Assessment of 2-phase solvers for low capillary number flows in lung airways

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Studying experimentally air-liquid flows in the finer lung airways is almost impossible since these are inaccessible. Computational methods can shed light on phenomena such as mucus plug formation and rupture in the deep lung airways[1,2]. However, there are issues when applying interface capturing methods in surface-tension-dominated flows in microchannels, since these methods cannot resolve the interface location with sub-grid resolution and/or do not guarantee mass conservation[3]. Another known issue of algebraic Volume of Fluid (VoF) methods when applied at low Capillary (Ca) numbers is the generation of parasitic currents, which originate from errors in calculating the curvature of the interface. The purpose of this study is to assess the performance of different 2-phase approaches, namely, algebraic (aVoF) or geometric (gVoF) VoF, and a simple coupled level-set/VoF (sclsVoF) method, for low Ca number flows found inside the deeper lung airways. The algebraic VoF and sclsVoF solvers as implemented in OpenFOAM are used and the geometric VoF solver of Basilisk.

The first test case concerns bubble rise at low Ca number. This test is carried out to fine-tune the solvers's settings for low capillary flows. Predicted terminal velocity is plotted in figure 1(a) for bubble diameters ranging from 0.5-2 mm and compared to experimental data[4]. sclsVoF and gVoF (Basilisk) outperform the aVoF method at smaller bubble diameters (lower Ca). The second examined case concerns axisymmetric liquid plug propagation in a tube[1], which resembles mucus plug propagation in the lung airways. The predicted liquid plug length evolution in time (until rupture) is shown in figure 1(b) for Laplace numbers λ=50&1000, in comparison to available numerical data[1]. sclsVoF and gVoF predict the plug length quite well for λ=50 and show better performance compared to aVoF for λ=1000. The effect of mucus viscoplastic properties will be studied using the Herschel-Bulkley model.

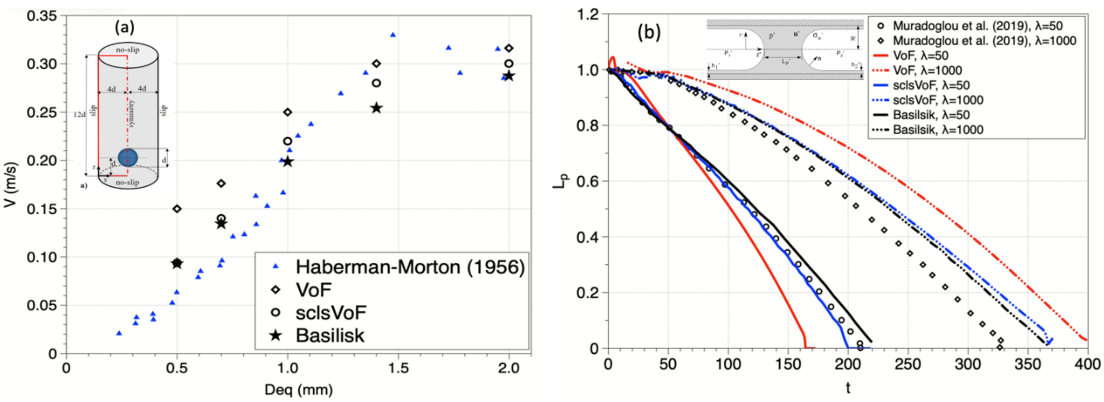

Figure 1: (a) Bubble terminal velocity vs bubble diameter. (b) Liquid plug length evolution in time.

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