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Experimental study on diffusion property of methane gas in coal and its influencing factors

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HIGHLIGHTS

- Diffusion coefficients of methane gas in different rank coals were analyzed.
- Relationship between diffusion coefficient and confining pressure was established.
- Relationship between diffusion coefficient and injected pressure was established.
- Influence of temperature on diffusion property of methane in coal was analyzed.
- Controlled mechanism of methane gas diffusion in coal was revealed.

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ABSTRACT

The diffusion property of methane gas in coal is one of the key parameters which would influence the production of coal-bed methane well. The diffusion property of methane gas under different coal ranks, confining pressure, injected gas pressure, temperature and moisture content are analyzed by the experiment in methane gas diffusion. Relationships and their models between diffusion coefficient and the factors, such as vitrinite reflectance, confining pressure, injected gas pressure, temperature and moisture content are established. Controlled mechanism of methane gas diffusion in coal is revealed. The results indicate that under the same temperature, gas pressure and confining pressure, the diffusion coefficient of methane gas in different rank coals exhibit a trend of first dropping rapidly and then rising slowly (asymmetric "U" shape) with the metamorphic degree of coal increases. At the same temperature and gas pressure, with the increase of confining pressure, diffusion coefficient of methane gas in coal dropped by the power function. The diffusion coefficient of methane gas in coal increases with the increase of injected gas pressure. With the increase of temperature, the diffusion coefficient of methane gas in coal increases logarithmically. The diffusion coefficient of methane gas in saturated coal is smaller than that of dry coal. These results effectively guide coal-bed methane (CBM) development, and it has theoretical and practical significance.

1. Introduction

The diffusion property of methane gas in coal is one of the key parameters which would influence the production of coal-bed methane well. Diffusion is the migration phenomenon of the random movement of methane molecules under gas concentration gradients. On the basis of the molecular mean free path and the pore diameter of porous medium, the diffusion modes can be divided into three types: Fick diffusion, Knudsen diffusion and transitional diffusion. And the diffusion of coal-bed methane is the result of those three types either alone or in combination [1–5]. Currently, the study of methane diffusion model in coal is focused on the Knudsen diffusion model. On this basis, by using experiment and theoretical calculation analysis method, the gas diffusion in coal has been studied, and the diffusion law of desorption gas from matrix pores into the fractures under the action of concentration difference, then seepage from fractures to the production wells under the action of pressure difference is revealed [6,7]. The diffusion coefficient is used to describe the diffusion property of methane gas in coal. The diffusion coefficient is defined as the amount of gas in coal which through the unit area in unit time with the concentration gradient is one unit; Methane

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gas diffusion coefficient in the porous medium usually use direct test method or isothermal adsorption test data combining the kinetics of adsorption theory model to solve. The diffusion property of methane gas in coal is closely related to metamorphic degree of coal, pore structure of coal reservoir, coal-bed methane (CBM) composition and temperature/pressure of coal reservoir, theoretical and experimental studies have been carried out [8–16]. And early on Sevenster [17] studied transient diffusion in coal by measuring the volumetric uptake of oxygen and water into coal particles. Nandi and Walker [18] studied the diffusion of nitrogen and carbon dioxide from coals of various ranks. Thimons and Kissell [19] investigated the diffusion performance of methane and helium in three different coal samples of the eastern United States by using flow experiments. Through the years, Xu et al. [20] used coal matrix flakes to measuring the methane diffusion coefficient in coal matrixes, and the order of methane diffusion coefficients were from 10^{-11} m^2/s to 10^{-9} m^2/s in coal matrixes, and the factors influencing methane diffusion coefficients such as gas pressure, coal rank and moisture content were also analyzed. Zhang et al. [21] analyzed the adsorption and diffusion behaviors of methane (CH_4) and carbon dioxide (CO_2) on various rank coals with a volumetric method, based on the second Fick's Law, the relationship between diffusion coefficient and adsorption capacity /specific surface area was established, then the effective diffusivities presented a U-shaped trend with coal rank. He et al. [22] discussed the effect rules of pressure and temperature on the mean molecule free path of gas in microcosm according to molecule dynamics, it is found that the macro-parameters of gas diffusion is determined all by the micro-parameters of gas molecules. Zhang et al. [23] studied pore structure of high rank coals and its controlling effect on methane gas diffusion, which combined observation and measurement of the difference of pore. With the coals from Lorraine Basin in France, Charriere et al. [24] compared the carbon dioxide and methane diffusion coefficients, which indicated that temperature and pressure are the two key factors controlling the diffusion coefficient. Li et al. [25] studied the influence of pressure and temperature on gas diffusion by the experiment, and the research results indicate that gas diffusion capacity increases with the increase of temperature under the same pressure for the same coal sample. Zhao et al. [26] measured methane gas diffusion coefficient in micropore of coal and indicated that the pressure of coal reservoir, concentration of methane and moisture content were influencing on methane gas diffusion coefficient. Mallikarjun Pillalamarry et al. [27] studied and evaluated the sorption and diffusion properties of methane in Illinois basin coals. There is a negative correlation between diffusion coefficient and pressure in the low pressure range, besides that diffusion coefficient also depended on the surface coverage, which presents a positive relationship with pressure. Tang et al. [28] studied the influence of temperature on gas diffusion coefficient, the study indicated that diffusion coefficient increases with increasing temperature, and the diffusion coefficient is dependent on temperature and adsorption equilibrium pressure, when temperature rises from 30 °C to 90 °C, diffusion coefficients range from 8.53×10^{-8} cm^2/s to 1.97×10^{-7} cm^2/s. Pan et al. [29] studied the relationship between the diffusion of carbon dioxide and diffusion of methane under different moisture contents, which further indicated that the methane diffusion coefficient is more easily affected by moisture than that of carbon dioxide. Busch et al. [30] demonstrated that diffusion coefficient decreases with the particle size increasing. These results have laid a foundation for the study of gas diffusion in coal.

However, due to the complexity of coal reservoirs and its influence factors, the study on the performance of the gas diffusion in coal is insufficient, most of the experiments only considered methane diffusion under the single condition, the factors considered are less. So, it is difficult to meet the actual demand of CBM well to analyze gas diffusion performance in coal by theoretical calculation method.

In this work, we used cylinder-shaped coal samples, which are different rank coals of permo-carboniferous in the southern Qinshui basin and the east edge of Ordos basin. The methane gas diffusion property under different coal ranks, confining pressures, injected pressures, temperatures and moisture contents are analyzed by the experiment in methane gas diffusion. Correlation between diffusion coefficient and the factors, such as vitrinite reflectance, confining pressure, injected pressure, temperature and moisture content are proposed, and its models are established to revealed controlled mechanism, which can effectively guide the CBM development. And it has theoretical and practical significance.

2. Experiment of methane gas diffusion in coal

2.1. Experiment apparatus and procedure

The experiment is carried out according to the free diffusion principle of the methane gas to seep through coal sample under concentration gradient. In the diffusion chambers at both ends of the coal sample, one end is filled with the hydrocarbon gas (CH_4), the other end is filled with the nitrogen gas (N_2), and the both ends are always maintained without pressure difference. At constant temperature and pressure, gas concentration of each component changes with time. And the gas concentration of each component in both diffusion chambers varies with time, then methane gas and nitrogen diffusion coefficient in coal are calculated.

Gas diffusion measuring device is mainly composed of core holder, casing pressure system, gas supply system, vacuum system and thermostatic system, as shown in Fig. 1.

Test procedures: Put the sample into core holder with confining pressure more than 3 MPa. According to the formation temperature, the test temperature of the thermostatic system is set, and temperature at constant value is maintained from 2 h to 2.5 h; When the diffusion coefficient of hydrocarbon gas in dry sample is determined, the vacuum pump is switched on and the vacuum pump is connected to the coal core holder and the corresponding pipeline for about 1–1.5 h, but in the determination of coal sample with saturated water does not draw a vacuum. Next, the two diffusion chambers are respectively communicated with the

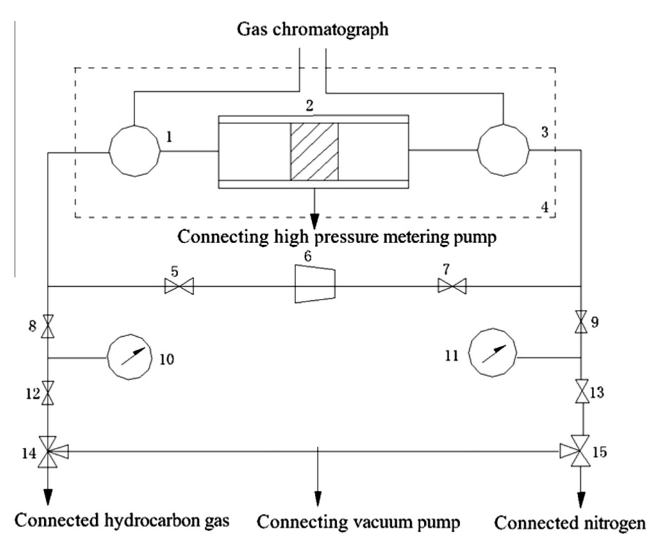

Fig. 1. Sketch map of measurement diffusion coefficient of hydrocarbon gas (1,3-sampling valve; 2-core holder; 4-thermotank; 5,7,8,9,12,13-shutoff valve; 6-differential pressure transducer; 10,11-pressure gauge; 14,15-three-way valve).