Influence of sedimentation heterogeneity on CO2 flooding

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Abstract

Understanding the flow mechanisms of CO2 in reservoir rock is important for CO2 geological sequestration and EOR (Enhanced Oil Recovery). It is essential to understand the influence of the rock heterogeneity on CO2 flow. To study CO2 flow mechanisms in heterogeneous rock, we designed a laboratory experimental system which visualizes CO2 movements during flooding experiments by using X-ray CT. We carried out laboratory experiments of CO2 flooding in porous sandstone, together with porosity mapping, in-situ fluid saturation monitoring based on CT images, and mass flow measurements for ejected fluids. On the basis of experimental results, we try to understand the flooding characteristics of CO2 in inhomogeneous rocks having complex sedimentary structures, which will contribute to CO2 geological sequestration and oil recovery.

Berea sandstone (diameter: 34.95mm, length: 80.00mm) and Sarukawa sandstone (diameter: 34.80mm, length: 79.85mm, from Japan) were used in this study. Porosities of Berea sandstone and Sarukawa sandstone determined by X-ray CT imaging were 20.2% and 31.2%, respectively. As shown in figure 1a, Berea sandstone has bedding planes perpendicular to the core axis. The bedding planes repeatedly appear at almost same intervals and their directions are the same. Thus we consider this specimen as homogeneous in terms of REV (Representative Elementary Volume). On the other hand, Sarukawa sandstone has a heterogeneous structure. Especially, upper part of specimen is more complex than the lower part (Figure 1b).

The experiments were carried out under the pressure and temperature conditions that simulate underground environments; pore pressure: 10MPa, temperature: 40 degrees Celsius. The confining pressure of 12MPa was selected in this study. Fluid pressure and its injection rate were controlled by high-precision syringe pumps. A high-pressure vessel having high transparency for X-ray was utilized in this study. Specimens were first saturated with KI aqueous solution (12.5%), and then oil was injected to change the specimens into oil-water mixed states. Five and ten steps of CO2 flooding were performed for Berea sandstone and Sarukawa sandstone, respectively. For each step, KI aqueous solution and oil were carefully recovered from the syringe pump which plays a role of back pressure. The CO2 flooding tests were carried out until the CO2 injection reaches 2PV (pore volume) and 3PV for the Berea sandstone and Sarukawa sandstone. Finally, about 71.9% and 74.1% of oil recovery for the Berea sandstone and Sarukawa sandstone were confirmed. Figures 1c and d show the differential CT images when the CO2 injection reaches 0.25PV and 0.26PV for the Berea sandstone and Sarukawa sandstone.

CO2 is spreading evenly from the injection part through the Berea sandstone (Figure 1c). In the case of Sarukawa sandstone, almost all of the CO2 preferentially moves through the upper part of specimen.
This represents that the sedimentation heterogeneity is the main factor that affects the CO₂ flooding pattern. When injected CO₂ reached 1.0PV in both specimens, the oil recoveries were identified as 68.6% and 48.9% in Berea sandstone and Sarukawa sandstone, respectively. We increased the differential pressure only for the Sarukawa sandstone to confirm the influence of differential pressure on oil recovery in heterogeneous media. The oil recoveries were 71.9% and 69.7% for Berea sandstone and Sarukawa sandstone, respectively when injected CO₂ reached 2.0PV. The differences in the pressurized oil recovery between Berea and Sarukawa sandstone, 3.3% and 20.8% correspond to more CO₂ flooding into the non-recovering zone (low porosity) due to increasing of capillary pressure. As shown in Figure 1f, the differential CT image in Sarukawa sandstone also indicates more CO₂ flooding in the lower part of the specimen.

![X-ray CT images of CO₂ flooding experiment](image)

Figure 1: X-ray CT images of CO₂ flooding experiment. Cores in dry condition: a) Berea sandstone, b) Sarukawa sandstone. Differential CT images: c) Berea sandstone after 0.25PV CO₂ injected, d) Sarukawa sandstone after 0.26PV CO₂ injected, e) Berea sandstone after 2.00PV CO₂ injected, f) Sarukawa sandstone after 2.09PV CO₂ injected