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Research Article

Bonding-strengthening technology in coalbed cementing through wettability improvement

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Abstract

Coalbeds are characterized by high organic matter content, presence of joints and smooth joint surface, which lead to weak bonding between coal and set cement and poor cementing quality of coalbeds, and consequently the economic and effective development of coalbed methane (CBM) is restricted seriously. In this paper, components, compositions and wetting characteristics of coal were analyzed in order to improve the water wettability of coal, the effects of different surfactants and their concentration and soaking time on the surface wetting angle of coal and interfacial bonding strength were tested and measured. The high-efficiency hydrophilic wettability modifier was optimized. The strengthened coalbed bonding prepad fluid system was developed and applied practically in the Qinshui Basin, Shanxi province. The results of laboratory tests and field applications show that the compact adsorption of surfactant containing ether and sulfate radical on the surface of coal can convert the surface wettability into strong hydrophilicity at the concentration of 0.3% within 30 s, thus improving significantly the interface bonding strength (up to 65.5%) between coal and set cement. The field application in CBM well cementing shows that the strengthened coalbed bonding prepad fluid can improve the cementing quality from unqualified level to high level, and play a significant role in improving CBM hole interval cementing quality. It is concluded that this technology provides an effective guarantee for coalbed cementing quality improvement and smooth implementation of stimulation measures like fracturing.

Keywords: Coalbed methane (CBM); Coal; Well cementing; Wettability; Interfacial bonding strength; Cementing quality; Surfactant; Prepad fluid

Coalbed methane (CBM) is an associated mineral resource of coal. It belongs to unconventional natural gas and is a clean and high-quality energy source [1–3]. In China, CBM is rich, with recoverable reserves of about 470 × 10^{12} m^3, suggesting a huge potential. It is an important supplement to China's energy resources. As a clean, efficient and safe new energy resource, CBM exploitation and utilization are economically meaningful, and also helpful in assuring the safety of coal mining [4–10]. The Qinshui Basin in Shanxi province is China's first mono-block CBM field with reserves up to a hundred billion cubic meters. Coal resources in this area are mainly anthracite formed by magmatic thermal metamorphism, and main coal seams are No.3 and No.15, which are characterized by low reservoir pressure, good preservation of the primary structural fracture of coal body, and the presence of cleat and fissure. In view of the problem of low-pressure leakage and the presence of cracks and cleats in CBM wells, the "low-pressure cementing" technology with low/ultra-low density cement slurry, foam cement slurry cementing technology, and two-stage cementing technology are mainly used in the cementing of CBM wells [11,12]. However, these technologies are based on the engineering conditions of CBM wells, but don't consider the effects of coal features on cementing operations. The main component of coal is organic matter, and the basic unit is an organic polymer with the dominance of condensed aromatic rings. It consists of

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carbon, hydrogen, oxygen and a small amount of nitrogen, sulfur and phosphorus. The surface of coal can hardly be wetted with water, and there is usually a smooth joint surface since the coal matrix is tight. Therefore, the poor water wettability and smooth joint surface of coal are not conducive to the bonding between coal and set cement, which reduces the bonding strength of the second interface and then affects the cementing quality of coalbeds. In this paper, a study on the new method for the improvement of the wettability, hydrophilicity and cementing quality was conducted based on the analysis of the structure and surface wetting characteristics of coal. Through R&D and field application of intensified prepad fluid, the problem of poor cementing quality in the coalbed was solved, which provided an effective guarantee for the smooth implementation of stimulation measures like fracturing.

1. Experimental materials and methods

1.1. Experimental materials

The coal from No.3 coalbed in the South Qinshui Basin was made into a 2.5 cm × 5.0 cm standard coal core.

In view of the site environment of CBM cementing (low temperature, high alkali and high Ca^{2+}), two kinds of betaine-type zwitterionic surfactants (labeled as No.1 and 2 surfactants, respectively), alkanolamid-type nonionic surfactant (labeled as No.3 surfactant), and anionic surfactant containing ether and sulfate (labeled as No.4 surfactant) were selected according to the characteristics, use and HLB range of surfactants. All these surfactants are industrial products.

1.2. Coal composition

A slice of the coal core was adhered on the copper sample holder and subject to vacuum metallizing. Then the microstructure of the experimental core was observed by using a Hitachi S4800 field emission scanning electron microscope and an elemental analysis was carried out.

1.3. Wettability tests

Coal cores were respectively soaked in four kinds of surfactant solution with a certain concentration, and then titrated with distilled water. The DSA100 instrument produced by KRUSS was used for high-speed recording of the titration process of each core. Compared with the contact angle of the original coal samples, the effects of four kinds of surfactants on the wettability of coal cores were analyzed.

1.4. Interfacial bonding strength tests

Coal core were soaked in clean water and 4 kinds of surfactant solution for 24 h, and slurry was prepared according to GB/T19139-2003 Procedure for testing well cements. The coal cores treated with different solutions were placed in the middle of the bottom of the bonding strength mold to simulate the coalbed and then cement slurry was poured into the mold. The bonding strength mold was sealed and then put into a 75 °C water bath curing box for 72 h. In the NYL-300 pressure testing machine made by the Wuxi Building Materials Instrument Factory, the cement ring and coal core in the mold were respectively displaced to measure the interfacial bonding force, which was divided by the interfacial bonding area to obtain the interfacial bonding strength. A comparative analysis between the obtained interfacial bonding strength and the interfacial bonding strength of the contrast coal sample was performed [13–15].

2. Results and discussion

2.1. Coal composition analysis and wettability test

Coal surface is heterogeneous, and characterized by a complex combination of inorganic substances and organic substances. Organic matter is composed of small clustered aromatic units with different polar functional groups, and most of them cannot be easily wetted with water. Table 1 shows the elemental analysis of coal. Accordingly, coal is mainly composed of carbon and oxygen elements with a concentration of more than 96%, and the content of organic matter is high, so its surface hydrophilicity is poor.

The SEM image of the microstructure of coal is shown in Fig. 1. The following characteristics of coal microstructure can be found. First, the tight coal matrix causes the presence of joints and smooth joint surface, which is not conducive to the effective bonding between coal and set cement. Second, the pore space is mainly composed of cavities and fractures. Third, there is a small number of clay minerals on the surface, with plate-like and flaky micro-morphology. An energy spectrum analysis was performed on a small surface area of the coal core (Point C). The results are shown in Fig. 2. According to energy spectrum analysis, the main elements of coal are C and O elements, indicating that the content of organic matter in coal is high. The surface wettability of coal was further quantitatively analyzed, and the surface contact angle of the original coal and the coal after soaking in water was measured. The results are shown in Table 2.

The results show that the wetting angle of coal is 94.06°, and it is difficult to be wetted with water. The hydrophilicity of coal is still poor after being soaked in water, which indicates that the hydrophilic wettability of coal cannot be improved by clean water drilling. The surface modification method is needed to improve the surface hydrophilic wettability of coal.

2.2. Wettability modification of coal surface

Since surfactant molecules contain hydrophilic groups and hydrophobic groups, the surface hydrophilic wettability of coal can be improved by making the hydrophobic groups adsorbed on the surface of coal and making the hydrophilic groups exposed outside. The effect of different surfactant solutions on the wettability of coal was tested. Coal cores were respectively soaked in No.1, No.2, No.3 and No.4 surfactant

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