CFD Investigation of Bubble Column

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***Abstract:*-Mixing and transport bubbles in bubble column is an important activity which affects the reaction conditions. In this paper, we have studied the effect of different bubble diameters at same velocity in a conical bubble column using CFD code ANSYS fluent 15.0. The dispersed gas-liquid flow in bubble column using the multiphase mixture model was adopted. A set of equations of continuity, momentum & volume fraction were solved by pressure implicit splitting operator (PISO) algorithm to observe the pattern of bubble rising.**

I. INTRODUCTION

Gas-liquid bubble columns are commonly used as multi-phase reactors in chemical, petrochemical, biochemical and metallurgical industries [1]. Bubble column reactor is basically a cylindrical vessel with a gas distributor at the bottom. The gas is sparged in the form of bubbles into either a liquid phase or a liquid-solid suspension. They are used especially in chemical processes involving reactions such as oxidation, chlorination, alkylation, polymerization, and hydrogenation in manufacture of synthetic fuels by gas conversion processes and in biochemical processes such as fermentation. The famous chemical applications are Fischer Tropsch process which is indirect coal liquefaction process to produce gasoline and other synthetic fuel[1].

An important application area of bubble columns is their use as bioreactors in which microorganisms are utilized in order to produce industrially valuable products such as enzymes, proteins, antibiotics, etc.

Bubble column reactors have high mass & heat transfer coefficients. Little maintenance and low operating costs are required due to lack of moving parts and compactness. Due to industrial importance and wide application area, the design and scale-up of bubble column reactors. Investigation of importance of hydrodynamic and operating parameter characterizing their operation have gained considerable attention during the past 20 years

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Recent research with bubble columns focuses on the following topics: gas holdup studies[3,4], bubble characteristics[2,5], flow regime investigations and computational fluid dynamics studies[1,7], local and average heat transfer measurements, and mass transfer studies. The effect of operating conditions, i.e. pressure and temperature, the effect of superficial gas velocity, solid type and concentration are commonly investigated in these studies.

The design of the bubble columns have gained considerable attention in recent years due to complex hydrodynamics and its influence on transport characteristics. Although the construction of bubble columns is simple, accurate and successful design require an improved understanding of multiphase fluid dynamics and its influence. Large reactor height is required to obtain large conversion levels.

The gas flow into the column is measured via rotameter and superficial gas velocity is adjusted. An electric heater can be used to maintain constant temperature in the column. The pressure measurement system may contain liquid manometer. Pressure measurements are used to estimate gas holdup in the system.

II. SYSTEM ADOPTED FOR STUDY

The geometry of bubble column is shown in a figure 1and given in a table 1.

Table 1: Dimensions of bubble column.

Length (cm)	40
Breadth (cm)	30
Location of cut from the edge (m)	1.5

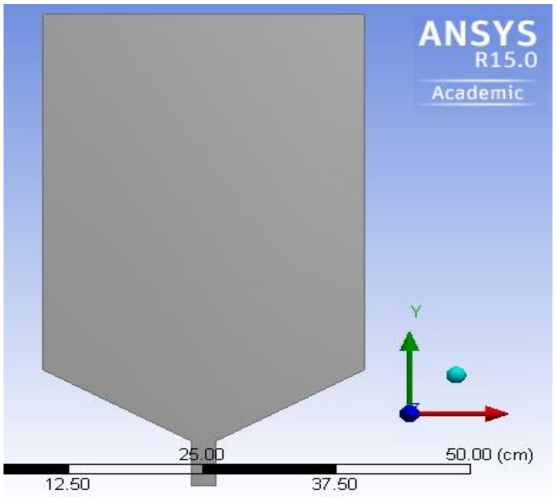

Figure 1: Schematic of gas-iquid bubble column

The mesh of fluid geometry is shown in figure 2. The square meshing was adopted through ANSYS fluent 15.0. ANSYS mesh was fine.

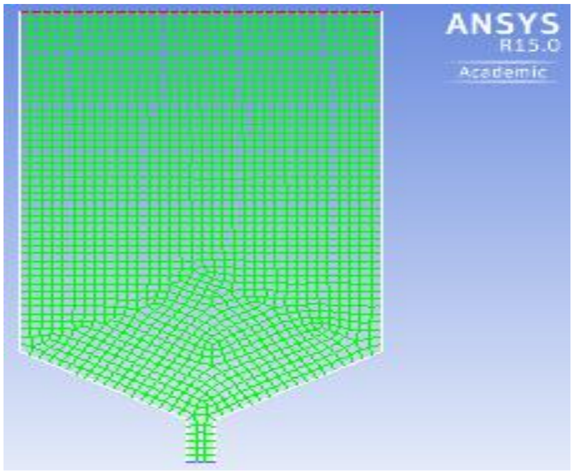

Figure 2: 2-D Mesh of bubble column

III. MODEL EQUATION ADOPTED FOR STUDY

For incompressible flow and a constant density fluid, the continuity, momentum and volume fraction equation was as follows:

Continuity equation:

$$\frac{\partial}{\partial x}(u) + \frac{\partial}{\partial y}(v) + \frac{\partial}{\partial z}(w) = 0 \qquad (1)$$

x-component of momentum equation:

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho uu)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial \mathrm{p}}{\partial x} + \frac{\partial}{\partial x}\left(\lambda\nabla.\vec{V} + 2\mu\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)\right] + \rho f_{\mathrm{x}} \qquad (2)$$

y-component of momentum equation:

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho vv)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial \mathrm{p}}{\partial y} + \frac{\partial}{\partial y}\left(\lambda\nabla.\vec{V} + 2\mu\frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)\right] + \rho f_{\mathrm{y}} \qquad (3)$$

Volume fraction equation for secondary phase (air):

From continuity equation for secondary phase (p), the volume fraction equation of secondary phase (q) can be obtained:

$$\frac{\partial}{\partial t}(\alpha_{\mathrm{p}}\,\rho_{\mathrm{p}}) + \nabla.(\alpha_{\mathrm{p}}\,\rho_{\mathrm{p}}\,\vec{V}_{\mathrm{m}}) = -\nabla.(\alpha_{\mathrm{p}}\,\rho_{\mathrm{p}}\,\vec{V}\,\mathrm{dr.p}) + \sum_{q=1}^{n}(\dot{m}_{\mathrm{qp}} - \dot{m}_{\mathrm{pq}}) \qquad (4)$$

Where,

$$\vec{V}\,\mathrm{dr.p} = \vec{V}_{\mathrm{pq}} - \sum_{k=1}^{n} C_{\mathrm{k}}\,\vec{V}_{\mathrm{qk}}$$

Relative velocity or slip velocity:

Relative velocity is defined as difference between velocity of a secondary phase (p) and velocity of primary phase (q) :

$$\vec{V}_{\mathrm{pq}} = \vec{V}_{\mathrm{p}} - \vec{V}_{\mathrm{q}} \qquad (5)$$

IV. PARAMETERS TAKEN FOR STUDY

Study of bubble column was done on different diameter of bubble at velocity 0.66e-3 m/s and at different time steps.

Table 2: Parameters adopted for study

Bubble diameter (cm)	0.002	0.005
Time step	1	0.1

V. SOLUTION STRATEGY ADOPTED BY ANSYS 15.0

The side and bottom walls of the domain are assigned as no slip velocity condition and the top wall as pressure outlet boundary condition. Operating pressure is set to be equal to the ambient pressure, i.e., 101325 Pa & the gravitational force (g) of 9.81 m/s^2 is assigned along – Y axis. The continuity, momentum & volume of fluid fraction equations were solved using the ANSYS-FLUENT, which is based on the finite volume method. The pressure implicit with splitting operators (PISO) algorithm was applied to solve the pressure-velocity coupling [6], which allows a rapid converge rate without a significant loss of solution stability & accuracy. Pressure was solved using a body force weighted scheme & an implicit body force treatment was applied to improve the solution converge.

VI. RESULT AND DISCUSSION

Modeling of gas-liquid flow in a bubble column has been successfully carried out using mixture modeling approach. It was suggested that the prediction accuracy can be significantly affected by bubble size. Bubble size has a great influence on the gas-liquid flow in bubble columns because they affected directly the interphase forces between gas and liquid. Results are based on laminar regime.

The figure 3 shows the contours of volume fraction with bubble diameter of 0.005, which is good agreement with the literature. Figure 4 shows the velocity vectors at bubble diameter 0.005.

It is necessary to have a sufficient fine grid for gas-liquid simulation, as the coarser grid may not be small enough to resolve the multiphase flow pattern. In the case where the experimental data are available, grid refinement need to be applied until a reasonable agreement is obtained. If the experimental data are not available, a grid independence analysis might be necessary.

Convergence is about to accurate at time step 1 then time step 0.1. It was observed that mixing is good in smaller bubble diameter then larger diameter.

The figure 5 shows the contours of volume fraction volume fraction with bubble diameter of 0.002, which is good agreement with the literature . Figure 4 shows the velocity vectors of bubble diameter 0.002.

The vector plots are shown in figure 4 and figure 6 for the diameters (0.005) and (0.002) respectively. The velocity vector direction of smaller bubble is very good compare to bigger bubble diameter.

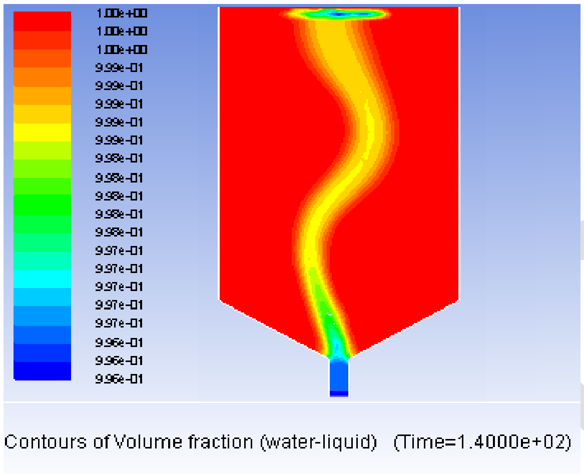

Figure 3: contours of volume fraction having bubble diameter 0.005

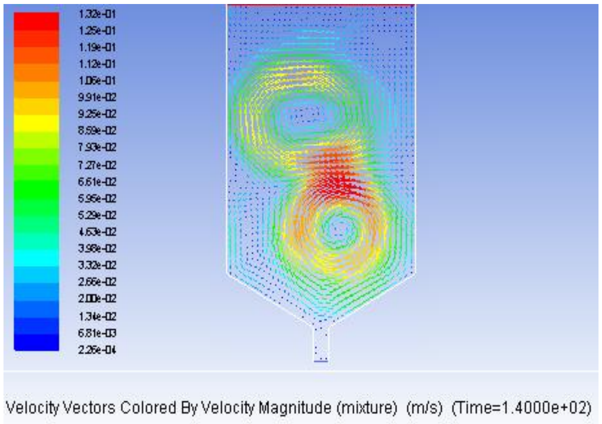

Figure 4: velocity vector of diameter of 0.005

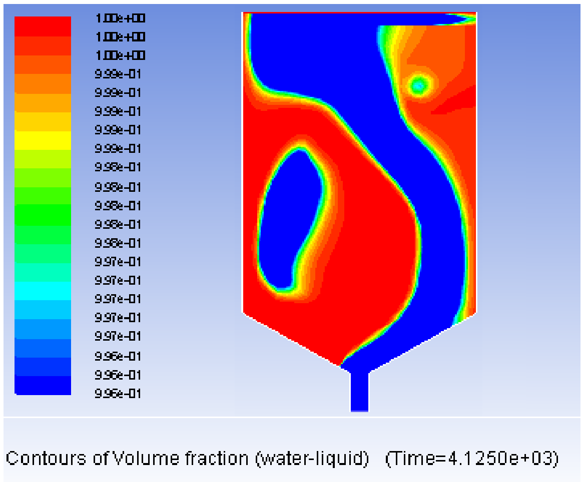

Figure 5: contours of volume fraction having bubble diameter 0.002

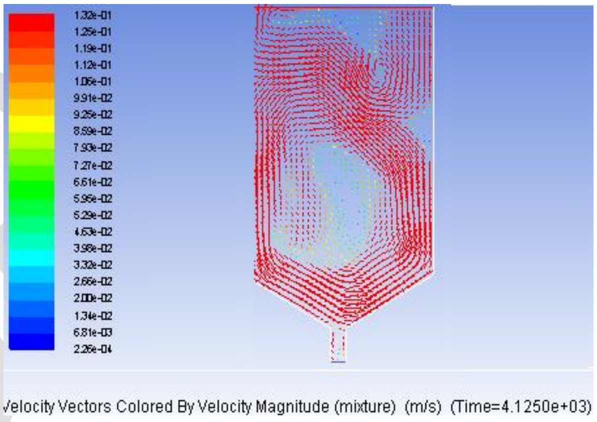

Figure 6: velocity vectors of bubble diameter 0.002

Mathematical Symbols

ρ - density
u - velocity in x-direction
v - velocity in y-direction
w - velocity in z-direction
λ - bulk viscosity coefficient
μ - molecular viscosity coefficient
C_k - mass fraction for any phase
α_p - volume fraction of phase p

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