MULTIPHASE LATTICE BOLTZMANN MODEL DEVELOPMENT FOR FLOW REGIME ANALYSIS

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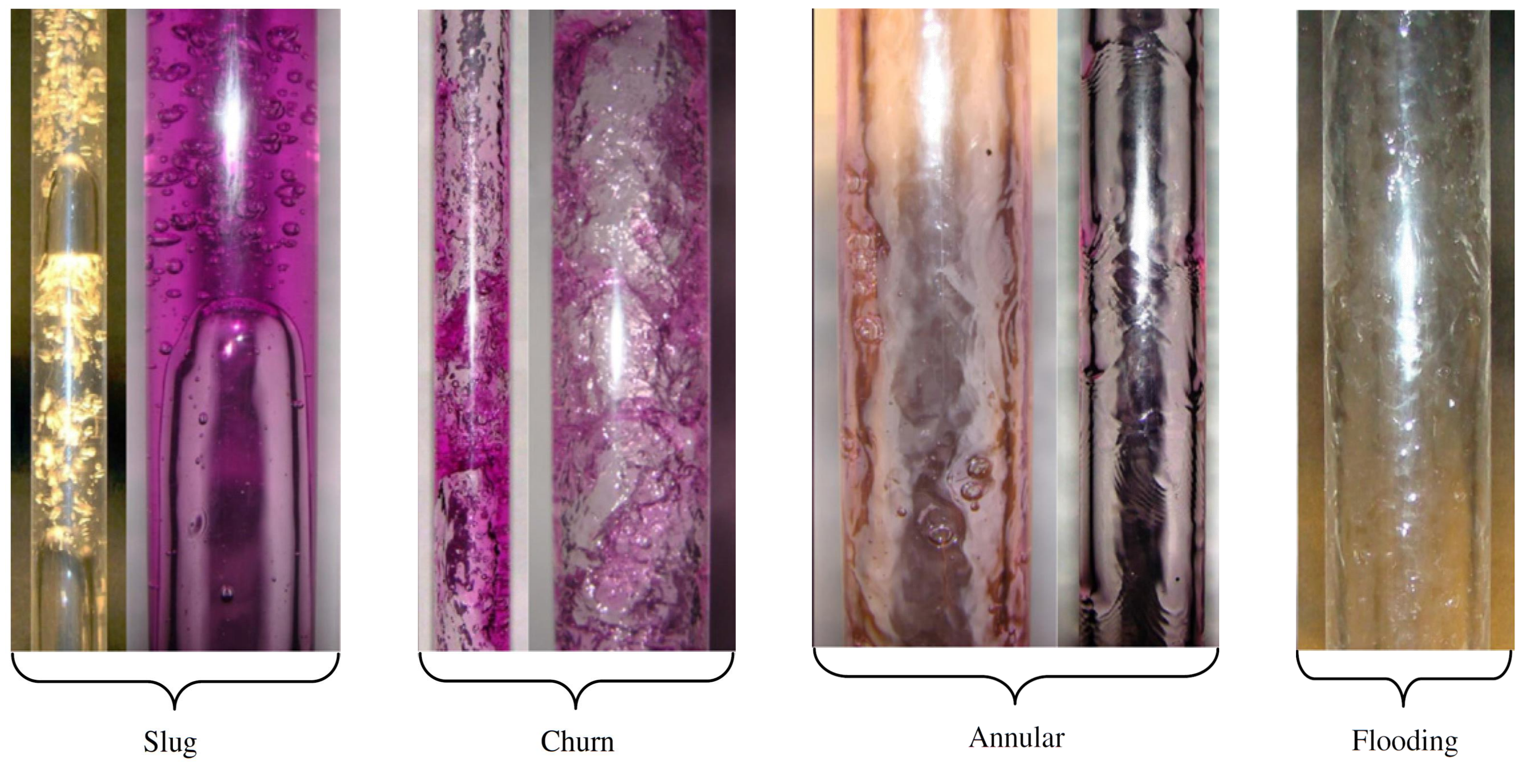
Project Background

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. However, these are not expected to hold for the counter-current regimes present in coal seam gas (CSG) extraction. Therefore, this research aims to develop **computational fluid dynamic** (CFD) techniques in order to analyse the simultaneous transport of gas and fluid in CSG wells. This will look to provide **fundamental understanding** of the possible flow regimes and ultimately the pressure profiles for various subsurface conditions.



Research Objectives

1. Development of **lattice Boltzmann** (LB) multiphase flow solver capable of simulating high density ratio, high Reynolds number confined flows;
2. **Verification** and **validation** of the model with assessment of ability to capture the relevant flow configurations;
3. Simulation of flow regimes under varying production conditions to develop **understanding** and improve pressure drop **predictions**;
4. Incorporation of findings into **large-scale** wellbore flow model to assist in the design and operations of CSG wells.

Developed Theory and Benchmarking

Basic Theory:

LB techniques to recover the Navier-Stokes equations:

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

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

As well as tracking the evolution of the liquid-gas interface through phase-field theory:

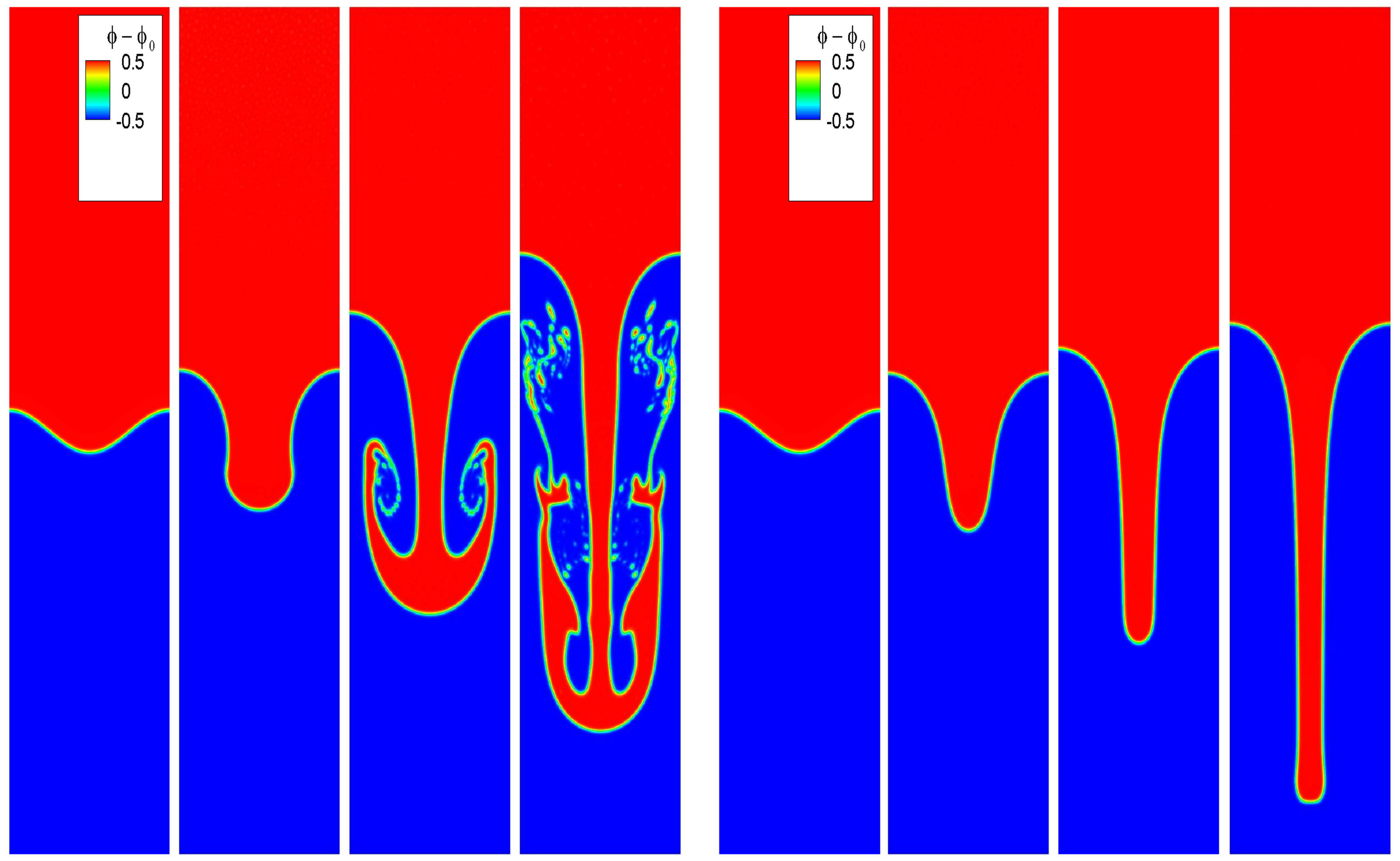
$$\frac{\partial \phi}{\partial t} + \nabla \cdot \phi \boldsymbol{u} = \nabla \cdot M\left[\nabla \phi - \frac{\boldsymbol{n}(1-4(\phi-\phi_0)^2)}{W}\right]$$

To solve these equations, we proposed [1] a modified multiphase LB model based on the work of Zu and He [2], with interface tracking by the Allen-Cahn equation described in the work of Geier et al. [3]:

$$\underbrace{g_\alpha(\boldsymbol{x}+\boldsymbol{e}_\alpha, t+1) - g_\alpha(\boldsymbol{x},t)}_{streaming} = \underbrace{\Omega\big(f_\alpha(\boldsymbol{x},t)\big) + \frac{w_\alpha(\boldsymbol{e}_\alpha \cdot \boldsymbol{F})}{\rho c_s^2}}_{collision\ and\ forcing}$$

Example Benchmark Case:

A number of verification procedures were conducted, starting with the well-known Rayleigh-Taylor instability:



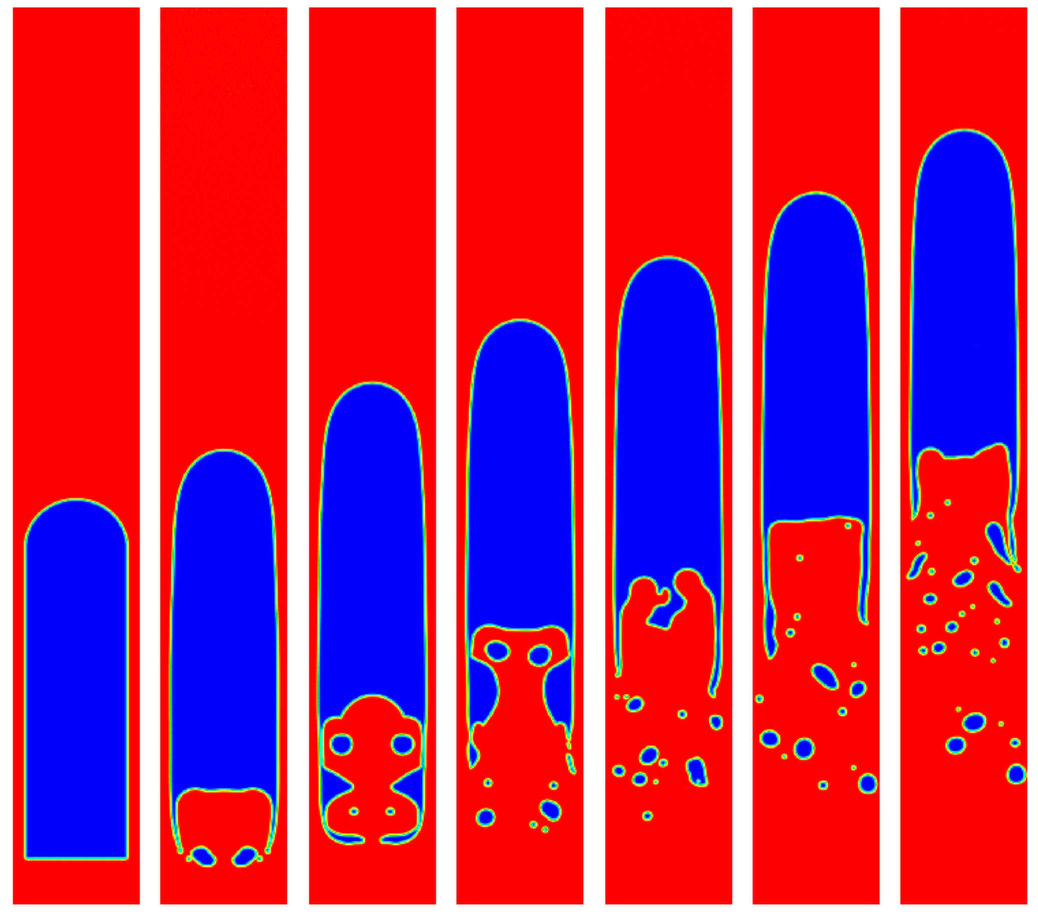
Base case (left) has a density ratio of 3 for comparison to previous works, extension case (right) has water-air-like properties.

Results and Discussion

Taylor Bubble Validation:

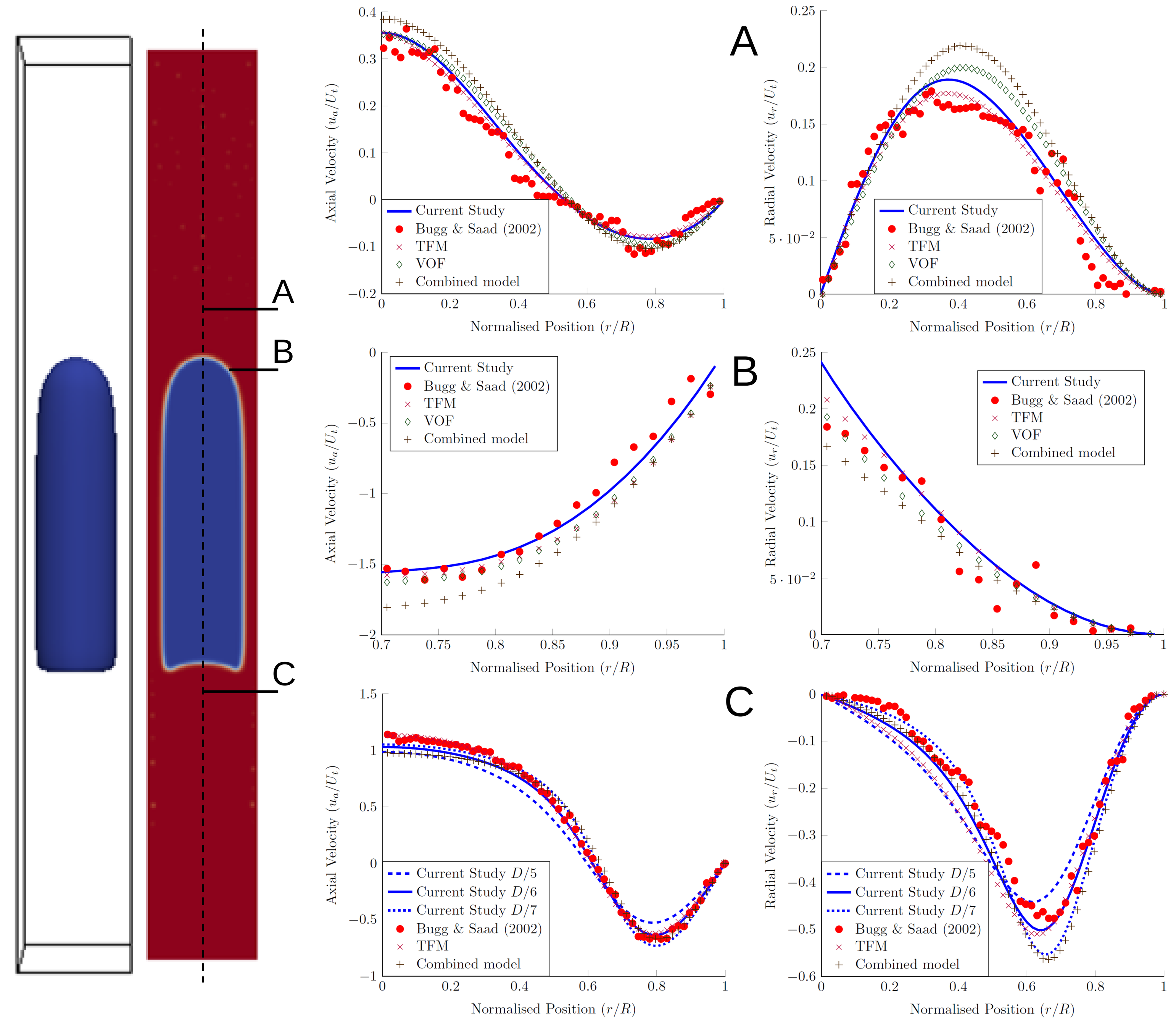
Continuing on the 2D trend we simulated the rise of planar Taylor bubbles in an inertial regime with water-air properties.

- Achieved a stable rise velocity and interface profile in line with theoretical, numerical and experimental data;
- The expansion of the liquid film behind the bubble generates a wake region. The shear force on the bubble tail is observed to displace small bubbles into the wake.



The move to 3D:

Taylor bubble in olive oil – experimental comparison



[1] A. Fakhari, T. Mitchell, C. Leonardi and D. Bolster, Robust phase-field lattice Boltzmann model for immiscible fluids at high density ratio, Phys. Rev. E (*Under Review*).
[2] Y. Zu and S. He, Phase-field-based lattice Boltzmann model for incompressible binary fluid systems with density and viscosity contrasts, Phys. Rev. E. **87**, 043301, 2013.
[3] M. Geier, A. Fakhari and T. Lee, Conservative phase-field lattice Boltzmann model for interface tracking equation, Phys. Rev. E. **91**, 063309, 2015.

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