International Journal of Mining Science and Technology 25 (2015) 665–670

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

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

Permeability variation characteristics of coal after injecting carbon dioxide into a coal seam

Ni Xiaoming [a,b,*], Li Quanzhong [a], Wang Yanbin [c], Gao Shasha [c]

[a] School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo 454000, China
[b] Collaborative Innovation Center of Coalbed Methane and Shale Gas for Central Plains Economic Region, Jiaozuo 454000, China
[c] College of Geoscience and Surveying Engineering, China University of Mining & Technology, Beijing 100083, China

ARTICLE INFO

Article history:
Received 21 December 2014
Received in revised form 23 January 2015
Accepted 27 February 2015
Available online 6 June 2015

Keywords:
Carbon dioxide
Coal reservoir
Permeability
Change characteristics

ABSTRACT

A theoretical basis for the optimization of carbon dioxide injection parameters and the development of the drainage system can be provided by identifying the permeability change characteristic of coal and rock after injection of carbon dioxide into the coal seam. Sihe, Yuwu, and Changcun mines were used as research sites. Scanning electron microscopy and permeability instruments were used to measure coal properties such as permeability and surface structure of the coal samples at different pH values of carbon dioxide solution and over different timescales. The results show that the reaction between minerals in coal and carbonate solution exhibit positive and negative aspects of permeability-the dissolution reaction between carbonate minerals in coal and acid solution improves the conductivity of coal whilst, on the other hand, the clay minerals in the coal (mainly including montmorillonite, illite and kaolinite) exhibit expansion as a result of ion exchange with the H^+ in acid solution, which has a negative effect on the permeability of the coal. The permeability of coal samples increased at first and then decreased with immersion time, and when the soaking time is 2–3 months the permeability of the coal reached a maximum. In general, for coals with permeabilities less than 0.2 mD or greater than 2 mD, the effect on the permeability is low; when the permeability of the coal is in the range 0.2–2 mD, the effect on the permeability is highest. Research into permeability change characteristics can provide a theoretical basis for carbon dioxide injection under different reservoir permeability conditions and subsequent drainage.

1. Introduction

In recent years, environmental problems caused by carbon dioxide emissions have become hot topics. In order to reduce the emissions of carbon dioxide to the atmosphere, based on the Langmuir isotherm adsorption/desorption curve, domestic and foreign researchers have conducted adsorption/desorption experiments on methane and carbon dioxide under different conditions. The conclusion is that the adsorption of carbon dioxide is greater than the adsorption of coal bed methane under the same conditions. On this basis, the concept of injecting carbon dioxide into the coal seam has been proposed. On the one hand, injecting carbon dioxide can sequester part of the carbon dioxide whilst, on the other hand, the competitive adsorption between coalbed methane and carbon dioxide can improve the recovery of coal bed methane wells [1–4]. Based on this theory, the United States, Japan, China and other countries have conducted pilot tests of enhanced coalbed methane production by injecting carbon dioxide, and although some of the tests were successful, gas production from some wells was unsatisfactory [5–7].

Researchers have begun to consider coal reservoir permeability by the adsorption expansion effects between coal and gas. The main research methods include: using a gas permeability tester, the permeability before and after adsorption was measured, the relationships among adsorbed amount, deformation and the permeability were obtained [8–12]; or applying surface chemistry, elasticity theory, porosity, permeability mathematical models after coal adsorption expansion were established, the relationships between adsorption swelling deformation and permeability was analyzed. However, researchers have ignored the fact that carbon dioxide will dissolve in the coal seam water and form an acid solution, and thus play a role with the minerals in the coal. The effect is more pronounced at higher coal reservoir pressures. This effect will have an influence on the pore fissure structure of the coal and thus sequestration of carbon dioxide in coal reservoirs and displacement effects are affected. In order to investigate the effect of injecting carbon dioxide into coal seams at different reservoir pressures,

* Corresponding author. Tel.: +86 13598539437.
E-mail address: nxm1979@126.com (X. Ni).

http://dx.doi.org/10.1016/j.ijmst.2015.05.022
2095-2686/

the author prepared carbon dioxide solutions having various acidities in the laboratory, simulated different reservoir pressures, conducted reaction experiments between carbon dioxide solutions and minerals in coal and measured the change of coal permeability before and after the reaction was tested. The variation characteristics of coal and rock permeability were identified which can provide a theoretical basis for injecting carbon dioxide on site.

2. Experimental

2.1. Samples and preparation

Samples of Sihe mine anthracite, Yuwu and Changcun coal mine lean coal from Shanxi were collected for use in the research. The diameter of the coal samples is 25 mm and the heights range from 25 mm to 50 mm, the specific sizes being measured by Vernier caliper. Nine coal samples were used in the experiments. Examples of the coal samples are shown in Fig. 1. According to the provisions of the People's Republic of China National Petroleum Industry Standard SY/T 5163-2010 "clay minerals and common non-clay mineral of sedimentary rocks X-ray diffraction analysis method", using a D8 DISCOVER X-ray diffractometer, the mineral components in coal samples were analyzed. The analysis results are shown in Table 1.

2.2. Program

In order to simulate a series of reactions of carbon dioxide injected into coal seams (in this experiment, pH values of carbon dioxide solution were respectively 4.3, 5.0, and 5.7), coal samples were soaked in the different pH values in a hermetic container over different timescales. The soaking times were 1 month, 2 months, 3 months and 4 months, and the permeability of coal samples at different soaking times was tested using a penetration instrument. The surface microscopic changes in the coal samples before and after reaction of the coal with acid were observed using scanning electron microscopy.

Fig. 1. Part of experimental the coal samples.

The method of preparation of the carbon dioxide solutions was to place 2000 mL of mine water into the jar, then add the dry ice and, when it is fully dissolved, the pH value of the solution was tested with a pH meter. If the pH value was not the desired value, dry ice was added continuously until the pH value reached the desired value.

The method of testing the permeability was to use an experimental instrument-a ULTRA PERMTM200 permeability testing machine-according to the People's Republic of China Petroleum and natural gas industry standard SY/T5336-2006 "core analysis method". The coal samples were dried 12–24 h before the experiment in a 60 °C drier.

The test method for the scanning electron microscopy was to use a HITACHI scanning electron microscope S-3400N, according to the People's Republic of China national standard GB/T 20307-2006 "scanning electron microscope method for measuring nanometer length rule". Using this equipment, the surface structure of the coal can be tested.

3. Results and discussions

3.1. Results

3.1.1. Permeability

The permeability values of coal samples after reaction under different pH values of carbon dioxide solution and over different time scales are shown in Table 2 and Fig. 2.

We can see from Table 2 and Fig. 2 that:

(1) When the pH value is low, the permeability variation of coal samples is greater.
(2) When the initial permeability of a coal sample is less than 0.2 mD, the coal reservoir permeability is small after soaking and the effect of the acid solution on the coal reservoir permeability is minimal. When the initial permeability of a coal sample is between 0.2 mD and 2 mD, the permeability of the coal is greatly increased and the effect of acid solution on the coal reservoir permeability is obvious. When the initial permeability of a coal sample is greater than 2 mD, the permeability of the coal shows a downward trend after soaking and the effect of the acid solution on the coal reservoir permeability is not obvious. In general, the permeability of coal samples with increasing immersion time increases at first and then decreases. From the permeability test results, the permeability changes in the nine samples with soaking time were analyzed by regression analysis. The relationships between permeability and reaction times were obtained from Table 3.

When the initial permeability of a coal sample is less than 0.2 mD, the fitting relationships between permeability and

Table 1
Testing results of the mineral components in coal samples.

Coal sample	Content of clay minerals (%)				Quantitative analysis of whole-rock (%)				
	Kaolinite	Chlorite	Illite	Montmorillonite	Quartz	K-feldspar	Plagioclase	Calcite	Dolomite
SH-1-1	0.89	23.14	20.91	44.05	5	0	1	0	5
YW-1-1	5.95	0.00	27.41	51.63	1	0	0	8	6
CC-1-1	0.00	2.46	24.43	55.10	1	4	0	9	4
SH-2-1	1.90	26.13	20.42	46.55	1	0	0	0	4
YW-2-1	0.00	0.00	19.38	37.62	1	0	0	16	26
CC-2-1	0.00	4.40	27.98	55.62	1	4	0	3	4
SH-3-1	5.85	8.45	21.12	29.58	0	0	0	1	34
YW-3-1	12.42	0.00	19.04	37.54	1	0	0	16	14
CC-3-1	0.00	1.68	24.52	57.80	1	4	0	5	6