Micro-PIV Measurements of Multiphase Flow of Water and Liquid/Supercritical CO₂ in 2D Heterogeneous Porous Micromodels

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Keywords: Micro-PIV, CO₂ sequestration, Porous media, Multiphase flow

HIGHLIGHTS

• Fluorescent microscopy and micro-PIV are simultaneously employed for studying multiphase flow in 2D heterogeneous porous micromodels.
• Simultaneous measurement of the spatially-resolved instantaneous velocity field and instantaneous spatial configuration of the phases.
• First quantitative measurement of pore-scale flow dynamics that incorporates both reservoir-relevant conditions and rock heterogeneity.
• The entire CO₂ infiltration process is presented, including the evolution of individual menisci and the growth of dendritic structures.
• Velocity burst events, terms Haines jumps, are captured, during which the importance of inertial effects is quantified.

ABSTRACT

The pore-scale flow dynamics of liquid/supercritical CO₂ infiltration into water-saturated 2D heterogeneous porous micro-models, inspired by the structure of real reservoir rock, was studied at reservoir relevant conditions (80 bar, 21 °C). Fluorescent microscopy and the micro-PIV method were simultaneously employed by seeding the water phase with fluorescent particles and tagging the CO₂ phase with a fluorescent dye of a different spectral emission. Doing so allows for simultaneous measurement of the spatially-resolved instantaneous water velocity field and quantification of the instantaneous spatial configuration of both phases. The results, which are spatially and temporally-resolved, provide a unique view of the flow during the migration of the CO₂ front, the evolution of individual menisci and the growth of dendritic structures, so-called fingers. As expected, before the arrival of the CO₂ front in the porous section the flow of water is steady. As the front approaches, a short period of quiescence was observed. This was followed by CO₂ suddenly breaking through the resident water. CO₂ is observed forming fingers which grow in directions both along and normal to the bulk pressure gradient, and even against the bulk pressure gradient, thus indicating the establishment of the capillary fingering regime. Velocity burst events were also captured, during which the peak velocity was estimated to be up to 30 times greater than the bulk velocity, supporting the notion of Haines jumps. The Reynolds numbers during these events are estimated to be in the order of 10 in the CO₂ phase, which indicates the potential significance of inertial effects. To our knowledge, this study is the very first quantitative measurement that incorporates both real reservoir-relevant conditions and real rock heterogeneity, and will thus be useful for pore-scale model development and validation.