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Prediction of Solid holdup in an Internal Loop Airlift Fluidized Bed Reactor

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Abstract : In the present work, an attempt has been made to study the influence of phase velocities (gas and liquid), particle size and shape, physical properties of liquids on solid holdup in an internal loop airlift fluidized bed reactor. Water, Commercial grade % % *n*-Butanol, 60% and 80% glycerol were used as Newtonian liquids and various concentrations (0.25 %, 0.6 % and 1.0 %) of carboxy methyl cellulose (CMC) solutions were used as non-Newtonian liquids. Spheres, Beryl saddles and Raschig rings were used as solid phases. Superficial gas velocity was varied from 0.000142 to 0.005662 m/s and superficial liquid velocity was varied from 0.001 to 0.12 m/s. The experimental results showed that an increase in superficial gas velocity increases the solid holdup, whereas it decreased with increase in superficial liquid velocity. The solid holdup decreased with increase in particle size and increased with increases fluid behaviour index. Based on the experimental results, a generalized dimensionless correlation was developed for the prediction of the solid holdup for both Newtonian and non-Newtonian liquids with a wide range of fundamental and operating conditions.

Keywords: Superficial gas and liquid velocity, Particle diameter, Sphericity, Newtonian liquids, and non-Newtonian liquids.

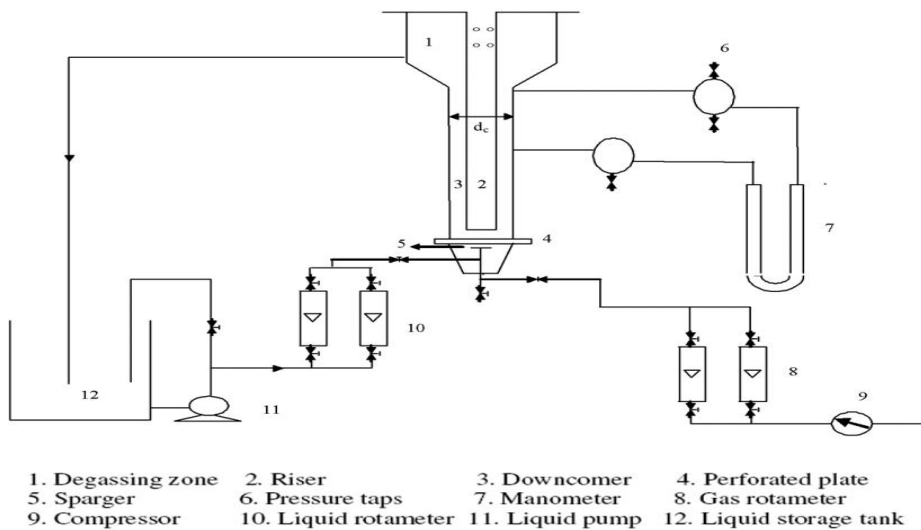
Introduction

Three phase Internal loop airlift fluidized bed reactors are mainly used in chemical industries, biotechnological and environmental processes¹ for the advantages like high mixing, definite circulation flow pattern, low investment, easy operation and maintenance², lower gas requirement for complete fluidization of solids, elimination of stagnant zones etc.³. In biochemical industries, it is used for high oxygen transfer rate and cell rupture rate comes down compared to external driven mixing system such as agitated vessels. Tyagi et al.⁴ treated the effluents using airlift bio reactors and produced stabilized sludge in shorter retention times than the conventional digesters. Visnovsky et al⁵ reported that the internal loop airlift fluidized bed reactor provides a good mixing and low shear stress on the cell surface, which brings the death rate of cells to minimum. Chavez – Parga et al⁶. produced gibberellic acid by using airlift bioreactor. Many authors studied the hydrodynamic

parameters like gas holdup^{1,7-11}, Minimum fluidization velocity^{7,12-14}, and liquid holdup^{15,16,19}. From the literature, it is observed that only very few authors^{2, 17} studied the effect of superficial gas velocity on solid holdup and also there studies were restricted to stagnant liquid systems. For the design, operation and scale up of three phase internal loop airlift fluidized bed reactors the knowledge of hydrodynamic parameter such as solid holdup is essential. In this present work, an attempt has been made to study the effect of superficial gas and liquid phase velocities, particle size and shape, physical properties of liquid systems on solid holdup in a three-phase internal loop airlift fluidized bed reactor and based on the experimental results a unified dimensionless correlation was developed to predict the solid holdup in terms of the fundamental and operating variables.

Experimental Setup and Procedure

Fig.1 Schematic diagram of Internal loop Airlift Fluidized Bed Reactor



All the experiments were carried out in a Perspex column of 0.15 m in inner diameter, 1.63 m in height, with a flat bottom and draft tube 1.54 m in height with 0.084 m diameter as shown in Fig. 1. The bottom clearance between draft tube and gas distributor was 0.09 m and the top clearance between the free-gas liquid level and the draft tube was 0.12 m. Air was sparged through triangular pitch sparger which was 0.08 m in diameter with 180 holes of 0.00008 m diameter each located slightly below the perforated plate. The gas flow rate was measured by calibrated rotameters with an accuracy of $\pm 2\%$. The properties of the liquids were measured at room temperature. The densities of the liquids were measured with a specific gravity bottle and the rheological properties of non-Newtonian liquids were measured by using Brookfield Rheometer (Model LVDV-II+). Superficial gas and liquid phase velocities were calculated based on the column diameter. Superficial liquid velocities were varied from 0.001 to 0.12 m/s, superficial gas velocities were varied from 0.000142 - 0.005662 m/s. The solid holdup was measured by using bed height method. It was calculated based on the weight of the dry particles and the expanded bed height by using the following formula¹⁸.

$$\varepsilon_S = \frac{m_s}{\rho_p A h_B} \quad (1)$$

In the present work, spheres, bearl saddles and raschig rings of different sizes and shapes were used as solid phases. Water, Commercial grade 5 % *n*-Butanol, 60 % and 80 % concentrations of Glycerol were used as Newtonian fluids (Commercial grade) and different concentrations of Carboxy Methyl Cellulose (0.25 %, 0.6 % and 1.0 %) were used as non-Newtonian fluids. The experiments were conducted in an atmospheric temperature with air as gas phase. A minimum of 3-5 readings were taken and the average value was used for calculations and the error was found to be less than $\pm 3\%$. The properties of liquid systems and solid particles used in the present study are given in Tables I and II.

Table-1 Properties of liquids used in the present study

Type of liquids	Density of liquids, $kg.m^{-3}$	Surface tension, $N.m^{-1}$	Viscosity, $kg m^{-1} s^{-1}$	
			K $kg.m^{-1} s^{2-n}$	n
Water	1000	0.0700	0.00083	1
5 % <i>n</i> -Butanol	1008	0.0350	0.00098	1
80% Glycerol (Commercial grade)	1180	0.0650	0.030	1
60% Glycerol (Commercial grade)	1155	0.0660	0.0185	1
0.25% CMC	1026	0.0730	0.0197	0.87
0.6% CMC	1020	0.0735	0.0308	0.86
1.0% CMC	1017	0.0740	0.0565	0.85

Table-2 Properties of solids used in the present study

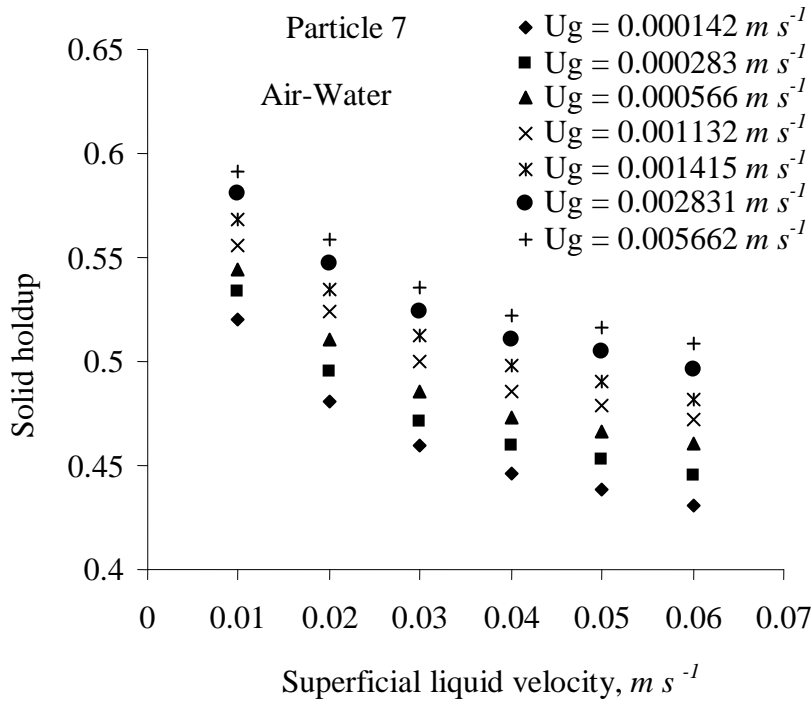
Sl.No.	Particle Description	Size / m	Density / $kg.m^{-3}$	Particle Sphericity/ ϕ_p
1	Particle 1(Spheres)	0.001	2478	1
2	Particle 2(Spheres)	0.002	2478	1
3	Particle 3(Spheres)	0.003	2478	1
4	Particle 4(Spheres)	0.004	2478	1
5	Particle 5(Spheres)	0.005	2478	1
6	Particle 6(Spheres)	0.006	2478	1
7	Particle 7(Spheres)	0.01036	2478	1
8	Particle 8(Bearl Saddles)	0.0115	2456	0.33
9	Particle 9(Raschig rings)	0.01366	2083	0.58

Results and Discussions

Effect of phase velocities on Gas Holdup

Fig.2 shows the effect of superficial gas and liquid velocity on the solid holdup for Air-Water system. It is observed that an increase in superficial liquid velocity make the solid beds to expand and hence solid holdup decreases, to compensate this liquid holdup increased. Increase in superficial gas velocity increases solid holdup which is also shown in Fig. 2.

Fig.2 Effect of phase velocities on solid holdup for Air-Water system using particle 7



Effect of Partilce diameter and Spercicity on solid Holdup

To study the effect of particle diameter on solid holdup, different solid particles with different diameters were used. Fig.3 is drawn between superficial liquid velocity and solid holdup for Air-Water system. From this graph it is observed that an increase in particle diameter decreases solid holdup in the column. This is due to the fact that increase in particle diameter does not break the gas bubbles as the smaller particles, so large gas bubbles move faster in the column, hence the solid holdup increases. Fig.4 shows the effect of sphericity of particles on solid holdup for the superficial gas velocity 0.0002831 m/s for Air-Water system. It is observed that increase in particle sphericity increases the solid holdup.

Fig.3 Effect of particle diameter on solid holdup for Air-Water system.

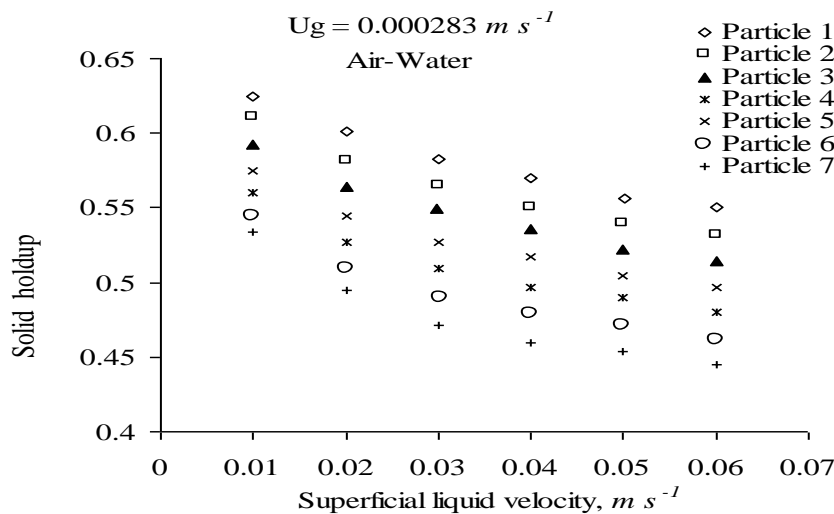
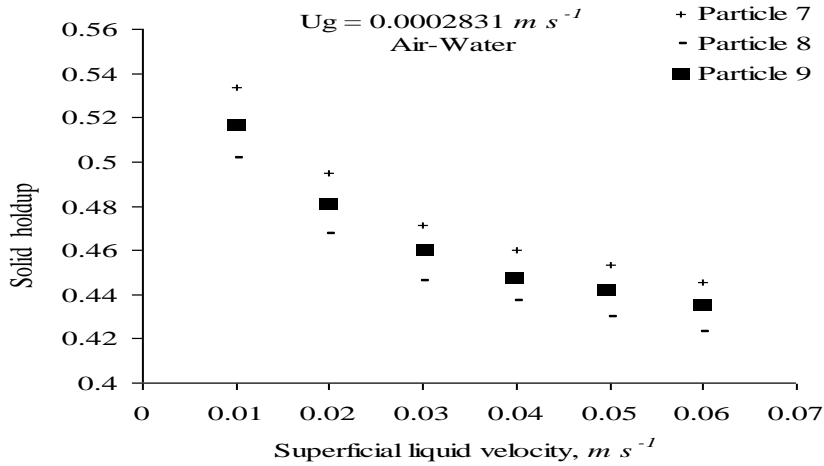


Fig.4 Effect of particle sphericity on solid holdup for Air-Water system.



Effect of Physical properties of liquids on solid Holdup

Fig.5 show the effect of physical properties of Air-Water, Air-n-Butanol, Air-60 % Glycerol and Air-80% Glycerol systems on solid holdup for the superficial gas velocity 0.000283 m/s. The figure shows that an increase in viscosity of liquid increases the solid holdup. From this figure it is also observed that decreasing surface tension of liquid increases solid holdup. From the experimental results it is observed that an increase in flow consistency index of non-Newtonian liquids increases the solid holdup.

Fig.5 Effect of physical properties of liquids on solid holdup.

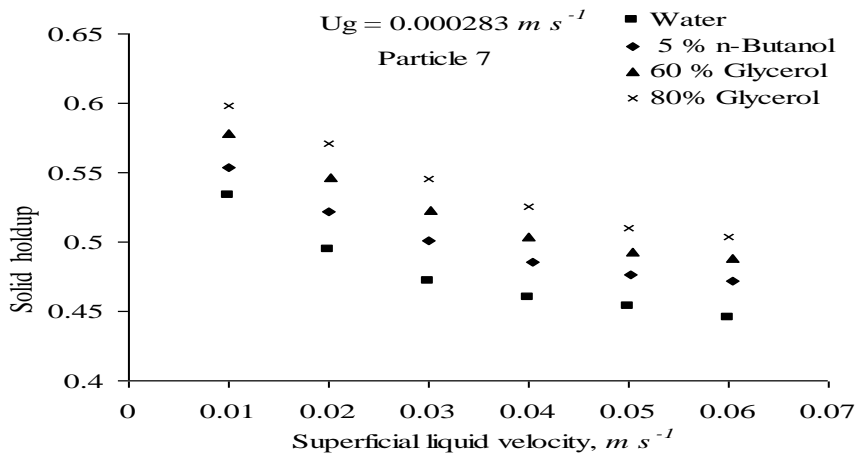
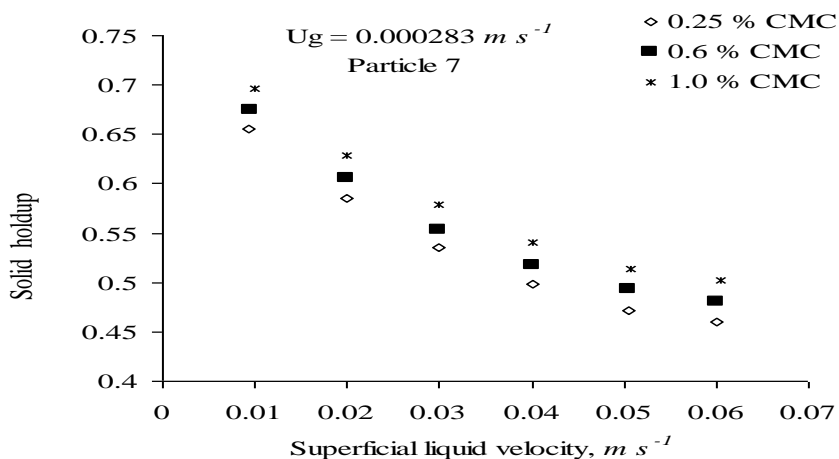


Fig.6 Effect of rheological properties of liquids on solid holdup.



Correlation

From the analysis of literature it is found that none of the authors developed correlation to predict solid holdup for a wide range of operating variables using Newtonian and non-Newtonian liquids. From the experimental data 1549 for solid holdup, a dimensionless correlation was developed to predict solid holdup,

$$\epsilon_s = 0.98(Fr_g)^{0.0414} (Fr_l)^{-0.011} \left(\frac{d_p}{d_c}\right)^{-0.062} (\phi_p)^{0.168} \left(\frac{\rho_p - \rho_l}{\rho_l}\right)^{-0.22} (Mo)^{0.009} \tag{1}$$

The predicting ability of the proposed correlation was calculated and shown in figures 7 and 8 for Newtonian and non-Newtonian liquids. Figures 7 and 8 shows good agreement between the experimental and calculated solid holdup with the average deviation of $\pm 15\%$. None of the authors have been reported their hydrodynamic results on solid holdup, in terms of fundamental operating variable such as superficial gas and liquid velocities, particle diameter, physical properties of liquids etc, and also their works were restricted to stagnant liquid and hence the proposed correlation was not validate with the literature data.

Fig.7. Comparison between the experimental and calculated values of solid holdup for Newtonian liquids

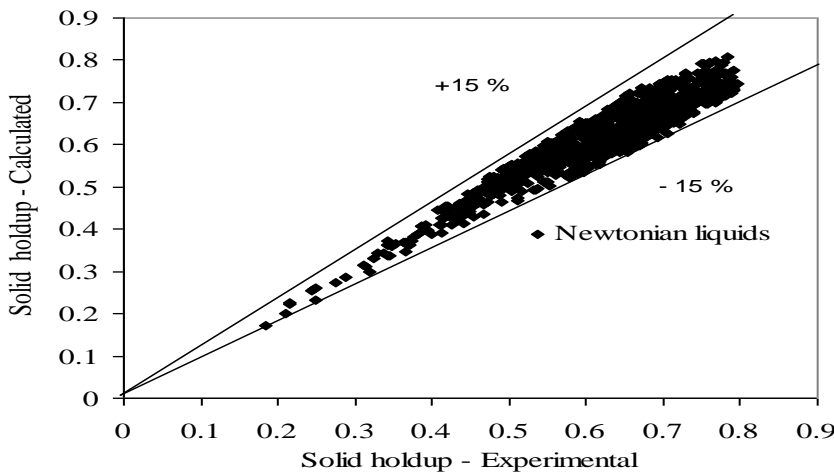
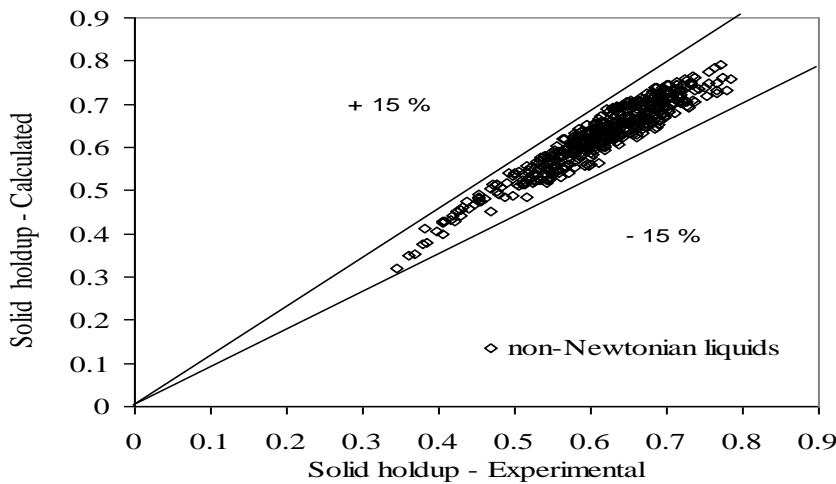


Fig.8. Comparison between the experimental and calculated values of solid holdup for non - Newtonian liquids



Conclusion

In the novel three-phase internal loop air lift fluidized bed reactor solid hold up was studied for different solid and liquid properties using Newtonian and non-Newtonian liquids. It is observed that the solid holdup in internal loop airlift fluidized bed reactor is dependent on the superficial gas and liquid velocities. The increase in superficial liquid velocity and particle diameter decreases the solid holdup, whereas solid holdup increases with increase in superficial gas velocity. The increase in viscosity and fluid consistency index of

Newtonian and non – Newtonian liquids increases solid holdup. A unified dimensionless correlation was developed based on the properties of liquid and solid phases for solid holdup and found to be coinciding with the experimental results. This correlation could confidently be used for design of commercial internal loop airlift fluidized bed reactors.

Nomenclature

d_p - Diameter of the particle, m

d_c - Overall column diameter, m

Fr_g - Froude number for gas- $Fr_g = \frac{U_g^2}{g \cdot d_p}$

Fr_l - Froude number for liquid- $Fr_l = \frac{U_l^2}{g \cdot d_p}$

g - Acceleration due to gravity, $m s^{-2}$

K – Flow consistency index, $kg s^{2-n} m^{-1}$

M_o - Morton number- $= \frac{\left[K \left(\frac{U_l}{d_p} \right)^{n-1} \right]^4}{\rho_l \sigma_l^3} g$

n - Flow behavior index, dimensionless

U_g - Superficial gas velocity, $m s^{-1}$

U_l - Superficial liquid velocity, $m s^{-1}$

ρ_p - Density of the solid, $kg m^{-3}$

ρ_l - Density of the liquid, $kg m^{-3}$

ϕ_p - Particle sphericity

ε_s - Solid holdup

σ_L – Surface tension of liquid, $N m^{-1}$

h_B - expanded bed height, m

m_s - Mass of the bed, kg

A - Cross sectional area of bed, m^2

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