Prediction of Formation Damage, Fluid Loss and Rheological Properties of Water Based Mud with Corn Cob

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Abstract — The extent of damage to formation caused by water based drilling mud containing corn cob treated with sodium hydroxide to partially replace polyanionic cellulose (PAC) as a fluid loss control additive has been studied. Core samples were obtained from a well in Niger Delta for this study with a permeameter used to force the drilling mud into core samples at high pressures. Physio-chemical properties (moisture content, cellulose and lignin) of the samples were measured and the result after treatment showed reduction. The corn cob was combined with the PAC in the ratio of 25-75%, 50-50% and 75-25% in the mud. Analyzed drilling mud rheological properties such as plastic viscosity, apparent viscosity, yield point and gel strength all decreased as percentage of corn cob increased in the combination and steadily decreased as temperature increased to 200°F. Measured fluid loss and pH of the mud showed an increase in fluid loss and pH in mud sample with 100% corn cob. The extent of formation damage was determined by the differences in the initial and final permeability of the core samples. Experimental data were used to develop analytical models that can serve as effective tool to predict fluid loss, rheological properties of the drilling mud at temperature up to 200°F and percentage formation damage at 100 psi.

Index Terms — corn cob, fluid loss, formation damage, water based mud.

I. INTRODUCTION

Damage is reduction in the reservoir natural capability to produce its fluids as a result of changes in permeability or porosity, or both. Formation damage adversely affects both drilling and production operations and therefore directly impacts economic viability. Although formation damage severity may vary from one well to the other, one thing that is certain is that any reduction in recovery potential is unwanted.

Generally, formation damage mechanisms include scales, solids, asphaltenes, waxes, polymers, bacteria, clay swelling and hydrates that may plug the rock matrix in the near wellbore region. The drilling fluid is the main source of damage due to the invasion of foreign fluids and / or solids into the exposed section around the wellbore [1]. The major component of drilling operation success is the drilling fluid performance. Deep water hostile environment requires fluids that excel in performance. Measuring fluids performance requires the evaluation of all key drilling parameters and their associated cost. Simply put, the effectiveness of fluid is judged by its influence on overall well cost [2]. Since non-damaging fluids do not exist, importance should be given to the understanding and control of formation damage when designing drilling fluids [3].

The loss of fluid to the formation represents a financial loss and the impact is directly tied to the per barrel cost of the drilling fluid [4]. Drilling fluid therefore are typically formulated with fluid loss additives that plug the zone of loss in the formation away from the borehole face to forestall further fluid losses [5]-[15]. However, when drilling operation in a fresh formation commences before mud cake is formed, the producing formation is exposed to the drilling fluid, solids and chemicals contained in the fluid. Some invasion of fluid filtrate and / or solids into the formation is inevitable. This invasion is a potential cause of damage to the formation. The basic damage mechanism associated with drilling mud systems include damage caused by drilling fluid and reservoir rock incompatibility (e.g. clay hydration), from drilling fluid and formation fluid incompatibility (e.g. formation of emulsion), from mud filter cake not listed off or by-passed in non-perforated completion and from invasion of the pores by solids contained in the mud. The mechanisms result in near-wellbore permeability and porosity reduction and can severely reduce productivity.

II. MATERIALS AND METHODS

A. Equipment and Materials

The following equipment and reagents were used: Wiley mill, 270 mesh (53 μm) screen, knife, thermometer, drying oven, stop clock, Hamilton beach mixer, mud balance, Fann viscometer, API filter press, weighing balance, pH indicator, scale rule, transparent glass water containing vessel, Ruska liquid permeameter model 1013-801, Whatman filter paper, heating mantle, cornical flask, beakers, desiccators, crucible, muffle furnace, corn cob, sodium hydroxide, deionized water, dilute acetic acid solution (for removing remaining alkali), bentonite, barite, xanthan gum, polyamionic cellulose, ethanol, H₂SO₄.

B. Experimental Procedure

1. Mechanism of Sodium Hydroxide Treatment of Corn Cob

Mechanism of treatment of corn cob using sodium hydroxide solution is shown in Fig. 1.
Lignin forms a protective barrier by encasing cellulose and hemicellulose. This however becomes an obstacle in cellulose and hemicellulose degradation. Ferulic acid which links cellulose and hemicellulose forms an ester bond through its carboxylic group with hydroxyl of arabinocylan side chain of xylan and an ether bond with lignin through hydroxyl group covalently linked to lignin monomer as shown in Fig. 2. Sodium hydroxide reacts with the ester bond of the carbohydrate because it is highly susceptible to alkaline degradation.

![Fig. 2. Base hydrolysis of the ester bond [15].](image)

The hydroxide ion from the sodium hydroxide attacks the carbon of the ester bond to form a tetrahedral intermediate. This intermediate collapses when a negatively charged oxygen expels an alkoxide (−OCH₃) from the carboxylic acid. The alkoxide acts as a base to deprotonate the carboxylic acid. This results in the irreversible hydrolysis of the ester bond which breaks the protective lignin barrier with hemicellulose of the corn cob and causes lignin to be solubilized giving way for degradation of hemicellulose fractions. Sodium hydroxide also increases the surface area and greater accessibility to cellulose fractions.

2. Mud Formulation
Mud samples were formulated using corn cob particles but with the combination of PAC and corn cob particles as the fluid loss material in the mud as shown in table 1.

| Sample | Polyanionic Cellulose, PAC (%) | Corn Cob (%) | Total Concentration (grams/barrel) |
|--------|-------------------------------|--------------|-----------------------------------|
| A      | 100                           | 0            | 5                                 |
| B      | 75                            | 25           | 5                                 |
| C      | 50                            | 50           | 5                                 |
| D      | 25                            | 75           | 5                                 |
| E      | 0                             | 100          | 5                                 |

3. Properties of the samples
The bulk volume of the sample was obtained by direct measurement of core length and diameter with a scale rule and determined using equation (1).

$$V_b = \pi D^2L/4$$  \hspace{1cm} (1)

where $V_b$ is the bulk volume, $D$ is diameter and $L$ is length.

The effective pore volume was obtained from dry weight, saturated weight and density of the sample after immersing the core in water for 2 days (48 hours). The expression for the pore volume is presented in equation (2).

$$V_p = \frac{W_{core-sat} - W_d}{\sigma_L}$$  \hspace{1cm} (2)

where $W_{core-sat}$ is the weight of the saturated core, $W_d$ is the weight of dry core and $\sigma_L$ is density.

Effective porosity was determined from equation (3):

$$\text{Effective porosity} = \frac{V_p}{V_b}$$  \hspace{1cm} (3)

where $V_p$ is the effective pore volume and $V_b$ is the bulk volume.

Placing the core in a core holder, the core vacuumed for one hour with a vacuum pump, at 200psi confining pressure, injection of water into the core sample was made. The initial liquid permeability was obtained at 50 psi, the prepared conventional and corn cob fluid samples were placed into a container and pressurized with nitrogen gas. The fluid was pumped to the face of the core in the core holder at a constant pressure of 50psi and 100psi respectively to cause damage in the core samples. With the formation damage process completed, the final permeability of the sample was measured by liquid flooding at 50 psi same as for the initial permeability measurement and permeability was obtained from equation (4).

$$K = \frac{\mu Q L}{A \Delta P}$$  \hspace{1cm} (4)

where $K$ is permeability, $Q$ is flow rate, $L$ is length, $A$ is area and $\Delta P$ is pressure difference.

4. Formation Damage
Fluid loss and Rheological properties of Formulated mud
The fluid loss was measured with filter press and the rheological properties (plastic viscosity, apparent viscosity, yield point, gel strength) of the formulated water based mud with 8-speed rheometer.

The magnitude of formation damage by drilling fluid was determined from equation (5):

$$\% \text{ Mud damage} = \frac{K_b - K_E}{K_b} \times 100$$  \hspace{1cm} (5)

where $K_b$ is permeability of formation and $K_E$ is permeability of the formation after mud damage.

With the use of data fit tool, data points for fluid loss, rheological properties at 200°F and formation damage were fit using experimental result. This was done to develop analytical models to predict fluid loss after 30 minutes, formation damage at 100 psi and rheological properties such
as plastic viscosity, apparent viscosity, yield point and gel strength at 200°F respectively.

III. RESULTS

A. Fluid Loss Model

The model equation developed for fluid loss as a function of percentage concentration of Corn cob and time of 30 minutes in the drilling mud is presented in equation (6).

\[ FL(\text{mls}) = 3.07 + 9.23(C_c) + 6.31/t \]

where: FL = Fluid loss, \( C_c \) = percentage concentration of Corn cob, \( t \) = time, 3.07, 9.23 and 6.31 are constants.

![Fig. 3. Fitting fluid loss of the formulated water based mud.](image)

B. Formation Damage Model at 100 psi.

The model equation developed for percentage formation damage by formulated water based mud as a function of percentage concentration of Corn cob and injection pressure is presented in equation (7).

\[ FD(\%) = 147.53 \times 1.2539^{C_c} \times P^{-0.4288} \]

where: FD = Formation damage, \( C_c \) = Percentage concentration of Corn cob, \( P \) = Mud injection pressure, 147.53, 1.2539 and -0.4288 are constants.

![Fig. 4. Fitting formation damage of formulated water based mud at 100 psi.](image)

C. Apparent Viscosity Model

The model equation developed for effect of temperature on apparent viscosity in formulated Corn cob water based mud as a function of percentage concentration of Corn cob and temperature at 200°F is presented in equation (8).

\[ AV(C_c) = 0.5242 \times 0.7743^{C_c} \times T^{-0.8965} \]  

(8)

where: \( AV \) = Apparent viscosity, \( C_c \) = Percentage concentration of Corn cob, \( T \) = Temperature (°F), 0.5242, 0.7743 and 0.8965 are constants.

![Fig. 5. Fitting apparent viscosity of the formulated water based mud.](image)

D. Plastic Viscosity Model

The model equation developed for effect of temperature on plastic viscosity in formulated Corn cob water based mud as a function of percentage concentration of Corn cob and temperature at 200°F is shown in equation (9).

\[ PV(C_c) = 0.3524 \times 1.1288^{C_c} \times T^{0.8393} \]  

(9)

where: \( PV \) = Plastic viscosity, \( C_c \) = Percentage concentration of Corn cob, 200 = Temperature (°F), 0.3524, 1.1288 and 0.8393 are constants.

![Fig. 6. Fitting plastic viscosity of the formulated water based mud.](image)

E. Yield Point Model

The model equation developed for effect of temperature on yield point in formulated Corn cob water based mud as a function of percentage concentration of Corn cob and temperature at 200°F is shown in equation (10).

\[ YPV(\text{lb} / 1000 \text{ ft}^2) = 13312.5675 + (-25093.4196) \times \ln T \]  

(10)
where: YP = Yield point, Cc = Percentage concentration of Corn cob, T = Temperature (°F), 133012.5675, -34.6666 and -25093.4196 are constants.

F. Model for Gel Strength

The model equation developed for effect of temperature on 10 minutes gel strength in formulated Corn cob water based mud as a function of percentage concentration of Corn cob and temperature at 200°F is presented in equation (11).

\[
Gel (lb/1000 ft^2) = 133236.3186 + (-10.666 \times C_c) \times (-2514.1236 \times \ln T)
\] (11)

where: Gel = gel strength, Cc = Percentage concentration of Corn cob, T = Temperature (°F), 133236.3186, -10.6666 and -2514.1236 are constants.

IV. CONCLUSION

Model for formation damage, fluid loss, plastic viscosity, apparent viscosity, yield point and gel strength were developed and they predicted within the range of the experimental values. The fluid was found highest in mud sample with only corn cob (100%) as additive and with the greatest damage on the sample. The values of rheological properties increased as the percentage of corn cob decreased in the mud samples and upon increase in temperature the values all decreased. The developed analytical models were able to predict fluid loss, formation damage and effect of temperature on rheological properties of the corn cob mud with very little error and can be a vital tool for successful drilling operation minimizing fluid loss and formation damage.

ACKNOWLEDGMENT

The authors Sincerely appreciate Prof E. N Wami for his all-round support to the success of this work. Also, sincere appreciation to Mrs H. Chiemzie-Nwosu for her endless encouragement throughout the duration of this work.

| Table 3: Validation of Model for Formation Damage at 100 PSI Mud Injection Pressure |
|---------------------------------|-------------|-------------|-----------|
| Corn Cob (%)                   | Experimental Result | Model Results | Error     |
| 25                             | 48.25        | 48.12       | 0.13      |
| 50                             | 52.84        | 52.30       | 0.54      |
| 75                             | 57.46        | 56.70       | 0.76      |
| 100                            | 62.56        | 61.79       | 0.77      |

| Table 4: Validation of Model for Effect of Temperature at 200°F on Apparent Viscosity |
|---------------------------------|-------------|-------------|-----------|
| Corn Cob (%)                   | Experimental Result | Model Results | Error     |
| 25                             | 57.00        | 56.83       | 0.17      |
| 50                             | 53.90        | 53.31       | 0.59      |
| 75                             | 50.85        | 50.01       | 0.84      |
| 100                            | 47.50        | 46.91       | 0.59      |

| Table 5: Validation of Model for Effect of Temperature at 200°F on Plastic Viscosity |
|---------------------------------|-------------|-------------|-----------|
| Corn Cob (%)                   | Experimental Result | Model Results | Error     |
| 25                             | 31.00        | 31.00       | 0.00      |
| 50                             | 32.85        | 31.95       | 0.90      |
| 75                             | 34.23        | 33.40       | 0.83      |
| 100                            | 34.00        | 33.95       | 0.05      |

| Table 6: Validation of Model for Effect of Temperature at 200°F on Yield Point |
|---------------------------------|-------------|-------------|-----------|
| Corn Cob (%)                   | Experimental Result | Model Results | Error     |
| 25                             | 31.00        | 50.9        | 0.10      |
| 50                             | 42.50        | 42.23       | 0.17      |
| 75                             | 33.74        | 33.66       | 0.08      |
| 100                            | 25.00        | 25.00       | 0.00      |

| Table 7: Validation of Model for Effect of Temperature at 200°F on 10 Minutes Gel Strength |
|---------------------------------|-------------|-------------|-----------|
| Corn Cob (%)                   | Experimental Result | Model Results | Error     |
| 25                             | 29.00        | 28.00       | 1.00      |
| 50                             | 25.75        | 25.33       | 0.42      |
| 75                             | 22.90        | 22.66       | 0.24      |
| 100                            | 20.00        | 20.00       | 0.00      |
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