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Computational Modelling of Counter-Current Multiphase Flows in CSG Wellbores

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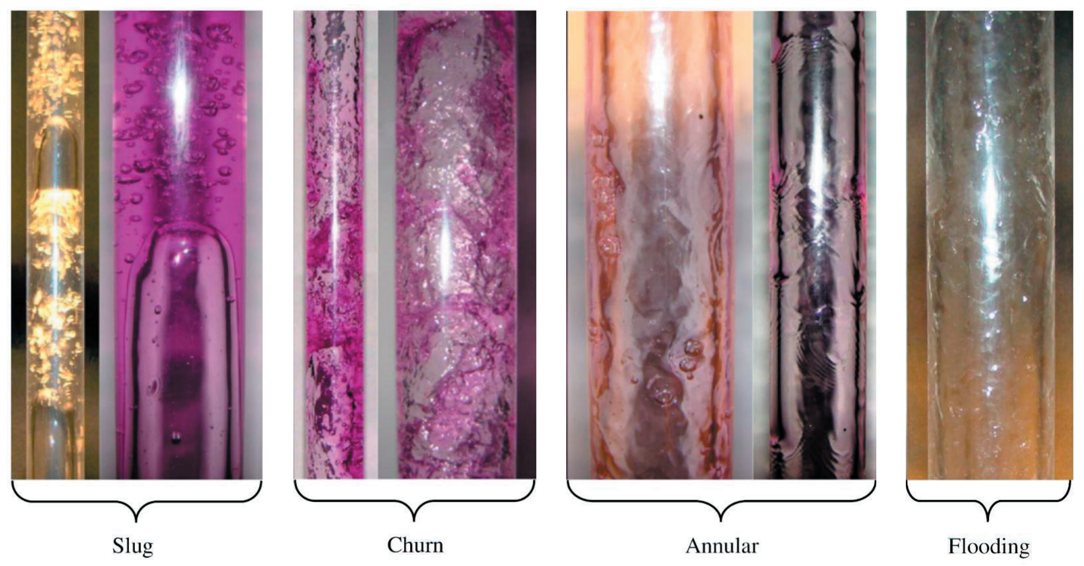
Project Background

The **bottom hole pressure** (BHP) in natural gas wells is an important parameter in the effective design of well completions and artificial lifting systems. Poor estimation of this can lead to liquid loading in the wellbore and reduced efficiency of the extraction process. The complex interaction of gas and associated water can increase the **uncertainty in pressure gradients** and ultimately affect BHP estimation.

A significant body of research has explored pressure gradients in the co-current multiphase flows found in conventional gas extraction, but these are not expected to hold for the counter-current regimes present in coal seam gas (CSG) extraction. Therefore, this research aims to develop a **computational fluid dynamics** (CFD) model of simultaneous gas and fluid transport in CSG wells. This will look to provide **fundamental understanding** of the possible flow regimes and ultimately the pressure profiles for various subsurface conditions.



High Level Objectives

1. Implement, **verify and validate** multiphase CFD models based on lattice Boltzmann techniques.
2. Model **comparison** to test applicability for liquid/gas flows at high Reynolds numbers.
3. Model development in **GPU framework** [1] for increased efficiency and resolution of simulations.
4. Simulation of wellbore geometries and flow conditions to **understand** flow transitions and **predict** pressure gradients.

Computational Fluid Dynamics

- Look to solve the Navier-Stokes equations in multiple dimensions (i.e. continuity of mass and momentum)

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \boldsymbol{u} = 0$$

$$\rho\left(\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u} \cdot \nabla \boldsymbol{u}\right) = -\nabla p + \nabla \cdot [\mu(\nabla \boldsymbol{u} + \boldsymbol{u}\nabla)] + \boldsymbol{F_s} + \boldsymbol{F_b}$$

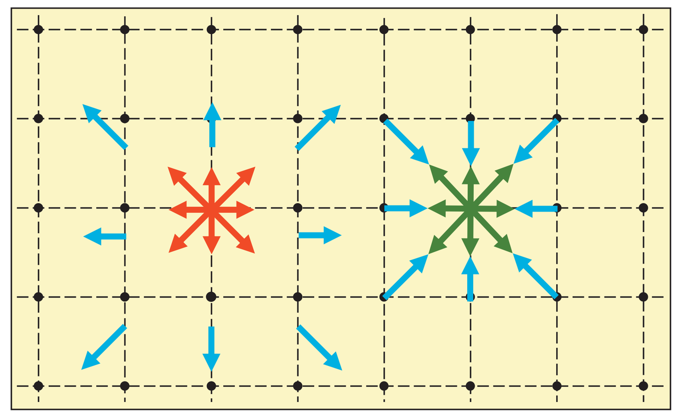
- Grid generation can be a bottleneck in CFD studies
- Implementation of microscale interactions (e.g. surface tension) in macroscale equations requires special treatment
- Common methods include:
  - Volume of Fluid (VoF)
  - Level Set (LS)

Multiphase Lattice Boltzmann

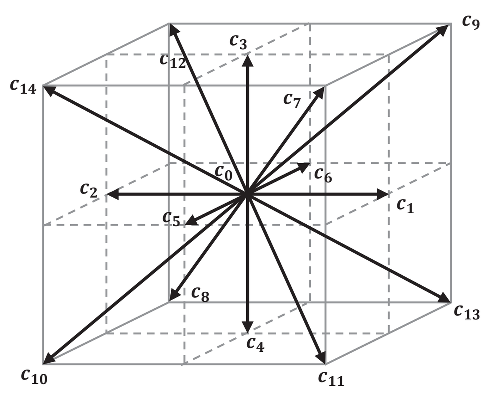
- Look to solve the Boltzmann transport equation that recovers Navier-Stokes at the macroscale:

$$\underbrace{f_\alpha(\boldsymbol{x} + \boldsymbol{e}_\alpha, t+1) - f_\alpha(\boldsymbol{x}, t)}_{Streaming} = \underbrace{\Omega\big(f_\alpha(\boldsymbol{x}, t)\big) + \frac{(\boldsymbol{e}_\alpha - \boldsymbol{u}) \cdot \boldsymbol{F}}{c_s^2}\Gamma_\alpha}_{Collision}$$

- Standard lattice configurations eliminate bottleneck of grid generation



In 2D we discretise velocity space to 9 directions (D2Q9) and stream (left) then collide (right)

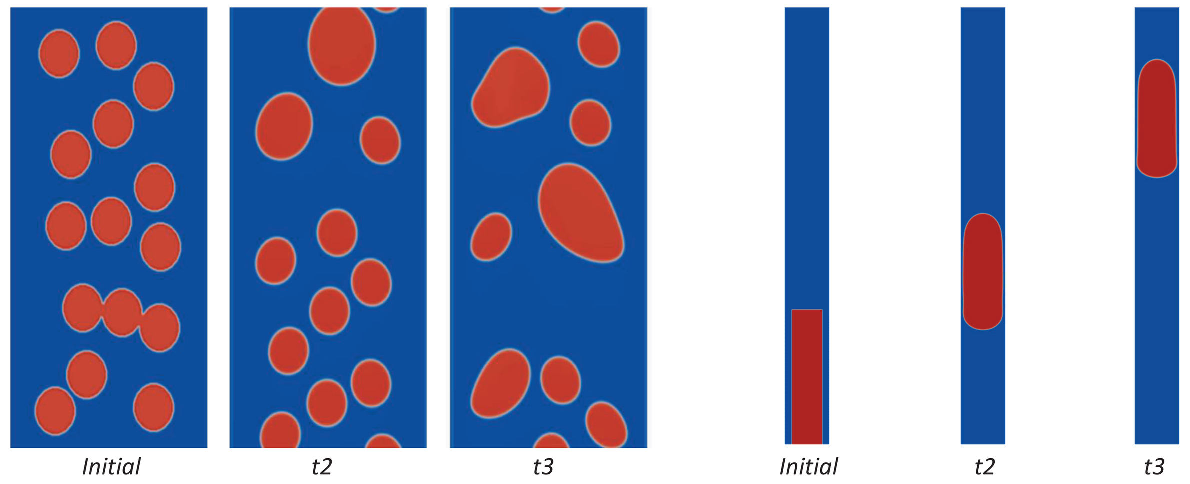


D3Q15 model is shown above

- The mesoscopic nature of LBM allows interface interactions to be directly captured or tracked:
  - Pseudopotential methods naturally solve the interface locations
  - Phase-field theory tracks interface regions
  - LBM can also be used with VoF and LS techniques

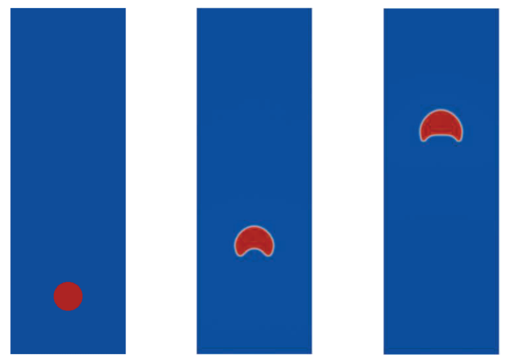
Examples of Work to Date

Test 1: ***Concurrent Bubbly Flow*** Test 2: ***Concurrent Slug Flow***



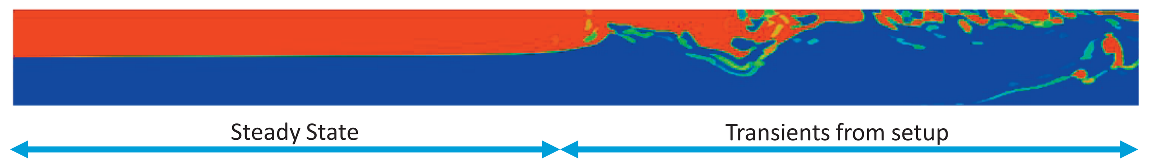
- Proof of concept showing the ability of pseudopotential LBM to capture interface interactions (*Test 1*) and gas slug transport (*Test 2*)

Test 3: ***Buoyant Bubble Rise***



- Implementation of a phase field LBM to simulate a gas bubble rising through stagnant fluid.
- Shape is consistent with benchmark experimental work of Clift, R., Grace, J. and Weber, M. (1978)

Test 4: ***Concurrent Flow in OpenFoam***



- Simulation developed to analyse the use of OpenFoam to allow for potential verification of implemented LBM codes

Upcoming Work

- Validation of rise velocities of single and multiple bubble in stagnant and flowing fluid
- Implementation of gas inlet boundary conditions to assess the formation of flow regimes for varying inlet velocities

Acknowledgement & References

- Dr. Mahshid Firouzi and the multiphase flow project team at the CCSG
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[1] **CudneLB -** https://github.com/CFD-GO/TCLB

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