Experimental Analysis of Pulverized Oyster and Periwinkle Shells Used as Additives in Water Based Mud and Oilwell Cement

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ABSTRACT

In the drilling and cementing of oil and gas wells, additives are crucial. Many distinct oil and gas well activities have led to the development of numerous mud and cement additives. The proper additive must be chosen and applied in the proper amount to create the ideal mud for every drilling operation and cement slurry for any cementing activity. Different additives serve various purposes. To investigate the impacts of periwinkle and oyster shells as drilling mud and oil well cement as additives, laboratory tests were carried out in this study. After pulverization of the oyster and periwinkle shell samples to particle sizes of 125µm and 250µm, they were used as additives for formulating sixteen samples of water-based mud and oil well cement. The formulated mud and cement samples were subjected to rheological, pH, filtrate loss, and cement setting tests, as well as consistency and cement slurry tests that closely complied with API recommendations. The rheological test's outcomes show that the mud's rheological characteristics declined as their particle sizes varied. The pH of these mud samples increased as their concentration increased, and their filtrate volumes decreased. Additionally, a decrease in cement curing time was seen when the additives' concentration was increased. The findings suggest that additives in mud formulation and cement slurry operate as an accelerator for the cement slurry and that the amount of additive employed has an impact on the mud's rheological properties, pH, density, and filtration qualities. Therefore, using these shells as additives rather than traditional ones can be more cost-effective because it will cut down on overall drilling operations and minimize environmental damage.

Keywords: *Oyster; Periwinkle; water based mud; Oilwell cement*

1. Introduction

Drilling fluid, commonly known as drilling mud, is used in geotechnical engineering to facilitate the drilling of boreholes into the earth. In order to drill oil and natural gas wells, complex heterogeneous fluids called drilling fluids are used (Johannes, 2011; Joel et al., 2012). These fluids are divided into three categories, the first of which is the pneumatic fluid, which contains both air and natural gas and is used in formations where there is a chance of circulation loss. Water base muds and oil base muds are two different types of liquid muds. Water is the continuous phase in the water base muds, while oil is the continuous phase for oil based muds. Oil base muds are preferred for high temperature formation, yet water based mud is favoured above oil base mud because of its economic worth. Aerated muds (mainly water) and foam (primarily gas) make up the pneumatic liquid mixture. The active and inactive substances found in the mud are the two solid categories into which additives are divided. Inactive solids are those that do not significantly react with water and chemicals while active solids are those that react with the water phase and dissolve in chemicals. According to Moore (1974), several additives were added to drilling fluids to improve their efficiency, and a straightforward fluid was transformed into a complex mixture of solid liquid and chemicals.

Mud additives are substances that are added to drilling fluids to carry out one or more specialized tasks, such as weighing agents, viscosifiers, thinners, and elements lost in circulation. Additionally, Oil well cement additives are substances that are mixed with cement slurry to change or improve desirable properties. These substances include fluid loss extenders, fluid loss accelerators, fluid loss retarders, and circulatory loss additives.

According to Zamora (2007), weighted elements are additives added to change the drilling mud's density. To produce low rheology in high density mud and low sag is the most important consideration when choosing the weighting materials to be utilized in drilling fluid. Due to its relative abundance, barite was introduced for use in drilling operations in the petroleum sector.

In 2019, an anticipated 9.5 million metric tons of barite were produced and sold, with China leading the way as the main producer and India coming in second. The fact that barite contains several heavy metals like cadmium, lead, arsenic, etc., which are most likely released and dissolved in the water during drilling operations, has also been proved to make it one of the largest contributors of pollution.

The Federal Government of Nigeria established the Local Content Initiative in the Petroleum Sector under the auspices of the Nigerian National Petroleum Corporation (NNPC) in order to utilize locally available minerals or assets which could serve the same purpose as the foreign and imported materials in order to decrease the financial expense of drilling operations in the country which has brought about this research work of utilizing periwinkle and oyster shell as substitutes.

The goal of the study was to determine whether locally available materials, such as periwinkle and oyster shells, might be used as additives for drilling mud and oil well cement. The study involved gathering and grinding shell samples, formulating cement slurry and water-based mud, calculating rheological properties, assessing the impact of shell additives on mud properties, figuring out cement setting time, and contrasting the effectiveness of the shell additives with conventional ones.

2. Literature Review

This section of the work collected studies relevant to the use of seashells as mud and oilwell cement additives in one piece, analyzed them, and published the findings because it is very valuable to look at the connections between historical events and their implications for the future. The results of this study are presented in straightforward tables for easy reference in order to make them clear. Phansalkar and Popham (1959) presented one of the most important experimental experiments that formed the basis of using seashells as filter loss materials. The two researchers patented their work, which has since become the practical and methodological benchmark that other academics follow. Since then, advancements with numerous shells put to the test have further enhanced investigations into employing seashells.

Table 1: Previous experimental work on the use of seashells in mud & oilwell cement

Author(s), Year	Material/Seashell	Study category	Mud type
Phansalkar and Popham (1959)	Oyster shell	Fluid loss, viscosity and gel strength	OBM
Akeju *et al.* (2014)	Oyster shell	Rheology, gel strength	WBM
Dantas *et al.*, (2014)	Calcite, HV-CMC, Starch	Rheological and filtration properties	Inhibited drilling mud (Potassium citrate)
Odabasi (2015)	$CaCO_3$	Rheology, cake quality and filtrate volume	Drill in fluids
Toka and Toka (2015)	$CaCO_3$	Rheology, cake quality and filtrate volume	WBM
Igwe and Kinate (2015)	Periwinkle shell ash (PSA)	Filter loss, filter cake	WBM
Fagundes *et al.* (2018)	$CaCO_3$	Rheology, filtrate volume, zeta potential	Brine
Dehghani *et al.* (2019)	$CaCO_3$ nanoparticle	Filter loss, cake thickness, surface morphology & rheological properties	WBM

3. Materials and Methods

Oyster and periwinkle shells, bentonite, a Fann V.G viscometer, mixer, analytical weighing balance, Vicat apparatus, measuring cylinder, beaker, stopwatch, pH meter, steel rule, Whatman No.50 Filter Paper, and a spatula were among the tools needed for the lab work. The periwinkle shells were purchased at Itam Market in Uyo, Akwa Ibom State, and contaminants were removed by soaking them in warm water treated with sodium chloride. The periwinkle shells were put in an electric furnace at about 350°C to create fine ash particles after being washed and air-dried. To obtain fine powdered particles for use in the formulation of mud samples, these particles were subsequently sieved using 125- and 250-micron sieves.

3.1 Determination of Density

The mud balance was calibrated with distilled water in order to ascertain the density of the mud sample. The balancing cup was first thoroughly cleaned, dried, then filled with the mud sample. To make sure there was no air within the cup, the lid was then put on it. To ensure precise measurement, the cup and lid were cleansed to remove any mud from the surface. The fulcrum was the knife edge, and the rider was adjusted until the cup's contents and the rider were in balance. On the calibrated arm of the mud balance, the density of the mud sample was read.

3.2 Determination of Mud pH

Using a pH meter, the pH of the mud was established. With the aid of de-ionized water, the pH meter was calibrated. The mud was poured into a beaker made of glass. The pH meter probe was dipped into the sample of mud, maintaining the stable pH level shown on the meter. This was noted as the mud sample's pH level.

3.3 Determination of Rheological Properties

The rotational viscometer was used to establish the rheological characteristics of the mud samples, including their gel strength, viscosity, and yield point. When the viscometer's rotor was set to 600, 300, 200, 100, 6, or 3 revolutions per minute (rpm), the mud sample was poured into the cup to the scribed mark and set on the viscometer's stand. The corresponding dial readings were then taken at steady readings and recorded. The difference between these readings at 600 and 300 revolutions per minute therefore provided the plastic viscosity. The following is how it was expressed mathematically:

Plastic Viscosity (PV) = Dial reading 600rpm - Dial reading 300rpm

Apparent Viscosity was determined mathematically as follows:

Apparent Viscosity = (Dial reading 600rpm)/2

Yield Point was determined mathematically as follows:

Yield Point (lb/100ft^2) = 0.478*(Dial Reading300rpm - PV)

The initial gel strength of the mud was calculated by allowing it to stand still in the viscometer for 10 seconds and recording the maximum dial deflection that resulted from turning the viscometer. The maximum dial deflection obtained after the mud was static in the viscometer for 10 minutes was noted as the 10-min gel.

3.4 Fluid Loss and Mud cake

At room temperature and 100 psi of pressure, the API standard low temperature-low pressure filtration test was conducted for thirty (30) minutes. The 3-inch-diameter by 5-inch-tall cylindrical cell that made up the low temperature, low pressure filter press was used to hold the drilling mud. The Whatman No. 5 filter paper was attached to the bottom of the cell, which was then filled with the mud samples for measurement.

3.4 Methodology

3.4.1 Mud preparation procedures with the pulverized shell samples

Table2 shows the amounts of the additives used for formulating the fresh mud sample. Table 3 shows the amounts of additives in grams which were used to formulate the mud with pulverized oyster shells while Table 4 indicates the quantities of additives used for formulating the muds with pulverized periwinkle shells.

Table 2: Mud Formulation for Fresh Mud

Materials	Quantity
Bentonite	25g
Water	350mL

Table 3: Mud Formulation with Oyster Shell additive (125µm and 250µm)

Materials	Quantity
Bentonite	25 g
Water	350 mL
Oyster Shell	5g,10g,15g,20g

Table 4: Mud Formulation for Periwinkle Shell (125µm and 250µm)

Materials	Quantity
Bentonite	25g
Water	350mL
Periwinkle Shell	5g,10g,15g,20g

3.4.2 Preparation of cement slurry for Consistency Test

In the laboratory experiment, Portland cement slurry was used both neat (without any additives) and with variable concentrations of various additives to see how they affected the cement slurry's setting time. The API's suggested specification was strictly followed in the manufacture of the cement slurry.

4. Results and Discussion

4.1 Particle Sizes Obtained from the Shells

The result of the different particle sizes obtained is as shown in Table 5.

Table 5: Sample Size Distribution

Samples	Size Distribution (µm)	
Oyster Shell	125	250
Periwinkle Shell	125	250

4.2 Results for the Mud Formulations

The mud was formulated following or using the API standard. The order and content proportions are as presented in Table 6 and the result for the measured rheological properties (gel strength, plastic viscosity, apparent viscosity, yield point), fluid loss and well cake.

Table 6: Composition of Formulated Water Based Mud

Mud Composition	Contents				
	Base Mud	Oyster shell (125µm) O1	Oyster shell (250µm) O2	Periwinkle shell (125µm) P1	Periwinkle shell(250µm) P2
Water, ml	350	350	350	350	350
Bentonite, g	25	25	25	25	25
CMC, g	0.5,1,1.5,2	-	-	-	-
O1		5,10,15,20	-	-	-
O2			5,10,15,20	-	-
P1				5,10,15,20	
P2					5,10,15,20

Table 7 are the results obtained from the rheological tests for carboxymethyl cellulose – a conventional fluid loss control additive.

Table 7: Rheological Properties Test Result for Carboxyl Methyl Cellulose (CMC)

	Drilling Mud Sample + CMC			
CMC Mud Properties	**0.5g**	**1g**	**1.5g**	**2g**
Viscosity (cp)	58.00	80	113	208
600 rpm	42.00	57	83	148
300 rpm	16.00	23	30	40
Plastic Viscosity	29.00	40	56.5	104
Apparent Viscosity	7.00	14	23	28
Gel strength lb/100ft^2) 10 sec	10.00	24	29	35
10 min gel	26.00	34	53	60
Yield point (lb/100ft^2)	7	10.8	12	15

Table 8 presents the results of the filter loss, pH and density tests for CMC.

Table 8: Filtration properties, pH and density test result for carboxyl methyl cellulose (CMC)

CMC Mud	Drilling Mud Sample + CMC			
Properties	**0.5g**	**1g**	**1.5g**	**2g**
pH	8.20	8.22	8.24	8.28
Density (ppg)	8.70	8.75	8.80	8.95
Filtrate Loss (ml)				
10min.	15.50	14.00	12.50	11.00
30min.	19.00	17.00	15.50	15.00
Wall cake (inches)	0.07	0.11	0.13	0.14

Table 9 presents the results of rheological tests for the muds formulated with the pulverized shells respectively for 15g and 20g of the additive.

Table 9: Rheological Properties test result for fresh mud, oyster shell, periwinkle shell

Mud Properties	**Fresh Mud**	**15g of sample**				**20 g of sample**			
		O1	**O2**	**P1**	**P2**	**O1**	**O2**	**P1**	**P2**
Viscosity (cp)									
600 rpm	11.50	16.00	19.00	13.00	16.00	12.00	13.00	9.00	9.50
300 rpm	6.50	11.00	13.00	9.00	5.00	9.00	11.00	7.00	8.00
Plastic Viscosity	5.00	5.00	4.00	4.00	5.00	8.00	8.00	4.00	7.00
Apparent Viscosity	5.75	8.00	9.50	6.50	8.00	11.00	8.50	8.00	10.00
Gel strength	2.00	6.50	9.00	5.00	6.00	9.00	11.00	7.00	8.00
($lb/100ft^2$) 10 sec.		9.50	10.50	7.00	8.00				
10 min.	4.00	2.87	3.35	2.39	2.87	12.00	13.00	9.00	9.50
Yield point	0.72					2.88	4.30	3.82	
($lb/100ft^2$)						3.35			

Table 10 presents the results of the filter loss, pH and density tests for the muds formulated with the pulverized shells at 5g and 10 g whereas Table 11shows the same tests for the additives at 15g and 20g concentration.

Table 10: Filtration Properties, pH and density test result for fresh mud, oyster shell, periwinkle shell

Mud Properties	Fresh Mud	5g of sample				10g of sample			
		O1	O2	P1	P2	O1	O2	P1	P2
pH	9.60	9.44	9.61	9.32	9.50	9.57	9.63	9.57	9.39
Density (ppg)	8.70	8.40	8.50	8.60	8.65	8.50	8.50	8.63	8.75
Fluid loss (ml)									
10mins	14.00	15.00	19.00	23.00	30.00	8.70	17.00	20.00	26.00
30mins	22.00	28.00	32.00	37.00	44.00	22.00	27.50	34.00	44.00
Wall cake (inches)	0.13	0.01	0.01	0.25	0.30	0.01	0.02	0.31	0.35

Table 11: Filtration properties, pH and density test result for fresh mud, oyster shell, periwinkle shell

Mud Properties	Fresh Mud	15g of sample				20g of sample			
		O1	O2	P1	P2	O1	O2	P1	P2
pH	9.60	9.70	9.64	9.45	9.62	9.78	9.78	9.51	9.68
Density (ppg)	8.70	8.55	8.70	8.80	9.01	8.60	8.75	8.75	9.20
Fluid loss (ml)									
10mins	14.00	9.00	14.00	17.00	22.00	7.00	12.00	11.00	16.00
30mins	22.00	19.00	22.00	32.00	31.00	16.00	19.00	27.00	28.00
Wall cake (inches)	0.13	0.02	0.02	0.39	0.36	0.02	0.03	0.40	0.39

4.3 Discussion of Results

4.3.1 Viscosity Results

The viscometer speeds and dial readings were converted to shear rate and shear stress, by multiplying the dial reading with the factor 1.073 and 1.067 respectively. Figure 1, Figure 2, Figure 3 and Figure 4 represent the shear stress-shear rate profile (rheogram) of the formulated mud from the experimental results for the different additives at 5g, 10g, 15g and 20g concentration respectively.

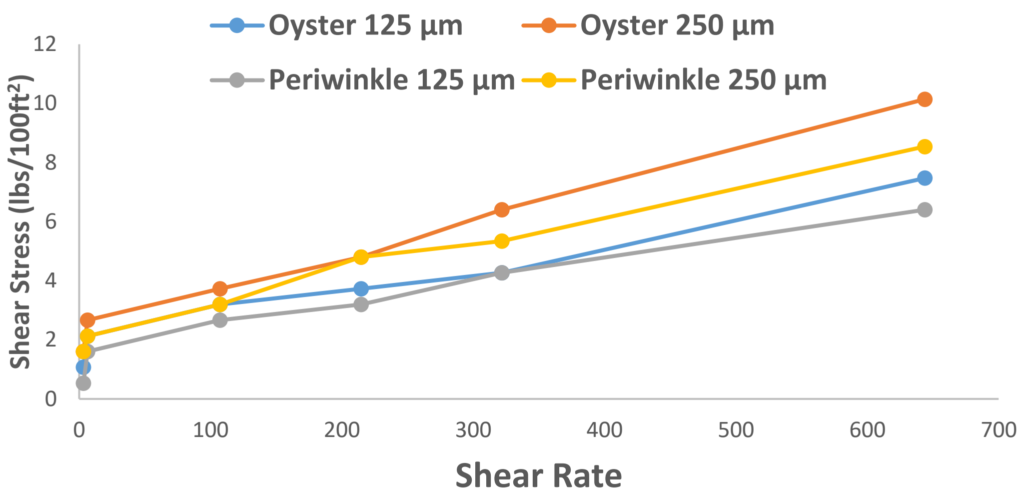

Figure 1: Shear Stress –Shear Rate Profile for 5.0g of Samples

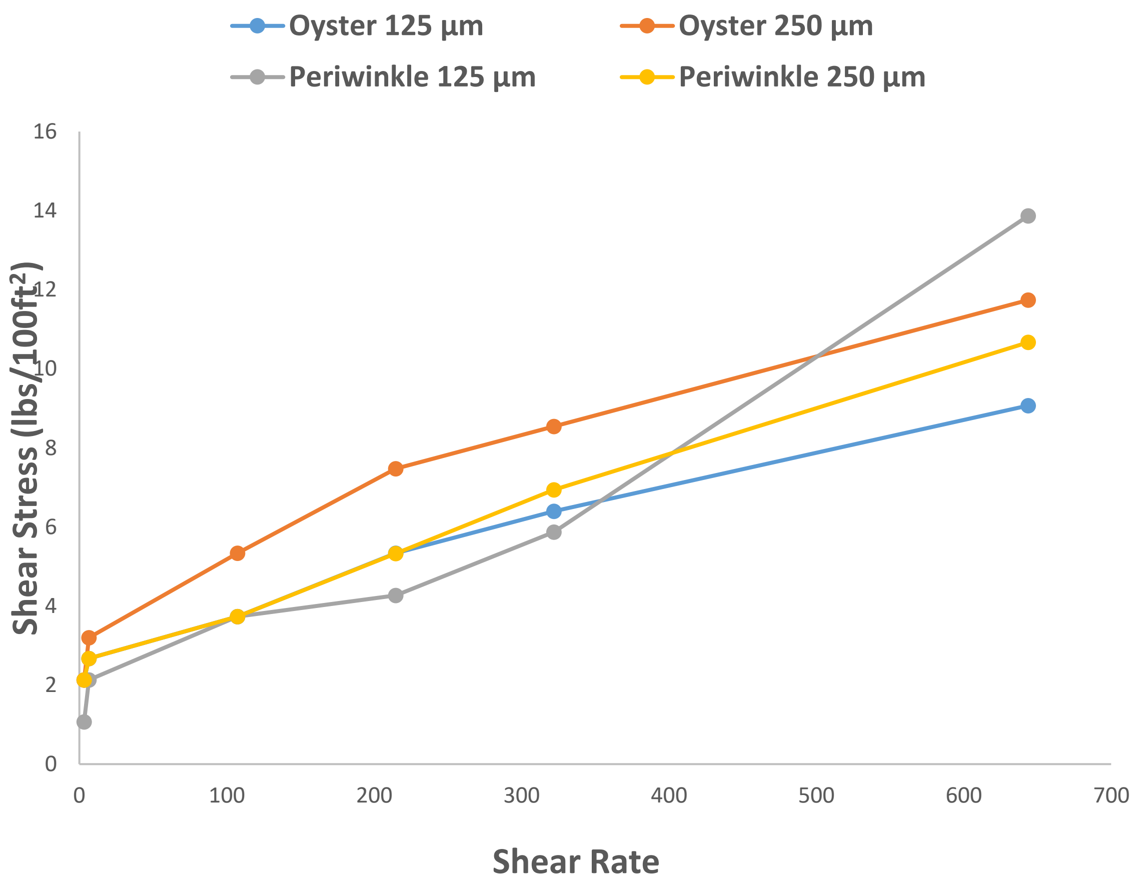

Figure 2: Shear Stress –Shear Rate Profile for 10.0g of Samples

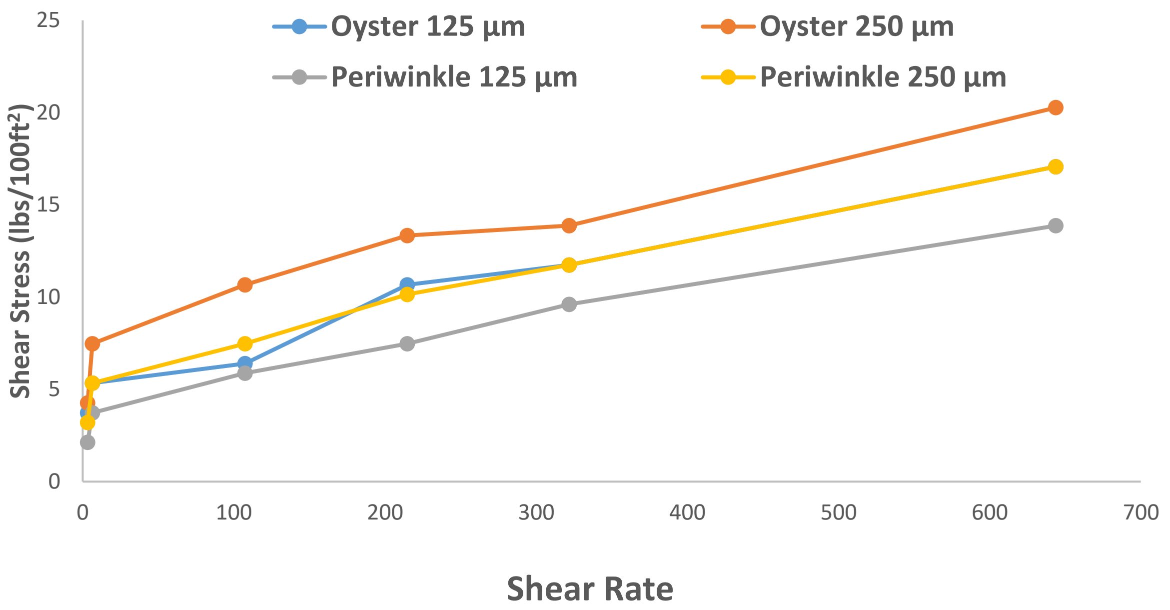

Figure 3: Shear Stress –Shear Rate Profile for 15.0g of Samples

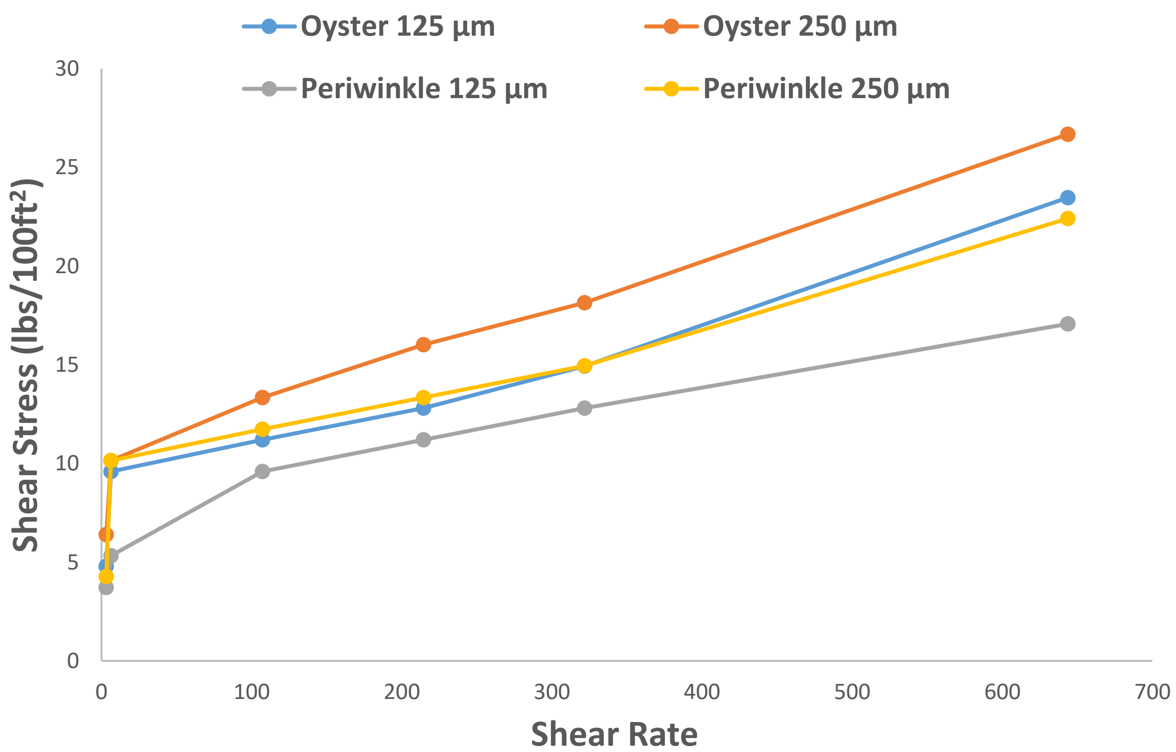

Figure 4: Shear Stress –Shear Rate Profile for 20.0g of Samples

The model samples share a similar rheology, which is an increase from left to right with a vertical axis intercept. In this regard, it is evident that the rheological behaviour of the mud samples is comparable. The water based mud (WBM) formulation displays a rheological model resembling the Bingham plastic model. The yield point (YP), also known as the shear stress minimum, is the point at which a Bingham plastic fluid ceases to flow. Plastic viscosity (PV) refers to the changes in shear stress that occur after the yield point has been reached and where the proportionality constant is present.

4.3.2 Density Results

The key requirement for the drilling fluid system's mud density is the regulation of the formation pressure. Additionally, when mud density increases, the likelihood of a fracture and the rate of penetration decreases. From Figure 5, it can be seen that the periwinkle shells mud has a higher density compared to the oyster shells mud and that the periwinkle shell mud at 250 microns (P2) displays the highest density (9.20 lb/gal) hence the periwinkle shell will act as a better weighting agent.

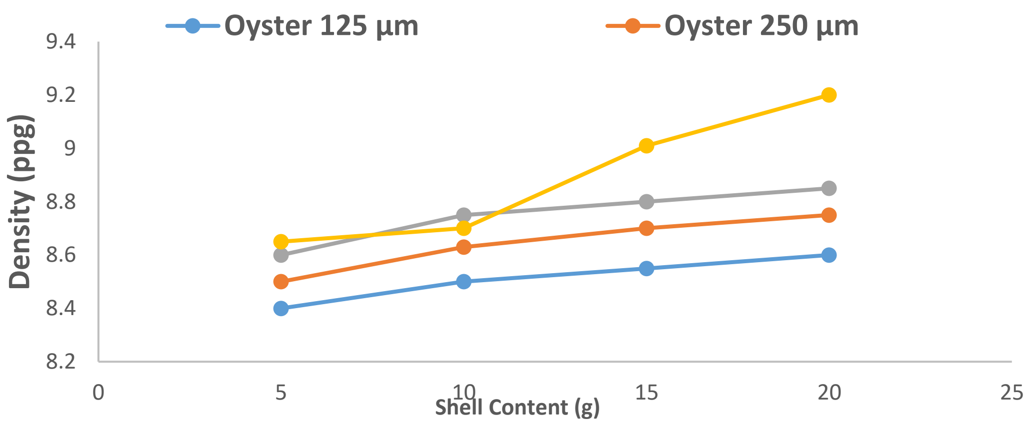

Figure 5: Density Profile

4.3.3 Fluid Loss Results

One of the most crucial characteristics of drilling fluid is filtration rate, particularly when drilling an unconsolidated or permeable formation when the hydrostatic pressure is higher than the formation pressure. The primary source of pipe sticking and drag is wall sticking, which can be avoided or minimized with proper filtration monitoring and control. In some cases, this can also increase borehole stability. Figure 6 shows the filtrate volume from the formulated water based muds collected after 10 and 30 minutes respectively. the result shows that the water volume collected from oyster 125µm (O1) mud 16 mL at 20g (shell) was less than the oyster 250µm (O2) mud 19 mL, periwinkle 125µm (P1) mud 27 mL and periwinkle 250µm (P2) of the same masses at 30min. Hence, this will make the oyster 125µm (O1) a more preferable fluid loss control additive.

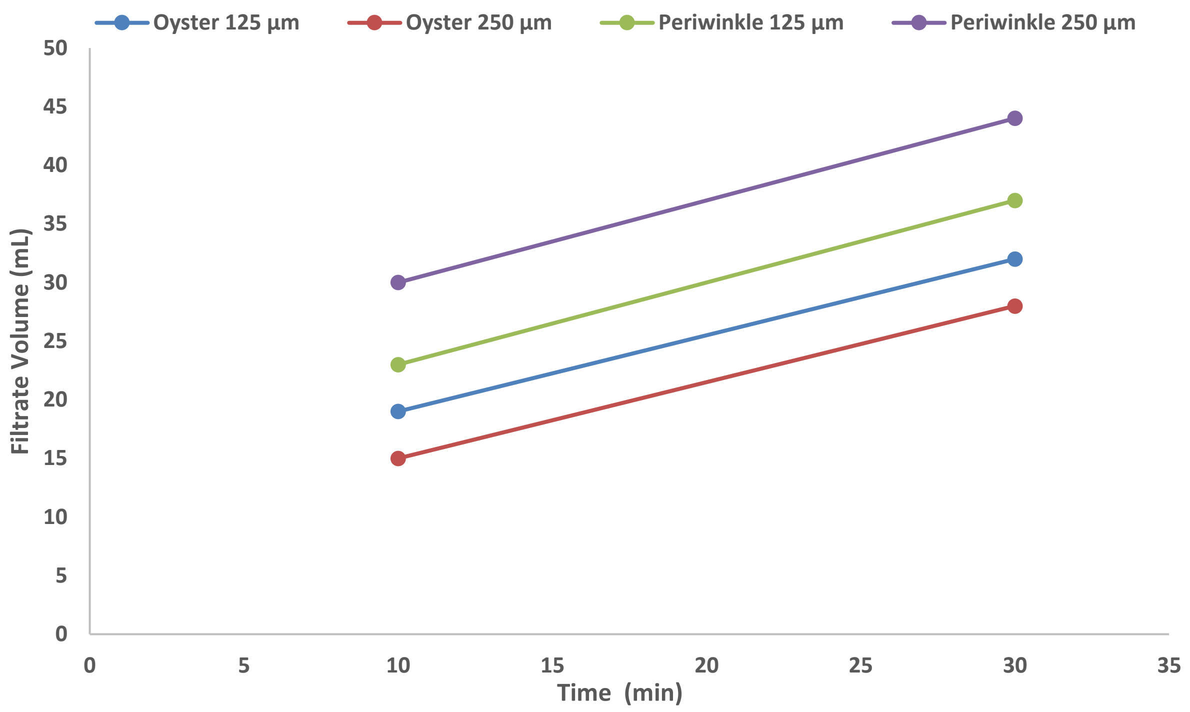

Figure 6: Fluid loss profile at 5.0g

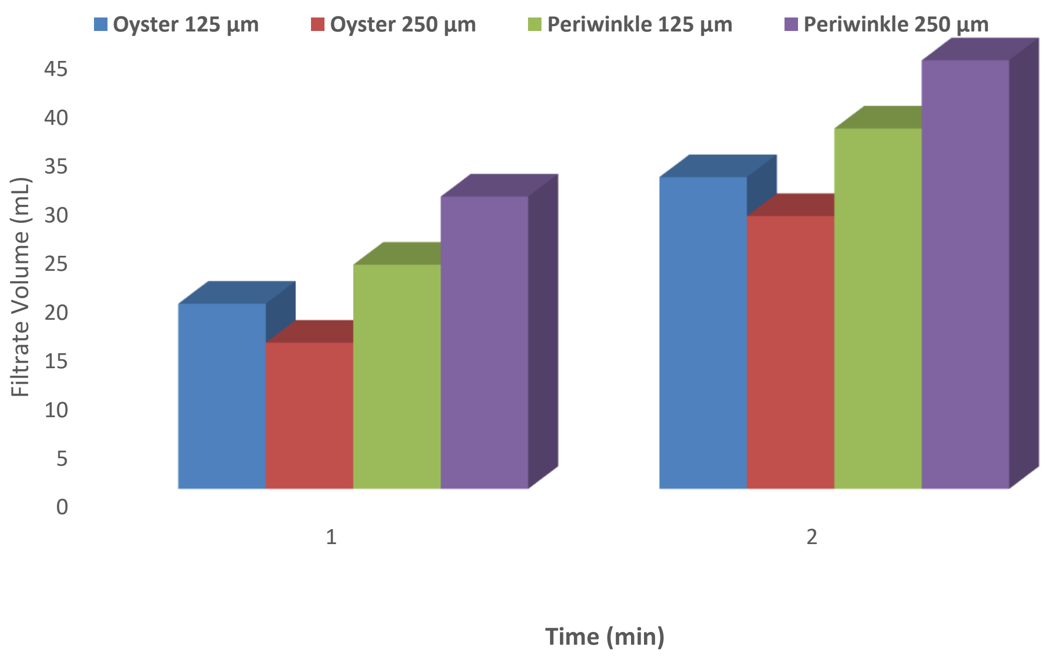

Figure 7: Comparison of Filtrate Loss with Time

4.3.4 Gel Strength Results

Another crucial characteristic of drilling fluids is their ability to suspend drill solids (drilled cuttings) and weighting material after mud circulation is stopped. This is achieved by the gel strength of the mud. Figure 8 and Figure 9 depicts the gel strength of the formulated muds. Table 4 and Table 5 indicate that oyster 250µm (O2) mud at 15 and 20g addition has a high gel strength value at both 10 second and 10 minutes compared to oyster 125µm, periwinkle 125µm and Periwinkle 250µm muds. Thus, the gel strength value of oyster 125µm, periwinkle 125µm and periwinkle 250µm muds shows that the exhibit a flat gel structure, meaning that the mud will remain pumpable with time if left static in the hole. On the other hand, the gel strength value of oyster 125µm mud at 10-minute gel value were higher than the 10-seconds gel value indicating that the 250µm oyster mud exhibits a progressive gel structure. This is an indication that the gelation of the 250µm oyster mud is rapidly gaining strength with time, which generally is an undesirable feature of a drilling mud.

Therefore, the weak or fragile property of 125µm oyster, 125µm periwinkle, 250 µm periwinkle muds is desirable during drilling operation as the gel can be broken easily lower pump pressure to make circulation. On the other hand, the high value of 250µm oyster gel strength would lead to high circulation breakdown pressure and increase pumping costs as high pump power is required to overcome this gelling potential of 250 oyster water based muds.

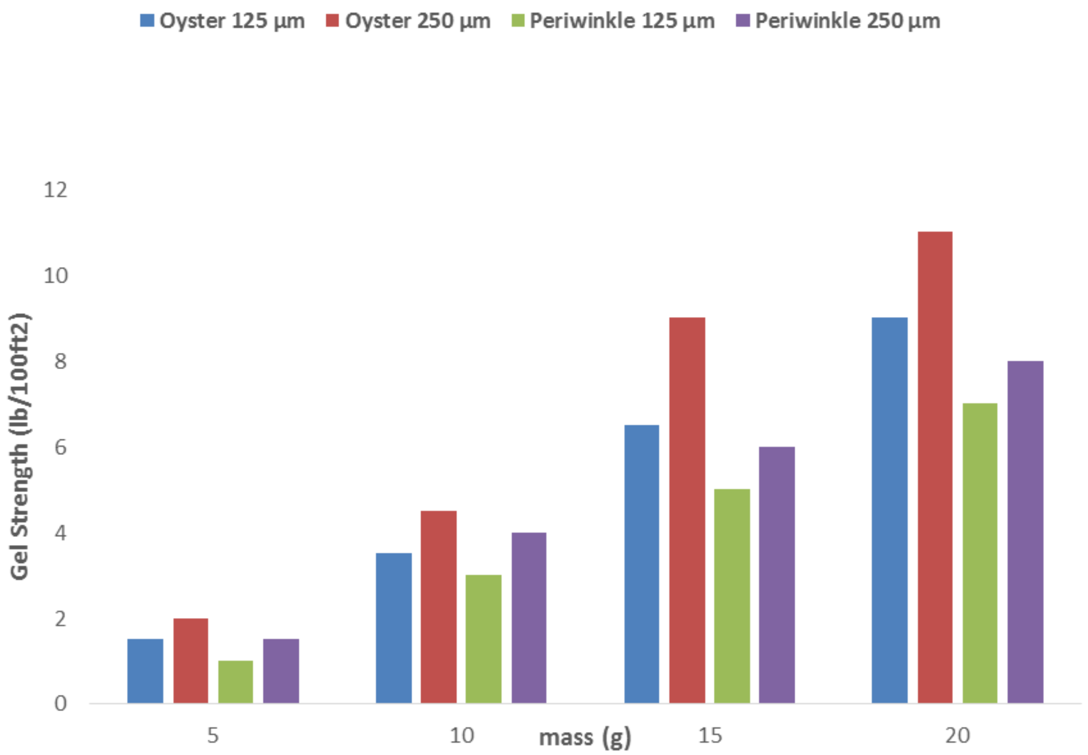

Figure 8: Gel strength at 10 seconds

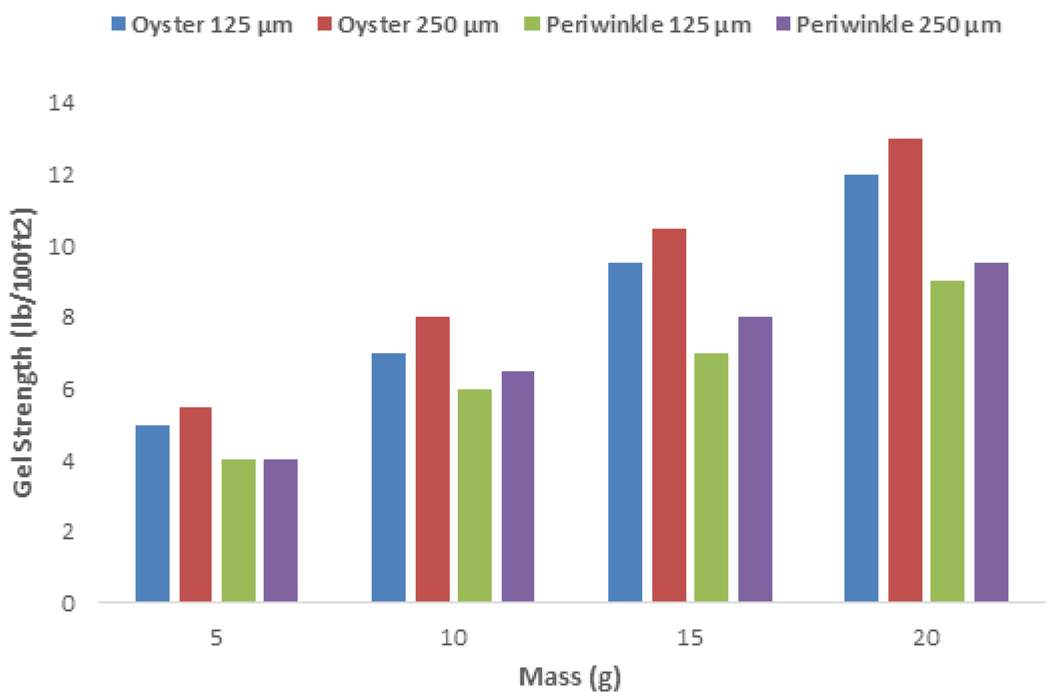

Figure 9: Gel Strength at 10 min

4.3.5 pH Measurement

The pH of a mud plays a role in controlling the solubility of calcium when drilling carbonate formations. The oyster 125µm has a low pH and is best suited when drilling a formation as shown in Figure 10.

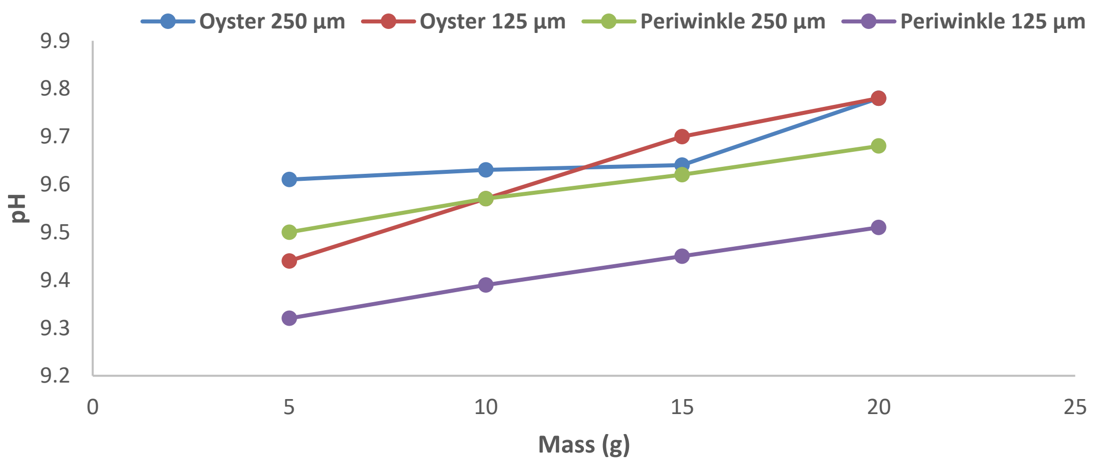

Figure 10: pH Profile

4.3.6 Wall Cake Thickness Measurement

The 250 microns of periwinkle shell mud has a higher filtrate volume compared to other mud samples. Generally, high filtrate volume is associated with thick filter cake because the cake is associated by deposition of clay particles on the walls of the hole during filtrate loss to the formations. Therefore, the higher the filter volume, the thicker the filter cake and the less efficient the drilling mud. In view of its high filtrate rate, 250um Periwinkle has a thicker mud cake (0.40 inch.) than Oyster 125µm, Oyster 250µm and Periwinkle 125µm respectively as presented in Figure 11. The effect of this is that a thick wall cake reduces the effective diameter of the drilled wellbore, thereby increasing the area of contact between the drilled pipe and the cake leading to increase of stuck pipe incidents. Based on this result Oyster 125µm mud formulated has good filtrate properties that will be effective for drilling purposes as it would prevent pipe sticking.

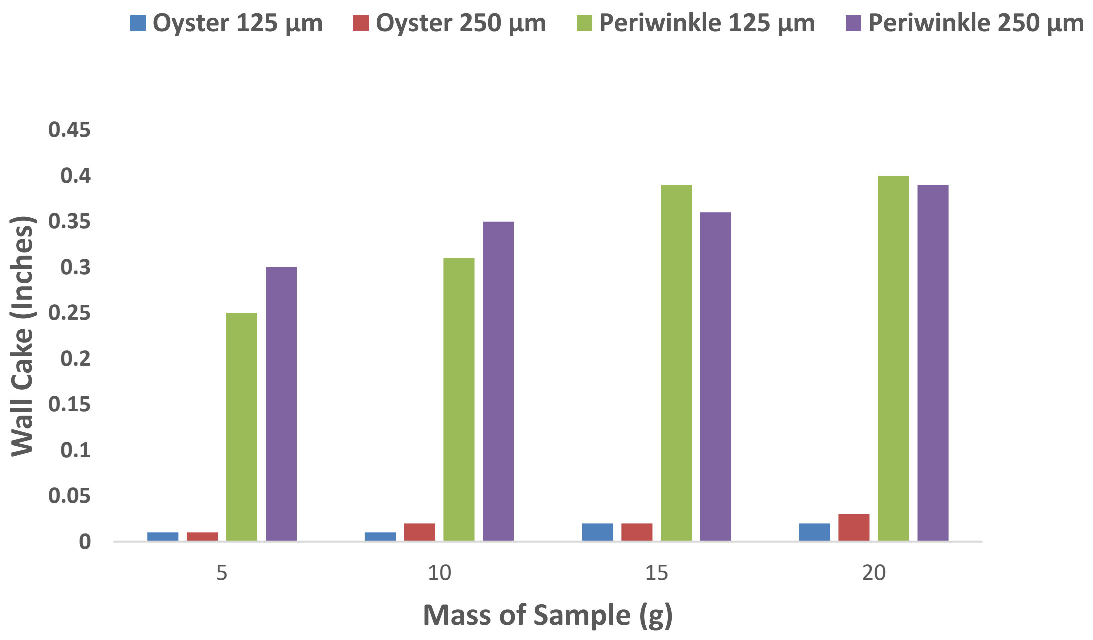

Figure 11: Mud Thickness

4.4 Cement Consistency Test Results

4.4.1 Initial Setting Time

The initial setting time of a given cement paste is the interval between the time the cement and water first come into contact and the time a $1mm^2$ cross-section needle reads between 5-7 mm from the bottom in a typical Vicat apparatus. The initial setting time must not be shorter than 45 minutes in accordance with American Petroleum Institution (API) requirements, however in the field, initial setting times of at least 90 minutes are desirable.

4.4.2 Final Setting Time

This is essentially the amount of time that has passed from the moment that cement and water first come into contact and the moment when the smaller needle, which has a $1mm^2$ cross-section and 0.5mm of depth, has completely pierced the paste and the outer metal attachment, which has a 5mm diameter, has left no trace on the cement paste. It is always preferable to have a lower final setting time value to avoid incurring significant form work costs. The majority of the criteria state that the final setting time must not be less than (90 + 1.2 x (initial setting time) min. and must not be more than (90 + 1.2 x (initial setting time) min. final setting time 10 hrs.

4.4.3 Effect of Oyster and Periwinkle Shells on Portland Cement Setting Time

Additives can change the pace at which cement hydrates after being combined with water. Table 12 displays the results of the consistency test. In order to make a typical consistency test, 140 mL of water are needed. This is the same as using 26% of the weight of regular Portland cement. This results in a water to cement ratio of 0.26, which was used to create the oyster and periwinkle shell ash paste on which the setting time test was performed. based on the setting time test results, as shown in the image. The cement paste alone takes longer to set than the oyster and periwinkle shell ash paste. This demonstrated that the setting time of cement is lowered by the addition of oyster and periwinkle shell ash.

Table 12: Setting time test result for Ordinary Portland Cement

Mass of Sample (g)	**Initial Setting time (min)**	**Final Setting time (min)**
400	150	390

Table 13: Setting time test result for Periwinkle (125µm)

Mass of Sample(g)	Initial Setting time (min)	Final Setting time (min)
5	130	210
10	123	175
15	114	163
20	110	158

Table 14: Setting time test result for Periwinkle (250µm)

Mass of Sample(g)	**Initial Setting time (min)**	**Final Setting time (min)**
5	127	230
10	119	221
15	111	213
20	107	205

Table 15: Setting time test result for Oyster (125µm)

Mass of Sample(g)	Initial Setting time (min)	Final Setting time (min)
5	133	311
10	107	285
15	84	258
20	73	247

Table 16: Setting time test result for Oyster (250µm)

Mass of Sample(g)	Initial Setting time (min)	Final Setting time (min)
5	117	206
10	113	194
15	107	185
20	104	179

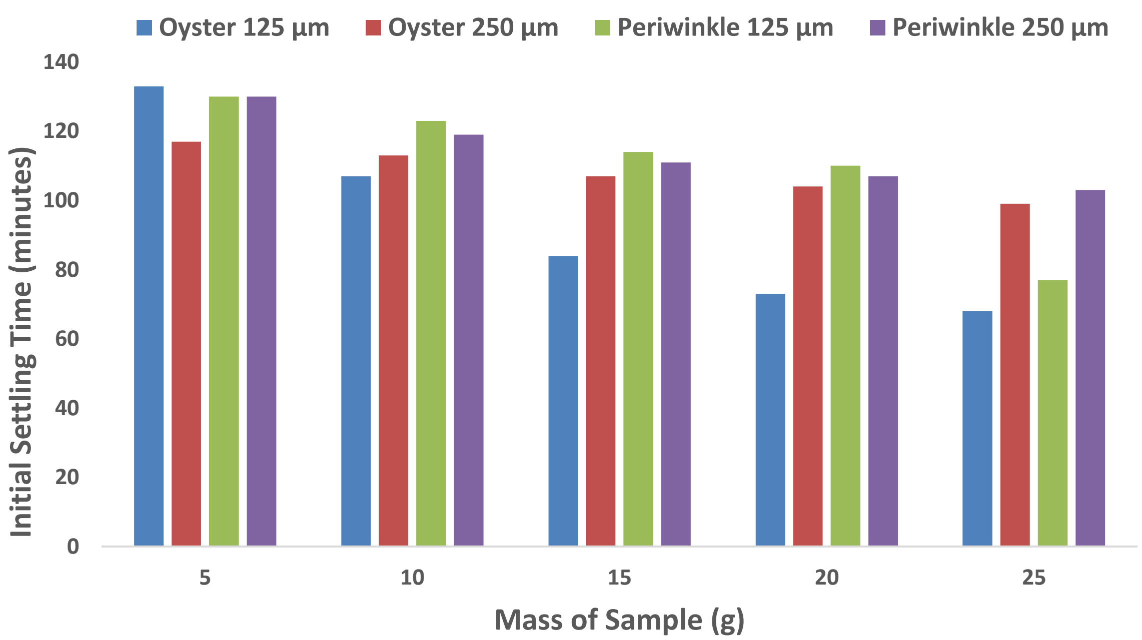

Figure 12: Consistency Test Initial Setting Time

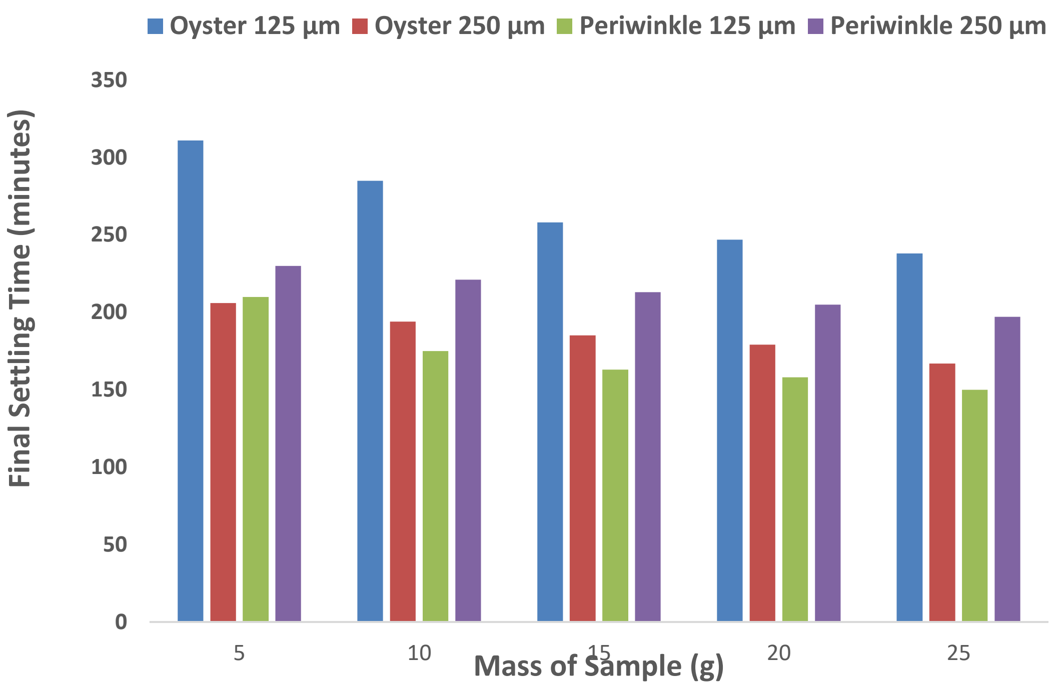

Figure 13: Consistency Test Final Setting Time

5. Conclusion

This article presents the findings of laboratory experiments and comes to the conclusion that oyster shell (125um) and periwinkle shell (250) can be utilized to control filtration loss and act as weighing agents, respectively. The work has equally shown that oyster and periwinkle shell ash can be employed as accelerators in oil well cement since they shorten the setting period when added to cement. In all, the API-recommended criteria are met by the cement paste and mud which were formulated using pulverized oyster and periwinkle shells.

6. Recommendations

On the basis of this work's findings, the following recommendations are made:

i. Oyster and periwinkle shells were added to water-based muds as filtration control loss materials, and the findings were encouraging, necessitating further research into their effects on viscosity and gel strength in oil-based muds.

ii. Accelerators should be made out of the ash from oyster and periwinkle shells.

iii. During the laboratory testing, the shells were subjected to 350°C and added to muds and oilwell cements. Vigorous stirring with a trowel was used to create uniformity for 3 to 5 minutes before the addition of water. Further testing utilizing this mixing procedure at various temperatures is advised as a continuation of this work because the observed setting time may vary with temperature changes.

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Conflicts of Interest

No conflicts of interest exist.

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