Received: July 09, 2023
Revised: October 10, 2023
Accepted: October 11, 2023

Evaluation and Treatment of Cement Contamination in Water Based Mud

Tahir Ahmed Aliyu[1] | Ikechukwu Okafor[1] | Ayuba Salihu[1]* | Khaleel Jakada[1] Oghenorume Ogolo[1] | Petrus Nzerem[1] | Abdullahi Gimba[1] | Oluogun M Olawal[1]

[1] Petroleum and Gas Engineering Department, Nile University of Nigeria, Abuja.

Corresponding Author's Name: Ayuba Salihu
Corresponding Author's E-mail: a.salihu@nileuniversity.edu.ng

ABSTRACT

Drilling mud is susceptible to contamination, particularly from cement, yet monitoring its characteristics and implementing control and remediation strategies is critical for its performance in safe and cost-effective drilling operations. This study presents an experimental investigation into the evaluation and treatment of cement contamination in Water Based Mud (WBM). Four mud samples were prepared and three were contaminated with 4g, 8g and 12g of cement. A chemical treatment using 6g of sodium bicarbonate was applied as a remedy for contamination. The Rheological properties, mud pH and mud densities of the contaminated and treated Water Based Mud at temperatures of 35^0C, 55^0C, 75^0C and 95^0C were determined. Furthermore, the elemental composition of samples of contaminated and treated Water Based Mud was determined using an X-Ray Fluorescence Spectrometer. From the results obtained the mud density increased with a rise in cement concentration for both contamination and treatment with the exception of 8g cement concentration at 75^0C and 95^0C and 12g cement concentration at 55^0C and 75^0C where a decrease was observed in the treatment process. The yield point and 10second gel increased for both contamination and treatment process. In contrast, the 10minute gel decreased for both contamination and treatment process. The yield point and 10 second gel increased for both contamination and treatment process. In contrast, the 10-minute gel decreased for both contamination and treatment process. With some exceptions, increasing cement concentration resulted in a decrease in plastic viscosity, whereas treatment with sodium bicarbonate resulted in an increase with some exceptions. The mud pH for the contamination process increased as cement concentration increased, while treatment only marginally increased it with exception of 12g at 75^0C and 95^0C where a decrease was observed. Sodium bicarbonate treatment improves stability by decreasing excessive calcium and lime contamination from cement, reducing pollutants and enhancing the pH stability of the drilling mud.

Keywords: Water based mud, sodium bicarbonate, Cement contamination, Yield Point, Gel Strength, Plastic Viscosity, Mud pH and Mud Density.

NJEAS — NILE JOURNAL OF ENGINEERING & APPLIED SCIENCE

DOI: *https://doi.org/10.5455/NJEAS.160345*

1 | INTRODUCTION

Drilling an oil and gas well is a risky, challenging, and complicated operation. Despite these difficulties, wells are still being drilled all over the world, with recent drilling operations only being slow or nonexistent due to the global decline in oil prices. The objective of every field operator is to safely and cheaply transport oil or gas from the reservoir rock to the surface production facilities while maximizing profit by minimizing the cost of drilling the necessary number of wells to drain the reservoir fluid [1].

Drilling muds are essential in the process of drilling for oil and gas because they perform multiple functions that are critical to the operation's success [2]. Drilling mud that is well-designed can improve drilling efficiency, protect the wellbore, and prevent drilling problems such as lost circulation, differential sticking, and borehole instability [1].

Cement contamination can occur during drilling operations, affecting mud characteristics. The extent of contamination is influenced by factors such as cement volume, deflocculant type and concentration, and solids content [3].

Low calcium levels in drilling mud are essential for safe and effective drilling operations. Cement contamination can raise calcium levels, causing a variety of problems. To solve this, chemical treatment with sodium bicarbonate is advised because it generates insoluble calcium carbonate, allowing calcium and lime to be removed from the drilling mud while retaining pH stability [3].

The research conducted in [4], focused on the effects of contaminants on the rheological properties of oil-based mud. In particular, the study examined how different concentrations of salt and cement contaminants impacted the performance of drilling mud samples obtained from the Nigerian Niger delta. To carry out the research, the team obtained oil-based mud samples from the Niger delta and added various molar concentrations of salt and cement contaminants to them. The samples were then subjected to a constant temperature of 48.8°C (120°F) and their rheological properties were measured. The results of the study showed that an increase in the concentration of contaminants led to a negative impact on the rheological properties of the drilling mud samples. The team found that the cement contaminants had the most significant and devastating effect on the mud, as compared to the salt contaminants

The effect of cement contamination in water-based mud was studied in [5]. Three of the four mud samples were polluted with varied quantities of class G cement. The pH, fluid loss, density, and rheological properties of the mud were examined at three different temperatures (20°C, 40°C and 60°C). Increasing the cement concentration resulted in a higher yield point and gel strength, indicating enhanced viscosity and better solids suspension. The effect on plastic viscosity, however, varied with temperature and cement concentration. Higher cement concentrations also increased fluid loss, density, and pH of the mud, which can impair mud stability and performance during drilling.

The impact of sodium carbonate and bicarbonate impurities on the rheological properties of water-based mud was conducted by [6]. The concentration of cement contamination was discovered to alter the mud's thickness and pumping difficulty. The mud pH increased with sodium carbonate concentration but decreased with bicarbonate concentration, demonstrating that contaminants have an effect on chemical characteristics. The yield point increased as cement contamination concentration increased, whereas plastic viscosity dropped as treatment agent and cement contamination concentrations increased. Fluid loss increased with increasing pollutant concentrations, indicating a reduction in fluid retention capacity. The study suggests more research into the rheological properties of water-based mud in drilling operations at high temperatures and pressures.

The effects of different contaminants on the rheological properties and performance of water-based mud was examined in [1]. They studied the effects of salt, silica sand, cement, and carbonate on the mud system. Through experimental analysis, they observed that the presence of sodium salt in the mud system led to an increase in fluid loss into the formation. This suggests that sodium salt acts as a contaminant in water-based mud and negatively impacts its performance. They also found that the presence of a contaminant on the drilling mud could either reduce or increase the rheological properties of the mud system. This, in turn, affected the rate of penetration during drilling. For instance, the presence of silica sand and cement led to an increase in the yield point and viscosity of the mud, resulting in a slower rate of penetration. However, the presence of carbonate reduced the yield point and viscosity, leading to a faster rate of penetration.

The study conducted by [7], worked on the effect of monovalent and divalent salts, especially potassium chloride (KCl), calcium chloride ($CaCl_2$), and magnesium chloride ($MgCl_2$) on the rheological properties of a contaminated water-based mud (WBM) system. Sixteen mud samples were generated, fifteen of which were polluted with various salt concentrations at room temperature. The findings revealed that when salt concentrations increased, the rheological properties of the mud such as plastic viscosity, apparent viscosity and yield point reduced. According to the study, contamination with monovalent and divalent salts has a considerable impact on drilling mud performance, influencing particle dispersion, hydration, and flocculation. When compared to KCl salt, the effects were more evident with $CaCl_2$ and $MgCl_2$ salts.

The effect of temperature on the density of water-based mud (WBM) was studied in [8], which is utilized in drilling operations. The mud was subjected to temperatures ranging from 28°C to 70°C, and its density was measured at each temperature. According to the findings, when the temperature rose, the mud weight fell, indicating a decrease in density. This drop in density was related to mud component deterioration caused by high temperatures. WBM contains a variety of components, including polymers, clays, and weighing agents, all of which are temperature sensitive. High temperatures can cause polymers and organic compounds to degrade, resulting in mud characteristics that are no longer desired. Furthermore, temperature fluctuations can affect the amount of dissolved gas in the mud, impacting its density. The aim of this research work is to evaluate and treat cement contamination in Water Based Mud.

A modified microsphere tracer approach, developed by [9], uses an aqueous fluorescent pigment dispersion with a similar concentration of fluorescent particles as previously used microsphere tracers to assess contamination during drilling operations. However, because it is four orders of magnitude less expensive, it can be used more freely even in large operations. Two International Continental Drilling Program (ICDP) drilling campaigns at Lake Towuti, Sulawesi, Indonesia, and Lake Chalco, Mexico, successfully tested its suitability for deep drilling campaigns. This technique offers a quick, low-cost alternative for determining contamination levels during drilling operations.

In [10], the effect of cement contamination on the rheological properties of water-based mud was investigated. They prepared fresh mud, cement-contaminated mud, and sodium bicarbonate-treated cement-contaminated mud. Rheological experiments were carried out, with apparent viscosity, annular viscosity, gel strength, and yield point all being measured. In cement-contaminated mud, cement inclusion increased viscosity, gel strength, and yield point, while sodium bicarbonate addition decreased these properties.

The effect of geopolymer cement contamination on the rheological and mechanical performance of geopolymer was examined in [11]. First, at atmospheric pressure and room temperature (24 °C), the optimized geopolymer was prepared and mixed with various drilling fluid ratios of 0%, 5%, and 10% by weight of cement. The same percentages were used to compare Portland cement to geopolymer.To ascertain how drilling fluids affected rheology, density, fluid loss, and compressive strength at various curing times, four tests were conducted (1 day, 3 days, and 7 days). The results obtained indicate that geopolymer can withstand drilling fluid contamination.

The rheological properties of oil-based muds used in oil reservoirs in Nigeria's Niger Delta region was reported [12]. The researchers used standard methods to test the samples' rheological properties using a rotational viscometer. The study aimed to determine whether the mud samples met the specifications recommended by the American Association of Drilling Engineers (AADE). Three different oil-based mud samples were tested, and they found that two of the samples met the specifications recommended by the AADE, while the third sample did not. This suggests that the rheological properties of the third sample were not optimal for drilling operations, and could potentially lead to drilling problems

2 | MATERIALS AND EQUIPMENT

The experimental design approach for this study is shown in Figure 1

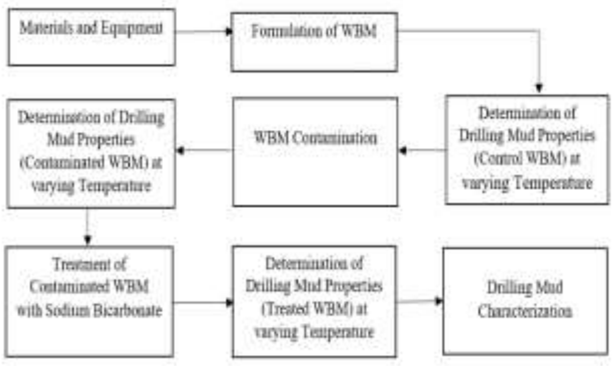

Figure 1: Design and work flow process

The materials and equipment that were used for the experiment were Portland cement, bentonite, mix-water, carboxyl methyl cellulose (cmc), Mud balance, mud mixer, viscometer, measuring cylinder, thermometer, stop watch, pH meter, and an air-dry oven.

Figure 2: Viscometer

Figure 3: pH meter

Figure 4: Mud balance

Figure 5: Dry oven

Figure 6: Mud mixer

Figure 7: Measuring cylinder

2.1 Formulation of Water Based Mud

A measuring cylinder was used to measure 350ml of water, which was then poured into a mud mixer cup. The mixer cup was then placed in the mud mixer and turned on. While the water was mixing, 20g of bentonite clay followed by 2g of CMC were gradually added to the mud mixer mixture. For about 5 minutes, the mixture was allowed to mix.

2.2 Determination of Drilling Mud Properties (Control Mud)

The control sample was prepared using 20g of bentonite, 2g of CMC and 350ml of water. It was mixed for 5 minutes and the drilling fluid properties were determined at the specified temperatures of 35^0C, 55^0C, 75^0C and 95^0C.

The viscosity dial and gel strength readings were obtained using a viscometer as shown in Figure 2 and the yield point, plastic and apparent viscosity were determined using the equations below:

Plastic viscosity (cP) = PV = 600 RPM Reading – 300 RPM Reading (1)

Yield Point ($\frac{Ib}{100}ft^2$) = YP = 300 RPM Reading – Plastic Viscosity (2)

The drilling mud properties, which include the rheological properties, mud density and mud pH of the control mud at different temperatures were obtained as shown in Table 1.

2.3 Water Based Mud Contamination

Three samples of fresh mud were prepared using 350ml of water, 20g of bentonite, 2g of CMC and cement (4g, 8g, 12g) which was stirred for five minutes each.

2.4 Determination of Drilling Mud Properties (Contaminated Mud)

The rheological properties, mud density and mud pH of the contaminated mud with varying cement concentrations (4g, 8g, 12g) at different temperatures were obtained as shown in Tables 2-4 respectively.

2.5 Treatment of Contaminated Mud with Sodium Bicarbonate

The mud contaminated samples of varying cement concentration were treated by adding 6g sodium bicarbonate and mixing for five minutes.

2.6 Determination of Drilling Mud Properties (Treated Mud)

The rheological properties, mud density and mud pH of the contaminated mud at varying cement concentrations of 4g and 8g were treated using 6g of sodium bicarbonate at different temperatures. The results were obtained as shown in the Tables 5- 7 respectively.

2.7 Drilling Mud Characterization

Fresh mud samples of contaminated and treated WBM were prepared and subjected to a drying procedure. After the drying process was completed, the mud samples were then analysed using an X-Ray Fluorescence Spectrometer to determine the elemental composition of the contaminated and treated Water Based Mud. The results were obtained as shown in Tables 8 and 9 respectively.

3 | RESULTS AND DISCUSSION

The results for the experiment as described under the materials and methods are presented as follows in the table 1 – Table 7: Table 1 presents the results obtained for drilling mud control sample at different temperatures.

Table 1: Drilling mud properties of control mud at different temperatures

Mud properties	Temperature ^{0}C			
	35^0C	55^0C	75^0C	95^0C
θ_{600} dial reading (cP)	46	38	30	24
θ_{300} dial reading (cP)	27	22	17	14
Plastic Viscosity (cP)	19	16	13	10
Yield point (Ib/100ft^2)	8	6	4	4
10 sec gel (Ib/100ft^2)	25	17	15	14
10 min gel (Ib/100ft^2)	25	20	16	10
Mud pH	9.5	9.0	8.6	7.9
Mud Density (Ib/gal)	9.2	8.8	8.7	8.6

In the Table 2, 3 and 4 below are the results obtained for drilling mud with 4g, 8g and 12g cement contaminated mud at different temperatures.

Table 2: Drilling mud properties for 4g cement contaminated mud different temperatures

Mud properties	Temperature ^{0}C			
	35^0C	55^0C	75^0C	95^0C
θ_{600} dial reading (cP)	58	46	32	29

θ_{300} dial reading (cP)	44	36	17	14
Plastic Viscosity (cP)	14	10	9	9
Yield point (Ib/100ft^2)	30	26	23	20
10 sec gel (Ib/100ft^2)	19	17	17	14
10 min gel (Ib/100ft^2)	26.5	25	23.5	18
Mud pH	10.5	9.8	9.0	8.2
Mud Density (Ib/gal)	10.6	9.6	9.2	8.9

Table 3: Drilling mud properties for 8g cement contaminated mud different temperatures

Mud properties	Temperature ^{0}C			
	35^0C	55^0C	75^0C	95^0C
θ_{600} dial reading (cP)	66	58	50	42
θ_{300} dial reading (cP)	52	47	40	32
Plastic Viscosity (cP)	14	11	10	10
Yield point (Ib/100ft^2)	38	36	30	22
10 sec gel (Ib/100ft^2)	27	25	22	16
10 min gel (Ib/100ft^2)	25	20	16	10
Mud pH	11.5	10.6	9.4	8.6
Mud Density (Ib/gal)	11.2	10.4	10.0	9.8

Table 4: Drilling mud properties for 12g cement contaminated mud at different temperatures

Mud properties	Temperature ^{0}C			
	35^0C	55^0C	75^0C	95^0C
θ_{600} dial reading (cP)	74	68	55	51
θ_{300} dial reading (cP)	64	59	47	43
Plastic Viscosity (cP)	10	9	8	8
Yield point (Ib/100ft^2)	54	50	39	35
10 sec gel (Ib/100ft^2)	33	30	30	19
10 min gel (Ib/100ft^2)	22	16	10	6
Mud pH	11.8	10.9	9.8	8.9
Mud Density (Ib/gal)	11.9	10.7	10.3	10.1

In the Table 5, 6 and 7 below are the results obtained for treated drilling mud with 4g, 8g and 12g cement contamination at different temperatures.

Table 5: Drilling mud properties of treated mud with 4g cement contamination at different temperatures

Mud properties	Temperature ^{0}C			
	35^0C	55^0C	75^0C	95^0C
θ_{600} dial reading (cP)	56	45	40	36
θ_{300} dial reading (cP)	42.0	34.0	30.0	24.5
Plastic Viscosity (cP)	14	13	10	6
Yield point (Ib/100ft^2)	28	21	20	8
10 sec gel (Ib/100ft^2)	22.0	20.0	20.0	17.5
10 min gel (Ib/100ft^2)	28.0	27.0	24.5	22.0
Mud pH	9.9	9.2	8.7	8.4
Mud Density (Ib/gal)	10.8	11.0	8.9	8.5

Table 6: Drilling mud properties of treated mud with 8g cement contamination at different temperatures

Mud properties	Temperature ^{0}C			
	35^0C	55^0C	75^0C	95^0C
θ_{600} dial reading (cP)	64	56.5	47.5	41
θ_{300} dial reading (cP)	49.5	45.0	37.0	30.5
Plastic Viscosity (cP)	14.5	11.5	10.5	7.5
Yield point (Ib/100ft^2)	35.0	33.5	26.5	19.0
10 sec gel (Ib/100ft^2)	25.5	23.0	21.5	19.2

10 min gel (Ib/100ft^2)	28.0	25.5	24.0	17.5
Mud pH	11.0	9.2	8.7	8.4
Mud Density (Ib/gal)	11.3	11.4	8.9	8.4

Table 7: Drilling mud properties of treated mud with 12g cement contamination at different temperatures

Mud properties	Temperature ^{0}C			
	35^{0}C	55^{0}C	75^{0}C	95^{0}C
θ_{600} dial reading (cP)	71	65	56	47
θ_{300} dial reading (cP)	55.0	50.5	44.0	36.5
Plastic Viscosity (cP)	16.0	14.5	12.0	10.5
Yield point (Ib/100ft^2)	39	36	32	26
10 sec gel (Ib/100ft^2)	31.3	27.0	23.5	21.4
10 min gel (Ib/100ft^2)	26.0	23.0	22.5	17.0
Mud pH	11.9	9.5	8.6	8.2
Mud Density (Ib/gal)	11.7	11.8	9.0	8.4

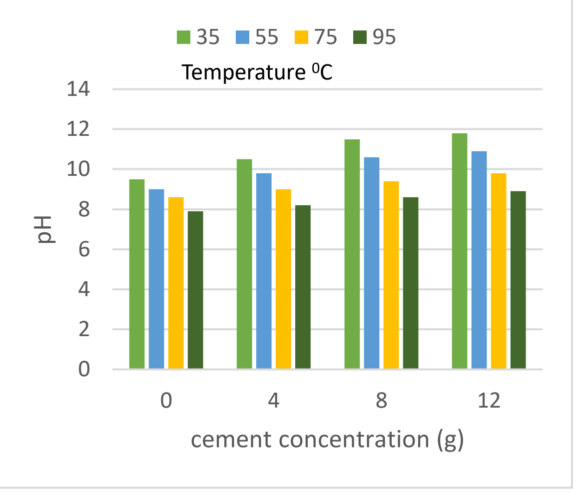

Figure 8: pH of contaminated mud

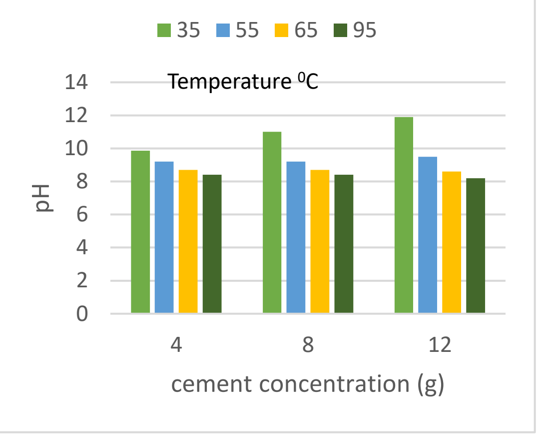

Figure 9: pH of treated mud

3.1 Mud PH

From Figure 2 it can be seen that the pH of the WBM increased with a rise in contamination. The formation of calcium hydroxide as a result of the reaction between the calcium component of the cement and the water portion of the mud is responsible for the increase in pH of drilling mud. This has significant implications for the drilling mud's performance, including its ability to control corrosion and inhibit shale formation swelling.

Additionally, in Figure 3 treatment of the contaminated mud with 6g of sodium bicarbonate shows less significant increase in the pH with the exception of 12g at 55^{0}C and 75^{0}C. This demonstrates enhanced stability gained by decomposing sodium bicarbonate to counteract excessive calcium and lime contamination from cement.

3.2 Plastic Viscosity

From Figure 4 it was observed that the plastic viscosity of the mud decreases with increasing cement concentration except for 8g at 55^{0}C, 75^{0}C and 95^{0}C.

Furthermore, the trend shown in Figure 5 indicates that the plastic viscosity increased on treatment with sodium bicarbonate with the exception of 8g at 55^{0}C which decreased. The decrease in plastic viscosity observed with increasing temperature can be attributed to the increased thermal energy available in the system, which improves particle mobility and reduces the forces holding particles together.

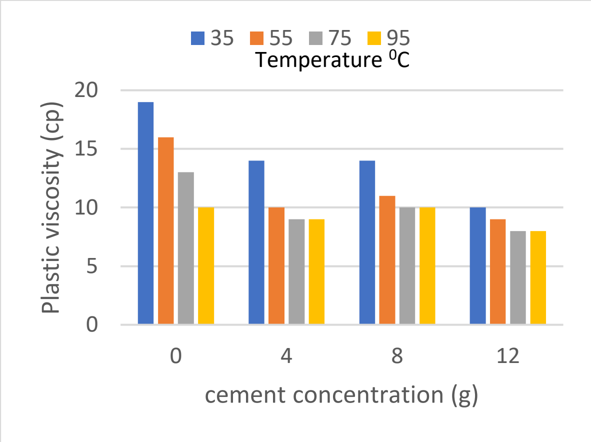

Figure 10: Plastic viscosity of contaminated mud

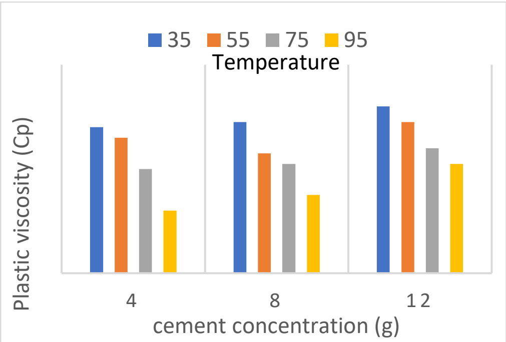

Figure 11: Plastic viscosity of treated mud

3.3 Yield Point

From the results obtained in Figure 6, the yield point increased rapidly with a rise in cement contamination and temperature. Also, in Figure 7 the same trend repeated where the yield point also increased after treatment. This may be explained by the fact that cement contamination can increase the concentration of solid particles in the water-based mud, causing the yield point to rise.

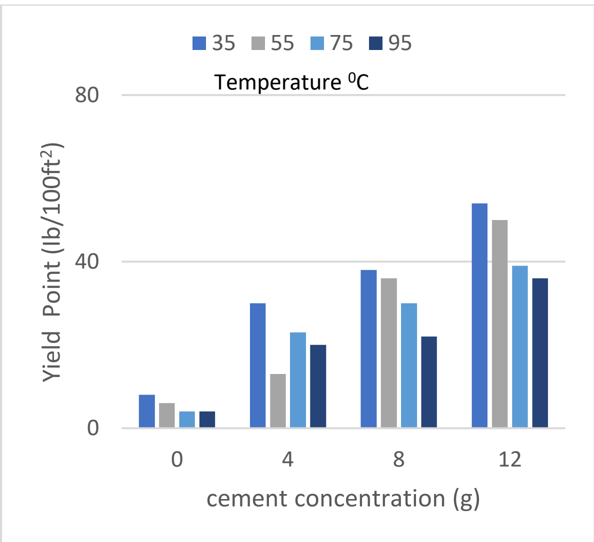

Figure 12: Yield point for contaminated mud

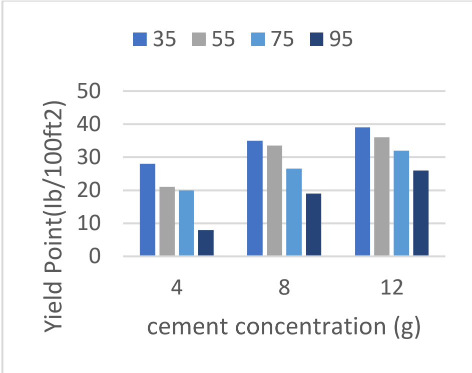

Figure 13: Yield point for treated mud

3.4 Gel strength

The experimental results from Figure 8 and 9 show that the size of the 10-second gel increased for both contamination and treatment processes. From Figure 10 and 11 it was observed that the 10-minute gel strength decreased with an increase in temperature for both contamination and treatment processes.

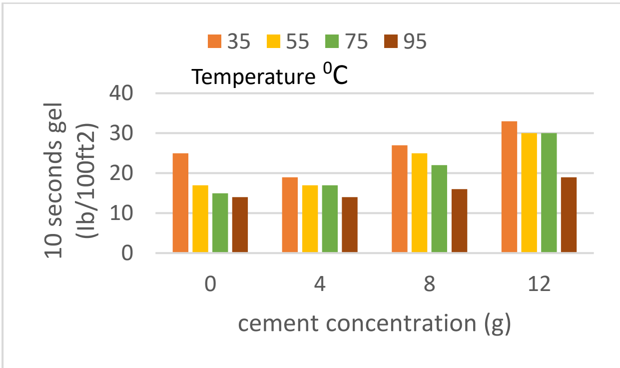

Figure 14: 10 sec gel of contaminated mud

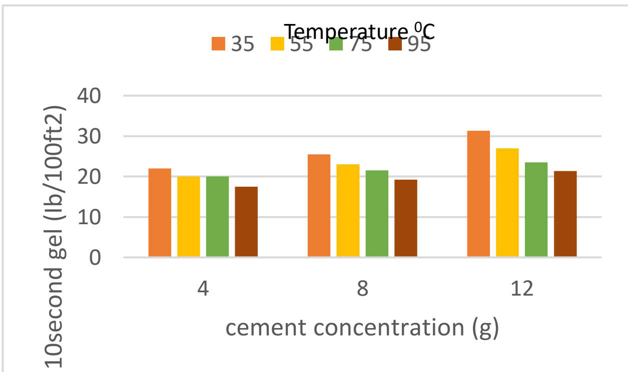

Figure 15: 10 sec gel for treated mud

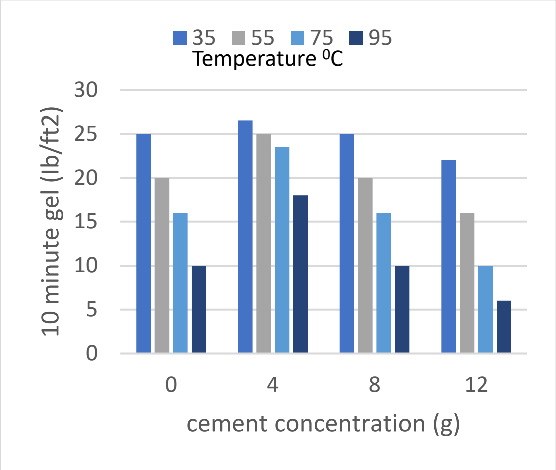

Figure 16: 10 min gel for contaminated mud

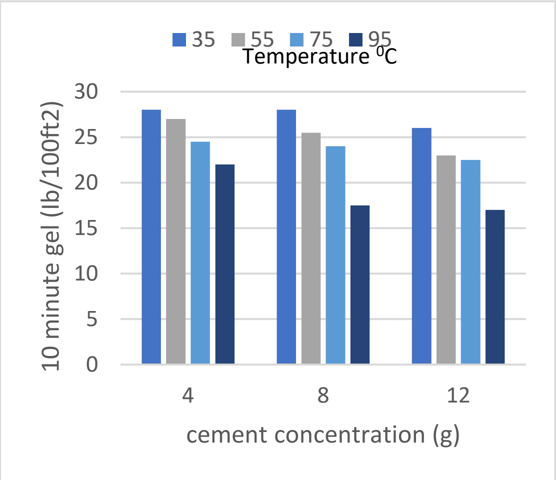

Figure 17: 10 min gel for treated mud

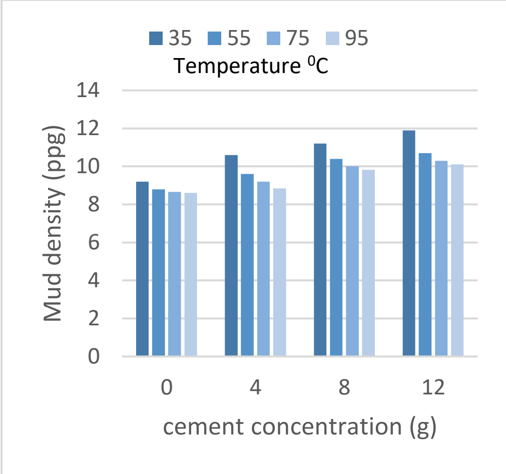

Figure 18: 10 min gel for contaminated mud

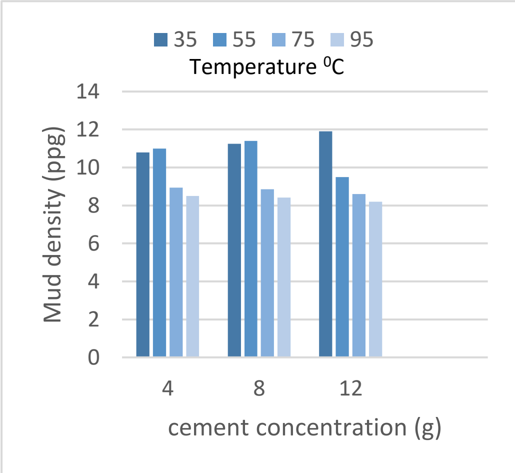

Figure 19: 10 min gel for contaminated mud

3.5 Mud density

Figure 12 shows that there was an increase in mud density as cement concentration increased. This is attributed to the presence of fine solid particles contributed by the cement causing the density of a Water-Based Mud (WBM) to increase when cement is added [1]. These solid particles fill the mud's voids, increasing its overall density. Furthermore, Figure 13 shows that, with the exception of 4g at 75^{0}C and 95^{0}C, the mud density increased, while it decreased for 12g at 55^{0}C, 75^{0}C and 95^{0}C.

Table 8 Elemental analysis of contaminated mud

Compound 1	MgO	Al_2O_3	SiO_2	Cl	K_2O
Conc Unit	3.143 %	14.304 %	43.834 %	717.0 ppm	1.180 %
Compound 2	NiO	CuO	ZnO	Ga_2O_3	As_2O_3
Conc Unit	22.4 ppm	71.1 ppm	195.7 ppm	32.8 ppm	38.2 ppm
Compound 3	Ag_2O	SnO_2	TeO_2	BaO	Eu_2O_3
Conc Unit	721.6 ppm	82.1 ppm	45.2 ppm	0.170 %	306.1 ppm

Compound 1	CaO	TiO_2	V_2O_5	MnO	Fe_2O_3
Conc Unit	17.692 %	0.977 %	336.5 ppm	530.8 ppm	6.927 %

Compound 2	Rb_2O	SrO	Y_2O_3	ZrO_2	Nb_2O_5
Conc Unit	80.7 ppm	973.4 ppm	27.2 ppm	270.5 ppm	10.9 ppm
Compound 3	Yb_2O_3	IrO_2	PbO	ThO_2	LOI
Conc Unit	24.6 ppm	0.0 ppm	22.1 ppm	6.2 ppm	10.000 %

Table 9 Elemental analysis of treated mud

Compound 1	Na_2O	MgO	Al_2O_3	SiO_2	SO_3
Conc Unit	5.247 %	3.112 %	14.691 %	44.518 %	0.833 %
Compound 2	Cr_2O_3	MnO	Fe_2O_3	NiO	CuO
Conc Unit	35.2 ppm	509.9 ppm	7.130 %	27.2 ppm	72.9 ppm
Compound 3	Y_2O_3	ZrO_2	Nb_2O_5	Ag_2O	BaO
Conc Unit	26.1 ppm	246.4 ppm	10.1 ppm	713.4 ppm	0.114 %

Compound 1	Cl	K_2O	CaO	TiO_2	V_2O_5
Conc Unit	701.7 ppm	1.162 %	15.710 %	1.051 %	361.2 ppm
Compound 2	ZnO	Ga_2O_3	As_2O_3	Rb_2O	SrO
Conc Unit	162.0 ppm	34.9 ppm	40.3 ppm	71.2 ppm	901.5 ppm
Compound 3	Eu_2O_3	Yb_2O_3	IrO_2	PbO	ThO_2
Conc Unit	319.8 ppm	42.6 ppm	0.0 ppm	26.7 ppm	12.4 ppm

4 | CONCLUSION

The following conclusions were reached from the study:

- The plastic viscosity decreased with cement contamination except for 8g at 55^0C, 75^0C and 95^0C which increased. On treatment with sodium bicarbonate there was an increase except for 8g at 55^0C;
- The yield point increased for both contamination and treatment process. This may be due to an increase in solid particles in the WBM;
- For both contamination and treatment processes the 10second gel strength increased with an increase in cement concentration. In contrast, the 10minute gel strength decreased with an increase in temperature for both contamination and treatment process;
- The mud density increased with a rise in cement concentration. This is attributed to the presence of fine solid particles contributed by the cement. Upon treatment with sodium bicarbonate there was still an increase except for 8g at 75^0C and 95^0C. and 12g at 55^0C and 75^0C were a decrease was observed;
- The mud pH for the contamination process increased as cement concentration increased, while treatment only marginally increased it with exception of 12g at 75^0C and 95^0C were a decrease was observed. This demonstrates enhanced stability gained by decomposing sodium bicarbonate to counteract excessive calcium and lime contamination from cement. The treatment minimizes pollutants and improves mud pH stability;
- The elemental composition indicates a percentage decrease in lime (CaO) for the treatment process which agrees with literature.

Further research is recommended to explore the impact of cement contamination and treatment on the fluid loss properties of water-based mud (WBM) under different temperature conditions. Also, further investigation should be undertaken to examine the effect of various contaminants and treatments on drilling fluid properties at varying temperatures.

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