Chemical Technology
ISSN: 0974-7443

Chemical Technology: An Indian Journal

Research | Vol11 Iss 5

Mass Transfer in a Gas-liquid Up Flow Bubble Column in the Presence of Angled Disc Promoter

Ramaprasad BSG[1], Niranjan Rao B[2], Ashok Kumar K[3] and Ramesh KV[3*]

[1]Gas Authority of India Ltd., Chennai-600020, India

[2]Department of Chemical Engineering, GMRIT, Rajam-532127, India

[3]Department of Chemical Engineering, Andhra University, Visakhapatnam-530003, India

[*]**Corresponding author:** Ramesh KV, Department of Chemical Engineering, Andhra University, Visakhapatnam-530003, India, Tel: 919490109683; E-mail: kvramesh69@yahoo.com

Abstract

Mass transfer coefficient data were computed from limiting current data measured at point electrodes fixed flush with the inner wall of outer cylinder of an electrochemical cell. A gas-liquid up flow bubble column acted as electrochemical reactor. Nitrogen is employed as gas phase and an electrolyte belonging to ferricyanide-ferrocyanide redox system is used as liquid phase. Angled discs arranged on a central rod with different pitches were used as turbulent promoters. The mass transfer coefficient data were found to increase with liquid velocity and disc diameter. An increase in disc angle caused a decrease in mass transfer coefficient value. No significant effect has been observed with gas velocity, rod diameter and pitch. A correlation in the jD-Re format has been obtained for mass transfer data by regression analysis.

Keywords: *Mass transfer coefficient; Bubble column; Gas-liquid upflow; Turbulent promoter; Inclined disc.*

Introduction

The design engineer is always in search of equipment that offers savings in energy coupled with effective operation. These tasks can be achieved through augmenting the rates of heat and mass transfer. Significant improvements in heat and mass transfer rates were observed in gas-liquid flow in comparison with homogeneous flow in electrochemical reactors [1-2]. Also, the gas-liquid flow provides isothermal conditions and uniform concentrations that facilitate good temperature control.

Turbulent promotes are widely used to enhance heat and mass transfer rates. Thus reduction in size of the equipment is possible leading to less initial capital investment. Application of the disc promoter to increase mass transfer rates between a liquid and a column wall has attracted the attention of several investigators [3-6]. Specific to gas-liquid upflow bubble columns, magnitudes of improvements in mass transfer rates were reported in the presence of helicoidal tapes on a rod [2], disc promoters [6], hourglass promoter internals [7] and twisted tapes [8]. It is understood that the disc promoter is much superior compared to other internal elements in mass transfer operations [5].

Citation: Ramaprasad BSG (2016) Mass Transfer in a Gas-liquid Up Flow Bubble Column in the Presence of Angled Disc Promoter, Chemical Technology: An Indian Journal, 11

Although the disc promoter has the potential to yield high values of mass transfer, it has the drawback of offering no uniform mass transfer coefficient values in the longitudinal direction [4-6]. The angled discs are found to offer uniform mass transfer coefficient values along the axial direction in homogeneous flow due to non-symmetric wake formation leading to thorough mixing fluid elements, however yielding magnitudes of improvement in mass transfer coefficient [9-10]. In view of this, an attempt is made to investigate the wall-to-bulk mass transfer in a gas-liquid upflow bubble column in the presence of angled disc promoter elements. The gas and liquid velocities were varied from 0.04-0.28 m/s and 0.014-0.07 m/s respectively. The diameters of the rod considered were 06, 1.0 and 1.3 cm. The disc diameters used were 3.0, 4.5 and 6.0 cm. The pitch was changed from 3.0-10.0 cm. The disc angles employed were 0, 22.5, 45 and 67.5 degrees.

Experimental

The schematic representation of the experimental set up used in the present investigation was shown in Figure 1. The equipment and apparatus consisted of a storage tank, a centrifugal pump, two rotameters, a nitrogen cylinder, a U-tube differential manometer and seven valves. The capacity of storage tank was 100 litres.

The main experimental column consisted of three sections viz., a calming section (A), the test section (B) and the exit section which was a gas liquid separator (C). To eliminate the tangential entry effects the calming section (A) was filled with marble stones of random size. Nitrogen gas was admitted into the experimental column uniformly through a sparger provided at the bottom inlet point. The test section (B), which served as the electrochemical cell, was made of smooth perspex tube of 6.73 cm inner diameter and 0.6 m height. The inner wall of the test section was provided with 34 numbers of copper point electrodes each having a diameter of 3.42 mm. One end of these electrodes was fixed flush with the surface of the inner wall of the test section while the other end projected outward was connected to the external circuit. Two pressure taps, provided across the test section were connected to the limbs of a U-tube manometer to measure the pressure drop. A stainless steel wire mesh (W) was placed at the bottom of the test section to allow uniform distribution of liquid and gas into the test section. The wire mesh also served as a support for holding the angled disc promoter in the test section. The exit section (C) was a gas-liquid separator. An open end was provided to vent the nitrogen gas into the atmosphere (V) and the electrolyte was sent back to the storage tank from the bottom of the separator (D).

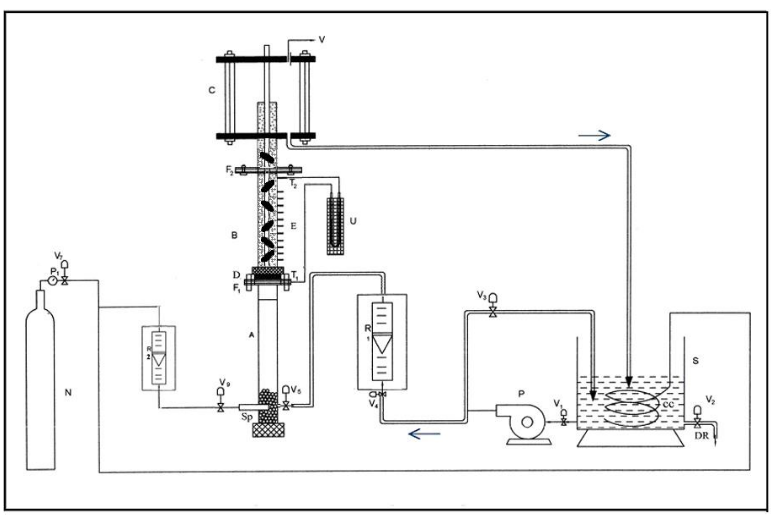

Figure1: Schematic diagram of the experimental unit.

wire mesh; DR: Drain; E: Electrodes; F_1, F_2: Flanges; N: Nitrogen cylinder; P: Pump, R_1, R_2: Rotameters of liquid and gas flows; S: Storage tank; T_1, T_2: Pressure tapings; U: Manometer; V: Vent; V_1-V_7: Valves

Discs of different diameters d_K were placed concentrically on a stainless steel rod of diameter d_r with varied pitch value p arranged at a given angle θ. Prior to the commencement of experimentation, the surfaces of the point electrodes were polished with a very fine emery paper and cleaned thoroughly. About 70 liters of equimolar solution of potassium ferrocyanide and potassium ferricyanide of about 0.01 N and 0.5 N of sodium hydroxide were prepared from analytical grade reagents using distilled water. This solution was used as the electrolyte. The liquid rotameter R_1 was calibrated using this electrolyte. The electrolyte from the storage tank was metered and circulated through the test section. After the flow was stabilized nitrogen gas, which was metered through rotameter R_2 was admitted into the experimental column. The measurement of limiting current was made in the lines similar to those reported earlier in the studies on ionic mass transfer [11]. The electrode reaction involved in this study is

$$[Fe(CN)_6]^{3-} + e \rightarrow [Fe(CN)_6]^{4-} \qquad \text{(Reduction)} \qquad \ldots (1)$$

From the measured limiting current value the mass transfer coefficient was evaluated from the equation

$$k_L = \frac{i_L}{nAFC_0} \qquad \ldots (2)$$

Results and Discussion

Initially mass transfer coefficient data were obtained in homogeneous flow and gas-liquid upflow in the presence of disc promoter. It was found that the mass transfer coefficient data were in good agreement with that of Venkateswarlu et al. [4] and Sarma et al. [6] respectively.

Figure 2 gives the data of the present study plotted as average mass transfer coefficient k_L against liquid velocity U_L for three cases of (i) homogeneous flow (Plot A), (ii) homogeneous liquid flow with angled disc promoter (Plot B) and (iii) gas-liquid flow with angled disc promoter (Plot C). Plot A shows the data predicted from Lin et al. [11] for the case of homogeneous annular flow and Plot B shows the data obtained in the present investigation for the case of homogeneous flow in the presence of angled disc promoter. The present data obtained in two-phase bubble column with angled disc promoter (Plot C) were taken at a constant gas velocity of 0.0234 m/s. The enhancement in mass transfer coefficient in homogeneous flow due to the introduction of the angled disc promoter is about 8 times (plots A and B). The enhancement due to the introduction of the gas in otherwise homogeneous flow in the presence of angled disc promoter is about 54 percent in the lower liquid velocity end and upto 32 percent in the higher liquid velocity end (Plots B and C). These observations indicate that the presence of angled disc promoter assembly in a two-phase gas-liquid upflow bubble column is definitely advantageous as it intensifies turbulence resulting in augmented mass transfer.

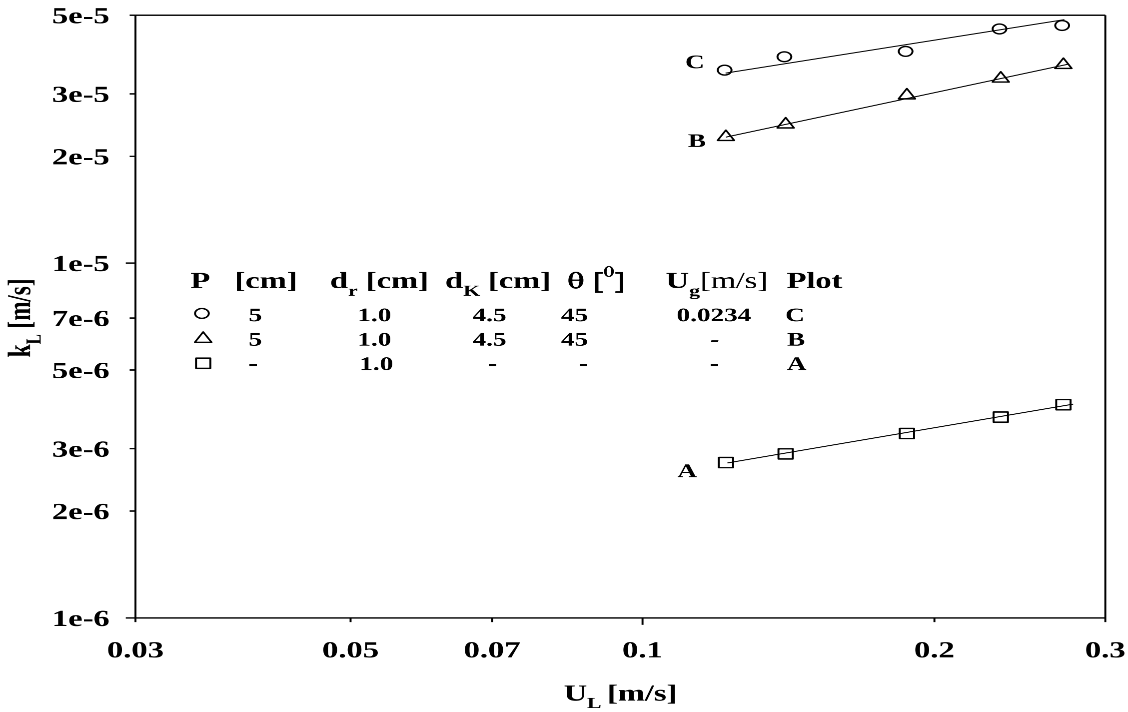

Figure 2: Augmentation of mass transfer coefficient with angled disc promoter.

The presence of angled disc promoter in the test section would subject the flowing fluid to a series of sudden contractions and expansions resulting in regions of varied turbulence intensity. Hence, one can expect that the mass transfer coefficient would vary along the length of the test section. The longitudinal variation of mass transfer coefficient in the presence of disc promoter assembly has been reported for the cases of homogeneous flow [4], gas-liquid three-phase fluidized bed [5] and gas-liquid two phase flow [6]. However no significant variation has been reported for the case of liquid fluidized beds with disc promoter [3]. In case of angled disc promoter the longitudinal variation of mass transfer coefficient was found to be marginal in homogeneous flow [9] and also in liquid fluidized bed [10]. In the present experiment also, no significant variation of mass transfer coefficient was observed. The reason for this can be explained in the following way. The wakes that appear between two successive discs, being asymmetric move randomly causing intense churning resulting in maximum reduction of the resistance film thickness. Since no appreciable variation of mass transfer coefficient in the axial direction was observed, all 34 electrodes were shorted and for all subsequent runs, the limiting current was measured for this combined electrode.

Effect of liquid and gas velocities

In gas-liquid upflow bubble columns, in the absence of internals as reported by Ramesh et al. [2], the effect of gas velocity was very significant and liquid velocity exhibited only marginal influence on mass transfer coefficient. The effect of liquid and gas velocities was found to be significant in the presence of internals as reported by Ramesh et al. [2], Sarma et al. [6], Suresh et al. [7] and Subramanyam et al. [8]. To examine the influence of gas and liquid velocities in the present case also, the data on k_L were plotted against liquid velocity in the presence of angled disc promoters and shown in Figure 3. The plots revealed that the mass transfer coefficient increased slightly with increasing liquid velocity. Similarly, data on k_L were plotted against gas velocity and shown in Figure 4. It is revealed from the plots of the figure that the effect of gas velocity on k_L was marginal.

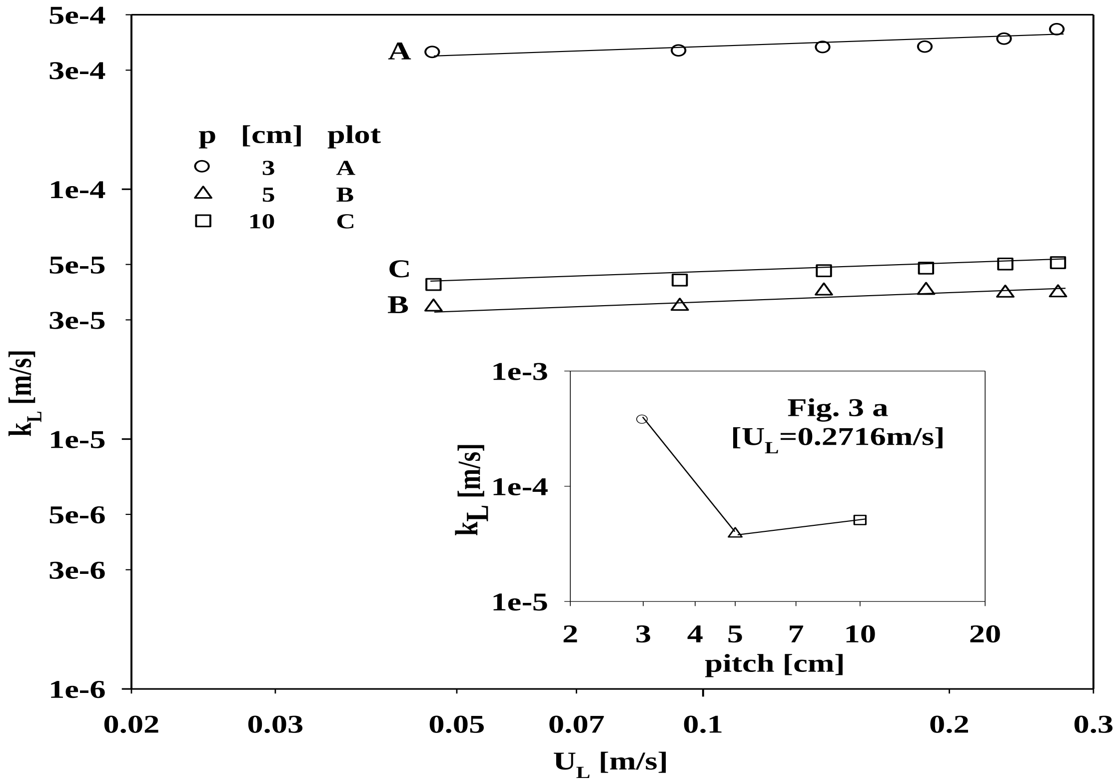

Figure 3: Variation of k_L with pitch for d_r = 1.0 cm, d_k = 4.5 cm, $\theta = 45^0$, U_L=0.0936 m/s.

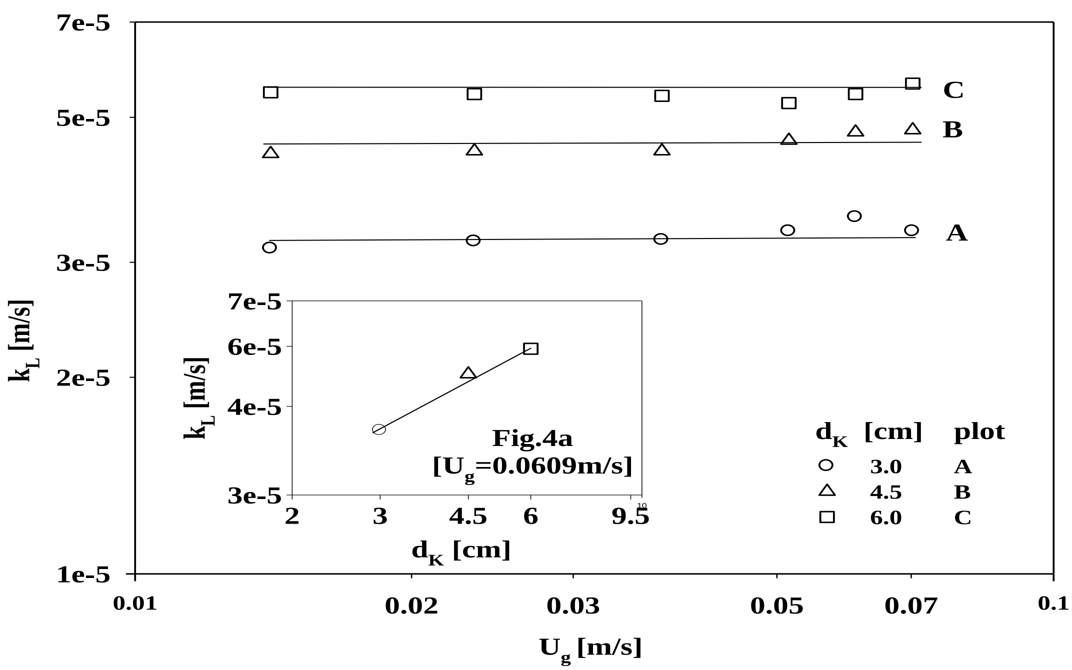

Figure 4: Variation of k_L with disc diameter for d_r = 10 cm, p= 5 cm, $\theta = 45^0$, U_L=0.168 m/s.

Effect of pitch

Pitch between successive discs is a prominent parameter that influences the flow pattern at the wall. Hence significant influence of pitch on k_L can be anticipated. Figure 3 represents the data on k_L plotted against liquid velocity for three different values of pitch viz., 3, 5 and 10 cm. The corresponding plots have been represented by A, B and C respectively. An examination of the plots A and B reveals that the k_L value decreased sharply with an increase in pitch from 3-5 cm. However when the pitch is increased further from 5-10 cm as represented by plots B and C, only a marginal effect of pitch on k_L was observed i.e., the k_L value increased very marginally with increase in pitch. These observations are also evident from the inset Figure 3a. Similar trends have been observed from the plots drawn against gas velocity (figure not shown). In view of this observation, the entire data on mass transfer coefficient have been segregated into two regions: The decreasing mass transfer coefficient region for p = 3 to 5 cm and an increasing mass transfer coefficient region for p = 5 to 10 cm.

Effect of disc diameter

In the present study the flow past a disc internal is identical to flow past a bluff body. The flow is slanting to the direction of the angled disc orientation and one can expect vigorous wake formation on the rear side of the disc geometry resulting in severe turbulence. Increasing disc diameter means decreased flow area, subsequently resulting in an increase in the local velocity of the fluid through the channels between promoter and wall. This could be established from the trends of the mass transfer coefficient data plotted against gas velocity in Figure 4. Plot A shows k_L data with an angled disc of diameter of 3.0 cm, plot B corresponding to 4.5 cm and plot C that of 6.0 cm. A close inspection of the plots of the figure revealed that the mass transfer coefficient values were found to increase with increasing disc diameter. This observation is also evident from the inset Figure 4a.

Effect of rod diameter

In the current investigation the central rod on which a string of angled discs were mounted extended all through the test section. It can be anticipated that the effect of the rod diameter would be insignificant. Because the projection of rod normal to the flow direction is completely covered by the disc diameter. Further, the cross sectional area of the rod is very small compared to the cross sectional area of the projected area of angled disc normal to the flow direction. The graphs (not shown) confirmed this behavior.

Effect of angle of disc

Figure 5 shows the graph drawn between the mass transfer coefficient and liquid velocity for three disc angles i.e., 0, 45 and 67.5 degrees. A constant pitch of 5.0 cm, a disc diameter of 4.5 cm and rod diameter of 1.0 cm were taken. A constant gas velocity of 0.0327 m/s was maintained. The plots A, B and C represent the data for the disc angles 0, 45 and 67.5 degrees respectively. A close inspection of these plots reveals that the mass transfer coefficient obtained was higher for horizontal disc which corresponds to an angle of 0 degrees. It was also found that the k_L decreased with disc angle as shown in inset Figure 5a. The following explanation can be provided for this trend. As the angle of disc is increased, the sizes of the wakes reduce; hence the turbulence intensity decreases in presence of both the fluid flows. Therefore, the resistance film thickness decreases. Hence the mass transfer coefficient decreases.

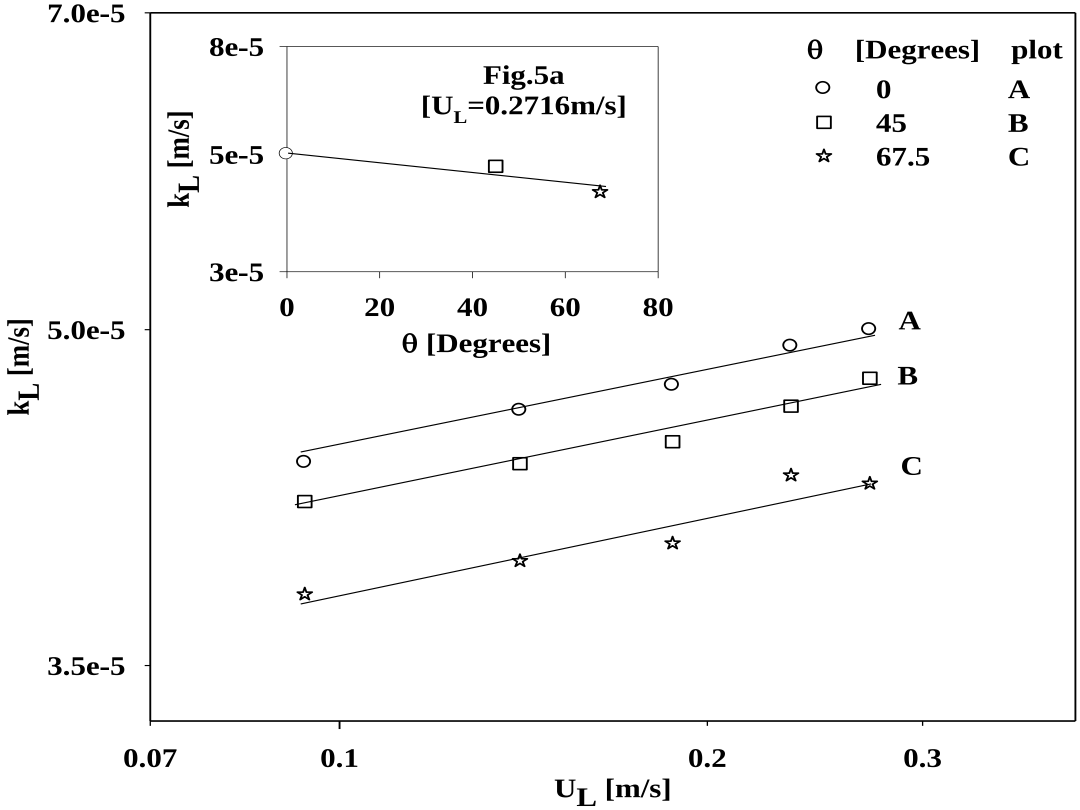

Figure 5: Variation of k_L with disc angle for d_r = 1.0 cm, d_K = 4.5 cm, p= 5 cm, U_g=0.0327 m/s.

Correlations

Based on the discussion presented in section on "Effect of pitch", the entire data on k_L obtained in the present investigation have been segregated into two parts. For the decreasing pitch region, the data corresponding to the pitch values between 3 and 5 cm, were correlated using regression analysis and the following equation is obtained.

$$j_D = 212.4(\mathrm{Re})^{-0.89}\left(\frac{p}{D_C}\right)^{0.15}\left(\frac{d_K}{D_C}\right)^{0.71}\left(\frac{d_r}{D_C}\right)^{0.11}(1+\sin\theta)^{-0.23} \ldots(3)$$

Average deviation = 5.748 percent

Standard deviation = 7.392 percent

For the increasing pitch region, the data corresponding to the pitch values between 5 and 10 cm, were correlated using regression analysis and the following equation is obtained.

$$j_D = 257.3(\mathrm{Re})^{-0.92}\left(\frac{p}{D_C}\right)^{0.07}\left(\frac{d_K}{D_C}\right)^{0.71}\left(\frac{d_r}{D_C}\right)^{0.056}(1+\sin\theta)^{-0.23} \ldots(4)$$

Average deviation = 6.671 percent

Standard deviation = 8.335 percent

Conclusions

Based on about 370 limiting current measurements, the data were analyzed for individual parametric effects and the following conclusions were drawn:

Mass transfer coefficients increased with increase in liquid velocities.

The influence of gas velocity on k_L was found to be negligible.

When pitch was varied from 3 to 5 cm, k_L decreased. Further increase in pitch from 5-10 cm yielded a slight increase in k_L. Therefore, based on pitch the entire data were arranged into two regions: the former is decreasing pitch region and the latter is increasing pitch region.

Mass transfer coefficients increased with increase in disk diameter.

The parametric effect of the rod diameter was observed to be insignificant.

Nomenclature

A	Area of the reacting surface	[m^2]
C_0	Concentration of reacting ion (Fe^{2+} or Fe^{3+})	[$kmol/m^3$]
d_k	Disc diameter	[m]
d_r	Diameter of rod	[m]
D_c	Column diameter	[m]
D_L	Diffusivity of reacting species	[m^2/s]
F	Faraday constant	[C]
i_L	Limiting current	[A]
k_L	Mass transfer coefficient	[m/s]
n	Number of electrons released or consumed during the reaction	[-]
p	Pitch	[m]
U_g	Gas superficial velocity	[m/s]
U_L	Liquid superficial velocity	[m/s]

Greek Symbols

μ	Liquid viscosity	[kg/m s]
ρ	Liquid density	[kg/m^3]
θ	Angle of disc	[Degrees]

Dimensionless Groups

j_D Coulburn j-factor = $\dfrac{k_L}{V} Sc^{2/3}$

Re Reynolds number = $\dfrac{\rho\ D_C V}{\mu}$

References

1. Yasunishi A, Fukuma M, Muroyama K (1998) Wall-to-liquid mass transfer in packed and fluidized beds for liquid-solid and gas-liquid-solid system. J Chem Eng Japan 21: 522-528.

2. Ramesh KV, Raju GMJ, Murty MSN, Bhaskara Sarma C (2010) Wall-to-bulk mass transfer in a two-phase upflow bubble column with a composite promoter. Indian Chem Eng 51: 215-227.

3. Ravi T, Srinivasa Rao B, Gopala Krishna P, Venkateswarlu P (1996) Ionic mass transfer studies in fluidized beds with coaxially placed discs on a rod as internal. Chem Eng Processing 35: 187-193.

4. Venkateswarlu P, Gopichand T, Jagannadha Raju GJV (2000) Increased mass transfer in a circular column in the presence of disc promoter. J Energy Heat Mass Transf 22: 195-203.

5. Murty MSN, Ramesh KV, Prabhakar G, Venkateswarlu P (2011) Ionic mass transfer in three-phase fluidized beds in the presence of disc promoter. Chem Eng Commun 198: 1018-1032.

6. Sarma GVS, Murty MSN, Ramesh KV, Raju GMJ (2011) Wall-to-bulk mass transfer in a gas-liquid upflow bubble column with disc promoter. J Energy Heat Mass Transf 33: 233-249.

7. Suresh S, Murty MSN, Srinivas B, Ramesh KV (2013) Wall-to-bulk mass transfer in a concurrent gas-liquid upflow bubble column using hourglass promoters. J Instn Eng India Ser E 94: 91-96.

8. Subramanyam BS, Murty MSN, Surendra Babu B, Ramesh KV (2016) Wall-to-bulk mass transfer in a gas-liquid upflow bubble column with loose-fit twisted tape internals, in Proceedings of International Conference on Advances in Chemical

9. Engineering and Technology ICACE TKMCE, Kollam, India, pp: 82-85.

10. Niranjana Rao B, Ramaprasad BSG, Murty MSN, Ramesh KV (2014) Mass transfer at the confining wall of an electrochemical cell in the presence of angled disc promoter. American Journal of Heat and Mass Transfer 1: 113-129.

11. Niranjana Rao B, Rama Prasad BSG, Murty MSN, Ramesh KV (2015) Wall-to-bed mass transfer in a fluidized bed electrochemical reactor in the presence of angled disc promoter, AIChE Spring Meeting, April 27-30, Austin, Texas, USA.

Lin CS, Denton EB, Gaskill HK, Putnam GL (1951) Diffusion controlled electrode reactions. *Ind Eng Chem* 43: 2136-2143.