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A new low-cost drilling fluid for drilling in natural gas hydrate-bearing sediments

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ABSTRACT

With increasing concerns relating to nature gas hydrate exploration and development worldwide, increasing attention has been paid to drilling technology in gas hydrate-bearing sediment (GHBS). According to the drilling characteristics of hydrate formation and the existing nanomaterials, a new low-cost drilling fluid has been established through more than 120 groups of experiments for drilling in GHBS: seawater + 2% Nano SiO_2 + 3% bentonite + 1% Na-CMC (sodium carboxymethyl cellulose) + 3% SMP-2 (sulfomethylated phenolic resin) + 1% PVP (K90) (polyvinylpyrrolidone) + 2% KCl. Additionally, the traditional low-temperature performance and inhibition of hydrate formation of this drilling fluid have been evaluated. The experimental results show that this drilling fluid has optimal density, good low-temperature rheology, and sufficient shale hydration inhibition and is able to effectively inhibit free gas from undergoing hydrate dissociation near boreholes to reform the hydrate in the drilling fluid circulation system. In addition, the cost of per cubic meter of this drilling fluid is only $400–450, which is 15%–20% less expensive than existing drilling fluids for drilling in GHBS in the South China Sea. Therefore, this drilling fluid will contribute to safe and efficient borehole drilling operation in GHBS.

1. Introduction

Natural gas hydrates, which are widely distributed in the permafrost and continental slope (Sloan, 2003), are potential new energy resources that are shallow, have high energy density, and exist in huge reserves. These hydrates have attracted global attention because of their potential to relieve the increasingly serious crisis affecting conventional fossil fuel resources. As additional research has been performed, abundant gas hydrates have been discovered in the North Bay, Xisha Trough and Shenhu areas of the South China Sea. Because of their fragile stability, gas hydrates will readily decompose during drilling (George and Hyndman, 2001; Tan et al., 2005; Ning et al., 2008). The dissociated gas would then pass into the drilling fluid and change its properties (Tan et al., 2005) and would also reform as gas hydrates in the drilling fluid at the appropriate temperature and pressure, leading to blockage and even serious drilling failures (Ning et al., 2008). Therefore, when drilling in gas hydrates formations, the temperature and pressure must be firstly controlled within a reasonable range in order to inhibit the reformation of large amount of gas hydrates in drilling fluid circulating system, which makes the characteristics of the drilling fluid critical (Tan et al., 2005; Ning et al., 2008; Liu et al., 2009). Currently, the drilling fluids used in hydrate formations are water or oil based. Given the need to avoid hydrate decomposition, water-based drilling fluid systems have clear advantages over oil-based ones (Sun et al., 2004).

The traditional drilling fluid used in oceanic oil-gas drilling is primarily water based, and many scholars here and abroad have performed numerous studies on oceanic water-based drilling fluids for hydrate sediments in recent years. To inhibit the decomposition of gas hydrates in the sediments near the wellbore and the reformation of the hydrates in the drilling fluid, the addition of thermodynamic inhibitors (e.g., NaCl and KCl), kinetic inhibitors (e.g.,

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PVP K90) and high-molecular weight polymers (e.g., polyethylene glycol [Aqua-ColTMS], polyethylene glycol [EG], and sodium carboxymethyl cellulose [Na-CMC]) has been studied to improve the related performances at low temperatures (Liu et al., 2009; Sun et al., 2004; Zhang et al., 2007). In addition, to obtain good rheological properties and sufficient inhibition capacities against mud shale hydration, other traditional treatment agents (e.g., tackifiers, lubricants, and fluid loss agents) have also been added to drilling fluid. Compared to the thermodynamic inhibitors, kinetic inhibitors have the advantages requiring smaller amounts to be added and better activity and have been widely used. However, in low-temperature drilling fluids, inorganic salt inhibitors are used to improve the frost resistance and, thereby, inhibit hydrate dissociation (Sun et al., 2004). Currently, the environmental protection regulations affecting drilling are becoming increasingly severe. Polyethylene glycol and sodium carboxymethyl cellulose polymers, which are non-toxic, non-polluting, and free from the interference of fluorescence tagging, have been the subject of substantial attention (Liu et al., 2009; Yan, 2001). However, to obtain good rheological behavior, shale hydration inhibition, and the inhibition of hydrate dissociation at low temperatures, large amounts of these treatment agents (e.g., polymers or inorganic salts) must be added to the drilling fluid. However, there are some problems, such as complex maintenance and high costs (Zhang et al., 2007; Ning et al., 2006). Therefore, how to reduce the required amounts of polymer and inorganic salt that must be added to low-solid polymer drilling fluids for hydrate formations is currently a hot topic in this field.

In recent years, the application of nanomaterials in traditional oil and gas drilling has increased. This issue has also gradually attracted the attention of energy researchers. Because nanomaterials have special structures, their surface effects, quantum size effects, macroscopic quantum tunneling effects and mechanical effects are very different from those of other materials (Wang and Wang, 2005; Bicetano, 2009; Cai et al., 2011; Sayyadnejad et al., 2008). Currently a variety of types of nanoscale drilling fluids have been developed, combining the working principles of drilling fluids and the design requirements (Wang and Wang, 2005). Existing studies have shown that the use of nanomaterials in drilling fluids plays important roles in aggravation, increasing the viscosity, providing lubrication, inhibiting hydration dispersion in shale, removing sulfur, blocking pores, providing anti-sloughing activity, and reducing fluid loss. Additionally, they have the advantages of being added in low amounts, showing obviously improved performance, and reducing the necessary addition of other components to the drilling fluid (Cai et al., 2011; Sayyadnejad et al., 2008; Friedheim et al., 2012; Srivatsa and Ziaja, 2012; Mihaela, 2012; Javeri et al., 2011; Sharma et al., 2012; Bai et al., 2007). However, the present study on nanomaterials mainly focused on conventional oil and gas drilling fluids (Wang and Wang, 2005; Bicetano, 2009; Peng et al., 2011) rather than on drilling fluids for gas hydrate formations. Considering the highly desirable effects of Nano SiO_2 on conventional oil and gas well drilling (Yuan et al., 2013), it was selected as an additive in this paper. Based on the previously developed low-solid water-based Aqua-ColTMS drilling fluid (water + 10% Aqua-ColTMS + 3% bentonite + 1% Na-CMC + 3% SMP-2 + 3% PVP K90 + 10% KCl), the Nano SiO_2 was added to reduce the added amounts of Aqua-ColTMS and KCl and thereby reduce the drilling fluid costs. After performing many comparative experiments, a better Nano SiO_2 drilling fluid was developed, in which only a relatively small amount of KCl but no Aqua-ColTMS was added. Its performance at low temperature and ability to inhibit gas hydrate formation were studied experimentally, providing technical information supporting the potential reduction of drilling costs by 15%–20%.

2. Performance requirements for drilling fluids in marine gas hydrate-bearing sediments

Natural gas hydrates occur at low temperature and high pressure. Thus, the presence of thin hydrate deposits, low temperatures and sensitivity to changes in the temperature and pressure make drilling in hydrate-bearing sediments very difficult (Jiang et al., 2002; Cohen et al., 2002; Yang and Tohidi, 2011; Jensen et al., 2008). These difficulties and risks are very different from those of traditional oil and gas drilling, and as a result, the performance requirements of drilling fluids for this purpose are also very different:

(1) Compatible with seawater. Because of ocean drilling occurs far from land, freshwater transportation is extremely expensive. Therefore, the use of seawater as the base fluid substantially reduces the costs of drilling.
(2) Moderate density at low temperature (George and Hyndman, 2001; Tan et al., 2005; Ning et al., 2008; Liu et al., 2009; Jiang et al., 2002). To maintain the borehole wall stability, drilling fluids with appropriate densities are needed to balance the formation pressure. Moreover, reasonable values are required to efficiently clean the bottom of the hole, cool the drilling tools and maintain the low temperature of the hydrate formations during drilling. A drilling fluid density of 1.1–1.2 g/cm^3 was determined to be appropriate based on actual situations of marine gas hydrate formations.
(3) Good rheology and shale hydration inhibition at low temperature are necessary (George and Hyndman, 2001; Tan et al., 2005; Ning et al., 2008; Liu et al., 2009) to effectively carry and discharge cuttings, lubricate the drilling tools.
(4) Drilling fluids should also have a good ability to inhibit hydrate formation at low temperature and high pressure (George and Hyndman, 2001; Ning et al., 2008; Liu et al., 2009) to prevent the dissociated gas from entering the drilling fluids and reforming the gas hydrates, which could block the circulation line and lead to drilling accidents.

3. Experiments

3.1. Experimental materials

The natural seawater used in the experiments was taken from the South China Sea. A200 amorphous Nano SiO_2 powder reagent (hydrophilic type) was produced by the Shenzhen Chuanghui Magnets Co. (Shenzhen, Guangdong, China) with the following properties: average particle size of 12 nm, specific surface area of 200 m^2/g, and the ability to increase viscosity, reduce water loss, and improve rheology. Methane gas was supplied by Wuhan Huaxing Gas Co. (Wuhan, Hubei, China) at a purity of 99.9%.

3.2. Experimental apparatus

The instruments used in the experiments included a six-speed rotational viscometer, a drilling fluid filtration meter, a constant-temperature water bath mixer, a shale-expansion tester (Fig. 1) and a self-designed gas hydrate formation and decomposition simulation system (Fig. 2).

The simulation system was mainly composed of a water bath, gas and liquid pumps, pressure-control valves, a reactor and a data-logging system. The reactor was titanium alloy tank, with a volume of 1050 ml and temperature and pressure sensors installed inside. The working temperature range was −30 ~ + 150 °C and the working pressure range was 0–30 MPa.