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Prediction of the fingering CO2 flow in homogeneous and porous sandstone

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CO_2 flow mechanisms in porous geological materials are essential to understanding CO_2 behavior in CCS reservoirs. Recently, computer simulations based on Lattice Boltzmann method (LBM) illustrated characteristic fingering-flow patterns associated with invading CO_2 displacing the resident brine in porous materials. These studies also indicated that these fingering flow patterns are strongly controlled by transport properties (e.g., capillary number, C_a,; and viscosity ratio, M). On the other hand, injected CO_2 behavior in the reservoir is monitored by geophysical and geo-mechanical parameters. In particular, seismic survey is the most useful for CO_2 monitoring. Unfortunately, we have only a little knowledge about the relationships between mechanisms of two-phase flow in the porous rock and measurable physical properties. In this study, we conducted the V_p and strain measurements to elucidate the relationship between transport properties and geophysical properties by using Mt. Simon sandstone (porosity: ϕ=26.4). The Mt. Simon sandstone has a high absolute permeability (105 mD) and a unimodal pore-size distribution (peak size: 23 μm). We set three V_p-measurement lines and two strain gages (vertical and horizontal) at the center of core. We observed changes in flow rate, volumetric strain and the differential pressure between the two pumps during the drainage and imbibition processes. In the drainage stage, CO_2 is injected at a constant rate into the sample upto 2.17 PV (1PV=95.1 ml) for 429 min. During this stage, differential pore pressure increased slowly from 0.1 MPa to 0.12 MPa. The upward flow rate is constant at 0.5 ml/min during drainage, which corresponds to the flow velocity 1.6x10^{-5} m/s. All the V_p-measurement lines indicate simultaneous small velocity reductions ($<$2%), after 2.17PV CO_2 injection, lower than the values reported in previous studies. Some previous studies reported over 10 % V_p-reduction in drainage. In contrast, the strain data indicate expansions of over 2000$\mu\epsilon$ and 1400$\mu\epsilon$, at the up- and down-stream side of the flow, respectively. The amounts of the strain are consistent with previous studies. Since the changes in V_p should be directly related to the changes in CO_2-saturation around the P-wave propagation paths. These results suggest a possibility that there are no large saturation of CO_2 However, strain data indicate the existence of injected CO_2 in pore-space. Thus, we presume that the CO_2 makes a channel out of the Fresnel zones of all V_p-measurements lines. We also estimate the Ca based on flow rate data and viscosity ratio of CO_2 and water. Our estimated C_a is low (2 x10^{-8}). From these transport properties, it is clear that the flow within the porous rock resides in the capillary fingering domain. This estimation based on fluid mechanical analysis is supported by direct flow monitoring experiments with X-ray CT scanner. These studies illustrated the change of flow pattern of the non-wetting phase (CO_2). In the case of low flow rate, CO_2 makes a few thin paths through the porous rock. Together, these results suggest the potential for petro-physical properties to infer the characteristics of the heterogeneous two-phase flow in porous rock.

Keywords: two-phase flow, porous sandstone, Capillary number, fingering flow, P wave velocity, Carbon Capture and Storage