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Interplay between the capillary pressure, saturation and interfacial area: pore-network analysis

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Based on rational thermodynamics, Hassanizadeh and Gray [1] have suggested that the non-uniqueness in the capillary pressure-saturation (P_c-S_w) relationship is indeed due to the absence of specific interfacial area, which is defined as the total interfacial area divided by the volume. They introduced interfacial area as a separate thermodynamic entities, possessing mass, momentum, and energy. They proposed the following equation for capillary pressure:

$F(P_c, S_w, a_{nw}) = 0$

Understanding the behavior of fluid-fluid interfacial area regardless of the theoretical aspects is of great important to the mass transfer applications such as CO_2 sequestration.

A number of computational and experimental works have shown that under a wide range of drainage and imbibition histories under equilibrium conditions, P_c-S_w-a_{nw} surfaces more or less coincide. However, uniqueness of P_c-S_w-a_{nw} surface under non-equilibrium conditions is an unanswered question.

We employ a dynamic pore-network simulator as a pore-scale physical-based model. Computational and geometrical details of this DYnamic POre-network SImulator for Two-phase flow (DYPOSIT) are given in [2, 3]. DYPOSIT model can simulate transient behaviour of flow for various capillary numbers and viscosity ratios.

In this study, we simulate primary and main drainage, main imbibition and several drainage and imbibition scanning curves for three pairs of fluids. These pairs of fluids will have viscosity ratios equal to 0.1, 1, and 10 under dynamic and quasi-static conditions. For all dynamic and quasi-static conditions we will calculate averaged capillary pressure (within an REV), and specific interfacial area (a_{nw}) for a given saturation (S_w).

Results of these simulations will provide Pc-Sw-anw data points under different dynamic conditions. Results obtained from quasi-static simulations will be used to generate P_c-S_w-a_{nw} surfaces for drainage and imbibition separately. The relative error between these surfaces will be used as a criterion for comparing with the surfaces obtained from dynamic simulations. Furthermore, P_c-S_w-a_{nw} surfaces will be created for drainage and imbibition data points resulted from dynamic conditions and the discrepancies between these surfaces and the average quasi-static surface will be calculated. This statistical analysis will show to what extent the capillary pressure, saturation, interfacial area surface are directly correlated under equilibrium and non-equilibrium conditions.

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[3] Joekar-Niasar, V., and S. M. Hassanizadeh (2010), Effect of fluids properties on non-equilibrium capillarity effects; dynamic pore-network modelling, International Journal of Multiphase Flow, doi:10.1016/j.ijmultiphaseflow.2010.09.007