COMSOL MULTIPHYSICS®

UNIVERSITY OF CALGARY

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PORE-LEVEL BÉNARD–MARANGONI CONVECTION IN MICROGRAVITY

Peyman Mohammadmoradi, Apostolos Kantzas

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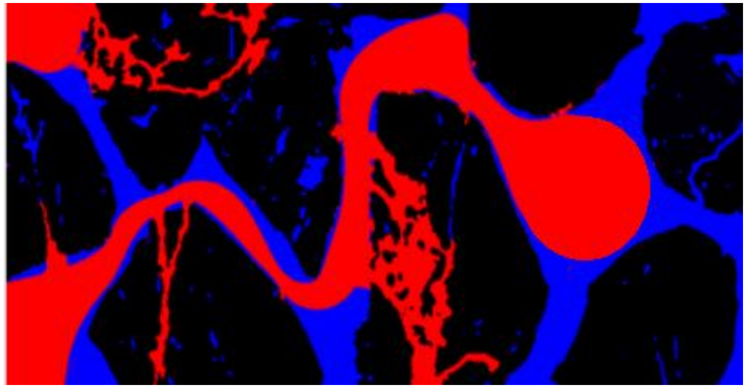
OVERVIEW

- Thermal operations
- Pore-level simulation approaches
- Bénard–Marangoni
- Case study
  - Governing equations
  - Invasion process
  - Results
- Conclusions

THERMAL OPERATIONS

Pore-level displacements during thermal operations is a complex and multi-scale phenomenon:

- The gravity drainage is the main macroscale depletion mechanism.
- The surface tension-related phenomena are dominant in intra-granular micropores.



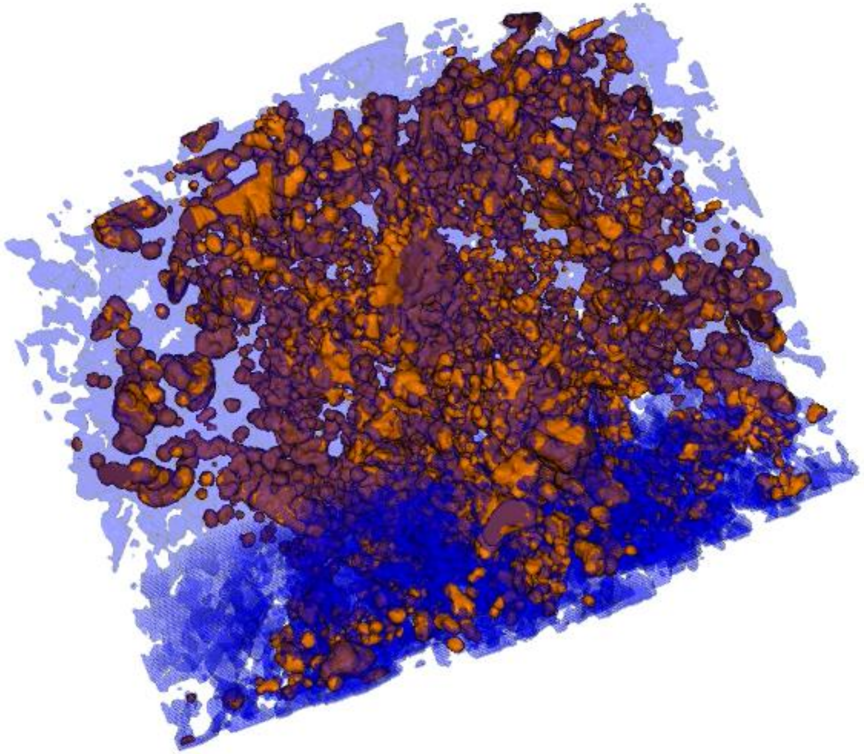
PORE-LEVEL SIMULATIONS

Direct:

- Dynamic CFD-Based Approaches
- Lattice-Boltzmann(LB)
- Pore morphology-based Techniques

Simplified:

- Pore-Network Modeling (PNM)



Volume fraction distribution in a 3D medium applying pore morphology-based technique

BÉNARD–MARANGONI

- The **Marangoni effect** is the mass transfer along the interface between two fluids due to surface tension gradient.

- In the case of temperature dependence, this phenomenon

  is called **thermo-capillary/Bénard–Marangoni convection**.

- Here, the effect of thermally induced interfacial tension gradient fluxes on the amount of residual oil saturation is investigated in a microgravity environment.

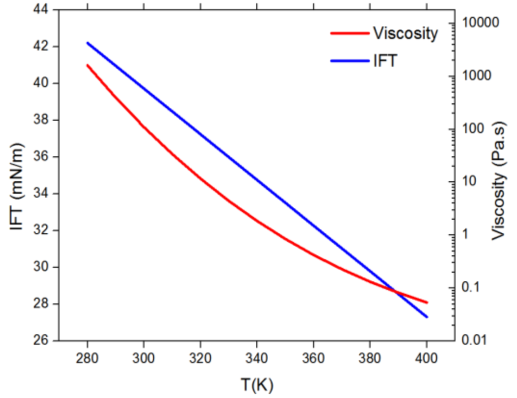
CASE STUDY

Boundary conditions

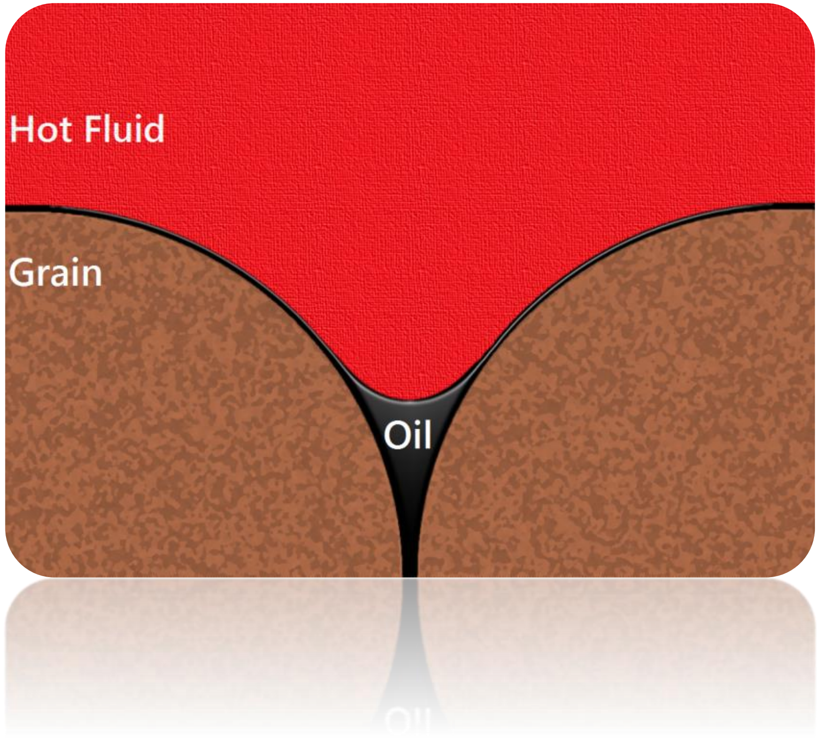
- The pressure difference is constant and equal to 30 Pa.
- The hot fluid temperature is variable between 300 to 400 K
- Oil can be produced via films or bulk flow.
- The solid phase is oil-wet.

Initial conditions

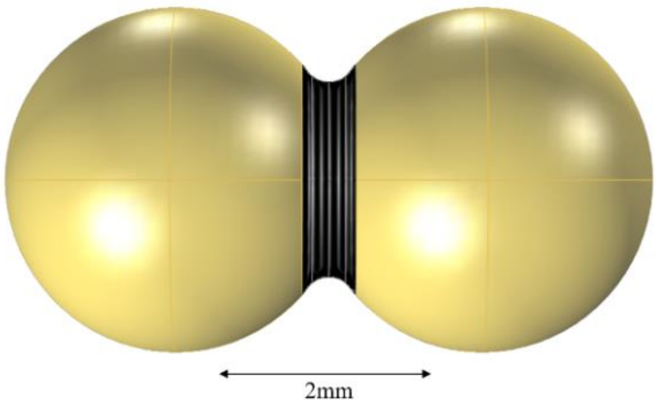
- The temperature of the whole system is 300K.
- The medium is initially filled by oil.
- Density, heat capacity and thermal conductivity of oil are assumed equal to 930 kg/m3, 2000 J/kg.K and 1.1 W/m.K, respectively.
- Hot fluid properties are same as water/steam properties.



IFT and viscosity of oil phase



GOVERNING EQUATIONS



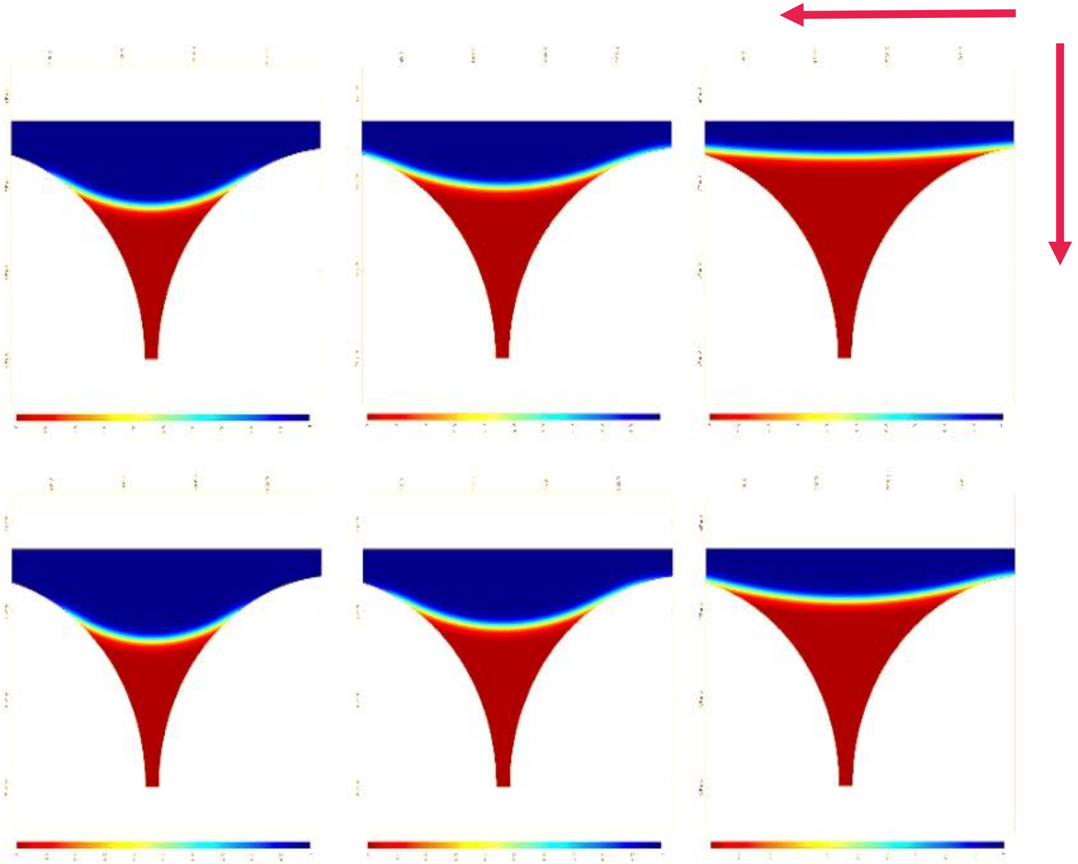
Schematic of the case study

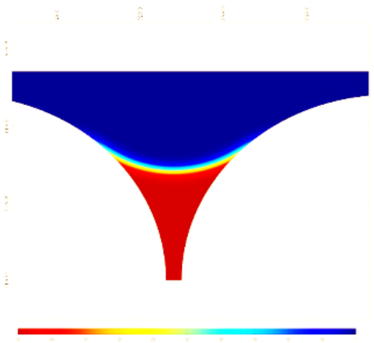
- $\rho \frac{\delta u}{\delta t} + \rho(u.\nabla)u = \nabla.[-p + \rho(\nabla u + (\nabla u)^T] + \rho g + F_{st} + F$
- $\nabla.u = 0$
- $\frac{\delta \phi}{\delta t} + u.\nabla\phi = \gamma\nabla.(\varepsilon_{ls}\nabla\phi - \phi(1-\phi)\frac{\nabla\phi}{|\nabla\phi|}$
- $\rho C_p \frac{\delta T}{\delta t} + \rho C_p u.\nabla T + \nabla.q = Q + q_o + Q_p + Q_{vd}$
- $q = -k\nabla T$

Assumptions

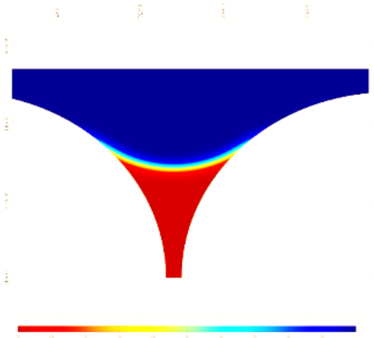
- There are three phases: oil, hot fluid (water or steam) and solid.
- The solid phase is strongly oil-wet.
- Fluids are compressible and immiscible.
- Heat transfer happens in both solid and fluid phases.
- Navier-Stokes and energy equations are solved, simultaneously.
- The process is non-isothermal.
- Surface tension and viscosity are temperature-dependent variables.
- Phase change is not taken into the account.
- Gravity effect is negligible; microgravity.

INVASION PROCESS





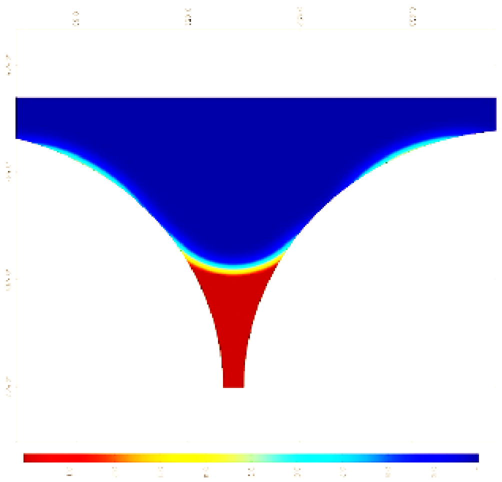
Isothermal process



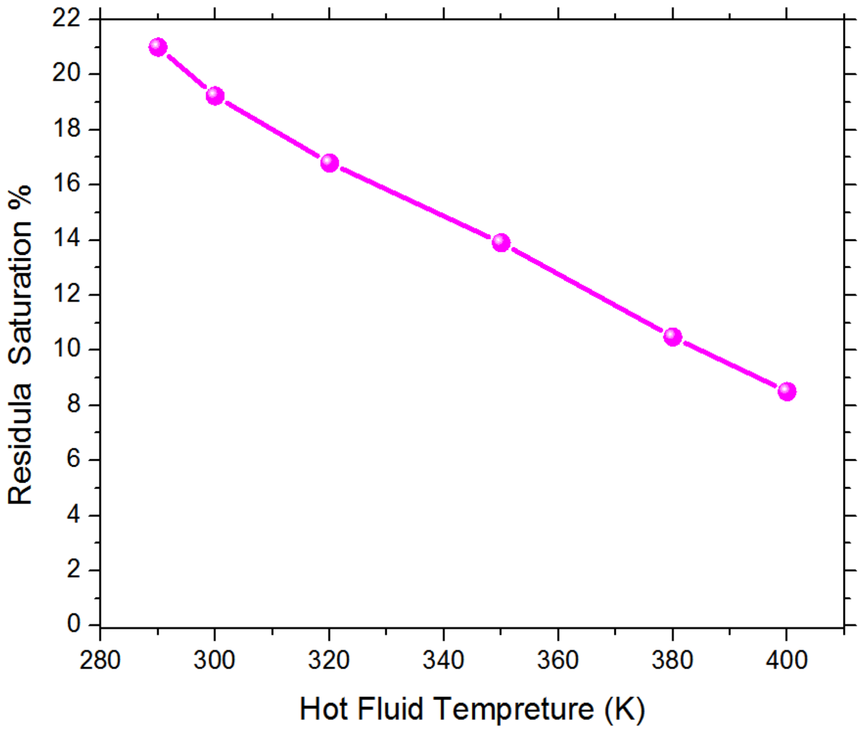
Variable viscosity

Residual oil at equilibrium condition

VARIABLE SURFACE TENSION AND VISCOSITY



2D demonstration of residual oil at equilibrium condition (S_{or}=10.2%)



Residual saturation versus hot fluid temperature

CONCLUSIONS

- A multidisciplinary study was conducted to investigate the effect of temperature on pore-level capillary dominant displacements.
- The effect of thermally induced thermocapillary convection on the amount of residual oil saturation was studied using an oil-wet single pore geometry.
- Results demonstrate that in thermal-based EOR operations, the temperature rise can profoundly change the surface tension in micro-pores and decrease the residual saturation.
- As the viscous and gravity forces are the main production mechanisms in macro-pores, the surface tension gradient is one of the important phenomena in micro-pores affecting fluid-fluid interface equilibriums.

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