Pore-scale Simulation of Coupled Two-phase Flow and Heat Transfer through Dual-permeability Porous Medium

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Introduction

Water conformance control in water-flooded reservoirs

Early water breakthrough happens due to

- ✓ Formation heterogeneities: fractures, high permeable zones
- ✓ Water-oil viscosity contrast

Early water breakthrough results in → Low sweep efficiency

→ Excessive water prod.

Remedy : To increase the viscosity of water using polymer

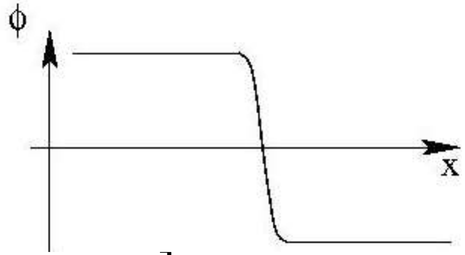
Objectives

2D pore-scale simulations of :

- ✓ the effects of permeability and viscosity contrasts on water flooding → **Two-phase flow**
- ✓ the polymer injection process in dual-permeability medium → **Two-phase flow + Heat transfer**

Theoretical Model

Two-phase flow model : Cahn-Hilliard phase field method



$$\frac{\partial \phi}{\partial t} + u.\nabla\phi = \nabla.(M\nabla G)$$

$$M = M_c\varepsilon^2 \qquad G = \lambda\left[\phi\,(\phi^2-1)/\varepsilon^2 - \nabla^2\phi\right]$$

$$\rho\frac{\partial u}{\partial t} + \rho\, u.\nabla u = -\nabla p + \nabla.\left[\mu(\nabla u + \nabla u^T)\right] + F_{st}$$

$$\nabla.u = 0$$

$$\mu = (\mu_2 - \mu_1)\times(1+\phi)/2 + \mu_1 \qquad \rho = (\rho_2 - \rho_1)\times(1+\phi)/2 + \rho_1$$

$$F_{st} = G\nabla\phi$$

Theoretical Model

Two-phase flow coupled with heat transfer

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u.\nabla T = \nabla.(k\nabla T)$$

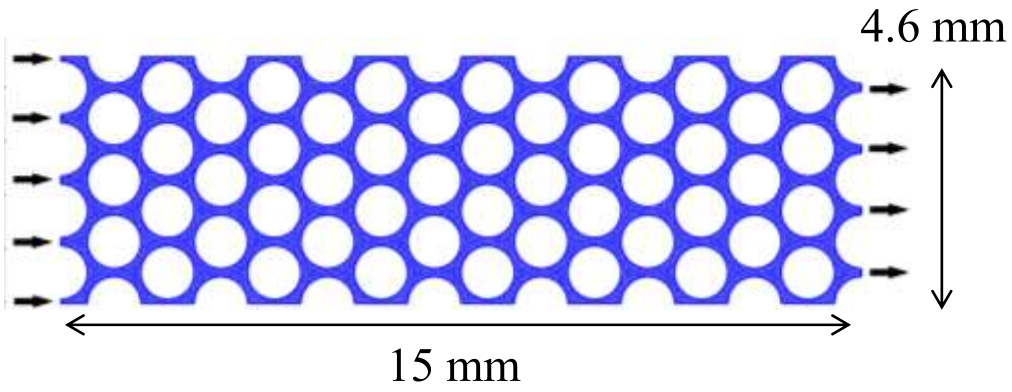
$$C_p = (C_{p2} - C_{p1}) \times (1+\phi)/2 + C_{p1}$$

$$k = (k_2 - k_1) \times (1+\phi)/2 + k_1$$

Model Geometries & Boundary conditions

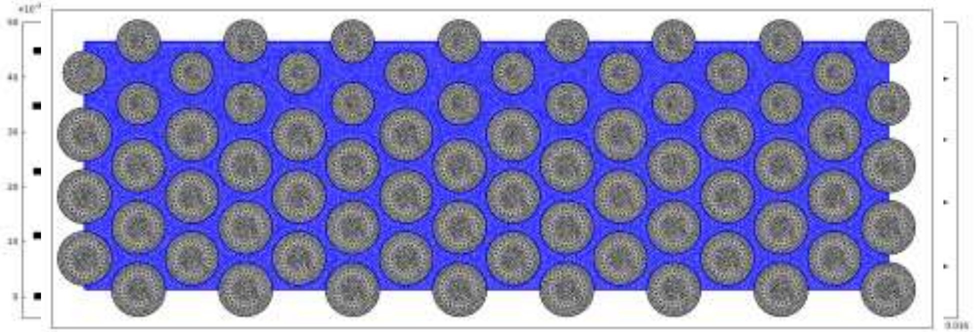
Homogenous model

D_g= 1 mm
D_t=0.15 mm



Dual-permeability model

D_g= 1 & 0.8 mm
D_t=0.15 & 0.35 mm

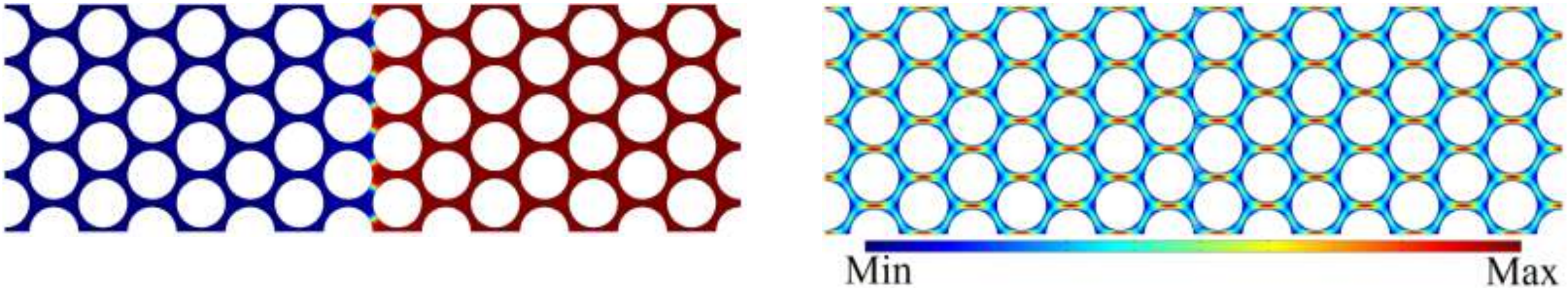


Grain walls: No-slip boundary conditions
Lateral sides: Symmetry boundary conditions
Inlets: Constant velocity
Outlets: Constant pressure (P_o=0)

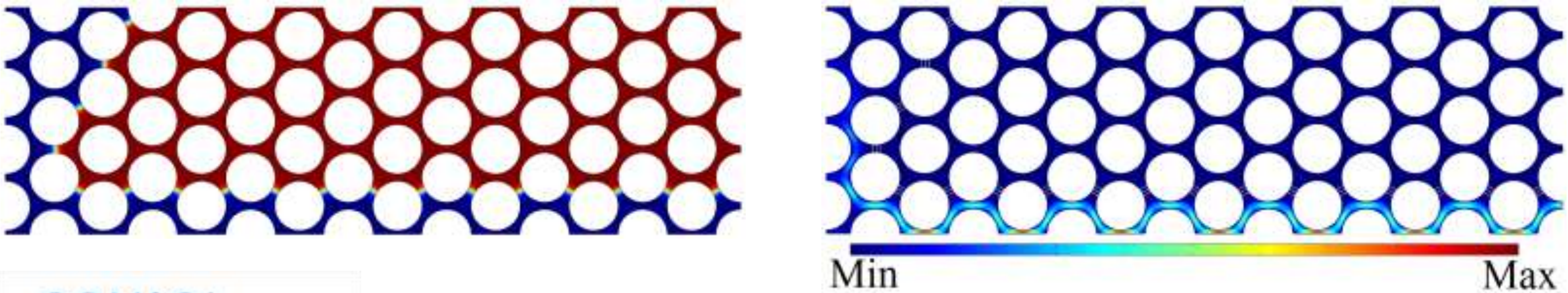
Results

Homogenous porous medium: Effect of viscosity ratio (β)

$$\beta \geq 1$$

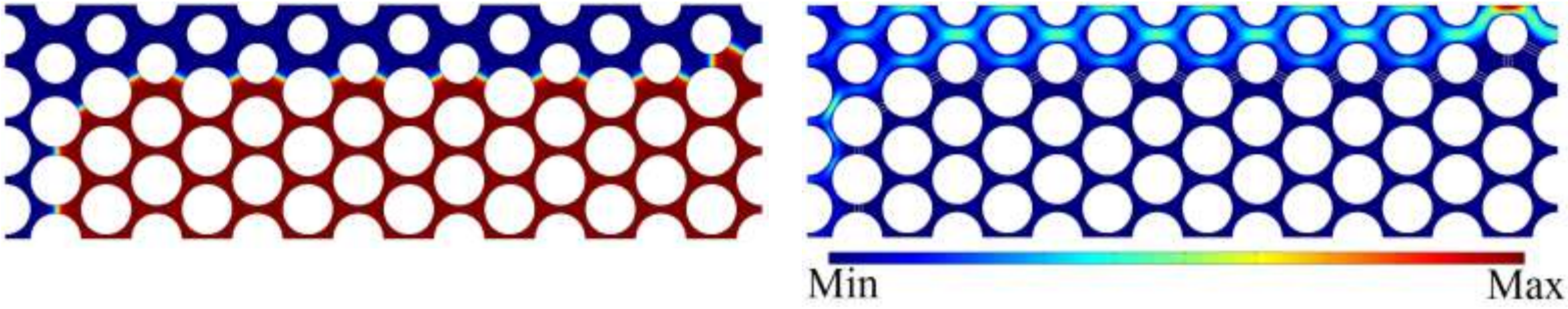


$$\beta < 1$$



Results

Dual-permeability porous medium: Effect of permeability contrast

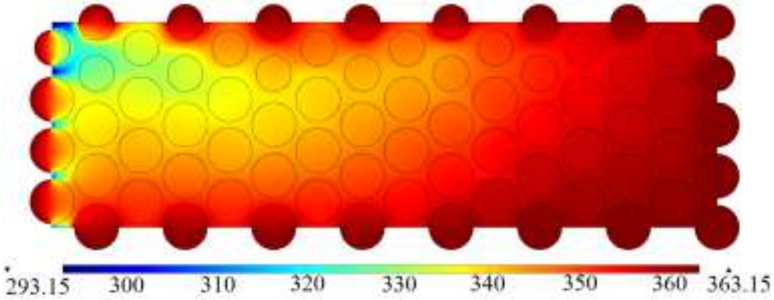


Results

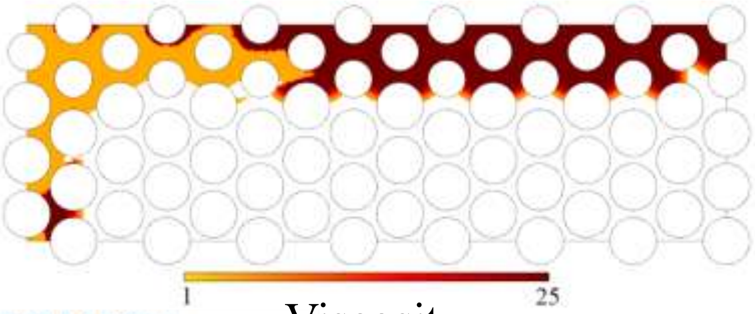
Dual-permeability porous medium: Polymer injection

Temperature profile after stabilization (t=4.5 s)

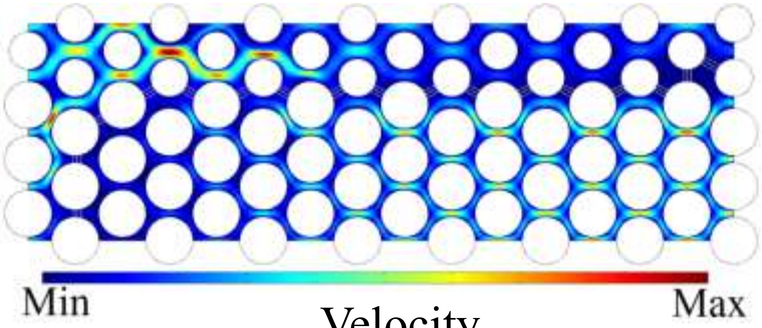
T_{in}=293.15 K (20 C)
T_0=363.15 K (90 C)



$$\mu_{aq} = 0.001 + 0.024 \times U_t(t-5) \times U_T(T-343.15)$$



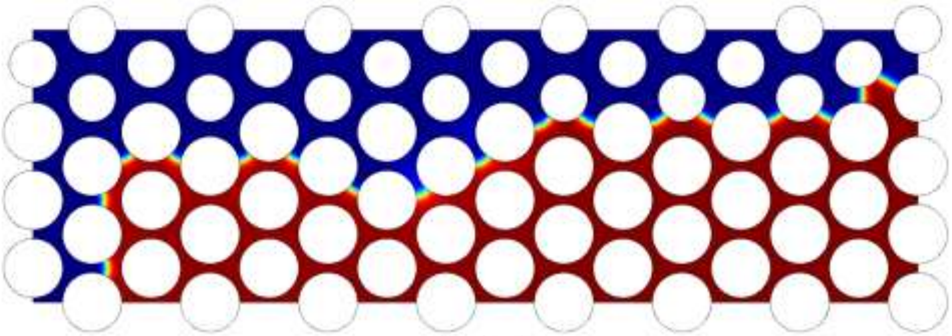
Viscosity



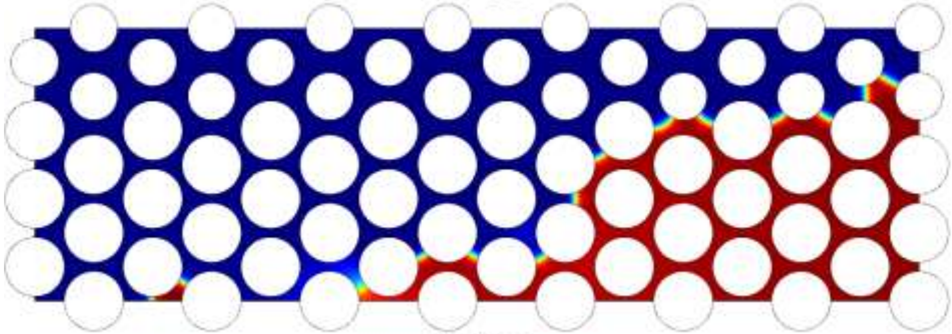
Velocity

Results

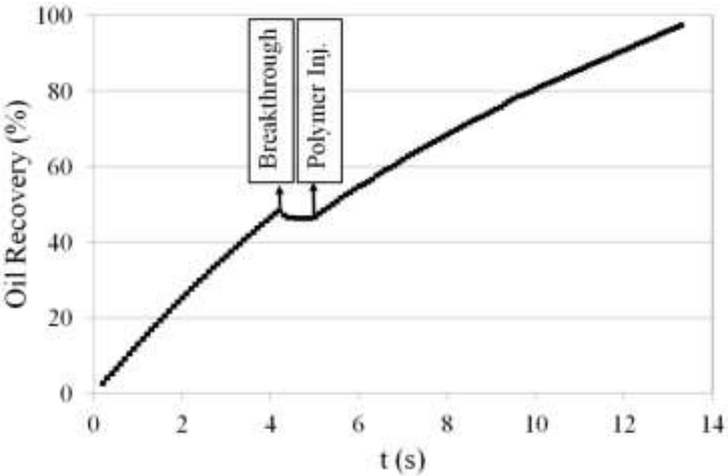
Dual-permeability porous medium: Polymer injection cont.



t= 6 *s*



t= 9 *s*



Conclusion

- COMSOL Multiphysics was used to solve the coupled two-phase flow and heat transfer at pore scale.
- The simulations could capture the effects of permeability and viscosity contrasts in lowering the water sweep efficiency in the porous media.
- The simulation of polymer injection in dual-permeability porous medium showed that proper polymer treatment enhances the oil recovery by creating high resistivity in the high permeable zone.

THANKS FOR YOUR ATTENTION