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3 dimensional hydrodynamic analysis of concentric draft tube airlift reactors with different tube diameters

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ABSTRACT

The CFD simulation for concentric draft tube airlift reactors with 3D analysis is developed in this study. The simulations were conducted for reactors considering two-phase flow. Simulation of two reactors of different sizes and tube diameters is presented here for investigating the effect of tube diameter in gas hold-up and velocities. The data which is obtained from the simulation is compared with the experimental data to determine the gas hold-up. The comparison between gas hold-up and superficial gas velocity was made and the velocities were set between 0.018 and 0.108.

1. Introduction

The use of airlift reactors in chemical engineering processes and biochemical technology has been given much attention and that is because of their special hydrodynamic characteristic. The advantages of these reactors give them use in research and industry [1]. These contactors have especially been used in environmental healing. The main advantages of airlift reactors are: easing scale ups, low pressure, high rate of mass transfers, low power requirements, good treatments of wastewater and non-mechanical stirring up [2]. So understanding the quality of the fluid dynamics in airlift reactors is necessary. The importance of these kinds of reactors in the biomass industry is because of the biomass effects on the gas phase and the influence on the viscosity of liquid phase [3]. Airlift reactors are discussed in two cases: external loop and internal loop. One sort of internal loop airlift reactor is the concentric draft tube airlift reactor. This type has a draft tube at the center of the column. So this contactor has a riser and two downcomers. Liquid circulation flow will develop between the riser and downcomers due to the gas holdup difference. Gas holdup is a special behavior in all types of airlift reactors. Sometimes gas will be circulated by liquid phase downflow too, when the small bubbles are entrained. The oxygen transfer from the gas to the liquid phase is developed due to the velocity of liquid circulation and gas holdup [4]. In 2004, a modified model was developed to study the performance of three types of bioreactors: airlift, bubble column and net column reactors. Experiments over heat mixing have been conducted to conclude the parameters of the relevant model and to confirm the resulting model. The dynamics of concentration and mixing manner of these three types of reactors has been investigated with a maximum non-zero Eigen value analysis. At last, the superior performance of the net column

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reactor over the airlift and bubble column reactors has been clearly displayed with this model [5]. In a few studies the hydrodynamics and mass-transfer characteristics of reactors with monolith loop, and upflow gas and liquid phases, have been studied and analogized with customary internal airlift and bubble column reactors. The corresponding data on gas holdup and volumetric mass-transfer coefficient, for both bubble column and airlift reactors have been developed, in which the same geometry and gas distribution has been used. Finally it was found that the volumetric mass-transfer coefficient per unit of volume of gas bubbles was dispersed and remarkably higher for monolith reactors than bubble columns. Airlifts and application of low-frequency vibrations has caused improvements on the volumetric mass-transfer coefficient for these entirely studied reactors [6]. Many efforts have been made to progress exact and practical predictive models of the flow regimes for improving the performance of these kinds of equipment in the past three decades. The simulation of two-phase flow for a concentric airlift reactor using computational fluid dynamics has been done by M. Blažej et al.. In their study, the simulated data has been compared with the data from the experiments obtained by tracking a magnetic particle and pressure drop analysis for calculating the gas hold-up. The similarity between superficial gas velocity and gas hold-up has been discussed for a series of experiments. In case of liquid velocities and gas holdup in the riser, an appropriate result has been followed and the modeled values have been revealed with good accuracy, but in the downcomer, there is no good accuracy [3]. This work presented here is a comparison between two simulated concentric draft tube airlift reactors with different sizes of tube diameters which is obtained with the CFD method. In this study the effect of diameter of the riser on the velocities and gas phase holdup has been investigated.

2. Simulation

The corresponding reactor is a concentric draft tube airlift reactor with an outer cylinder, there is a riser in the draft tube and two downcomers between the draft tube and outer cylinder. The outer cylinder has a diameter of 0.147 m and liquid height of 1.818 m. At the base of the cylinder, there is a gas sparger with a diameter of 0.079 m which contains 25 holes. At the height of 0.046 m above the sparger, there is the draft tube. The tube height was 1.710 m and the external diameter of the tube was 0.118 m. A gas disengage was located above the cylinder with a diameter of 0.294 m [3]. For the second reactor the external diameter of the tube has been reduced to half.

An unstructured pattern has been made to depict the cells of the reactor's domain which is simulated, after drawing the three dimensional configuration of the reactor figure. This unstructured form is considerable for reducing the used mesh cells and with this the computations are decreased. Furthermore, it was simpler to use an unstructured format for volume meshing because of the complexity of three dimension meshes. For running the program in the present study, the initial condition which has been applied for acceleration vector (g) has been set as $-9.8\ \mathrm{m/s^2}$ and for performing the flow boundary condition, water velocity has been set as 0 m/s and the air velocities as 0.018, 0.024, 0.036, 0.072, 0.090, and 0.108 m/s. It should be noted that these values have been obtained with respect to the cross sectional area of the sparger. As the correlations have been proposed by Kastanek [10], the bubble diameter has been set as 0.005 m and air fraction has been considered 1 (because at first only air is introduced to the sparger). Densities of air and water were 1.225 and $998.2\ \mathrm{kg/m^3}$ and their viscosities have been considered as 1.7498×10^{-5} and 1.003×10^{-3} kg/m s respectively. This work has been performed in an unsteady state model. The gas phase holdup has been defined as the ratio of air volume fraction every water volume fraction and it has been recorded after each time step. For this simulation the Eulerian model has been used. The Eulerian model often is used for altering a single phase model to a multiphase model. In the single phase model, a single set of conservation equations of continuity and momentum should be solved but many conservation equations for a multiphase model need to be added. For each phase the volume fraction has been introduced ($\alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_n$) and a modification has been done [11–22]. These introduced volume fractions show the space occupied by every one of these phases. So v_q is defined by:

$$\alpha_q = \int \alpha_q dv \tag{1}$$

where

$$\sum_{q=1}^{n} \alpha_q = 1. \tag{2}$$

Effective density of phase q will be defined by:

$$\hat{\rho} = \alpha_q \rho_q. \tag{3}$$

The overall conservation equation for this kind of model is derived by ensemble. The continuity equation for phase q [7]:

$$\frac{\partial}{\partial t}(\alpha_q \rho_q) + \nabla \cdot (\alpha_q \rho_q \overrightarrow{V_q}) = \sum_{p=1}^{n} \dot{m}_{pq} \tag{4}$$

where $\dot{m}_{pq}$ is the mass transfer from phase p to phase q. From the mass conservation:

$$\dot{m}_{pq} = -\dot{m}_{qp} \tag{5}$$

and