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Effects of diffusion and suction negative pressure on coalbed methane extraction and a new measure to increase the methane utilization rate

Jun Dong [a,b,c], Yuanping Cheng [a,b,c,d,*], Kan Jin [a,b,c], Hao Zhang [a,b,c], Qingquan Liu [a,b,c], Jingyu Jiang [a,b,c], Biao Hu [a,b,c]

[a] *Key Laboratory of Coal Methane and Fire Control, Ministry of Education, China University of Mining and Technology, Xuzhou, Jiangsu 221116, China*
[b] *National Engineering Research Center for Coal Gas Control, China University of Mining and Technology, Xuzhou, Jiangsu 221116, China*
[c] *School of Safety Engineering, China University of Mining and Technology, Xuzhou, Jiangsu 221116, China*
[d] *School of Civil, Mining & Environmental Engineering, University of Wollongong, New South Wales 2522, Australia*

HIGHLIGHTS

- The methane migration law in the process of underground CBM extraction is analyzed.
- The effects of diffusion and suction negative pressure on methane extraction are studied.
- A new measure to increase the methane concentration and utilization rate is proposed.

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ABSTRACT

A constant suction negative pressure is used in coal mines owing to a lack of research on the effects of diffusion and suction negative pressure on methane extraction, resulting in the low methane concentration and utilization rate. In this study, Comsol Multiphysics is used to conduct a numerical solution of a gas–solid coupling model considering pseudo-steady diffusion in coal matrix, seepage in fractures, permeability evolution and coal deformation. The simulation results reveal the methane migration law and the effect of the diffusion process on the methane migration. The role and the influence degree of the suction negative pressure on methane extraction are studied, demonstrating that the suction negative pressure effect weakens gradually with the increasing methane extraction time. The methane concentrations of different suction negative pressures are calculated considering the changing effects of diffusion and suction negative pressure combined with the parallel relation between the methane migration and the air leakage, indicating that reducing the suction negative pressure can effectively increase the methane concentration. To change the present situation of the low methane concentration and utilization rate in coal mines, a new technical measure of methane extraction through parallel boreholes in groups is proposed to adjust the suction negative pressure and increase the methane utilization rate.

1. Introduction

Coalbed methane (CBM), as a byproduct of coal, is a clean and high-efficiency fuel [1,2]. The energy released in the combustion of 1 m^3 of methane is 35.9 million Joules, equivalent to the combustion of 1.2 kg of standard coal. Although it is a highly efficient energy source, methane can also be the cause of serious disasters that kill hundreds of people every year in China [3]. Methane extraction can not only eliminate or weaken the danger of coal mining but also obtain clean energy and reduce pollution [4–6]. In 2015, Chinese coal mines drained 18 billion cubic meters (bm^3) of methane, but the utilization amount was only 8.6 bm^3, a utilization rate of merely 47.8%. Of all the drained methane, the amount of underground extraction was 13.6 bm^3, and the utilization rate was only 35.3%, which means that 8.8 bm^3 of the methane drained from underground was released into the atmosphere, causing a serious greenhouse effect. The fundamental reason for the low utilization rate is that the methane concentration is extremely low, especially during the late period of CBM extraction. Thus, the drained methane is difficult or uneconomical to utilize, and most of the low-concentration methane is wasted. For the sake

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* Corresponding author at: Key Laboratory of Coal Methane and Fire Control, Ministry of Education, China University of Mining and Technology, Xuzhou, Jiangsu 221116, China.

E-mail address: cumtchengyuanping@163.com (Y. Cheng).

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of maximizing methane extraction and utilization, many researchers have conducted deep research on the mechanism of coalbed methane migration and measures to improve the methane concentration [7–16].

One important factor that influences the methane extraction effect is the suction negative pressure, which induces a pressure gradient and drives methane to the boreholes through fractures [17,18]. Theoretically, a higher suction negative pressure will drain more methane than a lower suction negative pressure in the same time period. The methane concentration, however, will be low at the high suction negative pressure, leading to low methane utilization. Thus, a reasonable suction negative pressure is critical for increasing the methane extraction and utilization rates. At present, a constant suction negative pressure of 13 kPa is used in coal mines owing to a lack of research on the effect of suction negative pressure on methane extraction. With the increasing extraction time, the methane pressure and content will change, leading to different methane flow conditions. Therefore, the constant suction negative pressure is unsuitable for the whole extraction process. For reasonable and efficient methane extraction, the whole process of methane migration should be studied, and the effects of suction negative pressure on methane migration and extraction should be evaluated.

Typically, a coal seam is a dual-porosity system consisting of coal matrix and surrounding fractures [19]. The primary porosity mainly consists of micropores in the coal matrix, which store approximately 95% of the total methane on the internal surface of the micropores in adsorbed form. The secondary porosity, in contrast, consists of orthogonal fractures, called the cleat system or the natural fracture system [20]. Through-going cleats are referred to as face cleats, and cleats that end at intersections with through-going cleats are called butt cleats. In most cases, both the face cleats and butt cleats are perpendicular to the bedding [21,22]. The cleat system is the occurrence site and the flow channel for free methane, and the methane migration follows Darcy's law. The methane flow through the coal matrix is believed to be concentration-driven and follows Fick's law [23–25]. The general process of methane migration in coal is schematically shown in Fig. 1 [12,26,27].

As is widely known, most methane adsorbs on the internal surface of the micropores in coal. The adsorbed methane experiences the processes of desorption, diffusion and seepage before flowing into boreholes or well drillings. The process of diffusion should play the same important role as seepage in methane migration. There are still two opposing views on the effect of methane diffusion. Pan et al. [28] believe that the production rate of coalbed methane is mainly controlled by methane diffusion in the coal matrix and the seepage within the cleat system, whereas Zhou [24] argues that the production is controlled by the seepage and is little affected by the diffusion of methane in coal. We believe, however, that the effect of diffusion should not be overlooked because most of the methane undergoes the process of diffusion before being drained out.

In this study, a gas–solid coupling model is established to describe the CBM migration, combining the laws of methane diffusion in the coal matrix and seepage in fractures, the permeability evolution model and the coal seam deformation equation. The established model is used to conduct a numerical simulation of the whole process of CBM migration when extracting methane and to analyze the effect of diffusion on the methane migration. Simulation results also illustrate the influence degrees of the diffusion coefficient and the initial permeability on the ability of methane extraction. In addition, the effect of suction negative pressure on CBM extraction is quantified. A technical measure for optimizing CBM extraction is proposed, which can be taken to enhance the rate of methane utilization.

2. Methane migration model and numerical simulation

2.1. Model assumption

The methane migration model is based on the following assumptions:

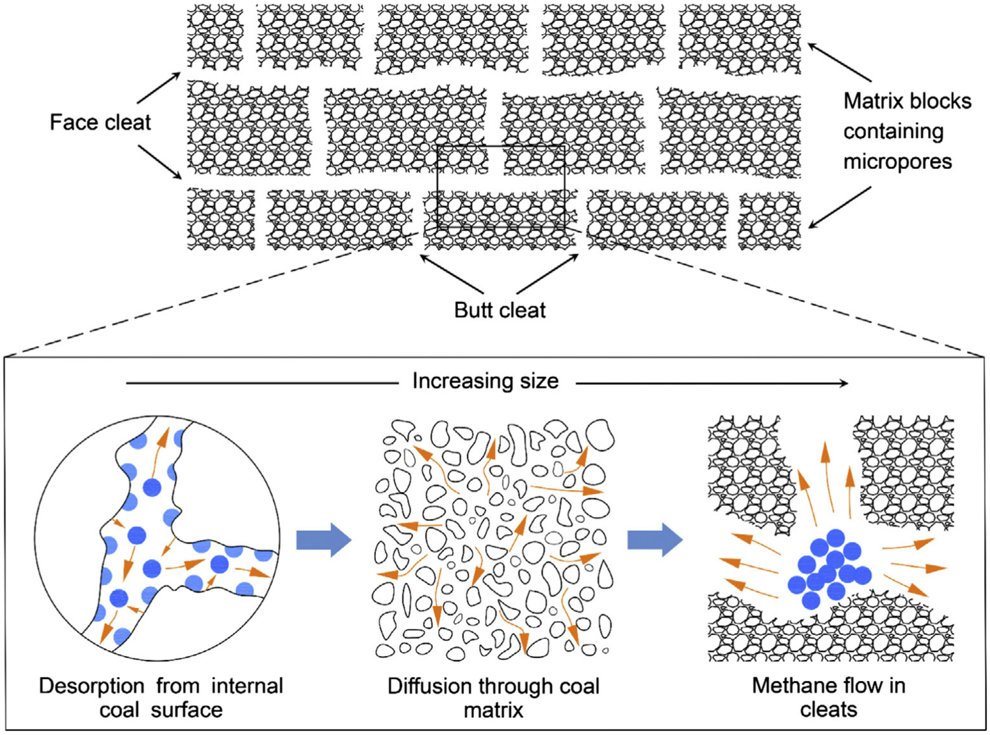

Fig. 1. Dual-porosity model of methane migration in a coal seam [12,26,27].