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Gas hold-up in three phase co-current bubble columns

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Abstract

Bubble columns are used in a large number of applications in chemical engineering. The important variables that affect the gas holdup, bubble dynamics and flow regime in a bubble column are gas and liquid velocities, liquid viscosity, liquid surface tension, design of the gas distributor, solid concentration and column diameter. Experiments have been performed in a 15 cm diameter co-current slurry bubble column with liquid phase as water and air as the gas phase. Glass beads of mean diameter 35 μm have been used as solid phase. Solid loading up to 9% has been used. The superficial gas velocity varies from 1.0 to 16.28 cm/s and superficial liquid velocity varies from 0 to 12.26 cm/s. Effects of liquid height, liquid velocity, gas velocity and solid concentration over gas holdup for both two and three phase co-current flows have been studied. For batch case the liquid height didn't affect the gas holdup. The gas holdup increases with increase in gas velocity for both two and three phase co-current columns. For two phase and three phase flow up to 1% solid loading; at low superficial gas velocity i.e. in the homogeneous regime, the increase in liquid velocity doesn't show any change in the gas holdup. For higher gas velocities i.e. in the heterogeneous regime, increase in liquid velocity decreases the gas holdup rapidly. Above 1% solid loading, liquid velocity effect over gas hold-up is negligible. With increase in solid concentration for co-current bubble column the gas holdup slightly increases or remains constant up to 5% loading; beyond this loading there is a significant decrease in gas holdup

Keywords: Bubble column; three phase flow; solid effect; co-current flows; gas hold-up

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1. Introduction

Bubble columns are mostly used as multiphase reactors in chemical, petrochemical, biochemical and metallurgical industries [1]. As compared to other reactors both in design and operation, the major advantages bubble columns provide are excellent heat and mass transfer characteristics, less maintenance and low operating costs due to lack of moving parts and can easily handle solids. The important variables affecting the gas hold up in a bubble column are gas and liquid velocities, liquid viscosity, surface tension, design of the gas distributor, solid concentration and column diameter [2-5].

Generally, at low superficial gas velocities bubbles are small and uniform in size [6]. Their size and uniformity depends on the properties of the liquid. It also depends on the design of the gas distributor and the column diameter. Here, bubble coalescence rate along the column is insignificant [7]. Hence, if the gas is distributed uniformly at the column inlet, a homogeneous bubble column is obtained.

At high superficial gas velocities, the bubble coalescence rate increases significantly, the gas-liquid flow becomes heterogeneous and the bubble column contains a mixture of large and small bubbles [7]. The size of large bubbles depends on the design of the gas distributor, column diameter and physical properties of the liquid. The hydrodynamics, mixing and transport properties of a heterogeneous bubble column are considerably different from that of a homogeneous column.

Numerous invasive and non-invasive techniques have been used to estimate the average gas hold up [8-9]. Measuring the gas holdup using DPT is non-invasive, hence does not interrupt bubble column operation. This method has been used in semi-batch bubble columns [10-12], and cocurrent bubble columns [13-14].

Shah et al. [15] studied the effect of liquid velocity in a downward flow bubble column. Tang and Heindel [16] studied the effect of sparger orientation in cocurrent and batch flow and observed a decrease in holdup with increasing liquid velocity. In cocurrent flow, the liquid velocity reduces the relative velocity between the liquid and gas and hence, the bubble- induced turbulence intensity. Hills has measured gas holdup in a 15cm diameter bubble column at gas superficial velocities of 0.07-3.5 m/s and liquid superficial velocities of 0-2.7 m/s. Hills [17]. He reported a decrease in gas holdup with an increase in liquid velocity. Fujie et al. [18] and Friedel et al. [19] also reported a decrease in gas holdup with an increase in liquid velocity in down flow bubble columns of 45 cm and 15 cm internal diameter, respectively.

Most of the published literature report that the gas holdup decreases with increasing solid concentration [13, 20-23]. The presence of solid increases the bubble size, which results in bigger and faster bubbles [13, 23-25]. In the presence of solid the increment in bubble population from small to large bubbles has been observed by Swart et al. [21]. Further, the reduction of bubble breakup [25-26] and increase of mixture viscosity [13, 22, 27-28] also contribute for the reduction of holdup.

Some other researchers have also observed a dual effect of solids on gas holdup [13, 29-32]. It indicates the presence of two counteracting physical mechanisms. Khare and Joshi [31] have shown that this dual effect leads to a maxima at about c = 0.6% of fine alumina particles. Banisi et al. [33] suggested that a small amount of fine particles (suppressing coalescence) and large amount of big particles (break up of large bubbles) tend to increase the holdup (reduce mean bubble speed).