Impact of surfactant in fracturing fluid on the adsorption–desorption processes of coalbed methane

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ARTICLE INFO

ABSTRACT

The effect of three surfactants in the fracturing fluid on the adsorption–desorption processes of coalbed methane (CBM) was studied by conducting an isothermal adsorption–desorption experiment. The adsorption capacity of surfactants and the wettability of the coal surface were also systematically investigated to illustrate the impact of surfactants. The experimental results showed that compared with the anionic surfactant sodium dodecyl sulfate (SDS) and the cationic surfactant octadecyl trimethyl ammonium chloride (OTAC), the nonionic surfactant N-(2-hydroxypropyl) perfluorooctane amide (FCS) exhibits lower Langmuir pressure during the entire CBM desorption process, which promotes the desorption of CBM. The adsorption capacity and contact angle results demonstrated that the nonionic surfactant FCS has the weakest adsorption capacity on the coal surface and can increase contact angle slightly, which enhances the hydrophobicity and inhibits water from entering the deep and fine pores of coal. This phenomenon results in reduced damage of the fracturing fluid for CBM desorption. This study is significant with regard to the selection of a fracturing fluid system with high surface activity, high desorption efficiency of CBM, and low damage to the coal reservoir.

1. Introduction

Hydraulic fracturing is the most important method to increase the production of coalbed methane (CBM). The selection of the fracturing fluid is essential for ensuring high fracturing performance, which has a direct impact on the adsorption–desorption performance of CBM (Al-Jubori et al., 2009; Xiangyi et al., 2012). New and high efficiency fracturing fluids, such as clean fracturing fluid and foam fracturing fluid, have been developed and used in field applications in recent decades; some results were excellent, but some were unsatisfactory, even worse than the results obtained using clear water fracturing fluid (Shangbin et al., 2009; Meng et al., 2011). The above two fracturing fluids are composed of different types of surfactants. However, different surfactants exert different effects on the surface properties of coal, and the effect on the adsorption–desorption performance of CBM are also different.

Coalbed methane, as an important and unconventional gas resource and strategic reserve resource, is attracting increasing attention worldwide (Moore, 2012). The reserves of CBM in China are abundant, and the proven reserves of CBM in Qinshui Basin alone amount to 325×108 m^3, which has good implications for rational development and utilization. However, due to the special characteristics of the coal reservoirs, coal is not only the source rock but also a reservoir for CBM. As a reservoir, coalbed is obviously different from a conventional gas reservoir. The main difference is the double pore structure in the coal reservoir, which includes matrix pores and network fractures. The size, shape, porosity, connectivity of matrix pore, and network fracture determine the storage, migration, and output of CBM (Yong et al., 2012; Mingzhai, 2005; Shenggui et al., 2013).

Currently, breakthroughs in CBM development technologies continue to be made. Because of the unique characteristics of coal reservoirs, CBM is mostly adsorbed on the surface of coal,

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accounting for over 90% of the total CBM reserves, while free gas and solution gas contribute less than 10%. Hydraulic fracturing has become an important method to obtain industrial gas flow. During fracturing for CBM, coal could be damaged by the invasion of water-based fracturing fluid; this damage is closely related to the properties of the fracturing fluid (Lianzhu et al., 2002).

Recently, water (including clear water and active water), linear gel, cross-linked gel, clean fracturing fluid, and foam fracturing fluid have been used in fracturing for CBM. As a fracturing fluid for CBM, active water has been used in a large number of field tests and has the advantage of causing only a small amount of damage to the coal reservoir and the disadvantages of high operational displacement, large fluid volume, and low sand proportion. Guar gum fracturing fluid has high viscosity and good sand-carrying performance, but the residue of the thickening agent seriously affects the fracture conductivity, which could result in damage to the coal reservoir. The cross-linked gel fracturing fluid has the advantages of high viscosity, small dosage, low fluid loss, and no residue after gel breaking, but it also damages the coal reservoir because of its macromolecule system (Ting, 2013; Cooke, 1975).

Clean fracturing fluid and foam fracturing fluid, which are high-quality and low-damage fracturing fluid systems, have the characteristics of high viscosity, low fluid loss, small damage, and easy flow-back; these characteristics allow a broad range of application prospects. The main purpose of fracturing stimulation for CBM is to establish high-speed channels for CBM desorption. The desorption efficiency of CBM is directly affected by the resistance of the channels. The fracturing fluids, especially the clean fracturing fluid and foam fracturing fluid, have been shown to also affect the desorption rate of CBM because the surfactant is an important part of both fluids. Therefore, the research on the desorption mechanism of CBM using fracturing fluid based on surfactants can aid in the selection of effective surfactants (Fu and Qin, 2006; Zhongqian et al., 2007; Zhenfu et al., 2005; Samuel et al., 2000; Jun et al., 2009; Mingwen et al., 2008).

In this study, the effects of different types of surfactants, which are compositions of clean and foam fracturing fluids, on the adsorption–desorption processes of CBM are investigated. In addition, quantitative results of the desorption process of CBM are obtained. The nonionic surfactant FCS is able to promote the adsorption–desorption of CBM, but the anionic surfactant SDS and cationic surfactant OTAC are able to inhibit the adsorption–desorption of CBM; thus, the nonionic surfactant FCS is better suited to be an important component of fracturing fluid. These results contribute to the selection of a fracturing fluid system with high surface activity, high CBM desorption efficiency, and low potential to damage the coal reservoir.

2. Experimental section

2.1. Experimental materials

Sodium dodecyl sulfate (SDS, Sinopharm Chemical Reagent Co., Ltd), octadecyl trimethyl ammonium chloride (OTAC, Beijing DM Oilfield High-Tech Co., Ltd), fluorocarbon surfactant N-(2-hydroxypropyl) perfluorooctane amide (FCS, China University of Petroleum), and coal powder (Hancheng block, Petrochina Coalbed Methane Company, China).

2.2. Equipment

An isothermal adsorption-desorption experimental instrument (Langfang Branch of Research Institute of Petroleum Exploration and Development, CNPC), PG-X static and dynamic contact angle analyzer (Fibro System AB Company, Sweden) were used in this study.

2.3. Experimental methods

2.3.1. CBM adsorption–desorption experiment

2.3.1.1. Sample preparation. The CBM adsorption–desorption experiment was conducted according to the standard of GB/T 19560-2004. The coal was crushed, ground, and then screened with 60–80 mesh sieves.

2.3.1.2. Equilibrium water treatment. The water should be balanced before performing the CBM desorption experiment according to the standards of GB/T 19560-2004 and American Society for Testing Material. The coal power sample was weighed, soaked, filtrated, and then humidity balanced. The equilibrium water content was calculated according to eq. (1):

$$M_e = \left(1 - \frac{G_2 - G_1}{G_2}\right) \times M_{ad} + \frac{G_2 - G_1}{G_2} \times 100 \tag{1}$$

where M_e is the equilibrium water content of the coal sample, %; G_1 is the weight of coal sample after humidity balanced, g; G_2 is the weight of the air dried coal sample, g; and M_{ad} is the water content of the air dried coal sample, %.

2.3.1.3. Equipment tightness check

① Put the above coal sample into a sample cylinder, and then seal it and load it into the incubator. Adjust the temperature of the sample cylinder and reference cylinder to coal reservoir temperature.

② Open each valve of the intake pipe, fill helium into the reference cylinder and allow the sample cylinder to reach a certain pressure, and then close the intake valve.

③ Keep the state for at least 6 h, and then observe the pressure variation of the sample cylinder and the reference cylinder. If the pressure exhibits an obvious variation, the joint must be checked. If there is no variation, the inflation pressure should be increased by repeating step ② until the inflation pressure reaches the maximum pressure of the experiment.

2.3.1.4. Determination of free space volume. The free space volume is the sum of the pore volume between the coal particles, the tiny pore volumes inside coal particles, the remaining space in the sample cylinder, and the interior space of the connected pipes and valves. The method for determining the free space volume of the sample cylinder is as follows: firstly, a gas with negligible adsorption (He) is selected, and then, the free space volume of the sample cylinder is determined through the expansion of the above gas; in other words, the volume of the reference gas is equivalent to the free space volume of the sample cylinder. The experimental procedure is described below:

① Adjust the temperature of the sample cylinder and the reference cylinder to the coal reservoir temperature.
② Open the helium tank, fill the system with helium, adjust the pressure of the reference cylinder to 2–3 MPa, and then close the valve of the reference cylinder.
③ Open the valves of the reference cylinder and the sample cylinder, and then record the data after the pressure is balanced.
④ Repeat the above processes twice; the value of the difference should be no more than 0.1 cm^3 between the two attempts.
⑤ Calculate the free space volume of the sample cylinder.