

## MASS TRANSFER STUDIES ON EXTERNAL LOOP AIRLIFT REACTOR

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### ABSTRACT

Experiments were conducted to investigate the influence of superficial gas velocity and fluid properties on the volumetric mass transfer coefficient in Newtonian and non-Newtonian systems in the riser and down comer of an external loop airlift reactor. Aqueous solutions of carboxy methyl cellulose, CMC was used as the non-Newtonian fluid. The  $k_L a$  increased with increase in  $U_{sg}$  and of alcohol concentrations and a decreasing trend was observed with increase in concentration of CMC for two-phase system. The proposed correlations predicted the experimental data well.

**KEYWORDS:** External loop airlift reactor, riser, three-phase, gas holdup, mass transfer coefficient and non-Newtonian fluid.

### I. INTRODUCTION

Airlift reactors are widely used in various industrial applications such as aerobic fermentations and biological treatment of wastewater due to its simple design, good mixing characteristics and low power requirements. In an external loop airlift reactor the riser and down comer are separate tubes connected at the top and bottom and the zone in which gas is sparged is known as the riser (Chisti and Moo-Young, 1987, Wang et al (2003), Ruen-ngam et al (2008)).

A three-phase airlift reactor offers considerable advantages over traditional three phase contactors such as bubble columns and fluidized beds. This includes a lowering of the gas requirement of complete suspension of the solids, elimination of stagnant zones, rapid mixing and the absence of the need for external circulation systems of which are desirable in range industrial processes. The hydrodynamic behavior in internal loop and multiphase mass transport in external loops have been studied by Livingston and Zhang (1993). The gas-liquid mass transfer characteristics of the ALC in forms of mass transfer coefficient and specific interfacial area. It was found that the specific interfacial area, rather than the mass transfer coefficient, played a more significant role in controlling the overall rate of mass transfer in the system examined by Wongsuchoto et al (2003) Quijano et al (2009). This present paper discusses experimental results on mass transfer coefficient in the riser of an external loop airlift reactor.

### II. EXPERIMENTAL SETUP

The schematic diagram of the experimental set-up is shown in Figure 1. The reactor was constructed of acrylic of inner diameter 0.084m and 2.6 m in height. The riser and down comer are connected with an inclined angle 45° at the top and bottom section of the reactor. Perforated plate

gas sparger with 243 holes of 1mm diameter on a triangular pitch was fixed at the base of the reactor and air from the compressor was passed to the reactor through an air filter, pressure regulator and calibrated rotameter.

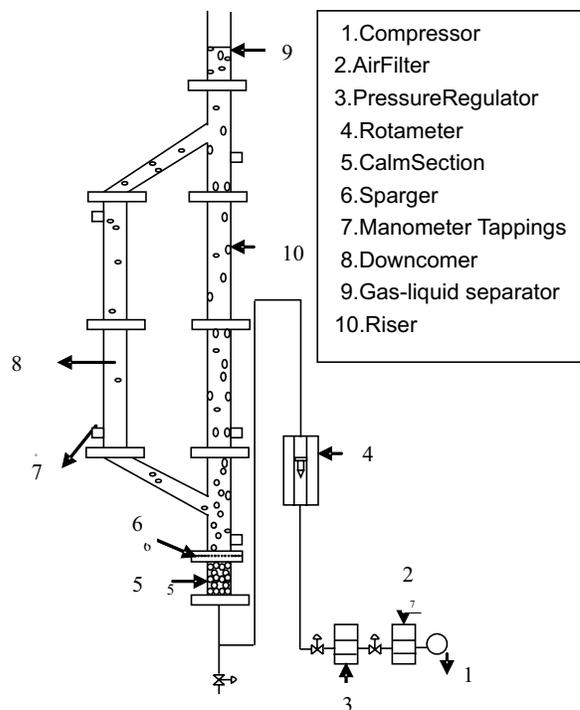


Fig.1 Experimental setup of External Loop Airlift Reactor

### III. MATERIALS AND METHODS

The rate of oxygen transfer is related to the overall volumetric mass transfer coefficient and the concentration driving force by the equation (ideal mixing of liquid phase in the reactor assumed).

$$dC_L / dt = k_L a (C^* - C_L) \quad (1)$$

where  $C_L$  and  $C^*$  are instantaneous and the saturation (or equilibrium) concentration respectively of the dissolved oxygen in the liquid. For steady hydrodynamic and physico-chemical conditions the  $k_L a$  is a time-variant, integration of equation 3.8 between the time limits  $C_L = C_{L0}$  at  $t = 0$  and  $C_L = C_L$  at  $t = t$ , yields

$$\ln(C^* - C_{L0}) / (C^* - C_L) = k_L a t \quad (2)$$

The coefficient  $k_L a$  was obtained from the plot of  $\ln(C^* - C_{L0}) / (C^* - C_L)$  versus  $t$ . The volumetric mass transfer coefficient values were also obtained at room temperature for three-phase systems using the same procedure.

The dissolved oxygen probe was mounted in the external loop airlift reactor. The column was purged with nitrogen until the level of oxygen dropped to almost zero before air could be introduced into the column. This was done for every flow rate of air used. The time-change in dissolved oxygen (DO) in the reactor was monitored continuously from the instant at which the airflow began using dissolved oxygen meter (Oximeter OXI 191). The response time of the probe E was found to be less than 10 sec. Since the condition  $k_L a < 1/E$  was fulfilled, the electrode dynamics was neglected in the calculation and the  $k_L a$  value for each run was obtained from the slope of the straight line in the plot  $\ln(C^* -$

$C_{L0}) / (C^* - C_L)$  versus  $t$  where  $C_L$  and  $C^*$  are the instantaneous and the saturation concentrations, respectively, of the dissolved oxygen in the liquid (Dunn and Einsele 1975).

#### A. Measurement of physical properties of particles

The diameters of various solid particles were found using the average diameter obtained from weight cumulative particle size distribution method. The densities were measured by weighing a known number of particles. The density was determined as the ratio of mass to volume and the values are given in Table 1.

**Table 1. Properties of solid particles**

Particle	Diameter, $d_p$ (m)	Density, $\rho_s$ (kg/m <sup>3</sup> )
Polystyrene	0.0036	1025.55
Nylon-6	0.0035	1084.24

#### B. Measurement of properties of liquids

The viscosity of different concentrations of aqueous glycerol was determined using Ostwald's viscometer and

surface tension was determined by drop weight method at room temperature (252C) and the values are given in Table 2.

**Table 2. Physical properties of aqueous solutions of glycerol**

Concentration of glycerol (v/v)	Density, $\rho$ (kg/m <sup>3</sup> )	Viscosity, $\mu$ (mPa.s)	Surface tension, $\sigma_l$ (N/m)
30%	1056	1.94	0.0704
40%	1088	2.56	0.0675
50%	1107	3.74	0.0669

The viscosity, surface tension of isoamyl alcohol and propanol were determined by drop weight method at room temperature (252C) and the values are given in Table 3.

The rheological properties of different concentration of aqueous solutions of CMC were measured using a concentric viscometer (Haake). The flow behavior of CMC is described by the power law model and the effective viscosity was calculated using equation proposed by Nishikawa et al 1977.

$$\eta_{eff} = K\dot{\gamma}^{n-1} \quad (3)$$

$$\gamma = 5000U_{sgr} \quad (4)$$

where  $K$  and  $n$  are the flow consistency index and flow index respectively. The deviation of the flow index  $n$ , indicates the degree of deviation from Newtonian flow behavior. The physical and rheological properties are listed in the Table 4.

**Table 3. Physical properties of aqueous solutions of isoamyl alcohol and propanol**

Additive	Concentrations	Density, $\rho$ (kg/m <sup>3</sup> )	Viscosity, $\mu$ (mPa.s)	Surface tension, $\sigma_l$ (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

**Table 4. Physical properties of aqueous solutions of CMC**

CMC (wt. % in water)	Density, $\rho_l$ (kg/m <sup>3</sup> )	Flow consistency index K (mPasn)	Flow index n	Surface tension, $\sigma$ (N/m)
0.1	999	10	0.88	0.0720
0.2	1000	34	0.80	0.0716
0.3	1000	41	0.66	0.0712

**IV. RESULTS AND DISCUSSION**

*A. Effect of volumetric mass transfer coefficient ( $k_L a$ ) with superficial gas velocity for air- alcohol systems*

The variation of volumetric mass transfer coefficient,  $k_L a$  with superficial gas velocity for air-alcohol systems is shown in Figures 2 a and 2 b. It was observed that the  $k_L a$  decreased with increase in the alcohol concentration and the observed values was found to be lower than that of air-water system. The addition of alcohol surfactant to water caused a reduction in  $k_L a$  values over entire ranges of superficial gas velocities. This may be due to the tendency of surfactants to accumulate at the bubble surface and the created surface tension gradients caused tangential stress along the bubble surface and also decreased in bubble surface due to hindered internal circulation within the bubble. The observed trend agreed well with those reported in the literature (Al-Masry and Dukkan (1997) and Vasconcelos et al (2003) Yazdian et al (2009)).

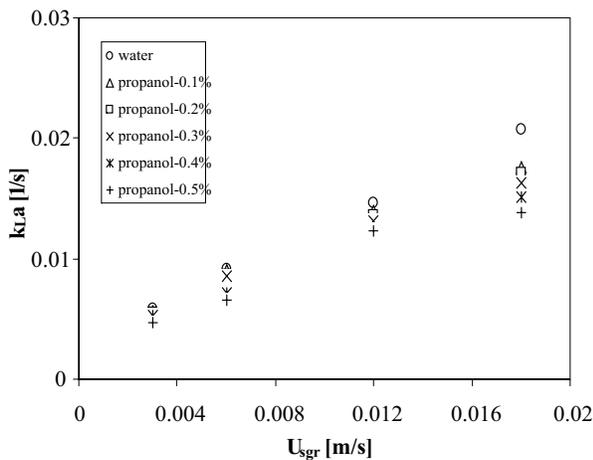


Fig. 2a Variation of  $k_L a$  with superficial gas velocity for air-propanol system

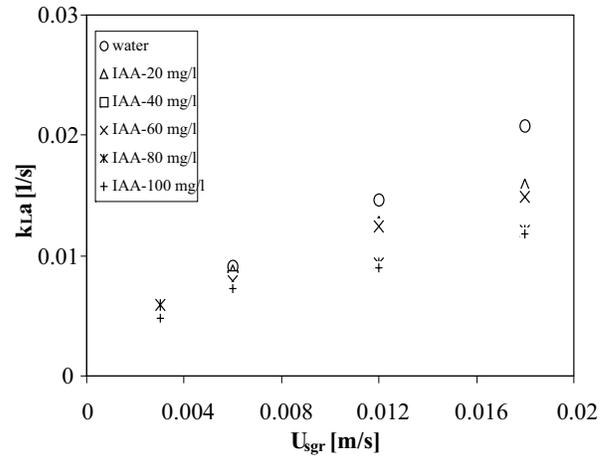


Fig. 2b Variation of  $k_L a$  with superficial gas velocity for air-IAA system

*B. Effect of volumetric mass transfer coefficient ( $k_L a$ ) with superficial gas velocity for air-glycerol system*

The variation of volumetric mass transfer coefficient,  $k_L a$  with superficial gas velocity for air-glycerol system is shown in Figure 3. It was observed that the  $k_L a$  increased with increase in superficial gas velocity in the riser and decreased with increase in the glycerol concentration. This may be due to the increase in liquid viscosity, which reduced the interfacial area available for mass transfer. The observed  $k_L a$  value was found to be lower than that of air-water system.

*C. Effect of volumetric mass transfer coefficient ( $k_L a$ ) with superficial gas velocity for air-CMC system*

The variation of volumetric mass transfer coefficient,  $k_L a$  with superficial gas velocity for air-CMC system is shown in Figure 4. It was observed that the  $k_L a$  increased with increase in superficial gas velocity in the riser

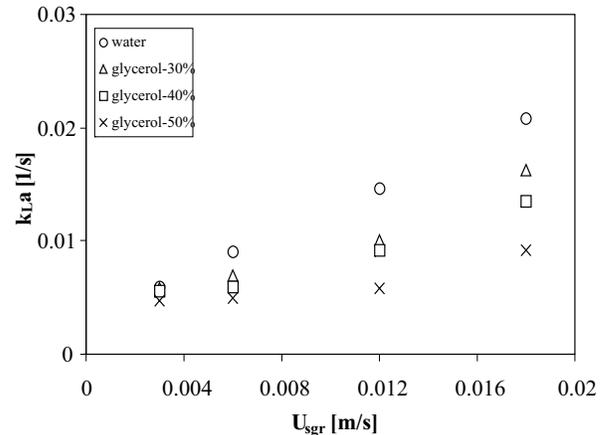


Fig. 3. Variation of  $k_L a$  with superficial gas velocity for air-glycerol system

and decreased with increasing CMC concentration. This may be due to increase in viscosity of liquid phase.

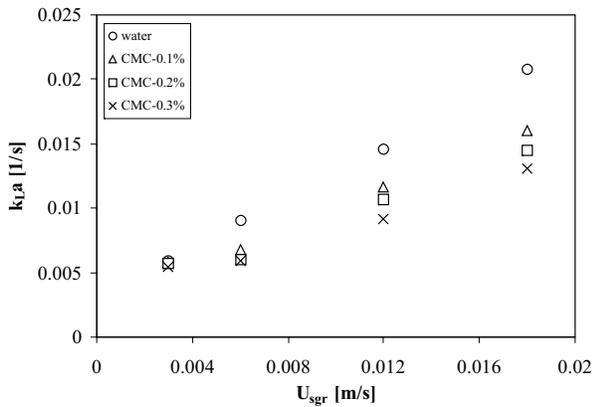


Fig. 4 Variation of  $k_L a$  with superficial gas velocity for air-CMC system

**Empirical correlation**

The value of volumetric mass transfer coefficient,  $k_L a$  for two-phase system have been well correlated in terms of operating variables as

**Newtonian System**

**Air-water system**

$$k_L a = 0.204U_{sgr}^{0.782} \mu^{-0.0595} \quad R^2=0.8 \quad (5)$$

Parity plots between experimental and predicted values of  $k_L a$  based on the proposed empirical equation 5 for air-water system is shown in Figure 5. The average RMS error for  $k_L a$  is 17%. It was found that the proposed equation fitted the experimental data well within 35%.

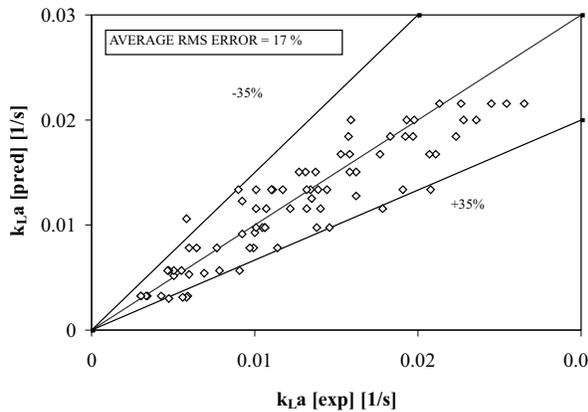


Fig. 5 Parity diagram for  $k_L a$  estimated from empirical Equation 5 for air-water system

**Air-alcohols-solid system**

The value of volumetric mass transfer coefficient,  $k_L a$  for two and three-phase system have been well correlated in terms of operating variables as

$$k_L a = 0.115U_{sgr}^{0.607} \sigma^{-0.065} \quad (6)$$

Parity plots between experimental and predicted values of  $k_L a$  based on the proposed empirical equation 6 for air-alcohol system is shown in Figure 6. The average RMS error for  $k_L a$  is 17%. It was found that the proposed equation fitted the experimental data well within 25%.

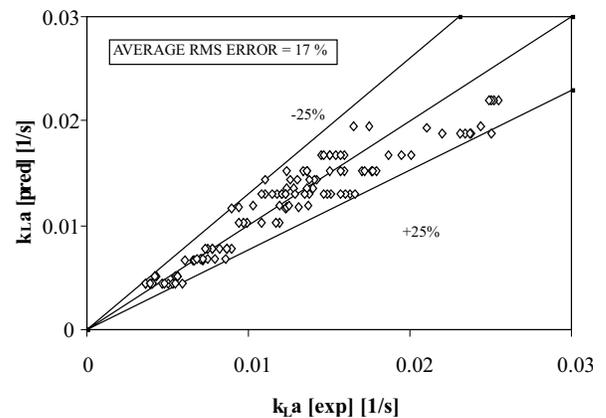


Fig. 6 Parity diagram for  $k_L a$  estimated from empirical Equation 6 for air-alcohol system

**Air-CMC-solids system**

The value of volumetric mass transfer coefficient for two and three-phase system have been well correlated in terms of operating variables as

$$k_L a = 0.0587U_{sgr}^{0.499} \eta_{eff}^{-0.079} \quad R^2=0.88 \quad (7)$$

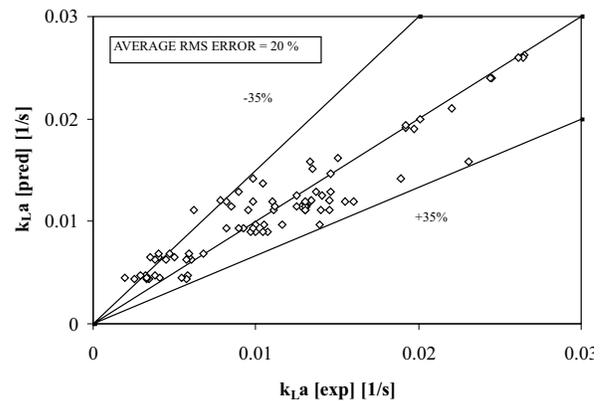


Fig. 7 Parity diagram for  $k_L a$  estimated from empirical Equation 4.15 for air-CMC-solids system

Parity plots between experimental and predicted values of  $k_L a$  based on the proposed empirical equation 7 for air-CMC-solids system is shown in Figure 7. The average RMS error for  $k_L a$  is 20%. It was found that the proposed equation fitted the experimental data well within 35%.

## V. CONCLUSION

The volumetric mass transfer coefficient is calculated from oxygen uptake rate using dynamic method. The volumetric mass transfer coefficient increased with an increase in the superficial gas velocity and decreased with increase in concentrations of liquid medium used. The proposed correlation for volumetric mass transfer coefficient predicted the experimental data well for both Newtonian and non-Newtonian systems.

### List of Symbols

U <sub>sg</sub>	Superficial gas velocity in the riser (m/s)
K	Consistency index in a power law model(mPa-s)
n	Flow index in a power law model
$k_L a$	Volumetric mass transfer coefficient (1/s)
s	Solid
	Liquid
g	Gas
	Riser
d	Downcomer

### Greek symbols

$\sigma$	Surface tension (mNm <sup>-1</sup> )
$\mu$	Viscosity (mPas)
$\eta$	Effective viscosity (mPas)
$\rho$	Density (kg/m <sup>3</sup> )

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