Two-phase flow comparative studies. Pore network model versus experiment.

N.K. Karadimitriou*, V. Joekar-Niasar, S.M. Hassanizadeh and P. J. Kleingeld.
Utrecht University, Earth Sciences Department, Faculty of Geosciences.
Budapestlaan 4, 3584 CD, Utrecht, The Netherlands.
*Corresponding author: N.K.Karadimitriou@uu.nl

Introduction

Pore network modeling is one of the most powerful tools that can be used in order to simulate multi-phase flow in a porous medium. However, the experimental verification of pore-network models needs to be present in order to evaluate the numerical models. In this work, a pore-network model based on Delaunay triangulation has been developed in order to simulate two-phase drainage and imbibition in a two-dimensional micro-model. The same pore network has been used to design the flow network of a real representation of a porous medium, a micro-model. Quasi-static numerical and real experiments have been conducted and the results were compared in order to test the validity of the numerical model and to calibrate the parameters of the experimental setup.

Pore network model

The pore network was based on Delaunay triangulation. A number of networks, with different numbers of pore bodies and pore throats were put to test. The entry capillary pressure of a pore throat was determined from the following equation:

$$P_c^{entry} = \sigma^{nw}\left(\frac{-(a+b)\cos\theta + \sqrt{(a+b)^2\cos^2\theta + 4ab(\frac{\pi}{4} - \theta - \sqrt{2}\cos\theta(\frac{\pi}{4}+\theta)\cos\theta)}}{4(\frac{\pi}{4} - \theta - \sqrt{2}\cos\theta(\frac{\pi}{4}+\theta)\cos\theta)}\right)^{-1}$$

where σ^{nw} is the interfacial tension between phases, *a* and *b* are the width and the depth of the throat respectively and θ is the contact angle between the fluid-fluid interface and the solid surface.

Micro-model setup

In order to experimentally investigate two-phase flow, a glass-etched micro-model with dimensions of 5x35 mm², 3000 pore bodies and approximately 9000 pore throats was constructed. The mean pore size in the micro-model was 70 μm and its depth was 43 μm. In figure 1, the micro-model can be seen. The fluids used in our experiments were water dyed with ink, as the wetting phase, and fluorinert as the non-wetting phase

Figure 1: Picture of the micro-model

In order to visualize flow through the micro-model, an innovative visualization setup was employed. This setup consisted of a collimated light source, a prism, an objective lens, three beam-splitters and four cameras. The externally applied pressure was measured and controlled by a differential pressure controller. The cameras and the pressure controller were connected to a computer for data acquisition and processing. In figure 2, the overall view of the experimental setup can be seen.

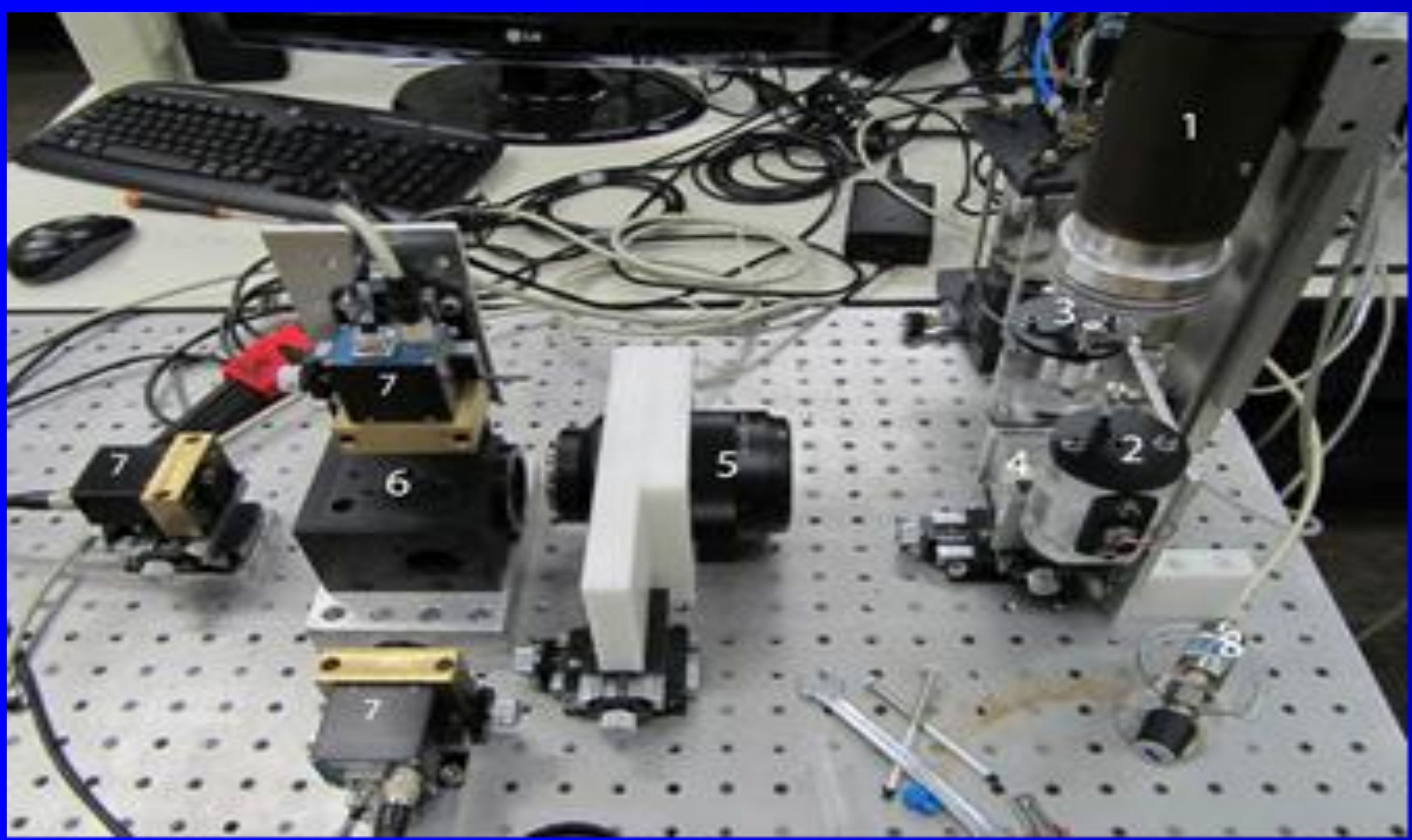

Figure 2. Picture of the experimental setup. Main components are: 1) Illumination, 2) Wetting phase reservoir, 3) Non-wetting phase reservoir, 4) prism, 5) lens, 6) box with beam-splitters, 7) cameras, 8) leak valve.

Results

Using numerical results for capillary pressure, saturation, and interfacial area, Pc-S-awn surfaces were constructed for drainage and imbibition. Results are shown in figures 3a and 3b.

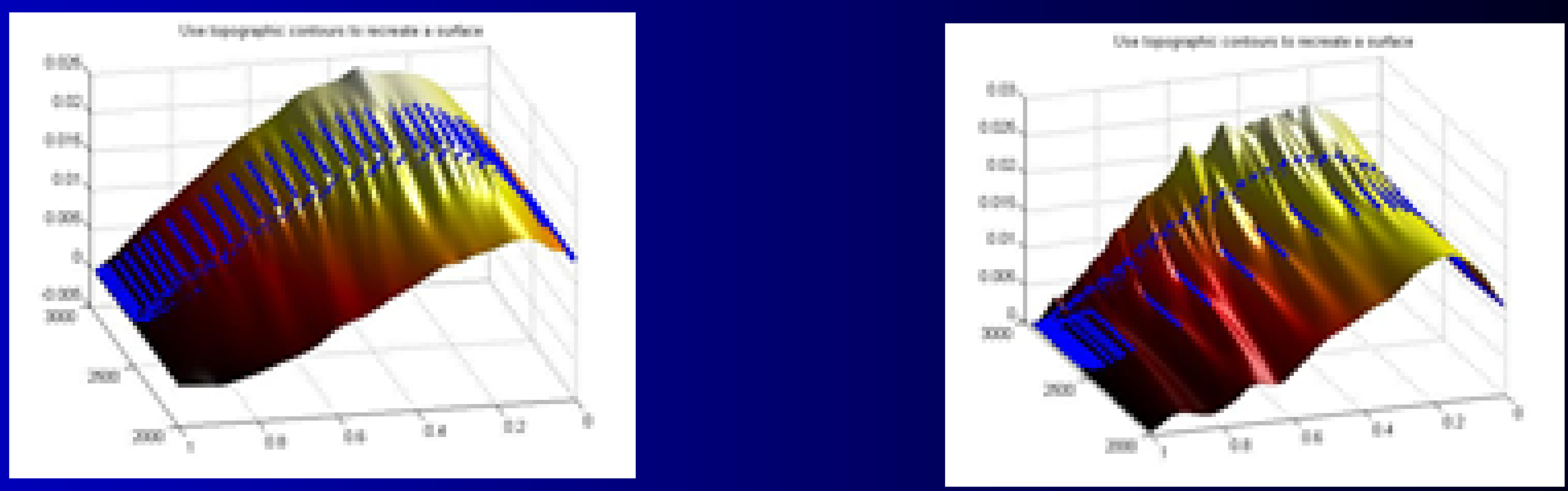

Figure 3. Pc-S-awn surfaces for imbibition (a) and drainage (b).

The relative difference between the two surfaces was found to be around 10%. By changing the number of pore bodies, or the distribution of sizes of the pore bodies in the network, the difference could be reduced to 2%.

Images were acquired from the micro-model during drainage, under quasi-static conditions. From these images, the saturation of each phase could be determined. In this way, the Pc-S curve could be constructed. This curve can is shown in figure 4. No Pc-S-awn surfaces are yet available, as that requires performing many (scanning) imbibtion and drainage experiments, which have to be carried out yet.

Discussion-conclusion

The resulting curve is compared with the Pc-S curve obtained from numerical simulations, as shown in figure 4. Clearly there is a good agreement. It must be mentioned that some tuning of the parameters employed in the numerical model, like the variance and the mean value of the log-normal size distribution, was done in order to improve the agreement with experimental results.

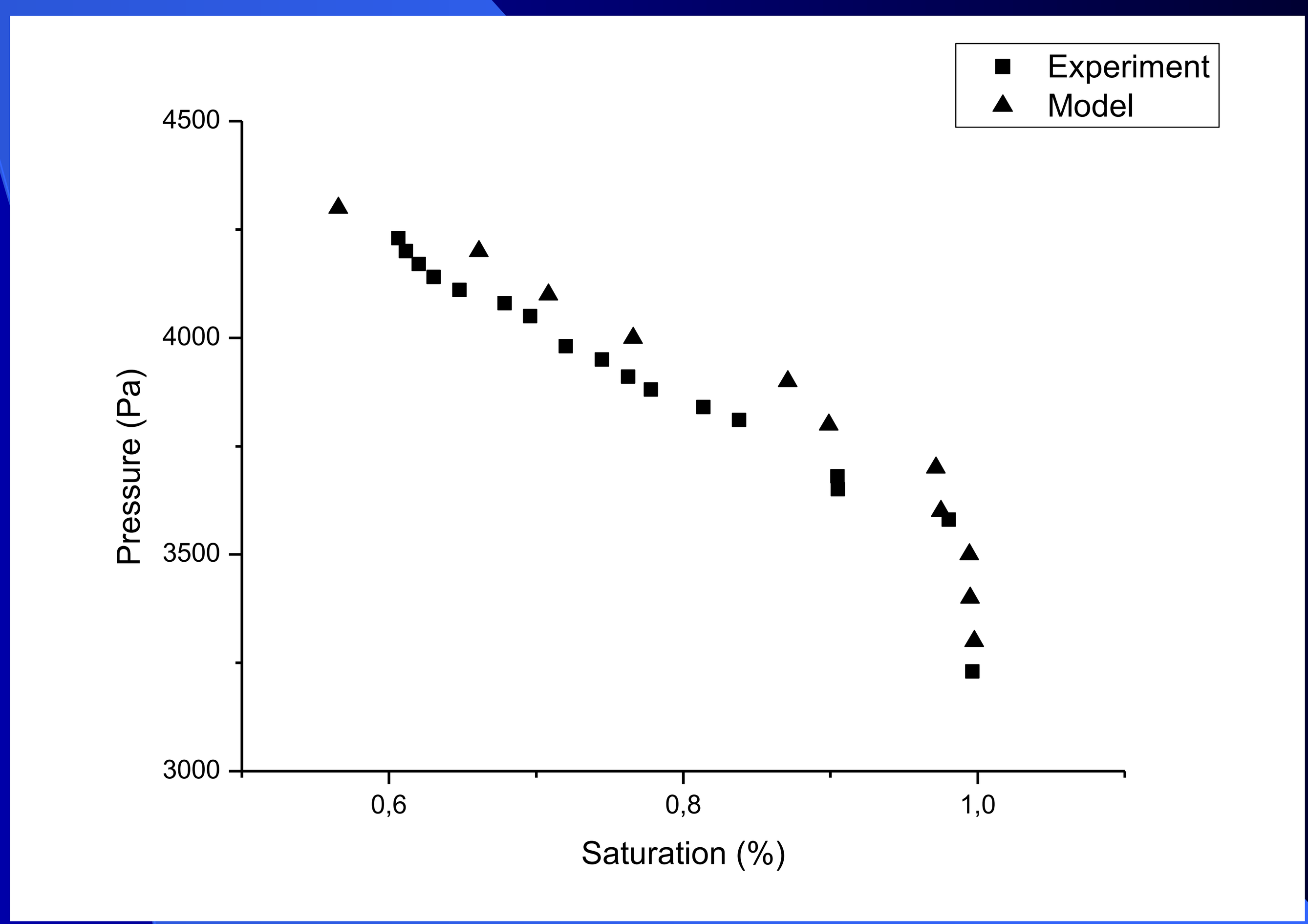

Figure 4. Pc-S curves for numerical model and experiment.

This agreement verified that the numerical model represents the micro-model adequately. In future work, transient two-phase flow experiments will be performed in order to test the applicability of the new extended theories of two-phase flow.

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