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Laboratory Investigation of the Effects of Kaolin on Water-Based Mud at High Temperature and High Pressure

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ABSTRACT

Higher fluid loss volumes and suspension capability are the critical limitations of Water-Based Muds (WBM). It can heighten problems during drilling operations. The rheological and filtration properties of all drilling muds have been continually considered as the most essential characteristics of drilling mud for a successful drilling operation. Various irreversible problems, such as differential sticking, borehole instability, formation damage, and uncontrollable formation of fluids intrusion to the wellbore, are directly related with drilling fluids filtration and rheological properties. The solution to these problems is of paramount importance, especially at high temperature and pressure conditions of the wellbore. This paper aims to formulate a low-solid drilling fluid by replacing Polyanionic Cellulose (PAC-R) in conventional Potassium Chloride (KCL) polymer fluids with an equal amount of Kaolin, a local material abundant in Nigeria. The effect of Kaolin on filtration characteristics of water-based muds in static conditions is investigated at elevated temperatures and pressures. Various mud blends were prepared containing the different kaolin samples from different locations in Nigeria and in the presence of PAC-R at different replacement levels. Result of this investigation suggests that addition of micro size kaolin is an alternative to the conventional additives that can significantly enhance the filtration characteristics but not the rheological properties of water-based mud at high-temperature and pressure conditions. Despite an impressive amount of experimental work already done over drilling mud additives and their effects on rheological and filtration properties, literature is still rare on the effects of kaolin. This paper will hopefully encourage further development and interests in kaolin as an effective additive of water-based mud.

Keywords: Kaolin, Fluid loss additives, High Temperature and High Pressure, Rheological Properties.

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INTRODUCTION

The demand for drilling fluid is on a high increase due to drilling operations in the oil and gas industry. Kaolin, a mineral additive to drilling fluids is considered as one of the most used mineral additives in formulating drilling fluids. The primary constituent of kaolin is the mineral kaolinite, a hydrous aluminum silicate formed by the decomposition of minerals such as feldspar. Kaolinite has a low shrink-swell capacity and a low cation-exchange capacity (1–15 meq/100 g) and its chemical formula is: Al2Si2O5 (OH) 4(frequently expressed as Al2O3.2SiO2.2H2O). When pure, it has the composition (by mass) of alumina 39.56 %, silica 46.54 %, water 13.90 %, with a 1:1 sheet silicate structure composed of a [Si2O5]2- layer and an [Al2(OH)4]2+ layer. Commercial kaolin contains 80 - 90% of the clay mineral, contaminated mainly with quartz and fined grade mica or hydrous mica but seldom with appreciable proportions of feldspar. There are basically two types of drilling fluids; water based mud (WBD) and oil based mud (OBD). Apart from WBD and OBD, other types are pneumatic drilling fluids and salt water fluid system. Drilling induced problems, including borehole instability, improper cuttings transportation, formation damage, and differential sticking in the near-wellbore region, are directly associated with drilling fluids rheological and filtration characteristics. These properties are dependent on the appropriate selection of additives utilized in the mud. Various polymers and other additives are added to improve the rheology and reduce the filtrate loss into the near-wellbore region. Imatiaz Ali, Maqsood Ahmad in 2022 stated that fluid loss control additives are used to prevent the dehydration of cement slurry into the formation. Water will naturally leak out of cement into the formation. The addition of a fluid loss control additive will reduce the amount of fluid that leaks out of the slurry, preventing dehydration of the cement slurry at the formation wall. Vikas in 2013 investigated the effect of activated charcoal on the rheological and filtration properties of water based drilling fluids with the objective of the development of non-damaging drilling fluids to drill the sensitive formations. To control the filtration loss characteristics, activated charcoal, a new bridging material was added with these drilling fluids and the performance of this additive was compared with calcium carbonate, a conventional bridging agent. Dias, et al, 2015 investigated the potential of using starch derivatives modified with vinyl esters from fatty acids, as additives to control filtrate in invert-emulsion (W/O) drilling fluids. The results indicate that the formulations developed from fatty esters from starch are able to compete technically with the standard drilling fluid, and the performance of these materials is associated with the degree of chemical modification of the polysaccharide. Shadfar et al, 2018 discovered ssustainable technologies are the main concerns of the 21st century modified oilfield industries. The insufficiency of conventional drilling fluid formulations and a combination of hardly degradable hazardous chemicals as additives raise the demands of field-applicable innovative and environmentally friendly methods. Pistachio Shell discards as degradable wastes, which can intellectually apply in drilling fluid formulation. The experimental oilfield investigations of utilizing pistachio shell powder prove the significant enhancement of rheological properties, reduction of fluid loss and mud cake thickness in both API (Low Pressure —Low Temperature) and High Pressure—High Temperature (HPHT) conditions. The relatively fine particle size (less than 75 µm) shows the maximum efficiency with 44% fluid loss reduction and the highest value of plastic viscosity, yield point, and gel strength, which are indicators of very appropriate rheology. Moreover, the cost analysis shows 13% reduction in the cost of preparing drilling fluid when compared to the fluid with polyanionic cellulose. Gursat Altun and Umran Serpen in 2005 using laboratory experimentation, investigates an attempt to better characterize the rheological properties of sepiolite based drilling fluids under a variety of conditions in mixing times, mixing speeds, brine concentrations, and temperatures. The finer the grain sizes the more the surface area of particles that controls the rheological behavior of slurry.

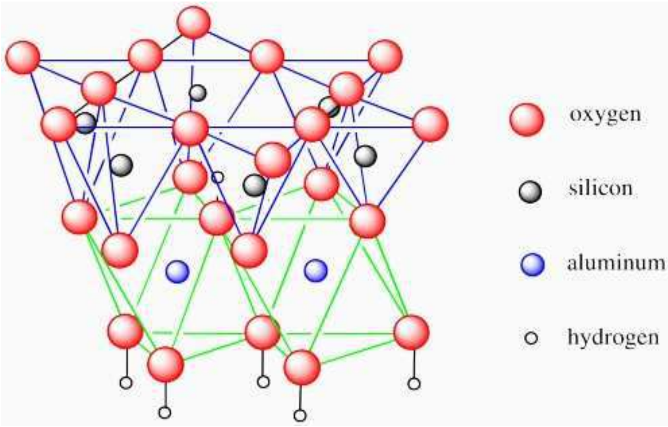

Fig 1: Structural Representation of Kaolin Mineral

METHODS AND MATERIALS

Laboratory experiments requires detailed descriptions of the chemicals used, method of the experiments which measured and estimated rheological properties of the drilling fluid, and that description contains clarify measurement principle, devices used, the tests carried out on each drilling fluid, preparation and how the testing process were achieved. Some of the fundamental equipment and chemicals used including but not limited to viscometer, viscometer cup heater, mud balance, weighting balance, mud balance, thermometer, stop watch, soda ash, caustic soda, kaolin pellet, polyanionic cellulosic polymer both the polymer and the slurry gel (PAC–L, PAC–R) calcium carbonate and adequate water etc. The flowchart below summaries the experimental procedures carried out.

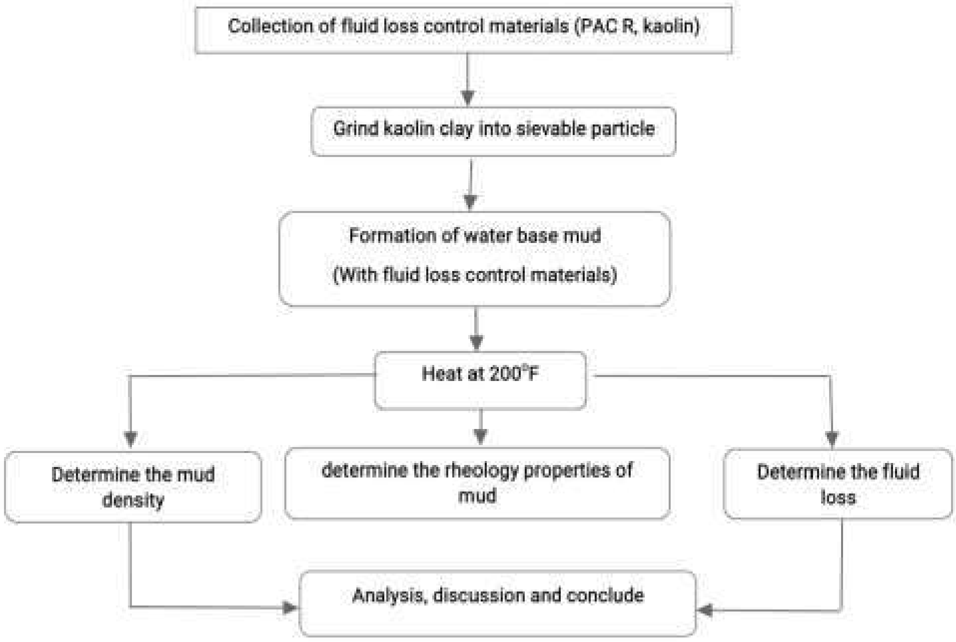

Fig: 2 Flowchart of Experimental Procedures

Fig 3(a-d): simple laboratory experiment; some laboratory equipments.

Standard API procedural methods for the formulation of water-based –mud, determinations of mud weight, rheological properties, filtrate loss, PH values were applied under controlled laboratory conditions using some of the selected equipment.

RESULTS AND DISCUSSION

RESULTS

KCL-polymer base fluid was prepared in the laboratory, and then two additives were tested in the laboratory:

(1) Polyanionic cellulose PAC R; (2) Kaolin (odunnya, igo, udogbo)

To study the effect of additives on the mud properties at an elevated temperature of 200°F, Mud Weight, Rheological properties, filtration of tested fluids were determined according to API recommended practice standard procedure for testing drilling fluids.

Table 1: Properties of tested water base mud with PAC R

properties	units	Quantity of additive					
		1.5	2.0	2.5	3.0	3.5	4.0
Mud weight	Ppg	8.3	8.3	8.3	8.3	8.3	8.3
Θ_{600}	rmp	39	47	52	67	88	93
Θ_{300}	Rmp	19	28	33	46	68	65
Plastic viscosity	Cp	18	19	19	21	20	28
Yield point	*lb/100ft²*	3	9	14	25	48	37
Mud PH	_	9.0	9.0	9.0	9.0	9.0	9.0
Mud cake	mm	0.2	0.2	0.2	0.2	9.0	9.0
filtration	ml	8	10	13	8	6	4
Gel strength 10sec	*lb/100ft²*	2	4	5	8	13	11
Gel strength 10mins	lb/100ft²	4	3	6	10	15	15

Table 2: Properties of tested water base mud with kaolin 1(udogbo sample)

properties	units	Quantity of additive					
		1.5	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Mud weight	Ppg	8.4	8.4	8.4	8.4	8.4	8.4
Θ_{600}	rmp	28	24	19	16	13	11
Θ_{300}	Rmp	16	13	12	10	9	8
Plastic viscosity	Cp	12	11	7	6	4	3
Yield point	*lb/100ft²*	4	4	5	4	5	5
Mud PH	_	9.5	9.5	9.5	9.5	9.5	9.5
Mud cake	mm	0.2	0.2	0.2	0.2	0.2	0.2
filtration	ml	9.0	7.0	6.0	4.5	4.0	3
Gel strength 10sec	*lb/100ft²*	1	2	4	6	6	7
Gel strength 10mins	*Lb/100ft²*	2	3	6	7	8	9

Table 3: Properties of tested water base mud with kaolin[3] (igo)

properties	units	Quantity of additive					
		1.5	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Mud weight	Ppg	8.4	8.4	8.4	8.4	9.4	9.4
Θ_{600}	rmp	55	50	46	41	34	27
Θ_{300}	Rmp	37	35	29	23	18	14
Plastic viscosity	Cp	18	15	17	18	16	13
Yield point	*b/100ft²*	19	20	12	5	2	1
Mud PH		9.5	9.5	9.5	9.5	9.5	9.5
Mud cake	mm	0.1	0.1	0.1	0.1	0.1	0.1
filtration	ml	7.0	5.5	5.0	4.0	3.0	2.5
Gel strength 10sec	*lb/100ft²*	5	5	6	7	8	9
Gel strength 10mins	*lb/100ft²*	6	7	7	8	9	11

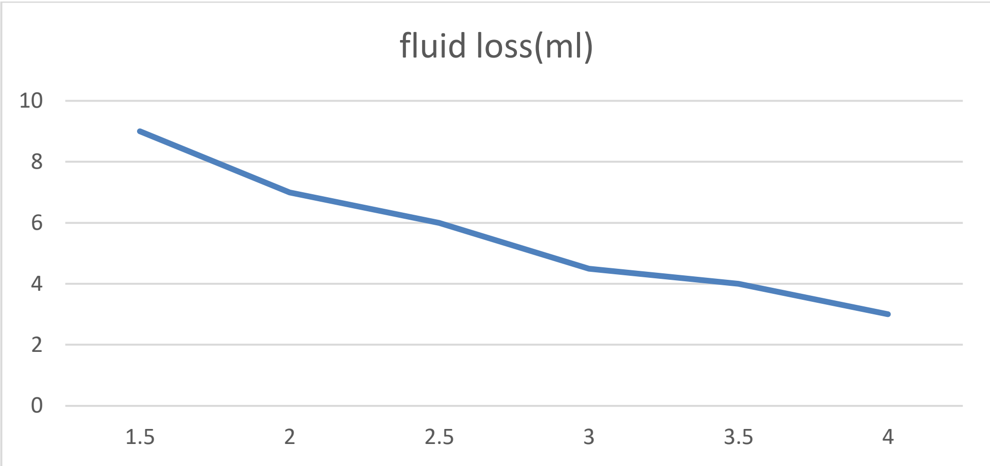

Fig 4: Fluid loss results for sample 1(udogbo)

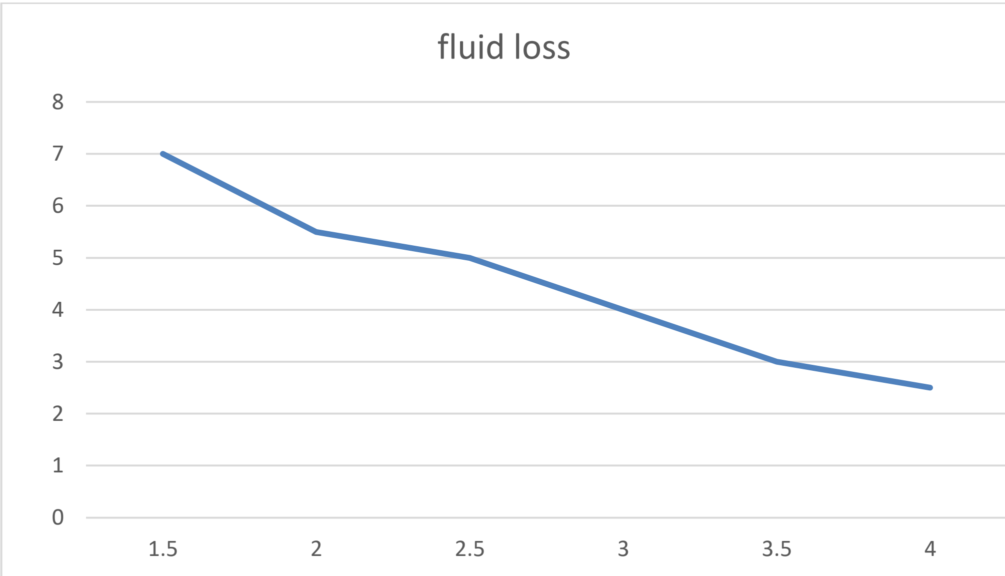

Fig 5: Fluid loss result for sample (igo)

DISCUSSION OF RESULTS

Mud weight or mud density is a weight of mud per unit volume. It is one of the most important drilling fluid properties because it controls formation pressure and it also helps wellbore stability. the density of the mud should be higher than the density of the cuttings to efficiently clean the bore hole. If the mud weight is too high, rate of drilling decreases. From the table, it shows that there is a slight increase in the mud density of the kaolin samples than PAC R. The mud density decreases with increase in temperature. pH is a value representing the hydrogen ion concentration in liquid and it is used to indicate acidity or alkalinity of drilling mud. The pH is presented in a numerical value (0-14), which means an inverse measurement of hydrogen concentration in the fluid. The pH formula is listed below;

PH = -log10 [H]………………………………………………………….. (1)

Where: H is the hydrogen ion concentration in mol.

According to the pH formula, the more hydrogen atoms present, the more acidity the substance. Generally speaking, a pH of 7 means neutral, fluids with a pH above 7 are considered as being alkaline while fluids with pH below 7 are defined as being acidic. pH measurement help place solution in their proper groupings, determining the need for chemical control and treatment to be given to the mud.

PLASTIC VISCOSITY AND YIELD POINT

Plastic viscosity (PV) can be defined as the resistance offered by a fluid to flow. This resistance is a result of friction between the liquid undergoing deformation under shear stress and the solids and liquids present in the drilling mud. PV is a parameter of the Bingham plastic model and is the slope of the shear stress/ shear rate line above the yield point. PV is an important rheological characteristic that affects properties of drilling fluid. Yield point is generally defined as the elastic limit at which a material will lose its elasticity and deform permanently. For drilling fluids, yield point refers to the resistance of initial flow of the fluid or in other words, the stress required to start the movement of the fluid. It is a parameter of the Bingham plastic model. Plastic viscosity and yield point can be computed from Fann V-G viscometer dial readings as Plastic viscosity, PV (cp), Yield point YP (1b/100ft), Where Dial reading at 600rpm speed shear stress; = dial reading at 300 rpm speed shear stress. From table 3, Plastic viscosity increases at higher concentration of PAC R, Plastic viscosity declines at higher concentration of kaolin. From figure 4, it shows that mud yield point reduces in values at higher concentration of kaolin and increases at higher concentration of PAC-R. The gel strength is the shear stress of drilling mud that is measured at a low shear rate after the drilling mud has been static for a certain period of time. The gel strength is one of the most important drilling fluid properties because it demonstrates the ability of the drilling mud to suspend drill cuttings and weighting material when circulation is ceased. Gel strength measurement is made on viscometer using the 3-rpm reading, and it is recorded after stirring the drilling fluid at 600 rpm to break gel. From Table 1, it is seen that the gel strength of the different mud samples of PAC R and kaolin increased at high temperature and pressure respectively.

CONCLUSION AND RECOMMENDATIONS

CONCLUSIONS

HPHT operations appear to be a new benchmark for oil and gas industry. Drilling into the reservoirs with elevated pressures and temperatures requires a fluid with stable rheological properties. Principally, Oil-Based mud is a proper choice for most of the HPHT applications if not violating the environmental regulations. Designing an eco-friendly Water-Based mud is a necessity for HPHT drilling. New environmentally safe WBM containing kaolin has been tested for drilling application with temperatures up to 200°F. The system components are newly developed and do not contain any environmentally harmful materials. From the experimental performed tests the following conclusions can be drawn:

- The presence of PAC R greatly enhanced the rheological characteristics of the mud. However, the impact of Kaolin on rheological behaviors was relatively minor.

- The third kaolin sample show great filtration loss properties, proving to be the most suitable additive. Owing to the availability and better performance of the kaolin, it could be not be completely utilized as a rheology enhancer at HPHT and but could be utilized as the filtration loss material. However, the findings showed significant improvements in fluid loss performance when compared with the PAC R.

RECOMMENDATIONS

It is recommended to conduct the laboratory tests under high pressure and high temperature; Extensive, studies and analysis should be carried out on the effect of kaolin on mud properties at high pressure; As this thesis focus on analyzing the performance of kaolin, accurate preparation of the mud is crucial for adequate results; Treatment on the kaolin could add to the success and that kaolin in it raw state alone might not be sufficient.

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