scientific reports

Article | Open Access | Published: 11 February 2023

Effects of grain size and small-scale bedform architecture on CO_2 saturation from buoyancy-driven flow

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Scientific Reports **13**, Article number: 2474 (2023)

Abstract

Small-scale (mm-dm scale) heterogeneity has been shown to significantly impact CO_2 migration and trapping. To investigate how and why different aspects of small-scale heterogeneity affect the amount of capillary trapping during buoyancy-driven upward migration of CO_2, we conducted modified invasion percolation simulations on heterogeneous domains. Realistic simulation domains are constructed by varying two important aspects of small-scale geologic heterogeneity: sedimentary bedform architecture and grain size contrast between the matrix and the laminae facies. Buoyancy-driven flow simulation runs cover 59 bedform architecture and 40 grain size contrast cases. Simulation results show that the domain effective CO_2 saturation is strongly affected by both grain size and bedform architecture. At high grain size contrasts, bedforms with continuous ripple lamination at the cm scale tend to retain higher CO_2 saturation than bedforms with discontinuous or cross lamination. In addition, the "extremely well sorted" grain sorting cases tend to have lower CO_2 saturation than expected for cross-laminated domains. Finally, both a denser CO_2

phase and greater interfacial tension increase CO_2 saturation. Again, variation in fluid properties seems to have a greater effect on CO_2 saturation for cross-laminated domains. This result suggests that differences in bedform architecture can impact how CO_2 saturation values respond to other variables such as grain sorting and fluid properties.

Introduction

CO_2 geologic storage, or the injection and sequestration of captured CO_2 in deep geologic formations such as saline aquifers, is an imperative measure to address climate change[1,2,3,4]. Prior research has shown that even small-scale (mm-dm scale) geologic heterogeneity can greatly affect CO_2 flow and trapping[5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21]. Depositional laminations and baffles are examples of such small-scale heterogeneity, and they have been shown to form effective capillary barriers that can retain a substantial amount of above-residual CO_2 saturation during both the injection (drainage) and the post-injection (imbibition) stages through the mechanism known as local capillary trapping (LCT), also called capillary heterogeneity trapping[5,8,16,22]. Hence, small-scale heterogeneity can greatly impact how much CO_2 is retained in the geologic material (the storage capacity of the reservoir) and it is also crucial in controlling the CO_2 plume migration speed and extent[16,19,20,23,24]. Therefore, it is important to conduct simulations that are capable of correctly incorporating this extra amount of CO_2 residual or capillary trapping in order to accurately predict how the CO_2 plume migrates through heterogeneous domains.

Conventional reservoir simulations used to study CO_2 plume migration and trapping employ coarse (10–100 m scale) grid blocks or cells greatly above the resolution of small-scale heterogeneity to save computational time and resources, but consequently run the risk of obtaining inaccurate simulation results without proper upscaling[16,19,20]. Furthermore, conventional full-physics simulators use continuum-scale Darcy-flow physics and have convergence issues modeling low-rate CO_2 flow through highly