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Investigating the Effect of Selected Nigerian Pozzolanic Materials on Rheological Properties of Oil Well Cement Slurries

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Highlights

- This paper focuses on the effects of some selected Nigerian pozzolanic materials on the pumpability of oil-well cement slurry.
- It is a laboratory analysis on the rheological properties of oil-well cement slurry that affect its pumpability.
- A highly precise and more accurate results were obtained.

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ABSTRACT

Oil well cementing is a crucial aspect of completion process when drilling oil and gas wells. It ensures the integrity of wellbores and prevents the migration of fluids into the wellbore. The rheological properties of oil well cement slurries play a crucial role in their successful placement and performance. Traditional oil well cements are composed primarily of Portland cement, water, and admixtures. However, concerns over environmental sustainability and resource depletion have driven the exploration of alternative cement additives, such as pozzolanic materials. Nigerian pozzolanic materials, such as silica fume, rice husk ash, and palm oil fly ash, have emerged as promising alternative additives in formulating cement slurries due to their sustainability benefits and potentials to enhance cement properties. A slurry of Class-G-cement and water only was initially formulated, with a water-cement ratio of 0.44 as per API Standard. The slurry was stirred for 5 minutes to get a good homogeneous mixture and the slurry's density was determined using Mud Balance which gives a cement density of approximately 15.8 ppg (lbm/gal). Bentonite was introduced as an extender and it reduced the slurry's density to 13.1 ppg. Bentonite is considered an extender additive in cement, which means bentonite reduces the cement density by increasing its volume (yield). Using a mixing ratio of 0.44 as per API standard for class G cement would give a slurry density of 15.8 ppg. The introduction of the extender (bentonite) at 8 % BWOC reduced the slurry's density from 15.8 ppg to 13.10 ppg and subsequently increased the slurry's yield,The rheology tests were performed at the temperature of 80, 100 and 120 °F for the cement slurries, and the tests were conducted when the temperatures in the slurry reached this temperature. Silica fume and rice husk ash performed credibly well at the determined temperature and pressure.

Keywords: Oil-well cement,Pozzolanic materials, palm oil fly ash, rice husks ash, thickening time

I. INTRODUCTION

Oil well cementing is a crucial aspect of completion process when drilling oil and gas wells [1]. It ensures the integrity of wellbores and prevents the migration of fluids into the wellbore. The rheological properties of oil well cement slurries play a crucial role in their successful placement and performance [2]. Rheology is the study of the flow and deformation of fluids, and it provides valuable insights into the behavior of cement slurries under various conditions [2]. Traditional oil well cements are composed primarily of Portland cement, water, and admixtures [3]. However, concerns over environmental sustainability and resource depletion have driven the exploration of alternative cement additives, such as pozzolanic materials. Pozzolanic materials are siliceous or aluminous substances that react with calcium hydroxide, a byproduct of cement hydration, to form additional cementations [4].

Nigeria, with its abundant natural resources, holds immense potential for the utilization of locally sourced pozzolanic materials in oil well cementing. Investigating the effect of these materials on the rheological properties of cement slurries is essential for optimizing their performance and ensuring wellbore integrity.

1.1 Oil WellCement Additives

Hydration progress pace in oil well cement when water is applied to powdered cement are controlled with the use of certain chemicals commonly refers to as additives [4-10]. Additives are chemicals or substances that are usually blended with base cement to improve the quality of the cement. Due to the important roles played by cement in the whole life of a well, the slurry's properties are usually modified to address quite unique and some specific conditions of each well. Many of the additives currently in use are organic in nature, polymeric materials which have been specifically formulated for oil and gas well cementing operations. There are wide varieties of chemical additives to be used as cement slurry accelerators, retarders, extenders, dispersants, fluid loss and loss circulation agents, (Table 1.1 below).

Table 1 Cement additives, functions and examples

S/No	Cement Additives	Function	Examples
1	Density control	Weighting agents	Barite, Hematite
		Extenders	Bentonite, Pozzolan
2	Setting time control	Accelerators	$CaCl_2$, NaCl
		Retarders	Boric acid, HEC
3	Loss circulation	Mitigate lost circulation	Cellophane, Gilsonite
4	Filtration control	Mitigate cement filtration	CMHEC, HEC
5	Viscosity control	Deflocculants	Calcium lignosulfonate
6	Special additives	Antifoam	Polypropylene glycol

1.2 Pozzolan

A pozzolan is a siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds having cementitious properties. It is therefore classified as cementitious material. There are both natural (ACI 232.1R) and artificial (fly ash, ACI 232.2R, and silica fume, ACI 234R) pozzolans. Descriptions of various kinds of pozzolans and specifications for them are given in ASTM C618 and ASTM C1240 [7-8, 12]. Pozzolanic materials occur both naturally in the earth's crust, as well as being produced as by-products of various industrial processes (e.g. fly ash, silica fume, rice husk and some non-ferrous slags).

II. MATERIALS AND METHODS

The materials and the additional additives used are listed in table 2.

Table 2: Cement additives and the quantity used in this work

Materials/Additives	Mass (g)	Function
Class G Cement	255	Cement
Calcium Chloride	4.6	Accelerator
Bentonite	35	Density reducing Additive
Antifoam agent (D-Air 5000)	1.5	Defoamer
Calcium lignosulfonate	8.5	Deflocculant (viscosity)
HEC	20.5	Fluid Loss Additive
Boric acid	0.45	Retarder
Fresh Water	112.2	Base fluid
Silica fume	Varies	Deflocculant (Viscosity)
Rice husk ash	Varies	Deflocculant (Viscosity)

2.2 Methodology

This section outlines the step-by-step method used in carrying out this research work. The sequence starts with sourcing of materials and identifying of equipment for the determination of the various cement slurry's properties and ends with the results discussions. The block diagram is presented in figure 2.1 below.

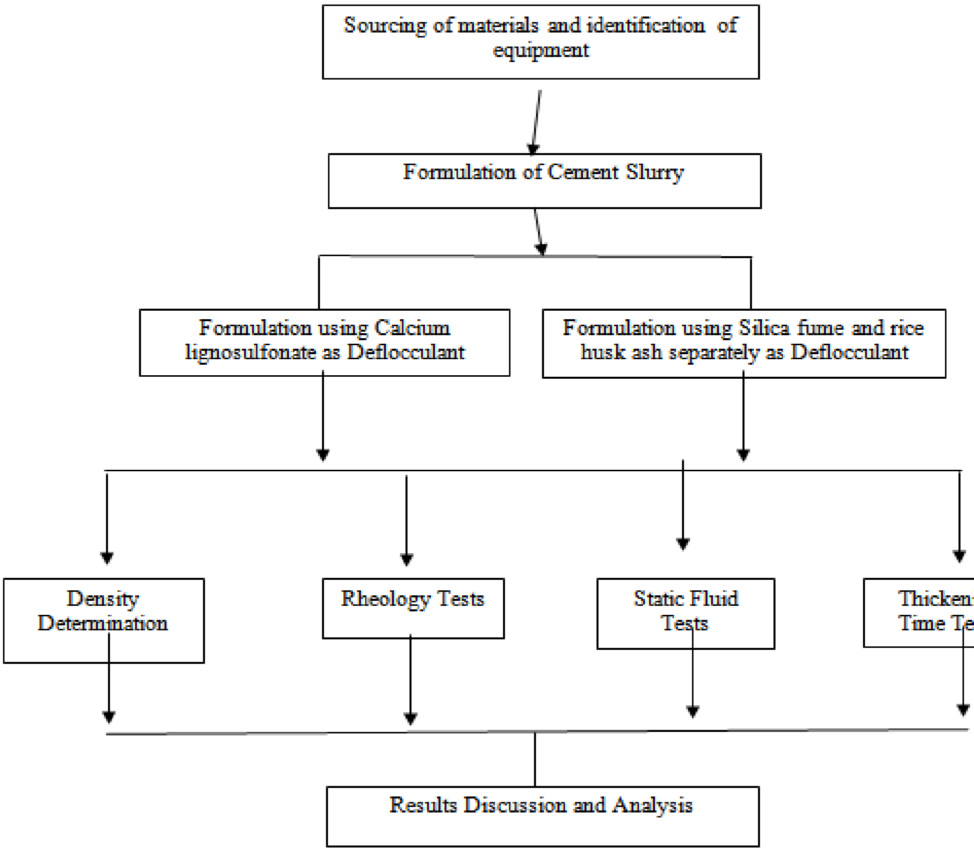

Figure 1 Process flow diagram

2.3 Formulation of Cement Slurry

A slurry of Class-G-cement and water only was initially formulated, with a water-cement ratio of 0.44 as per API Standard. The slurry was stirred for 5 minutes to get a good homogeneous mixture and the slurry's density was determined using Mud Balance which gives a cement density of approximately 15.8 ppg (lbm/gal). Bentonite was introduced as an extender and it reduced the slurry's density to 13.1 ppg. The bentonite was introduced to the bentonite water mixture before it was employed as extender.

2.4 Test Properties.

Four slurry and cement properties were tested to evaluate the effects of the Nigerian pozzolanic materials in the formulation, the properties are: slurry's density, thickening time, static fluid loss and rheology. The test procedures were repeated two or more times for accuracy.

III. RESULTS ANALYSIS AND DISCUSSION

3.1 Result of Addition of Extender (Bentonite) to Class G Cement

Cement slurries for shallow intervals usually are usually lighter (less dense) than the cement slurries designed for deeper intervals. In this case, Portland cement class G was selected, because class G and class H cements can be easily adjusted with additives to fit practically any job specification economically, to formulate light cement. Bentonite is considered an extender additive in cement, which means bentonite reduces the cement density by increasing its volume (yield). Using a mixing ratio of 0.44 as per API standard for class G cement would give a slurry density of 15.8 ppg. The introduction of the extender (bentonite) at 8 % BWOC reduced the slurry's density from 15.8 ppg to 13.10 ppg and subsequently increased the slurry's yield, as shown in Table 3.

Table 3 Effect of addition of bentonite on mixing ratio, slurry density and volume of slurry

Cement Slurry Composition	Mixing Ratio	Slurry Density ppg	Vol. of Slurry gal/sk
Water + Class G Cement	0.44	15.80	8.56
Water + Class G Cement + Bentonite	0.864	13.10	14.5

3.2 Result of Addition of Silica Fume on the Density of the Extended Slurry

The density of the formulated cement slurry with bentonite as extender would further be affected with the addition of silica fume as a viscosity control additive. Silica fume has a specific gravity of about 2.22 which is lower than Portland cement, hence the addition of silica fume to cement slurry will not increase the slurry's density, and rather it affected the flow properties of the cement. Silica fume like bentonite is an extender and ought to be added to Portland cement in the same percent mix as bentonite. Table 4 below show the results of the formulation. In order to maintain the slurry's density at 13.10 ppg, the extenders must be 8 % BWOC. By varying the proportions of the two extenders (Bentonite and Silica fume), Table 4 was generated.

Table 4 Effect of addition of SF on mixing ratio, slurry density and volume of slurry

Cement Slurry Composition	Mix Ratio	Slurry Density (ppg)	Vol. of Slurry (gal/sk)
Water + Class G Cement	0.44	15.80	8.56
Class G Cement + 7 % Bentonite + 1 % SF	0.864	13.10	14.50
Class G Cement + 6 % Bentonite + 2 % SF	0.864	13.10	14.50
Class G Cement + 5 % Bentonite + 3 % SF	0.864	13.10	14.50
Class G Cement + 4 % Bentonite + 4 % SF	0.864	13.10	14.50
Class G Cement + 3 % Bentonite + 5 % SF	0.864	13.10	14.50

3.3 Result of Addition of Rice Husk Ash on the Density of the Extended Slurry

Similarly, the density of the formulated cement slurry with bentonite as extender would further be affected with the addition of rice husk ash as a viscosity control additive. Rice husk ash has a specific gravity of about 2.14 which is quite lower than Portland cement, hence the addition of rice husk ash to cement slurry will not increase the slurry's density, rather it affects the flow properties of the cement. Rice husk ash like bentonite is an extender and ought to be added to Portland cement in the same percent mix as bentonite. Appendix C shows the adjustments in the percent mix of bentonite and rice husk ash in order to maintain the predetermined slurry's density while Table 5 below shows the results of the formulation. While the mixing ratio doubled from 44 % in class G without an extender to 86.4 % with an extender, the yield of the slurry also increased from 8.56 gal/sk to 14.50 gal/sk

Table 5 Effect of addition of RHA on mixing ratio, slurry density and volume of slurry

Cement Slurry Composition	Mix Ratio	Slurry Density(ppg)	Vol. of Slurry (gal/sk)
Water + Class G Cement	0.44	15.80	8.56
Class G Cement + 7 % Bentonite + 1 % RHA	0.864	13.10	14.50
Class G Cement + 6 % Bentonite + 2 % RHA	0.864	13.10	14.50
Class G Cement + 5 % Bentonite + 3 % RHA	0.864	13.10	14.50
Class G Cement + 4 % Bentonite + 4 % RHA	0.864	13.10	14.50
Class G Cement + 3 % Bentonite + 5 % RHA	0.864	13.10	14.50

3.4 Resultant Effect of Addition of Silica Fume and Rice Husk Ash Separately on Rheological Properties of the Slurry

The rheology tests were performed at the temperature of 80, 100 and 120 °F for the cement slurries, and the tests were conducted when the temperatures in the slurry reached these temperatures. Two different approaches of measuring the temperature were performed for the cement slurries. The first was carried out when the wall temperature of the slurry cup reached 80, 100 and 120 °F, and the second tests were conducted when the temperature within the slurries had reached 80, 100 and 120 °F. The readings of the rheometer were recorded after running for 1 minute at each speed, 600, 300, 200, 100, 6, and 3 RPM respectively. The results obtained were tabulated in Tables 6 to 11 below. Figures 2 to 7 show the charts for the two additives used at the various temperatures. The optimum value for silica fume and rice husk ash as deflocculants in the slurry's mixtures were at 100 °F, at a concentration of 3 % and 2 % for silica fume and rice husk ash respectively. At these points, the value of the control experiment and that of the test's experiments were the same, see Table 7 and Table 10.

Table 6 Effect of addition of SF on mixing ratio, slurry density and volume of slurry

	Bingham Plastic Model							
	Wall Temperature @ 80 ^{0}F				Slurry Temperature @ 80 ^{0}F			
Test Parameters	PV	Change from control	YP	Change from control	PV	Change from control	YP	Change from control
Unit	(cp)		(lb/100ft^2)		(cp)		(lb/100ft^2)	
Control	42.6		36.2		48.5		51.2	
1 % SF	38.2		41.4		44.8		56.5	
2 % SF	36.4		42.7		43.5		57.4	
3 % SF	34.6		44.9		42.3		58.3	
4 % SF	33.8		45.3		44.2		58.7	
5 % SF	33.1		46.1		46.1		59.0	

Table 7 Effect of addition of SF on mixing ratio, slurry density and volume of slurry

	Bingham Plastic Model							
	Wall Temperature @ 100 ^{0}F				Slurry Temperature @ 100 ^{0}F			
Test Parameters	PV	Change from control	YP	Change from control	PV	Change from control	YP	Change from control
Unit	(cp)		(lb/100ft^2)		(cp)		(lb/100ft^2)	
Control	40.9		38.3		46.2		53.5	
1 % SF	36.8		43.2		43.7		51.9	
2 % SF	35.7		45.5		45.8		52.7	
3 % SF	34.0		46.4		46.1		53.2	
4 % SF	34.5		46.9		47.2		54.4	
5 % SF	35.2		45.3		47.6		55.2	

Table 8 Effect of addition of SF on mixing ratio, slurry density and volume of slurry

	Bingham Plastic Model							
	Wall Temperature @ 120 ^{0}F				Slurry Temperature @ 120 ^{0}F			
Test Parameters	PV	Change from control	YP	Change from control	PV	Change from control	YP	Change from control
Unit	(cp)		(lb/100ft^2)		(cp)		(lb/100ft^2)	
Control	40.1		39.2		45.2		52.7	
1 % SF	35.4		42.6		42.7		48.6	

2 % SF	34.7		43.5		44.9		51.9	
3 % SF	33.3		45.1		45.6		53.4	
4 % SF	35.1		45.7		44.3		54.5	
5 % SF	36.2		45.9		43.8		55.6	

Table 9 Effect of addition of RHA on mixing ratio, slurry density and volume of slurry

	Bingham Plastic Model							
	Wall Temperature @ 80 ^{0}F				Slurry Temperature @ 80 ^{0}F			
Test Parameters	PV	Change from control	YP	Change from control	PV	Change from control	YP	Change from control
Unit	(cp)		(lb/100ft^2)		(cp)		(lb/100ft^2)	
Control	42.6		36.2		48.5		51.2	
1 % RHA	37.3		42.3		45.6		54.4	
2 % RHA	36.9		43.4		44.8		55.3	
3 % RHA	34.7		44.6		43.5		56.5	
4 % RHA	34.1		45.2		45.1		56.9	
5 % RHA	33.5		45.8		46.7		57.4	

Table 10 Effect of addition of RHA on mixing ratio, slurry density and volume of slurry

	Bingham Plastic Model							
	Wall Temperature @ 100 ^{0}F				Slurry Temperature @ 100 ^{0}F			
Test Parameters	PV	Change from control	YP	Change from control	PV	Change from control	YP	Change from control
Unit	(cp)		(lb/100ft^2)		(cp)		(lb/100ft^2)	
Control	40.9		38.3		46.2		53.5	
1 % RHA	37.9		42.5		45.3		52.3	
2 % RHA	36.8		43.7		46.5		54.1	
3 % RHA	35.5		44.8		47.1		56.4	
4 % RHA	35.8		45.2		47.6		56.7	
5 % RHA	36.2		45.6		48.4		57.2	

Table 11 Effect of addition of RHA on mixing ratio, slurry density and volume of slurry

	Bingham Plastic Model							
	Wall Temperature @ 120 ^{0}F				Slurry Temperature @ 120 ^{0}F			
Test Parameters	PV	Change from control	YP	Change from control	PV	Change from control	YP	Change from control
Unit	(cp)		(lb/100ft^2)		(cp)		(lb/100ft^2)	
Control	40.1		39.2		45.2		52.7	
1 % RHA	37.5		43.6		43.4		49.3	
2 % RHA	35.6		44.5		45.7		51.5	
3 % RHA	35.1		45.7		46.2		53.4	
4 % RHA	36.8		46.1		46.8		54.6	
5 % RHA	37.4		46.9		47.3		55.8	

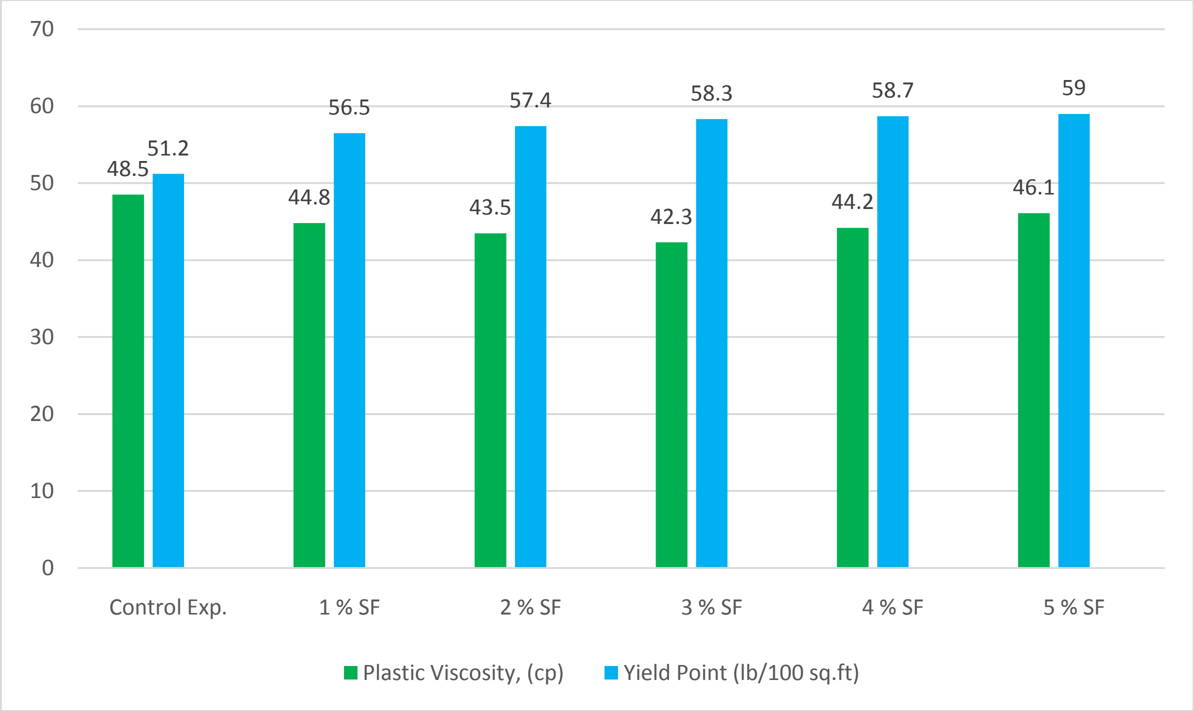

Figure 2 Plastic Viscosity and Yield Point of Silica fume as Viscosity control additive at 80^0 Fahrenheit.

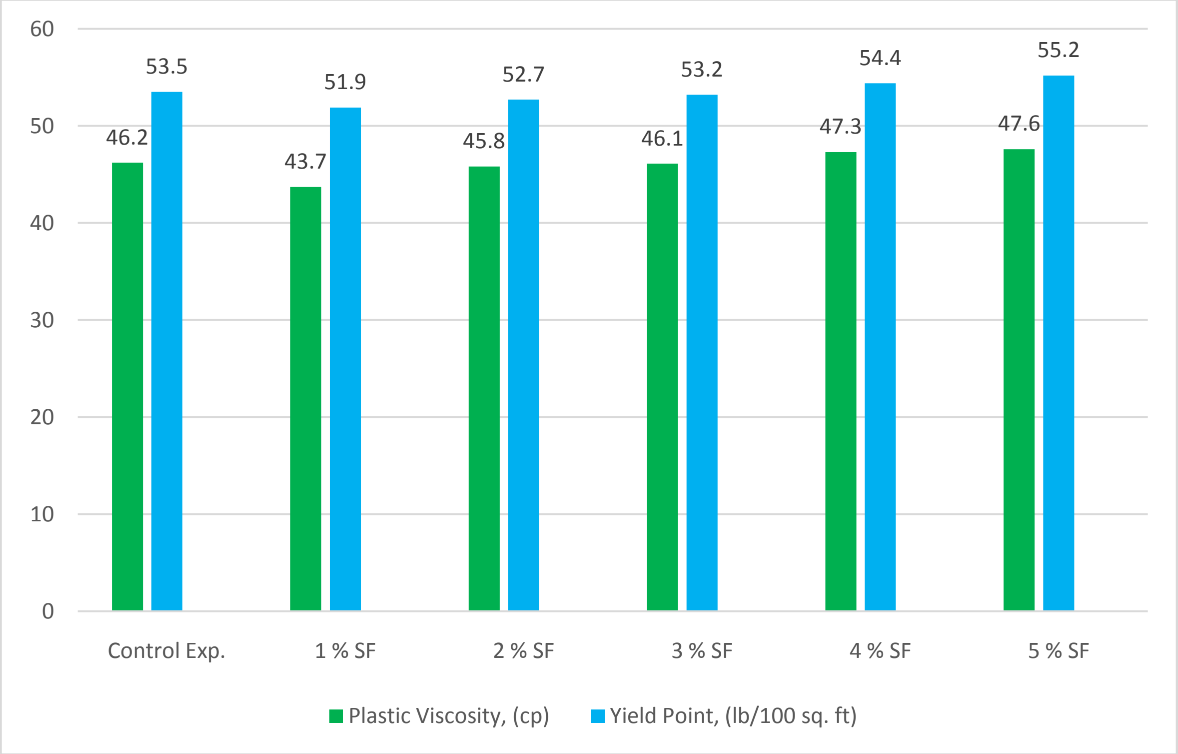

Figure 3 Plastic Viscosity and Yield Point of Silica fume as Viscosity control additive at 100^0 Fahrenheit

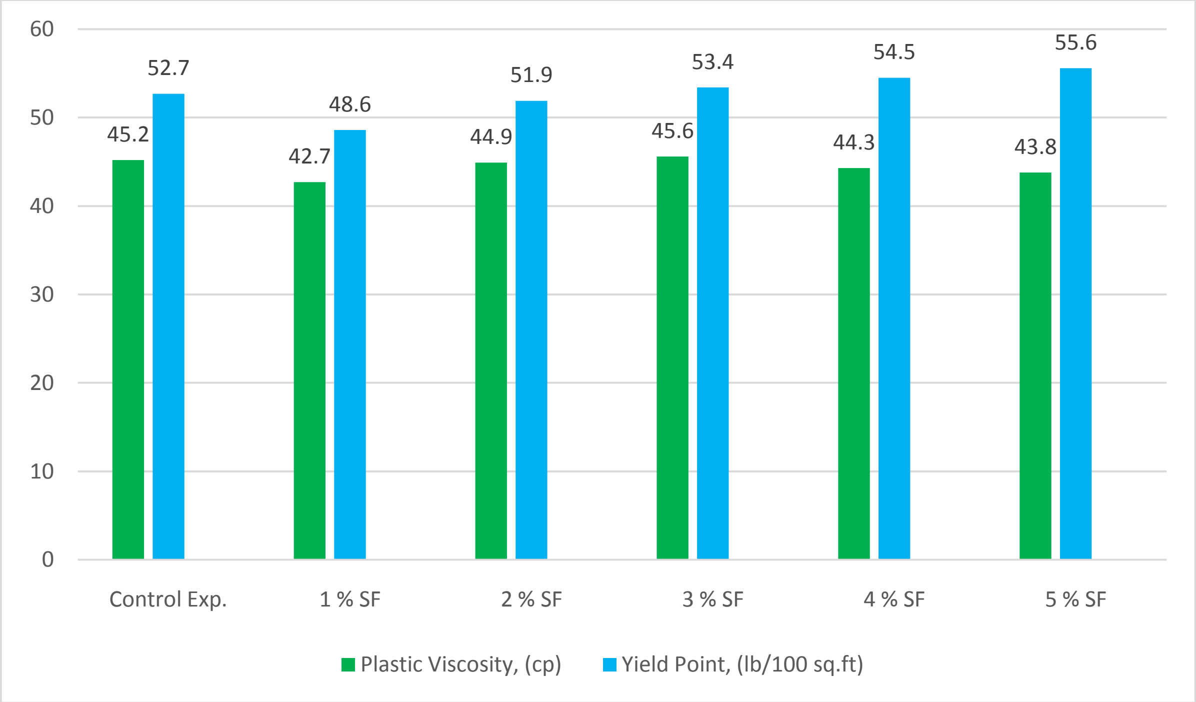

Figure 4 Plastic Viscosity and Yield Point of Silica fume as Viscosity control additive at 120^0 Fahrenheit

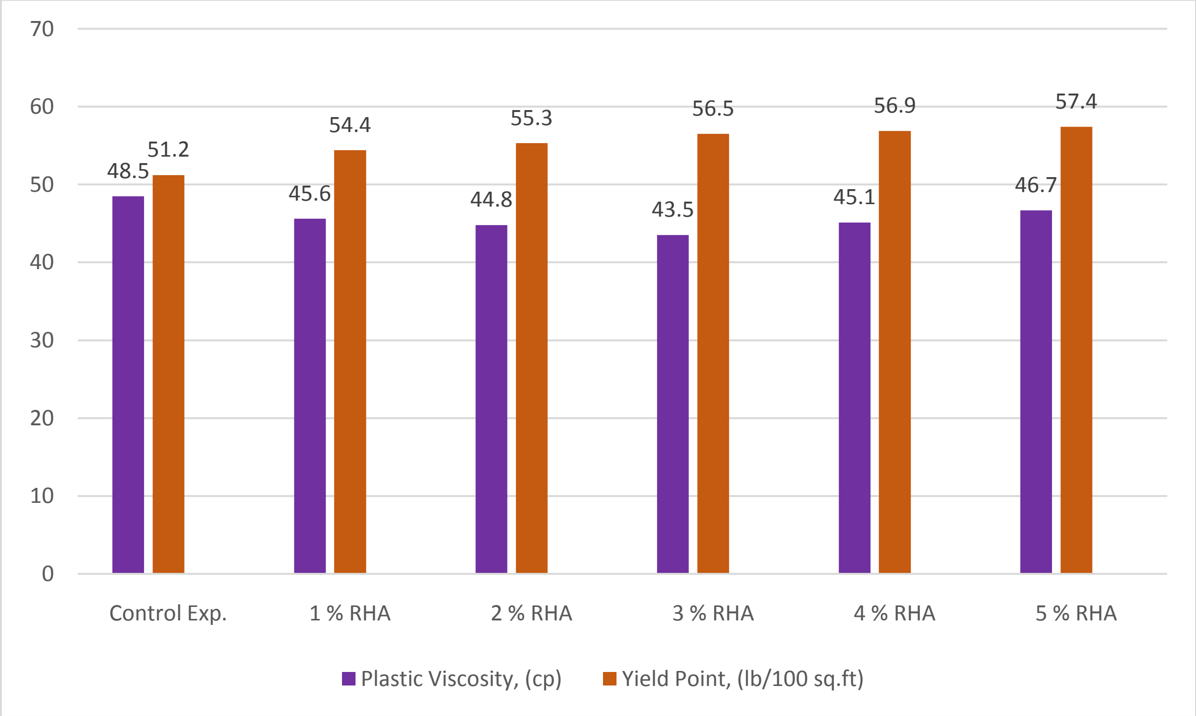

Figure 5 Plastic Viscosity and Yield Point of Rice Husk Ash as Viscosity control additive at 80^0 Fahrenheit

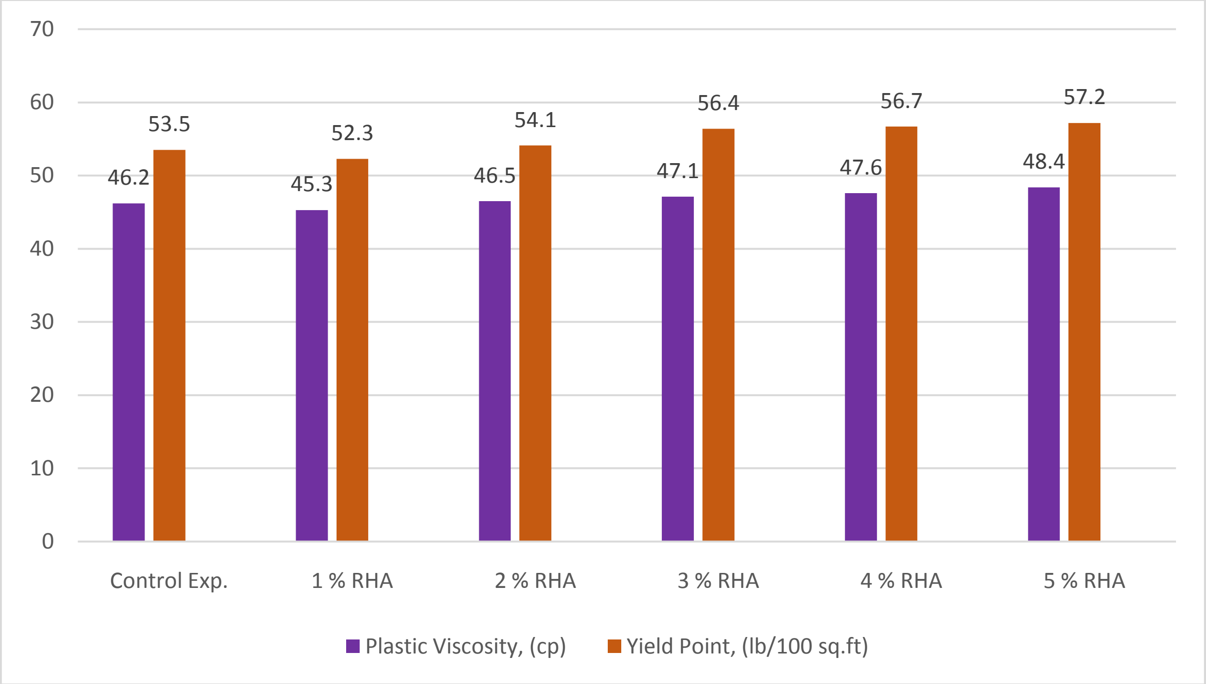

Figure 6 Plastic Viscosity and Yield Point of Rice Husk Ash as Viscosity control additive at 100^0 Fahrenheit

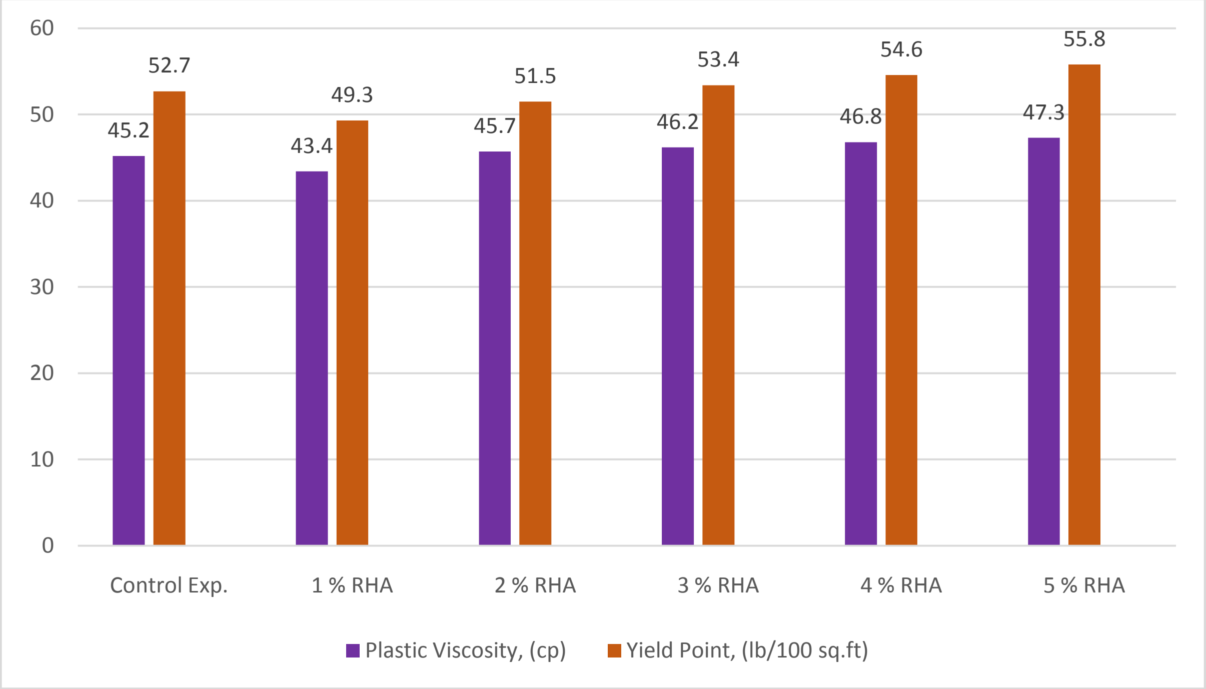

Figure 7 Plastic Viscosity and Yield Point of Rice Husk Ash as Viscosity control additive at 120^0 Fahrenheit.

3.5 Resultant Effect of Addition of Silica Fume and Rice Husk Ash Separately on Fluid Loss Properties of the Slurry

The fluid loss tests were performed at 100 °F for both the control and the test cement slurries. The pressure was 500 psi. 600psi upstream and 100psi downstream. The temperatures were measured in two different ways for both cement slurries, as wall temperature and as a slurry temperature. The summarized results for fluid loss with two different measurements of the slurry temperature are shown in Figures 8 and 9.

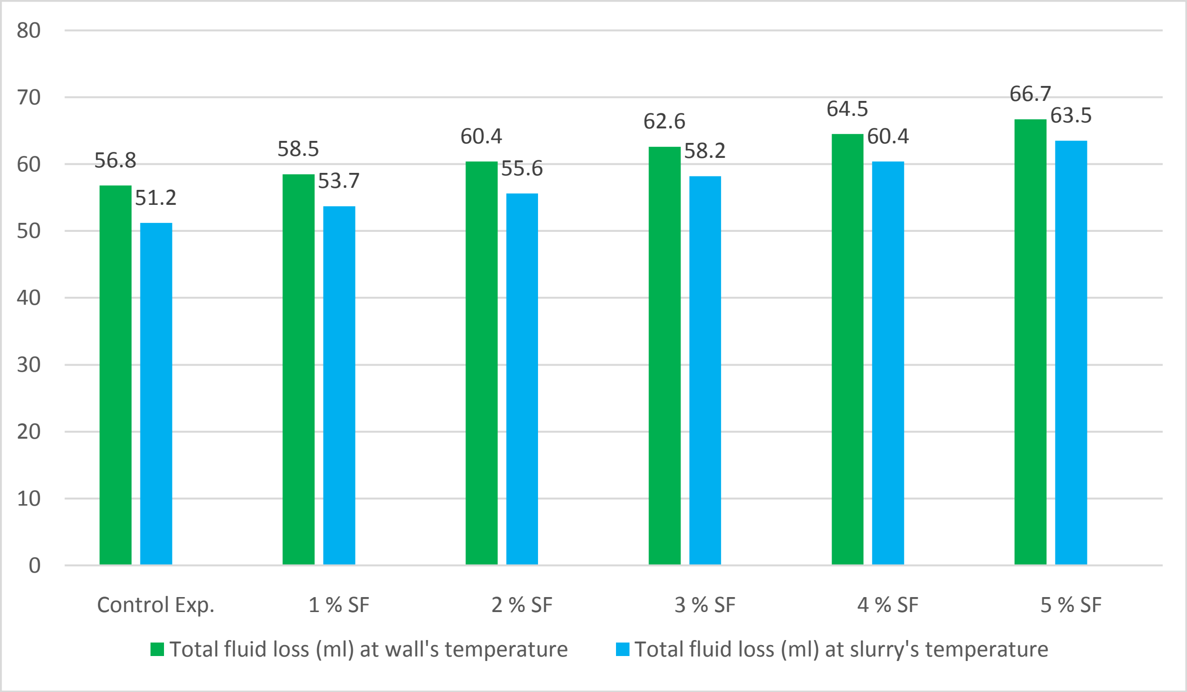

Figure 8 Total fluid loss at wall and slurry temperature of 100 ^{0}F for Silica fume as additive

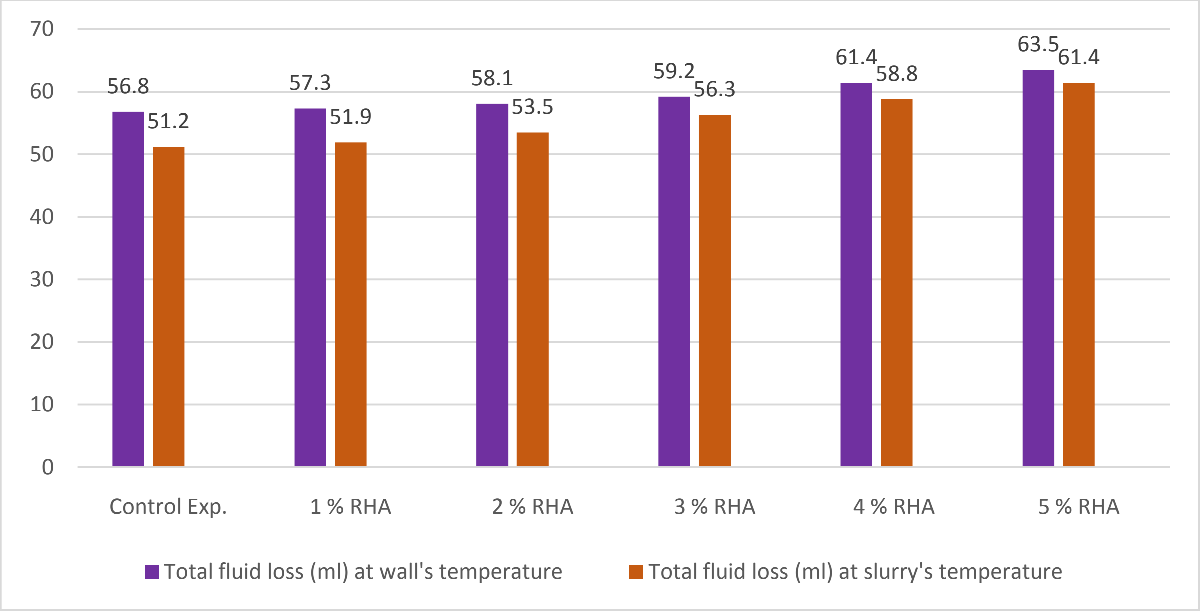

Figure 9 Total fluid loss at wall and slurry temperature of 100 ^{0}F for Rice husk ash as additive

Figures 8 and Figure 9 show proportional increasing trends with the increase of both additives BWOC. These implies that, as the percentage of bentonite BWOC was reduced to accommodate the increase in the percentage of each additive, the total fluid loss also increases

3.6 Resultant Effect of Addition of Silica Fume and Rice Husk Ash Separately on Thickening Time of the Slurry at the Optimum Rheology

The consistency tests on the prepared cement slurries for both additives (Silica fume and Rice husk ash) were done at 3000 psi and temperatures of 100 °F. Thickening times were determined when cement consistency reached 80 Bearden consistency (Bc). A set of tests were performed using cement containing calcium lignosulfonate as the control experiment and cement containing silica fume with another containing rice husk ash as deflocculatnts. From the results presented in Table 12 below. There were no significant differences in the value of the control and test experiments.

Table 12 The results of fluid loss at different concentrations of Rice hush ash and bentonite

	Thickening Time for Silica Fume at 3000 psi and 100 ^{0}F			Thickening Time for Rice husk ash at 3000 psi and 100 ^{0}F	
Slurry type	Hr:Min.	Minutes	. Slurry type	Hr:Min.	Minutes
Control Exp	3:10	190	Control Exp	3:10	190
3 % SF	3:22	202	2 % RHA	3:18	198

IV. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary

Oil well cementing, being an integral aspect of completion process, determined the integrity of the wellbore. The rheological properties of oil well cement slurries play a crucial role in their successful placement and futuristic performance of the well. Rheology which describes the flow and deformation of fluids in motion, is control by certain additives such as calcium lignosulfonate, sodium chloride, etc to deflocculate the cement slurry. In this studies, silica fume and rice husk ash were used as deflocculants separately in a light weight cement slurry to determine the flow and deformation properties of the slurry. The light cement slurry was prepared using class G cement, with bentonite and the pozzolan materials as extenders, the slurry's weight for the experiment was determined and maintained throughout the experiment. Silica fume at 3 % and bentonite at 5 % combination gives the same value as the control experiment, which has calcium lignosulfonate as deflocculant. Similarly, rice husk ash at 2 % and bentonite at 6 % gives the same value as the control experiment. Both silica fume and rice husk ash extended the slurry yield to about 14.5 gal/sk.

The fluid loss tests were performed at 100 °F for both the control and the test cement slurries. The fluid loss property of the slurries were affected as the percentage of the pozzolanic materials were increased in the mixture, due to the decreased amount of bentonite in the adjustments while the consistency tests of the prepared cement slurries for both additives (Silica fume and Rice husk ash) were carried out at 3000 psi and temperatures of 100 °F using an HPHT consistometer with insignificant differences in the thickening time.

4.2 Conclusion

The conclusions from this study were based on three different types of testing carried out, rheology, fluid loss and cement thickening time. The main conclusions for this study on the cement rheology were as follows: The Bingham Plastic rheology model should be used for cement slurries since the cement slurries have a yield value and the Nigerian pozzolanic materials performed comparatively like the conventional deflocculant (calcium lignosulfonate). The main conclusion on cement fluid loss was about 4 to 6 % higher than the control experiment for all the concentrations. Similarly, the main conclusions from this study on the cement thickening time was that a small amount of the pozzolanic materials (2-3 % BWOC) were needed for the desired thickening time of approximately three hours for the light cement.

4.3 Recommendation

From the above analysis, it is recommended that the two Nigerian pozzolanic materials, silica fume and rice husk ash should be considered as deflocculants in the formulation of oil well cement slurry, since they have the tendencies of improving the cement slurry flow parameters such as plastic viscosity and yield point, with little or no significant effects on the fluid loss properties and thickening time of the cement. Also, it is recommended that, further investigation of their suitability as viscosity control additives be carry out to establish their impacts on the cement's compressive strength

4.4 Contribution to Knowledge

More researches are ongoing on the usefulness of pozzolanic materials as cementation materials, but their suitability as deflocculants have not been exhaustively investigated. This research work focuses on utilizing the constituents' elements in the ashes of these pozzolans to reduce the viscosity and yield point of cement slurry during cement placements. Calcium lignosulfonate, sodium chloride and potassium chloride from inorganic sources have been used as dispersants or deflocculats to control the flow parameter of cement slurries, the ones from organic sources, especially those present in the ashes of rice husks and silica fume were utilized as potential deflocculants in the formulation of cement slurry with favorable results. Hence, silica fume and rice husk ash the ash can now be added to the list of possible or potential deflocculants in the formulation of cement slurry for the oil and gas industry.

4.5 Suggestions for further Studies

Future recommendations for studying cement slurries with Nigerian Pozzolanic materials as additives and other additives are listed below:

i. Evaluate different types of NPs that inherit different properties that could improve the cement quality and prevent a specific problem or enhance a specific property.
ii. Evaluate and test different weighting agents or extenders.
iii. Evaluate and test of different fluid loss controllers.
iv. Evaluate and test of different rheology controller.

V. ACKNOWLEDGEMENT

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