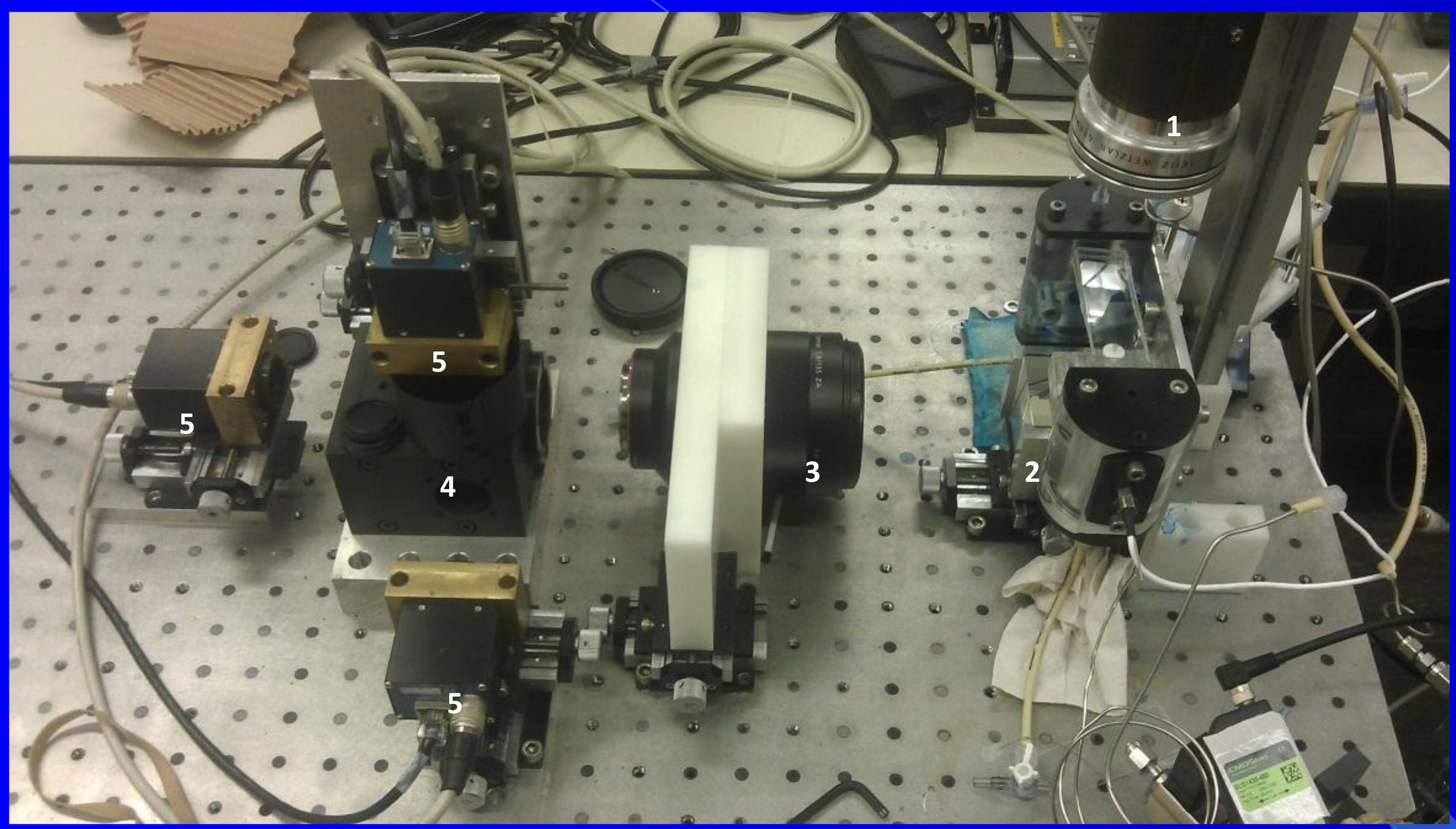
Two-phase flow studies in a micro-model. Interfacial area as a missing variable.

N.K. Karadimitriou, S.M. Hassanizadeh and P. J. Kleingeld.
Utrecht University, Earth Sciences Department, Faculty of Geosciences.
Budapestlaan 4, 3584 CD, Utrecht, The Netherlands.

Introduction

In order to investigate the significance of incorporating interfacial area as a separate variable in the governing equations of two-phase flow, an experimental setup was constructed to study and visualize two-phase flow in a micro-model under quasi-static. In this setup, a combination of lenses, three beam splitters, and four cameras were used to visualize flow in a two-dimensional micro-model. A PDMS micro-model with 3000 pore bodies and 9000 pore throats has been used. The mean pore size of the flow-network was 40 μm. With the use of four identical cameras equipped with CCD sensors, we visualized the distribution of phases in the micro-model. The size of the flow network was 5 mm x 30 mm^2. Given the overall size of the flow network and the pixel size of the camera sensors, a resolution of 2.8 μm per pixel at any given instant was obtained. This resolution ensured that the whole flow network could be visualized, and that there would be enough pixels to accurately visualize the distribution of phases in the flow network. We performed drainage and imbibition experiments under quasi-static conditions, and the results for capillary pressure, saturation, and interfacial area are presented and analyzed.

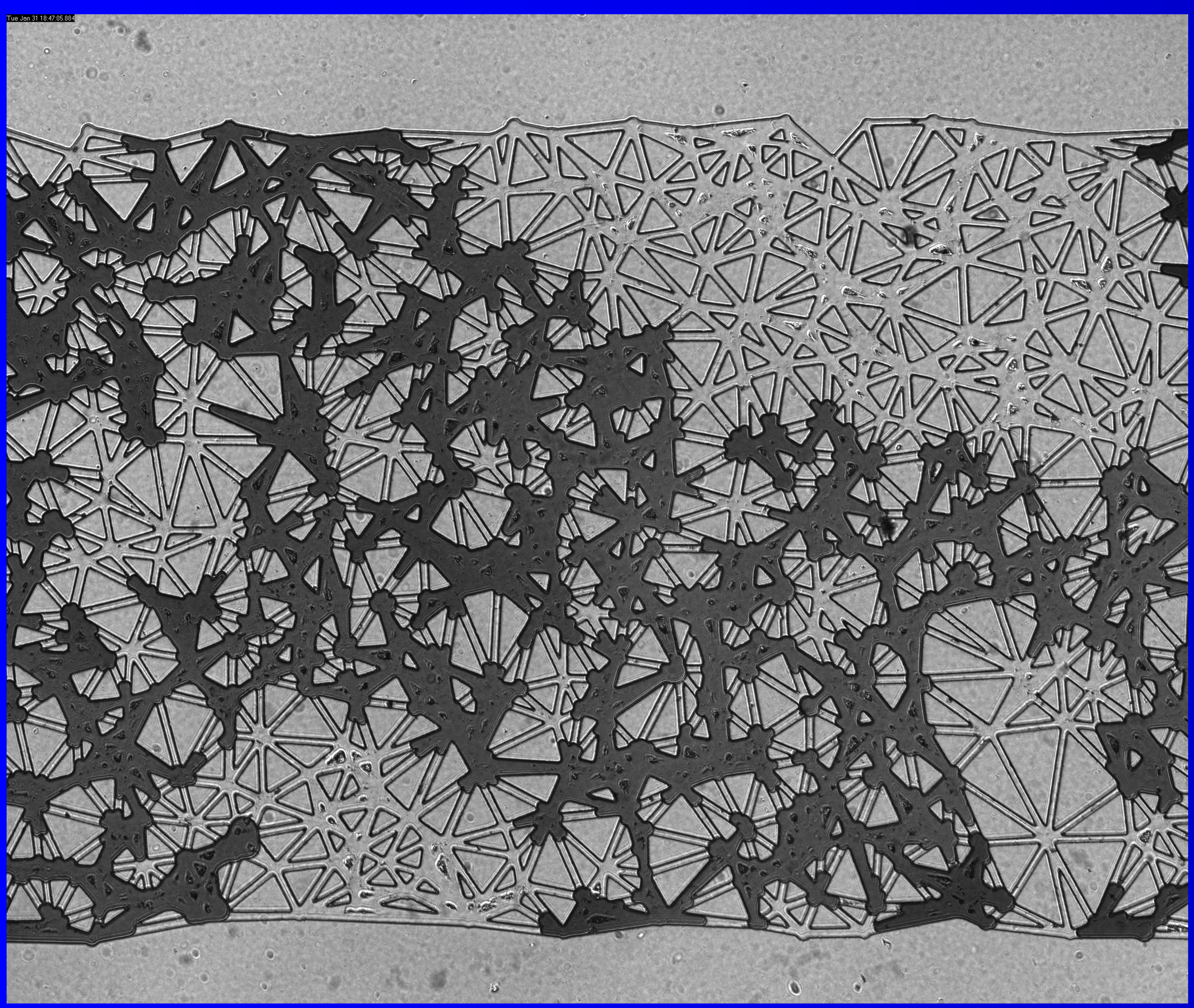
Experimental Setup



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.

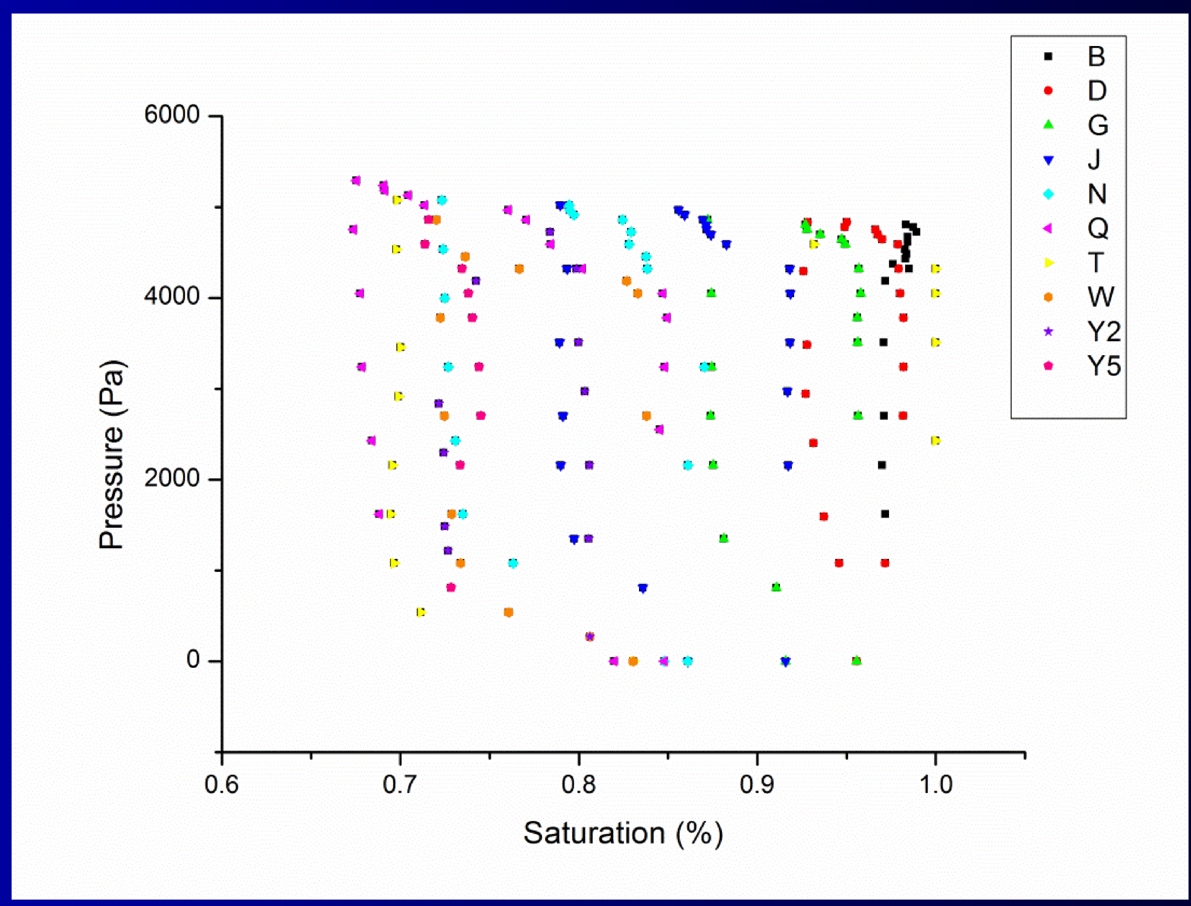
Experimental procedure

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. The beam splitters produced four identical images of the flow network at a magnification factor of 1.28. Each camera focused on a different area of the flow network and monitored an area of 5 mm x 7.8 mm at a resolution of 2.8 μm/pixel. In total, an area of 5 mm x 31.2 mm was monitored at all times. In the same time, the pressure difference between the inlet and the outlet of the micro-model was being recorded.



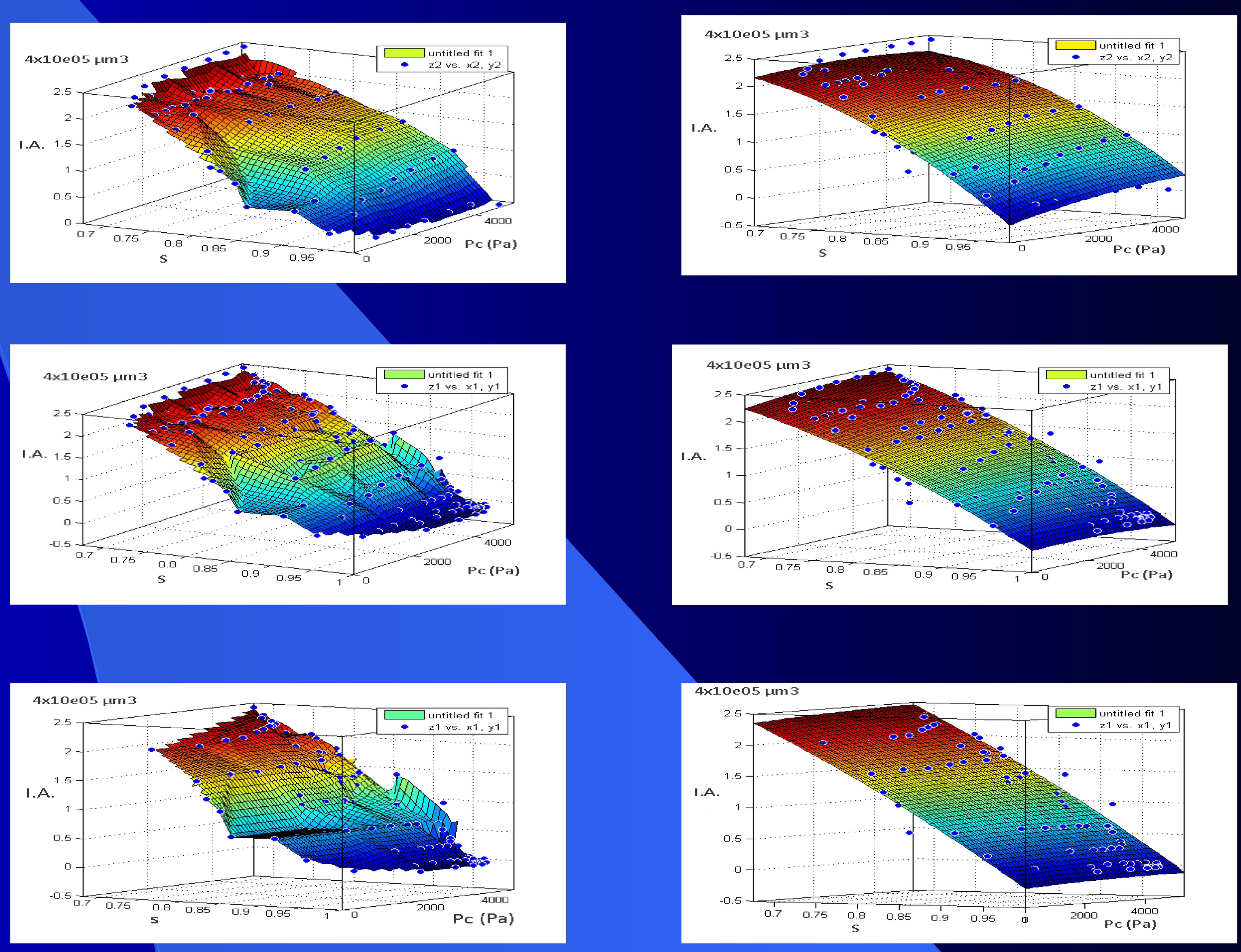
The image from the wetting-phase-saturated model was used as a reference. With the use of a code developed in IDL, phase saturation, as well as interfacial area could be calculated.

Experimental results



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

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.



The relative difference between the fitted surface for drainage and the common surface was found to be equal to 4.7%, while the relative difference between the fitted surface for imbibition and the common surface was found to be equal to 5.8%. The relative difference between the mean fitted surface for drainage and imbibition and the common one was found to be equal to -1.98%.

Conclusion

We have shown that the inclusion of interfacial area as a separate variable can be used to eliminate the hysteresis observed in capillary pressure-saturation measurements in two-phase flow. A single surface constructed by the experimental measurements can be used to estimate interfacial area for any given pair of capillary pressure and saturation

Acknowledgement

Special thanks to Prof. Mike Celia for very useful discussions and comments.