Journal of Natural Gas Science and Engineering xxx (2015) 1–8

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

The influence of viscoelastic surfactant fracturing fluids on gas desorption in soft seams

Yiyu Lu [a, b], Feng Yang [a, b], Zhaolong Ge [a, b, *], Shuqi Wang [a, b], Qin Wang [a]

[a] State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University, Chongqing 400044, China
[b] National and Local Joint Engineering Laboratory of Gas Drainage in Complex Coal Seams, Chongqing University, Chongqing 400044, China

ARTICLE INFO

Article history:
Received 4 August 2015
Received in revised form
22 October 2015
Accepted 23 October 2015
Available online xxx

Keywords:
Viscoelastic surfactant fracturing fluids
Soft seams
Gas desorption
Porosity

ABSTRACT

Hydraulic fracturing is an effective method of increasing the permeability of coal seams, which has gradually come into use in underground coal mines. Fracturing fluid is a key factor affecting the improvement. In this study, the way in which viscoelastic surfactant fracturing fluids affect gas desorption in soft seams was analyzed using the zeta potential and scanning electron microscope (SEM)-based methods. The results obtained with the zeta potential method indicated that due to the components of viscoelastic surfactant fracturing fluids, the potential at the coal surface jumped from −16.3 mV to 48 mV, the interaction energy between the fracturing fluid and the coal surface increased, the adsorption potential of the gas decreased and gas desorption increased. The SEM results demonstrated that the number of gas transport channels increased due to the effective dissolution of cement in the acidic viscoelastic surfactant fracturing solution. The cumulative pore volume of the coal samples processed with viscoelastic surfactant fracturing fluids was 0.001 cm^3/g, which was 1.8 times the cumulative pore volume of coal samples processed with water. The porosity and connectivity of the coal pores both increased, which was beneficial to gas desorption. Comparative experiments using water and viscoelastic surfactant fracturing fluids were conducted in underground coal mines. The results demonstrated that the amount of gas extracted increased by 26.1% when viscoelastic surfactant fracturing fluids were used. Gas desorption in soft seams was promoted by viscoelastic surfactant fracturing fluids. The new data reported in this study can be used to optimize the use of fluids for underground hydraulic fracturing in Chinese coal mines.

1. Introduction

The extraction of coal bed methane (CBM) plays an important role in the development of Chinese energy strategy. Because China is rich in CBM resources with 36 trillion cubic meters available for exploration, exploring and using CBM will alleviate the shortage of natural gas and meet the demand for its safe production in coal mines (Flores, 1998; Zhang et al., 2001). Underground extraction is the main source of CBM in China (Yuan et al., 2013). Various measures have been taken to enhance the amount of gas extracted underground (Zhou et al., 2012; Zhu et al., 2013). Hydraulic fracturing is an effective technology that creates cracks by injecting high-pressure fluids into coal seams. It has gradually come into use in underground coal mines in China because of its ease of operation and the resulting improvements in seam permeability improvement (Palmer, 2010; Aminto and Olson, 2012). For the low permeability and soft CBM reservoirs in China, the performance of the fracturing fluid is the key factor affecting the improvement of hydraulic fracturing. Guar gum fracturing fluids are difficult to use due to gel breaking and because serious pollution is caused when they remain in a reservoir. These issues counteract the fracturing effect (Wang et al., 2012). Due to the lack of efficient and economical alternatives, water is still widely used in underground fracturing. The problems with water are the high filtration requirements and the poor results (Zhang and Bian, 2014; Dag, 2009). Scholars (Khair et al., 2011; Zhang, 2012) determined that viscoelastic surfactant fracturing fluids enhance the amount of gas extracted well. Using fracturing fluids for coal gas extraction produces fractured channels and affects the adsorption characteristics of coal seams (Barati and Liang, 2014; Zhang et al., 2012). Because of the mechanical properties of soft seams and the lack of proppants,

* Corresponding author. State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University, Chongqing 400044, China.
E-mail address: gezhaolong@163.com (Z. Ge).

http://dx.doi.org/10.1016/j.jngse.2015.10.031
1875-5100/

hydraulic fracturing cannot create crack channels for gas migration in underground coal mines (Lu et al., 2014; Tian and Zhang, 2015). Affecting the gas desorption using viscoelastic surfactant fracturing fluids is a key factor in gas extraction in soft seams, but has not been studied extensively. Therefore, the widespread use of viscoelastic surfactant fracturing fluids in soft seams is limited.

The interactions between fracturing fluids and coal seams have been studied in recent years. Mather et al. found that viscoelastic surfactant fracturing fluids can improve coal seam permeability based on tests such fluids in low-permeability coal seams in comparison with conventional fracturing fluids (Mather, 2000). Li et al. conducted a field test using viscoelastic surfactant fracturing fluids in the coal-bed gas wells in the Qinshui Basin in China (Li et al., 2012). They found that viscoelastic surfactant fracturing fluids performed well at creating cracks and preventing the expansion of clay in coal seams. Wang et al. investigated the influence of fluids on the seam permeability and found that permeability of coal samples containing cracks was more strongly influenced by the performance of fracturing fluids (Wang et al., 2011). Lu et al. determined viscoelastic surfactant fracturing fluids could increase the size of gas migration channels and improve the permeability of coal seams because their surface tension was lower than that of water (Lu et al., 2015). Roman reported that the surfactant in viscoelastic surfactant fracturing fluids was able to adsorb onto coal surfaces and, therefore, affected the adsorption characteristics of coal (Roman and Boleslav, 2010). Chen et al. performed adsorption experiments and concluded that viscoelastic surfactant fracturing fluids restrained gas adsorption (Chen et al., 2009). At present, hydraulic fracturing is primarily used to create cracks in coal seams. Most of the theoretical studies on the improvement in permeability have focused on how the fracturing fluid affected the generation and propagation of cracks in coal seams; there have been few studies of the enhancement of gas desorption in soft coal seams (Lzadi et al., 2011). Because gas desorption is a key factor in the amount of gas extracted, the theory of how gas desorption in soft seams is affected by viscoelastic surfactant fracturing fluids should be studied.

There are many approaches that can be used to study the influence of fracturing fluids on soft seams. Currently, the zeta potential method is widely used in coal floatation (Jiang et al., 2011). It has been proven to effectively reflect changes in the adsorption characteristics of coal surfaces. Scanning electron microscopes (SEMs) are also commonly used because they allow visual observations at the nanometer scale (Gosiewska et al., 2002). As a result, pore structure changes can be studied intuitively using SEM-based methods.

In this study, the viscoelastic surfactant fracturing fluid used was a mixture of CTAC, NaSal and KCl that has been used for hydraulic fracturing in coal mines. To investigate the influence of viscoelastic surfactant fracturing fluids on gas desorption in soft seams, we determined the changes in the adsorption characteristics of coal surfaces using the zeta potential method and studied changes in the pore structures of coal samples using a SEM-based method and a porosity test. Then, we performed underground hydraulic fracturing experiments with water and viscoelastic surfactant fracturing fluids at the Yuyang coal mine in Chongqing, China to verify the results. The mechanism of gas desorption enhancement in soft seams using viscoelastic surfactant fracturing fluids was discussed, and the results provide fundamental data to promote field use of viscoelastic surfactant fracturing fluids.

2. Methodology

The zeta potential is the potential of the shear plane of dispersed particles. A change in its value directly reflects a change in the adsorption characteristics of the particle surfaces (Ren et al., 2015; Idrissa et al., 2015). Because coal adsorbs well, coal surfaces and their surrounding media have zeta potentials. To determine the effects of water and viscoelastic surfactant fracturing fluids on coal adsorption characteristics, we measure the zeta potentials of coal particles and compare them to determine the effects of the two liquids on coal surfaces. Therefore, the effects of viscoelastic surfactant fracturing fluids on the adsorption characteristics of coal samples are reflected by changes in the surface potential.

The gas desorption of coal seams are affected by pore structure and porosity. As the coal porosity increased, the gas migration rate accelerated and the free gas content increased. Gas desorption was promoted. This can be described using Equation (1) (Zhou and Lin, 1997):

$$X = \frac{VpT_0}{Tp_0\varepsilon} \tag{1}$$

where X [m^3/t] is the free gas content, V [m^3/t] is the pore volume per unit mass of coal, p [MPa] is the gas pressure, T_0 [K] and p_0 [MPa] are the temperature and pressure under standard conditions, respectively, T [K] is the gas temperature, and ε is the gas compression factor. So we studied changes in the pore structures of coal samples using a SEM-based method and a porosity test.

In the field procedure, experiments with water and viscoelastic surfactant fracturing fluids were performed underground a coal mine with soft seams. We recorded the volume of gas extracted after the experiments to verify the results for the gas desorption.

3. Experiments

3.1. The zeta potential test

The materials for the zeta potential test were N-Hexadecyltrimethylammonium Chloride ($C_{19}H_{42}ClN$, CTAC), sodium salicylate ($C_7H_5NaO_3$, Nasal), potassium chloride (KCl), hydrochloric acid (HCl), sodium hydroxide (NaOH), pure water, and Yuyang coal samples.

Fig. 1 shows the zeta test instrument (ZetasizerNano ZS90, British Malvern Instrument Ltd) and its principles of operation. The coal samples should be pulverized down below 200 mesh and dried for 24 h at 100 °C for measurement using the electrophoresis method (Milad et al., 2015). Then, the container was subjected to a vacuum to remove the gas adsorbed by the coal samples. Subsequently, the pure water and viscoelastic surfactant fracturing fluids were injected into the container. The PH was found to be 7 and regulated by the hydrochloric acid and sodium hydroxide in the presence of viscoelastic surfactant fracturing fluids. When the solution had been stirred for 48 h, the zeta potential analyzer was used to measure the zeta potential of the supernatant removed from the container. To ensure the accuracy of data, the tests were conducted repeatedly and questionable points were eliminated from the average value.

3.2. SEM observations and porosity tests of the coal samples

To compare the differences between the effects of the two fracturing fluids on the porosity of coal samples, coal samples were separated from a lump of fresh coal and added to the distilled water and viscoelastic surfactant fracturing fluids respectively. Then, the coal samples were soaked for 48 h and dried for 24 h in the oven. Finally, the porosity of these samples was observed and analyzed using a field emission scanning electron microscope (Field Emission Gun Scanning Election Microscope Nova400, German Zeiss Company (resolution: 1.0 nm)). The cumulative pore volumes of the