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Fluid Loss Control in Water Base Mud Using Ferric Oxide Nanoparticles and Local Additives

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Abstract
The success of well drilling operations is heavily dependent on the drilling fluid because drilling fluids cool down and lubricate the drill bit, remove cuttings, prevent formation instability, suspend cuttings and also cake off the permeable formations, thus retarding the passage of fluid into the formation. During drilling operations, the fluid part of the drilling fluid may be lost to the formation, a huge fluid loss lead to higher operational expenses. That is why, it is vital to design the drilling mud to minimize the mud invasion in to formation and prevent fluid loss. This study focused on improving the performance of water base drilling mud by the usage of ferric oxide nanoparticles and local additives such as corn cob powder from zea-mays and coconut husk powder from cocos nucifera as fluid loss control additives in the drilling mud. The laboratory measurements included measuring the filtrate loss using the standard API low temperature low pressure (LTLP) filter test, some properties of the mud such as the mud density and pH were measured using respective apparatus. Also, the filtration properties of water-based nano and local additive drilling fluids under static conditions were investigated. It was seen from the results that the lowest filtrate loss value of 14.4ml occurred for an addition of 1.0g of ferric oxide nanoparticles acting alone as the fluid lost material. Under API standard filtration test at LTLP, more than 70% reduction in fluid loss was achieved in the presence of 0.5 - 1.5 wt% nanoparticles. The results have also shown that the filter cake developed with the nano and local additive mud indicate thin filtration, which implies high potential for reducing the differential pressure sticking problem, as well as reducing formation damage and torque and drag problems while drilling. Nanoparticles (NPs) based drilling mud with specific characteristics is thus expected to play a promising role in controlling the fluid loss and other technical challenges faced with commercial drilling mud during oil and gas drilling
Keywords: Coconut Husk, Corn Cobs, Drilling Mud, Ferric Oxide, Filtrate Loss, Fluid Loss Additive, Mud Cake Thickness, Nanoparticles
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1. Introduction

The success of any well drilling operation depends on many factors and one of the most important is the drilling fluid. Drilling fluids are circulated from the surface into the drill string and subsequently introduced to the bottom of the borehole as fluid spray out of drill bit nozzles and back to surface via the annulus between the drill string and the well hole. Drilling fluids cool down and lubricate the drill bit, remove cuttings from the hole, prevent formation damage, suspend cuttings and weighting materials when circulation is stopped, and cake off the permeable formation by retarding the passage of fluid into the formation (ASME, 2005). However, drilling operations face great technical challenges with drilling fluid loss being the most notable of them. Drilling fluid loss is defined as the partial or complete loss of fluids into contacting subsurface formations during drilling operations. When drilling fluid losses becomes reoccurring during drilling operations, the cost impact of sustaining the quality of the drilling fluids so as to prevent related challenges associated with fluid losses becomes inevitable. The challenges associated with drilling fluid loss may include non – productive time, high cost of drilling fluids, near wellbore damage, pipe sticking, in some instance may lead to formation contamination etc. The different solutions recorded in literatures are grouped into loss circulation materials (LCM) solution and mechanical solution [13]. Increase in the concentration of LCM pills in mitigating severe drilling fluid losses has been introduced [11], [10], [12], [6], while in some cases, the drilling fluids were chemically activated by cross-linked pills (CACP) [4], [5]. Contaminants also contribute to filtration loss to the formation, [15] discloses the impart of static-filtration experiments of various additives to minimize filtration invasion at elevated temperatures when the mud contains certain common contaminants The involvement of nanotechnology in controlling fluid loss was achieved by developing a nano-composite gel [9]. [7] applied fiber laden pill to control lost circulation in natural fractures and this proved to be effective. Using water base mud in drilling shale formations leads to water invading it, this is due to the high affinity of shale materials to water, NPs were skillfully applied to shale formations from “Atoka and Gulf of Mexico” to minimize the invasion of shale porous environment by water [16]. Therefore, nanoparticles (NPs) mixed with local additives as a form of loss circulation material could yield positive results. NPs can help in bridging empty gaps between macro and micro LCMs, and therefore, providing an effective seal to formation with larger pore throat size. Pore space is defined as a collection of channels through which fluid can flow and the effective width of such a channel varies along its length. Pore bodies are wide portions and pore openings or pore throats are the relatively narrow portions that separate these pores bodies [14]. Consequently, NPs can influence any of its contact surroundings because of its particle sizes and surface area. [1] Considered the design of mud to minimize rock impairment due to particle invasion, furthermore, the work showed that invasion and formation damage occurred with all muds but these can be controlled. Bridging materials reduces invasion and depends on the concentration of particle size of material and pore sizes of formation rock.

NPs thus could be a promising option for the development of drilling mud to provide the effective sealing, filling and cementing properties, which can lead to reduction of porosity, permeability of the wellbore formations and thereby prevent the loss of fluid. By forming a thin, low permeability filter cake which seals pores and other openings in the formations penetrated by the drill bit. NPs based drilling mud could also prevent unwanted influxes of formation fluids into the borehole from permeable rocks penetrated during drilling. Smaller particles aggregate around larger ones to fill the tinier spaces and hence effectively plug the pore opening spaces. This research closely study the effect of ferric oxide nanoparticles blended with local additives in water based drilling mud on the rheological properties of the drilling mud in low temperature and pressure conditions.

1.1 Materials And Methodology

The materials used in the formulation of the drilling mud include: Bentonite (20g for each sample), barite (80g for each sample), water (as the continuous phase), powdered coconut husk and corn cobs which serve as the LCM and ferric oxide (Fe2O3) Nanoparticles. The equipment used for these experiments are as follows; bariod mud balance, digital caliper, LTLP filter press and pH meter. The filtration properties of the different drilling fluids involved in this study were measured according to API 30-min test (API RP 13B-2, 2012; API RP 13B-1, 2003). Data were collected using a standard FANN filter press (Fann Model 300 LTLP, Fann Instrument Company, USA) and filter paper (pore size 2.7 µm, Fann Instrument Company, USA).

1.1.1 LTLP Test Procedures

A standard procedure was adopted for the low temperature low pressure (LTLP) test and it was conducted and recorded according to the following procedure; a volume of 350 mL of the drilling mud was poured into the filter press cup and a pressure of 100 psi was applied through CO2 which was supplied from a cylinder at a temperature of 90oC. The cumulative volume of permeate was reported after 7.5 min and 30 min from the graduated cylinder reading. Three replicates were prepared for every sample and 95% confidence intervals were recorded. The smoothness of the final filter cake was reported through visual observation, while the thickness was measured using a digital caliper. A Fann model 140 mud balance (Fann Instrument Company, USA) was used to measure the mud density. During the measurement, care was taken in order to eliminate any errors due to air entrapment, while the pH measurements were performed using a pH meter. Low temperature low pressure (LTLP) fluid loss test was conducted at a temperature of 90℃ and pressure of 100 psi. This experimental analysis was performed to study the effectiveness of the selected fluid loss agents.

1.1.2 Drilling Fluid Formulation

The corn cobs and coconut shell were prepared according to the method adopted by [2]. They were sourced, cleaned, dried, and grinded using a grinding machine. The raw materials used in the mud formulation were measured using the graduated cylinder and electronic balance. The following samples were prepared; mud samples were formulated without corncobs and coconut shell, another sample of mud was prepared by adding coconut shell alone, mud sample of corn cobs alone, and mud sample with the combination of the corn cobs and coconut shell, mud sample containing ferric oxide NPs, a combination of ferric oxide and corn cobs and a combination of ferric oxide, corncob and coconut shell. Furthermore, Table I shows the drilling fluid formulation weight with local additives and nanoparticles (NPs) at different concentrations. The basic rheological experimental test was conducted on each of the mud samples which include mud weight, fluid loss and mud cake thickness.

The experimental procedures applied here involved the formulation of the respective drilling muds used and were subjected to standard instruments and methods to characterize the resultant mixture. The following mud samples of mud without coconut shell and corn cobs; mud with corn cobs; mud with coconut shell; mud with a mixture of corn cobs and coconut shell; mud with ferric oxide NPs; mud with corn cobs and ferric oxides NPs and mud with a mixture of corn cobs, coconut shell and ferric oxides NPs were prepared to study the effects of these various inputs on the volume of fluid loss and mud cake thickness formations. The drilling fluid was characterized using the bariod mud balance for density and Fann V-G viscometer for viscosity and gel strength measurements. Its' filtration properties were evaluated using API low temperature low pressure (LTLP) and the mud cake thickness measured by a caliper. The accuracy of any measurement depends on the apparatus used and the method applied, when evaluating the performance of LCM treatments the fluid losses were considered by [13]. In some case, specialized techniques such as particle plugging apparatus (PPA) and high pressure high temperature (HPHT) were used to measure the fluid loss volume of lost circulation materials [8]. In this study, the texture and smoothness of the filter cake was determined by visual inspection and touch. Mud having low filtration characteristics deposited as thick filter cakes [15].

Table 1: Drilling Fluid Formulation at Different Concentration

Mud Samples	I	II	III	IV	V	VI	VII
Bentonite (g)	20	20	20	20	20	20	20
Barite (g)	80	80	80	80	80	80	80
Water (ml)	350	350	350	350	350	350	350
Corn cobs (g)	-	6,8,10	-	-	-	-	-
Coconut Shell (g)	-	-	6,8,10	-	-	-	-
Corn cob and Coconut shell (g)	-	-	-	6,8,10	-	-	-
Corn cob and ferric oxide (g)	-	-	-	-	7.5,9,10.5	-	-
Corn cob, ferric oxide and Coconut shell (g)	-	-	-	-	-	-	7.5,9,10.5
Ferric oxide (g)	-	-	-	-	-	0.5,1,1.5	-

Table Acronyms:

- Sample I - Fresh Mud
- Sample II - Fresh Mud with Corn Cobs
- Sample III - Fresh Mud with Coconut Shell
- Sample IV - Fresh Mud with Coconut Shell and Corn Cobs
- Sample V - Fresh Mud with Corn Cob and Ferric Oxide NPs
- Sample VI - Fresh Mud with Ferric Oxide NPs
- Sample VII - Fresh Mud with Ferric Oxide NPs, Corn Cob and Coconut Shell.

1.2 Results and Discussion

Table 2: Fresh Mud

Physical Properties	**Value**
Ph	9
Mud Density (ppg)	8.7
Fluid Loss (ml)	24
Mud Cake Thickness (mm)	1.45

Table 3: Fresh Mud Sample with Corn Cobs

Physical Properties	**Concentration of Corn Cobs**		
	6g	**8g**	**10g**
pH	9	9	9
Mud Density (*ppg*)	8.7	8.8	8.9
Fluid Loss (*ml*)	20	19	18
Mud Cake Thickness (*mm*)	1.2	1.3	1.55

Table 4: Fresh Mud Sample with Coconut Shell

Physical Properties	**Concentration of Corn Cobs**		
	6g	**8g**	**10g**
pH	9	9	9
Mud Density (*ppg*)	8.7	8.8	8.9
Fluid Loss (*ml*)	20	19	18
Mud Cake Thickness (*mm*)	1.2	1.3	1.55

Table 5: Fresh Mud Sample with Corn Cobs and Coconut Shell

Physical Properties	**Concentration of Combined Coconut Shell and Corn Cobs**		
	6g	**8g**	**10g**
pH	9	9	9
Mud Density (*ppg*)	9.21	9.43	9.6
Fluid Loss (*ml*)	18	17	16
Mud Cake Thickness (*mm*)	1.3	1.4	1.6

Table 6: Fresh Mud Sample with Fe_2O_3 NPs and Corn Cobs

Physical Properties	**Concentration of Combined Fe_2O_3 NPs and Corn Cobs**		
	7.5g	9g	10.5g
pH	7	6	6
Mud Density (*ppg*)	9.8	9.7	9.75
Fluid Loss (*ml*)	22.0	16.0	23.0
Mud Cake Thickness (*mm*)	1.1	1.45	2.01

Table 7: Fresh Mud with Fe_2O_3 NPs, Corn Cobs and Coconut Shell

Physical Properties	**Concentration of combined Fe_2O_3 NPs, Corn Cobs and Coconut Shell**		
	7.5g	9g	10.5g
pH	7	6	6
Mud Density (*ppg*)	9.8	9.7	9.75
Fluid Loss (*ml*)	16.0	20.0	18.8
Mud Cake Thickness (*mm*)	1.04	1.02	1.04

Table 8: Fresh Mud Sample with Fe_2O_3 NPs

Physical Properties	**Concentration of Fe_2O_3 NPs**		
	0.5g	**1.0g**	**1.5g**
pH	7	7	7
Mud Density (*ppg*)	9.3	9.35	9.8
Fluid Loss (*ml*)	15.6	14.4	14.8
Mud Cake Thickness (*mm*)	1.01	1.03	1.01

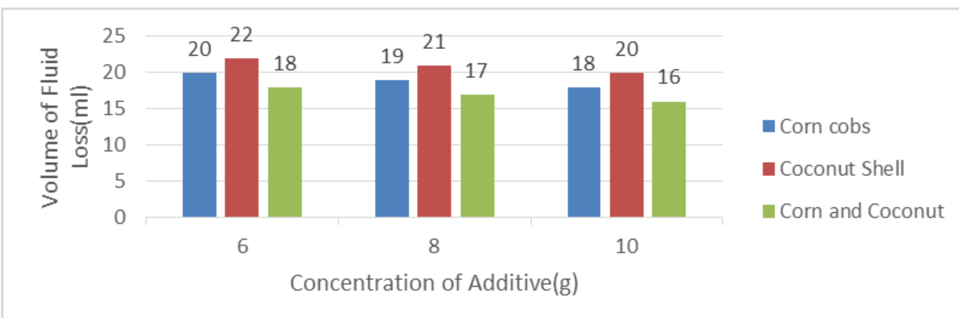

Figure 1: Effect of Local Additives on Fluid Loss

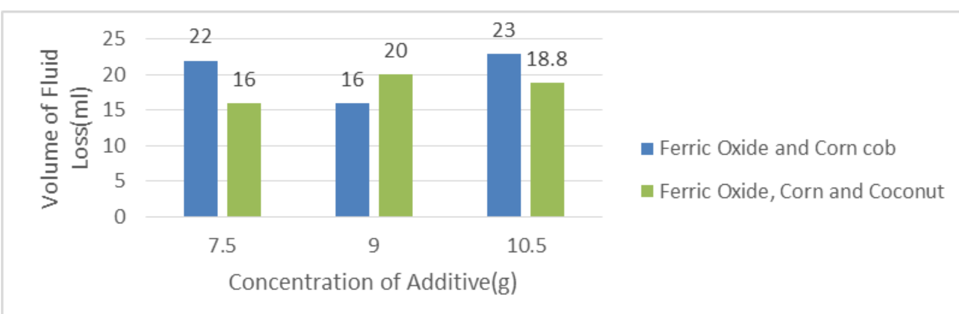

Figure 2: Effect of Ferric Oxide NPs and Local Additive on Fluid Loss

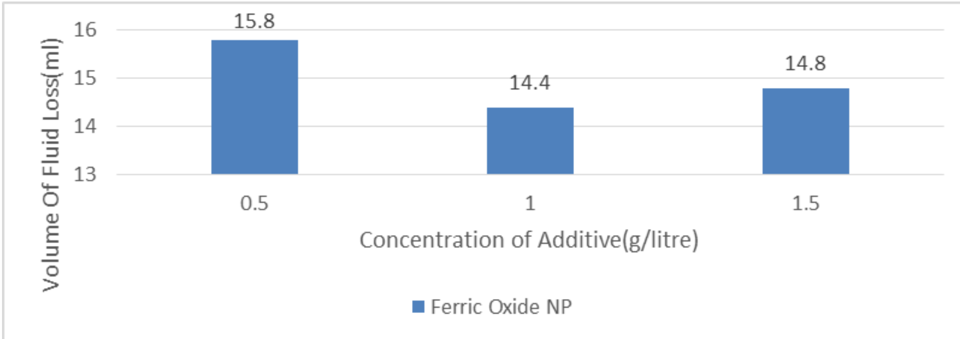

Figure 3: Effect of Ferric Oxide NP on Fluid Loss

This study has brought out different perspective of the behaviour of the NPs with local materials and drilling fluids. The data generated from the different experiments conducted are presented in tables 1 to 8 and figures 1 to 3. Table 2 highlights the physical properties of the mud sample without coconut shell and corn cobs, the pH obtained from this study falls within the acceptable range of API drilling fluids of between 8 and 12.5. Knowing the pH of the mud is critical because it affects the solubility of the organic materials like thinners and the dispersion of clays presents in the drilling fluid. A close look at table 3 revealed the effects of corn cobs in water base mud (WBM), an increase from 6 to 8 grams of corn cobs resulted in mud density increase and similarly from 8g to 10 g. The fluid lost dropped by 16.67%, 20.83% and 25% for 6g, 8g and 10g respectively when compared with the mud sample without corn cobs, this is shown in tables 2 and 3. The volume of fluid lost into the formation clearly showed from this study is proportional to the concentration of corn cobs present as additives in the mud samples. The behaviour noticed with the mud cake thickness similar to that of the fluid lost because, the reduction in fluid lost leads to the reduction in the thickness of mud cake formed. A high concentration of corn cobs favours low mud cake thickness formation. The results presented in table 5 revealed that the combined effects of coconut shell and corn cob additives increased the densities and reduced the fluid losses in accordance with the different concentrations while the mud cake thickness increased slightly when compared to that obtained with only corn cob additives showed in table 3. This indicates that coconut shells encourage the formation of mud cake and lead to increase in cake thickness. Ferric oxide NPs results are presented in tables 6 to 8 and it was observed that the introduction of NPs to the mud sample only and also with local additives of corn cobs and coconut shells reduces the fluid lost, consequently, reduce the mud cake thickness formed. This may be due to the surface area influencing of the different materials involved by the ferric oxides NPs during the processes of fluid lost and mud cake thickness formation. The mud sample densities increased with the addition of these NPs and modified the pH from alkaline state to neutral and slightly acidic in some cases, however, the alkaline state can be recovered with the introduction of lime. When the desired reductions are obtained, the high cost of sustaining the quality and quantity of drilling fluids can be reduced and whole stability maintained while drilling. These results also revealed in tables 3 and 4 that both the corn cobs and the coconut shells are good local additives in drilling fluids formulations, however, the corn cobs are better than the coconut shells in reducing fluid lost and mud cake thickness. The performance of each additive (corn cob, coconut shell and mixture of corn cob + coconut shell) is presented in figure 1, the combined corn cob and coconut shell gave lower volume of fluid lost. The volume of fluid lost further decreased when ferric oxides NPs were added to the local additives as shown in figure 2, and the results presented in figure 3 indicate that ferric oxides NPs performed better in reducing the volume of fluid lost when used without any additives. This performance may be connected to the magnetic ability of the ferric oxides NPs; such ability attracts materials favourable to fluid lost and also help to reduce the mobility of the mud in experiencing filtration of the less dense part of the mud system.

The results presented also revealed that the fluid lost and mud cake thickness depend on the varying concentrations of the additives, for an increase in concentration of corn cobs, coconut shell and ferric oxide NPs leads to a proportionate increase in the density of the mud. It was also observed that the lowest filtrate loss occurred for the addition of ferric oxide NPs alone at 1.0g which gave a value of filtrate loss of 14.4ml with a thin and smooth filter cake. Conversely, a good filtration characterized by the NPs-based fluids yielded thin mud cakes as shown in table 8. The thickness of the mud cake and its integrity can reveal that NPs deposited on the cake with optimum concentration established an effective seal. For combating formation damage, water-based mud would offer better protection with the appropriate additives like corn cobs and coconut shell in the presence of ferric oxides NPs. Formation damage due to filtrate and solids invasion is a major contributor to cost, lost time and lost production. One of the critical factors in avoiding formation damage during drilling is obtaining surface bridging on the formation face with minimum in-depth solids penetration. The results obtained from this work gives rise to the following characteristics for the nano-based drilling fluid; thin and firm filter cake, minimal fluid invasion because sealing takes place at the surface and this leads to minimal formation damage. Furthermore, only low ferric oxides NPs concentration is required to achieve the desired results, as well as saving huge time and cost. These properties entail the following practical applications; less fluid lost will lead to saving more money, lower torque and drag increases the chances of extended reach well, thereby reducing differential pressure sticking problem, reduces non-productive time and less solid concentration in mud and reduce mud impart in the formation.

1.3 Conclusion

This experimental research work looked at another possible ways of improving on the already established water base mud with locally sourced materials under nano fluid system. Consequently, the following conclusions can be derived from this study:

1) The ferric oxide nanoparticles are potential pH modifier in water base mud.
2) Corn cob acts as a better fluid loss control agent as well as for mud cake thickness reduction than the coconut shell, however, the combination of both yields a better result.
3) The addition of ferric oxide nanoparticles to water base drilling fluids leads to a significant reduction in the volume of filtrate loss and mud cake thickness formed during drilling operations.
4) The mud cake formed in a water base mud system and in the presence of ferric oxides NPs and the local additives were thin and smooth.

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