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Effects of superficial gas velocity and fluid property on the hydrodynamic performance of an airlift column with alcohol solution

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Abstract

In the present study, the influence of superficial gas velocity and fluid properties on gas holdup and liquid circulation velocity in a three-phase external loop airlift column using polystyrene (0.0036 m diameter and 1025.55 kg/m^3 density) and nylon-6 (0.0035 m diameter and 1084.24 kg/m^3 density) particles with aqueous solutions of alcohols (isoamyl alcohol and propanol) as liquids were investigated. The column was constructed using acrylic tube of inner diameter 0.084m and 2.6m in height. The gas holdup in the riser increased with increase in superficial gas velocity for air-alcohol-solid system. The presence of alcohol surfactants increased the gas holdup in the riser. It was also found that an increase in the superficial gas velocity increased the liquid circulation velocity for air-alcohol-solid system. Correlations were proposed for the prediction of gas holdup and liquid circulation velocity.

Keywords: External loop airlift bioreactor, three-phase, effect of additives, hydrodynamics

1. Introduction

Airlift reactors have several advantages: simple design concept, high mixing performance, high mass transfer ability, good heat transfer and low energy consumption. Airlift loop reactors find extensive applications in many areas of chemical engineering, especially for homogeneous as well as heterogeneous single and multiphase systems due to their simple construction and operation, directed circulation flow, good mixing and favorable ratio of interfacial area to energy dissipation rate per unit volume, low investment, operational costs and relatively lower power requirements (Merchuk and Siegel, 1988). Based on their configurations, airlift reactors can be classified into two groups: internal-loop and external-loop airlift reactors. An internal-loop airlift reactor contains a vertical baffle or a draft tube by which a loop channel for fluid circulation is formed in the reactor. An external-loop airlift reactor consists of two vertical tubes (a riser and a downcomer) which are connected by horizontal connections at the top and bottom. A distractive difference between the two groups is the presence of the horizontal connections (Choi, 2001).

Herskowitz and Merchuk (1986) reported the influence of solid particles on the gas hold and liquid superficial velocity in a novel three phase fluidized bed reactor. Posarac and Petrovic (1988) found that the minimum fluidization velocity of 3-6 mm glass spheres was found to increase with solids loading. Kochbeck *et al.* (1992) reported the hydrodynamics and local parameters in three-phase-flow in airlift-loop reactors of different scale. Douek *et al*. (1994) observed that gas holdup and the liquid circulation velocity in the riser increased with increase in gas superficial velocity. A new method for the measurement of solids holdup in gas-liquid-solid three-phase systems was proposed by Wenge *et al*. (1995). Guo *et al*. (1997) reported the influence of hydrodynamics and mass transfer studies in a novel external-loop airlift reactor. Freitas *et al*. (1997) proposed a new sampling device for measuring solids holdup in a three-phase system. Freitas and Teixeira (1998) reported on solid-phase distribution in an airlift reactor with an enlarged degassing zone.

Freitas *et al*. (2000) reported the influence of the diameter of the distributor orifice, superficial gas velocity, solid loading and solid density on the hydrodynamics of a three-phase external-loop airlift bioreactor. The development and use of simple method for regime identification and flow characterization in bubble columns and airlift reactors was reported by Vial *et al*. (2001). Shimizu *et al*. (2001) developed the phenomenological simulation model for prediction of gas hold-up and volumetric mass transfer coefficients in external-loop airlift reactors. Meng *et al*. (2002) reported the use of a modified volume expansion (inclined tube) method for determination of overall gas holdup in an external loop airlift bubble column. Wang *et al*. (2003) reported the determination of gas holdup, liquid circulating velocity and mass transfer coefficient in a mini-scale external- loop airlift bubble column. Blazej *et al*. (2004) reported the simulation of gas-liquid flow in an airlift reactor using commercially available software Fluent.

From the literature, it is observed that most of the studies used pure water as liquid while all applications in wastewater treatment or biochemical reactors use complex aqueous solutions. Studies conducted with regular fluidized beds have shown that the presence of minor liquid impurities can greatly affect the bed hydrodynamics (Saberian-Broujenni *et al.*, 1984; Nacef *et al.*, 1988; Song *et al*., 1989; Prakash, 1991; Del Pozo *et al.*, 1994). However, little attention has been focused on the effect of additives in the hydrodynamic performance studies in external loop airlift bioreactors. The main objective of the present study is to establish whether changes in liquid coalescing properties caused by minute concentrations of additives can greatly affect the hydrodynamic properties of a three-phase external loop airlift column and to investigate the influence of superficial gas velocity and fluid properties on gas holdup and liquid circulation velocity.

2. Material and methods

The schematic diagram of the external loop airlift column used in the present investigation is shown (Figure 1). The column was constructed using acrylic tube of inner diameter 0.084 m and 2.6 m in height. The column consisted of four sections namely riser, downcomer, base and gas-liquid separator. The riser and downcomer were connected with an inclined angle 45^{o} at the top and the bottom section of the column. In order to avoid solids settling, the connection pipes between the riser and downcomer were inclined. The external loop airlift column had a perforated plate gas sparger with 243 holes of 1mm diameter on a triangular pitch placed at the base of the column. Air from the compressor was sparged to the column through an air filter, pressure regulator and calibrated rotameter. Provision was made to insert the dissolved oxygen meter probe above the gas sparger. All runs were made at room temperature (25±2°C).

The solid particles used are polystyrene of 0.0036m diameter (1025.55 kg/m^3 density) and nylon-6 of 0.0035m diameter (1084.24 kg/m^3 density). The physical properties of aqueous solutions of alcohols were given in Table 1. The gas holdup in the riser in three-phase system was determined by manometric technique and the liquid circulation velocity in the downcomer of the column was determined by tracer technique using 10 mm polystyrene spherical particle of density of 1012 kg/m^3.

Table 1. Physical properties of aqueous solutions of isoamyl alcohol and propanol

Additive	Concentrations	Density, ρ_l (kg/m^3)	Viscosity, μ_l (mPa.s)	Surface tension, σ_l (N/m)
Isoamyl alcohol	20 mg/l	998	1.0	0.072
Isoamyl alcohol	40 mg/l	998	1.0	0.071
Isoamyl alcohol	60 mg/l	998	0.98	0.069
Isoamyl alcohol	80 mg/l	998	0.97	0.069
Isoamyl alcohol	100 mg/l	997	0.97	0.067
Propanol	0.1 wt %	998	1.0	0.072
Propanol	0.2 wt %	998	1.0	0.072
Propanol	0.3 wt %	998	0.98	0.070
Propanol	0.4 wt %	998	0.97	0.069
Propanol	0.5 wt %	998	0.97	0.068

2.1 Measurement of gas holdup in three-phase system

In the three-phase systems, two different types of solid particles Polystyrene and Nylon-6 at various solids loading were used and the solid loadings were varied from 1000-3000 ml (4.25-12.765% (Vol.)). The gas holdup in the riser in three-phase system was determined by manometric technique and are related to solid holdup, ϕ_s by

$$\in_{gr} = \left(\frac{(\rho_s - \rho_l)\phi_s + (\rho_l \Delta h / z)}{(\rho_s - \rho_l)\phi_s + (\rho_l - \rho_g)} \right) \tag{1}$$

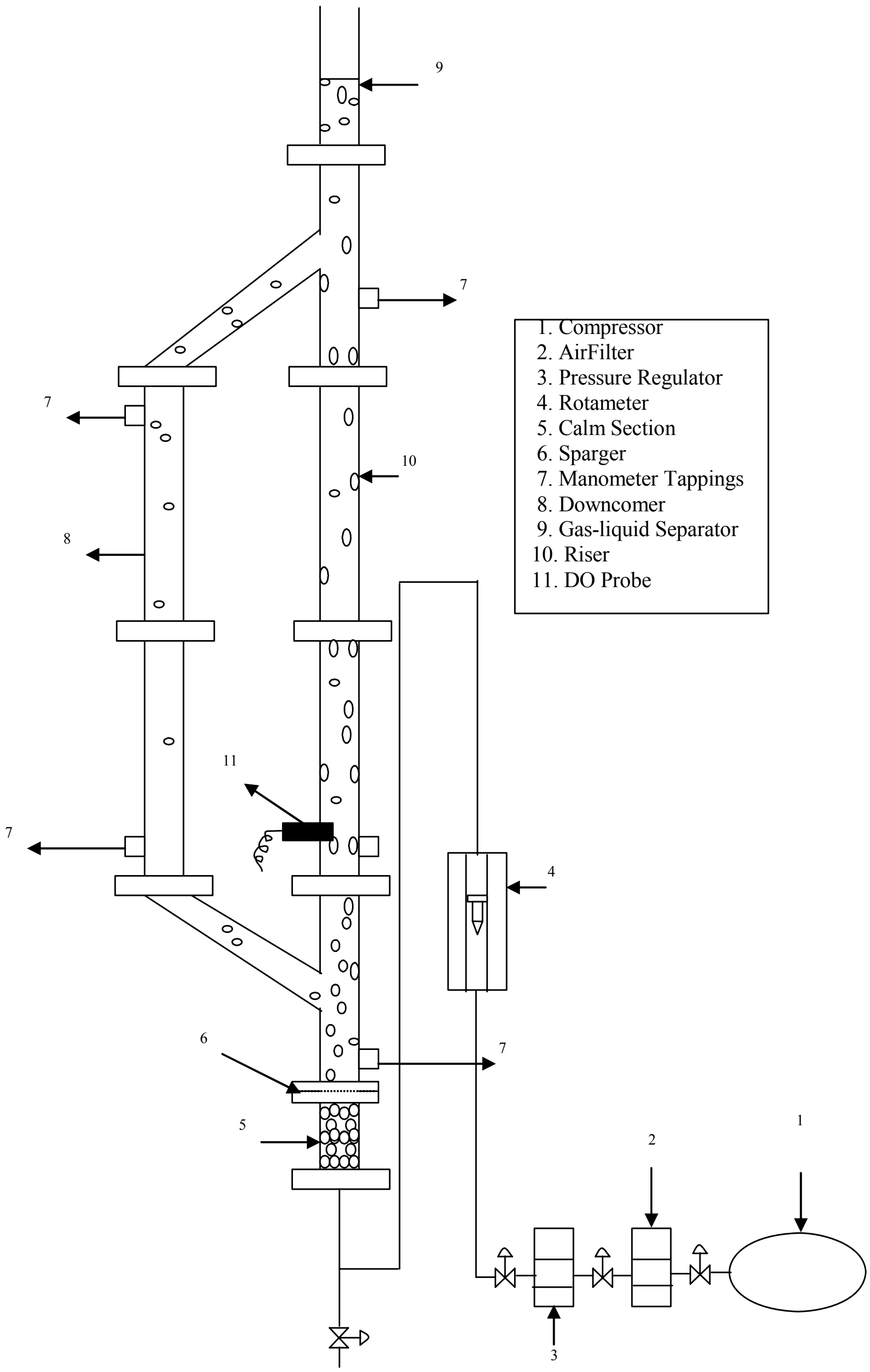


Figure 1. Schematic diagram of external loop airlift column

$$\phi_s = -\frac{\rho_l}{(\rho_s - \rho_l)}\frac{\Delta h}{z} \tag{2}$$

2.2 Measurement of liquid circulation velocity

The liquid circulation velocity in the downcomer of the column was determined by tracer technique using 10 mm polystyrene spherical particle of density of 1012 kg/m^3. The time required for the particle to travel between two ports on the wall of the downcomer was observed to calculate the liquid circulation velocity in the downcomer (U_{ld}). Thirty measurements were taken for each calculation of liquid velocity in the downcomer. The measurement of tracer particle traveling close to the column wall was excluded from the data (Bello *et al*., 1984; Kawase, 1990; Kemblowski *et al*., 1993; Wang *et al*., 2003).

The liquid circulation velocity in the riser and downcomer were obtained by

$$U_{ld} = x_c / t_c \tag{3}$$

$$U_{lr} A_r = U_{ld} A_d \tag{4}$$

$$U_{lr} = U_{ld} (A_r / A_d) \tag{5}$$

3. Results and discussion

3.1 Variation of gas holdup in the riser with superficial gas velocity for air-alcohol-solid systems

The variation of gas holdup in the riser, ε_{gr} with superficial gas velocity for air-alcohol-solid systems is shown in Figure 2. The experiments were carried out with an optimized solids loading of 2000 ml. It was observed that the ε_{gr} increased linearly with increase in superficial gas velocity. The presence of alcohol surfactants increased the ε_{gr}. This was mainly due to the suppression of bubble coalescence i.e. number of small bubbles produced in the riser had an insufficient bubble rise velocity to escape from the liquid. A similar trend was observed by Koide *et al.* (1985), Nicol and Davidson (1988) and Al-Masry and Dukkan (1997).

3.2 Effect of alcohol concentrations on ε_{gr}

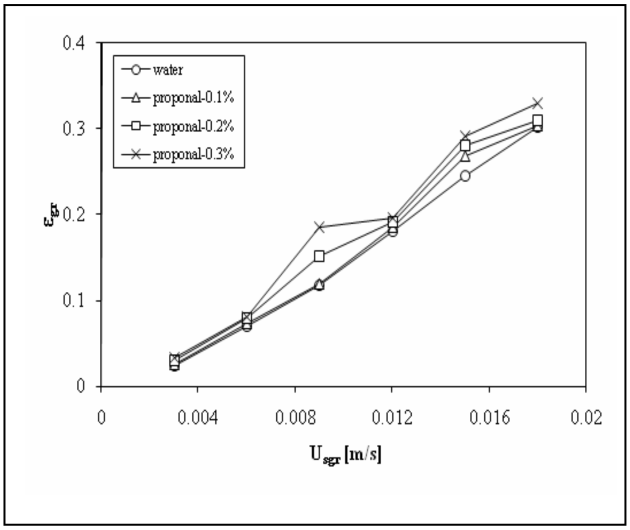
The effects of propanol and isoamyl alcohol concentrations on ε_{gr} are shown in Figures 3. The addition of propanol and isoamyl alcohol was found to increase the ε_{gr}. The bubble diameter and bubble rise-velocity were the functional parameters, which govern the riser gas holdup for alcohol surfactants. The increase in concentration of surfactants decreased the bubble diameter and rise velocity, which increased the ε_{gr}. This may be due to the decrease in the surface tension of the liquid phase.

3.3 Variation of liquid circulation velocity in the riser with superficial gas velocity for air-alcohol-solid systems

The variation of liquid circulation velocity, U_{lr} with superficial gas velocity for three-phase systems is shown in Figure 4. It was found that an increase in the superficial gas velocity increased the U_{lr}. The addition of alcohol surfactants decreased the U_{lr}. It was also observed that the concentrations of alcohol surfactants did not have any marginal effects on the U_{lr}, which was obtained by Al-Masry and Dukkan.

3.4 Effect of alcohol concentrations on U_{lr}

The effect of propanol and isoamyl alcohol concentrations on U_{lr} is shown in Figures 5 for 2000 ml solids loading. It was observed that the addition of solids and an increase in alcohol concentration decreased the U_{lr}. The alcohol surfactants did not have any marginal effects on the U_{lr}. A same trend was reported by Al-Masry and Dukkan.



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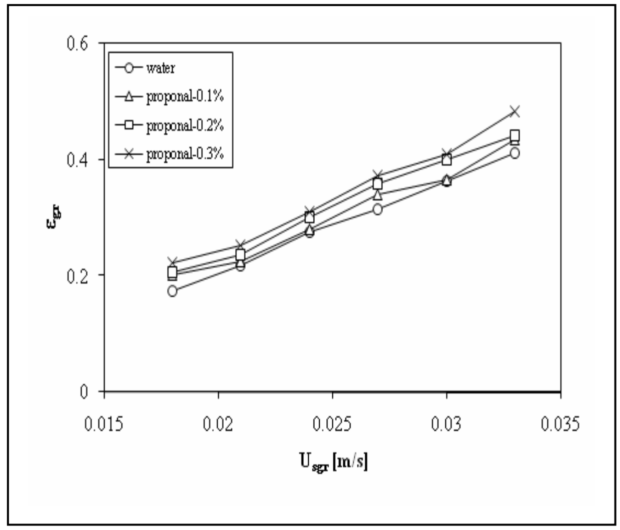

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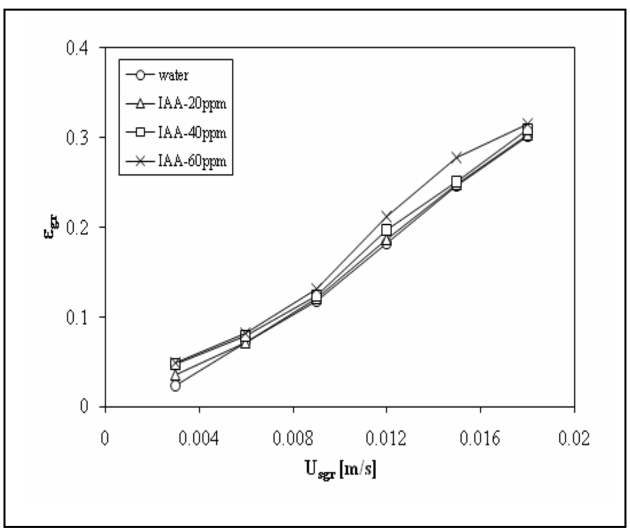

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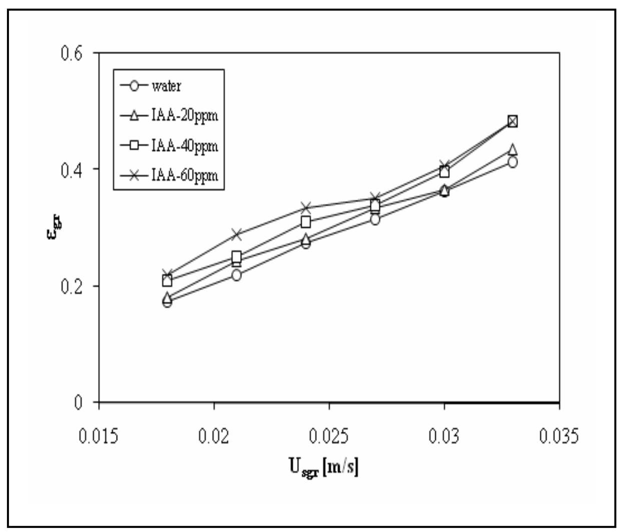

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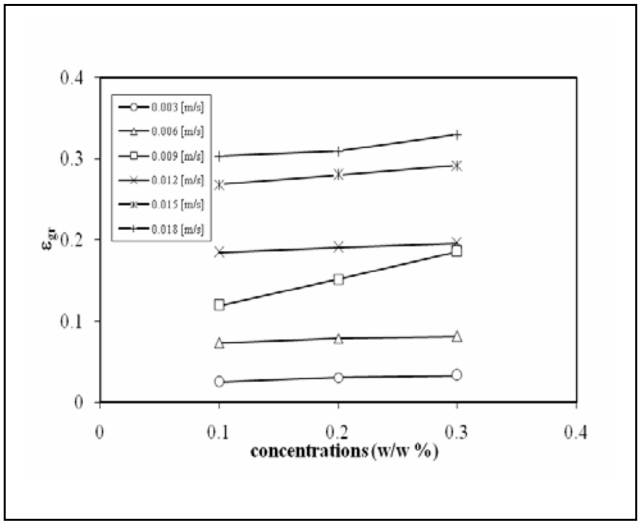
Figure 2. Variation of gas holdup in the riser with superficial gas velocity for (a) Air-propanol-polystyrene system; (b) Air-propanol-nylon-6-system; (c) Air-IAA-polystyrene system; (d) Air-IAA-nylon-6 system



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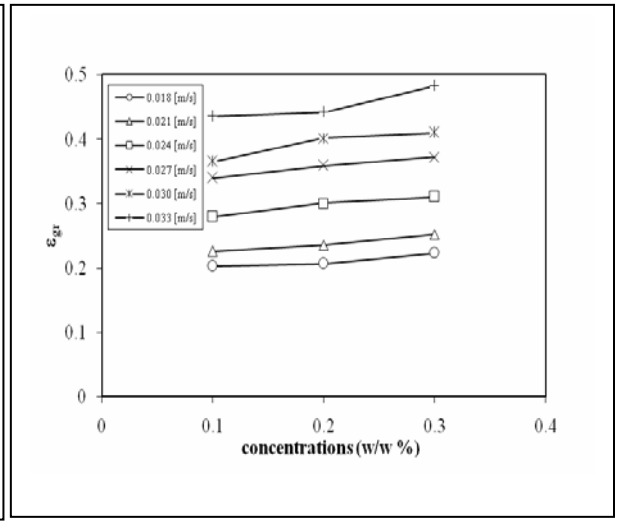

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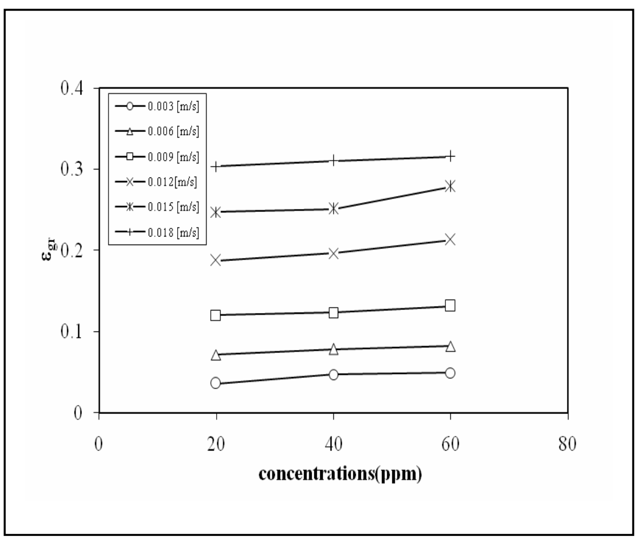

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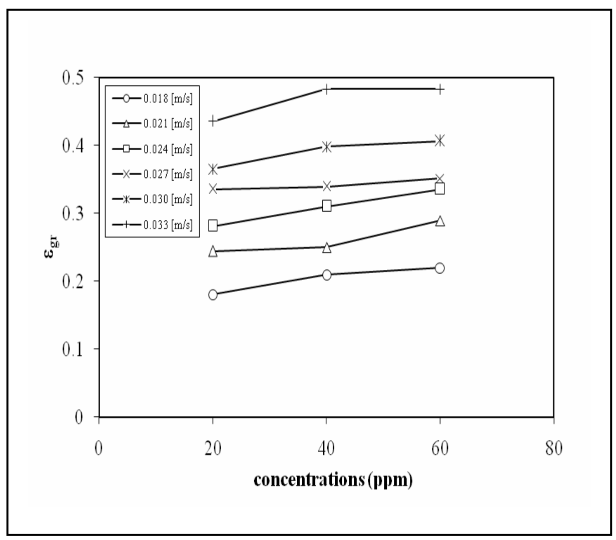

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Figure 3. Effect of alcohol concentrations on ε_{gr} for (a) Air-propanol-polystyrene system; (b) Air-propanol-nylon-6-system; (c) Air-IAA-polystyrene system; (d) Air-IAA-nylon-6 system

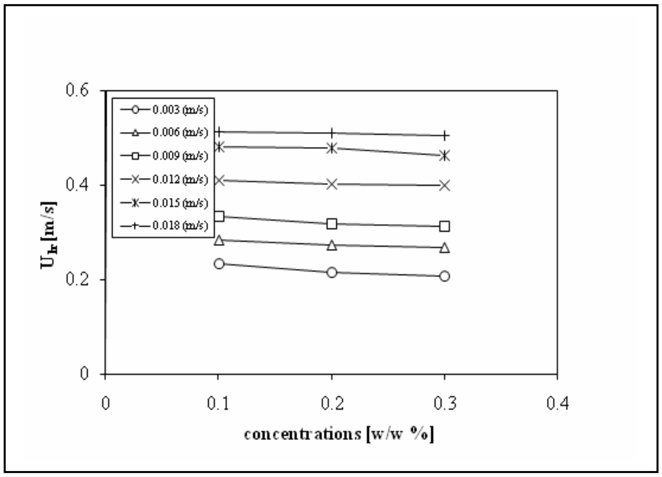
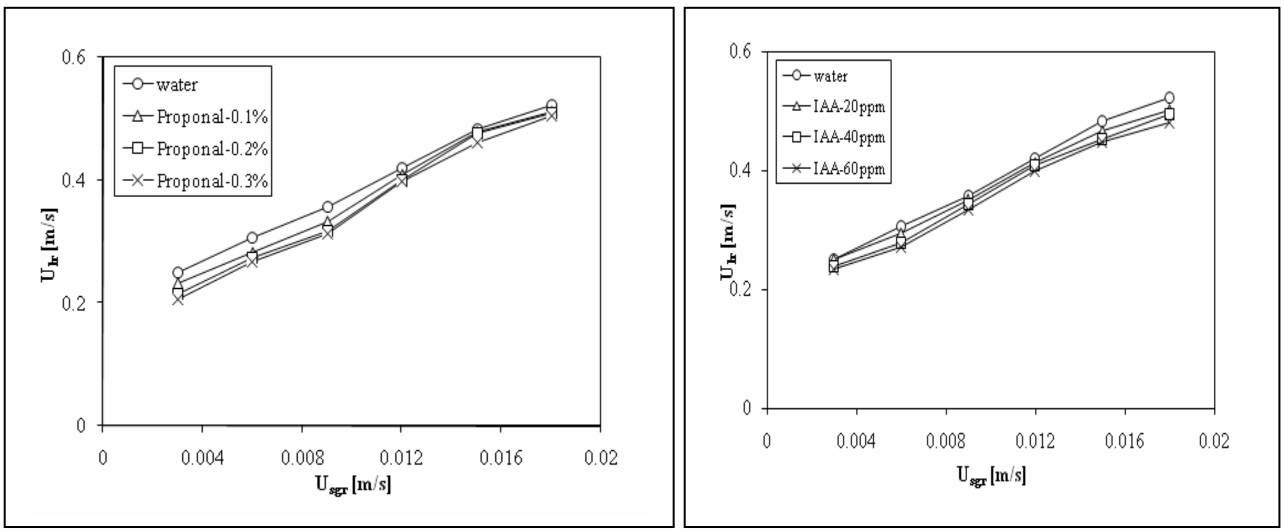


Figure 4. Variation of liquid circulation velocity in the riser with superficial gas velocity for air-propanol-polystyrene system



a b

Figure 5. Effect of alcohol concentration on liquid circulation velocity in the riser for (a) air-propanol-polystyrene system; (b) air-IAA-polystyrene system

3.5 Correlation for gas holdup in the riser and liquid circulation velocity for air-alcohol-solids system

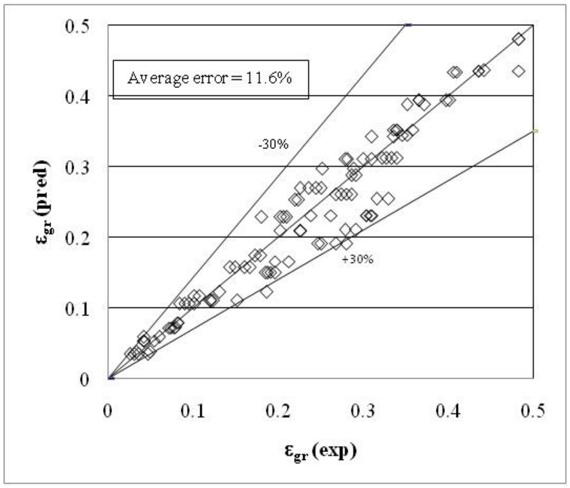
The value of gas holdup in the riser and liquid circulation velocity in the riser for three-phase system have been correlated as

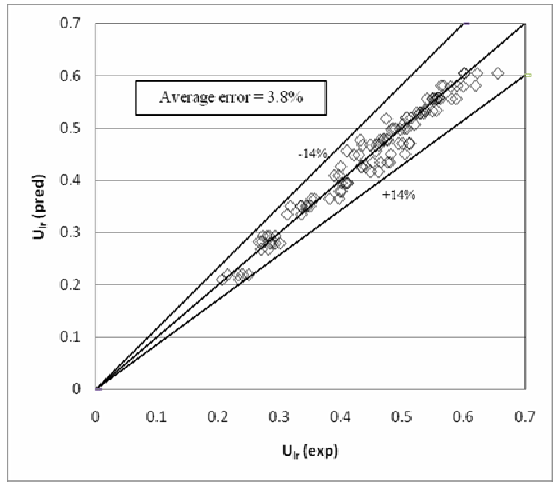
$$\in_{gr} = 18.577 U_{sgr}^{(0.984+1.16\times10^{-4} C_s)} \sigma^{0.05} \rho_l^{-0.038} \mu_l^{0.996} \qquad R^2 = 0.93 \qquad (6)$$

$$U_{ld} = U_{lr} = 2.727 U_{sgr}^{(0.384+6.52\times10^{-5} C_s)} \sigma^{-0.0096} \rho_l^{-0.0034} \mu_l^{0.997} \qquad R^2 = 1 \qquad (7)$$

$$0 \le U_{sgr} \le 0.033$$

Parity plots between experimental and predicted values of ε_{gr} and U_{lr} based on the proposed empirical equations 6 and 7 for air-alcohol-solids system are shown in Figures 6a and b respectively. The average RMS error for ε_{gr} and U_{lr} are 11.6 and 3.8% respectively. It was found that the proposed equations fitted the experimental data well within ± 30 and ± 14% respectively.





a b

Figure 6. Parity diagram of predicted and experimental values for (a)ε_{gr} estimated from empirical Eqn 6 for air-alcohol-solid system; (b) U_{lr} estimated from empirical Eqn 7 for air-alcohol-solid system.

4. Conclusions

The gas holdup in riser, ε_{gr} increased linearly with increase in superficial gas velocity. The addition of propanol and isoamyl alcohol was found to increase the ε_{gr}. An increase in the superficial gas velocity increased the liquid circulation velocity in the riser, U_{lr}. It was observed that the addition of solids and an increase in alcohol concentration decreased the U_{lr}. The proposed correlations for gas holdup in the riser and liquid circulation velocity predicted the experimental data well for air-alcohol (propanol and isoamyl alcohol)-solid system.

Nomenclature

A_d	downcomer cross sectional area, m^2
A_r	riser cross sectional area, m^2
C_s	solids loading, w/v
d	diameter, m
t_c	time taken between two peaks, s
U_{sgr}	superficial gas velocity in the riser, m/s
U_{lr}, U_{ld}	liquid circulation velocity in the riser and the downcomer, m/s
x_c	distance between the two adjacent peaks, m
IAA	iso amyl alcohol
z	distance between two ports, m
Δh	manometric reading, m
Greek symbols	
ε_g	gas holdup
ϕ	volume fraction of solids in liquid - solid two-phase slurry
σ	surface tension, mN/m
μ	viscosity, mPas
ρ	density, kg/m^3
Subscripts	
d	downcomer
g	gas
l	liquid
r	riser
s	solid

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