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Holdups in a Three Phase Fluidized Bed Reactor with String of Cones Internal

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Abstract:

This paper consists of an experimental study to obtain gas and liquid holdups in a Solid-Liquid-Gas fluidized bed with a centrally placed strand of cones as turbulent promoter internal. Gas holdup data are acquired from measured pressure drop data. The impacts of significant variables such as gas velocity, liquid velocity, cone diameter, rod diameter, pitch, particle diameter and half apex angle of cone on gas as well as liquid holdups are discussed. The holdup data were extorted to least squares regression analysis and correlation equations are achieved. These equations were useful in the design of three phase fluidized bed reactors.

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

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I. INTRODUCTION

A large number of gas-liquid reactions of industrial importance are usually catalytic in nature and most of the times, the catalyst happens to be a solid substance. In order to accomplish required separation or conversion, an adequate contact between gas, liquid and solid is required. Three phase fluidized beds serve as devices that provide good mixing of bed contents, uniform temperature and concentration, catalyst protection etc [1]. For realizing higher rates of heat and mass transfer, use of turbulent promoters has been widely adopted [2]. Without the knowledge of phase holdups, the design of equipment in this direction would not possible. Although few studies were reported using some internals such as twisted tapes, to the best knowledge of the authors, investigations on phase holdups pertaining to string of cones were scarce [3]. However, the said promoter was reported to yield higher mass transfer coefficient values as per Vijay et al[4]. As a consequence, the current investigation is worked out.

II. EXPERIMENTAL SETUP

In the current investigation, fabrication of equipment is brought out with a focus of measurement of gas holdups from pressure difference [5]. A line drawing of the equipment used is depicted in Fig.1. The liquid phase chosen was water and the gas phase was nitrogen. This equipment is similar to the one used by Krishna Reddy [6] for studies carried out using a string of inverted cones. A detailed description of this unit can be obtained from this reference. Identical conical elements have been arranged as an array on a central rod with uniform spacings. Such assembly has been used a promoter internal. Different promoter assemblies with varied dimensional properties like diameter of rod d_r, half apex angle of cone θ, diameter of the cone d_c and pitch p were fabricated and used in this study.

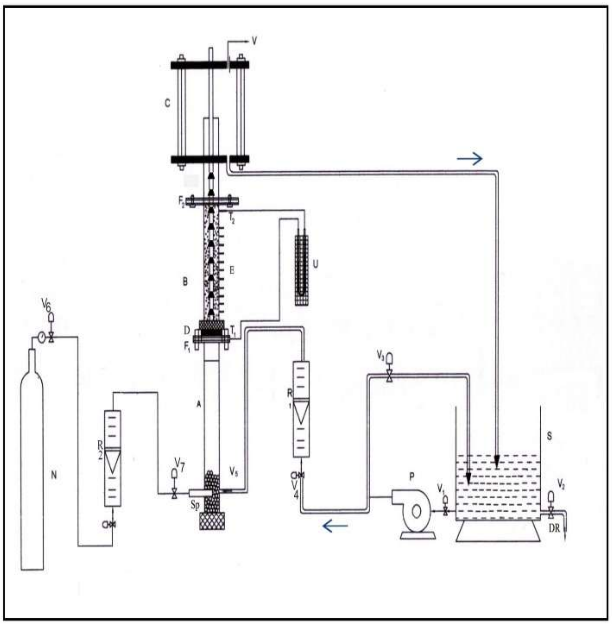

Fig.1. Line diagram of the investigational unit

III. Results and discussion

In this section discussion on trends obtained for gas holdup, liquid holdup and bed porosity were obtained.

III.1 Gas holdup

The gas holdup data in a Solid-Liquid-Gas phase fluidized bed with regular cone promoter assembly {p = 5.0 cm, d_r = 1.0 cm, d_c = 4.0 cm, d_P = 4.243mm, θ=45^0} for three different gas velocities 0.014, 0.0234 and 0.0374 m/s were drawn versus superficial liquid velocity as presented in Fig.2. It is noticed that the gas holdup was not influenced by increasing liquid velocity (U_L). However, from Fig.3, it is observed that the gas holdup raised with gas velocity. As more gas entered into the bed, the bed expands accommodating more gas in the bed. Hence a raise in gas velocity has no effect on gas hold up.

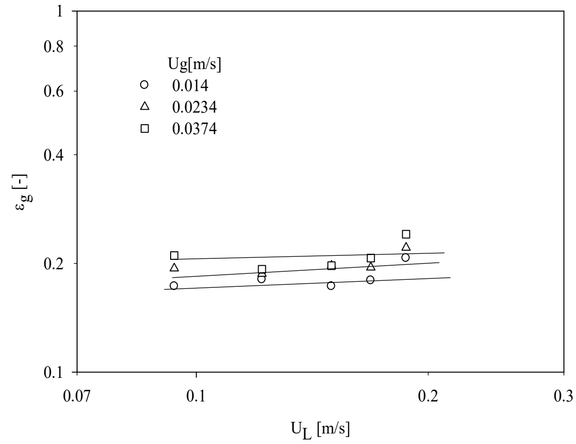

Fig.2. Effect of liquid velocity on gas holdup

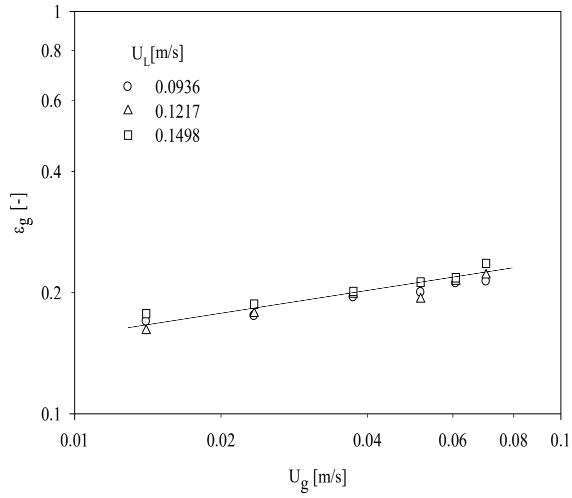

Fig.3. Effect of gas velocity on gas holdup

Fig.4. reveals the gas holdup data drawn versus superficial gas velocity for three unlike pitch values. The inspection of the graphs of the picture reports that the gas holdup enhanced with enhancing pitch. As the pitch rises, the free space available in the experimental column for occupation of the fluids would be more, hence one can understand that as rise in pitch the gas holdup increases.

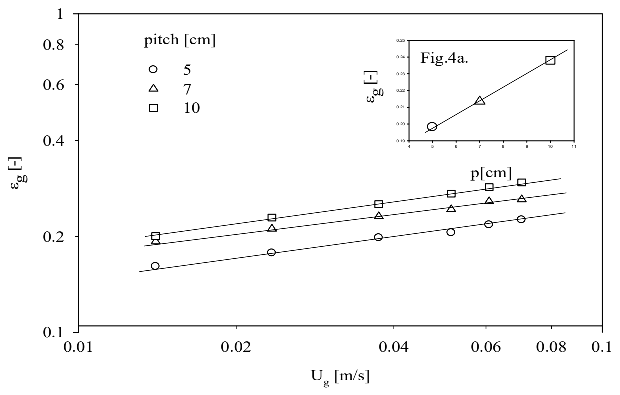

Fig.4. Effect of pitch on gas holdup

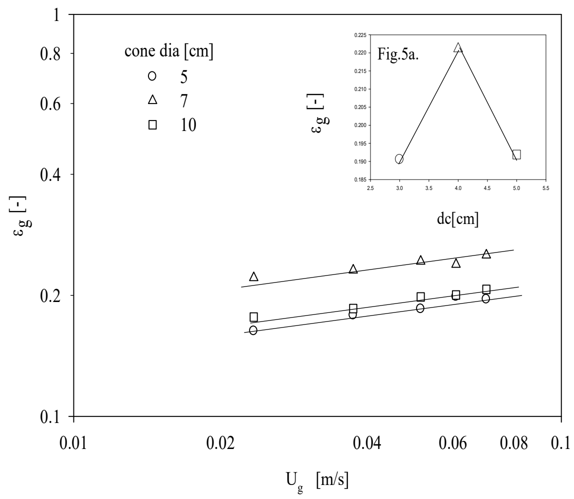

Fig.5. Effect of cone diameter on gas holdup

The gas holdup data were drawn versus superficial gas velocity for three unlike cone diameters like., 3.0, 4.0 and 5.0 cm employed in the present investigation for the promoter geometry {p = 10.0 cm, d_r = 1.0 cm, d_P = 5.613 mm} at a persistent superficial liquid velocity U_L= 0.122 m/s and thus the final result is shown in Fig.5. For change of cone diameter from 3.0 to 4.0 cm, the gas holdup increased and for change of cone diameter from 4.0 to 5.0 cm, the gas holdup decreased. This behaviour is also clearly seen from inset Fig.5a.

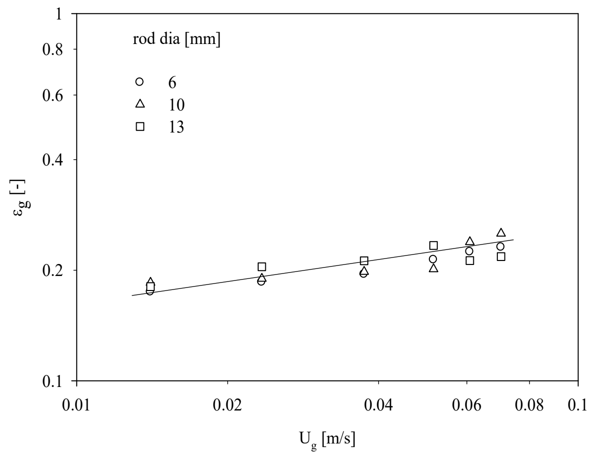

Fig.6. Effect of rod diameter on gas holdup

The gas holdup data was drawn versus s superficial gas velocity in Fig.6 for three different rod dr values viz., 0.6, 1.0 and 1.3 cm w.r.t. Centrally arranged strand of cones {p = 5.0 cm, d_c = 4.0 cm, d_P = 5.613 mm}. By close inspection of the plots of this figure, it is observe that impact of rod diameter on gas holdup is nearly inconsiderable. Fig.7 shows the impact of cone angle on gas holdup. It is observed that the gas holdup raised with cone angle for change of cone angle from 30^o to 45^o with farther rise in cone angle from 45^o to 60^o, the gas holdup decreased. This kind of behaviour can be attributed to the changed flow patterns of the fluids in the bed. The gas holdup data was drawn versus superficial liquid velocity in Fig.8 for three different particle sizes in case of centrally placed strand of cones { p = 7.0 cm, d_r = 1.0 cm, d_c = 4.0 cm} at a constant superficial liquid velocity of 0.122 m/s. By clear observation of the graphs of this picture reports that the gas holdup increased with particle size.

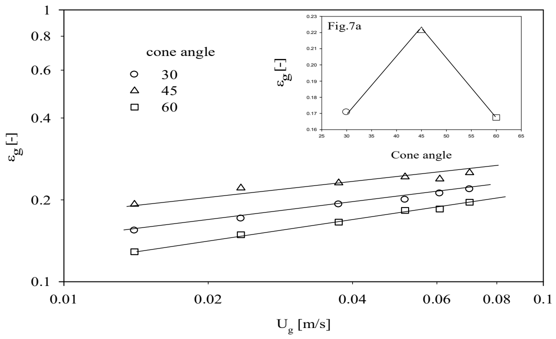

Fig.7. Effect of Cone angle on gas holdup

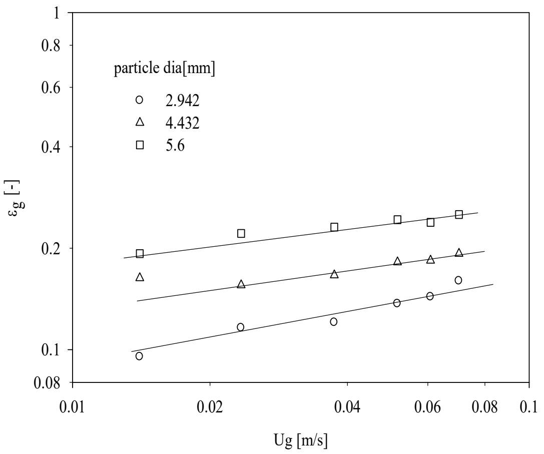

Fig.8.Effect of particle diameter on gas holdup

The complete gas holdup data collected in the present investigation are administered to regression analysis and the following equation is resulted.

$$\varepsilon_g = 0.021(Re_p)^{0.43}\ (Fr_g)^{0.047}(P/D_c)^{0.62}\ (1+\sin(\theta))^{-0.435} \quad \ldots\ldots(1)$$

Average deviation = 7.84percent;
Standard deviation = 10.96 percent.

III.2 Liquid holdup:

The liquid holdup data in the presence of regular cone Promoter Assembly in the three phase fluidized bed **{$p = 5.0$ cm, $d_r = 1.0$ cm, $d_C = 4.0$ cm, $d_P = 0.424$cm, $\theta = 45^0$}** for three unlike gas velocities 0.014, 0.023 and 0.037 metre per second were drawn versus Superficial liquid velocity as presented in Fig. 9. It is noticed from the plots of this sketch that the liquid holdup raised with raising superficial liquid velocity play. One can reason that As the liquid velocity is raised, At a constant gas velocity, The bed expands leading to a decrease in solids hold up. As the gas holdup is not impacted by liquid velocity and As the sum of phase holdups becomes unity , It is the liquid holdup that shows an increasing trend . Similar observations can also be made from Fig. 10. The effect of pitch was shown in Fig. 11. By clear inspection of the graphs Of the sketch Reports that the liquid holdup had reduced with pitch value.

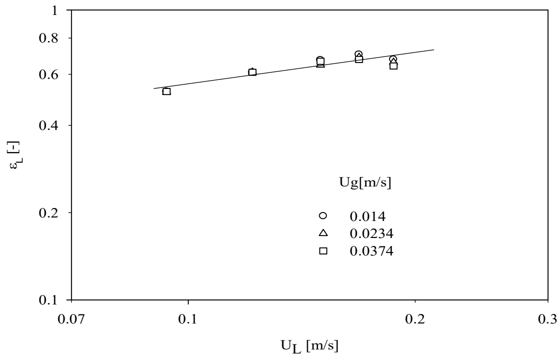

Fig.9. Effect of liquid velocity on liquid hold up

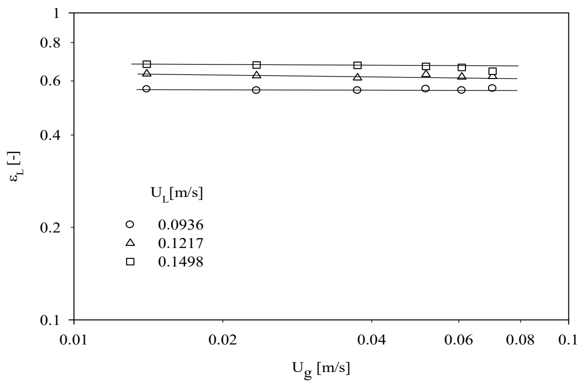

Fig.10. Effect of gas velocity on liquid hold up

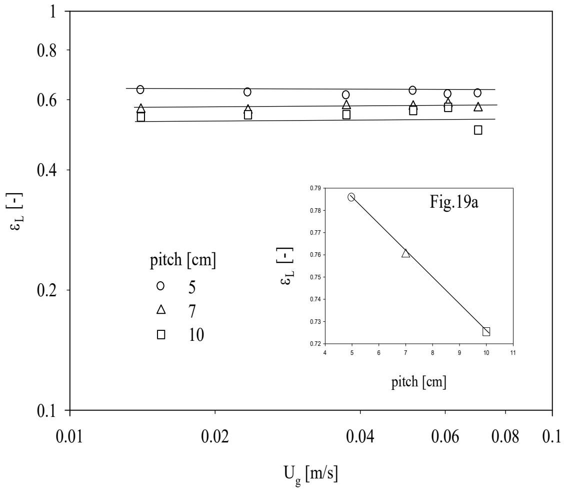

Fig.11. Effect of pitch on liquid hold up

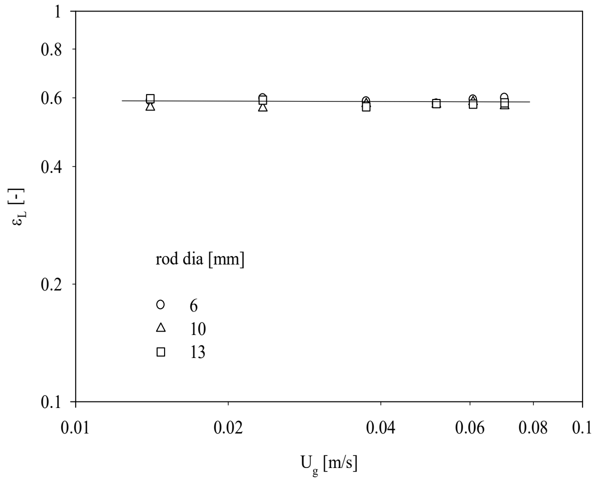

Fig.13. Effect of rod diameter on liquid holdup

It is found from the plots of This Fig. 12 That the liquid holdup raised with Change in cone dia from 5.0 to 7.0 And Declined with further change in cone dia from 7.0 to 10.0 cm. The reason for this behaviour can be attributed to the Changed flow patterns of the fluids. The impact of rod diameter on liquid holdup is Shown Fig.13. From which one can observe that the rod diameter exhibited no noticeable influence on liquid holdup.

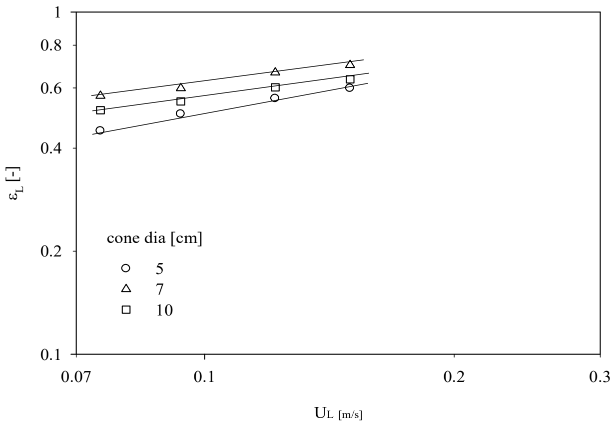

Fig.12. Effect of cone diameter on liquid hold up

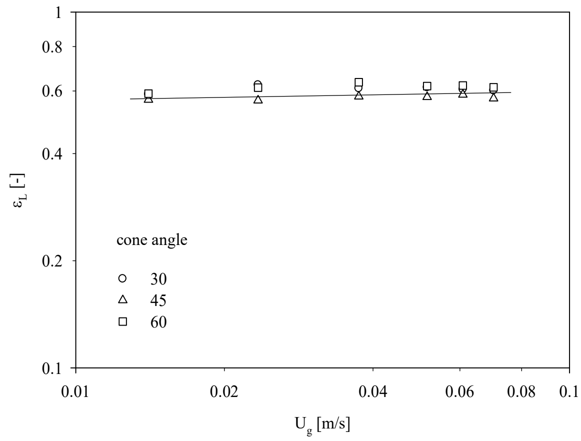

Fig.14. Effect of cone angle on liquid hold up

The impact of half apex angle of cone on liquid holdup is presented in Fig.14. It is observed that All points are clustered together Signifying that the effect of cone Angle On liquid holdup is negligible. Figure 15 represents the Impact of particle diameter on liquid holdup. It is noticed that the liquid holdup decreased with particle diameter because the particles are suspended in bed mainly due to the movement of liquid. The bed volume will be less for larger particles because of which the liquid holdup decreases.

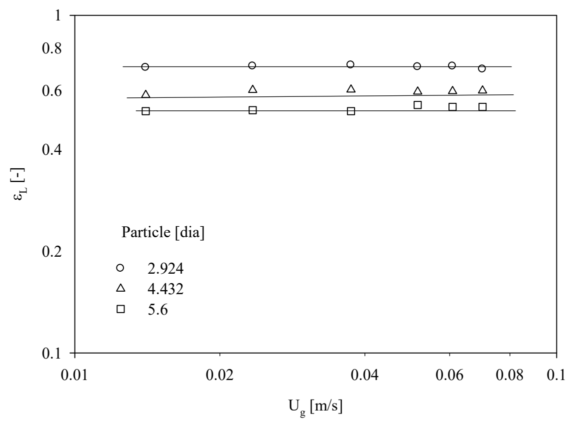

Fig.15. Effect of particle diameter on liquid holdup

The complete liquid holdup data procured in the present study are applied to regression analysis and the following equation is achieved.

$\varepsilon_L = \varepsilon_L = 0.37(Re_p)^{0.075}(P/D_c)^{0.36}$ …………(2)

Average deviation = 8.024 percent;
Standard deviation = 10.12percent.

III.3 Bed Porosity:

It was reported that the presence of promoter to be edged because a uniform expansion of the bed as promoted by the promoter internal. Hence the present data on bed porosity in three phase fluidized beds has been analysed in the alliance suggested by Richardson-Zaki[--]. Fig.15. Gives the plot of the data on Rep for Entire bed porosity data Obtained in the current experiment in case of invented cone Promoter internal. The reported equation is obtained by Least squares regression analysis.

$Re_p = 1533(\varepsilon)^{3.56}$ ……..(3)

Average deviation is equal to 16.1 %;
Standard deviation is equal to 20.88%.

The exponent value of n was found to be 3.56 Compared to 2.39 reported by Richardson-Zaki[--]. In two phase fluidized beds, the deviation is accounted due to the presence of gas phase and promoter internal.

IV. CONCLUSIONS

Gas holdup was not influenced by liquid velocity. Gas holdup raised with gas velocity. The gas holdup was noticed to be raising with pitch. With cone diameter variation, the gas holdup initially increased and for further increase in cone diameter, the gas holdup declined. The impact of rod diameter on gas holdup was in. Cone angle could not exhibit any influence on gas holdup. . The effect of particle diameter on gas holdup was found to be inconsiderable. The liquid holdup raised with raising superficial liquid velocity. The pitch had not shown any impact on liquid holdup. The liquid holdup enhanced with change in cone diameter from 5.0 to 7.0 cm and decreased with further change in cone diameter from 7.0 to 10.0 cm. The rod diameter has exhibited no noticeable influence on liquid holdup. The effect of cone angle on liquid holdup is negligible. The liquid holdup dropped with particle diameter. Richardson-Zaki exponent was found to be 3.56.

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 = $\dfrac{U_g^2}{gD_c}$

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