



## INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

### Effect of Adding Alcohols, Superficial Gas Velocity and Solid-Suspended on Design Parameters in Circulation Loop Bubble Columns

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#### Abstract

The influence of superficial gas velocity and the addition of alcohols with respect to oxygen mass transfer ( $K_{La}$ ), and gas hold-up ( $\epsilon_g$ ) in circulation loop bubble column using three aqueous solutions of 10% concentration methanol, ethanol and isopropanol as liquids were investigated. The column was constructed using a plexiglass tube of inner diameter of 0.9m and 1.3m in height with draught tube. The ratio of draught tube diameter to the column diameter equals 0.5 and the air dispersion into the base of the draught tube using a porous gas distributor.

The various gas velocities (0.01-0.1) m/sec are used and the results were compared in the case of using water only without the addition of alcohols. The solid particles (polyethylene 3.4mm particle diameter and the density 853.5 Kg/m<sup>3</sup>) were added to the liquid in the column. The concentration of solid particles was (50) kg/m<sup>3</sup>. From experimental observations, ( $\epsilon_g$ ) and ( $K_{La}$ ) increase with increasing gas velocity and with the coalescence inhibition of liquid.

**Keywords:** Internal Loop Bubble Column Reactor; Three-Phase; Alcohols; Design Parameters.

#### Introduction

Three phase internal air lift loop reactors are increasingly used in the fields of chemical and biotechnology as simple and effective contactors for processes involving gases, liquids and solids. The internal loop reactor has found many applications in many industrial processes such as hydrogenation, desulfurization, coal liquefaction, Fisher Tropsh synthesis etc. The simplicity of their design and construction, high heat and mass transfer capacity, and excellent mixing properties with low power requirements are making them very attractive [1,2].

Several investigators have studied the hydrodynamics of three-phase internal-loop airlift reactors. Miyahara and Kawate,[3] measured the gas holdup in the riser and the down comer, and the pressure drop at the upper and lower ends of the riser due to flow reversal for a solid-suspended air-lift reactor containing low-density particles Karamanev et al.,[4] , used 3 mm soft polyurethane foam particles in their experiments. They found that the gas holdup decreased significantly with increasing solids loading and the gas holdup was proportional to  $v_g^{1.2}$ . However, most works in the literature that study the hydrodynamics in slurry reactors have been performed under conditions of low solid concentrations. These works showed that particles with typical particle sizes smaller than 100 $\mu$ m are uniformly

suspended in both the axial and radial directions in a slurry system [5,6].

In the concentric-tube airlift bioreactor, some geometrical parameters affect gas holdup, liquid circulation, mixing time and the volumetric oxygen transfer coefficient. Extensive study of reactor hydrodynamics and reactor geometry enhances the importance of the geometrical parameters in the design and scale-up of concentric tube airlift bioreactors [7-9].

The volumetric gas-liquid mass transfer coefficient, ( $K_{La}$ ), plays an important role in the characterization of the performance of bioreactors [10-12]. A large number of researchers, Koide et al., [13]; Chisti and Moo, [14]; Choi and Lee, [15]; Merchuk et al., [16]; Shimizu et al., [17], Zhang et al., [18]; Tongwang et al., [19] have investigated the mass transfer performance in the air lift loop reactors together with their hydrodynamic behavior. Airlift reactors are agitated pneumatically and circulation takes place in a defined cyclic pattern through a loop, which divides the reactor into two zones: a flow-upward and a flow-downward zone. The gas-sparged zone or the riser has higher gas holdup than the relatively gas-free zone, the down comer, where the flow is downward [2]. However, few studies have addressed three-phase airlift reactors with low density solids [20,21]. However, little attention has been

focused on the effect of alcohols additive in the hydrodynamic design parameters in internal air lift loop reactors. The main objective of the present study is to establish whether changes in liquid coalescing properties caused by alcohols additive can greatly affect the hydrodynamic properties of a three-phase internal loop column and to investigate the influence of the superficial gas velocity and fluid properties on gas holdup and mass transfer coefficient.

### Experimental Section

A schematic diagram of the experimental setup in this work is shown in Figures 1, 1a and 1b. A Plexiglass column of 9 cm inside diameter and about 130cm total height with draught tube dimensions of 4.5cm inside diameter and 90 cm total height was used. The top and bottom clearances were maintained constant at 5 cm. The draught tube was fitted with three support legs in the upper and the lower end of the column so as to locate it in a central position at any distance above the base. The column consists of two main sections namely, the gas inlet section and the liquid recycling testing section. The gas inlet section consists of a gas distributor. At the bottom of this section, two lines are connected together before entering the distributor section each line has a valve to be opened or closed as required. One of these lines is the air inlet flow. Air compressor supplied the line with the desired amount of air needed; the amount of air was measured using a gas meter. The other line is the nitrogen gas inlet flow. The nitrogen gas was supplied from a cylinder. A gate valve was used in the nitrogen flow, which must be shut off when the air was sparged to the column, and must be opened during the desorption process. The liquid testing section contains two openings, one for liquid out-flow and the other for liquid in flow. The circulation of liquid in the column was achieved using a dosing pump placed in the recycling line. A ball valve placed in the middle of the recycling line was used to take various samples at various times to measure the concentration of the dissolved oxygen during the operation. The column was filled with water and alcohols to the desired height above the distributor 0.7 m. Then the solid particles (polyethylene 3.4mm particle diameter and the density 853.5 Kg/m<sup>3</sup>) were added to the liquid in the column. The concentration of solid particles was 50 kg/m<sup>3</sup>. Compressed air at (100-150) psig was supplied using a reciprocating compressor. The desired air flow rate was set-up using gate valve and the amount measured with a gas meter. The dissolved oxygen concentration in the liquid phase was measured using oxygen meter device type a (YSI-5100), which consists of a probe metal electrode. The liquid phase (batch) consists of the following systems (water and

solid, water, alcohols and solids) the chemicals used in the present study were procured from Permula Chemicals SDN.BHD., Malaysia. The gas distributor Figure 1.c was constructed from a ceramic material and the type is multi holes tyere.

### Results on Gas Hold Up ( $\epsilon_g$ ) and Solid Hold Up ( $\epsilon_s$ )

The average gas hold up  $\epsilon_g$  was calculated from the equation (1) using the data of the clear - liquid height ( $H_f$ ) and the height of the aerated liquid ( $H_f$ ) which was determined by visual observation:

$$\epsilon_g = \frac{H_f - H_L}{H_F - (V_i / S_o)} \quad (1)$$

( $V_i / S_o$ ) In Eq. (1) is a correction term for the volume of the draft tube [22]

The solid-hold-up was calculated from the equation(2). Using the date of static liquid height ( $H_F$ ) and the height of slurry after adding solid particles ( $H_F'$ ):

$$\epsilon_s = \frac{\overline{H}_F - H_L}{\overline{H}_F} \quad (2)$$

The experimental gas hold up was found by measuring the difference between initial liquid height and final liquid height. Since it was rather difficult to read directly the level of the aerated liquid the values of gas hold up thus obtained probably involves an error of about 5%, established via repeated measurements. Figure 3 shows the effect of gas velocity for water system with and without solid particles. The variation of a gas holdup in the riser ( $\epsilon_g$ ) with superficial gas velocity for air-alcohol-solid systems are shown in Figure 2. The experiments were carried out with constant solids (polyethylene 3.4mm particle diameter and the density 853.5 Kg/m<sup>3</sup>) loading of 50Kg/m<sup>3</sup> and the desired liquid height above the distributor (0.7) m. It was observed that the gas hold-up increased linearly with increase in gas throughput (gas velocity), but interact mutually, depending on liquid phase properties. The gas hold-up of isopropanol with solid is roughly twice that of water with solid. In the presence of alcohols, the bubbles become more rigid and hence have low rise velocities resulting in a bubbly flow regime up to surprisingly high gas velocities (0.1 m/sec). 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, for aqueous solutions of aliphatic alcohols, a considerable increase in

the gas hold-up in alcohol chain length was observed. The gas hold up decreased in the following order isopropanol > ethanol > methanol. The decrease in surface tension in the presence of alcohols was not sufficient to explain this phenomenon. Bubble dynamics and bubble swarm structure in the presence of surfactant solutions can explain this behavior qualitatively. A similar trend was observed by Koide et al., [23], Nicol and Davidson [24] and Al-Masry and Dukkan [25]. The solid particles retard the bubble rise velocity and prevent increases in bubble size.

### Mass Transfer Coefficient Results

The physical absorption of oxygen in the air by the liquid was employed to determine the mass transfer coefficient. A material balance of oxygen in the liquid gives:-

$$K_{La} = \frac{-2.303(1 - \varepsilon_g - \varepsilon_s)}{t} \cdot \text{Log} \frac{C_{Sa} - C_i}{C_{Sa} - C_o} \quad (3)$$

Rearranging equation (3) gives

$$\text{Log} \frac{C_{Sa} - C_i}{C_{Sa} - C_o} = \frac{K_{La}}{2.303(1 - \varepsilon_g - \varepsilon_s)} t \quad (4)$$

Plotting the left hand side of equation (4) with (t), the average slope of the plot will give the term  $K_{La}/2.303(1 - \varepsilon_g - \varepsilon_s)$  the values of ( $\varepsilon_g$ ) and ( $\varepsilon_s$ ) were determined as mentioned in (1) and (2) respectively, then ( $k_{La}$ ) can be calculated. Figure 3 shows that the mass transfer coefficients increase with increasing gas velocity. The axial dispersion coefficients ( $D_L$ ) increase with increasing gas velocity and therefore increase ( $K_{La}$ ). On account of the strong coalescence inhibition the volumetric mass transfer coefficient in (water-isopropanol+ solid) system reach double the values as in (water- solid). For aqueous solutions of aliphatic alcohols with solid, (Ethanol, Methanol), the presence of solid particles retards the bubble rise velocity and prevent increases in bubble size, so that the mass transfer coefficients are larger than that in (water-solid).

### Conclusions

For the present study the following conclusions were made:

The gas hold-up and mass transfer coefficient increase with increasing gas velocity for  $V_g \leq 0.1$  m/sec and decrease with increasing liquid surface tension in an air lift loop reactor in the presence of alcohol and suspended solid particles (polyethylene) and the ratio of draught tube diameter to the column diameter equals 0.5 and the air

dispersion into the base of draught tube using porous distributor.

### Nomenclature

$a$	Specific gas-liquid interfacial area based on aerated liquid volume $m^{-1}$
$C_i$	Concentration of dissolved oxygen at any time p.p.m
$C_0$	Initial Concentration of dissolved oxygen p.p.m
$C_{Sa}$	Saturated concentration of dissolved oxygen p.p.m
$C_s$	Solid particle concentration $K_g/m^3$
$D_C$	Column diameter
$D_d$	Draft tube diameter
$D_i$	Diffusivity of oxygen in solution $m^2/sec$
$D_L$	Axial dispersion coefficient (liquid) $m^2/sec$
$g$	Acceleration of gravity $m/sec^2$
$H_L$	Static slurry height (m)
$H_F$	Level of aerated slurry (m)
$\bar{H}_F$	Level of liquid phase+ solids (m)
$K_L$	Liquid phase mass transfer coefficient ( $m.s^{-1}$ )
$K_{La}$	Overall mass transfer coefficient, based on aerated slurry volume. (Sec-1)
$t$	Time (min)
$V_g$	Gas velocity (m/sec)

### Greek symbol

$\varepsilon_g$	Gas hold up
$\varepsilon_s$	Solid hold up
$\rho_L$	Liquid phase density $kg/m^3$
$\rho_S$	Solid phase density $kg/m^3$
$\mu_L$	Liquid phase viscosity ( $C_p$ )
$\nu_L$	Kinematic viscosity of liquid phase ( $cm^2/sec$ )
$\sigma_L$	Liquid phase surface tension $dyn/cm$

### Subscripts

G	gas
L	liquid

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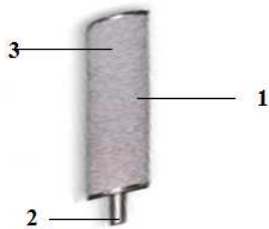
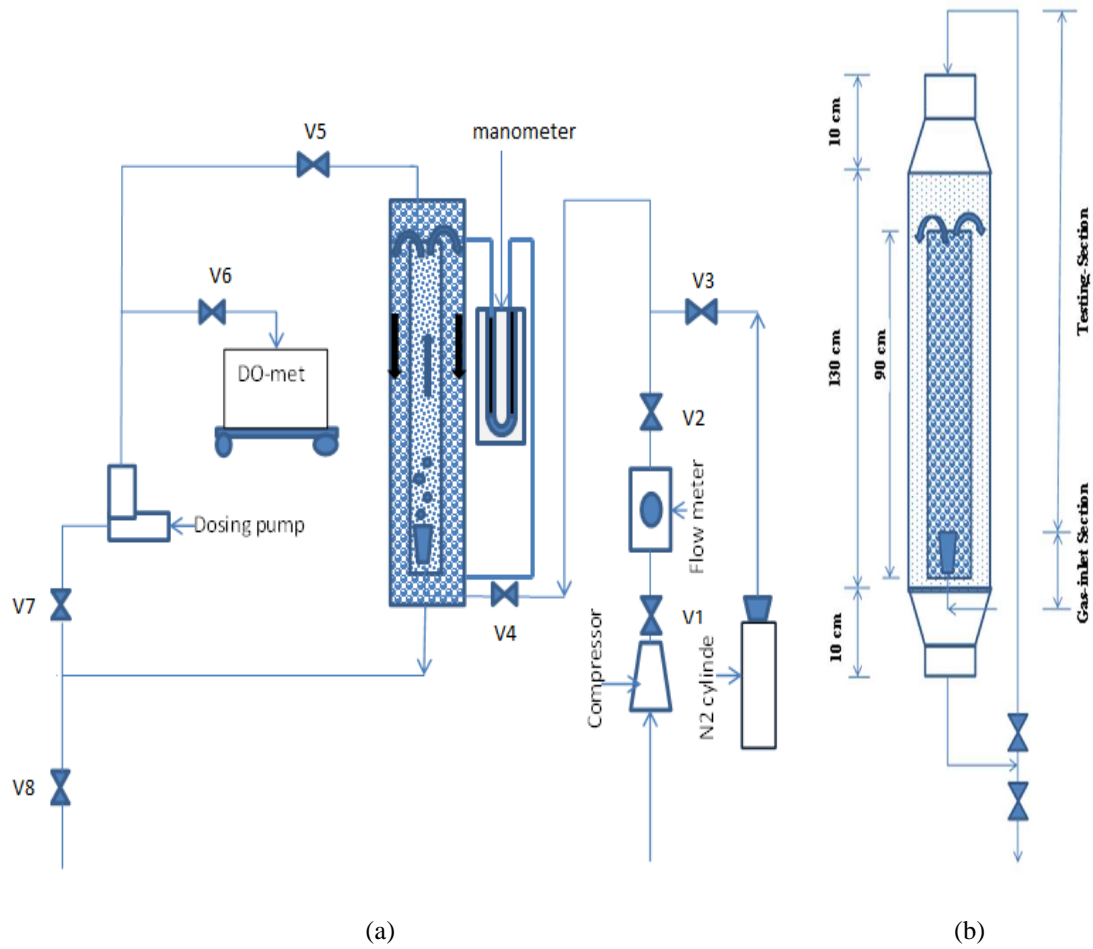
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**Table1. physical-properties for pure liquids at T=20 °c**

	$\rho$ density Kg/m <sup>3</sup> ×10 <sup>3</sup>	$\mu$ CP	$\sigma$ dyn/cm	$V_{Lcm}$ <sup>2</sup> /sec
Water	0.998	1.002	72.86	1.004
Methanol	0.791	0.584	22.61	0.738
Ethanol	0.789	1.200	22.27	1.520
Iso-propanol	0.785	0.85	66.6	0.9792

**Table 2. physical properties for mixtures used with various concentration at T=20°C**

	$\rho$ densitykg/m <sup>3</sup> ×10 <sup>3</sup>	$\mu$ CP	$\sigma$ dyn/cm	$V_{Lcm}$ <sup>2</sup> /sec
Water-Methanol 10%	0.9815	0.795	22.63	0.8226
Water-Ethanol 10%	0.981	0.910	22.64	0.9400
Water-isopropanol 10%	0.982	0.972	62.42	0.8932



- 1-Ceramic Material
- 2- Pipe
- 3-Hole

(c)

Fig.1. (a) Experimental-Apparatus; (b) Column and (c) Gas distributor.

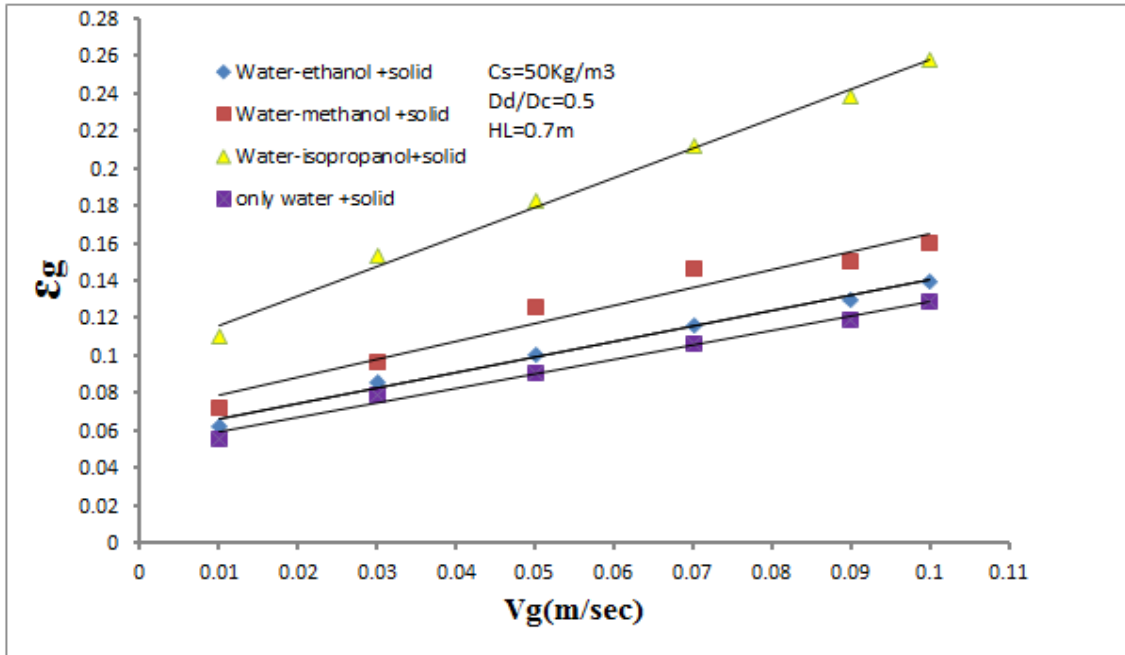


Fig.2.Gas hold-up versus gas velocities for various systems.

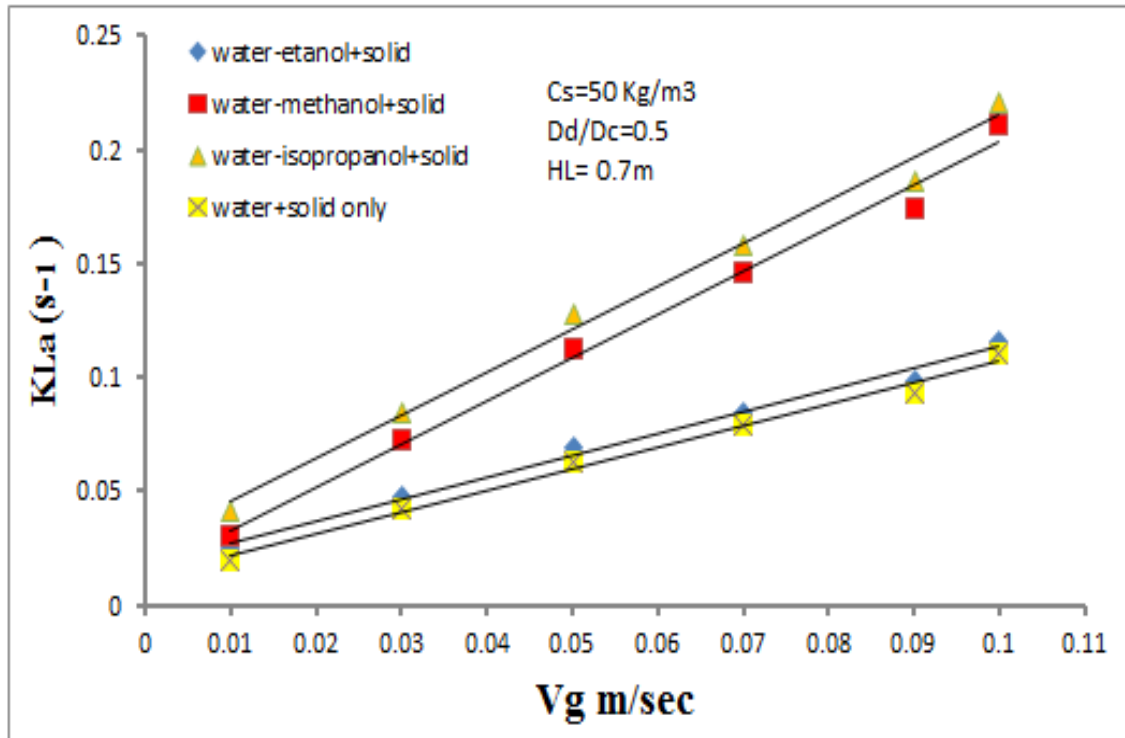


Fig.3.Mass Transfer Coefficient vs. Gas Velocity for Various Systems.