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The bubble formation and dynamics in the liquid phase affect the heat and mass transfer mechanism between phases, which is crucial in determining the equipment's performance. The commercial applications include floatation, absorbers, reactors, and distillers [1,2]. Thus, it is vital to understand the bubble hydrodynamics such as bubble rise velocity, residence time, shape formation, coalescence and break-up, better equipment design, and enhanced process optimization. The specifics of the bubble hydrodynamics and the coalescent combination of the co-axial and lateral engagements of individual bubbles are essential factors to analyze the bubbles flow in the column [3,4]. Several researchers have experimentally, numerically, and analytically studied and discussed the bubble dynamics. Lin et al. [5] experimentally examined the co-axial bubble coalescence process in the non-Newtonian fluid. They also observed that in bubble coalescence, the shear-thinning and viscoelastic effects play a crucial role. Ganesan et al. [6] numerically analyzed the coalescence of axial and lateral bubbles having diameters ranging from 4 – 10 mm for small Weber numbers. They validated their model with the experimental data available in the literature. They concluded that the profile of trailing bubble changes significantly for non-Newtonian fluid as compared to Newtonian fluids. Faik and Mohammed [7] performed experiments to investigate the effect of temperature on the bubble rise and shape. They found that the bubble stability along the vertical path decreases and bubble rise velocity increases with the rise in temperature, respectively.

The present work focuses on examining two bubbles' motion characteristics co-axially (in the vertical direction) with a center-to-center distance of 50 mm. The width and height of the column are 100 mm and 300 mm, respectively. The water level is kept constant at 250 mm for all cases, and the rest 50 mm represents the air phase. A two-dimensional computational fluid dynamics (CFD) model has been developed in Ansys fluent v18.0 to formulate air bubble flow in the quiescent water column. The domain has meshed into quadrilateral elements. Furthermore, the volume of fluid (VOF) method [8] has been employed to formulate multiphase flow, which is extensively used where the liquid-gas interfaces are distinctive [9–11]. Along with the VOF model, the continuum surface (CSF) model [12] is also incorporated to address the surface tension effects. For accurate liquid-gas tracing, a geo-reconstruct scheme is implemented. Mass and momentum conservations are discretized and solved in a transient manner by using a non-iterative time advancement scheme.

The bottom and the two sidewalls are equipped with the no-slip boundary condition, while the top wall has the pressure outlet boundary condition. The operating pressure is equal to the atmospheric pressure, that is 101 325 Pa, and the gravitational force acts in the negative y-direction. A time step of 0.0001 s is set after the time dependency test, based on an explicit method. The under-relaxation factor of 0.3 and 0.7 was set for the momentum and pressure. At first, the CFD model with a single bubble of 20 mm diameter is analyzed. For validating the model, the bubble's terminal velocity is compared with the literature's available data. The CFD results show 0.69 %, 1.03 % and 8.11 % errors when compared with Clift et al. [13], Krishna and van Baten [14], and Rodrigue [15], respectively.

To investigate co-axial bubble flow, two cases of 15 mm and 20 mm bubble diameters are considered, as shown in Figure 1. For the 15 mm diameter case, the bubbles start to rise upward due to buoyant force. At t = 0.03 s, the shape of the bubbles begins to distort, and t = 0.11 s, the shape changes from circular to a crescent shape. As the surface tension, drag, and lift forces play a vital role in shape development. The bubbles continue to rise, and the shape transforms from crescent to ellipsoidal cap at t = 0.2 s. Until t = 0.2 s, the profile and centerline velocities of both bubbles are similar. However, the drag force on the leading bubble is more as compared to the trailing bubble. Because of less resistance, the trailing bubble's shape becomes similar to the Taylor bubble (identical to slug shape) at t = 0.3 s. As the trailing bubble cover less frontal area, the centerline velocity of the bubble increases to 0.75 m/s, and as it reaches near the leading bubble, it breaks up into two bubbles at t = 0.4 s. The bubbles merge at 0.48 s and reach the top at 0.77 s. The 20 mm diameter case exhibits a similar trend; however, when the shape of the bubbles changes from crescent to an ellipsoidal cap, tiny bubbles form at the trail of each bubble at t = 0.15 s because of the instability. The trailing bubble begins to elongate further, and the top and the trailing bubbles have entirely different profiles. This process changes the bubbles' mobility and speeds up the merging mechanism. The trailing bubble separates into a couple of tiny bubbles after joining the leading bubble.

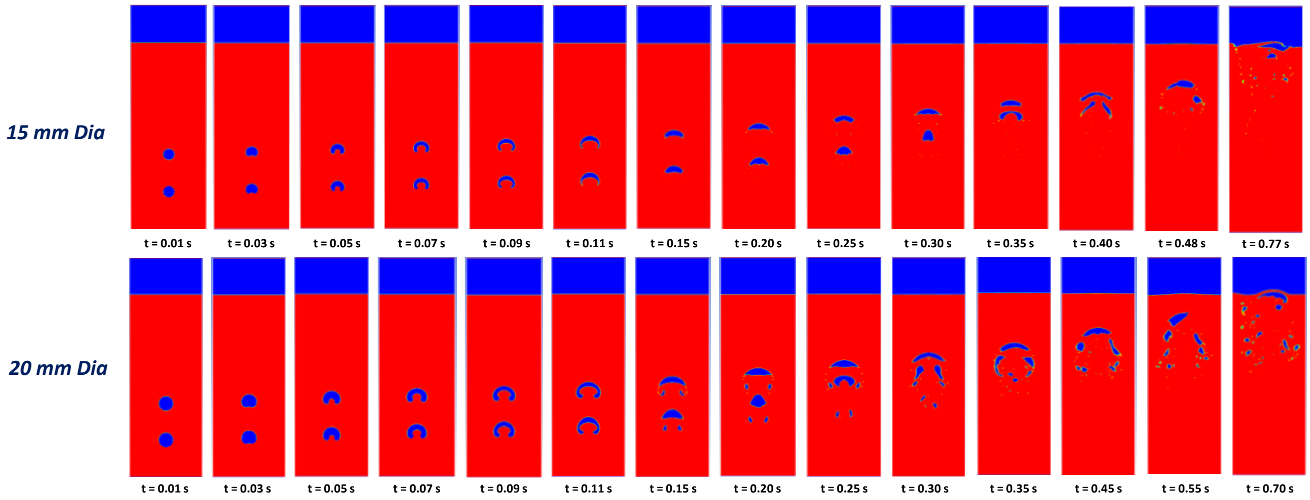

Figure 1. Transient behavior of 15 mm and 20 mm co-axial bubbles in the stagnant liquid

It can be seen that for larger diameter bubbles, the bubble collapses before merging into the leading bubble. This is because of the flow field around the bubble that causes instability. Furthermore, the change in the pressure field below the leading bubble changes the rising velocities. The present study outcomes help understate the fundamentals of bubble rise and can be used in large-scale problems. This work sets a basis in examining the mass transfer mechanisms such as bioreactors, bubble columns, etc.

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