Micro-Scale Simulation of Bubble-Water Flow in Coal Seam Gas Reservoirs by Lattice Boltzmann Method

Jie Yi, Centre for Geoscience Computing, School of Earth Sciences, UQ
Supervisors: Associate Professor Huilin Xing, Professor Victor Rudolph

1. Background and research objectives
   ➢ Background
   The gas/water two-phase flow in cleat networks has been a critical issue in coal seam gas (CSG) reservoirs. A key parameter affecting the flow of gas in coal cleats is the wetting potential of gas/water (Li et al., 2012; Zhang et al., 2015). However, our understanding of wettability effects on gas flow still needs further research.

   ➢ Main objectives
   This research seeks to understand the gas flow behaviours in cleats, and the main objectives are:
   • To build a LBM model to simulate bubble-water dynamics at pore scale;
   • To analyse the effects of wettability and capillary pressure on gas-water flow capacity.

2. Wettability
   • $\theta < 90^\circ$: High wettability
   • $\theta > 90^\circ$: Low wettability

   Fig. 2 Schematic diagram of (a) contact angle and (b) capillary imbibition phenomenon (http://www.reservoirengineering.org.uk)

3. Methodology
   ➢ Lattice Boltzmann equations
     \[
     \begin{aligned}
     &f(x+e_{ij}t+\delta t)-f(x,t) + (1-q)[g(x+e_{ij}t+\delta t) - g(x,t)] + \frac{\tau_p}{\delta t} \int_{e_{ij}t}^{\delta t} f(x+e_{ij}t+\delta t) - f(x,t) \, dt \\
     & \quad - f(x,t) - f(x,t) + \frac{1}{\tau_p} \int_{e_{ij}t}^{\delta t} f(x+e_{ij}t+\delta t) - f(x,t) \, dt \\
     &= \int_{e_{ij}t}^{\delta t} [\mu \nabla \phi + F_b] \, dt \\
     \end{aligned}
     \]
   ➢ To distinguish different points on the fluid/solid interaction

4. Benchmark
   • For different contact angles, the gas bubble shape and movement are significantly different, which means the relative permeability highly depends on wettability of coal.
   • For bubble-water flowing in a cleat with a narrow throat, the capillary pressure plays an important role in determining the fluid flow capacity.
   • These phenomena are likely to have significant impacts on drainage rates and relative permeability within a coal seam.

5. Simulation results and conclusions
   ➢ Simulation results
     Fig. 6 Dynamic behaviour of bubble-water flow in a single cleat with different contact angles: (a) $68^\circ$, (b) $90^\circ$, (c) $112^\circ$

   ➢ Conclusions
     • For different contact angles, the gas bubble shape and movement are significantly different, which means the relative permeability highly depends on wettability of coal.
     • For bubble-water flowing in a cleat with a narrow throat, the capillary pressure plays an important role in determining the fluid flow capacity.
     • These phenomena are likely to have significant impacts on drainage rates and relative permeability within a coal seam.

Acknowledgements
The author appreciates the funding provided by the UQ Centre for Coal Seam Gas (CCSG) and its industry members APLNG, Arrow Energy, QGC & Santos.