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Procedia Engineering 42 (2012) 842 – 853

Procedia Engineering

www.elsevier.com/locate/procedia

20th International Congress of Chemical and Process Engineering CHISA 2012
25 – 29 August 2012, Prague, Czech Republic

High pressure experiments and simulations in cocurent bubble columns

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Abstract

Bubble column is a multiphase reactor in which gas is passes through the liquid in two phase flow. When liquid is stationary the operation is called as batch mode and co-current when both gas and liquid are moving in the same direction. The gas hold-up increases with increase in pressure for both batch & co-current column. This increment in gas holdup is very sharp initially, but soon it becomes insignificant. The increase in liquid velocity decreases the gas hold-up at all pressures. As we increase the pressure, the effect of liquid velocity is less. Three dimensional Euler-Euler two-phase fluid model has been used to simulate two-phase up-flow in bubble column (15cm diameter) using ANSYS 12.1. These experiments and simulations were operated over a range of superficial gas velocities (1 to10 cm/s) at ambient conditions as well as high pressures. The liquid velocity range was 0 to 16 cm/s. The turbulence in the liquid phase has been modeled using the standard k-ε model. The interactions between the two phases are described through Schiller Neumann drag coefficient formulation. The objectives are to find the effect of pressure and liquid velocity over gas holdup and to validate the CFD simulations with experimental data. Quantitatively good agreements are obtained between experimental data for hold-up and simulation values. Radial gas holdup profiles and axial liquid velocity profiles were also obtained for the simulation.

Keywords: Co-current flow; gas hold-up; high pressure;three dimensional simulation

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doi:10.1016/j.proeng.2012.07.477

1. Introduction

Bubble columns are used in the methanol synthesis, resid hydro-treating, Fischer-Tropsch synthesis and benzene hydrogenation at high pressures [1]. The gas hold-up increases considerably as the pressure is increased for both homogeneous and heterogeneous regimes [2, 3]. Increase in pressure delays the transition from homogeneous to heterogeneous regime by reducing the probability of propagation of instabilities [4]. It also enhances the breakup of the large bubbles due to decreased bubble stability as shown by Letzel et al. using the Kelvin–Helmoltz stability analysis [3]. Because of these two reasons, the gas hold-up increases with increase in pressure. Fan et al have shown that with an increase in pressure the rise velocity of bubbles in liquids and liquid-solid suspensions decreases, which also attributes for higher gas hold-up [5]. Li et al have shown that increase in pressure reduces the bubble size formed at the sparger, thus increasing the hold-up [6]. All of them have studied the batch operation mode only. Behkish in his experiments on N_2 and He in Isopar-M has shown that the increase of gas hold-up with pressure is mainly due to holdup of small bubbles, whereas hold-up of large bubbles remains constant [7]. In addition, he reports that the gas holdup also increases with increasing superficial gas velocity and temperature [7]. Ishiyama et al. found that there was no effect of pressure on gas holdup when a single nozzle of 4.0 mm was used, but when a single nozzle of 1.0 mm was used, the pressure effect was observed [8].

Computational fluid dynamics (CFD) has gained wide attention for bubble column, because of its ability to predict the fluid hydrodynamics properly. Two main approaches are generally used while modeling gas-liquid flow in bubble columns: Euler-Euler (E-E) [9] and Euler-Lagrange (E-L) [10]. The E-E approach (the two-fluid model) considers the gas and liquid phases as two interpenetrating fluids in a eulerian framework. The phases interact through the inter-phase transfer terms [11]. On the contrary, in the E-L approach the liquid phase is treated as a continuum; and in the gas phase each bubble is tracked separately. It's easy to introduce coalescence, break-up and collisions in the E-L model, but it's computationally very expensive due to tracking of each bubble separately. Additionally, E-E simulations are applicable to a wider range of volume fractions, while E-L is restricted to low particle volume fractions as the fraction of volume taken by the particles is not included in the continuous phase calculation. Furthermore, the use of high order discretization schemes with the E-E approach solve the problem of the higher numerical diffusion obtained in comparison with the E-L approach, as found by Sokolichin et al. [12].

In this present work E-E approach is adapted. All the simulations are done using ANSYS 12.1. The aim of this work is to study the effect of pressure and liquid velocity over gas hold-up in a co-current bubble column and also to validate the experimental gas hold-up with simulation values.

2. Experimental Set-up

The column is 2.72 m long and made of stainless steel (SS-304). Its inner diameter is 15.4 cm. Thickness of the material is 5 mm. 5 ports have been welded to it at different locations for measuring the pressure through differential pressure transducers. These are piezoelectric sensors supplied by the Honeywell International, USA (ST 3000 Smart Pressure Transmitter). A pressure release valve has been installed in the top section of the column. The whole set-up has been tested to withstand a pressure of 13 bars. The diameter of tank is 96 cm and thickness of the material is 5 mm. Total height of tank is 115 cm. Volume of tank is 850 liters. The outlet of the column is maintained at the operating pressure using the back pressure regulator. In the separator the gas and liquid phase separate out and gas phase is discharged to ambient with the help of a pressure release valve. The volume of the separator is 175 liter. The liquid