Pore-Scale Modeling of Immiscible Two-Phase Flow in Predominantly 2D Microfluidic Porous Domains

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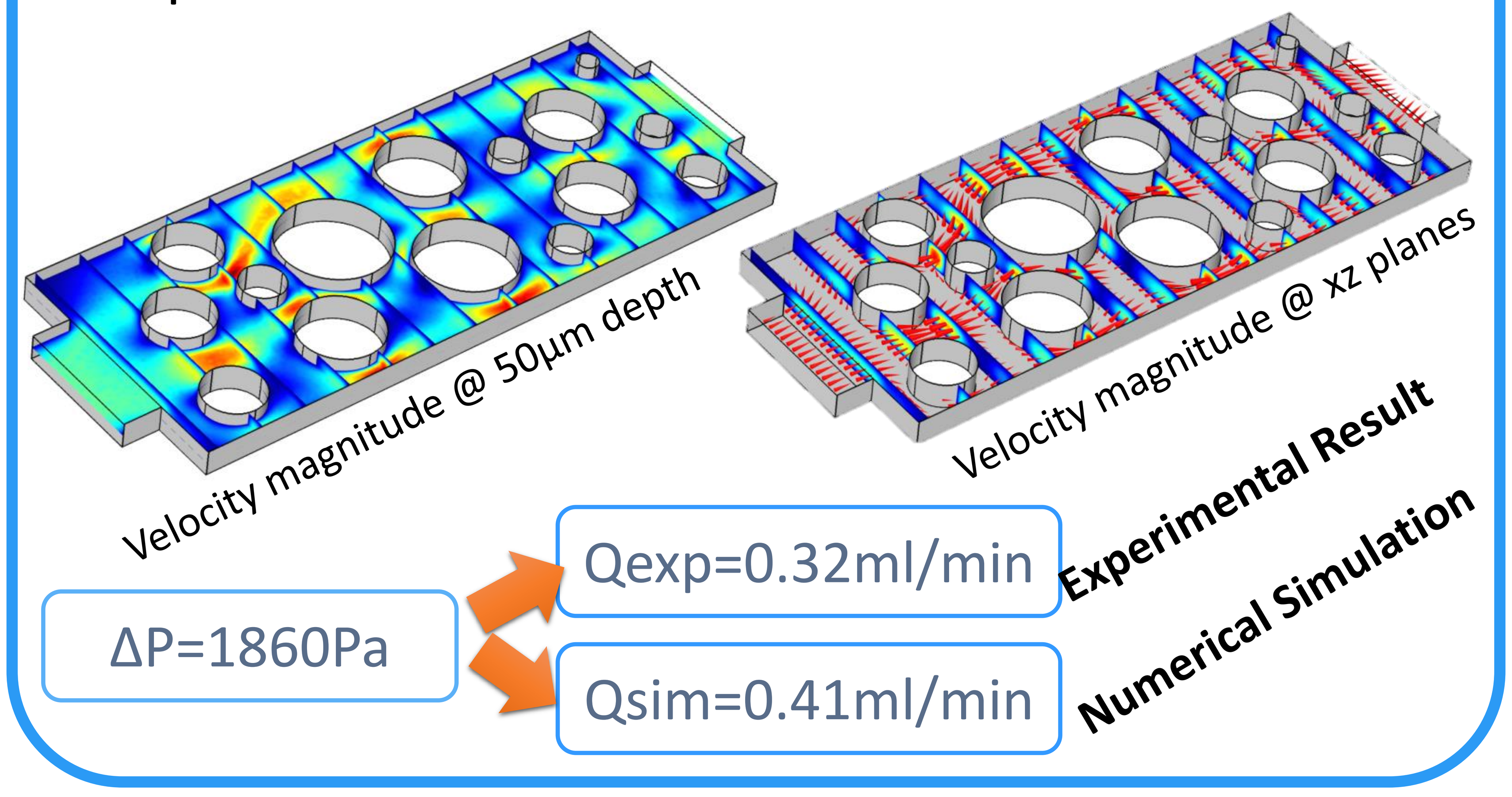
Introduction

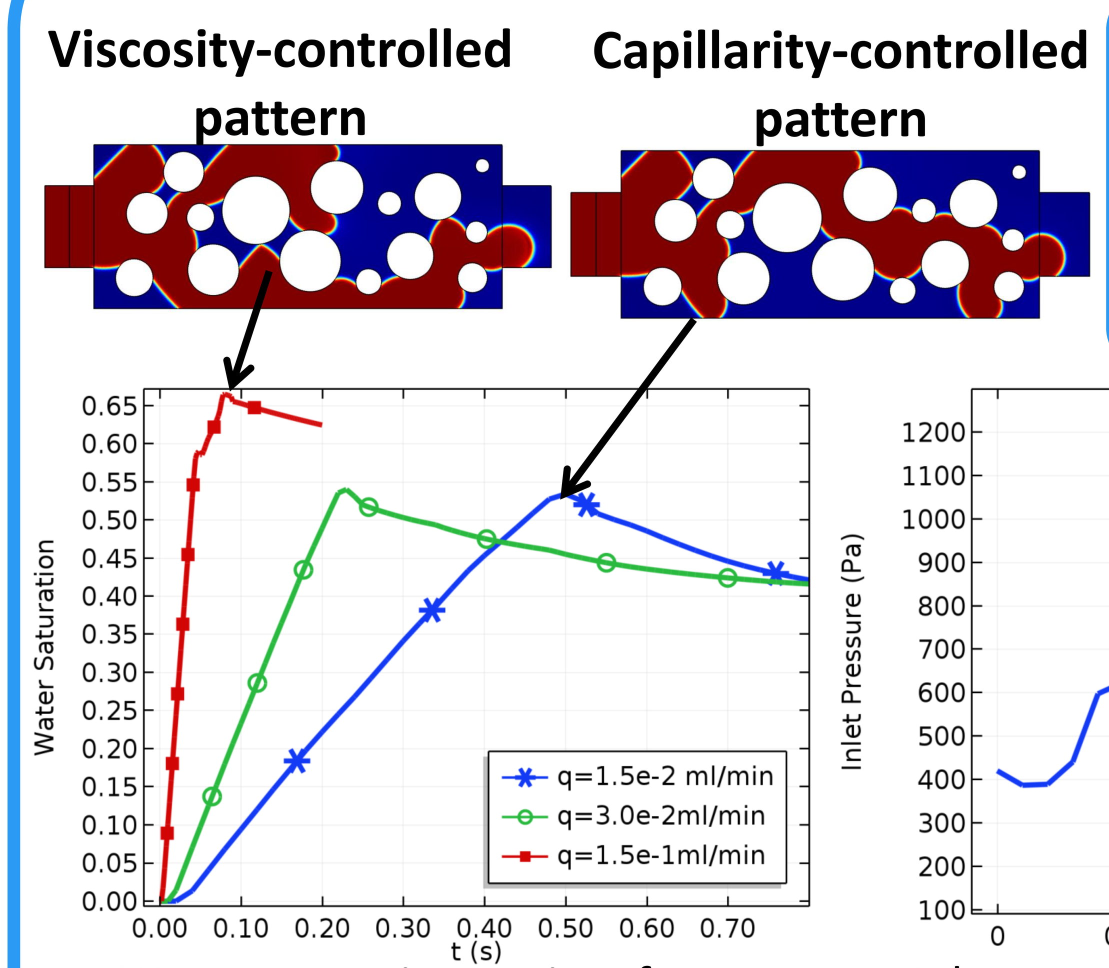
We study the dynamics of immiscible two-phase flow in a microfluidic device that consists of randomly distributed cylindrical obstacles to "mimic" flows within the tortuous space of macroporous geological porous media (e.g. soils, fractured rocks etc). The flow problem is solved in a reduced-order 2D computational domain using the Level-Set method, assuming a negligible effect of domain's depth on the interfacial dynamics and a fixed contribution of the z-direction on the capillary pressure drop across the interface. The computational results are then compared to experimental results obtained using an actual 3D microfluidic device by the Enviromental Hydrogeology Group of Utrecht University

Single phase flow 3D simulations

Initially, we employ the Laminar flow Physics Interface of COMSOL Multiphysics® in the actual 3D device (2.5 x 1.0 x 0.1mm^3) using the Inflow/ Outflow approximation in the 2.5mm inlet/outlet channels to compare flow rates for fixed ΔP



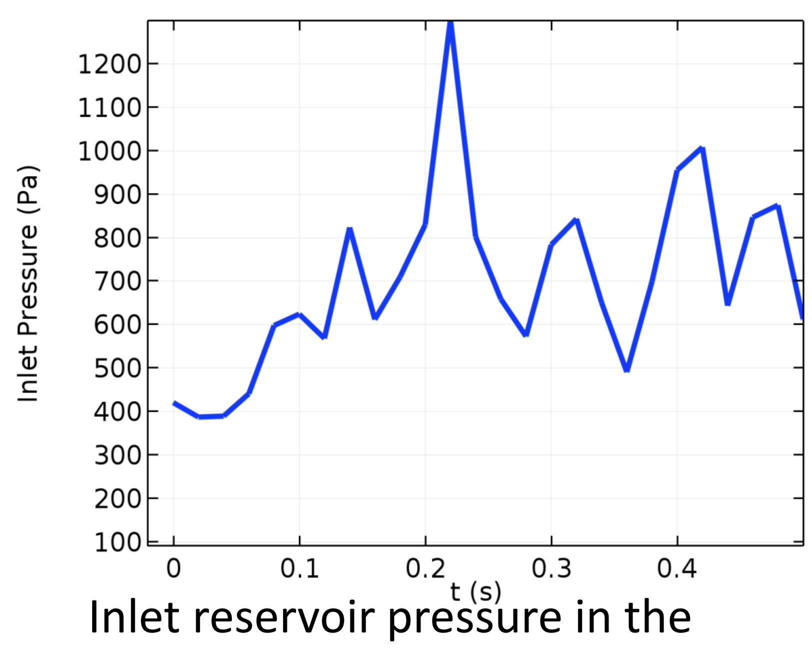
From capillarity to viscous-controlled 2-phase flow



Capillary Number = Viscous/Capillary forces

$$Ca = \mu u/\gamma$$

Water saturation vs time for various fixed flow rates

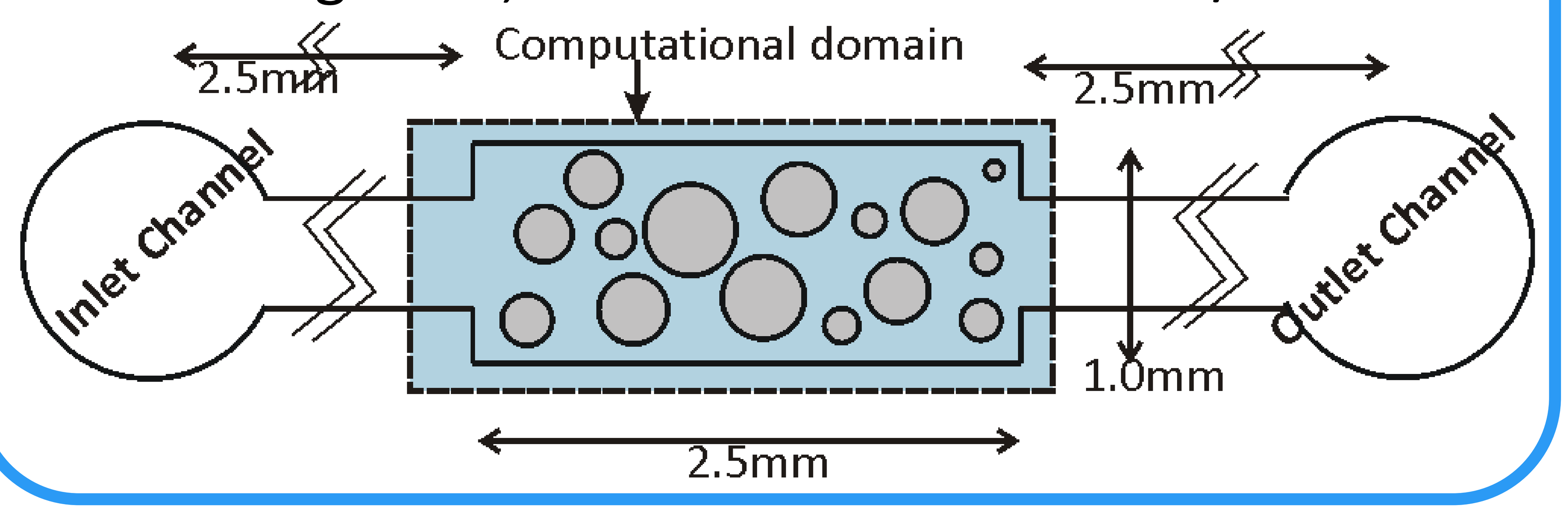


Inlet reservoir pressure in the capillary regime, q=1.5e^{-2} ml/min

Experimental Setup

The microfluidic device is of size 2.5 x 1.0mm^2 (central area) and depth 0.1mm. The device is initially saturated by Fluorinert (wetting fluid, ρ=1800kg/m^3, μ=4.7 mPa*s) and died water (ρ=1000kg/m^3, μ=1 mPa*s) is injected from the inlet channel (0.5mm x 0.1mm cross-section, 2.5mm long)

Contact angle 45˚, interfacial tension 55mN/m.



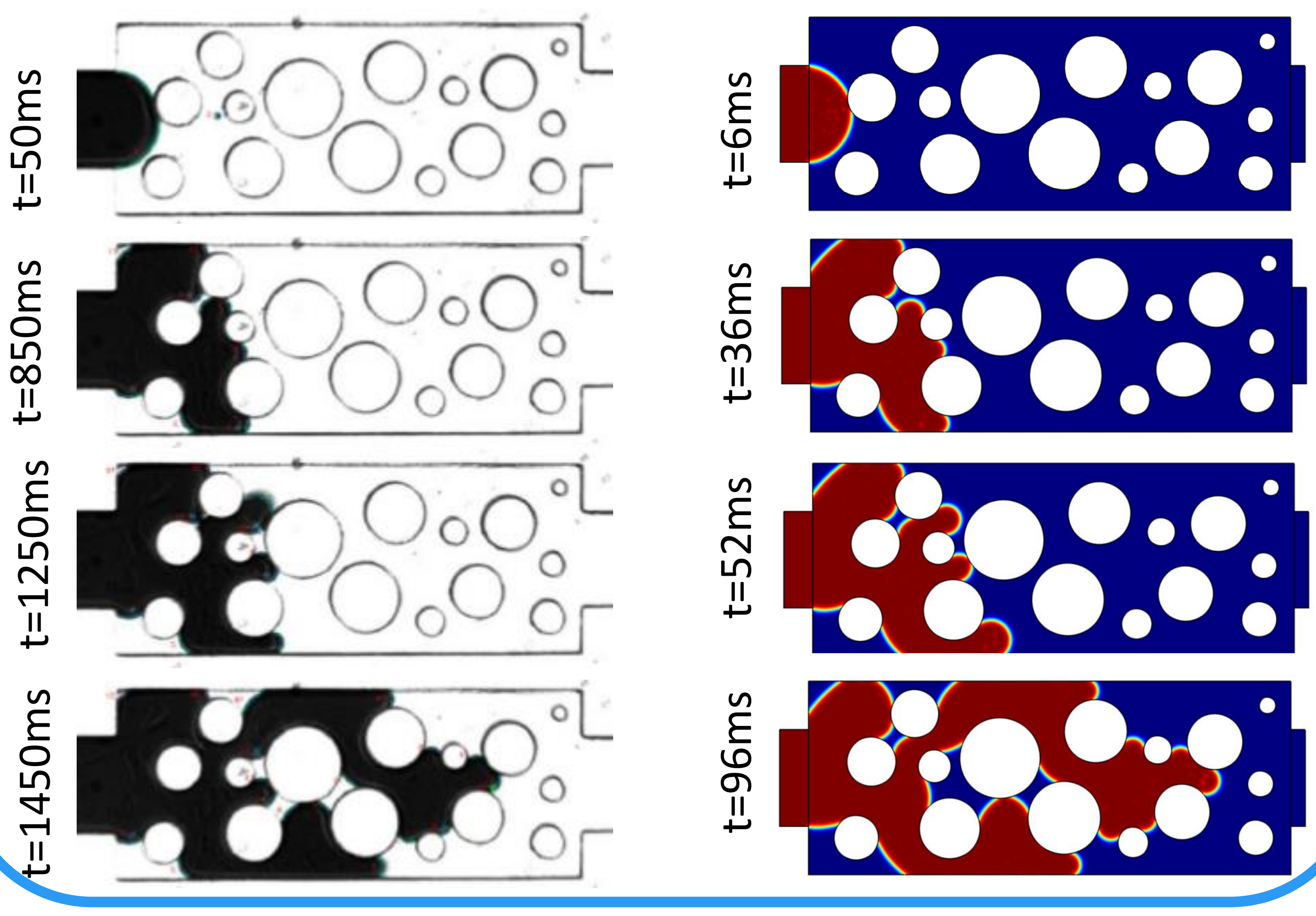
2-phase flow 2D simulations- Comparison w. Experiments

We employ the coupled Level-Set and Laminar flow Physics interfaces to solve for immiscible 2-phase flow in a simplified 2D domain.

Assumptions:

- Constant wetting angle θ=0.2π, Fixed ΔP
- Fixed capillary pressure drop due to the depth
- Shallow channel approximations for viscous flow

Experimental Result, ΔP=1860Pa **Simulations,** ΔP=2290Pa



Results-Discussion

- Efficient description of 2-phase flow dynamics using both Level-set and Phase-field interfaces
- Saturation profiles compare very well with experimental results
- Differences in actual time scale could be due to order reduction (3D -> 2D) and microroughness

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2. Karadimitriou N.K., Musterd M., Kleingeld P.J., Kreutzer M.T., Hassanizadeh S.M., Joekar-Niasar V., Water Resources Research, 49, 2056-2067 (2013)