Fuel 194 (2017) 1–6

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

Influence of viscoelastic surfactant fracturing fluid on permeability of coal seams

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HIGHLIGHTS

- Permeability of coal seam was enhanced by viscoelastic surfactant fracturing fluid.
- Influence on coal porosity was studied using N_2 adsorption and SEM.
- Permeability of saturated coal seams changed exponentially with effective stress.

ARTICLE INFO

Article history:
Received 18 August 2016
Received in revised form 27 November 2016
Accepted 22 December 2016
Available online 4 January 2017

Keywords:
Viscoelastic surfactant fracturing fluid
Coal
Methane
Clays
Porosity
Gas permeability

ABSTRACT

Hydraulic fracturing is an effective way of improving permeability of coal seams. Performance of the fracturing fluid is a key factor affecting the extent of improvement. Coal-seam permeability directly affects the difficulty of coal-bed methane extraction and is mainly related to the pore size. Comparison of the influence of water, which is widely used in underground fracturing, and viscoelastic surfactant fracturing fluid on the composition, pore structure, and gas permeability at different buried depths of coal samples were experimentally investigated. The X-ray diffraction and atomic emission spectrometry results showed that the viscoelastic surfactant fracturing fluid decreased the content of clay minerals that easily block pores and fractures in the coal. Scanning electron microscopy observations of coal pores were consistent with these changes of mineral composition. Low-temperature N_2 adsorption showed that the cumulative pore volume of coal samples processed with the viscoelastic surfactant fracturing fluid was 0.00092 cm^3/g, which was an increase of 33.3% compared with that of coal samples processed with water. Analysis of the pore structure showed that the influence of fracturing fluid adsorption on gas permeability was mainly affected by its surface tension. Use of the viscoelastic surfactant fracturing fluid reduced the occupation of migration channels and improved the gas flow compared with water. Permeability contrast tests conducted on the coal samples processed with viscoelastic surfactant fracturing fluid and water showed that permeability of the former was greater by almost 178%, which verified the results of the above analyses. As the effective stress increased, the permeability decreased exponentially.

1. Introduction

Development of processes to recover methane from coal sources (coal-bed methane; CBM) has the potential to effectively alleviate the current natural gas shortage. This is therefore a priority of the Chinese national energy strategy. Such technologies will also improve the safety of coal mine production and promote the supply of coal [1–3]. CBM reservoirs in China are characterized by low permeability and high ground stress. CBM extraction is difficult and measures have to be taken to increase the permeability and improve the efficiency of extraction [4,5]. Hydraulic fracturing is an effective method of increasing the extraction of CBM that has gradually come into use in underground coal mines in recent years [6,7]. To create fractures, a fluid is injected under high pressure to beyond the absorptive capacity of the reservoir rock to hydraulically fracture the rock. The contained gas then desorbs and diffuses to the fractures and can be extracted.

Fracturing fluids create fractures in reservoir rock under high pressure. The fluids also enter the cracks and pores and thereby influence the pore structures and gas seepage [8,9]. Water is widely used in underground fracturing because of its low cost and ready availability; however, water suffers from high filtration

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http://dx.doi.org/10.1016/j.fuel.2016.12.078
0016-2361/

and poor results [10,11]. Studies to improve fracturing fluids have found that viscoelastic surfactant fracturing fluids can increase the amount of gas efficiently extracted after hydraulic fracturing as a consequence of their special properties of gel behavior. The mechanism of this permeability improvement, however, remains unclear, so application of viscoelastic surfactant fracturing fluids is limited [12,13]. Research on the influence of viscoelastic surfactant fracturing fluids on pore structures and coal seepage can promote the analysis of permeability improvement and the use of these fluids, instead of water, for underground fracturing.

Several studies have focused on the influence of fracturing fluids on coal porosity and gas seepage. Lzadi and Wang investigated the influence of moisture content on gas seepage experimentally and by numerical simulation, and found that the absolute and relative permeability were damaged by water [14,15]. Field tests showed that viscoelastic surfactant fracturing fluids improved coal-seam permeability and the amount of gas extracted in comparison with conventional fracturing fluids [16,17]. Kang et al. reported that viscoelastic surfactants were able to adsorb onto coal surfaces, and thereby affect adsorption characteristics [18].

Coal is a mixture of multiple components: in addition to carbonaceous organic materials, it also contains clay and metal-containing minerals [19]. Jin determined that clay minerals have a strong influence on the adsorption of fracturing fluids and gases [20]. Viscoelastic surfactant fracturing fluids are composed of surfactants and other additives and react easily with clay minerals [21]. Pore structure directly affects the permeability of a coal seam. Because variation of mineral components affects pore structure, the permeability of a coal seam may change as a result of the influence of the fracturing fluid on the clay mineral components. Vertical stress and horizontal stress of coal seams increase with increasing depth and affect the permeability [22], therefore, to obtain a comprehensive analysis of the influence of fracturing fluids on gas seepage, the permeability of coal seams processed under different effective stresses also needs to be studied. There have been few studies concerning how the fracturing fluid parameters affect coal-seam permeability and the influence of the fracturing fluid properties on gas seepage is still unclear.

This work used a viscoelastic surfactant fracturing fluid that is commonly used for hydraulic fracturing in coal mines. Comparative experiments on the influence of water and the viscoelastic surfactant fracturing fluid on permeability were conducted. The composition and mineralogy of coal samples processed with these fracturing fluids were evaluated using X-ray diffraction (XRD) and atomic emission spectrometry (AES). Pore structures of coal samples were observed by scanning electron microscopy (SEM). Low-temperature N_2 adsorption tests were conducted to measure changes of porosity and parameters of the fracturing fluids that affect the pore structure and seepage were analyzed. Permeability contrast experiments on samples processed with the two fracturing fluids were conducted and the effect of coal buried depth determined. Results of this study can promote the analysis of the influence of fracturing fluids on permeability of coal seams at different buried depths and optimize the use of viscoelastic surfactant fracturing fluid for hydraulic fracturing in coal mines.

2. Experimental

2.1. Materials

One fresh coal block from the No. 7 coal seam of Songzao basin in Chongqing Province (China) was prepared for this study. The gas content and pressure in the coal seam were 14.5 m^3/t and 1.1 MPa, respectively [23]. The proximate analysis of the coal is summarized in Table 1. The viscoelastic surfactant comprised 0.8 wt.% N-hexadecyl trimethyl ammonium Chloride ($C_{19}H_{42}ClN$) as the surfactant, 0.2 wt.% sodium salicylate ($C_7H_5NaO_3$) as the micellar promoter, 1 wt.% potassium chloride (KCl) as a clay control agent, and deionized water. Characteristics of the fracturing fluids are shown in Table 2.

Table 1
Proximate analysis of coal samples.

Sample	Proximate analysis (%)			
	FC_{ad}	V_{daf}	A_d	M_{ad}
SZ 7#	63.48	23.73	11.63	1.16

Table 2
Characteristics of the fracturing fluids.

Fracturing fluids	Surface tension/(m N/m)	Contact angel/°
Deionized water	72	68.2
Viscoelastic surfactant fracturing fluid	30.4	19.8

2.2. Chemical and mineralogical analysis

The fresh coal sample was pulverized to below 200 mesh and an 80 g sample was divided into equal two parts. These were soaked for 48 h in 100 mL deionized water and 100 mL viscoelastic surfactant fracturing fluid, respectively, and then dried for 24 h at 100 °C. The mineral components of the coal samples after treatment with the two fracturing fluids were identified by XRD (Panalytical B.V., Holland). Elemental components of the two fracturing fluids after the treatment were analyzed by AES (MPT, Haiguang Instrument Co., Ltd., China). Coal cubes with a volume of 1–2 cm^3 were soaked and dried using the same method. These were observed using a Nova 400 field-emission gun SEM (Zeiss, Germany; resolution: 1.0 nm) to analyze blocking of the pores.

2.3. Porosity

The influence of the viscoelastic surfactant fracturing fluid on coal porosity was determined by low-temperature N_2 adsorption. The pore volume distribution was analyzed using an ASAP2020 micropore analyzer (Micromeritics Instrument Company, USA). The measuring range (1.5–500 nm) included use of gas adsorption and seepage apertures that could meet the test requirements. Coal particles of 18–20 mesh were separated from the fresh coal and placed in either deionized water or the viscoelastic surfactant fracturing fluid for 48 h, then rinsed, dried for 24 h, and their pore volume distributions determined.

2.4. Permeability

For the permeability contrast measurements, cylindrical samples with a diameter of 50 mm were drilled from the coal block. The same drilling angels were selected and more than three sets of coal samples were performed for each permeability test. The top and bottom of the samples were trimmed to 100 mm in length and the surfaces polished to be parallel to each other and perpendicular to the sample axis. As the pressure used for underground hydraulic fracturing is usually greater than 20 MPa and the fracturing time exceeds 12 h, coal around the fractures is saturated with the fracturing fluid [24,25]. To simulate these field conditions, coal samples saturated with water and the viscoelastic surfactant fracturing fluid were prepared. Dry samples were treated by soaking in the respective fluids under vacuum until their mass stabilized.