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Research on the impact of inorganic components on the performance of a novel self-solidified spacer fluid

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ABSTRACT

To solve the problems that occur during cementing operations in the case of an incapable solidified layer, such as drilling fluid and spacer fluid, this paper investigated a novel self-solidified spacer fluid. The incapable solidified layer composes the interface of the well wall-cement ring-the casing wall had an empty ring and a gap, which seriously affected the cementing quality. Unlike the addition of various conventional chemical conditioning agents in the spacer fluid system, to optimally adjust the properties, this paper studied its impact on the system compatibility, rheological properties, sedimentation stability, a compressive strength by changing the percentage of the component substances, such as the inorganic suspension stabilizer, as well as CaO, MgO, Al_2O_3 and SiO_2, and analyzed test samples using X-Ray Diffractometer (XRD) and Scanning Electron Microscope (SEM) tests. The results showed that the novel self-solidified spacer fluid has strong compatibility with wellbore fluids. In addition, bentonite, the inorganic component of the suspension stabilizer, was found to adjust the rheological properties and sedimentation stability. CaO and MgO, the inorganic components of solidifiers, were found to increase the compressive strength of the samples. This study indicates that the self-solidified spacer fluid could adjust the percentage of inorganic components to meet the construction requirements in the actual cementing operations and provide a basis for the selection of other chemical conditioning agents.

1. Introduction

In cementing operations, drilling fluids (mud) and cement slurry contaminate different levels when directly contacting each other, reducing the displacement efficiency and the cementing quality (Morris and Motley, 1973; Fakhreldin et al., 2011; Aughenbaugh et al., 2014; Li et al., 2015a,b; Li et al., 2016). Thus, spacer fluid is a critical component of cementing operations in wellbore construction. Traditionally, suitably engineered spacer fluid in combination with good cementing practices effectively displaces mud and prevents mixing mud with cement slurry. A specialized spacer fluid can be designed (Lavoix et al., 2007; Quintero et al., 2010; Berge et al., 2012; Carrasquilla et al., 2012). In fact, it is difficult to completely clear mud because of its strong adhesion to the casing and well. As a result, the displacement efficiency cannot reach 100%. Thus, an empty ring and gap had formed in the wall-cement ring-casing wall, because the components of mud and spacer fluid are unable to solidify. This situation significantly affects the interface cementing strength. In view of the above questions, this study explored a novel spacer fluid system that can achieve its function in isolation with self-solidification. The goal is not only to prevent the contamination problem but also to solidify the cement slurry in the annulus space.

To improve the success rate of cementing operations, domestic and international scholars have completed many relevant works. However, most of the work done on the slag MTC is over a decade old (Ronald et al., 1995; Song et al., 2000) and discuss slag cements that are formulated with water and conventional cement additives to prevent gas migration and improve interface cementing strength. Conversely, little research has been done to describe self-

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solidified spacer fluid. However, the requirements of the material properties of solidifiers have been reported. For example, the properties of some activators change pozzolanic or latent hydraulic materials into hydraulic materials; the calcium-rich phase of glass phase materials in mineral slag is the main factor that leads to its thermodynamic instability and activates the formation of material through the chemical, mechanical or thermal mode (Dai and Wen, 2001; Zhang et al., 2011; Rashad, 2014; Gebregziabiher et al., 2015). Most reports focus on the impact of additives on the cement slurry material. In view of the requirements proposed by the relevant theories and material properties, this paper first studies the novel self-solidified spacer fluid and explores the degree of compatibility of wellbore fluids in cementing operations. This study tests the rheological properties and suspension stability of the spacer fluid by changing the percentage of inorganic components (bentonite) in the suspension stabilizer. In addition, this study analyzes the components of the solidifier and then discusses the effects of the solidifier inorganic components on the strength of the system at different temperatures and curing times, demonstrating the following: 1) the compatibility of the wellbore fluids of the novel self-solidified spacer meets cementing standards; 2) bentonite, the inorganic component of the suspension stabilizer, has strong suspension stability; and 3) the addition of CaO, MgO, Al_2O_3 and SiO_2 significantly affect the compressive strength of the self-solidified spacer fluid. To study the performance of the new spacer fluid, the experimental materials and methods used are discussed in the next section.

2. Material and methods

2.1. Experimental materials

Primary components of the suspension stabilizer GYW-301: modified starch and cellulose-based substances; primary components of bentonite: SiO_2 and Al_2O_3. Activator: JHQ, JHT and GSN (the mixture of Na_2CO_3, NaOH and Na_2CO_3); primary components of the solidifier: CaO, SiO_2, Al_2O_3 and MgO, with an average particle size at the surface of 5.163 μm. All of these chemicals were obtained from Chuanfeng Tannin Extracts Co., Ltd.

2.2. Experimental equipment

Constant speed mixer (OWC-9360) from the Institute of Applied Technology of the Shenyang Institute of Aeronautical Engineering; numerical Show Precise Power Mixer (JJ-1) from Jintan Jinnan Instrument Factory; rotational viscometer (ZNN-D6) from Qingdao Haitongda Special Instrument Co., Ltd; atmospheric consistometer (OWC-9350A) from the Institute of Applied Technology of the Shenyang Institute of Aeronautical Engineering; constant-temperature water bath (DZKW-4) from Beijing Zhongxingweiye Instrument Co., Ltd; TYE-300B presses from Wuxi Jianyi Instrument & Machinery Co., Ltd; Scanning Electron Microscope (JSM-6490LV) from Japan Electron Optics Laboratory Co., Ltd; and X-Ray Diffractometer (D/Max-2200/PC) from Japan Rigaku Co.

2.3. Experimental process

Each batch of the spacer fluid is mixed based on API RP 10A. The formula of the novel self-solidified base spacer fluid system is as follows:

$$H_2O + 1.7\%GYW\text{-}301 + 1\%bentonite + 1\%JHQ + 6\%JHT + 2\%GSN$$

After stirring for 24 h, a rotational viscometer (ZNN-D6) is used to determine the shear forces at different shear velocities based on the evaluation of its sedimentation stability according to the rheology performance of the base spacer. The test samples prepared are maintained in a constant-temperature water bath for 1 day or 7 days. Next, a TYE-300 B press is used to test the compressive strength.

The rheology and suspension stability are used to represent the base spacer system that have a stable performance by changing the percentage of the inorganic components (bentonite) in the suspension stabilizer. The alkali fusion method is used to test the main solidifier components and analyzes the chemical compositions. The impact of the inorganic components on the performance of spacer fluid is analyzed by changing the mass percentage via formulation among the different inorganic components. The mixture of the solidifier and the inorganic components is added to the base spacer fluid, and the mixture is subsequently preheated in an atmospheric consistometer to 50 °C or 70 °C. The samples are then characterized using XRD tests to determine their compositions and SEM imaging to analyze their microstructure to explain the macroscopic phenomena.

3. Results and discussion

3.1. Compatibility of wellbore fluids

It is very important to determine the degree of compatibility of wellbore fluids in cementing operations. The compatibility of wellbore fluids includes the examination of rheological properties and thickening time (Table 1 and Table 2). Compressive strength is also indispensable for the self-solidified spacer fluid (Table 3).

As shown in Table 1, self-solidified spacer fluid has strong rheological compatibility to mud and slurry. The flow index n is above 0.6, and the consistence coefficient k is less than 1.78, indicating that no flocculating substance is produced in the mixture. These properties ensure that the cementing operations are safe. The plastic viscosity and yield stress of the mixture are reduced as the temperature increases, which are conducive to improving the displacement efficiency at the bottom hole temperature.

Table 2 shows that the fluid loss of the self-solidifier spacer fluid is less than 50 ml after mixing mud, cement slurry and the mixture, which indicates the self-solidifier spacer fluid had a strong ability to control free water. Owing to the mud cannot solidify, the thickening time of the mixture increases with the increasing amount of mud. The thickening times are greater than the original spacer fluid and cement slurry, which also ensures that the cementing operations are safe. Therefore, spacer fluid mixed with mud, cement and the mixture will not be a flashing condensate.

Even if the mud cannot solidify, the spacer fluid mixed mud still has a strong activating effect on the overall solidification (Table 3). As the temperature increases, the stronger the activating ability is, the higher compressive strength of the mixed fluid is. The activation capacity of the spacer is still strong until the mixing proportion is 1:1. However, the compressive strength of the mixture can reach 4.6 MPa after curing for 7 d at 70 °C. As mud does not have a self-solidified capability, the mixing fluid does not solidify with excess mud. In the mixture with cement slurry, the compressive strength at 70 °C is higher than at 50 °C when the contents of the spacer fluid are less than 50%. However, the compressive strength at 70 °C is lower than at 50 °C when the spacer contents exceed 50%. The results indicate that the characteristics of the hydration reaction in spacer fluid are different than in cement. The compressive strength of cement increases with increasing temperature, but the self-solidified spacer fluid does not. The solidified characteristics ensure that mixing fluid with cement slurry can solidify spacer residues in the well. Under the condition of mixing mud and cement slurry, the compressive strength increases with the