Transient two-phase flow studies in a PDMS micro-model.

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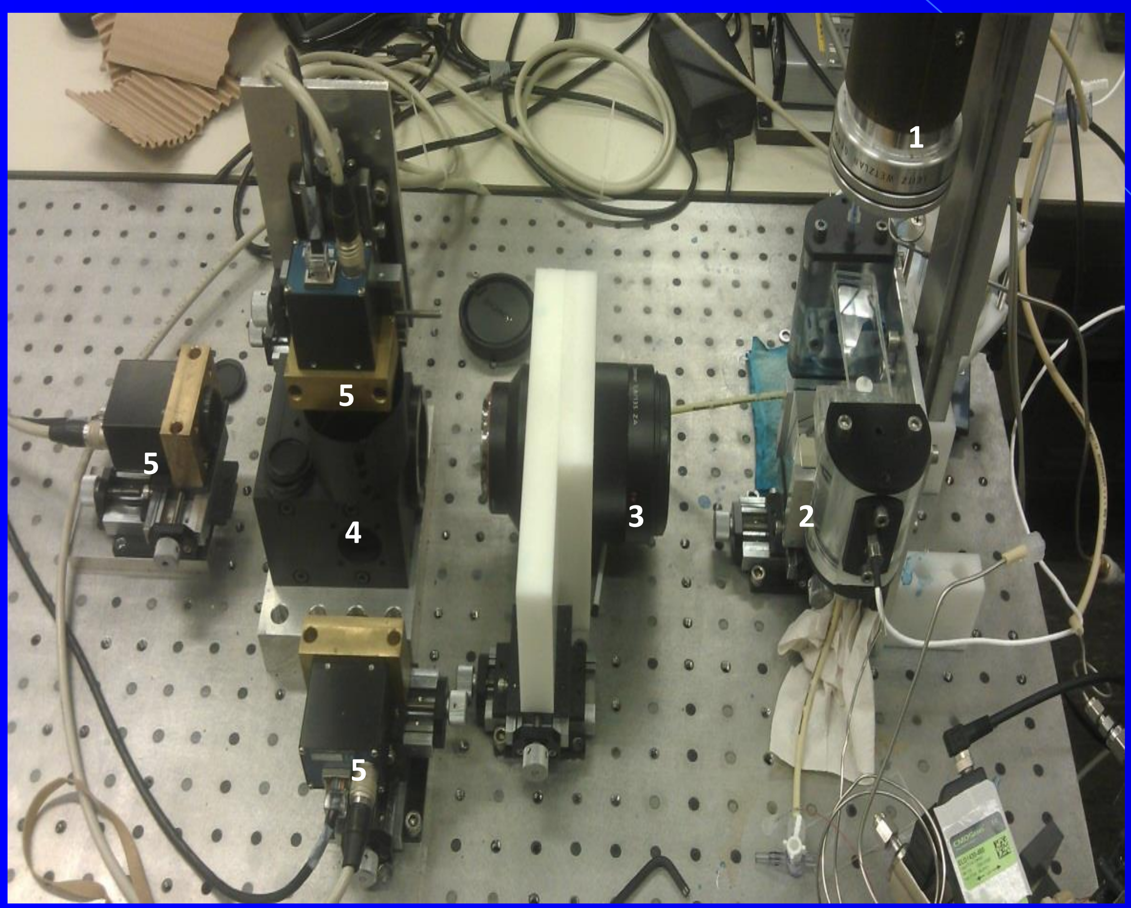
Introduction

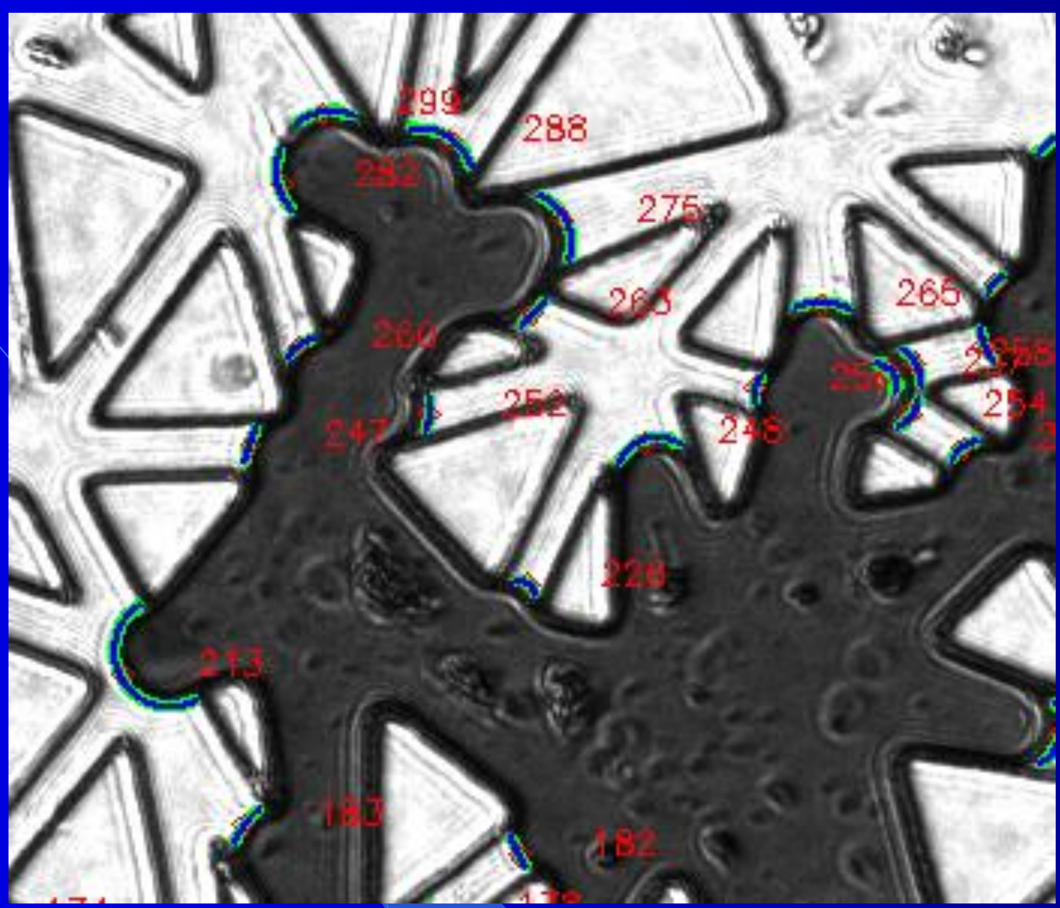
One of the constitutive relationships used in two-phase flow modeling, is the capillary pressure – saturation relationship. It is well known that this relationship is process dependent. One will obtain different capillary pressure – saturation curves for drainage and imbibition. This effect is called hysteresis. A theory derived by rational thermodynamics (Hassanizadeh and Gray, 1993a) suggests that the introduction of a new state variable, called specific interfacial area, can define a unique relation between capillary pressure, saturation, and specific interfacial area. Specific interfacial area is defined as the ratio of the total surface of the interfaces between the two-phases, over the total volume of the porous medium.

This study investigates the aspect of the capillary pressure – saturation relationship, as well as the relationship between capillary pressure-saturation and specific interfacial area, under transient conditions, with the use of an elongated, PDMS-made, micro-model. The experimental results show that the relationship between capillary pressure and saturation depends on the displacement process (drainage or imbibition). In addition to this, we provide experimental evidence to support the extended theories of two-phase flow, where specific interfacial area should be included as a separate state variable.

Experimental Setup

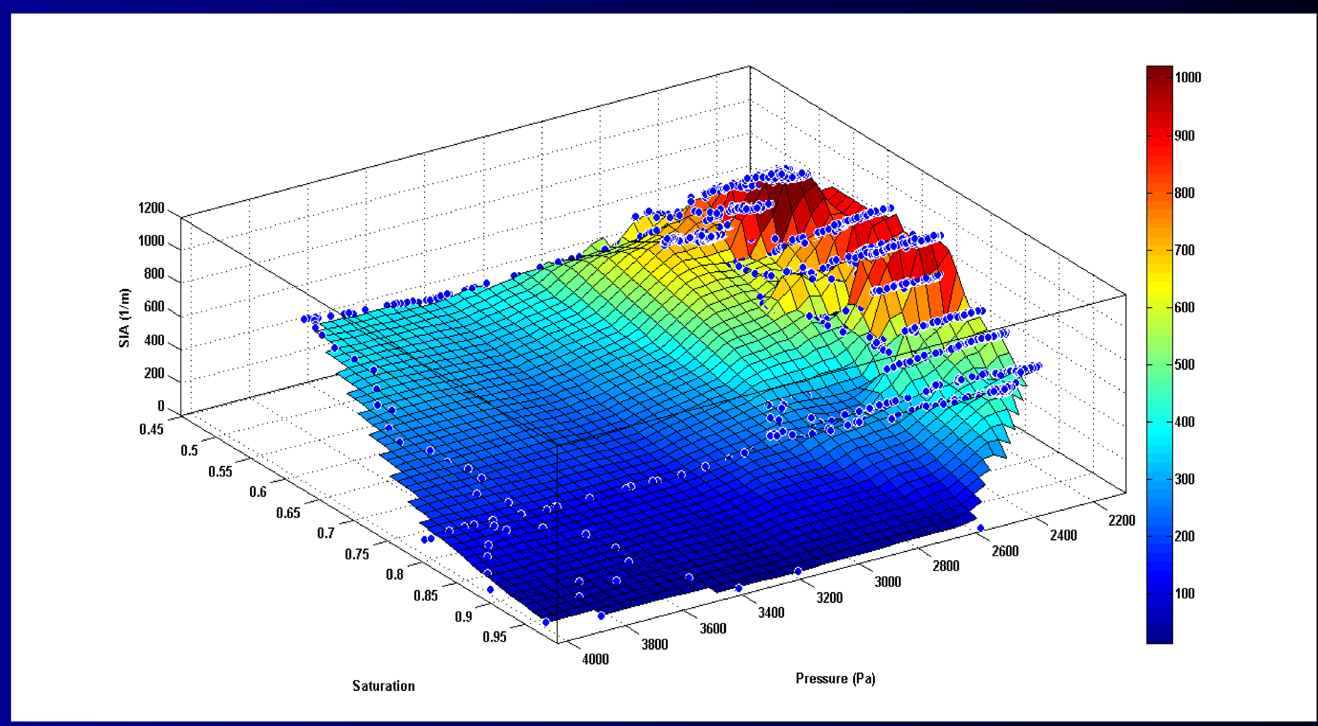


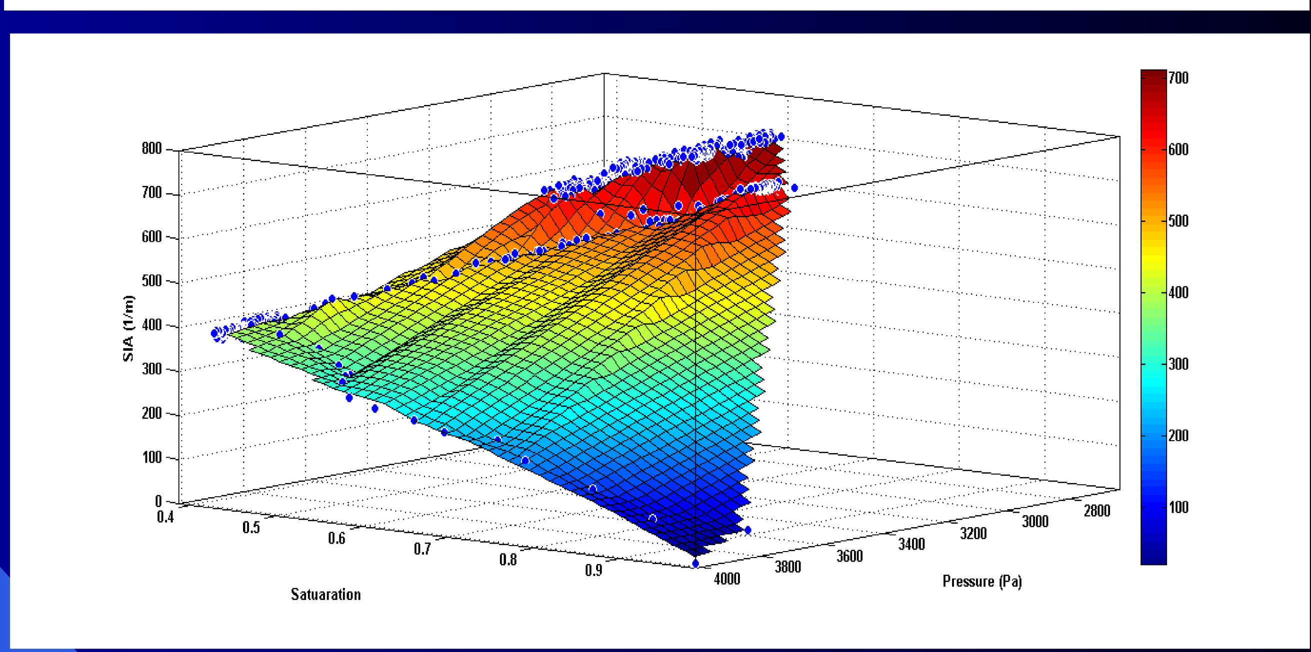
The optical setup for the visualization of flow through the micro-model. Components: 1) LED light source mounted with an objective lens. 2) Prism. 3) Magnifying lens. 4) Box with three beam-splitters. 5) High resolution CMOS cameras.



The wetting phase was Fluorinert FC-43 (colorless)
And the non-wetting phase was water dyed with ink. The interfaces were individually identified, and information on their position, curvature, chord length etc. was extracted

Capillary pressure-saturation-interfacial area surfaces were constructed for drainage and imbibition separately, as well as for all data points. The surfaces were plotted either with the use of interpolation between data points, or by fitting. For the fitting, second-order polynomial functions were used.





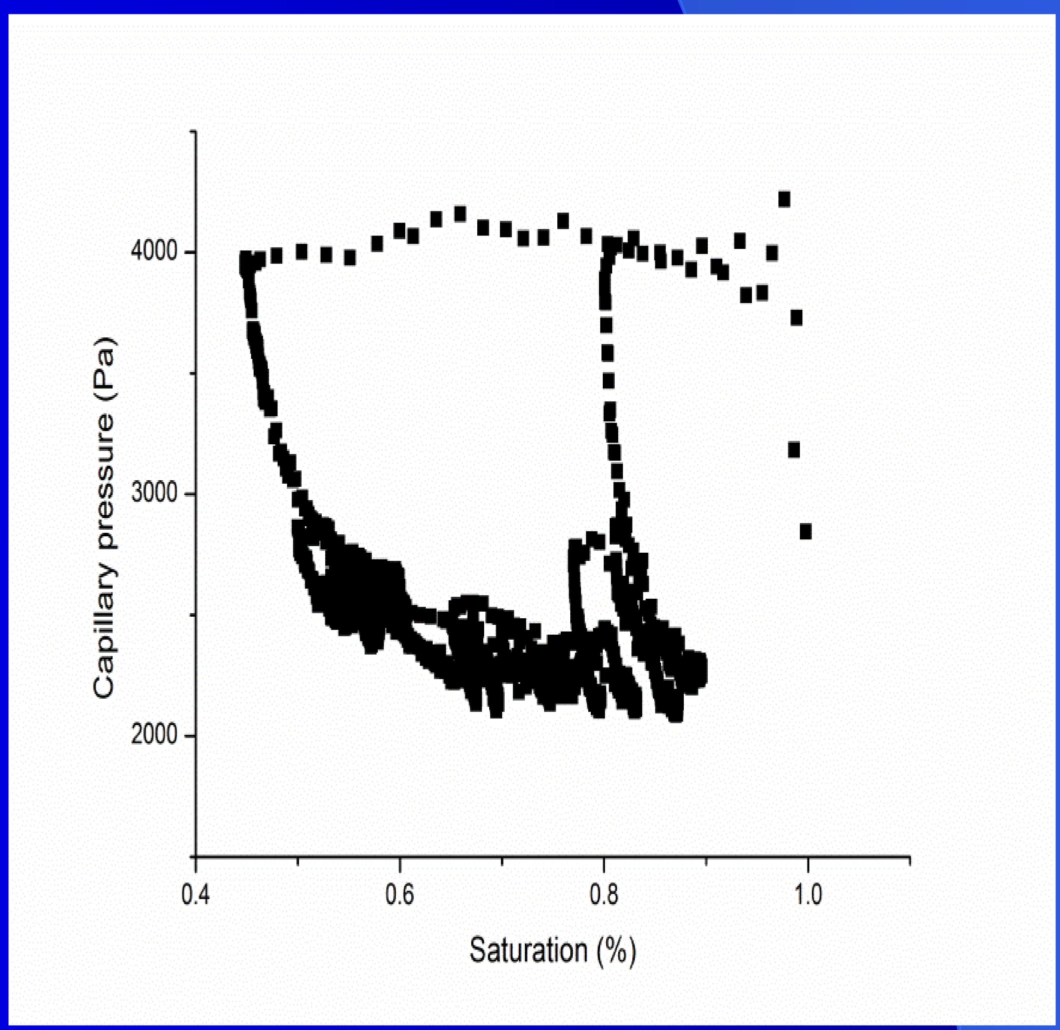
Capillary pressure-saturation-interfacial area surfaces for 6300 Pa (left), and 9500 Pa (right). Maximum values for capillary number were 2.10^{-5} and 6.10^{-5} respectively.

Experimental Procedure

Initially, the micro-model was fully saturated with the wetting phase (Fluorinert FC-43). The non-wetting phase (water dyed with ink) was introduced by increasing the pressure in the non-wetting phase reservoir. After breakthrough of the non-wetting phase the pressure was set to zero. This sequence was repeated several times, in order to obtain the scanning curves for drainage and imbibition. Two values for the externally applied pressure were used, namely 6300 Pa and 9500 Pa, for comparative purposes.

The image from the wetting-phase-saturated model was used as a reference. With the use of a code developed in IDL, local capillary pressure, phase saturation, as well as interfacial area could be calculated. Pc-S curves and Pc-S-Awn surfaces were constructed in order to investigate the significance of the inclusion of interfacial area as a separate variable.

Experimental results



Average capillary pressure plotted as a function of fluorinert saturation for primary drainage, main imbibition, and some scanning events.

Conclusion

This work is the first experimental work on the significance of the inclusion of interfacial area as a separate variable in two-phase flow under dynamic conditions. With the use of an elongated, PDMS-made micro-model, we have shown the validity of the hypothesis that capillary pressure- saturation-specific interfacial area data points form a unique surface for drainage and imbibition under transient flow conditions, and for given initial conditions. We have also shown that this surface is representative, within experimental error, not only for the whole flow network, but also for any area within the flow network with dimensions equal to 5 x 7 mm^2.
However, when this surface is compared to the surface obtained under equilibrium conditions, there is a mismatch between 25% and 40%, depending on the applied pressure. This means that one surface cannot describe well enough two-phase flow under dynamic and quasi-static.

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