

Phase Holdups in Three-Phase Fluidized Beds in The Presence of Hourglass Promoter

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Abstract

Three-phase fluidized beds are widely employed in process industries. The ongoing investigation fundamentally encompasses of the studies on liquid holdup, gas holdup and bed porosity in three-phase fluidized beds containing coaxially placed hourglasses as promoter element. Holdup data were acquired by measuring pressure drop and bed expansion. Analysing the data elucidated the effects of dynamic and geometric parameters on liquid holdup, gas holdup and bed porosity. Useful equations were attained from empirical modelling by correlating the data.

Key words: **Gas holdup, liquid holdup, turbulent promoter, fluidization, three-phase fluidized bed, bed porosity**

1. Introduction

Well-established contact among all phases may be attained resorting to a bed of three phase fluidization. The beds of three phase fluidization tender the benefits like intensified macro-mixing, yielding great axial dispersion of phases as well as promoting conversion of reactants intended for reaction kinetics supporting totally mixed flow patterns, capability in attaining temperature uniformity without the help of external means, noteworthy augmentations in heat transfer and therefore temperature controllability by the elimination of hotspots, little intraparticle diffusion resistance and external resistance to liquid to solid mass transfer, easy replacement of catalyst and thus more control on catalyst activity and minimum flow maldistribution etc.[1].

The three phase fluidized beds used to cover broad applications in the process industries like hydro treating, flue gas desulfurization, coal gasification, coal liquefaction, Fischer Tropsch synthesis in the petroleum industry. The

beds of three phase fluidization are employed in electro-winning, oxidation of ethylene as well as in the hydrogenation of glucose, α -methyl styrene, heptane, acetylene, cyclo-hexane etc. The three-phase bio-fluidized beds are applied to carry out the treatment of waste water.

Bergles[2] reported a complete analysis of studies with different kinds of internal promoters which are turbulence augmenters for the case of homogeneous flow. In current period, three phase fluidization had gained attention to its application in electrochemical processes. Employing a rectangular electrochemical cell[3], cross flow elements[4], annular conduits[5], helicoidal tape turbulent promoter element[6], string of discs[7], twisted tapes[8], string of spheres[9], string of hemispheres[10], string of angled discs[11] and string of cones[12] are the few investigations that were taken up in this way. Very few investigations

were taken up for examining the impact of promoter geometry on mass transfer as well as on hydrodynamics as revealed by the literature survey. Experiments had been conducted by using hourglass promoter as an internal to enhance mass transfer from wall to liquid for the case of homogenous flow[13], for the case of liquid-solid fluidized beds[14] as well as for the case of gas-liquid up flow bubble columns[15].

Experiments were conducted to examine the impact of relevant geometric and dynamic variables on holdups of individual phases in a bed of three-phase fluidization by using hourglass promoter as an internal. Attempts were also made for developing empirical correlations for phase holdups and bed porosity by regression analysis with the use of proper dimensional groups relating geometrical parameters and flow variables.

2. Experimental procedure

Suitable equipment was planned and invented to perform the studies on holdups of individual phases. The line diagram of the test unit had been presented in Fig. 1. The main components of the apparatus are sintex tank as a feed tank for storing electrolyte (S), centrifugal pump (P), nitrogen cylinder (N) having regulator (R), two rotameters (R₁ and R₂) and experimental column. A 'U' tube manometer (U) was used to measure the difference in pressure along the test section. Rate of electrolyte flow into the column was regulated by providing the valves V₁ to V₅ and the rate of nitrogen gas flow was regulated by providing the valves V₆ and V₇. One kilowatt is the capacity of the stainless steel centrifugal pump (P). The valve V₃ was provided for regulating the rate of flow through rotameter (R₁) in the bypass line that had fixed to the pump's discharge end. Rotameter (R₁) had been provided to measure the electrolyte flow rate. Globe valve V₄ had been provided at entrance point of liquid rotameter. The globe valve V₅ facilitates the electrolyte flow through the experimental column and it was fitted to the discharge end of the rotameter. Nitrogen gas was regulated by precision air regulator. The rotameter R₂ had

been utilized to measure the flow rate of nitrogen gas. The valve V₆ had been outfitted to the entrance of rotameter whereas a needle valve V₇ was set on the experimental column's entrance point as shown in Fig. 1.

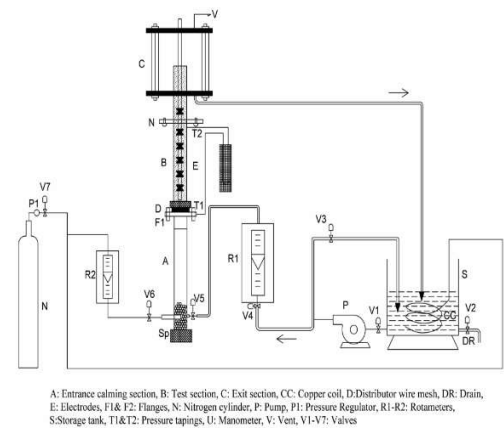


Fig. 1. Schematic of the Experimental set-up

Three sub sections namely an entry section or calming section(A), a test section(B) and exit section(C) constitute the main experimental column. The entrance section had 6.73 cm internal dia, 7.62 cm external dia and 1.07 m length. A perspex electrochemical cell with 6.73 cm internal dia and with 0.6-meter-tall was the test section (B). The bottom and top flanges of the test section were provided with two pressure tapings to gauge the difference of pressure across the test section. The glass beads of diameters 0.00293, 0.00424 and 0.00529 m were used. The hourglass promoter element encompasses an array of hourglasses of same characteristic length set at equivalent pitch or spacing on a rod of stainless steel. Values of 3, 4 and 5 cm were taken for characteristic length and values of 5, 7 and 10 cm were taken for pitch whereas 0.6, 1.0 and 1.3 cm were taken for rod diameter.

Glass balls of spherical shape with varying diameter are utilized as material for the bed in this

study. The particle diameters as well as the particle density are determined by subjecting the representative sample containing particles of known number to the method of water displacement. A high precision screw gauge is used to verify the acquired values for diameter in water displacement method. Measurement of bed heights is utilized to determine the solids holdup. Equations derived for the present case according to Ramesh et al[6] are used to calculate the phase holdups.

3. Results and discussion

3.1 Gas holdup

Fig. 2 displays the graph of holdup of gas plotted against superficial velocity of gas for three different superficial liquid velocities. Plot-A corresponds to a liquid velocity of 0.0936 m/s, Plot-B corresponds to 0.1217 m/s and Plot-C corresponds to 0.1498 m/s. It can be noticed from the plots that, the holdup of gas had been enhanced by improving velocity of gas but had a reduced trend with an improving velocity of liquid.

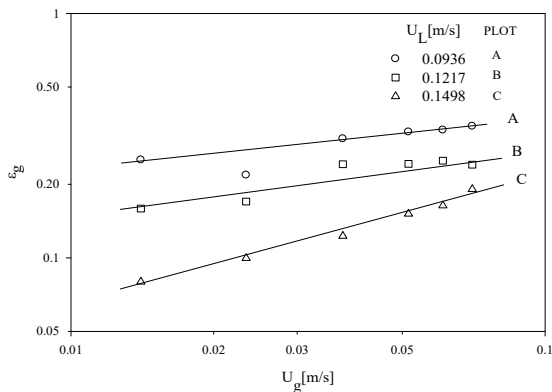


Fig. 2. Effect of velocities of gas and liquid on holdup of gas

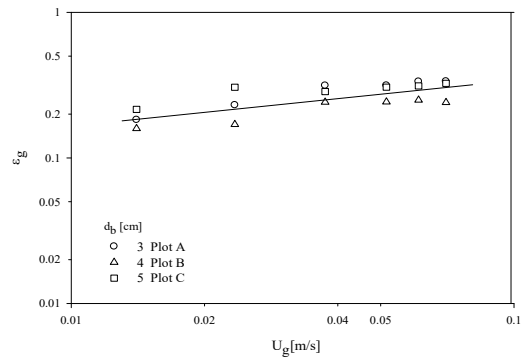


Fig. 3 Effect of characteristic length on holdup of gas

Fig. 3 displays the graph of holdup of gas plotted against superficial velocity of gas for three diverse characteristic lengths of hourglass promoter. Plot-A corresponds to a characteristic length of 3 cm, Plot-B corresponds to 4 cm and Plot-C corresponds to 5 cm. This figure reveals that the effect of characteristic length is not a very strong function that influences the gas holdup.

Fig. 4 displays the graph of holdup of gas plotted against superficial velocity of gas for three diverse pitches. Plot-A corresponds to a 5 cm pitch, Plot-B corresponds to 7 cm pitch and Plot-C corresponds to 10 cm pitch. It is noticed that with increasing pitch value, the gas holdup value also increased. The same trend is also visible in the inset Fig.5a.

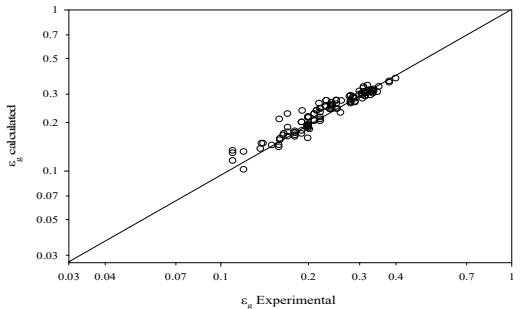
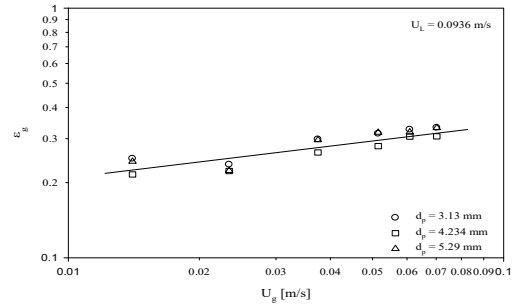
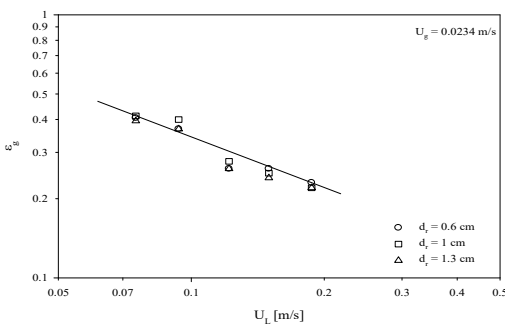
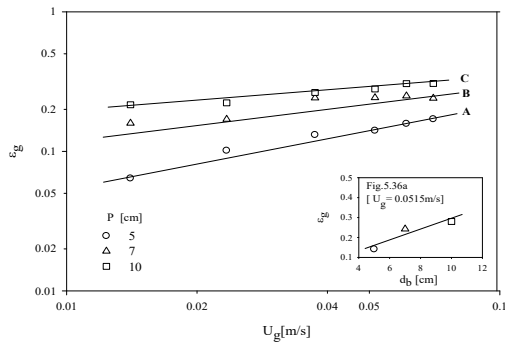


Fig. 6 Effect of dia of particle on gas holdup Fig. 7 Comparing experimental and calculated values of gas holdup

Fig. 4. Effect of pitch on gas holdup Fig. 5 Effect of rod dia on holdup of gas
Fig. 5 represents the effect of rod diameter on holdup of gas. Three rods with different dia viz., 0.6, 1.0 and 1.3 cm were taken. It can be understood that the rod had not exhibited any appreciable effect of the gas holdup.
Fig. 6 represents the how particle diameter effects the holdup of gas. Particles of diverse diameters viz., 3.13, 4.234 and 5.29 mm were taken. By examining the plots of this figure that, the impact of particle diameter on holdup of gas appears to be small.

The entire data on holdup of gas acquired in the presence of hourglass promoter have been subjected to regression analysis to obtain the following equation.

$$\epsilon_g = 7.373 (Re_p)^{-0.5192} (Fr_g)^{0.06917} \left(\frac{d_b}{D_c}\right)^{-0.5645} \left(\frac{P}{D_c}\right)^{0.9679} \dots(1)$$

According to eqn.(1), gas holdup data were computed and were compared with the experimental gas holdup data. The resulting graph is shown in Fig. 7.

3.2 Liquid holdup

Based on similar graphical analysis as prescribed in section 3.1, the data on liquid holdup were also analyzed and the following equations have been made. There is a decreased trend in holdup of liquid when the velocity of gas was increased whereas the holdup of liquid increased when liquid velocity was

increased. Liquid holdup had increased for the increase in characteristic length from 3 cm to 4 cm, but had reduced slightly for further increase of characteristic length from 4 cm to 5 cm. It can be noticed from the plots of this figure that, the holdup of liquid reduced when the pitch value was enhanced. The diameter of the rod had not exhibited any appreciable effect on the gas holdup. The impact of diameter of particle on holdup of liquid appeared to be small.

Entire data on liquid holdup acquired in the ongoing study have been subjected to regression analysis to obtain the following equation.

For $3 \leq d_b \leq 4$ cm:

$$\epsilon_L = 0.0019 (Re_p)^{0.96} (Fr_g)^{0.37} \left(\frac{d_b}{D_c}\right)^{0.81} \left(\frac{P}{D_c}\right)^{-0.490} \dots(2)$$

For $4 \leq d_b \leq 5$ cm:

$$\epsilon_L = 0.0078 (Re_p)^{0.77} (Fr_g)^{0.4} \left(\frac{d_b}{D_c}\right)^{1.0} \left(\frac{P}{D_c}\right)^{-0.49} \dots(3)$$

Bed porosity

In a fluidized bed, the porosity of bed represents the space available for the fluids. Hence, it is the most important design variable. In liquid-fluidized beds under particulate fluidization, Richardson-Zaki[16] showed that the exponent is 2.39. In the present case also, entire bed porosity data are analyzed according to Richardson-Zaki[16] and obtained the following equation.

$$Re_p = 1296 \epsilon^{2.666} \dots(4)$$

In the present case, the Richardson-Zaki exponent was found to be 2.666 which is nearly close to the reported value of 2.39 for liquid fluidized bed. This small deviation can be accredited to the gas phase and the turbulent promoter internal.

However, the error is a bit more in obtaining eqn.(4). Hence, to obtain a better equation with less error, another correlation equation is obtained by incorporating all pertinent variables. The equation thus obtained is given below:

$$\epsilon = 0.178 (Re_p)^{0.25} \left(\frac{d_b}{D_c}\right)^{1.26} \left(\frac{P}{D_c}\right)^{-0.056} \dots(5)$$

4. Conclusions

Gas holdup got increased by enhancing velocity of gas but reduced with enhancing velocity of liquid. The characteristic length did not exercise any strong influence on gas holdup. An increasing pitch value resulted in an increased holdup of gas. The influence of diameter of particle on holdup of gas appeared to be small. The diameter of the rod had not exhibited any appreciable effect on the gas and liquid holdups. There is a decreased trend in holdup of liquid with enhancing velocity of gas whereas the holdup of liquid increased with increasing velocity of liquid. Liquid hold up had increased initially for the increase in characteristic length but had reduced slightly with further increase of characteristic length. The holdup of liquid reduced with an improve in pitch value. Diameter of particle had not exercised any effect on liquid holdup. By analyzing the data on bed porosity, the Richardson-Zaki exponent was found to be 2.666 which is nearly close to the reported value of 2.39 for liquid fluidized bed.

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