Investigating Bubble Dynamics in Vertical Channel: A Comparative Analysis of Co-flow and Counter-flow Configurations

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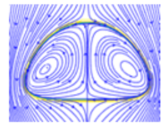
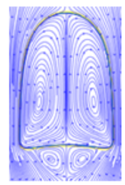
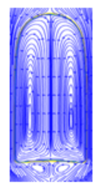
1. INTRODUCTION & OBJECTIVE

Bubbles in vertical channels hold implications for various industrial applications involving two-phase flows in vertical channels, such as chemical processes, heat exchangers, and fluid transport systems. The differences in bubble dynamics are attributed to the interplay of buoyant forces, fluid velocities, and surface tension effects. Co-flow involves the upward movement of the gas phase alongside the liquid, while counter-flow features opposing directions of gas and liquid motion. Co-flow and counter-flow arrangements present contrasting scenarios in which the dynamics of bubble can significantly vary. Numerous studies have explored bubble dynamics in vertical channels in quiescent liquid and liquid co-flow,[1]–[3] there appears to be a lack of comprehensive investigations directly comparing the effects of co-flow and counter-flow configurations on bubble behavior. Co-flow minimizes the adverse impact of gravity on bubble motion, leading to more controlled and predictable behavior. Counter-flow, on the other hand, presents a challenging environment where the competition between forces drives dynamic shape changes and vertical motion. Existing research often focuses on one flow arrangement or the other, but a systematic and detailed comparison between these two configurations is limited. This gap becomes evident when attempting to discern how variations in fluid flow patterns influence bubble stability, shape deformation, and ascent rates. This study aims to uncover the impact of these flow configurations on bubble behavior and sheds light on the nuanced interactions between fluid flows, buoyant forces, and capillary effects.

2. METHODOLOGY & RESULTS

An inhouse solver based on Level Set Method is developed to carry out the investigation numerically. The solver is validated with test problems taken from literature. The simulations were carried out for co-flow as well as counter flow configurations for different range of Bond Numbers (Bo) and initial bubble diameter (D). The study reveals distinctive patterns in bubble dynamics under co-flow and counter-flow conditions. **Table. 1** shows the case of co-flow wherein bubbles experience enhanced stability due to the collective upward motion of gas and liquid. They tend to exhibit more consistent shapes and slower ascent rates when the bond number is low. As the bond number increases the bubble rise velocity also increases, here the interesting point to be noted is that for longer bubble the thin film between wall and the bubble play an important role in increasing bubble rise velocity along with the wakes formed below the bubble which pushes it in upward direction and enhance the velocity. Hence, in case of elliptical bubble at Bo=50, the bubble rise velocity is high. The results for downward flow are under process.

Table 1. Results showing the effect of Bond Number (Bo) on shape of bubble in co-flow configuration at steady state and Re=100, Ca=0.5, ρ=0.001, μ=0.01.

Grid Size	Initial Diameter (D)	Bond Number (Bo)	Bubble Velocity (U_b)	Steady State shape at Bo=50	Major Highlights
120x300	0.5 (Circular)	0.5	0.0049		As Bo increases the bubble rising velocity also increases for the D=0.5.
		0.8	0.0078		
		1	0.0098		
		10	0.0835		
		50	0.190		
120x300	0.925 (Circular)	0.5	0.00011		As Diameter increases to 0.925 the bubble rising velocity decreases for same range of Bo compared to D=0.5 case.
		0.8	0.00018		
		1	0.00023		
		10	0.0211		
		50	0.188		
120x300	2 (Elliptical)	0.5	5.24x10e-5		In case of elliptical Bubble D=2, the bubble rising velocity is negligible for Bo<=1 and increases for Bo>1
		0.8	7.07x10e-5		
		1	7.53x10e-5		
		10	0.0277		
		50	0.203		

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