

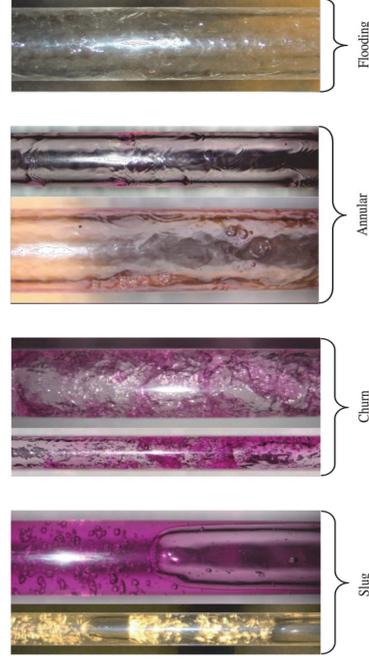
Computational Modelling of Counter-Current Multiphase Flows

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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 and use **computational fluid dynamics** in order to analyse the simultaneous transport of gas and fluid in CSG wells. This will provide a **fundamental understanding** of the possible flow regimes and ultimately the pressure profiles for various subsurface conditions.



References:

- [1] A. Fakhari, T. Mitchell, C. Leonard, D. Bolster, Phys. Rev. E **96**, 053301 (2017).
- [2] T. Mitchell, C. Leonard, A. Fakhari, Int. J. Multiphas. Flow **107**, 1-15 (2018).
- [3] Y. Q. Zu, S. He, Phys. Rev. E **87**, 043301 (2013).
- [4] M. Geier, A. Fakhari, T. Lee, Phys. Rev. E **91**, 063309 (2015).
- [5] J. D. Bugg, G. A. Saad, Int. J. Multiphas. Flow **28**(5), 791-803 (2002).
- [6] G. Das, P. K. Das, N. K. Purohit, A. K. Mitra, J. Fluid Eng-T. ASME **121**, 895-901 (1999).

Developed Theory and Validation

Basic Theory:

Lattice Boltzmann (LB) method to resolve Navier-Stokes:

$$\partial_t \rho + \nabla \cdot \mathbf{u} = 0$$

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

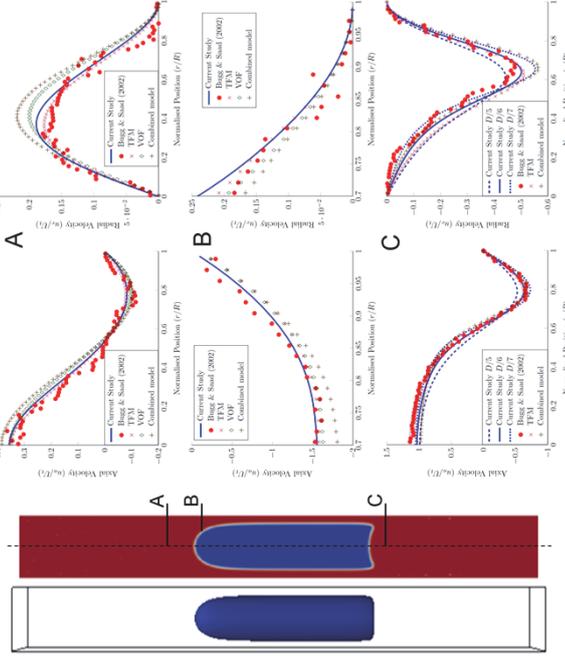
$$\partial_t \phi + \nabla \cdot \phi \mathbf{u} = \nabla \cdot \mathbf{M} \left[\nabla \phi - \frac{\mathbf{n}(1 - 4(\phi - \phi_0)^2)}{W} \right]$$

To solve these, we proposed [1,2] a modified LB model based on the work of Zu and He [3], with interface tracking by the Allen-Cahn equation described in the work of Geier et al. [4]:

$$g_\alpha(\mathbf{x} + \mathbf{e}_\alpha, t + 1) - g_\alpha(\mathbf{x}, t) = \Omega(f_\alpha(\mathbf{x}, t), \rho, \mathbf{u}) + \frac{w_\alpha(e_\alpha F)}{\rho c_s^2}$$

Experimental Validation:

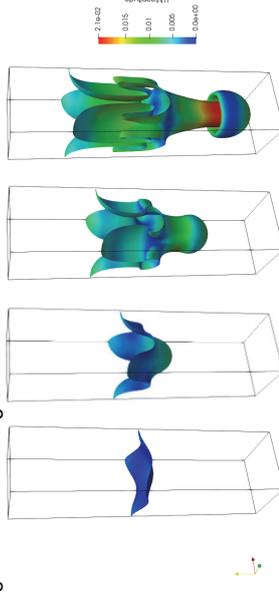
Obtained experimental results from Bugg and Saad [5] analysing the flow around an elongated (Taylor) bubble:



Results and Discussion

Rayleigh-Taylor Instability:

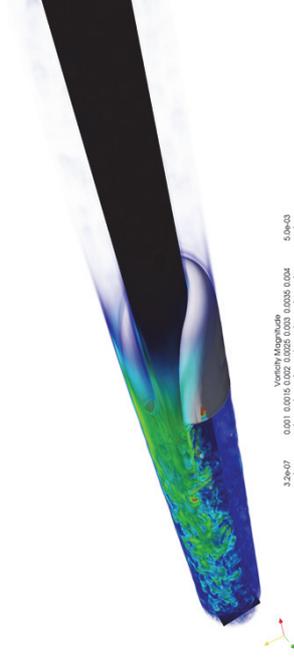
Assess the accuracy and stability of the proposed model through the well known instability that occurs when a heavy fluid is situated above a lighter fluid within a gravitational field.



Found very close agreement with other models as well as the capability to extend to higher density ratios and Reynolds numbers than current state-of-the-art practices.

Taylor Bubble in an Annular Pipe:

Able to simulate the observed behaviour of the Taylor bubble analysed in the experimental work of Das et al. [6]. Now looking at extending this to determine the flow behaviour of methane and brine as they propagate within natural gas wellbores.



Acknowledgements:

This project was supported by researchers from The University of Queensland Centre for Coal Seam Gas (UQ-CCSG) multiphase flow project. Also important to the project was support from the code developers of the open-source LBM framework, TCLB. This work was supported by resources provided by the Pawsey Supercomputing Centre with funding from the Australian Government and the Government of Western Australia. The Australian Government Research Training Program Scholarship is also acknowledged.