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Electrical resistivity and rheological properties of sensing bentonite drilling muds modified with lightweight polymer

Ahmed S. Mohammed

Department of Civil Engineering, University of Sulaimani, Iraq-Kurdistan Region-Sulaimani, Iraq

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ABSTRACT

In this study, the electrical resistivity and rheological properties of a water-based bentonite clay drilling mud modified with the lightweight polymer (guar gum) under various temperature were investigated. Based on the experimental and analytical study, the electrical resistivity was identified as the sensing property of the bentonite drilling mud so that the changes in the properties can be monitored in real-time during the construction. The bentonite contents in the drilling muds were varied up to 8% by the weight of water and temperature was varied from 25 °C to 85 °C. The guar gum content (GG%) was varied between 0% and 1% by the weight of the drilling mud to modify the rheological properties and enhance the sensing electrical resistivity of the drilling mud. The guar gum and bentonite clay were characterized using thermal gravimetric analysis (TGA). The total weight loss at 800 °C for the bentonite decreased from 12.96% to 0.7%, about 95% reduction, when the bentonite was mixed with 1% of guar gum. The results also showed that 1% guar gum decreased the electrical resistivity of the drilling mud from 50% to 90% based on the bentonite content and the temperature of the drilling mud. The guar gum modification increased the yield point (YP) and plastic viscosity (PV) by 58% to 230% and 44% to 77% respectively based on the bentonite content and temperature of the drilling mud. The rheological properties of the drilling muds have been correlated to the electrical resistivity of the drilling mud using nonlinear power and hyperbolic relationships. The model predictions agreed well with the experimental results. Hence the performance of the bentonite drilling muds with and without guar gum can be characterized based on the electrical resistivity which can be monitored real-time in the field.

1. Introduction

Water-bentonite clay suspensions have been used in the oil, gas and geothermal drilling industry for decades. Multi-functional drilling muds are required to transport the rock cuttings to the surface, lubricate and cool the drill bit and apply hydrostatic pressure in the wellbore to ensure well safety. The deeper wells that are being drilled calls for more advanced drilling fluids because of the changes in pressure, temperature and geology formations. The drilling fluid can react with certain types of formation or the pressure can cause the rock to crack, leading to massive loss of fluid into the formation [1,2]. Hence there needs to not only enhance the performance of bentonite based drilling mud but also monitor the performance of the drilling muds during the drilling operations [3]. Bentonite is a type of clay consisting mainly of a hydrous silicate of aluminum; its color varies from gray to brown. Bentonites have formed by weathering of volcanic tuff and ash and consist mainly of montmorillonite $[(Al,Mg)_2(OH)_2(Si,Al)_4O_{10}(Ca)_x$ on $H_2O]$ and contain varying amounts of other minerals such as quartz (SiO_2) and calcium and sodium feldspar $[(CaAl_2Si_2O_8),(NaAl_3Si_2O_8)]$ [4]. In general, the bentonite is classified into two types; Na-bentonite, which has a high swelling capacity, and Ca-bentonite, which is a non-swelling clay and forms colloidal very quickly in water. Bentonite suspensions are widely used in oil and gas industry because of their exceptional rheological properties [5]. Generally, the flow of bentonite dispersions is very sensitive to the Na^+/Ca^{+2} ratio. The rheological measurements of bentonite dispersions, an important route to revealing the flow and deformation behaviors of materials, cannot only improve the formulation process of commercial products but can also be very important in design and process evaluation, quality control, and storage stability [6]. The main function of the bentonite is to increase the viscosity of the mud and to reduce the fluid loss to the formation. A good quality bentonite should contain mainly montmorillonite [7]. Bentonite often contains other clay minerals such as illite and kaolinite and non-clay components such as quartz and feldspar [8]. Based on 72 data collected from the literature (CIGMAT data base) the

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E-mail address: ahmed.mohammed@univsul.edu.iq

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amount of bentonite used in water based drilling muds varied from 0.5 to 14% (by weight of water). Over 50% of the studies used up to 6% of bentonite in water based drilling mud [9].

Guar gum is defined as having the particle size in the range of 1 to 100 nm. Montmorillonite (MT) based guar gum is chemically a hydrated sodium calcium aluminum magnesium silicate hydroxide $(Na, Ca)_{0.33}(Al, Mg)_2 (Si_4O_{10}) (OH)_2 \cdot nH_2O$. Because montmorillonite clay is hydrophilic, it is not compatible with most polymers and must be chemically modified to make its surface more hydrophobic [10]. The guar gum particles can go throw the larger particles and block the flow through them [1]. Previous studies have shown that the guar gum reduced friction between steel and paraffin as the base fluid. The use of guar gum has attracted great interest in the polymer industry during the past decade as polymer modified clay exhibited much better mechanical properties when compared with the virgin polymer or conventional micro and macro-composites [11,12]. Effects of the drilling mud modified with polymer on the rheological properties and fluid loss of drilling muds have been documented in the literature by several researchers are summarized in Table 1.

Mathematical modeling studied concerning the well and pipeline flow of thixotropic drilling muds and crude oils. Drilling muds (oil-based muds, water-based muds) exhibit complex rheological behavior (Bingham or Herschel-Bulkley model). The limitations of the mathematical modeling studies concerning thixotropic drilling mud and crude oil flows have two main causes. Despite recent advancements in tools such as quality HTHP/LT (high-temperature/high-pressure/low- temperature) viscometers, a unified rheological model valid for a wide range of pressures, temperatures, and flow regimes which could account for complex rheological effects such as thixotropic and yield stress still does not exist [13,14]. The role of drilling fluid is to pass through formations with high porosity while keeping all its rheological properties and without causing damage to the crossed formations. To reduce the mud toxicity, the water-based mud was developed. The studies carried out used a drilling fluid containing water, a natural or synthetic polymer, and additives. The polymers currently used in the oil industry are cellulosic, guar gum, xanthan gum, polyacrylates, polyacrylamides and maleic anhydride derivatives. Control of drilling fluid properties is essential when encountering unconsolidated formations in complex geometries. These properties include fluid density, rheological parameters (viscosity and yield stress) [15].

In this study, enhancing the sensing and rheological properties of bentonite drilling mud modified with guar gum at different temperatures were tested and quantified with the electrical resistivity of the drilling mud.

2. Objectives

The overall objective was to quantify the effect of temperature on the electrical resistivity and rheological properties of bentonite drilling mud modified with guar gum. The specific objectives are as follows:

(i) Evaluate the effect of guar gum on the electrical resistivity (nondestructive and sensing properties) and rheological properties of the bentonite drilling muds at different temperatures.
(ii) Investigate the relationship between the electrical resistivity of the drilling mud and the rheological properties of the bentonite drilling mud so that it can be used as a real- time monitoring parameter.

3. Materials and methods

3.1. Guar gum

Commercially available guar gum, purity of 100% was used for this study, the appearance of yellowish-white, pH varied between 5.5 to 6.2 (1% solution) and density at 25 °C was 0.8 g/cm^3.

3.2. Bentonite

In this study, commercially available bentonite was used. The chemical composition of the bentonite has been identified using X-ray diffraction as shown in Fig. 1.

Table 1
Literature review on applications of polymer in drilling operations

References	Polymer type	% of polymer (by dry weight)	Applications	Temperature (°C)	Tests	Remarks
[2]	soda ash, Carboxi Methyl Cellulose (CMC) and Drispac polymer	Up to 1.5%	Water based drilling mud	25 °C ± 1 °C	Rheological properties (PV, YP, AV and Gel strength)	The rheological properties of drilling muds significantly improved
[13]	Starch and xanthan gum	Up to 10%	drilling fluid	95 °C	Fluid loos and filter cake	Increased the stability of the borehole
[15]	Xanthan gum and the scleroglucan	Up to 20%	Oil and water based drilling mud	25 °C ± 1 °C	Shear stress-shear strain rate, flow index, n and consistency, k	Rheological properties of drilling muds increased
[19]	Polyoxyalkyleneamine	Up to 27%	Water based drilling mud	70 °C	Rheological properties (PV, YP, AV and Gel strength)	Enhanced the rheological properties of drilling mud
[20]	Xanthan gum and Starch	Up to 2%	Water based drilling mud	25 °C ± 1 °C	Rheological properties and shear stress-shear strain rate	The rheological properties of drilling muds improved.
[21]	Guar gum	up to 2%	Hydraulic fracturing	85 °C	Permeability, and rheological properties	Permeability decreased and the rheological properties increased
[22]	Sugarcane and polyanionic cellulose	Up to 0.2%	Water based drilling mud	50 °C	Shear stress-shear strain rate, and rheological properties (PV, YP, AV)	Enhanced the rheological properties of drilling mud
Current Study	Guar gum	Up to 1%	Water based drilling mud	25 °C–85 °C	Electrical resistivity and rheological properties	Electrical resistivity correlated well with rheological properties
Remarks	Different polymer types were used	Up to 27% of polymer was used	Different applications were used	Temperature ranged between 25 °C to 95 °C	Rheological properties is the popular test to characterize the effect of polymer	No electrical resistivity properties has been studied

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