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Injection of Supercritical Carbon Dioxide into Granitic Rock and its Acoustic Emission Monitoring

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Abstract

We injected carbon dioxide (CO_2) into a hole drilled around 8 m long in a granitic hot rock from the floor of the tunnel. We drilled four AE (acoustic emission) monitoring holes parallel 1 m far away from the injection hole and monitored AE events induced with hydraulic fracturing (HF). When the breakdown (BD) pressure was recorded, the pressure and the temperature satisfied the supercritical condition of CO_2. The AE source distribution showed that two vertical cracks were initiated from the injection hole with BD. After 75 seconds from the occurrence of BD with no pressure increase, the AE sources started to distribute along the direction almost normal to that of the initial crack from the position around 0.7 m far away from the injection hole. It is most likely that the cracks initiated in intact rock with BD by HF and one of them bended and extended along pre-existing crack. These results suggest that CO_2 migrates easily and enhances AE occurrence in a pre-existing joint.

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Keywords: Carbon dioxide, Hydraulic fracturing; Acoustic emission; Field experiment; Pre-existing joint; Breakdown

1. Introduction

The carbon capture and storage (CCS) in underground is a promising and feasible method for mitigating the greenhouse effect by decreasing the amount of CO_2 emissions. If we can utilize CO_2 for energy production

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and compensate for the cost of CCS, which is called carbon capture, utilization and storage (CCUS), CCS will be much more eagerly developed and adopted. For example of CCUS, Xie et al. [1] shows enhance the recovery of oil (CO_2-EOR), coalbed methane (CO_2-ECBM), geothermal systems (CO_2-EGS), natural gas (CO_2-EGR), shale gas (CO_2-ESG) and others.

For EGS, EOR, ESG and ECBM, CO_2 is usually injected into rocks at a depth of more than 1000 m and sometimes more than 3000 m, and the temperature and pressure at these depths make CO_2 supercritical state. The viscosity of supercritical CO_2 (SC-CO_2) is one or two order of magnitude smaller than that of normal liquid water. To examine effect of fracturing fluid viscosity on a crack features induced by hydraulic fracturing (HF), Ishida et al. [2, 3] made HF experiments using SC-CO_2, liquid CO_2 (L-CO_2), water and viscous oil in 170×170×170 mm cubic granite blocks with a center hole of 20 mm diameter. They found in the laboratory experiments that fracturing with low-viscosity fluid such as SC-CO_2 tends to induce three-dimensionally sinuous cracks with many secondary branches, which seem to be desirable pathways for EGS, ESG and ECBM. However, the effect of fracturing fluid viscosity on HF in real rock mass including pre-existing cracks has not been still clarified. Thus, we made small field HF experiment using CO_2 in a hot rock mass under a tunnel floor which satisfies the temperature to form SC-CO_2, and monitored acoustic emission (AE) induced by HF to clarify crack extension.

2. Site and experimental setup

2.1. Site and method of CO_2 injection

The site was a small tunnel in a depth of around 50 m from the surface of the mountain area of Kurobe, central Japan, which has hot granitic rock mass formed from the late Miocene to the Pleiocene. As shown in Fig. 1 and 2, an HF hole was drilled downward around an eight meter from the tunnel floor and four AE monitoring holes were drilled parallel 1 m far away from the HF hole. Since the water level was around 1 m below the tunnel floor, the all experiments were made in a rock mass saturated with water. To inject CO_2, we drilled a 36 mm small diameter pilot hole at the bottom of the 86 mm large diameter HF hole. To drill the pilot hole at the center of the bottom of the large diameter hole, before drilling the pilot hole, we making the bottom of the large diameter hole in conical shape using a specially designed diamond bit as shown in Fig. 3(a). To inject CO_2, we sealed the upper section of the pilot hole with an O-ring equipped on the packer unit and poured cement paste above the O-ring, as shown in Fig. 3(b). The sealed section for injection was 0.16 m long from 7.24 to 7.40 m depth from the floor of the tunnel. After performing HF using CO_2 in the section, we over-cored the section with the 86 mm diameter drilling bit to inspect cracks induced by the HF. By repeating this procedure, we injected CO_2 four times and water three times. Among the seven trials, we report only one experiment that we could make HF with CO2 successfully without leaking.

Fig. 4 shows the injection system used for the experiments. We used two syringe pumps to inject CO_2 continuously without stop. We fed CO_2 from a bomb to two syringe pump cylinders, which had a capacity of 500 mL for each. To fill the cylinders as full as possible, we cooled the CO_2 in the cylinders to keep it in the liquid state by circulating coolant using a cooling unit. The phase diagram in Fig. 5 shows that CO_2 becomes supercritical under the temperature higher than 31°C and the pressure greater than 7.38 MPa. After discharging L-CO_2 from the cylinder of the syringe pump at a constant flow rate of 50 mL/min, we heated it the temperature of around 50°C with a heater unit and injected it into the sealed section in the rock having the temperature of 35°C and saturated with water.