

V_p monitoring for the channel formation of CO₂-brine flow in two different types of sandstones

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Recent pore-scale studies for CO₂-water two phase flow in porous materials illustrated strong effect of capillary number (C_a) on channel formation mechanism by theoretical and experimental methods. In this study, we tried to up-scale those results to core-scale CO₂-water flow and to monitor the channel flow by using compressional-wave velocities (V_p) by using experimental method. C_a is controlled by changing CO₂ injection rate (FR). We conducted two CO₂ injection experiments into different types of sandstone with changing FR under reservoir P-T conditions (40°C and 10 MPa). This study used high-permeable Berea-sand stone (10 mD) and ultra-low permeable-Ainoura sandstone (0.01mD) for CO₂ injection tests and estimated CO₂ saturation (S_{CO_2}) and differential pressure (DP) between up- and down-stream of sandstones. This studies also measured P-wave velocities (V_p) with injecting super critical CO₂. In ultra-low FR condition (0.01 ml/min), these samples showed different values, Berea sandstone is around 5 % and Ainoura is over 20 %. also showed large difference between Berea sandstone (0.005MPa) and Ainoura sandstone (0.3 MPa). V_p -reductions are 3% for Berea sandstone and 9% for Ainoura sandstone. Increasing FR up to 0.1 ml/min, Berea sandstone indicated increment both of S_{CO_2} (16%) and DP (0.01 MPa). Ainoura sandstone reached large value both of S_{CO_2} (near 60%) and DP (0.9 MPa). On the other hand, V_p did not indicate clear changes. The experiment for Ainoura sandstone was terminated this FR condition, because DP reaches safety limit (1MPa). The experiment for Berea sandstone increased FR up to 5 ml/min, stepwisely. Over 1 ml/min, S_{CO_2} showed large changes form 35% at 1ml/min to 47.5 % at 5ml/min. DP also changed from 0.05 MPa to 0.53 MPa. V_p showed large reduction from 5.5% to 7%. The experiment for Berea sandstone implied the changes CO₂ flow pattern between low FR (<0.5 ml/min) and high FR (>1.0ml/min). In low-FR conditions, CO₂ indicated still flow without pore-pressure buildup and CO₂ saturation. V_p reduced around 3% from water saturation condition at 0.01ml/min. Over this FR-condition V_p -reduction did not show large changes to 0.5ml/min. During this FR changes, S_{CO_2} increased up to 9.7%. In high-FR conditions, it seemed that CO₂ flow pattern changed. High-FR experiments, CO₂ flowed with increasing DP and S_{CO_2} . V_p -reduction showed clear changes again from 5.5 % to 7.1 %. In Ainoura sandstone experiment, it was suggested that CO₂ flow pattern is controlled only single mechanism. During this experiment, S_{CO_2} and DP increased almost linearly. In this experiment, V_p -indicated large reduction at 0.01ml/min. However, V_p -reductions showed no clear changes at 0.02 ml/min and 0.1 m/min. Then, we estimated changes of CO₂-cluster size during CO₂ injection with Gassmann-CRM model. This estimation suggested that CO₂ cluster size is reduced from 10mm to 5mm between 0.5 ml/min and 1 ml/min. In case of 5ml/min, the cluster size was estimated 2mm. In case of Ainoura sandstone, it was seemed that the cluster size did not change with increasing FR from 0.01 ml/min to 0.1 ml/min. These experimental results illustrated two types of CO₂ flow mechanisms into water filled pores. In low-FR conditions of Berea sandstone, CO₂ indicated still flow through the high porosity zone without build-up of DP. Increasing FR, CO₂ started the invasion to connected low-porosity zone with increasing DP. During this process, CO₂ cluster size were reduced. On the other hand, CO₂ did not easily intrude pore space of low-permeable Ainoura sandstone. Thus, CO₂ cluster was crushed in to small size with arising DP. These experimental campaigns suggested that the cannell-formation is monitored by the changes of V_p and DP in porous sandstone.

Keywords: channel formation, Vp monitoring, CO2 flow speed