Eulerian-Eulerian Approach to CFD Simulation of Two-Phase Bubble Column

Nur Khairunnisa Abd Halim¹, Siti Aslina Hussain¹,³, Mus’ab Abd. Razak¹, Mohd Amirul Syafiq Mohd Yunos²

¹Department of Chemical and Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
²Plant Assessment Technology, Industrial Technology Division, Malaysian Nuclear Agency, Bangi 43000 Kajang, Selangor Darul Ehsan, Malaysia
aslina@upm.edu.my

Abstract. Calculation work is carried out in the present project to study the effect of different parameters on hydrodynamics of gas-liquid flow by using CFD. The steady state and transient, three dimensional simulations are performed of the whole bubble column for various inlet gas and sparger designs. A standard k-ε is used to describe turbulence occurring in the continuous fluid. Results show he asymmetric recirculation stronger with an increase in the number of holes giving better mixing. The gas hold-up increased with superficial gas velocity but independent of the sparger design at high velocity. Comparison of simulation results with the previous experimental work data has provided a successful validation of the model.

1. Introduction
Bubble column reactors are frequently opted for multiphase flow system due to its easiness in mechanical part, low maintenance and cost operation, and have good heat and mass transfer characteristics [1]. The limitation of bubble column reactors is of their non-uniformity in back-mixing, bubble size distribution and gas hold-up have large diversities. Although bubble column reactors are widely used in industrial gas-liquid processes [2], detailed understanding is still lacking due to their complex flow encountered inside bubble column despite of its simple construction.

A range of works have been published to capture the dynamic characteristic of gas-liquid flow through experimental [3, 5, 6] and numerical [4, 7, 8]. Several number of frameworks for the description of flow dynamics in bubble column reactor have been considered particularly extensively, are gas distributor [2-4, 9]; superficial gas velocity [8]; gas hold-up distribution [2, 10]; operating and design variables [3]; as well as flow pattern [8, 11]. In most previous publications on computational studies, the model is evaluated based on data collected with a single sparger with a pair of air-water system.

The brief review of previous works points out the need to study the sparger configuration and its influence of gas flow rate on dynamics of gas-liquid flows. In order to compliment the simulation results, two different design of spargers were applied on the same domain model to observe the effect of sparger design on gas hold-up distribution along axial direction. Comparison of results of both spargers will develop the relationship between model design and gas velocity, and their effects on flow dynamics of vertical bubble column.
2. CFD Model

A 3D-computational vertical domain of rectangular shaped bubble column with dimensions of 0.2 m width, 0.2 m depth and 1.0 m height are used in this numerical modelling. The schematic diagram of actual design of bubble column reactor is shown in figure 1. Two different design of sparger is modelled to provide adequate mixing behaviour in reactor for scale-up purposes. The plate designs are frequently used by current chemical and petrochemical plants in their bubble column reactors. The specifications of spargers are given in table 1. The superficial gas velocity of 0.0125 m/s, 0.0501 m/s and 0.0627 m/s are applied for individual spargers.

![Sparger Diagram](image)

*All dimensions are in millimetres (mm)*

**Figure 1.** Schematic layout of bubble column.

| Sparger design | A | B |
|----------------|---|---|
| Sparger code   | A | B |
| No. of holes   | 1 | 4 |
| Holes diameter (mm) | 5.0 | 2.6 |

**Table 1.** Details of sparger design.

Commercially available CFD code, ANSYS™ 19.0 software is used to numerically model the hydrodynamics of the bubble column reactor. The code technique bases on the finite volume methods with Euler-Euler two-fluid models as proposed by Sato and Sekoguchi [12, 13]. The simulations are carried out with air and water taken as dispersed and continuous respectively. The model equations for the two-phase turbulence flow were solved in each cell of domain. No slip boundary conditions were used at all the impermeable cells. Normal liquid velocity was set to zero. Turbulence were modelled using k-ε equations [13, 14]. Grace correlation was used for interphase momentum transfer and Lopez de Bertonado for turbulence dispersion, with turbulent dispersion coefficient value of 0.3 [14, 12]. Calculations were performed in time dependent mode with first order implicit formulation. The Schiller and Naumann model (default in CFX) was used for interphase drag coefficient. The timestep of 0.1 s was used constantly throughout the simulation. Convergence criteria for continuity, momentum, turbulence, kinetic energy and rate of dissipation were set as $1 \times 10^{-6}$ for each timestep.
3. Results and Discussions

3.1. Effect of sparger design on flow pattern and gas hold-up profile
There are mainly two configurations of sparger plate used in this study which are as listed in table 1. To study the effect of the distributor configuration, simulations were performed at constant gas velocity. Figure 2 shows snapshots of contour plots of axial liquid velocity for both spargers at timestep of 0.1 s with constant bubble size diameter of 4 mm for superficial gas velocity of 0.0125 m/s. The bubble size diameter was specified based on experimental measurements using referral bubble column design and specification by Yunos et al. [6]. By comparing of the snapshots, it shows that the flow pattern evolution with different sparger was quite dissimilar. sparger B has the smaller diameter of holes and higher number of holes compared to sparger A. The contour plot shows the fluid flows upward towards dispersed area where the bubbles expanded and dispersed up to the surface of the liquid. Therefore, the asymmetry in the recirculation velocity pattern of fluid increases as the number of holes decreases which is in accordance with McClure et al. [9].

![Sparger A and B](image)

Figure 2. Plot contour of axial liquid velocity at vertical mid-plane of both sparger A and B at constant superficial gas velocity of 0.0125 m/s.

In contrast to liquid flow pattern, the gas hold-up is rather interrelated in complex way with the sparger hole size and numbers. However, one would expect that an increase in number of holes will increase the value of hold-up. This complex issue can be attributed into different modelling and physical phenomena. Firstly, from the experimental work by McClure et al. [9], it is explained that the difference in gas hold-up among different sparger becomes small at higher superficial gas velocity. For this present work, the superficial gas velocity is used toward the highest value could obtained of 0.0627 m/s, thus it is expected the variation of gas hold-up with respect to sparger design would be small. Secondly, gas hold-up is primarily function of the superficial gas velocity. Shah et al. [15] said that the gas hold-up increases linearly with the increasing superficial gas velocity. In these simulations, a constant value of superficial gas velocity is used therefore, the gas hold-up may remain independent of sparger design. Lastly, the gas hold-up is directly affected by the bubble size distribution in the bubble column. In this case, the bubble size is set constant at 4 mm to simplify numerical calculations. This proves another reason for the invariance of the gas hold-up distribution is required. However, according to Sanyal et al. [10] this model can be safely relied upon if the volume averaged steady state gas hold-up is of interest.
Figure 3. Axial hold-up velocity over column width at different heights for sparger A and B with constant superficial gas velocity of 0.0501 m/s.

Axial hold-up velocity accordance to width of column are plotted in figure 3 for both sparger at superficial gas velocity of 0.0501 m/s within three different heights. From figure 3, sparger B shows wider distribution of gas bubbles in the column compared to sparger A. Thus, for this case we have calculated the average holdup along vertical central line of column width for each height. As observed in the graphs plotted, we can predict on how the hydrodynamics of fluid occurs in the bubble column. The axial hold-up for sparger A starts lower and reached the highest values of 0.875 at h/D of 1.25. However, the velocity drops again after that specified width of column. On the other hand, sparger B shows highest value of axial hold-up at 0.975 near to the sparger plate and decreasing slowly with respect to width of column. This is because it assumed that the liquid enters the column uniformly over the entire cross section. As the liquid moves up the column, it develops a parabolic profile. The velocity of the liquid varies with time and location in the column which is consistent with existence literature values [8].

3.2. Effect of superficial gas velocity on flow pattern and local hold-up profile
To study the effect of varies values of superficial gas velocity, the simulations were performed using sparger with highest number of holes, which is sparger B to all superficial gas velocity values. Figure 4 shows liquid velocity vectors for the above simulation at timestep of 0.1 s for sparger B. Relatively axisymmetric flow pattern disappears for higher superficial gas velocity (>0.05 m/s) [9]. Thus, bubble column flow pattern should be treated with caution before create any qualitative conclusion, particularly when it involves extrapolations of process variables such as the superficial gas velocity.
Figure 4. Effect of superficial gas velocity on liquid velocity vectors for sparger B.

Figure 5. Distribution of average gas hold-up (a) at different heights along column width with sparger A and (b) comparison between sparger A and B at h/D value of 1.25.
Figure 5 shows the graphical plots of the average values of gas hold-up as a function of superficial gas velocity at total time of 5 s. From the graph plotted in figure 5(b), it shows that the values of gas hold-up increase as superficial gas velocity increases due to the increment in turbulence of the liquid phase. However, the values of average hold-up of sparger B is lower compared to values of sparger A shows that the gas hold-up is not interrelated with sparger design particularly at high superficial velocities. The hold-up starts to differs at lower superficial velocities where the sparger with smaller hole diameter has much higher hold-up. Such results are similarly reported by other authors [3, 4, 9]. Therefore, we could say that the gas hold-up is directly proportional to the superficial gas velocity which is accordance with previous literature by Wagh et al. [2].

3.3. Model validation
To achieve validation of the model used, axial velocity data of experimental and numerical results were plotted both sparger A and B at constant superficial velocity of 0.0501 m/s shown in figure 6. The numerical data were taken from earlier study by Yunos et al. [6] obtained by using high speed camera technique. From the graph plotted, it shows that the values plotted in sparger A is higher compared to data plotted in sparger B showing that the axial velocity is ignoring the distributor effect at high superficial velocities. Since this is an incipient studies, there is not much validation has been done to compare with the experimental data.

![Figure 6. Comparison of numerical and experimental data on axial velocity values for both sparger A and B.](image)

4. Conclusion
The overall gas hold-up and its distribution along axial direction of column is discussed. From the analysis, it shows that there is significance impact of sparger design and superficial gas velocity on dynamics of bubble column. The transition velocity from bubbly to churn-turbulent flow increases with increasing superficial gas velocity value. It was also found that the orifice diameter of sparger affect column performance the most at low superficial velocities (<0.05 m/s). Higher overall hold-up occurred at sparger with the smaller orifice diameter. However, the sparger holes does not affect much at higher superficial velocity. Therefore, we could say that the gas hold-up increased with superficial gas velocity but is independent on sparger design at high superficial velocity (>0.05 m/s).
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