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The Effects of Superficial Gas Velocity and Liquid Phase Properties on Gas Holdup and Mass Transfer In An Airlift Reactor

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Abstract: - Mass transfer coefficient (K_{La}) and gas hold up (ε_g) were characterized in 8 liter internal air lift loop reactor (down comer-to-riser cross-sectional area ratio = 0.249) as function of the superficial gas velocity in the riser (V_{gr}). Data were obtained in air–water, air-50% glycerol solution, air-10%acetic acid solution, air-10%NaCL solution and air-2% carboxyl methyl cellulose solution (CMC) systems. Extent different gas velocity ranges 0.01-0.1 m/s and air dispersed into the center of riser by using porous gas distributor. The results showed that(ε_g) and (K_{La}) increased with increasing gas velocity and coalescence inhibition in liquid , in (CMC) solution (K_{La}) is approximately similar to that in water while the increasing in coalescence and liquid viscosity reduces (ε_g) and (K_{La}) .

Keywords: - *Airlift reactor; Mass transfer; Gas hold up; Liquid-phase properties*

I. INTRODUCTION

Airlift reactors (ALRs) are suitable for many different processes. They are mainly used as bioreactors in fermentation processes and in the biotransformation of many substances [1, 2]. In wastewater treatment ALRs are increasingly being developed [3, 4, 5, 6]. 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 [7]. Based on their configurations, airlift reactors can be classified into two groups: internal-loop (IL- ALR) and external-loop airlift reactors (EL-ALR). 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 down comer) which are connected by horizontal connections at the top and bottom. [8]. The intrinsic complicated hydrodynamic structures induced by bubble motion and associated with wake interaction, have been recognized to be the key factors responsible for heat and mass transfers. Because bubble-induced flows in the airlift reactor are identified to be dynamic in nature, the time averaged flow properties cannot well represent the dynamic governing mechanisms of flow structures. IL-ALR and EL-ALR have been widely studied experimentally. Some of these studies focus on liquid velocity circulation, gas and solid phase hold-ups [5] and on mass transfer [9]. To design and operate ALRs with confidence, the knowledge of gas-liquid mass transfer is required to characterize the performance of the ALR. The main parameter used as an indicator for gas-liquid mass transfer rate is the gas-liquid mass transfer coefficient (K_{La}). A large number of researchers [10, 11, 12, 13, 14, 15, 16] have investigated the mass transfer performance in the ALRs together with their hydrodynamic behavior. It was found that the knowledge of hydrodynamic behavior is critical for design purposes because of their strong influence on mass transfer. Although a large number of investigations contributed to the knowledge of the effect of various parameters on hydrodynamic and mass transfer characteristics in ALRs, available information frequently showed wide variations and conflicting claims. The contradiction is regularly attributed to the difference in the reactor geometries, experimental conditions and experimental techniques. However the present knowledge suggests that this contradiction is brought about by some complicated phenomena taking place in ALR, such as the bubble size distribution, internal liquid circulation, etc [17, 18, 19, 20,21]. The purpose of this study is to clarify experimentally the effects of the gas velocity and liquid phase properties(viscosity and coalescing behavior) on gas hold-up, and mass transfer coefficient(K_{la}) in concentric-tube airlift loop reactor when the ratio of draught tube diameter to column diameter is equal to 0.5 and the air is sparged into the center of the riser.

II. EXPERIMENTAL SECTION

A schematic diagram of the experimental set-up used in this work is shown in Figures 1a and 1b. Aconcentric aplexiglass tube airlift reactor of an inside diameter of 0.9 m and about a total height of 1.30 m with draught tube dimensions inside diameter of 0.045m and a total height 0.90 m was used. The volume of the reactor was 8 liter and Ad /Ar=0.249,where Ad is the downcomer superficial area(m^2)and Ar is the riser superficial area (m^2). The water level in the reactor was 0.75 m. The draught tube was fitted with three support legs at the upper and the lower end of the column so as to locate it in 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; for the experiment, the amount of air was measured using a gas meter. The other line is the nitrogen gas inlet flow. The nitrogen was supplied from a cylinder. A gate valve was used in the nitrogen flow, which must be shut off when air was sparged to the column, and must be opened during 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 water is fed to the top of the column and discharged from the bottom of the column using adosing pump. 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 was 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 (only water, water- glycerol, water-CMC) the chemicals used in the present study were procured from Permula Chemicals SDN.BHD., Malaysia. The gas distributor in Fig 1.c was constructed from a ceramic material and the type is a multi hole tuyere. The distributor has equivalent pore diameter of 0.15 mm and a free section of 80%.

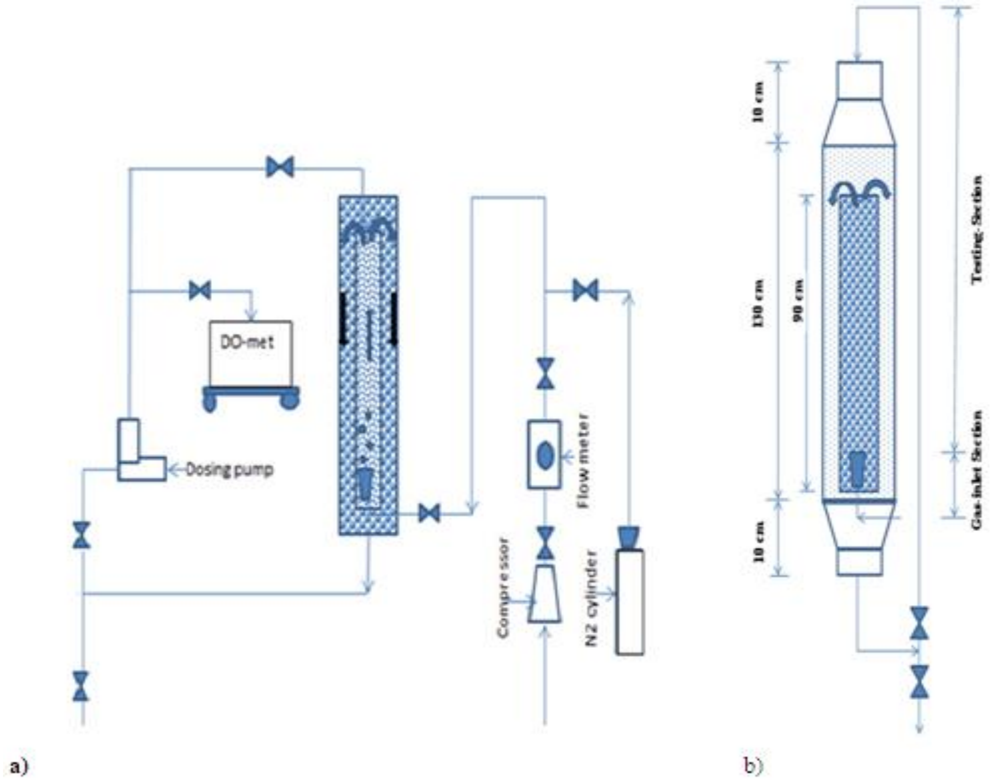

Figure 1: (a) Experimental apparatus; (b) column; (c) gas distributor

TABLE A1-Physical-properties for pure liquids at $T = 20\ ^{o}$C

	ρ (Kg/m^3)10^3	μ (CP)	σ (dyn/cm)	ν_L (cm^2/sec)
Water	0.998	1.002	72.86	1.004
Glycerol	1.261	1.005	6304	0.796
CMC	1.008	K=0.012 ps.s^n n=0.8	73	1.23
Acetic-Acid	1.049	1.219	27.6	1.162
NaCL	2.165	1.295	72	0.598

The solution of CMC (carboxy methyl celluose) shows non newtonian, pseudo plastic behavior, which can be described by the power law of ostwald and deweale:

$t = K\,\gamma^{n}$

Where:-

K: ostwald factor (consistency index)

n: flow behavior index

γ : shear rate 1/sec

t: shear stress

$\mu_{eff} = \gamma^{\,n-1}$

where μ_{eff}: effective liquid phase viscosity Pa.s

Y = 5000 Vg [22]

Where Vg: gas velocity m/sec.

TABLE A2- Physical properties for mixtures used with various concentration at T=20^{o}C

	ρ (kg/m^3)10^3	μ (CP)	σ (dyn/cm)	ν_L (cm^2/sec)
Water-Acetic Acid 10 %	1.026	0.916	22.225	0.8932
Water-glycerol 50%	1.126	6.00	64	0.8905
Water-CMC 2%	1.009	K=1.320 Pas^n n=0.5	69	0.09051
Water-NaCL 10%	1.0216	0.9247	48.375	0.9051

III. MEASUREMENTS OF GAS HOLD-UP AND VOLUMETRIC OXYGEN TRANSFER COEFFICIENT

The overall gas hold up ε_g in the reactor was determined by visual measurements of the static liquid height H_L and the aerated height H_F. The gas holdup ε_g was calculated from the following equation.

$$\varepsilon_g = \frac{H_F - H_L}{H_F - (V_i / S_o)} \qquad (1)$$

(V_i / S_o) In Eq. (1) is a correction term for the volume of the draft tube [23].

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:-

$$K_{La} = \frac{-2.303(1-\varepsilon_g)}{t}.Log\frac{C_{Sa-}C_i}{C_{Sa}-C_o} \qquad (2)$$

Rearranging Eq. (3) gives

$$Log\frac{C_{Sa}-C_i}{C_{Sa}-C_i} = \frac{K_{La}}{2.303(1-\varepsilon_g)}.t \qquad (3)$$

Plotting the left hand side of Eq. (3) with(t),the avarge slope of the plot will give the term $K_{La}/2.303(1-\varepsilon_g)$The values of ($\varepsilon_g$) were determine as mentioned in (1), then (k_{La}) can be calculated.

GASHOLD UP AND MASS TRANSFER COEFFICIENT RESULTS .IV

Fig 2 shows the influence of gas velocity for different liquid phase systems (water, water-glycerol, water-CMC) on gas hold-up when the down comer-to-riser cross-sectional area ratio = 0.249. The gas hold-up increases with increasing gas through put (gas velocity), but interact mutually, depending on liquid phase properties. Many Literatures revealed that increasing superficial gas velocity increased the gas holdup [24,25,19,21]. The viscous solutions of glycerol and CMC show only slightly higher gas hold-ups than water. In spite of similar a flow property of the CMC and glycerol solutions, gas hold-up in the CMC solution is somewhat larger, due to accompanying coalescence inhibiting. In general, low viscosity liquid exhibit bubble disintegration behavior. whereas, a trend towards bubble coalescing behavior has been observed with increasing the viscosity of the liquid media, as shown by many investigators [26, 27].

Fig 3 shows the effect of using different liquid phase (water, water-acetic acid, water-NaCl), on gas hold up. Low electrolyte concentrations have no noticeable effect on the surface tension of the solution. However the ionic forces in the liquid bulk reduce the bubble rise velocity and the bubble coalescence. As a result, the gas holds- up increase. For high electrolyte concentration, the interfacial tension increases, resulting in increased bubble size and reduce gas holdup.

Fig 4 shows the influence of gas velocity for different liquid phase systems (water, water-glycerol, water-CMC) on (K_{La}) when the down comer-to-riser cross-sectional area ratio = 0.249. The volumetric-mass transfer coefficient (K_{La}) is a function of gas hold-up and mean bubble size. The K_{la} values for water increases with increasing gas velocity because of the increase of the axial dispersion coefficient D_L. The mass transfer coefficient in (water-glycerol) system reaches its maximum value at gas velocity of about 0.02 m/sec; owing to the strong coalescence promoting properties of highly viscous liquid, large bubbles are formed already at very small gas throughputs. The reduction of bubble size with increasing gas velocity is a characteristic feature of pseudo-plastic (water-CMC) system [28], therefore the mass transfer coefficient are smaller than that in water, and larger than in (water-glycerol) system.

Fig 5 shows the effect of using different liquid phase (water, water-acetic acid, water-NaCl), on (K_{La}) when the down comer-to-riser cross-sectional area ratio = 0.249. For electrolytes as mentioned before, the ionic forces in the liquid bulk reduce the bubble rise velocity and the bubbles coalescence, so that the mass transfer coefficient is increased.

V. CONCLUSIONS

From the present study the following conclusions were made:

1. The gas hold-up and mass transfer coefficient in air lift loop reactor, where gas is dispersed into the center of base of inner draught tube using a porous multi hole distributor and the reactor volume equal to 8 liters increase with increasing gas velocity, for *Vg* equal or less than 0.1m/sec, only for the case of (water, glycerol) system, the mass transfer coefficient reaches its maximum at gas velocity of 0.02 m/sec. This observation is in agreement with many experimental works [29, 25, 30, 17, 15, 21].
2. Gas hold-up and mass transfer coefficient decrease with increasing liquid phase viscosity and liquid surface tension.

VI. 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
D_C	Column 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)
K_{La}	Overall mass transfer coefficient, based on aerated slurry volume. (Sec^{-1})
t	Time (min)
V_g	Gas velocity (m/sec)

Greek letters

ε_g	Gas hold up
ρ_L	Liquid phase density kg/m^3
μ_L	Liquid phase viscosity (C$_p$)
ν_L	Kinematic viscosity of liquid phase (cm^2/sec)
σ_L	Liquid phase surface tension dyn/cm

Subscripts

G	gas
L	liquid

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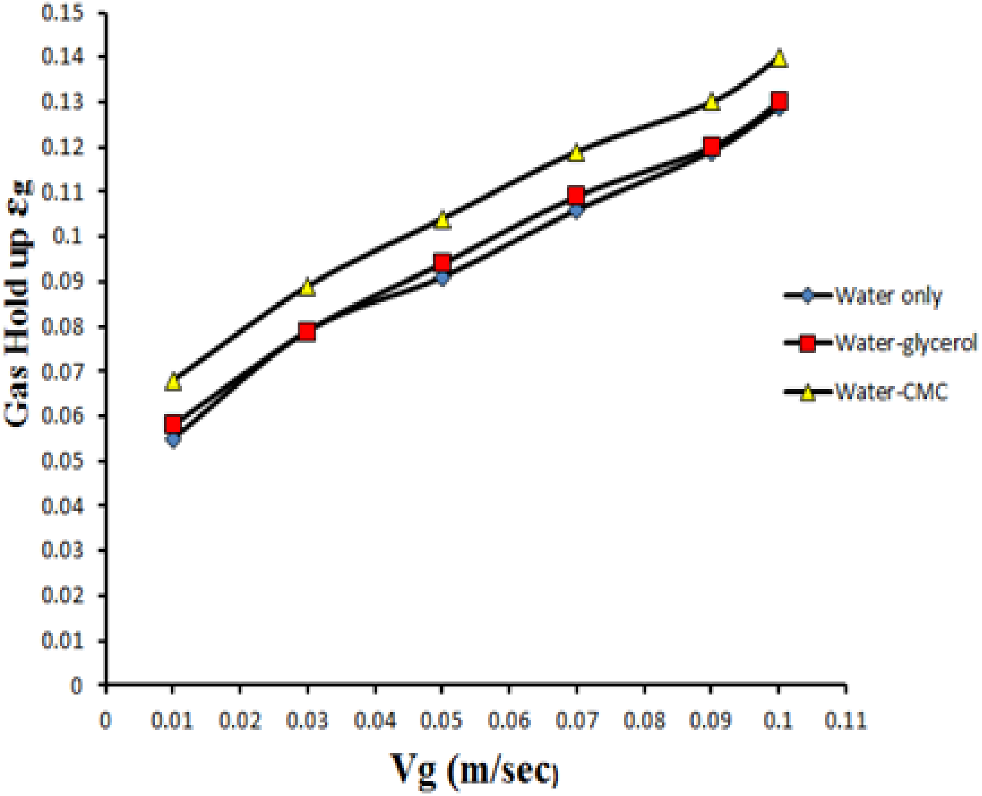


Figure 2: Gas hold up versus gas velocity for different liquid phase system.

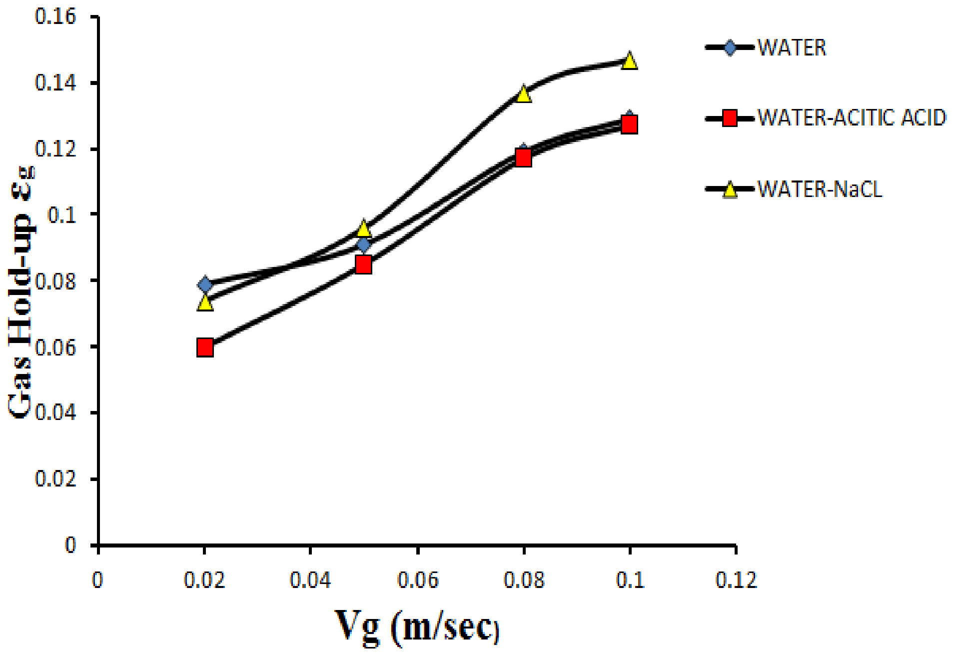


Figure 3: Gas hold up versus gas velocity for different liquid phase system.

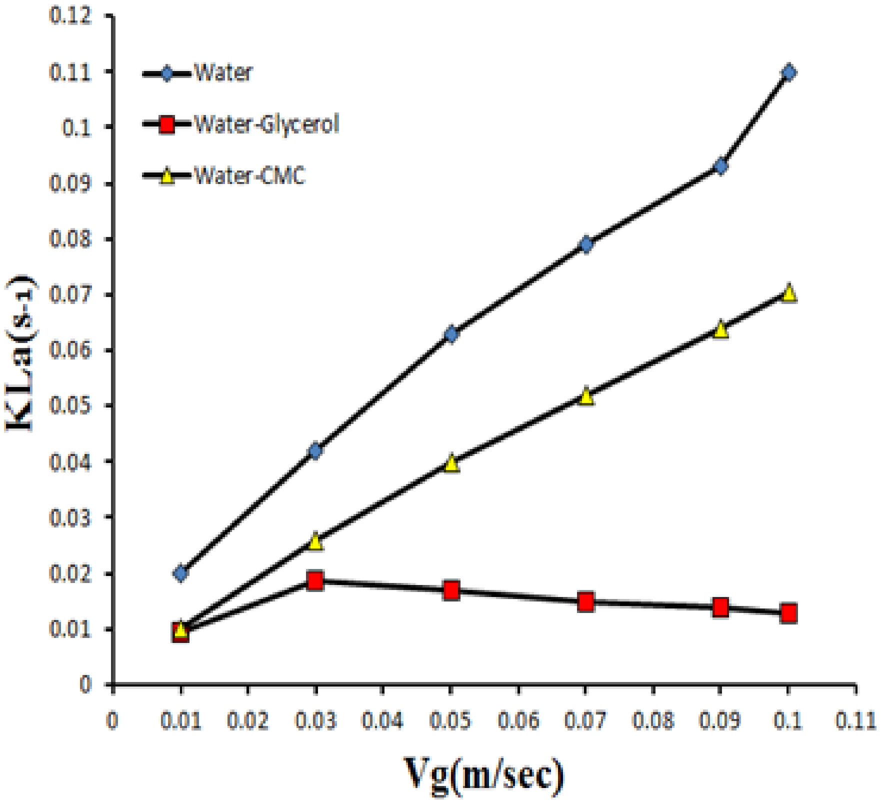
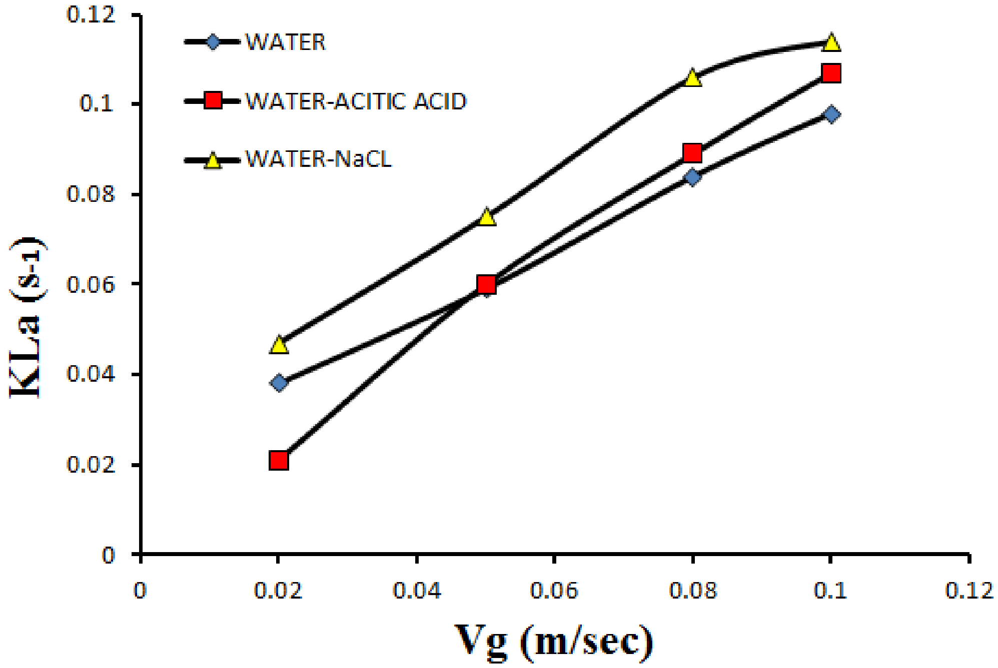


Figure 4: Mass transfer coefficient versus gas velocity for different liquid phase system.



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