Prediction of Mass Transfer Coefficient in Solid-Suspended Internal Air Lift Loop Reactor Using Newtonian and Non-Newtonian Liquids

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Abstract

The effect of superficial gas in the riser (V_{gr}) and liquid phase properties,solid-particle concentration (50, 100) Kg/m^3 and the static liquid height on mass transfer coefficient (K_{La}), were studied in a solid suspendedinternal loop airlift reactor. Air was used as a gas phase. Water, Ethanol, Iso-Propanol, NaCL were used as Newtonian liquids and (2.0 %) of carboxy methyl cellulose (CMC) solution were used as non-Newtonian liquids. Spheres, Polyethylene-non-porous-solid particles were used as solid phase. Superficial gas velocity varied from 0.01 m/s to 0.1 m/s. The experimental result shows that the (K_{La}) increase with increasing gas velocity and decrease with increasing solid particle concentration, static liquid height, viscosity and surface tension of liquid-phase.

Keywords:*Internal loop airlift reactor, Mass Transfer Coefficient, Newtonian, Non – Newtonian.*

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 Tropsch 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 airlift 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 100μm 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(different height to diameter ratio and different top and bottom clearances) 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 geometric parameters in the design and scale-up of concentric tube airlift bioreactors. [7, 8, 9] To design and operate the air lift loop reactors with confidence, the knowledge of gas-liquid mass transfer is required to characterize the performance of the air lift loop reactor. The main parameter used as an indicator for gas-liquid mass transfer rate is the gas-liquid mass transfer coefficient (K_{la}). [10, 11, 12] A large number of researchers [13, 14, 15, 16, 17, 18, 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 (<2%, v/v) .[20, 21] The purpose of this study is to clarify experimentally the effects of the gas velocity and liquid phase properties (coalescing , Newtonian and non Newtonian behavior) on mass transfer coefficient (K_{la}) in a solid suspends concentric tube airlift loop reactor when the ratio of draught tube diameter to column diameter is equal to 0.5 and the air is dispersion into the center of the riser.

Experimental Section

A schematic diagram of the experimental setup in this work is shown in Figures 1, 1.a and 1.b. A Plexiglass column of 0.09 m inside diameter and about 1.30 m total height with draught tube dimensions of 0.045 m inside diameter and 0.09 m 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 value 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 dispersed into 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 to the desired level above the distributor (0.3,0.5, and 0.7) m. Then the solid particles (polyethylene 3.4mm particle diameter and the density 853.5 Kg/m^3) were added to the liquid in the column. The concentration of solid particles to each level of static liquid were (50,100) kg solid /m^{3}slury respectively. 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 usingoxygen 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 and solid, water, alcohols and solids (Newtonian), water, CMC and solids (non Newtonian))the chemicals used in the present study were procured from Permula Chemicals Sdn.Bhd., Malaysia. The gas distributor Fig 1.b was constructed from a ceramic material and thetype is a porous gas distributor. The distributor has an equivalent pore diameter of 0.1 mm and free section of 70%.

Results and discussion

Mass transfer coefficient

The average gas hold up ε_g was calculated from the equation (1) usingthe data of the clear - liquid height (H_L) and the height of the aerated liquid (H_F) which was determined by visual observation:

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

(V_i / S_o) In equation (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 ($\overline{H}_F$):

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

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.

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

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

Rearranging equation (3) gives

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

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 (ε_g) and (ε_s) were determined as mentioned in (1) and (2) respectively, then (K_{La}) can be calculated. Figure (2)shows the effect of gas velocity on mass transfer coefficients for water system with and without solid particles. 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}). But the effect without solid particles is larger than that with solid particles. Figure (3) shows the effect of solid particle concentration on (K_{La}). The presence of solid particle in the liquid will decrease the axial dispersion coefficientand it enhances bubble coalescence. The bubble size will be larger and occupying larger space in the column and therefore reduces (K_{La}). At a higher gas velocity (0.1) m/sec, the effect of solid particles on (K_{La}) will be less than in low gas velocities (0.03 m/sec). Figures (4) and (5) show the effect of static liquid height on the mass transfer coefficient. As the static liquid height is increased, however the bubble has time to coalesce further and ultimately decreases the axial dispersion coefficient and the mass transfer coefficient. Figure (6) shows the effect of liquid phase properties on (K_{La}). The volumetric-mass transfer coefficient (K_{La}) is a function of gas hold-up and mean bubble size.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), the presence of solid particles retards the bubble rise velocity and prevents increases in bubble size, so that the mass transfer coefficients are larger than that in (water-solid).

The presence of alcohol surfactants increased the gas hold up in riser (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. The addition of small amounts of normal aliphatic alcohols (iso-propanol) changes the hydrodynamics of a draft tube air loop reactor (DT-ALR) while decreasing the surface tension. This leads to an increase in the gas holdup and a decrease in the down comer liquid velocity, in all investigated systems, in comparison to water. A similar trend was observed byAl-Masry and Dukkan[23]. The ionic forces in the liquid bulk reduce the bubble rise velocity and the bubble coalescence, so that the mass transfer coefficient is increased. The reduction of bubble size with increasing gas velocity is a characteristic feature of pseudo plastic (water-CMC) system [24]; therefore the mass transfer coefficient is smaller than that in water.

Conclusions

The presence of suspended solid particles in the concentric tube airlift loop reactor and the ratio of the draught tube diameter to column diameter equal to 0.5 reduce the values of the volumetric liquidphase mass transfer coefficient K_{La}. The reduction of K_{La}values due to an addition of solid particles to the column increases with increasing solid concentration and liquid phase (water, alcohols and solids, Newtonian and water, CMC non-Newtonian) viscosity.

The mass transfer coefficient in airlift loop reactor with a draught tube, where gas is dispersed into the center of the base of the inner draught tube using a pours multi hole distributor increase with increasing gas velocity, for Vg equal or less than 0.1 m/sec. This observation is in agreement with many experimental works [25, 26].

When the static liquid height is increased, the bubble has time to coalesce further and ultimately decreases the axial dispersion coefficient and reduce mass transfer coefficient.

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_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)
$\overline{H}_F$	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})
Sc	Slurry column
t	Time (min)
V_g	Gas velocity (m/sec)

Greek letters

ε_g	Gas hold up
ε_s	Solid hold up
ρ_L	Liquid phase density kg/m^3
ρ_S	Solid 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 dyne/cm

Subscripts

G	gas
L	liquid

Table 1.Physical-properties for pure liquids at *T* = 20 °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
Iso-ropanol	0.785	0.85	66	0.9792
Ethanol	0.789	1.200	22.27	1.520
NaCL	2.165	1.295	72	0.598
CMC	1.008	K=0.012 ps.s^n n=0.8	73	1.23

The solution of CMC (carboxy methyl cellulose) shows Newtonian, pseudo plastic behavior, which can be descri 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

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

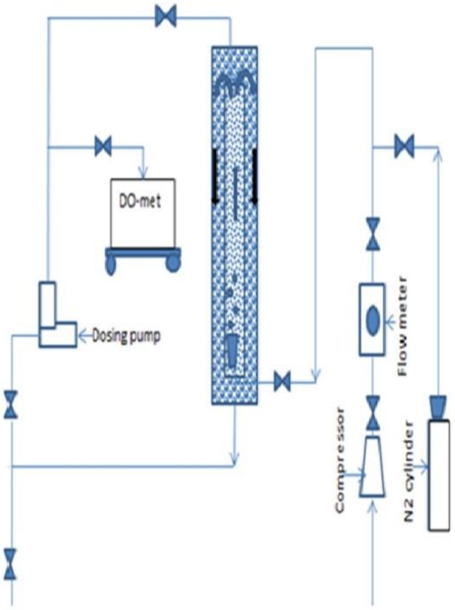
where μ_{eff}: effective liquid phase viscosity Pa.s

$Y = 5000\ V_g$[27]

Where V_g: gas velocity m/sec.

Table 2. Physical properties for mixtures used with various concentrations at T=20°C

	ρ (kg/m^3)10^3	μ (CP)	σ (dyn/cm)	ν_L(cm^2/sec)
Water-Isopropanol 10%	0.982	0.972	62.42	0.8932
Water-Ethanol 10%	0.981	0.910	22.64	0.9400
Water-NaCL, 10%	1.0216	0.9247	48.375	0.9051
Water-CMC 2%	1.009	K =1.320 Pas^nn=0.5	69	0.09051



(a)

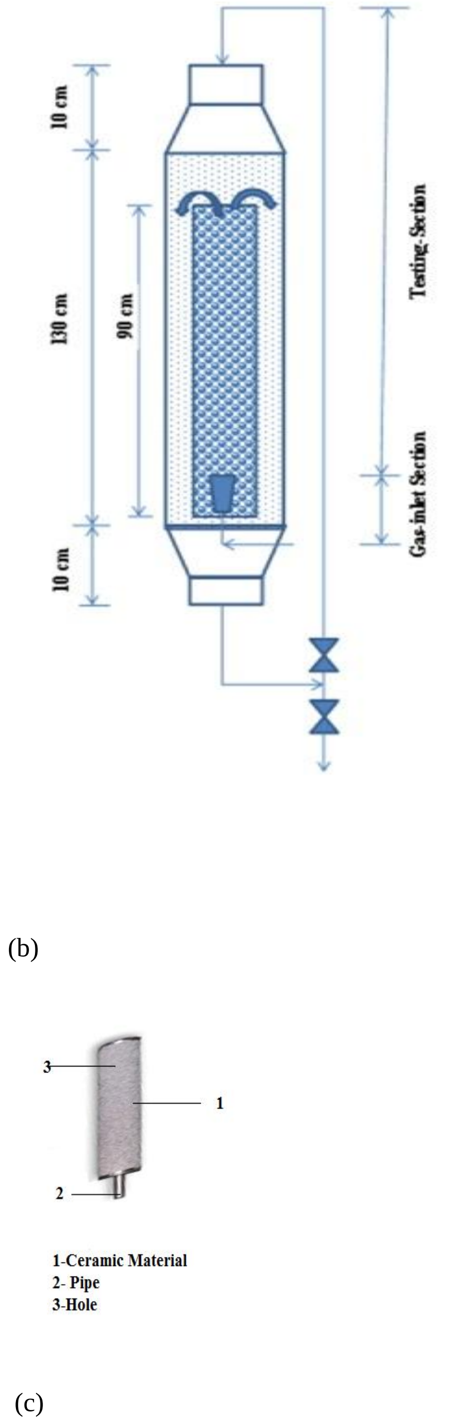


Figure 1. (a) Experimental-Apparatus; (b) Column and (c) Gas distributor

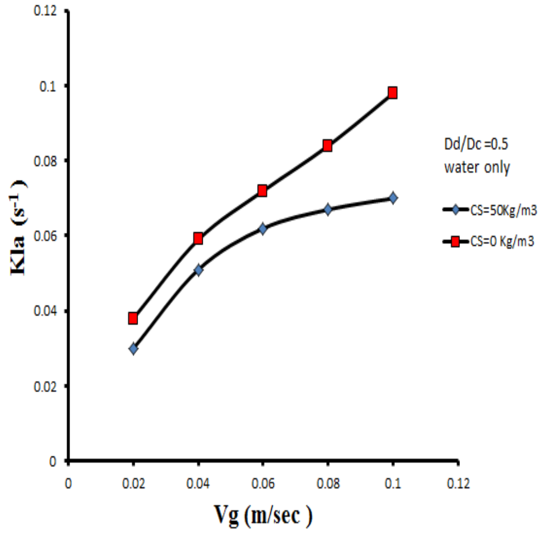


Figure 2.Mass transfer coefficient versus gas velocity for water systems

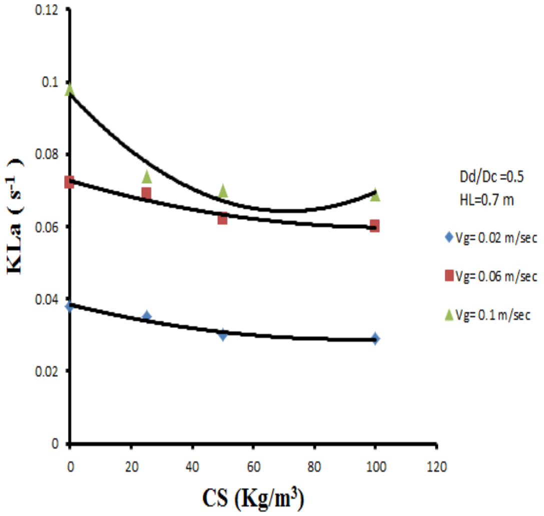


Figure 3. Mass transfer coefficient versus solid concentration for water system for various gas velocities

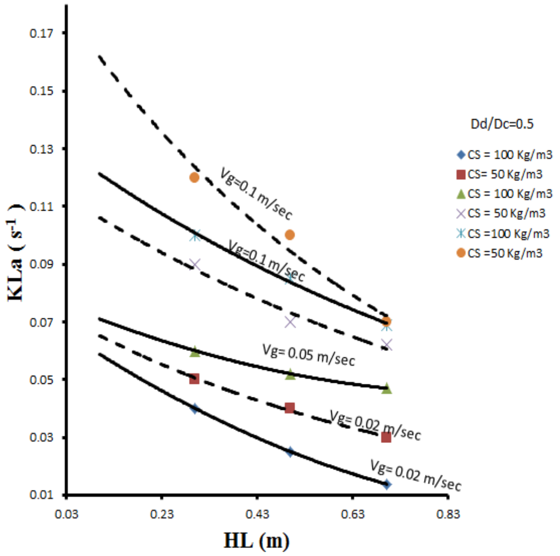


Figure 5. Mass transfer coefficient versus static liquid height for various solid concentrations and for various gas velocities

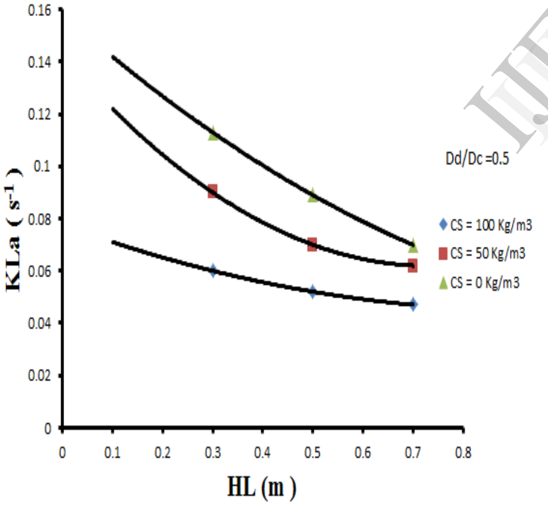


Figure 4. Mass transfer coefficient versus solid concentration for water system for various gas velocities

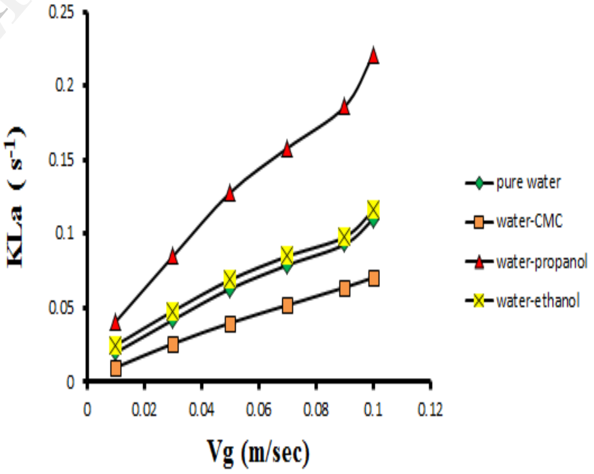


Figure 6. Mass transfer coefficient versus gas velocity for different liquid phase system

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