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Study of the CO_2 ECBM and sequestration in coalbed methane reservoirs with SRV

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ABSTRACT

Stimulated reservoir volume (SRV) and CO_2-enhanced coalbed methane recovery (ECBM) are two popular technologies used to develop coalbed methane (CBM) reservoirs. Anthracite coal samples were selected from the CBM reservoir in the southern part of Qinshui Basin. The CO_2 and CH_4 displacement experiments were conducted using two different methods, “gas injection/desorption” and “desorption/gas injection/desorption”. Based on the indoor experiment, and using the reservoir geological properties, fluid properties and stimulated measure data of the target CBM reservoir, three numerical simulation models of 5-point well groups with SRV were built. These models were used to conduct influence factor analysis of CO_2 storage and ECBM in the volume stimulated CBM reservoir. Using the above indoor experiments and numerical simulation experiments, the following conclusions were obtained: the method of “desorption/gas injection/desorption” is more favorable for CO_2 replacing CH_4 and realizing CO_2 storage and ECBM. The SRV measures can increase the flow conductivity and improve the single well productivity of CBM. The SRV size, SRV flow conductivity and gas saturation of the cleat system are the key influence factors of CO_2 storage and ECBM in volume stimulated CBM reservoir. The study described in this paper can offer technical support for implementing the synthesis technologies of SRV and CO_2 ECBM and storage in CBM reservoirs.

1. Introduction

The geological conditions of CBM reservoirs in China are complex. Although the CBM content is high, the reservoirs show “three low” (low pressure, low permeability and low saturation) characteristics, which lead to difficulty in CBM desorption and migration (Lv et al., 2011). How to enlarge the desorption volume and improve the desorption speed are two of the key problems that should be overcome in the near future (Liu et al., 2010). The stimulated reservoir volume (SRV) technologies, which are first used to develop the shale gas reservoir, have been gradually applied to the development of CBM, tight gas and tight oil reservoirs in recent years (Wu et al., 2012; Mayerhofer et al., 2006; Wang et al., 2014a). SRV uses the fracturing method to break up the effective permeable reservoirs to form the fracture network, maximize the contact area between fracture sides and the reservoir matrix, minimize the fluid seepage distance of oil and gas from the matrix in any direction to the fractures, greatly improve the permeability of the entire reservoir, and achieve volume stimulation of reservoirs. The CBM reservoirs are usually developed using horizontal fractured wells and dewatering for gas production, which involve depletion development depending on natural energy. Due to the objective conditions of CBM reservoirs in China, such as “three low” and strong stress sensitivity characteristics, the CBM recovery is limited (Lv et al., 2011). To make up for the defect of this method, many scholars have suggested the method of enhanced coalbed methane recovery (ECBM) by CO_2 injection. Zuber and Clarkson found that the CBM recovery can be enhanced by CO_2 injection experiments (Zuber, 1998; Clarkson and Bustin, 2000). Injecting CO_2 into a CBM reservoir can enhance not only CBM recovery but also CO_2 storage, thus realizing environmental benefits (Zhang et al., 2011, 2012). Fig. 1 shows that the CO_2 can be buried in CBM, saline aquifer, oil and gas reservoirs. In China, although there are many studies and field tests regarding CO_2 EOR and storage in oil reservoirs (Zhao and

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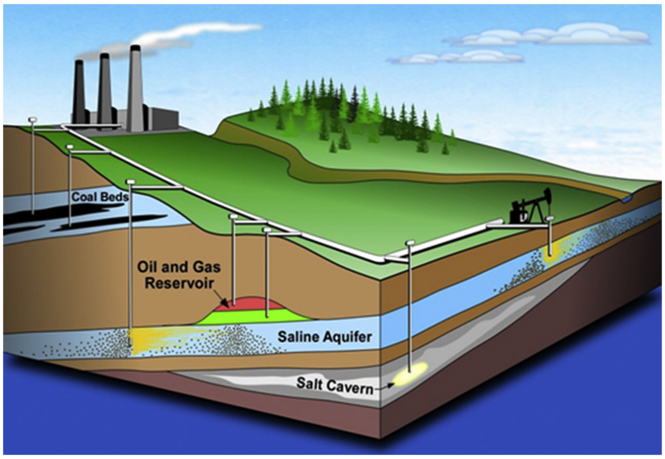

Fig. 1. Schematic of CO_2 geological sequestration and improving recovery.

Liao, 2012; Su et al., 2013; Wang et al., 2014b), the field test related to injecting CO_2 into CBM reservoirs is in the trial stage. In 2002, a CO_2 ECBM micro-pilot was conducted in southern Qinshui basin with the cooperation of the Chinese and Canadian governments (Ye et al., 2007). A total of 192.8 tons of liquid CO_2 was injected by well TL-003, which is only a small portion of the CO_2 output associated with the production gas in the subsequent production stage. Most of the CO_2 was buried in the coal seam. The CBM production rate is obviously improved compared with that before the CO_2 injection, which shows good potential for the CO_2 ECBM and storage.

At present, the technologies that combine SRV and CO_2 flooding measures are rarely used in the CBM field. Considering these two technologies comprehensively, studies that inject CO_2 into the volume stimulated CBM reservoir were described in this paper. Because there are many cleats and fractures in the CBM reservoir, which contains the coal matrix system and the cleat-fracture system, dual-porosity is used. The simulation of the hydraulic fracture network is achieved by the method of local grid refinement (LGR). CO_2/CH_4 replacement experiments were conducted using anthracite samples. Three numerical simulation models of 5-point well groups with SRV were built, and these models were used to conduct influence factor analysis of CO_2 ECBM and storage in volume stimulated CBM reservoir.

2. CO_2 ECBM theory and application criteria

2.1. CO_2-ECBM and storage theory

The core mechanism of CO_2 ECBM and storage is the dynamic process of CO_2 adsorption and flooding CH_4 (Wang et al., 2014a). Coal is an organic solid that is mainly composed of carbon atoms. The carbon atoms inside the coal body are attracted by the surrounding carbon atoms and are in a state of force balance. Because the surface carbon atoms of the coal body have no force to balance the attractive force generated by the internal carbon atoms of the coal body, they have strong surface free energy and exhibit characteristics of adsorbed gases (such as CO_2 and CH_4). The forces between various gases and coals are different, leading to the different coal adsorption capacities of various gases. Stevens (1999) reported the CH_4 and CO_2 adsorption capacities of coal seam, which are shown in Table 1 (Stevens, 1999).

Based on the adsorption/desorption mechanism of a coal seam, several scholars have performed CO_2/CH_4 replacement experiments (Wang et al., 2014a; Wang et al., 2009), and the following conclusions have been reported: (1) Injection of CO_2 can reduce the partial pressure of CH_4 in the free gas and accelerate the CH_4 desorption from the inner surface of the coal matrix. (2) There is a competitive adsorption mechanism between CO_2 and CH_4 in a coal seam. Because that the CO_2 adsorption capacity is higher than that of CH_4. Thus, CH_4 can be replaced by CO_2 from the coal matrix surface to enhance the CBM recovery. (3) The flow capacity of coal seam can be improved by the injection gas, increasing the speed of CH_4 flow to the wellbore. (4) A large portion of the injected CO_2 is adsorbed by the coal seam, and the cap rocks of coal seam are in most developments of impermeable formations, such as mudstone and shale, which is a benefit of CO_2 storage in coal seams. If there is no serious geological damage, the adsorption state of CO_2 is less dissipated and the CO_2 is stored in the coal seam permanently.

Table 1
Relations between the adsorption ability of CH_4 and CO_2 and their physical/chemical characteristics.

Physical/chemical parameters	CH_4	CO_2
Boiling point (°C)	−161.49	−78.48
Critical temperature (°C)	−82.01	31.04
Critical pressure (MPa)	4.6407	7.386
Critical density (kg m^{-3})	426	466
Ionization potential (ev)	13.79	15.6
Effective diameter (nm)	0.414	0.456
Relative adsorption capacity	large	small

2.2. Application criteria of CO_2 ECBM and storage

Coal matrix adsorption gas is maintained mainly by the water pressure in cleats. Therefore, a coal seam with a high adsorption capacity is more suitable for CO_2 storage. Stevens et al. proposed the following application criteria for CO_2 ECBM and storage, which are helpful to select the suitable CBM reservoirs for CO_2 storage (Stevens et al., 1998): (1) In a homogeneous CBM reservoir, the coal seam should be continuous laterally and isolated vertically. To guarantee the long-term storage of CO_2, the cap rocks should be impermeable formations. (2) The structure of the reservoir should be simple and have few faults and folds. The fractures provide the channel for CO_2 migration, while the sealing faults separate the CBM reservoir. (3) The permeability of the reservoir should be suitable; a lower limit of 1–5 mD is suggested. Reservoirs with insufficient permeability can also store CO_2, but the coal seam must be thick enough to ensure the proper CO_2 injection volume. (4) Suitable buried depth: A low reservoir pressure of shallow coal seam limits the CO_2 storage volume. A depth that is too great can reduce the reservoir permeability, which is adverse to CO_2 injection. (5) Geometry of coal seam: the reservoirs that have many thick layers with small spacings are more suitable for CO_2 ECBM and storage than the reservoirs with many thin layers with large spacings. (6) CH_4 saturation: higher CH_4 saturation of a coal seam is more favorable for CO_2 ECBM and storage. (7) For higher Langmuir volume and Langmuir pressure, the CO_2 ECBM and storage are more suitable.

3. CO_2/CH_4 replacement experiment

The CO_2/CH_4 replacement experiment refers to the procedure in which one gas first reaches the adsorption equilibrium and then the other gas, relying on a stronger adsorption capacity or gas partial pressure changes, causes the pre-adsorption gas to desorb from the coal sample. That is, the newly arrived CO_2 molecules replace the adsorption sites of CH_4 molecules. When conducting the replacement adsorption, after each adsorption equilibrium and the experimental data has been recorded, we must re-evacuate (the