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Assessing the Impact of Fly Ash on the Thermal Stability and Rheological Properties of three component-Based Drilling Fluids

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Abstract
"Our study focuses on the development of an environmentally friendly emulsion mud utilizing vegetable palm oil, surfactants, and polymers. Palm oil and its derivatives exhibit robust resistance to heat and oxidation, particularly at elevated temperatures, making them ideal for such applications. A significant advantage of employing palm oil lies in its inherent content of natural emulsifiers, such as trace amounts of phospholipids, which facilitate self-emulsification. Polymers are incorporated into the emulsion to enhance rheological and filtration properties, while surfactants serve as stabilizers for the preparation of stable oil-in-water emulsions. Additionally, the challenges associated with poor filtration properties in this emulsion system are effectively addressed by the inclusion of fly ash, an inexpensive industrial waste product readily available without environmental concerns.

I. Introduction

As global energy demand rises, oil and gas industries worldwide are expanding drilling activities to access highly sensitive formations such as shale gas deposits, shaly sandstones, and fractured reservoirs. To navigate these complex formations, advanced drilling technologies like multilateral, horizontal, open hole, and slim hole drilling are increasingly employed. However, these formations present challenges such as cuttings swelling/dispersion and formation instability, leading to issues like bit balling, high torque and drag, pipe sticking, additional reaming, and formation damage.

The instability of wellbores poses a significant concern when conventional water-based drilling fluid systems are used in sensitive formations. This instability arises from the interaction between these fluids and the formation. Wells drilled with aqueous drilling fluids often experience decreased permeability in pay zones due to water blockage of pore spaces and swelling of anhydrous clays within these spaces. Emulsions offer an efficient and effective solution to control drilling problems in sensitive formations.

The emulsion system is a sophisticated three-component fluid arrangement comprising an oleaginous fluid (including paraffins, olefins, diesel, and mineral oil), a non-oleaginous fluid (brine), and a stabilizing agent (surfactant). This system is adeptly formed by blending two incompatible liquids in the presence of an emulsifier, which reduces the interfacial surface tension of one liquid, facilitating the formation of stable dispersion of fine droplets within the other liquid. The stability of the emulsion hinges on the zeta potential of the emulsion droplets. Theoretically, a highly negative zeta potential prevents the aggregation of emulsion droplets, enhancing stability through electrostatic repulsion. Polysaccharides contribute to stabilization by promoting mutual repulsion between the electrical double layers of particles and through the adsorption of macromolecules at the oil droplets.

Furthermore, the stability of the emulsion is not solely reliant on the chemical stability of the emulsifier but also on its interaction with various additives loaded into the emulsion, such as weighing agents, fluid loss additives, rheology modifiers, and drilled cuttings. These interactions play a crucial role in maintaining the stability and functionality of the emulsion system.

Experimental Procedure

The experimental procedure commenced with the addition of potassium chloride salt to water, thoroughly mixed using a Hamilton Beach mixer. Subsequently, water-soluble polymers were sequentially added. After achieving complete polymer dispersion through stirring at high speed, palm oil and surfactant were introduced into the homogeneous solutions, allowed to mix until a stable emulsion was obtained. The zeta potentials of the oil droplets within the emulsions were determined using a Zetameter 4.0 from Zeta-Meter, USA, at 21°C, which is crucial for assessing emulsion stability.

The rheological and filtration properties of the samples were analyzed using a Fann V-G meter 35SA model. This assessment included determining parameters such as apparent viscosity, plastic viscosity, yield point, as well as initial and 10-minute gel strengths of the prepared emulsion. The API Filter press apparatus was utilized to measure the filtration properties of the emulsion. Subsequently, the emulsion was prepared again, with the addition of fly ash, serving as a bridging agent in the developed formulations. The impact of fly ash particles on the rheological and filtration properties of the emulsion mud was then assessed.

Finally, the temperature stability of the emulsion mud was investigated by subjecting it to aging in a hot roller oven at 90°C for 16 hours, followed by measuring its rheological and filtration properties post-aging. The following formulas, as per API recommended practices for standard procedures in field testing of drilling fluids, were used to calculate the rheological parameters:

- Apparent viscosity (µa) = Ø600/2 (cP)

- Plastic viscosity (µp) = Ø600 – Ø300 (cP)

- Yield point (yp) = (Ø300 – µp) (lb/100 ft^2)

II. RESULTS AND DISCUSSION

In this study, xanthan gum was employed to control the rheological properties of the emulsion muds for several key reasons, including emulsion stabilization, temperature stability up to 120°C, and its pseudoplastic rheological properties. Additionally, the optimal concentration of xanthan was determined through zeta potential measurements, ensuring the stability of the developed emulsions. The selected oil-in-water emulsion, optimized for drilling fluid application, exhibited desirable rheological and filtration properties for oil and gas well drilling.

Emulsion Stability

Zeta potential measurements revealed higher negative values (ranging from -66 to -42 mV) for various combinations, indicating greater electronegativity and stability. Figure 1 illustrates the zeta potential of the emulsion droplets as a function of xanthan gum concentration.

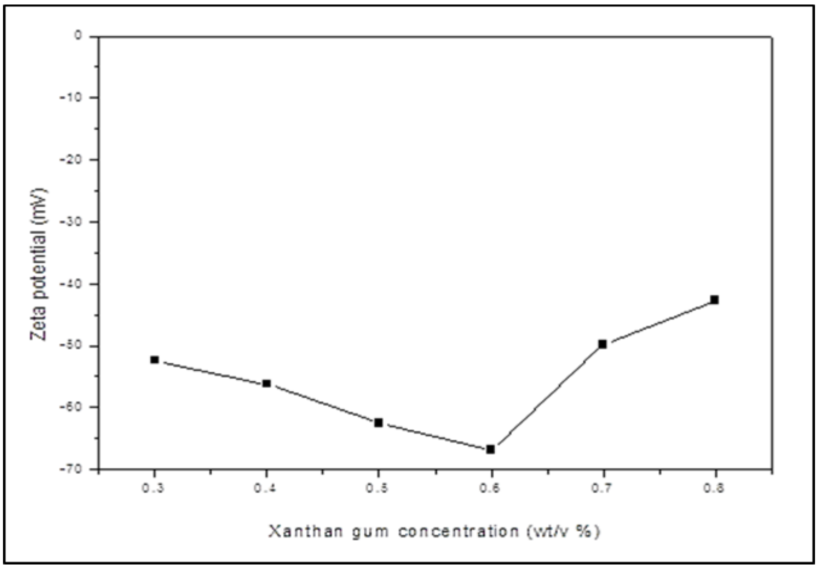

Fig. 1: Zeta Potential Variation with Xanthan Gum Concentration

Observations indicate an initial increase in the absolute value of zeta potential with rising xanthan gum concentration. However, beyond a concentration of 0.6 wt/v%, the trend of the graph shifts. This alteration may be attributed to the decrease in zeta potential (absolute value) due to the flocculation of smaller droplets. Xanthan gum, being a high molecular weight, long-chain polymer, has the capacity to wrap or bridge various droplets, forming larger droplet structures or flocs. This issue can potentially be alleviated by augmenting the amount of surfactant, facilitating the removal of adsorbed polymer from surfaces and resulting in the partitioning of particles from polymer-rich to polymer-deficient phases.

Rheological Properties of the Prepared Emulsions

Table 1. The detailed composition of the developed emulsion mud

Constituents	Composition	Unit
Water	90	% (vol/vol)
Oil	10	%(vol/vol)
Potassium chloride	5	%(wt/vol)
Sodium lauryl sulphate	0.3	%(wt/vol)
Xanthan gum	0.6	%(wt/vol)
Polyanionic cellulose	0.5	%(wt/vol)
Carboxy methyl cellulose	0.5	%(wt/vol)

To analyze the given constituents of the emulsion-based drilling fluid, let's break down their roles and contributions:

1. Water (90% vol/vol):
   - Water serves as the primary solvent in the drilling fluid.
   - It helps in dissolving other additives and maintaining the overall fluid volume.
   - Provides cooling during drilling operations.
2. Oil (10% vol/vol):
   - The oil phase in the emulsion contributes to lubrication and reduces friction during drilling.
   - It also helps in carrying drilling cuttings to the surface.
3. Potassium chloride (5% wt/vol):
   - Potassium chloride acts as a shale inhibitor, preventing swelling and dispersion of shale formations.
   - It helps stabilize the wellbore and maintains formation integrity.
4. Sodium lauryl sulfate (0.3% wt/vol):
   - Sodium lauryl sulfate serves as a surfactant or emulsifier.
   - It aids in the formation and stabilization of the oil-in-water emulsion by reducing interfacial tension between oil and water phases.
5. Xanthan gum (0.6% wt/vol):
   - Xanthan gum is a biopolymer that contributes to the rheological properties of the drilling fluid.
   - It imparts viscosity, shear-thinning behavior, and stability to the fluid.
   - Helps control fluid loss and suspension of solid particles.
6. Polyanionic cellulose (0.5% wt/vol):
   - Polyanionic cellulose is another rheology modifier and fluid loss control agent.
   - It enhances viscosity and provides filtration control, reducing fluid loss into the formation.
7. Carboxymethyl cellulose (0.5% wt/vol):
   - Carboxymethyl cellulose (CMC) also functions as a rheology modifier and fluid loss control agent.
   - It helps maintain viscosity, stabilizes the emulsion, and reduces fluid loss by forming a filter cake on the borehole wall.

The presence of a yield stress in xanthan gum solutions can be attributed to the numerous hydrogen bonds within its helix structure, which stabilize the configuration and offer resistance to flow. This structure remains intact until a shear stress of sufficient magnitude, surpassing the yield stress, is applied, causing its breakdown. Consequently, polymer chain orientation occurs, leading to shear-thinning flow behavior at higher shear rates.

The shear-thinning property of the system is evident in the developed formulations, characterized by the high yield point and plastic viscosity ratio, as depicted in Table 2.

Table 2: Rheological and Filtration Properties of the Developed Emulsion based Drilling Fluid.

Properties	Units	Values
Apparent viscosity	Centipoises	32.5
Plastic viscosity	Centipoises	20
Yield point	lb/100 ft^2	25
Initial gel strength	lb/100 ft^2	12
10 minutes gel strength	lb/100 ft^2	21
API, fluid loss	cc/30 min	46
Cake thickness	1/32 of an inch	1.20

The properties of the drilling fluid, as provided in the table, offer insights into its rheological behavior and filtration characteristics. The apparent viscosity of the fluid, measured at 32.5 centipoises, indicates its resistance to flow under applied shear stress, suggesting its ability to maintain stable flow conditions during drilling operations. Additionally, the plastic viscosity of 20 centipoises reflects the fluid's resistance to deformation under shear stress, which contributes to its overall stability and ability to suspend solid particles.
The yield point of 25 lb/100 ft^2 signifies the minimum stress required to initiate flow, representing the cohesive strength of the fluid. This property is crucial as it indicates the fluid's ability to support the weight of drilling cuttings and maintain wellbore stability. Furthermore, the initial gel strength of 12 lb/100 ft^2 and 10-minute gel strength of 21 lb/100 ft^2 highlight the fluid's ability to form a gel-like structure over time, which aids in reducing fluid loss and maintaining wellbore integrity.

The API fluid loss of 46 cc/30 min indicates the amount of fluid lost into the formation over a specified time period, providing insight into the filtration control properties of the drilling fluid. A lower fluid loss value suggests better filtration control, which is crucial for minimizing formation damage and maintaining wellbore stability. Additionally, the cake thickness of 1.20 1/32 of an inch demonstrates the thickness of the filter cake formed on the borehole wall, which further contributes to reducing fluid loss and stabilizing the wellbore. The properties of the drilling fluid indicate a well-balanced formulation with desirable rheological behavior, filtration control, and wellbore stability characteristics, essential for efficient drilling operations in challenging geological formations.

The drilling fluid system demonstrates various properties that fluctuate under different shear rate conditions within the borehole. Therefore, it is imperative for the emulsion mud to exhibit shear-thinning behavior. Maintaining a low plastic viscosity in the developed system, even with varying concentrations, is essential as it directly impacts the rate of penetration (ROP) during drilling operations. Optimal apparent viscosity is crucial for effective borehole cleaning, facilitating the circulation of cuttings up to the derrick floor under diverse shear rate conditions. Moreover, the drilling mud should possess excellent suspending ability to keep drilled cuttings suspended inside the borehole during pauses in drilling operations. This property can be evaluated by analyzing the gel strength of the emulsions, which is found to be suitable for drilling purposes.

In the context of filtration properties, sensitive formations exhibit significant interaction with the drilling fluid present within the wellbore. Filtrate invasion containing various ions can accelerate the diffusion process, ultimately disturbing the stress regime of the formation and potentially leading to formation damage, which adversely impacts productivity. Poor filtration properties, as indicated in Table 2, are a notable concern with emulsions. However, this issue can be addressed by selecting appropriate fluid loss additives and an inert bridging agent. In the absence of a bridging agent, the system may fail to form a filter cake quickly, exacerbating filtration problems. To mitigate this issue, fly ash, serving as an inert bridging agent, is incorporated to control the filtration properties of the developed emulsions. Remarkably, fly ash's inclusion has negligible impact on the rheological properties of the system.

Furthermore, the effect of fly ash on the emulsions and their thermal stability is noteworthy. Increasing the concentration of fly ash significantly controls the filtration properties, evidenced by the decrease in cake thickness and filtration volume across different emulsions, particularly with the addition of 2% fly ash, as depicted in Table 3.

Table 3: Effect of Fly Ash (2%) on the Rheological and Filtration Properties of Emulsion Based Drilling Fluid.

Properties	**Units**	**Values**
Apparent viscosity	Centipoises	32.5
Plastic viscosity	Centipoises	20
Yield point	lb/100 ft^2	25
Initial gel strength	lb/100 ft^2	12
10 minutes gel strength	lb/100 ft^2	21
API, fluid loss	cc/30 min.	5.5
Cake thickness	1/32 of an inch	0.44

The properties provided in the table offer critical insights into the rheological behavior, filtration characteristics, and overall performance of the drilling fluid. The apparent viscosity, measured at 32.5 centipoises, signifies the fluid's resistance to flow under applied shear stress. This property is crucial for maintaining stable flow conditions during drilling operations and ensuring effective cuttings transport to the surface. The plastic viscosity of 20 centipoises indicates the fluid's resistance to deformation under shear stress, contributing to its stability and ability to suspend solid particles. A yield point of 25 lb/100 ft^2 suggests the minimum stress required to initiate fluid flow, reflecting the cohesive strength of the fluid and its capacity to support the weight of drilling cuttings, thereby maintaining wellbore stability. The initial gel strength of 12 lb/100 ft^2 and 10-minute gel strength of 21 lb/100 ft^2 demonstrate the fluid's ability to form a gel-like structure over time, crucial for reducing fluid loss and maintaining wellbore integrity. The API fluid loss of 5.5 cc/30 min indicates the volume of fluid lost into the formation over a specified time period, providing insights into the filtration control properties of the drilling fluid. A lower fluid loss value suggests better filtration control, essential for minimizing formation damage and maintaining wellbore stability. Additionally, the cake thickness of 0.44 1/32 of an inch indicates the thickness of the filter cake formed on the borehole wall, which further contributes to reducing fluid loss and stabilizing the wellbore, crucial for efficient drilling operations in challenging geological formations.

The introduction of fly ash expedites cake formation significantly when subjected to hydrostatic pressure within the wellbore, thereby further enhancing filtration properties upon its addition to the emulsions.

Table 4: Rheological and Filtration Properties of Emulsions with 2% Fly Ash after Aging for 16 Hours at 90°C.

Properties	**Units**	**Values**
Apparent viscosity	Centipoises	37
Plastic viscosity	Centipoises	20
Yield point	lb/100 ft^2	34
Initial gel strength	lb/100 ft^2	14
10 minutes gel strength	lb/100 ft^2	23
API, fluid loss	cc/30 min.	5.5
Cake thickness	1/32 of an inch	0.38

The properties provided in the table offer crucial insights into the rheological behavior, filtration characteristics, and overall performance of the drilling fluid. The apparent viscosity, measured at 37 centipoises, signifies the fluid's resistance to flow under applied shear stress. This property is essential for maintaining stable flow conditions during drilling operations and ensuring effective cuttings transport to the surface. The plastic viscosity of 20 centipoises indicates the fluid's resistance to deformation under shear stress, contributing to its stability and ability to suspend solid particles. A yield point of 34 lb/100 ft^2 suggests the minimum stress required to initiate fluid flow, reflecting the cohesive strength of the fluid and its capacity to support the weight of drilling cuttings, thereby maintaining wellbore stability. The initial gel strength of 14 lb/100 ft^2 and 10-minute gel strength of 23 lb/100 ft^2 demonstrate the fluid's ability to form a gel-like structure over time, crucial for reducing fluid loss and maintaining wellbore integrity. The API fluid loss of 5.5 cc/30 min indicates the volume of fluid lost into the formation over a specified time period, providing insights into the filtration control properties of the drilling fluid. A lower fluid loss value suggests better filtration control, essential for minimizing formation damage and maintaining wellbore stability. Additionally, the cake thickness of 0.38 1/32 of an inch indicates the thickness of the filter cake formed on the borehole wall, which further contributes to reducing fluid loss and stabilizing the wellbore, crucial for efficient drilling operations in challenging geological formations.

Many components of drilling muds experience gradual degradation as temperature increases. Therefore, the thermal stability of the emulsions is assessed by subjecting them to varying temperatures in a roller oven. The rheological and filtration properties of the system containing 2% fly ash after aging for 16 hours at 90°C are detailed in Table 4. It is observed that these properties remain largely unaffected up to 90°C, demonstrating the potential of the emulsions for drilling sensitive formations at this temperature.

III. CONCLUSIONS

The study yields the following conclusions:

1. Zeta potential measurements confirm the stability of the developed oil-in-water emulsions.
2. The high yield stress plastic viscosity ratio indicates shear-thinning behavior, a critical property for drilling fluid performance.
3. Rheological parameters fall within optimal ranges, suggesting suitability for effective drilling fluid performance.
4. Filtration properties are effectively managed with the use of fly ash, serving as an inert bridging agent in various emulsion muds.
5. Palm oil-in-water emulsions offer potential benefits, potentially mitigating the toxic effects associated with conventional oil-based drilling fluids used in oil and gas well drilling operations.

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