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Mixing mechanism in a modified co-current downflow bubble column

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Abstract

Experimental measurements of longitudinal dispersion coefficients of liquid have been carried out in an ejector-induced bubble column operating with co-current downflow of gas and liquid. The experimental data obtained show that the hydrodynamics of the bubble column depend on nozzle diameter, liquid jet velocity and superficial liquid and gas velocities. A model with the consideration of combined action of velocity profile and the bubble motion was developed from Taylor's theory. The dispersion coefficient of bubble motion, D_b, and the characteristic factor of velocity distribution, k, depends on the nozzle diameter, fluid velocities, which give the corresponding model equations. The dispersion coefficient calculated from the model shows a good agreement with the experimental data of this investigation in the ejector-induced downflow bubble column.

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Keywords: Downflow bubble column; Liquid jet; RTD; Dispersion coefficient

1. Introduction

Bubble columns find numerous applications in the process industry due to their relatively simple construction, low operating costs, excellent heat transfer characteristics to immersed surfaces and the ease with which, the liquid residence time can be varied. However, many important fluid dynamical aspects of the prevailing gas–liquid two-phase flows are still poorly understood, despite their frequent use in variety of industrial processes. This is mainly due to the difficulty in understanding the complex flow fields in bubble columns and the relation between the flow pattern and design parameters such as pressure drop, fractional gas hold-up and liquid-phase mixing.

A lot of studies have been reported on the hydrodynamics of two-phase co-current flow in bubble columns but the majority of these studies deal with either horizontal two-phase flow or vertical two-phase up flow. Reports on two-phase vertical downflow in bubble columns are scanty. These studies can be categorized either under a plunging jet or sparger-type system. In the plunging jet system, a jet of liquid while plunging into a pool of the same liquid carries along with it some ambient gas, which disperses into bubbles due to momentum transfer of the jet. The liquid and gas bubbles move down through the liquid pool to some distance and the gas bubbles then move up. In the sparger-type system, gas is allowed to pass through the sparger and the liquid flowing past the sparger shears the gas and carries it down the column. In the gas–liquid ejector-induced co-current downflow bubble column reactor, both gas and liquid are concentrically introduced and the kinetic energy of the liquid jet is utilized to disperse gas into fine bubbles. Recently, this type of reactor has earned greater attention in industrial applications which make full use of the advantages of its finer and uniform bubble size, homogenization of the two phases, higher dispersion efficiency and higher residence time of gas bubbles, large interfacial areas and mass transfer rates. Some of the relevant work that have been published [3–5,8,14,15,17,18] are relevant to the liquid jet ejector systems.

Good knowledge of the extent of longitudinal mixing in the liquid phase is essential for the modeling, design and optimization of bubble column. Several studies have been done to account the mixing characteristics by residence time distribution techniques. Towell and Ackerman [27] studied

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Nomenclature

A_c	cross-sectional area of column (m^2)
A_n	cross-sectional area of nozzle (m^2)
C	tracer concentration of collected sample at time t (kg/m^3)
C_0	input tracer concentration (kg/m^3)
C_θ	normalized concentration (C/C_0)
D_b	diffusion coefficient of bubble motion (m^2/s)
D_C	diameter of the column (m)
D_m	molecular diffusion coefficient in liquid phase (m^2/s)
D_n	diameter of the nozzle (m)
D_T	diameter of tube (m)
E_z	longitudinal dispersion coefficient (m^2/s)
g	gravitational acceleration (m/s^2)
H	clear liquid height (m)
H_0	level of the bubbly flow (m)
k	characteristic factor of velocity distribution, dimensionless
ΔP	pressure drop (N/m^2)
Pe	Peclet number, dimensionless
Q_L	liquid flowrate (m^3/s)
Q_G	gas flowrate (m^3/s)
RTD	residence time distribution
R^2	correlation coefficient, dimensionless
t	time (s)
t_m	mean residence time (s)
V_G	interstitial gas velocity [V_{SG}/ε_G] (m/s)
V_j	liquid jet velocity [Q_L/A_n] (m/s)
V_L	interstitial liquid velocity [$V_{SL}/(1-\varepsilon_G)$] (m/s)
V_{L0}	interstitial liquid velocity in the centerline of the column
V_{SG}	superficial gas velocity [Q_G/A_C] (m/s)
V_{SL}	superficial liquid velocity [Q_L/A_c] (m/s)
V_0	representative local velocity defined in Eq. (6) (m/s)
X	parameter defined in Eq. (15)
Z	axial length (m)
Z_e	effective column length (m)

Greek letters

ε_G	fractional gas hold-up, dimensionless
μ_L	viscosity of the liquid (kg/(m s))
θ	dimensionless time (t/t_m), dimensionless

the axial mixing of liquid and gas in large bubble reactors with air–water system. They reported that the axial dispersion coefficient vary with the column diameter and the superficial gas velocity. Hikita and Kikukawa [11] studied the liquid-phase mixing on upflow bubble column reactor. They reported that not only column diameter and gas velocity effect the liquid dispersion but also the viscosity of the liquid has strong effect on the intensity of liquid-phase dispersion. Deckwer et al. [7] determined the liquid dispersion coefficient by stationary and a transient method in co-current bubble columns (15 and 20 cm diameter, 440 and 723 cm high) with different gas distributors. Ogawa et al. [21] studied the liquid-phase mixing in the upward gas–liquid jet reactor with liquid jet ejector. The longitudinal liquid-phase mixing pattern was quite different between the spouting section and the calm section. Groen et al. [9] investigated the axial dispersion phenomena in homogeneously aerated air–water bubble columns. They reported that axial dispersion in bubble column is regarded as transport with a typical velocity over a typical distance. They also proposed a model defining the axial dispersion coefficient as the product of the typical velocities with the column diameter which agrees well with existing literature data at lower superficial gas velocity conditions. Zahradník and Fialová [30] studied the extent of axial mixing in gas and liquid phases in tall upflow bubble column reactors with bubbling regimes. The experimental results proved an essential effect of gas dispersion mode (bubbling regime) on the extent of gas and liquid-phase mixing in the reactor. They also obtained the respective dependences of Peclet number of both gas and liquid on the superficial gas velocity. Hebrard et al. [10] studied axial liquid mixing in sparger-type upflow bubble columns and in membrane and perforated plate bubble columns. They observed that gas sparger has a strong effect on the gas flow regime and consequently on the axial liquid mixing. Krishna et al. [13] developed a reliable correlation for the liquid-phase longitudinal dispersion coefficient in upflow bubble column reactors. The measurements were performed in the churn-turbulent regime of operation with superficial gas velocities in the range 0.05–0.35 m/s. Ahmad [1] studied liquid axial dispersion and gas hydrodynamics in water–air upflow bubble column under slug flow conditions. In contrast to results reported by other investigators, his study showed that the liquid superficial velocity had significant effect on the longitudinal dispersion coefficient. Several other studies regarding mixing in bubble column have been reported by different authors [19,22,24,25,28,29].

Recently, downflow bubble column reactor with ejector-type of gas–liquid distributor for improved gas–liquid mixing, have been recommended for many industrial processes like absorption, desorption and scrubbing, gas–liquid reactions, aerobic fermentations, waste treatment, etc. Therefore, a precise knowledge of the hydrodynamics, mixing characteristics and mass transfer characteristics of the two phase in downflow bubble column, forming a part of an ejector system is of considerable interest.

From the literature, it is observed that there have been no reliable studies regarding the longitudinal mixing made on the ejector-induced downflow bubble column. The purpose of the present study is, therefore, to determine experimentally the longitudinal liquid dispersion coefficient in an ejector-induced downflow bubble column and to develop a model based on the above study. The model considering the combined action of velocity profile and bubble motion has been developed from Taylor's theory.

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