell powder as a viable alternative additive, offering promising results for enhancing cement slurry properties and hydraulic performance was highlighted.

Keywords: *Periwinkle Shell Powder; Silica flour; Cementing hydraulics; WellPlan; Local content.*

1. Introduction

The cementing of oil wells is a crucial stage in the drilling process. It is essential for maintaining the reliability, stability, and effectiveness of oil and gas wells. In order to build a strong and impermeable barrier that prevents fluid movement, improves wellbore stability, and establishes efficient zonal isolation, this procedure requires the precise application of specially formulated cement slurries in the annular gaps between the wellbore and casing [1-2]. Cement, water, and additives make up the cement slurry. The water and additives help to regulate the slurry's flow and rheology, while the cement contributes to the seal's strength and durability. Additionally, the cement's ability to bond and its resistance against corrosion and erosion can be enhanced by the additives [2-3]. The significance of efficient cementing becomes crucial as the exploration and exploitation of oil resources become more complicated and include a variety of geological, temperature, and pressure conditions [4]. The cement sheath that surrounds the casing acts as a vital barrier to prevent the mixing of various fluids and gases between various subterranean zones in addition to creating a mechanical bond between the wellbore and the surrounding rock formations [5]. The process of cementing necessitates a multidisciplinary approach that incorporates knowledge from numerous disciplines, including as fluid dynamics, geology, engineering, and materials science. The process of cementing is a union of scientific understanding and real-world application, from creating cement blends with precise qualities to utilizing improved placement techniques.

The effectiveness of the cementing job has a significant effect on the well's long-term performance, affecting production rates, safety, and environmental concerns. The difficulties in achieving effective zonal isolation, wellbore stability, and operational safety increase exponentially as drilling operations shift from conventional shallow wells to ultra-deep complex wells, which are characterized by both extreme depths and complex geological formations [6]. Cementing techniques have changed, nevertheless, to meet the special requirements placed on them by ultra-deep and complex wells, where a combination of pressures, temperatures, and geological complexity can make operations difficult.

HPHT settings are characterized by high temperatures, frequently reaching 220°F, as well as high pressures, frequently exceeding 9,000 psi [6]. Therefore, to maintain wellbore integrity, zonal isolation, and operational safety while cementing in HPHT wells, accurate engineering, cutting-edge cement formulas, exact placement procedures, and rigorous quality control are required [2].

Hydraulics is essential throughout the cementing process. Investigating and controlling fluid flow dynamics during the cementing process inside wellbores is a part of oil well cementing hydraulics. It includes knowledge of how cement interacts with the formation and slurries in the annular gaps between the casing and the wellbore [7]. Achieving correct zonal isolation, limiting fluid migration, improving displacement effectiveness, and ensuring the integrity of the cement sheath all depend on efficient cementing hydraulics [8]. The rheology, the cement flow rates and pressures, the pressure drop in the annulus, and the equivalent circulation density are some of the important factors examined during cementing hydraulics [9].

The hydraulic characteristics of cement slurries are greatly affected by additives. Additives aid in changing the cement slurries' rheological, thermal, fluid loss, and mechanical properties, which in turn affects its hydraulics [10]. Even when made from the same type of cement, cement slurries can display considerable flow differences because of various addition types and concentrations. Under conditions of high pressure and temperature, these differences become obvious. Notably, cement slurries' rheological features adhere to well-established models that are susceptible to variations in temperature and pressure and so affect their rheological characteristics [11-12].

In the past, silica components have been used to enhance the mechanical properties of cement slurries by reducing strength retrogression in the design of oil well cement [13]. These sources, which include microsilica and silica fumes, are made of non-crystalline, tiny, spherical particles in electric furnaces. However, due to their costs and disposal issues, their commercial use raises financial and environmental issues [14-15]. Recent trends encourage environmentally sound and economically viable materials as engineering shifts toward becoming more environmentally friendly [16]. The concept of substituting expensive commercial silica with inexpensive locally accessible additions has received a lot of popularity [17-18]. In terms of technology, cost, and environmental impact, this change competes favourably with commercial silica in preventing strength retrogression in high-pressure, high-temperature (HPHT) circumstances. In addition to being easily accessible domestically, local materials as additives also support Nigeria's local content policy, encouraging local participation, development, and reducing capital outflows [19]. In this study, the hydraulic performance of silica flour and periwinkle shell powder utilized as local and synthetic cement slurry additives, respectively, when used as mechanical strength modifiers in HPHT cementing operations, is examined.

2. Theoretical analysis

2.1. Wellbore hydraulics

Hydraulics deals with the energy of fluid flow. Hydraulics is encountered in oil and gas operations as fluid flows in various operations such as drilling, cementing, completion, well stimulation, etc [20]. As wells becomes more complex in their design and geometries, the fluids utilised in downhole operations becomes profoundly complicated giving rise to increased concerns on well hydraulics [2]. Wellbore hydraulics has received special attention as increase in deviated wells such as horizontal wells, multilateral and extended reach wells are drilled. During, wellbore hydraulics investigation, important hydraulics parameters such as the equivalent circulation density, the frictional pressure loss, and downhole circulating pressures are critical and must be accurately determined. Hydraulics modelling helps to optimise well operations by ensuring an economical and safe operation [8]. Hydraulic investigation during cementing operations differs from drilling hydraulics basically due to the difference in fluid used. The density of cement slurry is usually higher than that of drilling mud so that the cement can effectively clean out the mud prior to cementing [21]. Additionally, casing diameter during cementing is significantly higher than drill pipe diameter during drilling. As a result, the annular space encountered during cementing is smaller than that during drilling giving rise to higher frictional pressure losses in cementing operations than in drilling. Due to this, cementing hydraulics poses much more concern due to increased chances of formation fracture and loss circulation during cementing operation. Adequate design and modelling are required to ensure optimal hydraulic performance during cementing operations.

2.2. Frictional pressure losses

As cement moves through the annulus or pipe, energy is loss due to friction that exists between the flowing fluid and walls of the annulus/pipe; this is referred to as frictional pressure losses. Annular frictional pressure losses exist due to flowing fluid in the annulus. Thus, the frictional pressure loss is affected by main factors such as flowrate, fluid viscosity and pipe roughness. Other factors include wellbore eccentricity, string rotation, and annular diameter ratios. It must be noted that the flow of fluids in the annulus is complex due to many variables such as wellbore eccentricity, string rotation, fluid rheology, and the size of annular cross-section. Accurate determination of the pressure losses in the annulus is critical for well control [22]. Also, [23] experimental discovered that annular frictional pressure losses increase with increase in rotation rates for low-viscosity fluids but decreases with increase in rotation rates for high-viscosity shear thinning fluids. In their experimental study, [24] provided an efficient hydraulic model that described the effects of pipe rotation during annular frictional pressure loss determination

2.3. Equivalent circulation density

The ECD is the effective density of the circulating wellbore fluid in the wellbore which results from the combined effects of the hydrostatic pressure by the static fluid column and the frictional pressure. During cementing, ECD is essential as it determines the stability of the pressure system in the annulus of the well. High ECD is detrimental to the well as it fractures the formation and results to loss circulation. On the other hand, low ECD might results to sloughing of the borehole wall due to pressure underbalance. It must be understood that ECD becomes more of a concern in narrow annulus or wells with annulus whose radial size varies along the well path. Accelerated flow of cement slurry is observed when there is sudden shrinkage in the radial size of the annulus which considerably increases the frictional pressure loss and thus increases the ECD [25]. For ECD to be accurately determined there must be accurate determination of the frictional pressure loss. However, the factors which influence the determination of ECD is complex and is distributed among factors such as fluid properties, well configuration, and process parameters.

2.4. Annular circulating pressure

The annular circulating pressure of the cement is the net flowing pressure of the cement in the annulus. The pressure provided by the pump is the sum of the individual pressures in the circulating system. The pump pressure must be able to overcome the total frictional losses in the system. For cementing operations, annular pressure losses act as back pressures and must be compensated by the pump circulating pressure [26]. The circulating pressure is the pressure exerted by the equivalent circulation density (ECD) under static condition. The circulating pressure relates to the sum of the combined hydrostatic and the frictional pressure losses at the depth considered. Circulation pressure is necessary during cementing operation to prevent loss circulation. Some of the factors considered during the investigation of circulation pressure include fluid density, flowrate, wellbore eccentricity.

3. Materials and method

3.1. Materials

The material used for the experiments includes Dyckerhof G cement, Periwinkle shells, Silica flour, Fresh water, Fluid loss additive, Gas check control, Defoamer, Dispersant, Retarder, Bonding agent. The concentration of the materials used is as shown in Table 1

Table 1. Material concentration.

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
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
PSP/silica flour	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

3.1.1. Equipment

Variable speed viscometer was utilised in the measurement of the rheological properties of the cement slurry samples. The methods investigated include the experiments conducted to determine the rheological properties of the cement slurry samples based on the concentration of the additives and model simulation performed utilising the rheological data to investigate the hydraulics performance of the cement slurry in the annulus during cementing.

3.2. Experimental investigation

The experiments were conducted to determine the rheological properties of the cement slurry samples prepared with PSP and silica flour additives by varying their concentrations by BWOC.

3.2.1. Acquisition of the periwinkle shell and preparation of the Periwinkle Shell powder

Periwinkle shell have been used as fluid loss control agent in drilling fluids and some other purposes [27-29]. The periwinkle shell which is used as the local material was sourced from vendors at Ihiagwa market, Owerri, Nigeria. 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 achieved by adding distilled water at 32°C in a large container and then pouring the periwinkle shell into it ensuring that the water covered the shell by five inches. Using thongs, the periwinkle shells were agitated and picked up from the water and placed in a glass ware. The soaking and washing of the periwinkle shells lasted for 45 minutes because hot water was not utilised which would have required less time period. After soaking and washing, the washed periwinkle shell was sun dried at about 32°C for five days to remove the moisture content in the shells. After sun drying, a hammer mill (Model RLA 201–800,014, UK) was used to crush the periwinkle shell into powder which was further grinded into more finer particles using a Hamilton Beach dry grinder (Model: 80,385). After the crushing, the powder was sieved using a 200-mesh sieve for quality assurance and quality check (QA/QC). Thus, a sample of periwinkle shell powder was achieved at this point. The SEM image and sample are shown in Figures 1 and 2.

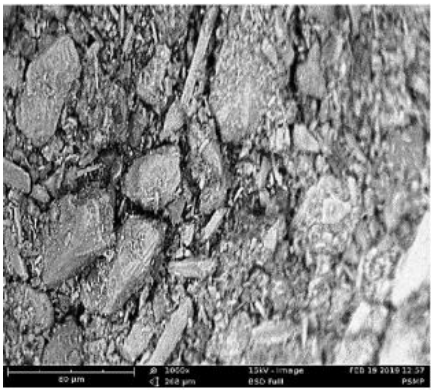

Figure 1. Periwinkle shell powder SEM image [3].

Figure 2. Periwinkle shells.

3.2.2. Preparation of the cement slurry

Slurry design is a key consideration in cementing design [30], and locally sourced materials have been proposed as additives [31-32]. Two major categories of cement slurry formulation were prepared using silica flour and periwinkle shell powder. Different concentrations of each of cement slurry formulation were prepared. The cement slurry formulations were prepared by adding several cement slurry additives with various concentrations of silica flour and periwinkle shell ash.

i. Cement slurry with silica flour

Cement slurry was prepared with silica flour additive by adding 25%, 30% ,35% and 40% concentrations (BWOC) with other cement additives. 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.

ii. Cement slurry with Periwinkle shell powder (PSP)

Cement slurry was prepared with Periwinkle shell powder as cement retrogression additive by adding 25%, 30%, 35% and 40% concentrations (BWOC) with other cement additives. 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. Table 2 shows the test conditions.

Table 2. Test conditions.

Parameter	Value	Parameter	Value
True vertical depth	14,700 ft	BHST	250^{o}f
RAMP time	55 minutes	BHCT	250^{o}f
Api schedule	9.33M	Initial pressure	1864 psi
Ambient temperature	80^{o}f	Final pressure	12689 psi
Temp grad	1.3^{o}f/100FT	Cement blend	Dyckerhoff – G
Slurry density	15.8 ppg	Consistometer	PCON-004

3.2.3. Conditioning of the cement slurry

The cement slurry was conditioned within a maximum temperature of 190°F (87.8°C). However, if at the test location, the boiling point of water is less than 212°F (100°C), then there is appropriate temperature adjustment.

The cement slurry is conditioned by filling the slurry container of the atmospheric pressure consistometer to the marked line after I minute of slurry mixing. This is then followed by from ambient temperature of the mean temperature of the conditioning and then placed in the atmospheric consistometer cell. Afterwards the slurry was allowed to reach the test temperature and then held for ±30 minutes so that the test fluid could reach equilibrium. Then the paddle was removed, and consistency was achieved by briskly stirring with a spatula.

3.2.4. Rheology test

To evaluate the rheological characteristics of cement slurries including silica flour and periwinkle shell powder additions, rheology tests were carried out. At a temperature of 250°F, these tests were carried out at different rotating speeds, including 300RPM, 200RPM, 100RPM, 60RPM, 30RPM, 6RPM, and 3RPM.

Both cement slurry compositions were subjected to rheology experiments using the Fann Model 35 viscometer. The rotor, bob, and cup of the viscometer were properly dried and heated to the test temperature (between 200°F and 250°F). The cement slurries were conditioned as specified, and the viscometer's components were reassembled. For each test, the conditioned slurry was poured into the preheated viscometer cup, ensuring the fluid level reached the scribed mark on the rotor without touching the cup's bottom. Initial dial readings were taken after 10 seconds of continuous rotation at 3 RPM. Subsequent dial readings were recorded as the speed increased and decreased, with the highest speed set at 300 RPM.

This procedure was conducted for cement slurries containing silica flour and periwinkle shell powder additives respectively, with concentrations of 25%, 30%, and 35% BWOC (by weight of cement). Tests were performed at both 200°F and 250°F to evaluate the additives' effects under different temperature conditions.

3.3. Modelling and simulation

The models comprise equations for equivalent circulation density (ECD), annular frictional pressure loss which is used in the determination of the annular circulating pressures

3.3.1. Equivalent circulation density (ECD)

The formula for ECD is given by Eq. (1):

$$ECD = \frac{\Delta P_A}{0.052 * TVD} \qquad (1)$$

where; ECD, equivalent circulation density (ppg); MW, mud weight (ppg); P_A, annular pressure loss due to friction (psi); TVD, true vertical depth (ft).

However, the ECD for multiple sections of the well having different strings and geometries can be given by Eq. (2):

$$ECD = MW + \frac{\sum_{i=1}^{n} \Delta P_A}{0.052 * \sum_{i=1}^{n} \Delta TVD} \qquad (2)$$

where n, number of sections.

3.3.2. Frictional pressure loss

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

The Reynolds number equation for HB fluid in the annulus is given as Eq. (3):

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

where;

Re_{AL}, Reynolds number for HB fluid flow in the annulus; n, Herschel Bulkley exponent; k, the consistency factor (PaS^n); τ_0, fluid shear force; ρ, density of the fluid (kg/m^3); υ, average velocity of the fluid (m/s); da, outer diameter of the pipe (m); Da, hole size (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; $Re_{AL1} \leq Re_{AL} \leq Re_{AL2}$

for turbulent flow; $Re_{AL} \geq Re_{AL2}$

The flow patterns are given as Eqs. (4) and (5):

$$Re_{AL1} = 3250 - 1150_n \qquad (4)$$

$$Re_{AL2} = 4150 - 1150_n \quad (5)$$

For laminar flow of HB fluid in the annulus, the frictional coefficient is given as Eq. (6):

$$f_a = \frac{24}{Re_{AL}} \quad (6)$$

For turbulent flow of HB fluid in the annulus, the frictional coefficient is given as Eq. (7):

$$\frac{1}{\sqrt{f_{tu}}} = \frac{4}{n^{0.75}} log\left[Re_{AL} f_{tu}{}^{(1-n/2)}\right] - \frac{4}{n^{1.2}} \quad (7)$$

For transitional flow of HB fluid in the annulus, the frictional coefficient is given as Eq. (8):

$$f_{tr} = f_{lc} + \frac{(Re - Re_{LC})(f_{tc} - f_{lc})}{Re_{TC}} \quad (8)$$

where: fa, coefficient of friction for laminar flow in the annulus; ftu, coefficient of friction for turbulent flow in the annulus; ftr, coefficient of friction for transition flow in the annulus; ftc, coefficient of friction for turbulent flow at critical Reynolds number ; flc, coefficient of friction for laminar flow at critical Reynolds number; Re, Reynolds number ; Re_{LC}, critical Reynolds number for laminar flow ; Re_{TC}, critical Reynolds number for turbulent flow.

The frictional pressure drop is thus given by Eq. (9):

$$\Delta P = \frac{2\rho v^2 f_a L}{(D_a - d_a)} \quad (9)$$

where; ΔP, frictional pressure loss (Pa); ρ, density of the fluid (kg/m^3); L, depth of the wellbore section (m).

3.3.3. Simulation

Cement slurry hydraulics is simulated to determine hydraulics parameters of the cement slurry flow in the annulus as it is being pumped from the surface. The following data was used for the simulation: wellbore trajectory data, casing data, hole data, fluid data, rig data, etc as shown in Tables 3 and 4. The operation considered is cementing operation for the cased hole section of the well.

Table 3. General input parameters.

S/N	Parameter	Value
1	Fluid density (base)	10.7 ppg
2	Block weight	90 kips
3	Block rating limit	1500 kips
4	Friction factors	0.15 OHFF, 0.2 OHFF and 0.25 OHFF
5	Casing deployment	9 5/8 in OD, 8.535in ID, 53.5 ppf casing from top to 17,880 ft
6	Total well depth	21,622.77 ft
7	Section of well under investigation	Top to 17880 ft
8	Reservoir temperature	220°F
9	Geothermal gradient	1.74°F/100ft
10	Trip speed	60 ft/min
11	Slack-off weight (sliding)	20 kips
12	Maximum yield of Overpull	90%
13	Rheological model	Herschel-Bulkley

Table 4. Casing data

Type	Length		Body		Linear weight		Grade [psi]	Material	Class
	Pipe [ft]	Total [ft]	OD [in]	ID [in]	Nominal [lb/ft]	Actual [lb/ft]			
Casing	17880	17889	9.625	8.535	53.5	53.5	80,000	CS	P

The simulation was done with WellPlan software. The hydraulics and cementing editor of the WellPlan software was used to analyse the annular equivalent circulation density, the annular pressure loss and the annular circulating pressure due to the flow of cement slurry in the annulus during cementing. The shape of the well is described by the vertical profile given in Figure 3.

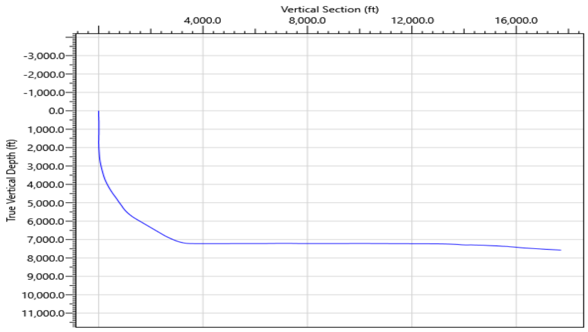

Figure 3. Vertical profile of the well

Figure 3 shows the vertical profile of the well for the cementing operation. The well comprises three distinct geometries. The vertical section which apparently starts from the surface till around 2900 ft of the well; the deviated (build) section which starts from the 2900 ft of the well to around 7215 ft of the well. The horizontal section is maintained at TVD of 7215 ft of the well.

4. Results and discussion

4.1. Results

The result of the hydraulics modelling is presented in this section. The results obtained from the simulation using WellPlan software comprises the annular equivalent circulation density as a function of true vertical depth (TVD), the annular pressure losses as a function of cement pump rate and the annular circulating pressures as a function of depth. These parameters were determined for the various fluid additive types and concentrations (BWOC) used.

4.1.1. Effect of cementing additive on equivalent circulation density

The effect of silica flour and periwinkle shell powder cement slurry additives in on the equivalent circulation density of the formulated cement slurry is investigated in this section. The density of each cement slurry sample modelled was kept constant at 15.8ppg, the difference in the cement slurry formulation lies in the cement additive type and concentration added during the slurry. Six slurries comprising of silica flour cement additive fluid of 25% BWOC, 30% BWOC and 35% BWOC and periwinkle shell powder cement slurry formulation with 25% BWOC, 30% BWOC and 35% BWOC concentrations were investigated.

4.1.2. Effect of silica flour additive on ECD

The ECD of the silica flour cement slurry additive was investigated for the various concentrations of the silica flour additive added to the cement slurry during formulation. Figure 4a shows the impact of silica flour concentration on cement slurry ECD in the annulus during flow of the cement in the annulus.

From Figure 4a, 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 to 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 imply that friction and pressure losses are minimised 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 and 30% BWOC of silica flour and 30% BWOC and 35% BWOC of silica flour cement additives in the cement slurry are 0.768 and 0.150 respectively.

4.1.3. Effect of periwinkle shell powder (PSP) additive on ECD

The ECD of PSP cement slurry additive was investigated for the various concentrations of the PSP additive added to the cement slurry during slurry formulation. Figure 4b shows the impact of PSP concentration on cement slurry annular ECD during cementing as cement is pumped and flows in the annulus.

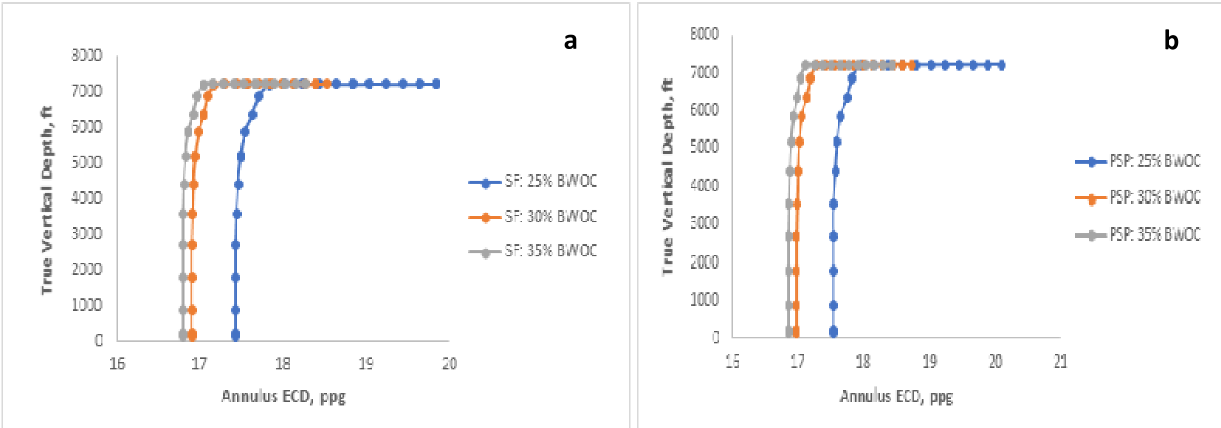

Figure 4. Effect of concentration of (a) silica flour and (b) PSP additives on annular ECD of cement slurry.

Figure 4b shows the effect of annular ECD with TVD for the annular flow of cement slurries formulated with varying concentrations of PSP additive. 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 to 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 figure it can be observed that the annular ECD decreases 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 lower PSP concentrations additive in the cement slurry, the ECD is higher than at higher PSP concentrations. This implies that ECD decreases with increase in PSP concentrations.

4.1.4.Comparison of annular ECD values of silica flour (SF) and periwinkle shell powder

From Figure 5a, it can be observed that the annular ECD values of PSP is slightly higher than that of the SF for various values of the TVD, however, the difference between the two is not profound. PSP tends to show higher ECD values due to higher viscosity which creates higher frictional pressure drop than SF. At the bottom of the well, the annular ECD values for PSP and SF were 20.1ppg and 19.84ppg respectively with a difference of 0.26 ppg.

From Figure 5b it can be observed that the annular ECD for PSP is slightly higher than that of SF cement additives during flow of cement in the annulus, although the difference between the annulus ECDs of the two additives with depth are not very profound. At the bottom of the well, the annular ECD values for PSP and SF were 18.73 ppg and 18.53 ppg respectively with a difference of 0.20 ppg.

From Figure 5c, it is seen that the annular ECD for PSP is also slightly higher than that of SF cement additives during flow of cement in the annulus, although the difference between the annulus ECDs of the two additives with depth are not very profound. At the bottom of the well, the annular ECD values for PSP and SF were 18.43 ppg and 18.27 ppg respectively with a difference of 0.16 ppg.

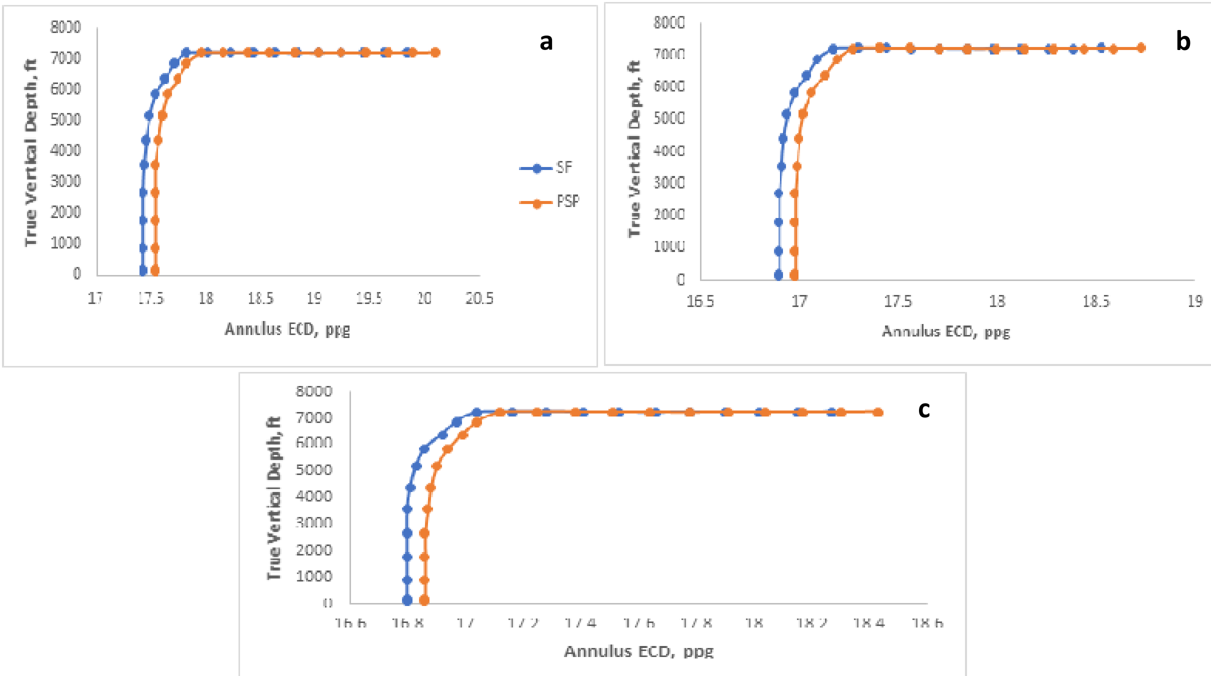

Figure 5. Comparison of annular ECDs for SF and PSP cement additives at (a) 25%, (b) 30% and (c) 35% BWOC concentration.

4.1.5. Effect of silica flour additive on annular pressure loss

The annular pressure loss vs pump rate for cement slurry formulation prepared with 25% BWOC, 30% BWOC and 35% BWOC silica flour is shown in Figure 6a.

Figure 6a shows the annular pressure loss due to varying pump rate of cement slurry for with 25% BWOC, 30% BWOC and 35% BWOC silica flour additive in the cement slurry formulation. It can also be seen that the annular pressure loss increases with increase in pump rate and decreases with increase in the concentration BWOC of silica flour additive in the cement slurry. Further inspection of figure reveals that the marginal difference in the annular pressures becomes less significant as concentrations of silica flour is increased. For example, the difference in annular pressure loss at the bottom of the well due to varying pump rates of silica flour of concentrations between 25% BWOC and 30% BWOC is 574.98 psi, while the average difference of the annular pressure loss due to varying pump rates for silica flour of concentrations between 30% BWOC and 35% BWOC is 100.24 psi. The result indicates that annular pressure loss can be optimised by changing the concentration of cement additive which in turn improves the rheology of the cement slurry.

4.1.6. Effect of PSP additive on annular pressure loss

The annular pressure loss vs pump rate for cement slurry formulation prepared with 25% BWOC, 30% BWOC and 35% BWOC periwinkle shell powder (PSP) is shown in Figure 6b.

The annular pressure loss for varying cement pump rate at different PSP additive concentration BWOC in the cement slurry is shown in Figure 6b. It was observed that the annular pressure loss increases with increase in pump rate of cement and decrease with increase in PSP additive concentration (BWOC). However, the margin of difference in the annular pressure drop varies with concentration of PSP in the cement slurry. For example, the difference in annular pressure loss of PSP at 600 GPM is for concentrations between 25% BWOC and 30% BWOC are 567.6 psi, but between 30% BWOC and 35% BWOC, the difference in annular pressure loss is 115.8 psi. The results indicate that pressure loss could be minimised by increasing the concentration (BWOC) of PSP. This helps to reduce the plastic viscosity and hence the annular frictional pressures.

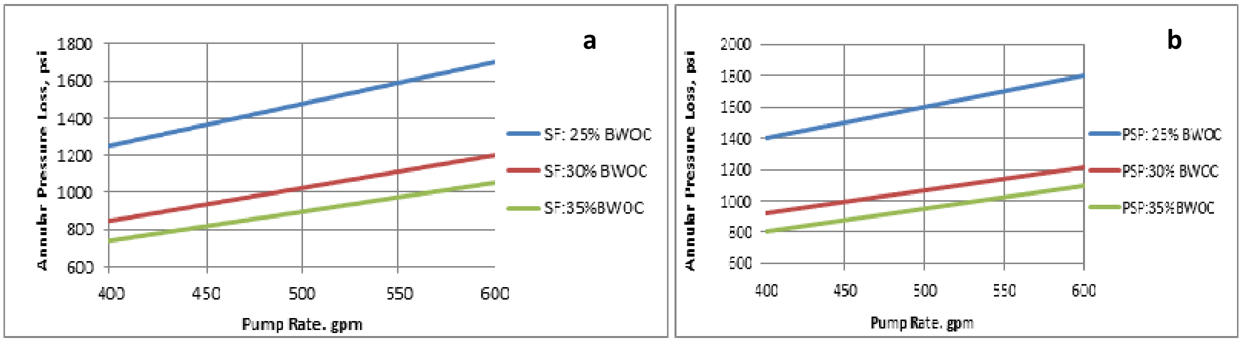

Figure 6. Effect of (a) silica flour and (b) PSP additives concentration annular pressure loss.

4.1.7. Comparison of annular pressure losses values of silica flour (sf) and Periwinkle shell powder

From Figure 7a, the annular pressure losses are higher for PSP additive than SF additive at different pump rates. The difference in annular pressure loss between PSP and SF at 600 GPM is 71.67 psi. Although, the difference is not so much, however, cementing operation utilising PSP additive in the cement requires higher pump pressures than SF additive due to higher annular pressure losses realised during cementing operation with PSP cement slurry.

From Figure 7b, also the annular pressure losses are higher for PSP additive than SF additive at different pump rates. The difference in annular pressure loss between PSP and SF at 600 GPM is 79 psi. Although, the difference is not so much, however, cementing operation utilising PSP additive in the cement requires higher pump pressures than SF additive due to higher annular pressure losses realised during cementing operation with PSP cement slurry.

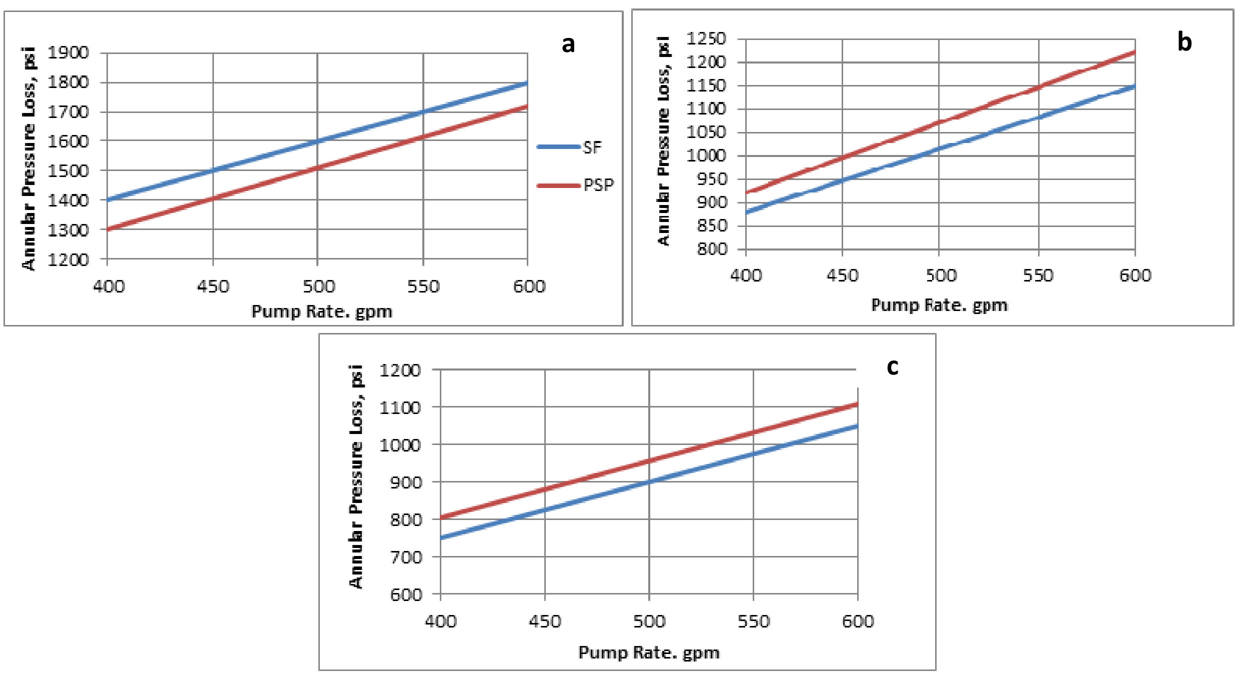

Figure 7. Comparison of annular pressure losses for SF and PSP cement additives at (a) 25%, (b) 30% and (c) 35% BWOC concentration.

From Figure 7c, the annular pressure losses are higher for PSP additive than SF additive at different pump rates. The difference in annular pressure loss between PSP and SF at 600 GPM is 63.54 psi. With the observed difference, however, cementing operation utilising PSP additive in the cement requires higher pump pressures than SF additive due to higher annular pressure losses realised during cementing operation with PSP cement slurry.

4.1.8. Effect of cementing additives on annulus circulating pressures

The circulating pressures in the annulus as the cement slurry is pumped down the annulus are investigated in this section. The circulating pressure is the pressure exerted by the equivalent circulation density (ECD) under static condition. The circulating pressure relates to the sum of the combined hydrostatic and the frictional pressure losses at the depth considered.

4.1.9. Effect of silica flour additive on annular circulating pressures

The effect of concentrations of silica flour cement additive on the annular circulating pressures at various TVDs is shown in Figure 8a.

From Figure 8a, it is observed that the annular circulating pressures increase with increase in true vertical depth of the well. Furthermore, it can also be observed that the circulating pressures decreases with increase in the concentration BWOC of silica flour. The changes in the annular circulating pressures become more apparent as the true vertical depth increases. At the bottom of the well (target depth) in the annulus, the annular circulating pressure of the cement slurry was 7,111 psi, 6,796 psi and 6,690 psi for 25% BWOC, 30% BWOC and 35% BWOC respectively.

4.1.10. Effect of PSP additive on annular circulating pressures

The effect of concentrations of PSP cement additive on the annular circulating pressures at various TVDs is shown in Figure 8b.

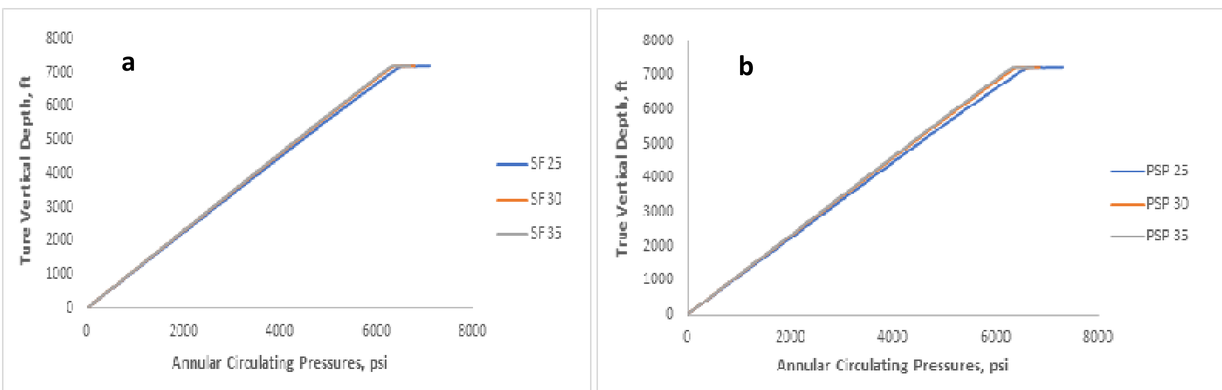

Figure 8. Annular circulating pressures vs TVD at various concentrations BWOC of (a) silica flour and (b) PSP additives.

Figure 8b shows the annular circulating pressure variation with depth for the flow of cement in the annulus formulated with PSP at various concentrations (BWOC). The annular circulating pressures at depths decreased with increase in the concentration (BWOC) of PSP cement additive. The changes in the annular circulating pressures become more apparent as the true vertical depth increases. The annular circulating pressures at the target depth (bottom of the well) were 7,309 psi, 6,869 psi and 6,752 psi for 25% BWOC, 30% BWOC and 35% BWOC respectively.

4.1.11. Comparison of annular circulating pressures of silica flour (sf) and Periwinkle shell powder

Comparison is made in this section on the annular circulating pressures of SF and PSP at the different concentrations (BWOC) considered. Figure 9a shows the annular circulating pressures at 25% BWOC of silica flour and PSP additives in the cement slurry. From Figure 9a, the annular circulating pressures of PSP were very close to that of SF at several TVDs. However, PSP showed slightly higher values than SF. The close values indicate that the circulating of

PSP is like that of SF in the well. This implies that PSP hydraulics is similar in terms of circulating pressure to PSP. At the bottom of the well, the annular circulating pressures of PSP and SF are 7309 psi and 7111 psi, the difference is 198 psi.

From Figure 9b, that the annular circulating pressures of PSP were very close to that of SF at several TVDs. However, PSP showed slightly higher values of annular circulating pressures than SF. These close values indicate that the circulation of PSP is like that of SF in the well. This implies that PSP hydraulics is similar in terms of circulating pressure to PSP. At the bottom of the well, the annular circulating pressures of PSP and SF are 6868 psi and 6796 psi, the difference is 72 psi.

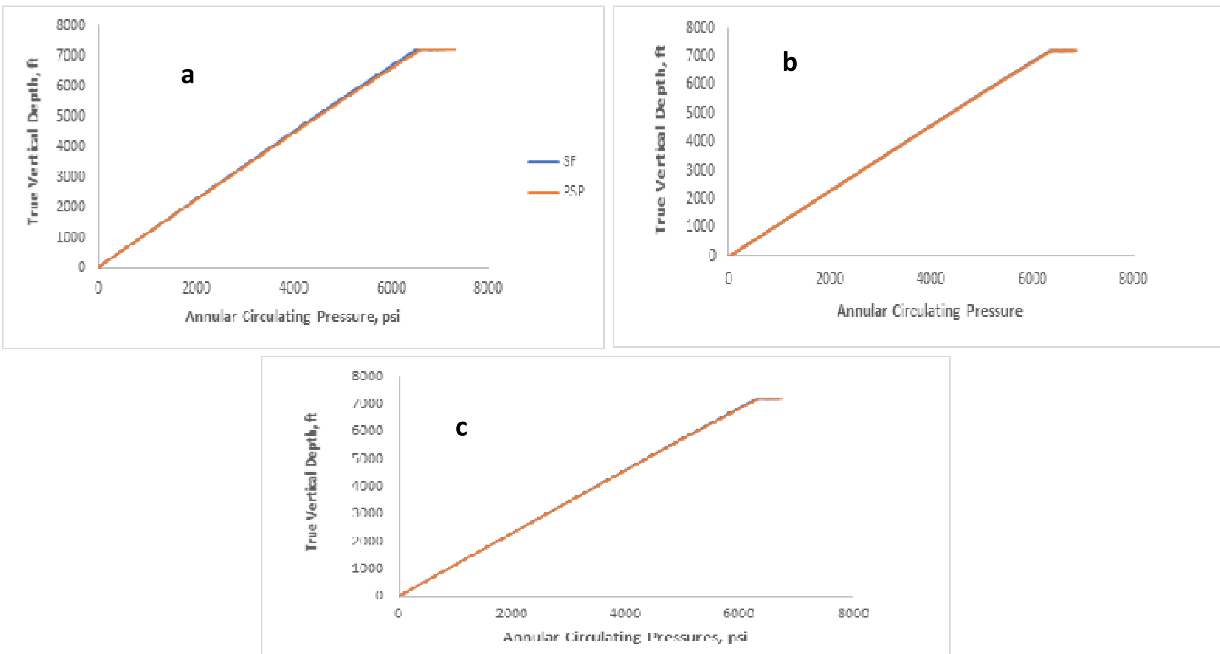

Figure 9. Annular circulating pressure vs depth for SF and PSP at (a) 25%, (b)30% and (c) 35% BWOC.

From Figure 9c, the annular circulating pressures of PSP were very close to that of SF at several TVDs. However, PSP showed slightly higher values of annular circulating pressures than SF. These close values indicate that the circulation of PSP is like that of SF in the well. This implies that PSP hydraulics is similar in terms of circulating pressure to PSP. At the bottom of the well, the annular circulating pressures of PSP and SF are 6751.5 psi and 6690 psi, the difference is 61.5 psi.

4.2. Discussion

The study presents a comprehensive experimental and simulation study conducted to investigate the rheological and hydraulic properties of cement slurries with different additives, which includes silica flour and periwinkle shell powder (PSP) with aim to optimize cementing operations by understanding how these additives affect the rheological behaviour, pressure losses, and circulating pressures of the cement slurry during the cementing process.

When cementing a wellbore, the equivalent circulation density (ECD) is a critical factor in assuring wellbore stability. The findings demonstrate that hydrostatic pressure causes ECD to rise with true vertical depth (TVD). Additionally, the ECD for both silica flour and PSP additives reduces with rising additive concentration (BWOC), suggesting that decreased friction and pressure losses result from greater additive concentrations. This suggests that the additive concentration can be changed to optimize the rheological behaviour of cement slurries.

The annular pressure losses during cementing were examined, and the findings show that pressure losses for both PSP and silica flour increases with increasing pump rates and decrease with higher additive concentrations. This shows that varying the additive concentration during cementing operations would influence annular pressure losses. To ensure effective and successful cementing, higher additive concentrations lead to less pressure losses.

The annular circulating pressures provide insights into the behaviour of the cement slurry as it is pumped down the wellbore. The circulating pressures increased with TVD but decreased with increased additive concentrations. Notably, PSP showed slightly higher circulating pressures compared to silica flour at various concentrations. This suggests that the pumping requirements for cementing with PSP additives might be slightly higher due to increased circulating pressures.

Generally, PSP demonstrated comparable behaviour to silica flour in terms of ECD, pressure losses, and circulating pressures. However, PSP consistently exhibited slightly higher values for these properties, indicating that using PSP as an additive might lead to slightly different operational requirements compared to silica flour. Both silica flour and PSP can be effective additives for optimizing rheological and hydraulic properties of cement slurries. The choice between these additives depends on specific well conditions, operational requirements, and economic considerations.

However, it is pertinent to also investigate PSP and silica flour relative to their environmental considerations, cost and reliability. The Oil and gas industry is increasingly concerned about environmental sustainability. Because silica flour is produced using energy-intensive methods, there are questions about its carbon footprint and role in environmental problems associated with mining. PSP, on the other hand, stands out as a sustainable option because it uses environmentally beneficial periwinkle shells, which are typically discarded as garbage. Utilizing PSP not only minimizes waste but also boosts local economies by encouraging the use of plentiful natural resources.

Additive costs are critical factors that influence the choice of additives in oil and gas operations. Silica flour, being an established additive, benefits from economies of scale and a well-defined market. However, its energy-intensive production process can contribute to higher costs. On the other hand, PSP, is sourced locally from periwinkle shells, and offers potential cost savings by utilizing a readily available, often discarded resource. Further research and optimization may lead to cost-effective production methods for PSP, making it an attractive option.

The reliability of cementing additives is paramount to the success of well operations. Silica flour has a proven field record and performance, it has been tested on a wide range of field conditions with notable performance. Its established usage guidelines and compatibility with cement formulations make it a reliable choice. On the other hand, PSP, being a new additive, with no proven field application requires further testing and validation to ascertain its performance under varying conditions. The reliability of PSP as a strength retrogression additive will depend on rigorous laboratory testing and field trials.

5. Conclusions

From the simulation results obtained, it was deduced that 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). Also, 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 slurries. Similarly, 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 increase 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, and the annular pressure losses were observed to be higher for PSP additive than SF irrespective of pump rates and concentration (BWOC). Moreso, 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, whereas 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.

Declaration of competing interest; *no conflict of interest has been declared by the authors.*

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