Pore-scale Visualization of Colloids Transport During Two-phase Flow in A Micro-model

Qiulan Zhang[a], S.M. Hassanizadeh[a], N.K. Karadimitriou[a], P.J. Kleingeld[a], and Arnout Imhof[b]

[a] Environmental Hydrogeology Group, Earth Sciences Department, Utrecht University

[b] Soft Condensed Matter, Debye Institute, Utrecht University

Introduction

- Colloids can serve as carriers and facilitate contaminant transport through the vadose zone to groundwater.
- Visualization of colloids transport, retention, and mobilization in unsaturated porous media is needed for a better understanding of these mechanisms.
- PDMS micro-models were designed and used to study of colloids transport, during two-phase flow.
- The main objective of this study was to directly observe colloids transport, and retention at interfaces (solid-water, water-fluorinert, water-fluorinert-PDMS contact line) using a confocal laser microscope.

Pore-scale Experiments

Pore-scale experimental system included the following main components:
A) Injection assembly (A reversal syringe pump; two syringes; three selection valves; bulk reservoirs for fluorinert, water, and colloids); B) Imaging system (a laser confocal microscope, with a 63×oil immersion objective); C) the PDMS micro-models (detailed information as in the following box); D) colloids (carboxylated fluorescent yellow-green microspheres, with an average diameter 300nm).
The experimental set-up is showed in Fig.1.

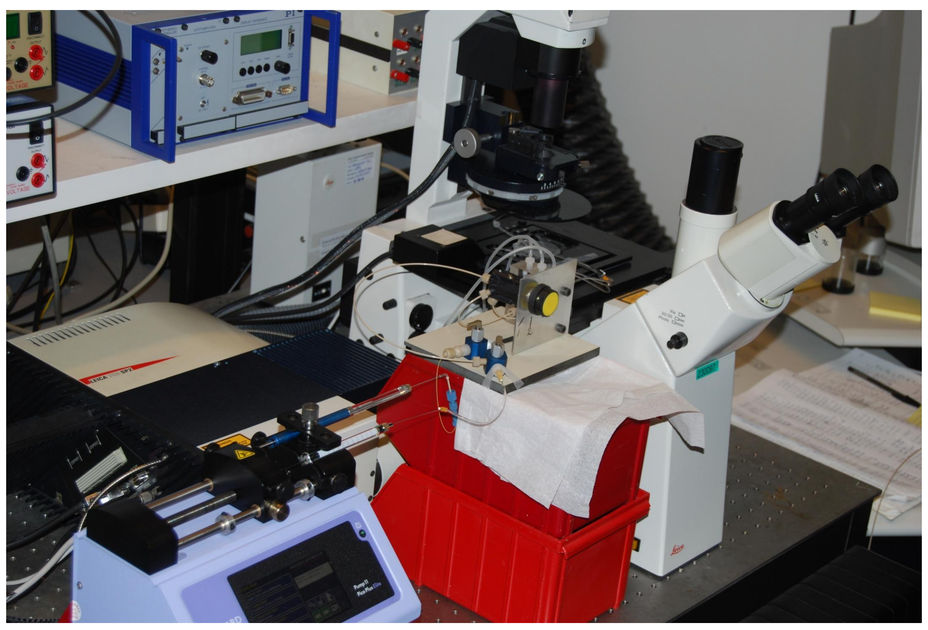

Fig.1 Experimental set-up.

Micro-model

The structure of the micro-model is shown in Fig. 3 with a magnified part in Fig. 2.
(1) The three inlet reservoirs are for wetting phase, non-wetting phase, and colloids suspension;
(2) The flow network dimensions are 1×10 mm;
(3) The flow network has 30 pore bodies and roughly 50 pore throats;
(4) The mean pore size around 30 μm;
(5) The micro-model was hydrophobic;
(6) Fluorinert was the wetting phase and water was the non-wetting phase.

Fig.2 Flow network of the micro-model under microscope.

- Static fluorinert water two phase flow experiments were performed.
- Pure fluorinert was injected into the micro-model for an extended period to expel the gas, then the diluted colloids water suspension was introduced uniformly in the model to some water content to generate a fluorinert-water interface.
- Once the interface was created, sequential still images were taken at correspond positions by confocal microscope.
- Particles behaved similarly during the repeated experiments.
- In the images, fluorescent particles are seen as green dots.

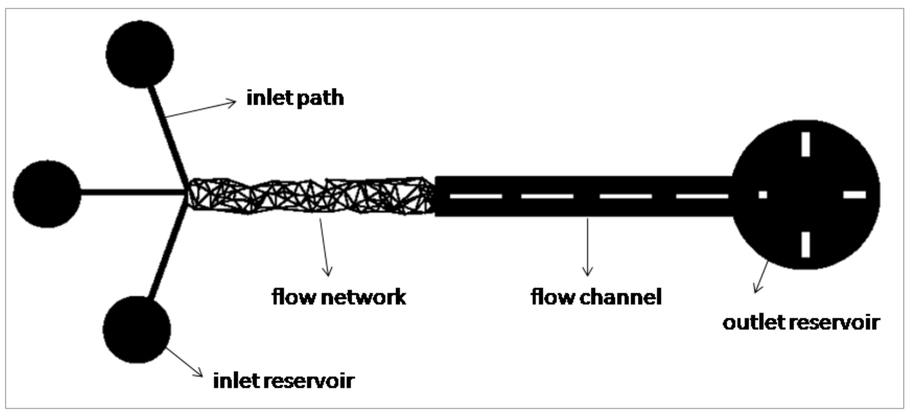

Fig.3 Schematic representation of the micro-model.

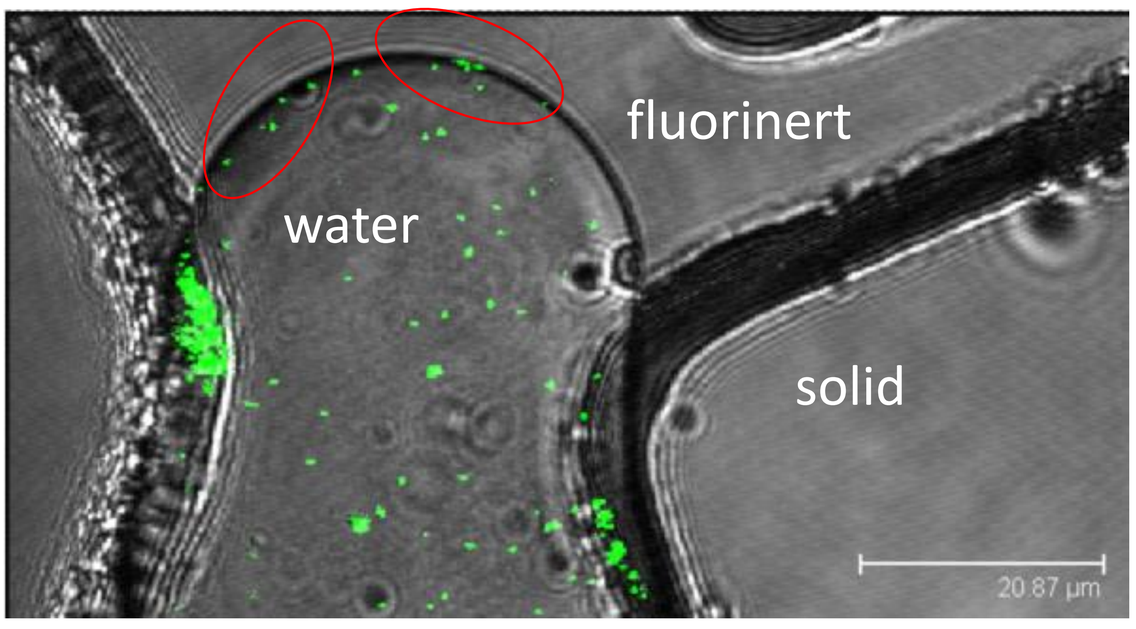

Fig.4 Confocal image of colloids transport in the fluorinert-water two phase system.

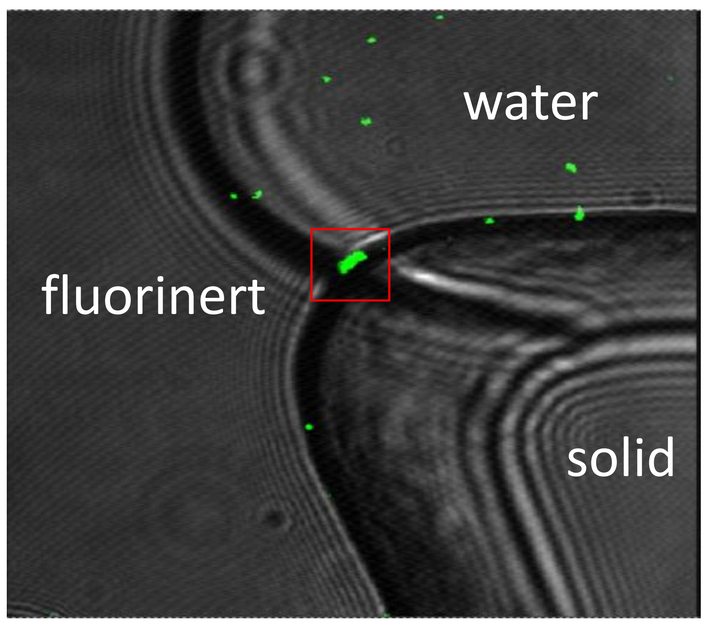

Fig.5 Colloids retention at the AWS contact line.

Future Work

Currently visualization experiments of colloids transport during transient hydraulic conditions (drainage/imbibition) are on the way to quantify the mobilization of colloids with the moving AWIs and AWS.

Results and Conclusions

(1) Apart from the dispersed colloids in water, retention of colloids at the AWI (as showed in Figure 4) and AWS contact line (showed in figure 5) were clearly observed with confocal microscope.
(2) Colloids retention on the SWIs were not uniform but in forms of clusters, this is in agreement with Zevi et al. (2009). Perhaps the roughness of the surface has a significant effect on colloids retention.
(3) The obtained images confirm the usefulness of PDMS micro-models combined with the confocal microscope in the study of colloids transport.

References

Zevi, Y., A. Dathe, B. Gao, W. Zhang, B.K. Richards, and T.S. Steenhuis. 2009. Water Resources Research.