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Double protection drilling fluid: Optimization for sandstone-like uranium formation

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ABSTRACT

Nuclear energy, an alternative for fossil fuel, is accompanied by the excavation of uranium ores and in turn the use of drilling fluids. Thus, the objective of this study was to optimize the formula of drilling fluid for sandstone-like uranium formation representing the Xinjiang's Yili Basin uranium formation in China. Additives such as Na_2CO_3, potassium humate (KHM), sodium carboxymethyl cellulose (Na-CMC), and vegetable gum (VG) were introduced to montmorillonite (Mt) slurry to maximize the performance of drilling fluid in terms of rheological behavior and filtration characteristics. Orthogonal testing, soaking test, and pressure-bearing test were conducted to find the optimum formula of drilling fluid. The maximized performance was achieved with a drilling fluid consisting of 4% Mt, 1.6% Na_2CO_3, 0.1% KHM, 1.5% Na-CMC, and 0.5% VG. The lowest density and water loss, with a sufficiently high viscosity were achieved with this concentration combination of each additive. Soaking and pressure-bearing tests exhibited no visual changes of a specimen treated with the drilling fluid, which confirmed the result of optimization.

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1. Introduction

Fossil fuels have been a main energy source making up over 87% of the world's energy consumption in the past 200 years (Demirbas, 2010). As a result, the conventional energy resources decline and the price is ever increasing, which will lead to an energy crisis in the near future (Turner, 1974). Nuclear energy has alternatively been used in several countries and proven to be cost-effective (Dresselhaus and Thomas, 2001; IAEA, 1997; Paker and Holt, 2007) and stabilize global climate (Hoffert et al., 2002). However, the use of nuclear energy is accompanied by the excavation of uranium which includes difficulties due to the complexity of uranium formation (Dahlkamp, 1978; Lyons et al., 1982).

Core samples of uranium drilled from the formation are often necessarily analyzed to understand the properties of mineral reservoir (Anderson, 1969; Ebenhack, 1987; Fitch, 1980; Meinrath et al., 1999; Morgan et al., 1997). During drilling core samples, a drilling mud has effectively been used to improve the borehole stability (Cherepanov, 1982; Hao, 2011; Zeynali, 2012). For example, a drilling mud has successfully been applied in uranium sandstone formation (Keas, 1974; Petri and Neto, 2010).

A drilling mud itself has also been developed in terms of its properties and composition. For example, a thixotropic drilling mud has been applied to form a radioactive filter cake for a purpose of analyzing the radioactivity of a formation (Ebenhack., 1987). The addition of polymers has been applied to improve the instability problem of shale field (Khodjaa et al., 2010). Nevertheless, there is a demand for protecting drilled core samples because those drilling mud technologies only consider the protection of wellbore. Water invasion often destroys core samples, preventing estimation of the potential producing capacities of the formations penetrated (Bailey and Keall, 1993; Patel and Salandanan, 1968). This is especially important for uranium formations or similar reservoirs, where its poor engineering properties, including loose soft/hard inter-bedding, water-containing strata, poor degree of consolidation, and cracks, often result in collapse of drilled samples as well as of wellbore (Borivoje et al., 2007; Bowes and Procter, 1997).

The objective of this study was to create a suitable drilling fluid for use in a sandstone uranium formation, which protects both borehole and core samples (double protection). In order to modify properties of drilling mud (bentonite), additives including Na_2CO_3, potassium humate (KHM), sodium carboxymethyl cellulose (Na-CMC), and vegetable gum (VG) were utilized. The orthogonal experimental method was employed to optimize the formula of drilling fluid. Soaking and

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pressure-bearing tests were conducted to confirm the optimum formula of drilling fluid.

2. Experimental study

2.1. Materials

Montmorillonite (Mt) is commonly used as a drilling mud due to its unique characteristics, such as negative surface charge, high specific surface, and high plasticity (Darley and Gray, 1988; Menezes et al., 2010). Calcium bentonite obtained from Xuzhou Wuzi Market (Xuzhou City, Jiangsu Province, China) was used as a source of Mt. Chemical components of the clay were SiO_2 (53.82%), Al_2O_3 (26.96%), Fe_2O_3 (12.81%), TiO_2 (2.96%), MgO (2.91%), and trace elements (0.54%).

Additives were used to improve the performance of drilling mud in terms of lubricity, and the ability of protecting cored samples from collapse and viscoelastic vibration generated by a rig. Na_2CO_3 and potassium humate (KHM) were applied as sources of Na^+ and K^+, respectively, to control the swelling behavior of Mt. The Ca^{2+} replacement with Na^+ increases the swelling of Mt, while K^+ hinders from further swelling of Mt, maintaining the stability of mud cake (Boek et al., 1995). Sodium carboxymethyl cellulose (Na-CMC) was used to decrease the hydraulic conductivity of mud cake, in turn reducing fluid loss (Hebeish et al., 2010). Vegetable gum (VG) was introduced to improve the viscosity of drilling fluid. All the additives were obtained from Xuzhou Wuzi Market (Xuzhou City, Jiangsu Province, China). VG is a water soluble organic polymer consisting mainly of mannose, galactose, xylose, and glucose polysaccharide (Caprita et al., 2010). Due to its hydrophilicity, VG tends to interact with water molecules leading to an increase in the viscosity of fluid (Caenna and Chillingarb, 1996; Finch, 1998; Jackson, 1979). The enhanced rheological property as well as the use of Na-CMC induces a decrease in fluid loss from mud cake. This process prevents Mt particles from flocculating or coagulating which may damage the borehole and cored samples.

2.2. Sample preparation

The bentonite was modified with the addition of Na_2CO_3 to replace the interlayer calcium ions with Na^+. The mixture was then mixed with distilled water for 24 h. The fully hydrated clay slurry (drilling mud) was mixed using different proportions of additives. The proportion of additives is tabulated in Table 1. The newly formed drilling fluid was used throughout this study.

2.3. Test procedures

2.3.1. Compatibility test

KHM, Na-CMC, and VG are all commonly used as a component of drilling fluids, thereby the compatibility of each additive has been well established. However, it is necessary to test the compatibility of all additives together with the inorganic salt (Na_2CO_3) used in this study, and the additives with the drilling mud (Mt) because they could be mutually influenced by each other leading to undesirable performance (Hao, 2011). Compatibility tests were conducted by adding 100 ml of mixture of Mt (8%) and additives to the inorganic salt (4% Na_2CO_3). The content of Mt was obtained from dispersivity tests which determine whether a drilling mud remains dispersive at a given content of additives. The content of the inorganic salt was decided based on the API regular criterion (API, 1988). The compatibility tests may provide an appropriate range in the content of each additive.

Table 1
Concentrations of each component of drilling fluids, s.

Concentration ID	Component (%)				
	Mt	Na_2CO_3	KHM	Na-CMC	VG
A	2	0.8	0.1	0.1	0.1
B	4	1.6	0.5	0.5	0.25
C	6	2.4	1	1	0.5
D	8	3.2	1.5	1.5	0.75

2.3.2. Optimization

Flow of drilling fluids exerts hydrodynamic forces on the borehole and drilled cores. In order to estimate such forces, viscosity, hydrodynamic shear stress created by fluid flow, and dynamic filtration were investigated on every combination. Orthogonal testing is a simple and efficient technique which is often used to find the optimum condition among various affecting factors simultaneously. Orthogonal testing with specimens shortlisted according to the results of compatibility tests would provide insight for the optimum formula of drilling fluids.

In this study, four different concentrations of each component of drilling fluids were selected from the pre-determined range of concentrations (Table 1). The performance of drilling fluids was evaluated based on the measurements of rheological properties and filtration characteristics including density, plastic viscosity, Marsh funnel viscosity, yield point, and water loss characteristics of the drilling fluids. The best performance would be achieved when the ratios of the four additives are optimized. Testing details can be found in Hao (2011).

2.3.3. Soaking test

Drilling fluid should be formulated to minimize damage due to the invasion of solids and mud filtrate (Jiao and Sharma, 1992). A stable, low-permeability mud cake should form rapidly on the reservoir rock in question. In order to investigate the stability of borehole and core samples, soaking tests were performed. The results of soaking tests imply the stability of the borehole as well as the core samples drilled from the borehole. Sand soil specimens, which simulate the sandstone-like uranium formation, were artificially made for soaking tests. The specimens with a diameter of 1.48 cm and a height of 3 cm consist of white quartz sands with grain diameter of 0.1–1 mm and silt with grain diameter less than 0.075 mm (at a ratio, quartz sands: silt = 4:3). The sand and silt were classified from soil samples obtained from Xinjiang's Yili Basin uranium formation in China. Crack formation and changes in specimen diameter were observed after 72 h of submerging a specimen under each drilling fluid proposed in this study (Table 1).

2.3.4. Pressure-bearing test

Laboratory experiments of core samples need to be conducted under simulated field conditions to minimize the differences in the measured properties (Towler, 1986). Pressure-bearing tests were carried out to investigate the stability of specimens in terms of in-situ groundwater pressure and the pressure caused by drilling fluid flow. The specimens used for soaking tests were subjected to a load bar which provides the specimens with a pressure of 2.73 kPa. Unless the specimens collapse after 1 min, an additional load bar was applied leading to the total pressure of 6.14 kPa. Distortion, fracture, or crack formation within the specimens was monitored over the next minute. The pressure of 2.73 kPa is similar to the groundwater pressure in sandstone uranium formation and the pressure of 6.14 kPa is approximately the sum of the groundwater pressure and the pressure caused by drilling fluid flow. The pressures were calculated based on pressure measurements of Xinjiang's Yili Basin uranium formation in China.

3. Results and discussion

3.1. Compatibility test

The compatibility tests were conducted to investigate the mutual interactions of each additive and to narrow down the range in concentration of each additive. From the experiment, it was seen that up to 1.5% by volume KHM can be dissolved into 100 ml of the modified Mt

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