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Contamination of cement slurries with oil based mud and its components in cementing operations

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ABSTRACT

Contamination will happen due to incompatibility during drilling fluid and cement slurry mixing. Therefore, this paper tests the effects of oil based mud (OBM) and its components on the performances of cement slurries, such as fluidity, thickening time, compressive strength, bonding strength, porosity, and permeability. This study combines the Ultrasonic Cement Analyzer (UCA), X-Ray Diffraction (XRD), Thermogravimetry (TG), Scanning Electron Microscope (SEM) and Fourier Transform Infrared Spectroscopy (FTIR) to explore OBM contamination in cement slurries. The results demonstrate that the changes in the rheological properties of mixed cement slurries are caused by the free water of the cement slurries effect from the O/W or O/W/O galactoid structures. The presence of OBM does not hinder the hydration of cement slurries. This finding is the main reason for contamination by OBM such that the many holes in the cement stone and the lubrication effect of the oil phase lead to a reduction in strength and an increase in the porosity.

1. Introduction

OBM provides certain advantages, such as borehole stability, temperature stability, resistance to contamination, lubricity, and superior penetration rates, in certain formations, particularly in offshore environments and when drilling through troublesome shales and salts. OBM facilitates trouble-free and safe drilling operations with excellent shale inhibition, penetration rate, and wellbore stability. So, OBM is widely used in drilling critical or difficult wells, such as shale gas wells and deep wells (Davison et al., 2001; Fossum et al., 2007; Nagarajan et al., 2010).

However, the use of OBM during drilling significantly impacts subsequent well operations such as the quality of the cement or the contamination of the slurry. Because OBM is miscible to some degree with all additives of slurry, OBM contamination causes an alteration in fluid properties including the cement slurries. OBM and its formulation can have a pronounced impact on cement performance in wellbores. This occurs when cement and OBM become mixed during normal well cementing operations (Mayank et al., 2010; Harder et al., 1993). The phenomenon will bring some challenges to the cementing operations. For a successful cementing operation, it is critical to determine the contamination of cement during installation so that a necessary remediation can be performed to minimize the effect.

OBM is a non-aqueous fluid (NAF) system. The most common OBM is invert (water-in-oil) emulsions formulated with base oil as an external phase and dispersed water as an internal phase. These emulsions may contain moderate to high concentrations of water (up to 60% in extreme cases). In addition, a number of chemicals are added to OBM to optimize its performance, such as lime to neutralize fatty acids, poly-acrylates for fluid loss control, wetting agents to oil-wet solids, viscosity enhancers (bentonite) to improve lubricity, and weighting agents (calcites or barites) for appropriate overbalance (Nagarajan et al., 2010). The water in cement exposed to a non-aqueous fluid (NAF) system with a high-salinity invert emulsion may flow high water activity/low salinity cement to the

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low water activity/high salinity invert phases due to osmotic forces, which would effectively remove water from the cement slurry and move it into the drilling mud (Skalle and Sveen, 1991). The hydration products of hardened cement slurries consist of calcium-silicate-hydrate, calcium hydroxide and minor iron/aluminum phases. The hydrated silicate is one of the greatest factors that affect strength development. If the water in cement slurries is not available for hydration, the strength of the cement stone will change. So, the higher concentration of OBM will reduce the amount of water in cement slurries, which causes a detrimental effect on the cement slurry properties.

The OBM system has resulted in poor cement slurry properties, such as fluidity, thickening times and strength (Fakhreldin et al., 2011; Katherine et al., 2014), however, little research has been conducted in recent years to describe the underlying mechanisms. Most of the works effectively studied spacer fluid (such as nano-emulsion spacer) and adding appropriate additives in cement slurries to prevent contamination (Maserati et al., 2010; Harder et al., 1992; Aditya et al., 2014; Farahani et al., 2014; Teodoriu and Asamba, 2015). However, OBM is difficult to clear because of its strong adhesion to the casing and well. As a result, the displacement efficiency cannot reach 100%. The OBM residue in the wellbore may mix with cement during cementing operations. It seems that the latter method is more practical, such as reasonable design of OBM and cement slurries can improve the anti-contamination performance (Velayati et al. 2015).

The contamination of cement slurries with OBM was suspected as the reason for the soft kick-off plugs. Harder et al. (1992) noted that the oil-wetting surfactants present in the OBM were impeded the cement hydration process, which would explain the field observed drill-out problems. To understand the influence of OBM on the performance of cement slurries and to explore the mechanisms of contamination, this study first quantifies the effects of OBM and its components on the fluidity, thickening times and strength of cement slurries at various temperature and curing durations, and then investigates the mechanisms of contamination by using the UCA, XRD, TG, SEM and FTIR tests. Thus, this research could supply the theoretical basis for solving problems in the process of shale gas well cementing.

2. Materials and experimental protocols

2.1. Experimental materials

The slurries used in this study consist of G-class cement, free water control additive, dispersant and so on. These are the additives for cement slurries. OBM includes the VERSACLEAN system diesel-based drilling fluid. The formula for the cement slurries system is G-class cement +2% anti-gas migration agent +25% silicon powder +5% filtrate reducer +1% dispersant+ 2% retarder +0.2% defoaming agent.

Diesel is the external oil phase of OBM. The primary emulsifier is used to stabilize the water-in-oil emulsions in OBM. The secondary emulsifier is dissolved in the oil phase and modifies the wettability of drilled formations and of dispersed minerals from water-wet with oil-wet. Organic clay is a type of colloidal solid that disperses in the oil to increase the yield stress and the viscosity of the OBM, thereby helping the transport of the cuttings to the surface (Berg et al., 2002). Emulsion is prepared from diesel, emulsifier and brine under the condition of high-speed mechanical agitation, and the dispersed phase is the high salinity phase.

2.2. Experimental methods

2.2.1. The influence of OBM on the performance of cement slurries

Each batch of slurry was mixed based on API Recommended Tests (API, 2013). The cement slurries are mixed with OBM, and the recommended ratios are 100/0, 95/5, 75/25, and 50/50. The constant speed mixer (OWC-9360) from the Institute of Applied Technology at the Shenyang Institute of Aeronautical Engineering is used for mixing cement slurries with OBM. Any ratio of fluids that can be incompatible or that can produce a high-viscosity mixture are recommended for the cement stone testing of their rheological properties, thickening time, compressive strengths and bonding strengths.

The HTHP consistometer (OWC-9380) from the Institute of Applied Technology at the Shenyang Institute of Aeronautical Engineering is used for testing the thickening time of mixed cement slurries. The compression-testing machine (JES-300) from the Wuxi Xidong Building Material Equipment Factory is used for testing the compressive strengths and bonding strengths of mixed cement slurries. The Permeability and Porosity Measuring Instrument (HKY-300) from the Haian Petroleum Research Instrument Co. Ltd. is used for testing the permeability and porosity of mixing cement slurries. The Ultrasonic Cement Analyzer (4265UCA) from Chandler Engineering is used for testing the condensation process of mixed cement slurries.

2.2.2. Components of the OBM effect on the performance of cement slurries

The main components of OBM are diesel oil, the primary emulsifier, the secondary emulsifier and organic soil. The diesel oil, primary emulsifier and secondary emulsifier would form the emulsion, so the diesel oil, primary emulsifier, secondary emulsifier, organic clay and emulsion are mixed with cement slurries at the same ratio. The test equipment is the same for the contamination of cement slurries with OBM.

2.2.3. The test of microstructure and hydration product analysis of mixing cement slurries

The microstructure and hydration products of the cement slurry are also analyzed using UCA, XRD, TG, SEM and FTIR, which explains how OBM affects the hydration process of oil-well cement (Ylmen et al., 2009; Ou et al., 2011; Fonseca and Jennings, 2010; Exteves, 2011; Soin et al., 2013).

UCA measurements were performed on a 4265UCA to analyze the cement hydration process and the strength of the mixed cement slurries.

XRD measurements were performed on an X Pert MPD PRO to analyze the phase composition in the cement stone. This study used $2\theta = 5–80°$ and a step width of 0.08° at 2 s per step.

FTIR measurements were performed using a Nicolet 6700 analyzer to determine the chemical composition changes of the mixing cement slurries.

SEM measurements were performed using an EVO MA15 analyzer to determine the microstructure of the cement stone containing the components of OBM.

TG measurements were performed on a Metiler Toledo TGA/DSC-1 analyzer to determine the total CH content of the pastes investigated. Approximately 15 mg of ground, dried cement stone was placed in a Pt/Rh crucible with a perforated lid and heated to 1000 °C at 10 °C/min with an empty reference crucible under a nitrogen flow of 50 mL/min.