COAL SWELLING IN SUPERCRITICAL CO_2 AND ITS EFFECTS ON ENHANCED COALBED-METHANE RECOVERY(ECBMR)

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論 文 名　：　COAL SWELLING IN SUPERCRITICAL CO_2 AND ITS EFFECTS ON ENHANCED COALBED-METHANE RECOVERY (ECBMR)
(超臨界 CO_2 中における石炭の膨潤および炭層メタン増進回収(ECBMR)に及ぼす影響)

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論　文　内　容　の　要　旨

Carbon dioxide (CO_2) injection into coal reservoirs is one of the options to enhance coal bed methane (CBM) recovery and at the same time secure long-term geological sequestration of CO_2 in coal reservoirs to reduce CO_2-emission into the atmosphere. It is expected to be economical by increasing clean natural gas supply from the coal reservoirs, especially from huge amount of low rank coal reservoirs to offset CO_2 injection cost. Although CO_2 is adsorbed in coal matrix with higher volume than methane (CH_4) for given pressure, it has been reported to give some issues on CH_4 gas production due to coal matrix swelling. Present study has investigated effects of coal swelling by CO_2 injection into coal reservoirs, in particular (1) examination of swelling behavior with low rank coals and its governing factors; (2) measurements the effect of it on permeability; and (3) numerical simulations on CO_2-ECBMR production forecast in considering stress-dependent permeability-models.

Three coal samples with Neogene-Paleogene in age, that used for this research, were sampled from South Sumatra and Kutai basins, Indonesia and an offshore coal seam at Kushiro Coal Mine, Japan. Based on huminite reflectance, the coal samples are classified into lignite to sub-bituminous in coal rank. Their properties including moisture, ash, volatile matter, and fixed carbon content (%wt, adb) range from 5.4 – 20.8; 0.6 – 12.0; 35.2 – 46.0 and 39.4 – 47.3, respectively.

This thesis is structured in six chapters as follows:

Chapter 1: This chapter provides a background on development of natural resources in term of stable, affordable and environmentally friendly by utilizing CO_2 to enhanced CBM recovery (CO_2-ECBMR). The basic knowledge of coal reservoirs and CO_2-ECBMR processes were presented briefly and the research objectives as well as thesis structures were described in this chapter.

Chapter 2: This chapter studies coal swelling behavior of crushed coal samples in CO_2. A visualization method has been developed to measure its swelling evaluated by surface movement of the column packing the crushed coal samples in a high pressure cell. This method was used to solve the limited availability of core sample and to get average properties of coal swelling in CO_2. The results shows in a good agreement with previous published data for the same coal rank. The maximum of volumetric swelling was 3.16 for dry coal and 1.53 for wet coal at pressure 10 MPa. This method has the advantages in terms of sample preparation and experimental execution.

Chapter 3: This chapter describes the effect of megascopic texture on swelling characteristics from

Neogene-Paleogene low rank coal in supercritical CO_2. A set of blocks samples was prepared parallel and perpendicular to bedding orientation and strain gauges were attached in its long axis on the block surface to measure the length of change. In this study, samples were divided into two group, i.e banded and non-banded coal. The banded samples showed anisotropic linear swelling where swelling in perpendicular to bedding plane is always greater than that in parallel. In contrast, the non-banded samples showed more isotropic behaviour without much preference to bedding plane orientation. The average ratio of swelling perpendicular to parallel was evaluated as 1.28 and 1.05 for banded and non-banded coal samples, respectively. Thus, it is considered that swelling is not always anisotropic to bedding plane orientation, particularly in young low rank coal. This difference in swelling characteristics can be concluded as a result of different megascopic textures of coal samples with respect to bedding orientation.

Chapter 4: This chapter discusses the relationship between coal matrix swelling and gas permeability during CO_2 injection processes. A continuous measurements of coal swelling and permeability was conducted using core samples with 50 mm in diameter under various triaxial stress conditions using a Hassler type core holder. The results show that permeability decrease with increasing confining stress under constant effective stress that is difference between confining stress and pore pressure. For 3 MPa as an example of constant effective stress, CO_2 gas permeability reduced by 60% with increasing average pore pressure from 0.5 to 2.5 MPa where He gas did not show apparent permeability reduction. Since there is increasing adsorption volume with increasing pore pressure, thus adsorption-induced coal swelling has a direct impact on decreasing of permeability. However, under constant confining pressure, reduction of CO_2 gas permeability due to coal matrix swelling with increasing pore pressure was not observed since it was compensated by decreasing of effective stress. This result shows that decreasing process of effective stress has a larger complex effect on gas permeability than coal matrix swelling.

Chapter 5: This chapter presents numerical simulations to investigate the effect of swelling on gas production performances at coal reservoirs. The stress-dependent permeability-models to express effect of coal matrix shrinkage/swelling using Palmer and Mansoori (P&M) and Shi and Durucan (S&D) models were constructed based on present experimental results for typical coal reservoirs with the distance of 400 to 800 m between injection and production wells. By applying the P&M and S&D models, the numerical simulation results showed that CH_4 production rate was decreasing and peak production time was delayed due to effect of stress and permeability changes caused by coal matrix swelling. The total CH_4 production ratio of swelling effect/no-swelling was simulated as 0.18 to 0.95 for permeability 1 to 100 mD, respectively, and it has been cleared that swelling affects gas production at permeability 1 to 15 mD, however, it can be negligible at permeability over 15 mD.

Chapter 6: This chapter presents the conclusion of the study. It contains the summary of the overall swelling measurement data and its major controlling factors, the effect of swelling on permeability and gas production performance during CO_2-ECBMR processes as well as the suggestions for the future studies on field projects.