An Experimental Investigation of Three-phase Flow in a Carbonate Rock during Water-Alternating-Gas Injection Using In-Situ Saturation Measurement Technique

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Abstract. Water alternating gas (WAG) injection is a tertiary enhanced oil recovery technique that involves the intermittent injection of brine and gas into oil reservoirs in order to improve mobility ratio and sweep efficiency. While some research has been dedicated to understanding the WAG injection process and its underlying attributes, such as cyclic relative permeability hysteresis and phase trapping, the majority of these studies have focused on sandstones and sand packs, and therefore our understanding of WAG injection in natural carbonate rocks is limited. This is primarily due to their inherent heterogeneity and the complexity of three-phase core-flooding experiments. Additionally, insights gained in three-phase WAG studies have often been limited due to lack of access to in-situ saturation measurement technology.

In this study, we aim to investigate the three-phase flow behavior and displacement mechanisms during WAG injection in a carbonate rock, with a particular focus on the effect of saturation history on fluid distributions and phase trapping. We also examine (through end-point relative permeability measurements) the extent and rate of injectivity loss resulting from phase trapping during WAG injection. A series of flow experiments are conducted on a water-wet outcrop rock using a three-phase core-flooding setup that is integrated with a cutting-edge robotic x-ray imaging platform featuring a resolution of 180 µm for in-situ saturation measurements at the core scale. To this end, a core plug measuring 10 inches in length and 1.5 inches in diameter is first drilled from a block of the carbonate. The relative homogeneity of the core sample is subsequently verified using the x-ray CT scanner. The fluid system used in the experiments comprises brine, Soltrol 170, and N2. The experiments are started by injecting the gas phase either into a core sample at initial water saturation (WAG-G) or into a sample at waterflood remaining oil saturation (WAG-W), followed by alternating between brine and gas for multiple cycles. Both flooding sequences (i.e., saturation histories) are investigated in this study while using the imaging platform mentioned earlier to generate three-dimensional in-situ saturation data across the sample. The experimental data are carefully analyzed to gain insights into the physics of three-phase flow during WAG injection in carbonates, including phase trapping and distribution as well as injectivity loss.