Gas Holdup In Gas-Liquid Up flow Bubble Column With Inverted Cones As Turbulent Promoter

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Abstract: In the present work, data on gas holdup were obtained in a bubble column in the presence of a string of inverted cones as turbulent promoter. Water was chosen as liquid phase and nitrogen was employed as gas phase. The parameters considered were superficial liquid velocity, superficial gas velocity, cone diameter, cone angle, pitch and rod diameter. It was found that the gas holdup increased with gas velocity and decreased with liquid velocity. The influence of rod diameter was insignificant. An increase in cone angle resulted in an increase in gas holdup. With pitch and cone angle, the gas holdup initially increased and then followed a decreasing trend. A correlation n in ε_g-Re format has been developed from regression analysis.

Keywords: Gas holdup, bubble column, turbulent promoter, gas-liquid flow, internal.

I. Introduction

Simultaneous flow of liquid and gas phases occurs very often in chemical process industry. Such gas-liquid two phase flow system could be found across entire range of process industry. Now-a-days, the presence of minerals in the available ores is getting impoverished. Therefore, there is a huge demand for the development of suitable methods and technologies that aim at mineral extraction by processing of such ores. In this direction gas-liquid upflow bubble columns are found to be useful as electrochemical reactors for metal winning from dilute solutions[1]. Generally, the gas phase employed would be an inert gas such as nitrogen, the presence of which was found to result in magnitudes of augmentation of mass transfer coefficient. However, information on gas holdup is needed for designing of such reactors. It is also understood that the presence of string of cones as a coaxially placed turbulent promoter could yield reckonable augmentation in mass transfer coefficient[2]. An examination of literature revealed that there is no information available on gas holdups in gas-liquid upflow bubble columns in the presence of coaxially placed string of cones when inverted cone (apex in the bottom and base in the top) acted as a repeated element in the string of cone turbulent promoter. Since the flow takes place from bottom to top, i.e., in the upward direction, the apex of the cone appears as the leading edge and the base of the cone falls as the trailing edge. Although a few studies[3-7] have been carried out to determine gas holdups in bubble columns in the presence of internals, there is no systematic investigation reported so far on using string of inverted cones for obtaining gas holdup in a bubble column. Hence the present work is undertaken essentially with an aim to elicit information on the influence of liquid velocity, gas velocity, pitch, cone diameter, cone angle and rod diameter on gas holdup. The range of variables covered in the present study are compiled in Table.1.

Table 1. Range of variables covered in the present study

S.No	Parameters studied	Minimum	Maximum
1	Superficial velocity of gas, m/s	0.014	0.07
2	Superficial velocity of liquid, m/s	0.04	0.27
3	Diameter of the rod, cm	0.6	1.3
4	Pitch, cm	7.0	10.0
5	Diameter of cone, cm	3.0	5.0
6	Apex angle, degrees	30	60

II.Experimental

In the present investigation, fabrication of equipment is carried out with a focus of measurement of gas holdups from pressure difference[7]. A line diagram has been depicted and shown in Fig.1 that represents the details of the present experimental unit. The test rig comprises of a storage tank, a centrifugal pump, two rotameters, a nitrogen gas cylinder with regulator, a U-tube manometer, and globe valves. Two inlets are provided in the bottom of the experimental column for admitting liquid and gas. The liquid phase chosen was water and the gas phase chosen was nitrogen. A wire mesh was provided at the entering point of the test section. This wire mesh facilitated uniform distribution of gas and liquid phases. At the top of the column, a gas liquid separator was provided. The gas was vented into atmosphere and the liquid was drained into the storage tank enabling recirculation into the test section.

The turbulent promoter comprises of an array of uniform diameter of cones fixed at a given pitch on a stainless steel rod as shown in Fig.2. The string of cones promoter assembly arranged coaxially in the test section, essentially acted as promoter internal in the present experimental studies. The promoter elements of different geometric characteristics viz., diameter of rod d_r, half apex angle of cone θ, diameter of the cone d_c and pitch p were fabricated and used. Fig.2 shows the details of the promoter assembly.

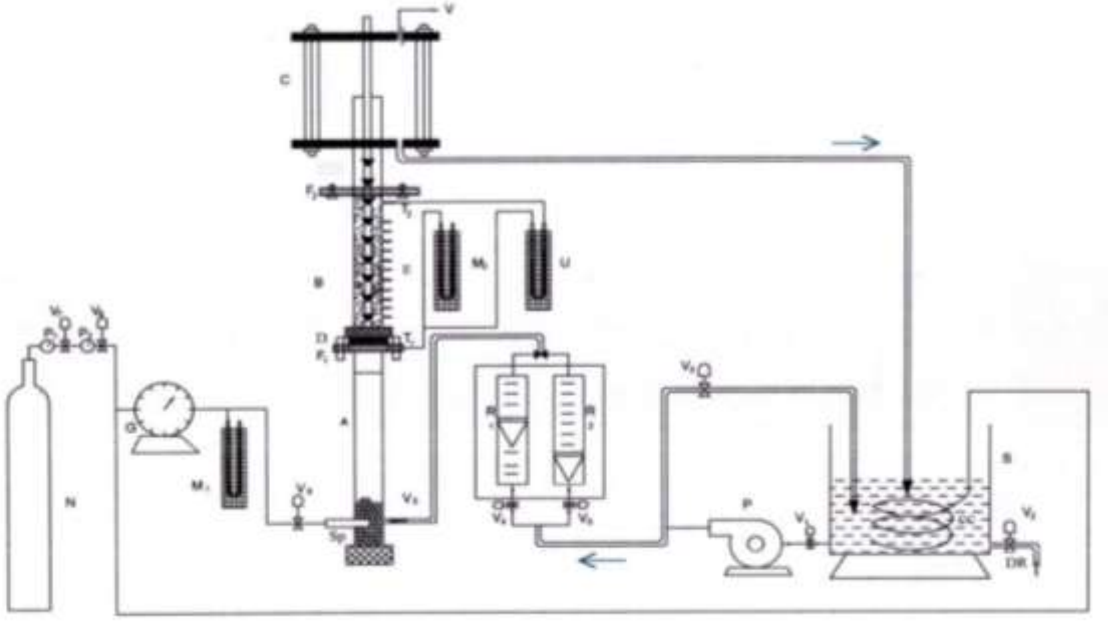

Fig.1. Schematic of the experimental unit

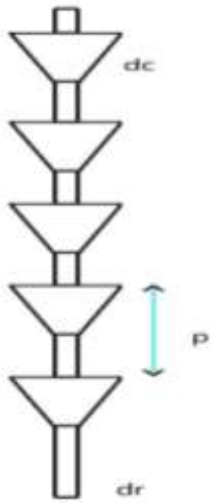

Fig.2. Details of promoter

III.Results and discussion

Fig.3 shows the data on gas holdup plotted against liquid velocity in the presence of string of cone promoter. It is observed from the plot that the gas holdup decreased with increasing liquid velocity. Fig.4 shows the data on gas holdup plotted against gas velocity in the presence of same promoter. It can be seen from the plot of this figure that the gas holdup increased with increasing gas velocity. Same trends are also conspicuous from the inset figures 3a and 4a.

Fig.5 represents the data obtained by varying pitch values. Here gas holdup is taken on y-axis and liquid velocity is taken on x-axis. The pitch values considered were: 5, 7 and 10 cm. A close examination of the plots of this figure reveals that the gas holdup increased with pitch as pitch varies from 5 to 7 cm and decreased with further increase in pitch from 7 to 10 cm. This kind of abnormal behavior of the gas holdup can be attributed to the presence of gas phase and its quick escaping nature. The said trend can be conspicuously seen from the inset figure 5a.

The effect of cone diameter on gas holdup is observed from Fig.6. It is seen from the plots of this graph that the gas holdup decreased when the cone diameter is increased from 3 to 5 cm. The reason for this behavior can be attributed to the variation in the cross section that is brought by variation in the cone diameter.

Since the cross sectional area that would be occupied by the central rod of the promoter was negligible when compared with entire cross sectional area of the test section, it can be expected that the variation in rod diameter would not bring any significant changes in the behavior of gas holdup. In agreement with this reasoning, the gas holdup was nearly unaffected by the variation in rod diameter. This trend is revealed from Fig.7.

One can anticipate that the apex angle of cone would have significant effect on the behavior of the gas holdup. The reason for this can be arrived at in the following way. At low angles, the presence of cone simply acts as a streamlined body and at higher angles, it acts as a bluff body. At moderate angles, both streamlined and bluff body behavior would be exhibited. The influence of apex angle of the cone is shown in Fig.8. It can be found from the plots of this figure that the gas holdup increased initially with the cone angle and decreased with further increase in cone angle. This trend is clearly seen from the inset figure also. One can anticipate that the apex angle of cone would have significant effect on the behavior of the gas holdup. The reason for this can be arrived at in the following way. At low angles, the presence of cone simply acts as a streamlined body and at higher angles, it acts as a bluff body. At moderate angles, both streamlined and bluff body behavior would be exhibited. The influence of apex angle of the cone is shown in Fig.8. It can be found from the plots of this figure that the gas holdup increased initially with the cone angle and decreased with further increase in cone angle. This trend is clearly seen from the inset figure also.

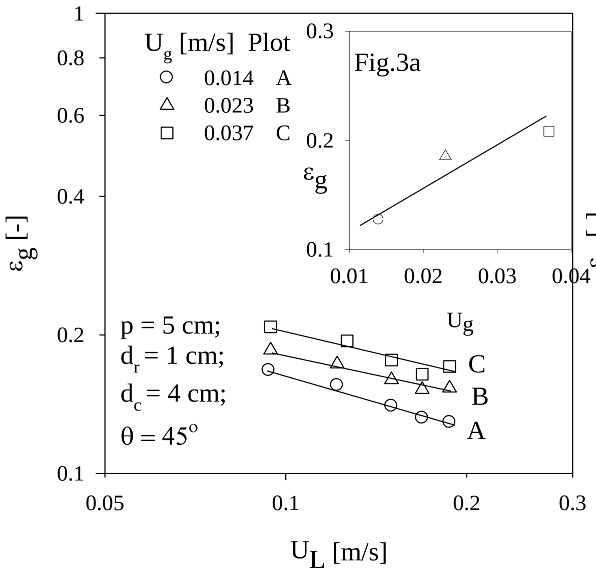

Fig.3. Variation of gas holdup with liquid velocity

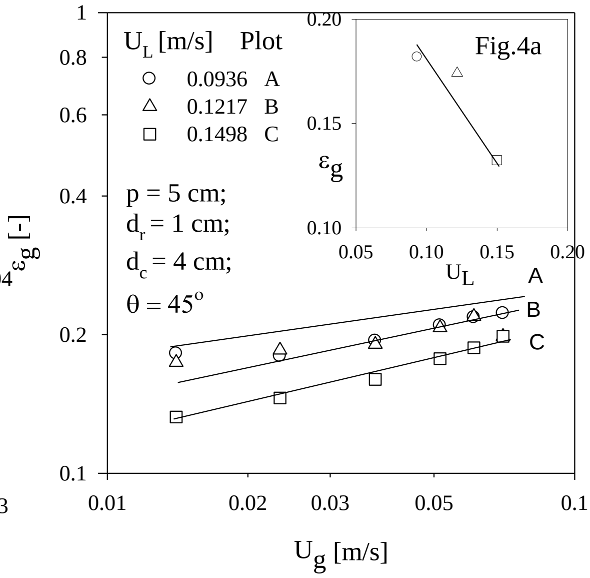

Fig.4. Variation of gas holdup with gas velocity

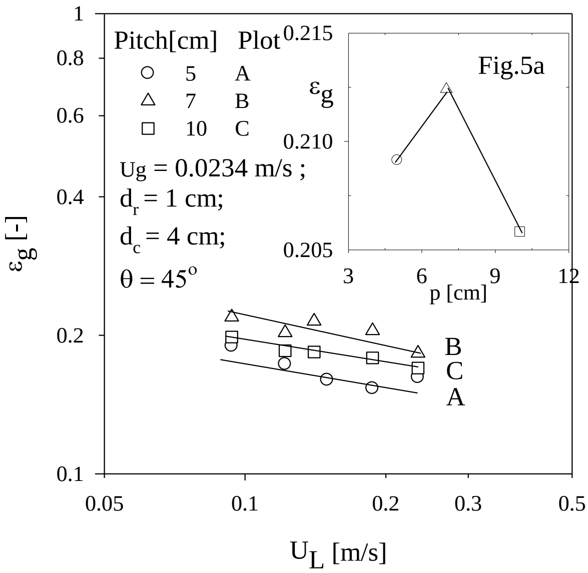

Fig.5. Variation of gas holdup with pitch

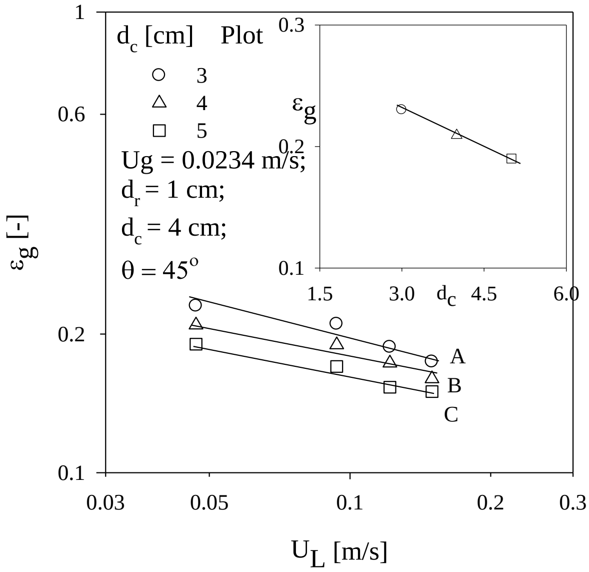

Fig.6. Variation of gas holdup with cone dia

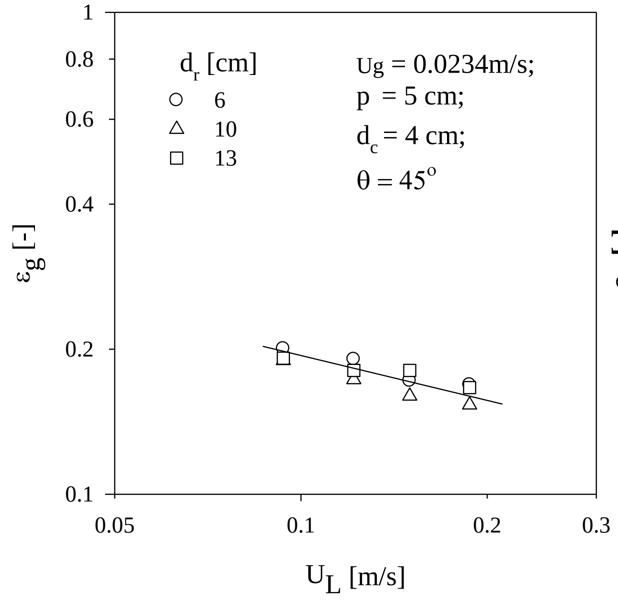

Fig.7. Variation of gas holdup with rod dia

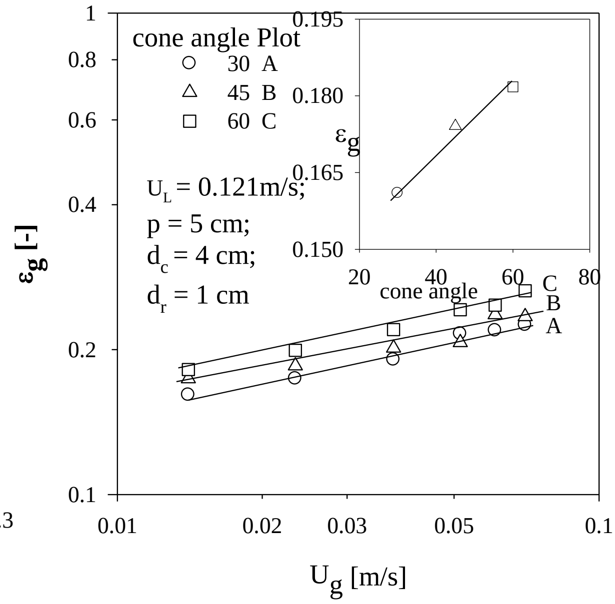

Fig.8. Variation of gas holdup with cone angle

The entire data obtained on gas holdup in the present study are divided in two parts based on discussion subjected to regression analysis and the following correlation equation is obtained.

For $5 \leq p \leq 7$ cm,

$$\varepsilon_g = 7.418\,(N_{Re})^{-0.27}\,(F_{rg})^{0.087}\,(P/D_c)^{0.84}\,(d_c/D_c)^{0.74}\,(1+\sin(\theta))^{-0.087} \quad \ldots(1)$$

Average deviation = 8.78 percent; Standard deviation = 12.03 percent.

For $7 \leq p \leq 10$ cm

$$\varepsilon_g = 4.076\,(N_{Re})^{-0.20}(F_{rg})^{0.1}\,(P/D_c)^{-0.03}\,(d_c/D_c)^{0.17}\,(1+\sin(\theta))^{-0.56} \quad \ldots(2)$$

Average deviation = 8.74 percent; Standard deviation = 11.30 percent.

Conclusions

Based on about 800 gas holdup measurements, in the presence of string of inverted cone promote element in a two phase upflow bubble column, the following observations were made.

(i) Gas hold up increased with gas velocity and decreased with liquid velocity.
(ii) With variation in pitch, the behavior of gas holdup exhibited a maximum.
(iii) The effect of rod diameter on gas holdup was observed to be insignificant.
(iv) The gas holdup decreased with increase in cone diameter.
(v) With an increase in cone angle, the gas holdup was found to increase.
(vi) Two correlation equations were proposed for predicting gas holdup.

Nomenclature

D_c	diameter of the test section	[m]
d_c	cone diameter	[m]
d_r	rod diameter	[m]
g	acceleration due to gravity	[m/s^2]
p	pitch or cone spacing	[m]
U_g	superficial gas velocity	[m/s]
U_L	superficial liquid velocity	[m/s]

Greek Symbols

θ	half-apex angle of cone	[degree]
μ_L	liquid viscosity	[kg/m.s]
ρ_L	liquid density	[kg/m^3]
ε_g	gas holdup	[-]

Dimensionless groups

Re Reynolds number = $\dfrac{\rho_L D_C U_L}{\mu_L}$

Fr_g Froude number = $\dfrac{U_g^2}{g D_c}$

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