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Effect of swelling of coal induced by carbon dioxide adsorption on permeability and P-wave velocity

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ABSTRACT

Enhanced coal bed methane recovery (ECBM) is considered as a promising way to produce methane from coal beds while storing carbon dioxide (CO_2). The adsorption of CO_2 on coal surfaces is known to render softening and swelling of coals, however, to what extent it will affect to permeability and P-wave velocity is still poorly understood. This study investigated the effect of swelling of coal induced by CO_2 adsorption on permeability and P-wave velocity. It appeared that CO_2 adsorption caused decreases in permeability and an increase in P-wave velocity. This study presents valuable laboratory test results of transport and geophysical properties and the obtained results provide a direct evidence of swelling effect caused by CO_2 adsorption on coals.

1. INTRODUCTION

Enhanced coalbed methane recovery (ECBM) is considered as a promising way to reduce the atmospheric carbon dioxide (CO_2) concentration while producing methane from coal beds. Because carbon dioxide is the most adsorbable gas among nitrogen, carbon dioxide, and methane [Anne et al., 2007], when CO_2 is injected to methane-bearing coal beds, CO_2 is adsorbed and stored on coal surfaces, replacing and releasing pre-adsorbed methane. However, it is known that the adsorption of CO_2 on coal surfaces changes the mechanical characteristics of coals. For examples, CO_2 adsorption led to the swelling and permeability reduction of the coals [Yang and Zobak, 2011]. Swelling of coals under no confining stress implies the softening of the media, which leads to the collapse of pores and thus the reduction of permeability. The degree of swelling increases with the carbon content in the coal [Karacan, 2003]. Emphasis by many previous studies has been on the transport properties, mostly gas permeability of coals [Durucan and Edwards, 1986; Larsen, 2004]. However, researches as to the effect of CO_2 on a powdered coal sample have been insufficient. Therefore, this study investigated the effect of CO_2 adsorption on the permeability and P-wave velocity of

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powdered coal sample. The experiment data presented in this manuscript were gathered from our previous studies [Lee and Kwon, 2015; Lee et al., 2016].

2. EXPERIMENTAL PROGRAM

2.1 Measurement of Permeability Affected by CO_2 Adsorption

A specimen for this experiment was made by oven dried coarse-grained coal which is anthracite from Kyung Dong in Korea and sieved with the sieve No. 60 (opening size: 0.25 mm). A diameter and a height of the specimen were 38 mm and 76 mm respectively. After set up the specimen in a modified triaxial cell maintaining a temperature of 30°C by electric heating jacket as shown as Fig. 1, a confining stress of 2 MPa of Nitrogen (N_2) gas was applied to the specimen for preconsolidation. And then, the air in the specimen was eliminated by suction using a vacuum pump. The both processes lasted 30 minutes and the confining stress decreased to 1.5 MPa and a pore pressure of 1 MPa of carbon dioxide (CO_2) was applied to the specimen using a syringe pump (500HP, ISCO Teledyne). After all, the effective stress of 0.5 MPa was applied to the specimen. For the adsorption of CO_2 to the coal surface, the state which the effective stress of 0.5 MPa was applied was continued for 18 hours. After the adsorption period of 18 hours was passed, CO_2 gas was injected into the specimen at a constant flow rate of 5 cm^3/min with flow direction from the bottom to the top of the specimen using the syringe pump while the back pressure was kept as 1 MPa using a back pressure regulator. This pressure and CO_2 adsorption process was repeated twice more with elevating confining pressure and pore pressure to 2.0 MPa and 1.5 MPa respectively and 2.5 MPa and 2.0 MPa respectively. All the temperature conditions were maintained as 30°C. The calculation of permeability was conducted by Darcy's law using the data of the difference of the pressure between the bottom and the top of the specimen measured by a differential pressure transducer.

2.2 Measurement of P-wave Velocity Affected by CO_2 Adsorption

P-wave velocity of the specimen was measured by a piezoceramic disc (SMC14H12111; Steminc Inc.; the thickness = 12 mm and the diameter = 14 mm) and an accelerometer (353B14; PCB Piezotronics, Inc.), embedded in the bottom of the triaxial cell and the top cap, respectively (Fig. 1). P-wave velocity was measured at the CO_2 pressures of 1 MPa, 1.5 MPa, and 2 MPa. Square waves of 100 Hz with 100 V amplitude were applied to the piezoceramic disc using a signal generator (335ARB1U, Agilent) and a power amplifier (7602M, Krohn-Hite). The measurement of P-wave was conducted every hour during CO_2 adsorption at the each step of the pore pressures. The signal delay caused by the thickness of the bottom and top cap where the piezoceramic disc and accelerometer were installed was calibrated for calculation of P-wave velocity. It was also assumed that a change in the height of the specimen was negligible during the CO_2 adsorption processes.

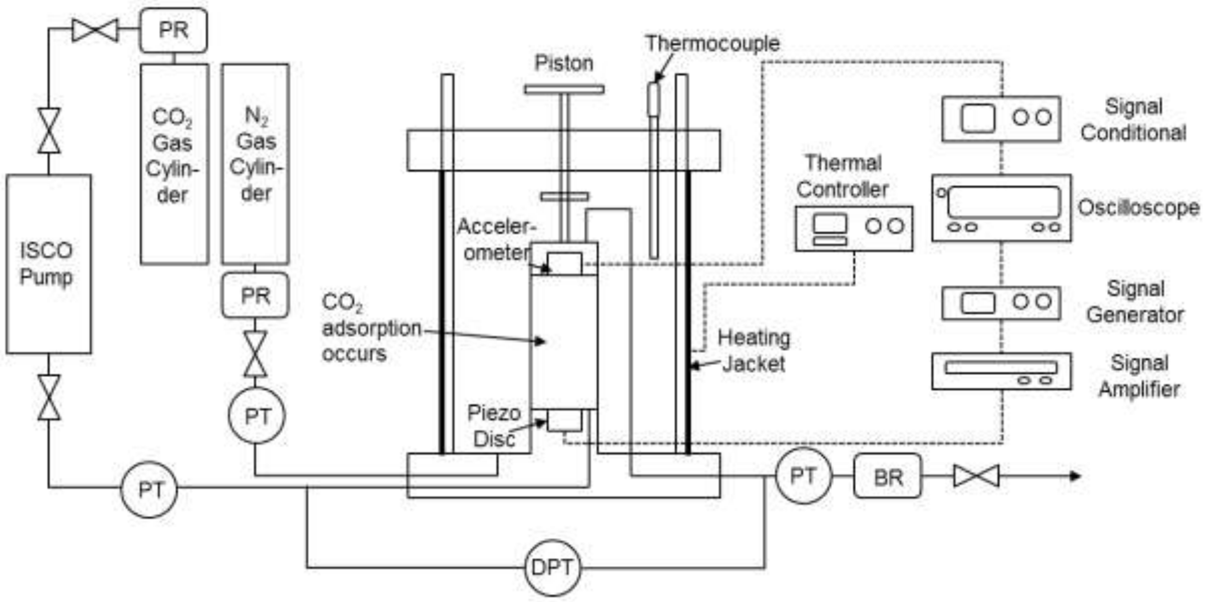


Fig. 1. Schematic diagram of the experiment set-up.

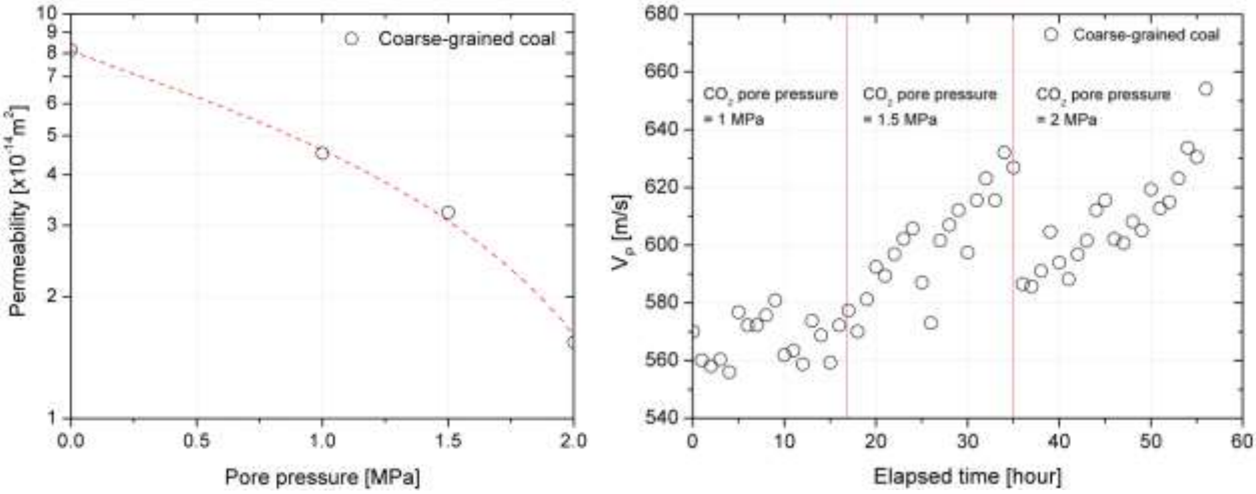
3. RESULTS AND DISCUSSION

3.1 Effect of CO_2 Adsorption on Permeability

The permeability of the specimen decreased totally from 8.2×10^{-14} m^2 (k_0) to 1.5×10^{-14} m^2, by ~81% through the CO_2 adsorption processes (Fig. 2a). It implies that the voids of the specimen decreased with the CO_2 adsorption. A rate of the decreasing permeability increased with the increasing adsorption pressure of CO_2. It suggests that increasing CO_2 pore pressure led to the more CO_2 adsorption and reduction of the permeability. After all, it is presumed that the permeability reduction occurred by swelling of the coal caused by CO_2 adsorption.

3.2 Effect of CO_2 Adsorption on P-wave Velocity

As shown in Fig. 2b, when the CO_2 pore pressure of 1 MPa was applied to the specimen, the V_p was shown as constant tendency of velocity of ~550-580 m/s. When the CO_2 pore pressure of 1.5 MPa applied to the specimen, the V_p increased from ~580 m/s to ~630 m/s, by approximately 9%. When the applied CO_2 pore pressure increased to 2 MPa, the V_p increased from ~590 m/s to 650 m/s, by approximately 10%. The rate of the increasing V_p increased just as when the rate of the decreasing permeability increased. It is presumed that the decreased voids of the specimen by the CO_2 adsorption processes caused the increase of the V_p. It is suggested that swelling occurred during the CO_2 adsorption processes.



(a) (b)

Fig. 2. (a) Permeability reduction with CO_2 pore pressure, and (b) P-wave velocity during the CO_2 adsorption processes.

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