COMSOL CONFERENCE 2014 CAMBRIDGE

Pore-level Influence of Contact Angle on Fluid Displacements In Porous Media

H. A. Akhlaghi Amiri [1]

1. University of Stavanger, Department of Petroleum Engineering, 4036 Stavanger, Norway.

University of Stavanger

Introduction: Flow instabilities (fingering) of the displacing phase is the major cause for inefficient immiscible displacements in porous media. Understanding the morphology of the observations is always challenging. The macroscopic transport of the fluids is predictable provided that the pore-level physics of the phenomena is sufficiently understood. One of the factors which impact the flow regimes in porous media is wettability.

Medium wettability affects the displacement by determining the microscopic distribution of fluids in pore-spaces. A deeper understanding of wettability effects demands pore-level investigations which are still limited. The degree of wettability is usually related to contact angle (Θ), which is a boundary condition in determining the interfacial shape. A grain surface is generally considered water wet if and oil wet if .

This paper addresses two phase flow in 2D uniform porous media simulated using coupled Navier-Stokes and Cahn-Hilliard phase field method (PFM). PFM was selected since it is able to realistically capture phenomena related to viscous and capillary forces with a reasonable computational time, compared to other methods such as level set method. The equation system was solved by COMSOL Multiphysics® with finite element method. Adaptive interfacial mesh refinement was used to reduce the running time. The developed method was validated using non-isothermal Poiseuille flow through a channel, and the results showed good accuracy compared to analytical solution. It is then used to address pore-scale water-oil displacements for investigating the effect of contact angle on the flow patterns and fluid saturations and pressure.

Model description: The governing equations were supplemented by standard boundary conditions (e.g., inlet, outlet, no-slip, wetted wall and symmetry). On the solid grains, wetted wall was implemented with different contact angles. To avoid numerical distortions, the interface was thin enough to approximate a sharp interface. The interface layer, was also resolved by fine mesh, using interfacial adaptive mesh refinement technique.

A uniform medium with the dimension of 0.015×0.009 m^2 was simulated, in which the grains were represented by equilateral triangular array of circles (Figure 1). The bulk grain diameter and pore throat diameter were set as 0.001 *m* and 0.00015 *m*, respectively. The homogeneity of the medium was slightly disturbed by enlarging the diameter of ten randomly distributed grains by 10%. The grain surfaces were defined as wetted walls having a certain contact angle. Oil in the medium was displaced by water, injected through inlets on the left hand side of the medium. Water was injected with constant velocity (u_{inj}). The pressure is assumed to be zero at the outlets on the right hand side of the medium. Capillary number is defined as $\mu_w \times u_{inj}/\sigma$. *Ca* and viscosity ratio (*M*) quantify fluid characteristics and determine the types of flow instabilities in absence of gravity forces.

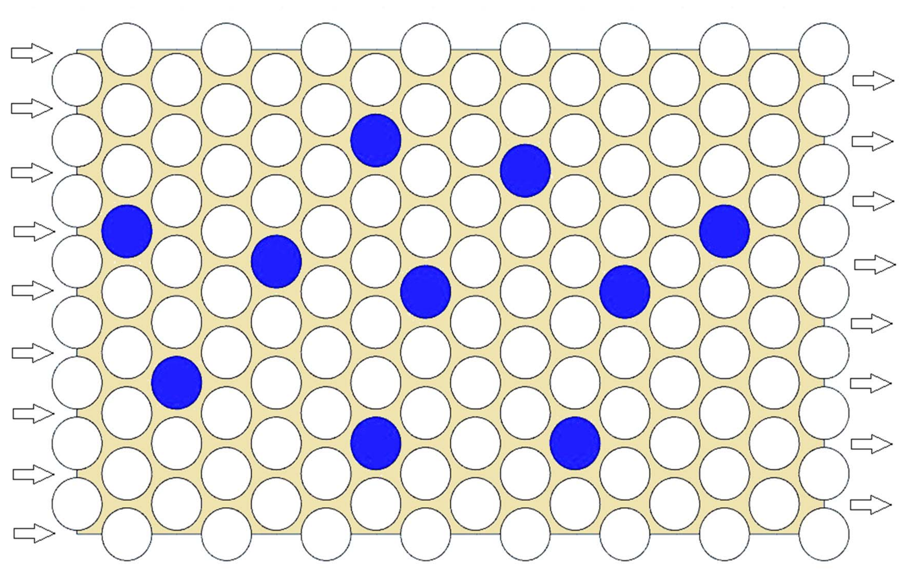

Figure 1. Schematic of the simulated medium. Marked blue circles are the enlarged grains by 10%.

Results: Figure 2 shows the fluid distributions after stabilization for different values of contact angles, corresponding to strongly water wet, water wet, intermediate wet oil wet and strongly oil wet conditions, respectively. The water fingers become thinner as the medium becomes less water wet, as shown in Figure 2.

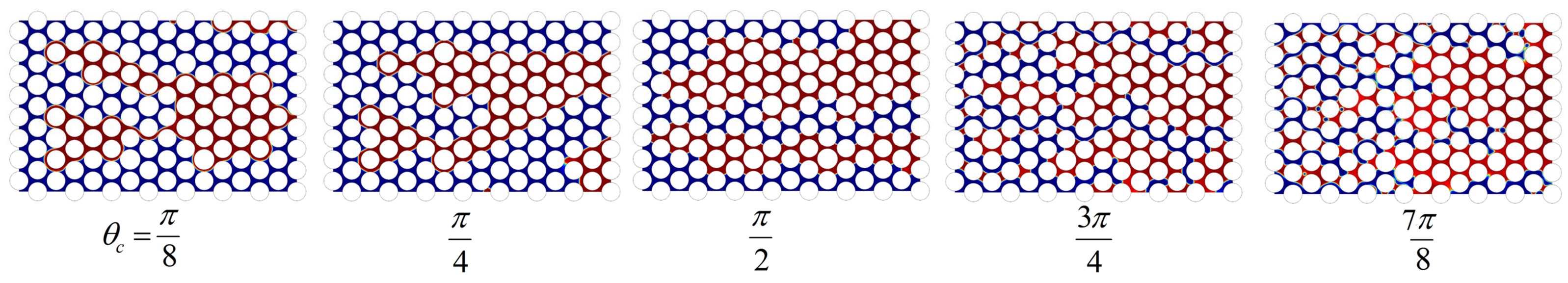

Figure 2. Snapshots of fluid distributions at water breakthrough times for the simulated model with different grain contact angles.

Stabilized s_w and average inlet pressure versus s_w for the different tested wetting conditions are plotted in Figure 3. As shown in Figure 3a, higher water saturations are obtained when the medium is more water wet. Water saturation is below 0.5 when medium is oil wet, while it increases more than 30% as the medium becomes strongly water wet. For all values of contact angle, the declining pressure trends as a function of s_w are almost the same, however higher pressure trends correspond to a less water wet situation.

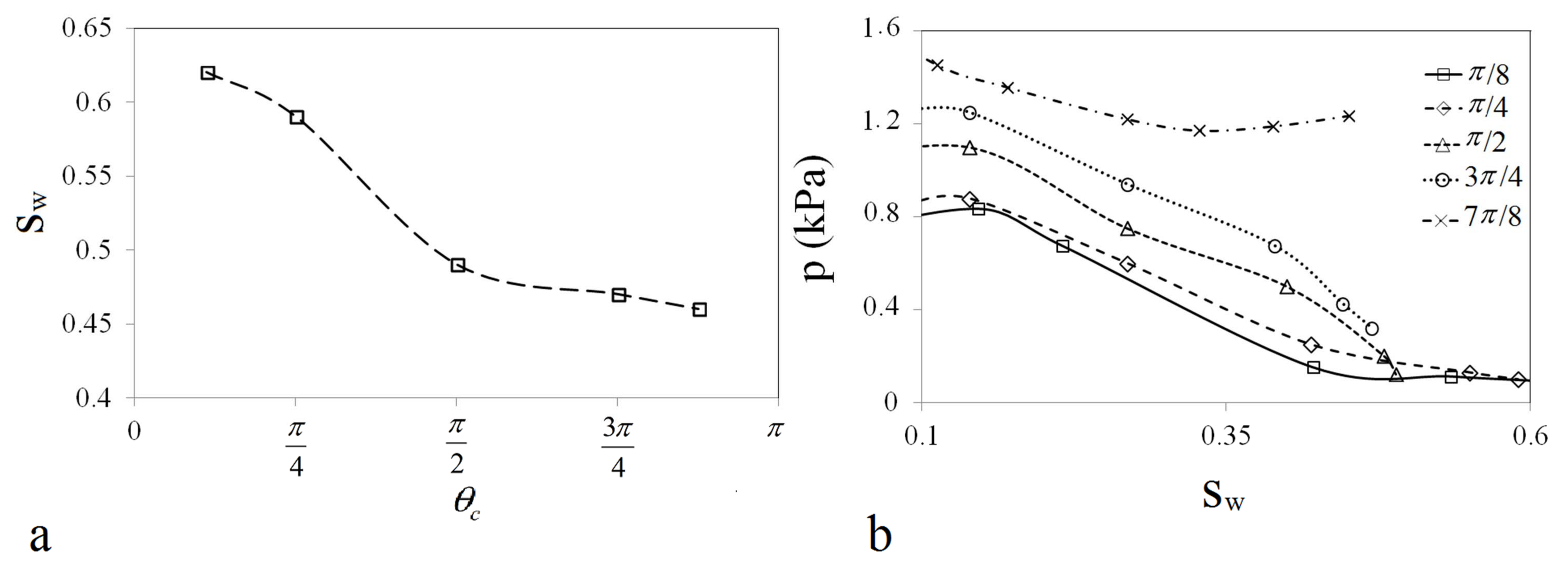

Figure 3. Illustrates the effect of contact angle on (a) water saturation (s_w) at breakthrough time and (b) injection pressure (*p*) as a function of s_w .

Different pore-scale mechanisms are observed in water wet and oil wet conditions which affect the efficiency of the displacements. Figure 4 demonstrates four instants in enlarged sections of the medium during water invasion in strongly water wet and strongly oil wet conditions. In strongly water wet condition ($\Theta_c=\pi/8$), three mechanisms of oil film thinning and rupture, water-oil contact line movement and oil drop formation and detachment are observed.

In strongly oil wet media ($\Theta_c=7\pi/8$), two pore-scale displacement mechanisms of water finger thinning and splitting and water blob trapping are identified.

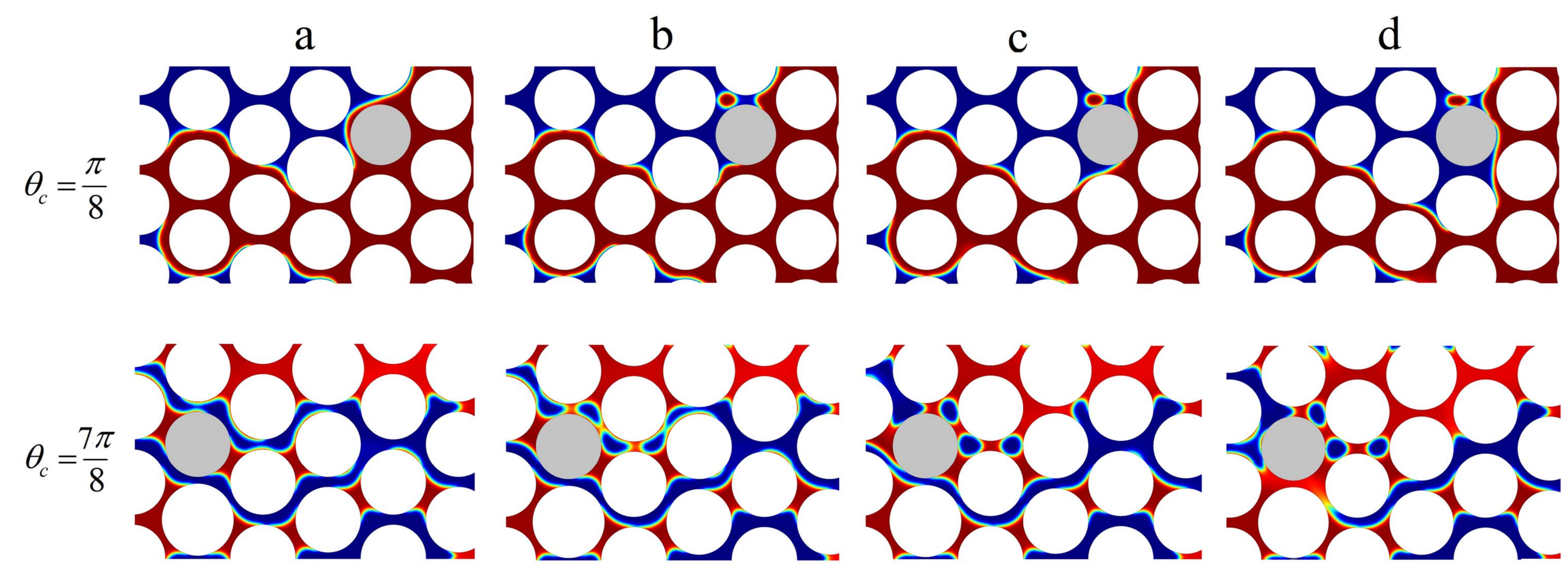

Figure 4. Snapshots of fluid distributions in enlarged section of the medium at successive instants of a, b, c and d for water wet and oil wet conditions

Conclusions: Phase field method was employed to model the influence of contact angle on two-phase displacements at pore scale. The simulated models were able to realistically capture the impact of wettability on the fluid distributions and flow parameters such as pressure and fluid saturations. It was found that fluid distributions, saturations and pore-level displacement mechanisms are totally dependent on the medium wettability.

References:

1. H.A. Akhlaghi Amiri, A.A. Hamouda, Pore-scale modeling of non-isothermal two phase flow in 2D porous media: Influences of viscosity, capillarity, wettability and heterogeneity. *Int. J. Multiphase Flow.* **61**, 14-27 (2014)
2. R. Lenormand, E. Touboul, C. Zarcone, Numerical models and experiments on immiscible displacement in porous media. *J. Fluid Mech.***189**, 165–187 (1988)