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A CFD STUDY OF SWIRL EFFECT ON HYDRODYNAMICS IN A GAS-LIQUID BUBBLY FLOW REACTOR

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ABSTRACT

Gas liquid bubbly flow reactors are used in chemical and bioprocess industries to enhance the mass transfer between the gas and liquid phases. In bubbly flow reactors, the mass transfer is most important parameter, which affects the product conversion and reactor performance. Mass transfer can be enhanced by achieving more efficient mixing. One such method is the application of rotation or swirl to the gas liquid mixture. Commercial code, Ansys Fluent 14.0 has been used to simulate the phenomenon prevailing in the bubbly reactors with conventional gas injection as well as rotating bottom plate through which the gas is introduced into the column. An attempt has been made to assess the effect of gas injection and swirl bubbly flow, gas void fraction and shear stress by the use of CFD Code. The results of the investigation showed that the gas void fraction increased with increasing in air gas rate for both conventional and swirl gas injection.

Keywords: bubbly flow, mass transfer, swirl flow, CFD.

INTRODUCTION

Bubbly flows occur in many industrial processes especially in power plant for heat transfer through boiling and bubble driven circulation systems such as steel making, ladle metallurgy and refining of aluminium [1]. The two-phase bubble column has gained huge attention in studies in recent years due to its complex hydrodynamics and its influence on transport characteristics [12, 8]. Gas liquid bubbly flow reactor is used in chemical and bioprocess industries to enhance the mass transfer between the two phases. In bubbly flow reactor, the mass transfer is vital because this gives rise to the yield through enhanced reactor performance. Mass transfer can be enhanced due to an efficient mixing, which can be achieved, in addition to conventional means, by the use of rotating or swirl flow to the fluids. The rate of mass transfer between gas and liquid is essential to the reactor performance [6]. It remains a difficult problem to understand the rate of mass transfer in the reactor and it is essential to know how to describe the interphase mass transfer phenomenon of bubbly flow.

In chemical processes, swirling flow can enhance the mixing of reactants, which leads to the increase in the mixing efficiency as well as mass transfer rate of the reactants and hence the production yield is increased. Swirl flow also enhances heat and mass transfer in pipe flow [2] and can affect the mixing behaviour and thus the hydrodynamic characteristics. Shaikh (2007) stated that different hydrodynamic characteristics (e.g. velocity, turbulent intensity) result in different mixing as well as heat and mass transfer for different flow regimes. Sreevisanan and Raghavan (2002) found that the pressure drop in swirling regime is not constant, but it can increases with increase in gas flow rate. The dominant process occurring inside the column is the mass transfer between bubble and liquid [17].

Computational Fluid Dynamic (CFD) has gained attention towards the design and scale up of reactor with low cost and high reliability, especially for reactors operating under harsh conditions (e.g. high pressure and high temperature [6]). CFD has gained wide attention for bubble column, as it has the ability to predict the fluid hydrodynamics. Among prominent mathematical approaches, used to simulate gas - liquid flow in bubble column, Euler - Euler and Euler - Langrarian gained particular attention. Euler - Euler approach is useful when considering the gas and liquid phases as 2 interpenetrating fluids in a Eularian framework. Euler - Lagrarian approach is used when liquid phase is treated as continuum, while in the gas phase each bubble is tracked separately [9].

In generalized gas–liquid two-phase flows, bubbles are observed in different sizes and shapes; behave differently in terms of relative motion and interaction mechanisms [20]. Bubbles are categorized into various groups with its own transport phenomena. For a special case of bubbly flows, all of the bubbles are in spherical or distorted shape. The injection of air bubbles can increase the wall shear stress, which bubbles travelling close to the wall create a periodic perturbation. The small bubbles will tend to move to the wall, hence more bubble will move to the wall. As more air bubbles travel in the wall region, the mean shear stress increases [5].

This paper focuses on finding out the effect of gas inlet pressure onto gas void fraction and shear stress in the bubble column with swirl gas injection by rotating the bottom plate of the vessel. CFD has been used to simulate the hydrodynamics of such bubbly flow reactors.

METHODS

CFD has been used to simulate the bubbly flow in a column with conventional gas injection and swirl bubble injection. Void fraction and flow pattern and shear stress have been determined for the two cases by use of CFD Code, Ansys Fluent 14. Three dimensional Euler - Euler phase fluid approach has been used to achieve this flow. The turbulence in the liquid phase has been modelled using the standard k - ε model. The interactions between air - water phases are described through Schiller - Neumann drag coefficient formulation. The technique used for pressure coupling was phase coupled scheme, and the relaxation values for the pressure and momentum equation were set to 0.3 and 0.7 respectively. Relaxation factor were used in the pressure - based solver to stabilise the convergence behaviour of the outer non - linear iterations and prevent the solution from diverging. These simulations were operated over a range of gas rate (i.e. 0.023 - 0.091 kg/s) at ambient conditions in the column. Table-1 shows the properties of air and water and Table-2 describes the operating conditions used in the simulation.

Table-1. Properties of air and water.

Phases	Density	Viscosity
Liquid (Water)	998.2 kg/m^3	0.001003 kg/m-s
Gas (Air)	1.225 kg/m^3	1.7894e-5 kg/m-s

Table-2. Operating conditions used in simulation.

Parameters	Conditions
Temperature (K)	298
Gas rat (kg/s)	0.023 – 0.091
Phases	Liquid (Water) & Gas (Air)

An air - water bubble column of diameter 0.254 m and height0.3048 m has been simulated using commercial CFD software package Fluent 14.0. All simulations were carried out by injecting bubbles into an initially quiescent liquid. Depending on the injection pattern, bubbles will rise through the liquid and occupy the column space with different patterns until a fully developed condition is reached [4]. Use of fine mesh system can gives more accurate picture of various simulated parameters. A mesh size of 0.005m are used in order to have better accuracy with 426,644 numbers of cells. The mesh grid for the bubble column used in the simulation is shown in Figure-1.

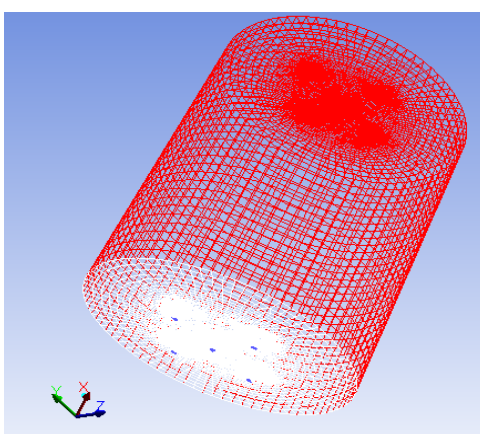

Figure-1. Mesh grid for the bubble column design.

RESULTS AND DISCUSSIONS

Void fraction

The contour plots of gas void fraction at a different gas rate inlet of 3D bubble column are shown in Figure-2. It is seen from the contour that the gas void fraction is higher at the bottom section compared to the section above the bubble column. Also, it is observed from the figure that the gas void fraction varies non - uniformly due to non-uniform distribution of gas injection at the bottom of the column.

Gas void fraction plays an important role in gas - liquid mass transfer, as higher void fraction usually gives rise to higher mass transfer. The mean void fraction across the column is shown in Figures-3 and 4.

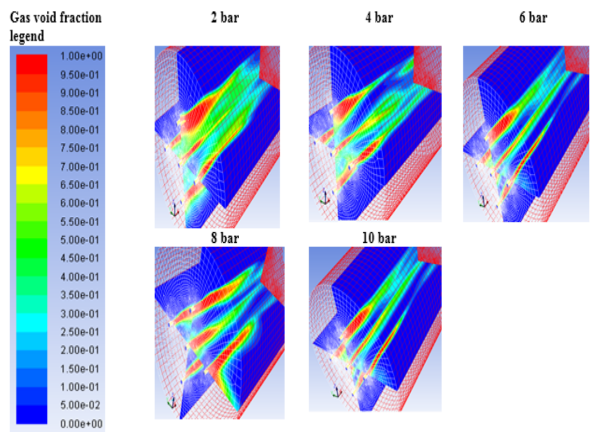

Figure-2. Contour of gas void fraction for conventional gas injection in bubble column.

From these figures, it is observed that the gas void fraction increases with an increase in inlet gas rate. The gas void fraction is highest at the bottom of the column and the void fraction decreases progressively as the bubbles move up the column.

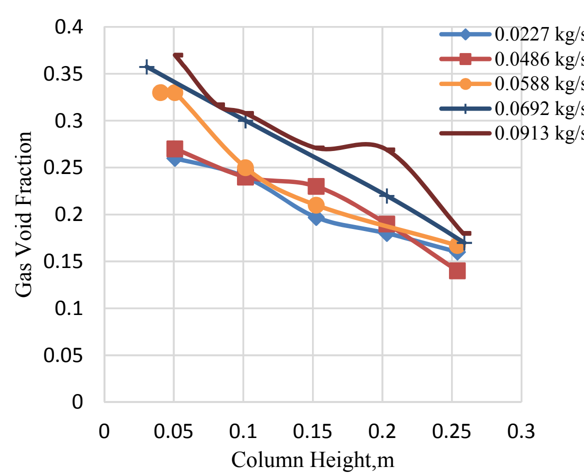

Figure-3. Gas void fraction versus bubble column position for conventional gas injection.

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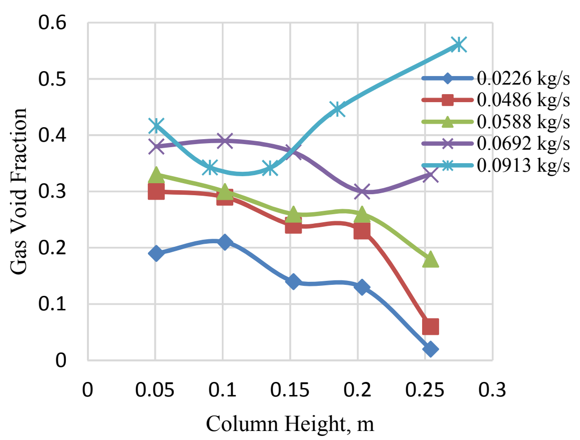

Figure-4. Gas void fraction versus bubble column position for rotating system at 60rpm.

When the bubbles move up, they disperse and cover the whole cross - section of the column. Increase in void fraction due to the increase in the gas rate here, can be verified from experiments done by Wilkinson and Dierendonck (1990), Letzel *et al.* (1999) and Clark (1990). The increase in gas void fraction at high gas rate is due to the formation of the small bubbles [16] because of the bubble breakup and less buoyancy force which it results in lower difference in phase densities [15]. Axial and radial distribution also has been affected by the gas void fraction and gas rate. As the gas void fraction is higher in the center of the column, the axial and radial distribution increased, but decrease at the top of the column. When gas inlet pressure is increased, the axial distribution also increase, but radial distribution is decreased due to at high pressure air moves towards the top of the bubble column.

Shear stress

Figure-5 shows computed values for wall shear stress against gas rate. This figure shows that wall shear stress increases by increase of gas rate. This is consistent to the general understanding that increased bubble buoyancy contributes to the water velocity profile that gives rise to increased wall shear stress. As seen from figure, the wall shear stress for rotating air injection is higher compared to the conventional gas injection due to induced eddies occurred in rotating flow.

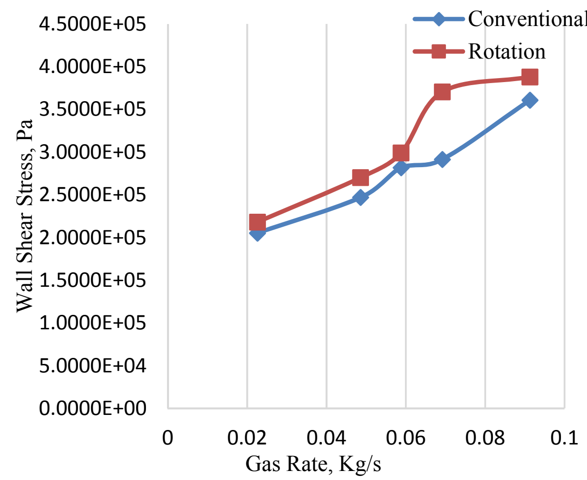

Figure-5. Wall shear stress at different air inlet pressure.

CONCLUSIONS

CFD simulation has been carried out on gas hold up characteristics of two phase for direct and rotating gas injection. The gas holdup is found to be decreasing with decrease air pressure inlet. This phenomenon accord due to the presence of rotating fluid which change the flow pattern of water and air bubbles. Thus resulted in formation of eddies and which recirculate the air inside the air water bubbly flow led to higher gas void fraction and shear stress.

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