International Journal of General Engineering and Technology (IJGET)
Vol.1, Issue 1 Aug 2012 10-25

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

MASS TRANSFER IN CIRCULAR TUBE USING PERFORATED DISC AS TURBULENCE PROMOTER

D.S.SEETHARAMA RAJU, M.GANGADHAR, V. NAGESWARA RAO & N. CHITTI BABU

Department of Chemical Engineering, College of Engineering, Andhra University, Visakhapatnam-530 003, Andhra Pradesh, India

ABSTRACT

Mass transfer data were obtained in circular conduit using an electrochemical technique with a potassium ferri-ferro cyanide couple. In circular conduit coaxially placed entry region perforated disc was used as turbulence promoter. The study comprised of evaluation of mass transfer rates at the outer wall of the electrochemical cell. Mass transfer coefficients were evaluated from the measured limiting currents. The study covered a wide range of geometric parameters such as diameter of the disc (d_d),thickness of the disc(d_t) and distance of the disc from the entrance of the test section (h). The results revealed that the mass transfer coefficient increased with increase in velocity, diameter of the disc (d_d), thickness of the disc(d_t) and decreased with increase in distance of the disc from the entrance of the test section(h). Within the range of variables covered, the augmentation achieved in mass transfer coefficients were up to 2.1 fold over the tube flow in absence of promoter. The entire mass transfer data were correlated with Colburn J_D factor and *Reynolds number*. The following correlation was reported out of the study.

$$J_D = 0.155(Re)^{-0.9432}(\phi_1)^{0.641}(\phi_2)^{0.4658}(\phi_3)^{-0.3775}(Sc)^{1.1521}$$

Where $\phi_1=d_d/d$, $\phi_2=d_t/d$, $\phi_3=h/d$ are dimensionless groups. d is diameter of test section

KEYWORDS: Mass transfer, perforated disc, turbulence promoter

INTRODUCTION

Researcher will always aim at the maximum output with reduced equipment size so as to minimize the unit product cost. This is particularly true in the design of electrolytic cells where the mass transfer limiting conditions exist. Use of turbulence promoter is one such technique that increases the mass transfer coefficients by several folds over the smooth flow. This disturbance continues to its effect on either side of disc and continues to a longer distance which in turn influences the wall mass transfer coefficient over the length of the tube. The study was conducted to know the effectiveness of perforated disc in augmenting mass transfer coefficient. Burns and Jachuck[1] determined liquid solid mass transfer performance on a 30cm diameter spinning disc reactor by use of the limiting current technique. Ravi et al [2] conducted experiments and obtained mass transfer data on the walls of fluidized beds using an electro chemical technique with a potassium ferro-ferri cyanide couple. The disc promoter assembly was used as an internal in fluidized beds. Sherwood and Stone [3] determined the flow of a viscous fluid around disc in a pipe and the added mass of the accelerating disc and flow profiles were also presented. Padesta et al [4] obtained a dimensionless correlation for an ionic mass transfer at horizontal disc electrode under longitudinal vibration. Escudie et al [5] carried out experiments in water fluidized binary mixtures of Teflon spheres, discs and rods. Venkateswarlu et al [6] studied the effect of string of discs placed co-axially in a circular conduit on mass and momentum transfer. Data on mass and momentum transfer in a circular conduit with coaxially placed perforated disc as turbulent promoter has been taken up since the data on the present system has not been reported in literature. Based on the data a semi theoretical model has been developed.

Parameters covered in the present study are shown below in Table 1

Table 1

Variable	Minimum	Maximum	Max/Min
Diameter of the disc, (d_d), m	0.025	0.045	1.8
Disc thickness, (d_t), m	0.005	0.06	12
Distance of the disc			
from the entrance			
of the test section, (h),m	0.14	0.3	2.14
Velocity, V, m/s	0.0984	0.3936	4
Reynolds number, Re	5264	21059	4
Schmidt number	891	990	1.1111

EXPERIMENTAL SET UP AND PROCEDURE

Schematic diagram of experimental set up is shown in figure 1. It is similar in layout to that used in earlier studies [7,8,9,10]. It essentially consisted of a storage tank (TS), centrifugal pump (P), rotameter (R), entrance calming section (E1), test section (T) and exit calming section (E2). The storage tank is cylindrical copper vessel of 100 liter capacity with a drain pipe and a gate valve (V1) for periodical cleaning. A copper coil (H) with perforations is provided to bubble nitrogen through the electrolyte. The tank is connected to the pump with a 0.025m diameter copper pipe on the suction line of the centrifugal pump. The suction line is also provided with a gate valve (V2). The discharge line from the pump splits into two. One served as a bypass line and controlled by valve (V3). The other connects the pump to the entrance calming section (E1) through rotameter. The rotameter is connected to a valve (V4) for adjusting the flow at the desired value. The rotameter has a range of 0 to 166×10^{-5} m^3/s. The entrance calming section consisted of 0.05 m ID circular copper pipe with a flange and is closed at the bottom with a gland nut (G). The up-stream side of the entrance calming section is filled with capillary tubes to damp the flow fluctuations and to facilitate steady flow of the electrolyte through the test section. It is made of a graduated Perspex tube of 0.36m length with point electrodes fixed flush with the inner surface of the tube. The point electrodes are made out of a copper rod and machined to the size. They are fixed flush with the inner surface of the test section at equal spacing of 0.01m. Exit calming section is also of the same diameter copper tube of 0.5 m long, and it is provided with a flange on the upstream side for assembling the test section. It has gland nuts (G) at the top and bottom ends to hold the central tube. Two thermo wells (t1, t2) were provided, one at upstream side of the entrance calming section and the other at the down stream side of exit calming section for measurement of temperature of the electrolyte. Perforated disc serving as turbulence promoter is made of Nylon of various sizes with a provision to fix it rigidly within the test section. The perforated disc has four round holes of each 2mm diameter. The Perforated disc is placed concentrically in the test section. The promoters used are shown in photograph in figure 2. The details of perforated disc promoter are shown in figure3. The limiting current measuring equipment consisted of multimeter of Motwane make which has 0.01mA accuracy and vacuum tube voltmeter is used for potential measurements. The other equipments used in circuit are rheostat, key, commutator, selector switch, and a lead acid battery as the power source. The commutator facilitated the measurement of limiting currents for oxidation and reduction process under identical operating conditions by the change of polarity while the selector switch facilitated the measurements of limiting currents at any desired electrode. The circuit diagram used for the measurement of limiting currents is shown in the figure4.

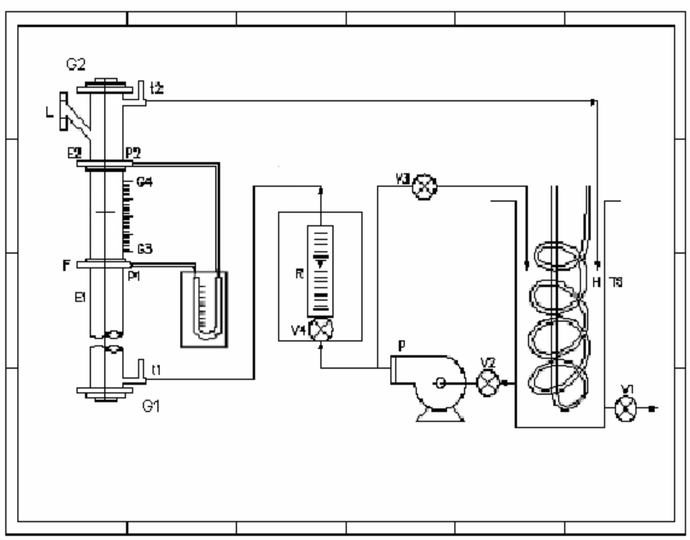

Figure 1: Schematic Diagram of Experimental Setup

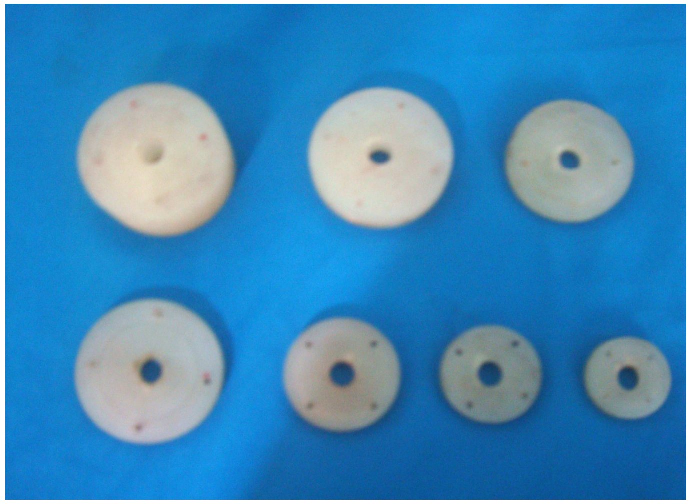

Figure 2: Turbulence Promoters

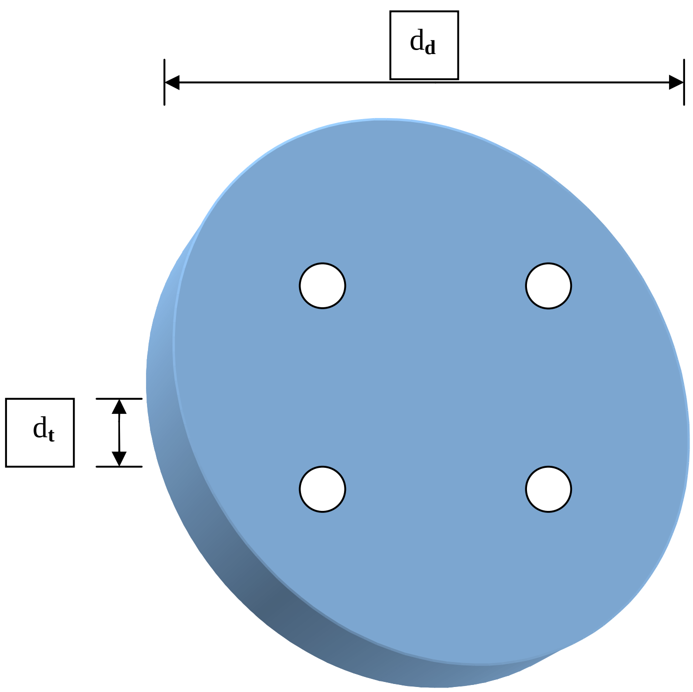

Figure 3: Details of Promoter

d_d = Diameter of Perforated Disc

d_t = Thickness of Perforated Disc

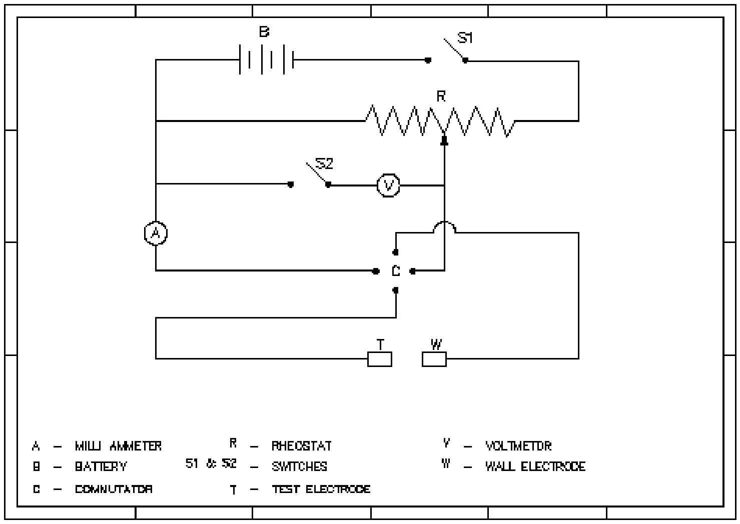

Figure 4: Circuit Diagram

Data on limiting currents for the case of reduction of ferricyanide ion is obtained for fluid flow in circular conduits in the presence of perforated disc as insert promoter. The following electrode reaction is involved.

Cathodic reduction of ferricyanide ion:

$[Fe(CN)_6]^{-3} + e$ ------------- $[Fe(CN)_6]^{-4}$ ...... (1)

Initially blank runs are conducted with indifferent electrolyte (sodium hydroxide solution) alone to ensure that the limiting currents obtained in the subsequent runs are due to diffusion of reacting ions (Ferri cyanide ion) only. The electrolyte was pumped at a desired flow rate (through the test section) by operating the control and by-pass valves. After steady state is attained, potentials are applied across the test electrode and wall electrode in small increments of potentials (100mV) and the corresponding currents were measured for each increment. In view of the large area of the counter electrode in relation to the test electrode nearly constant potential is maintained at the test electrode. Since the potential values are not of criteria in the present study, the limiting currents were determined from the measurements of applied potentials and currents as has been done in several earlier works [7, 8, 9,10]. The attainment of limiting current is indicated by the constancy of current with a large increase in the potential. Mass transfer coefficients are computed from the measured limiting currents by the following equation:

$k_L = i_L/nFAC_0$ ……(2)

RESULTS AND DISCUSSIONS

Perforated disc is taken as turbulence promoter in the present study. The disc is having four round holes in the four quarters. Each perforation is of 2 mm. The disc is made up of Nylon. From the literature, presence of turbulence promoter enhances mass transfer rates. Transfer rates are found to vary along the test section and depend upon the region in which it falls because of localized nature of turbulence. The transfer rates are computed for each point electrode as they are placed all along the test section.

Table 2 indicates the exponent on velocity of the present study together with the other works. The exponent on velocity is comparable to that in the studies on mass transfer with different turbulence generating systems.

Table 2

Author	Promoter	System	Exponent on velocity	Range of Re
Klaczack [15]	Spiral coil	Mass transfer	0.52	1700-20000
Sujatha [16]	Tapes mounted on a rod	Mass transfer	0.49	1348-30605
Venkateswarlu [6]	String of discs	Mass transfer	0.498	3300-18650
Sitaraman [12]	String of spheres	Mass transfer	0.556	100-34000
Sarveswara Rao [13]	String of cones	Mass transfer	0.431	690-20200
Changal Raju [14]	Wires wound on a rod	Mass transfer	0.49	1500-20000
Nageswara Rao [17]	Tape-disc assembly	Mass transfer	0.485	1300-12000
Teja Latha et al [18]	Square grooved serrated disc	Mass transfer	0.205	1933-19337
Present study	Perforated disc	Mass transfer	0.488	5264-21059

EFFECT OF GEOMETRIC PARAMETERS

Effect of disc diameter

k_L versus velocity of electrolyte (V) is drawn for different perforated disc diameters and is shown in figure 5.Various disc diameters used in the present study are $d_{\mathbf{d}}$=0.025m, 0.030m, 0.035m, 0.040m, 0.045m.Mass transfer coefficient increases with increase in disc diameter. The augmentation in mass transfer coefficient is 1.23 times over the smooth tube [11] for disc diameter 0.025m at a velocity of 0.3936m/s while the augmentation is 1.79 times over the smooth tube [11] for the disc diameter 0.045m at the same velocity 0.3936m/s. Figure 6 is drawn for the mass transfer coefficient versus disc diameter at the velocity of 0.3936m/s. Mass transfer coefficient increases with disc diameter with an exponent on d_d of 0.641. This observation is consistent with the other sets. Figure 7 is drawn for St / Sto against Reynolds number (Re) to show the effect of disc diameter on augmentation. Mass transfer increases as the disc diameter increases.

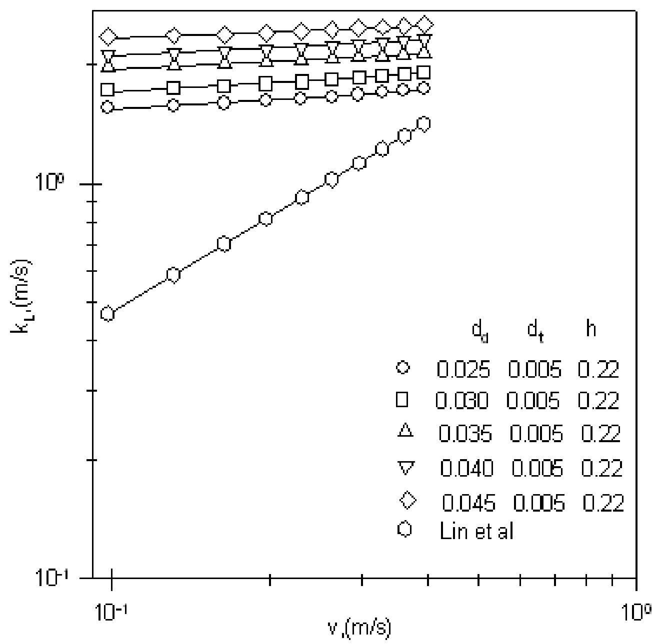

Figure 5: Variation of mass transfer coefficient with velocity - Effect of diameter of perforated disc

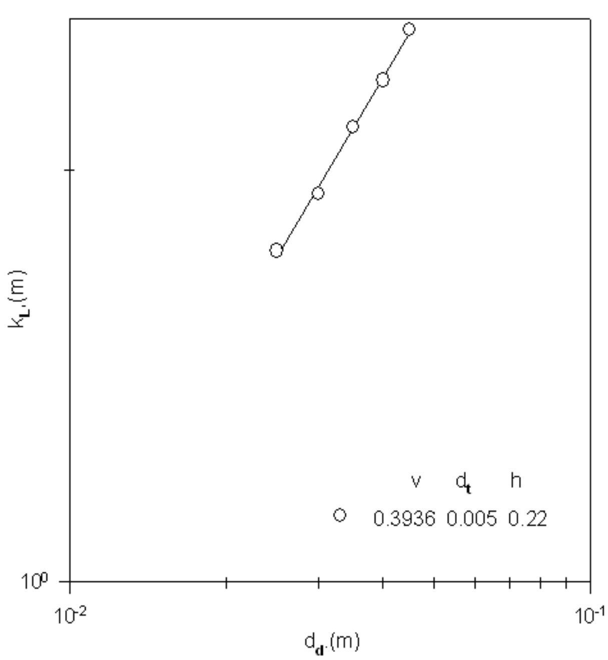

Figure 6: Variation of mass transfer coefficient with disc diameter

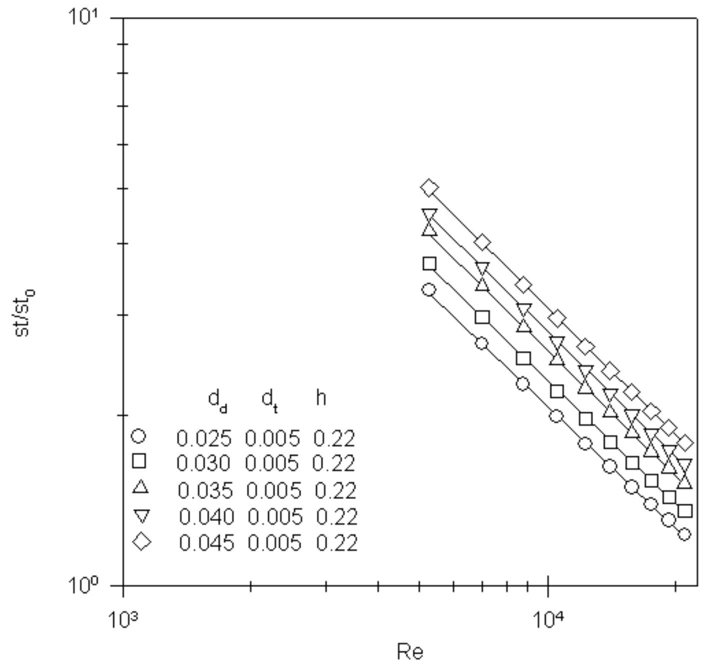

Figure 7: Variation of St/St_0 with Reynolds number -Effect of perforated disc diameter

Effect of disc thickness

In figure8, mass transfer coefficient k_L is drawn against velocity of electrolyte to study the effect of disc thickness on mass transfer by keeping all the other parameters constant. The thickness of the disc used in the present study are d_t=0.005m, 0.020m, 0.040m, 0.060m. Mass transfer coefficient increases from 1.79 times to 5.95 times as the thickness of the disc increases from 0.005m to 0.060m at the velocity of 0.3936 m/s over Lin et al[11].

Figure 9 shows variation of mass transfer coefficient, k_L with thickness of the disc(d_t) for the set d_d=0.045m, h=0.22m and at the velocity 0.3936m/s. Mass transfer coefficient increases with increase in disc thickness and the exponent on d_t is 0.46.

Figure 10 is drawn as St / Sto against Reynolds number to study the effect of disc thickness (d_t) on mass transfer. Augmentation in mass transfer is found to fall rapidly as Reynolds number increases. It is observed that the thickness of the disc d_t= 0.060m is better in augmenting mass transfer when compared to 0.005m.

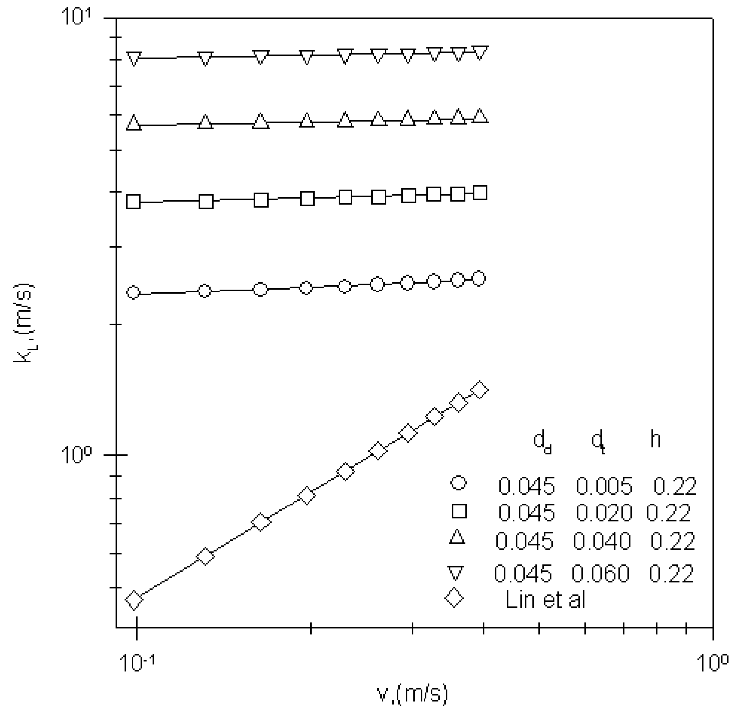

Figure8: Variation of mass transfer coefficient with velocity -Effect of disc thickness

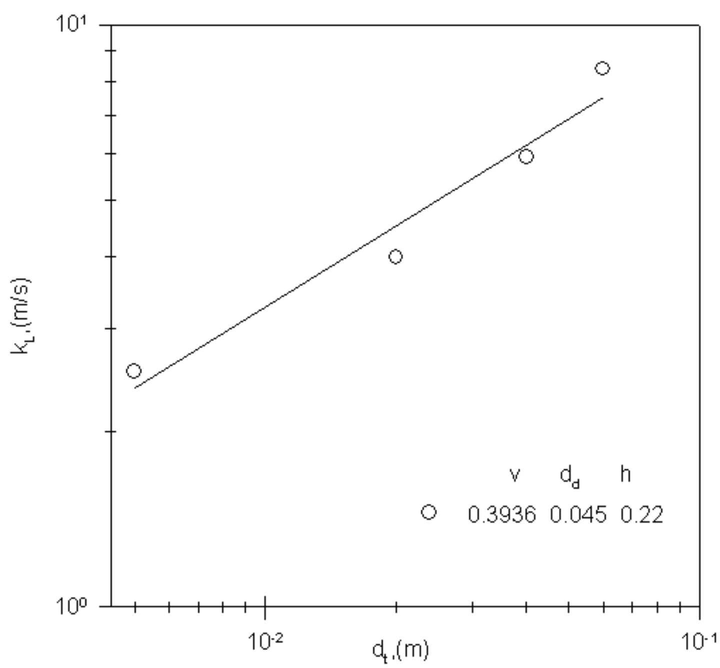

Figure9: Variation of mass transfer coefficient with disc thickness

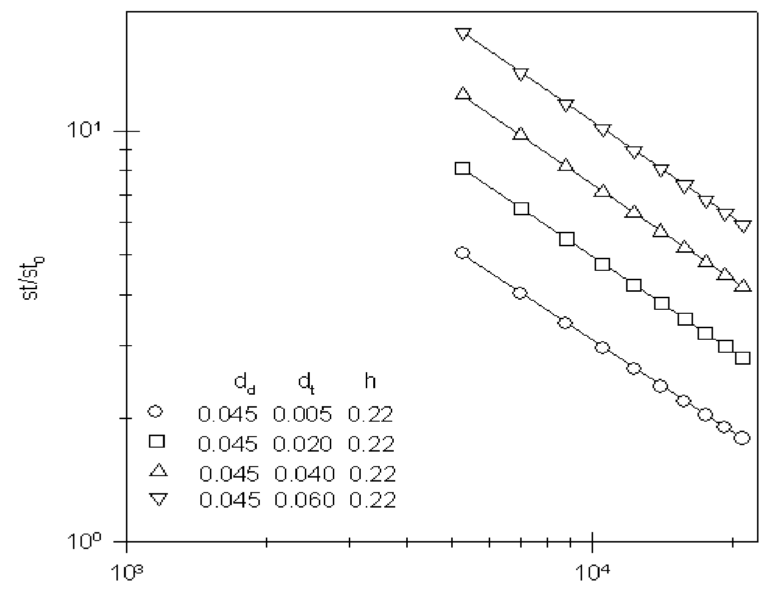

Figure10: variation of st/st$_0$ with Reynolds number -Effect of perforated disc thickness

Effect of spacing inside the test section

As the distance of the perforated disc from the entrance of the test section varied, extent of turbulence also varied because of change in circulating pattern and it is extended to both perforated disc region and downstream region to disc region. Mass transfer coefficient (k_L) versus velocity for different distances of the disc(h) from the entrance of the test section are plotted and is shown in figure11. Mass transfer coefficients are decreased from 2.09 to 1.5 times over Lin et al[11] for the smooth tube, while the distance of the disc from the entrance of the test section increases from 0.14 m to 0.30m

Figure 12 is a cross plot of figure11 which is drawn for mass transfer coefficient against distance (h) of the perforated disc from the entrance of the test section for the set d_d=0.045m, d_t=0.005m, and at a velocity of 0.3936m/s. Mass transfer decreases as the distance of the disc from the entrance of the test section increases and the exponent on distance is -0.426.

Figure 13 shows the variation of St / Sto with Reynolds number with different values of “h” by keeping all the other geometric parameters constant. From the figure it is observed that the lower the ‘h’, the higher is the mass transfer.

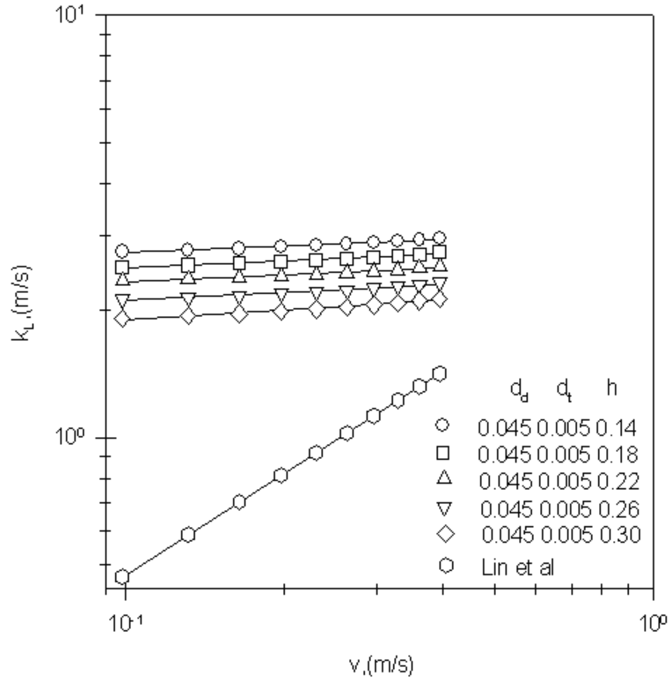

Figure 11: Variation of mass transfer coefficient with velocity of electrolyte

- Effect of distance of disc from entrance of test section

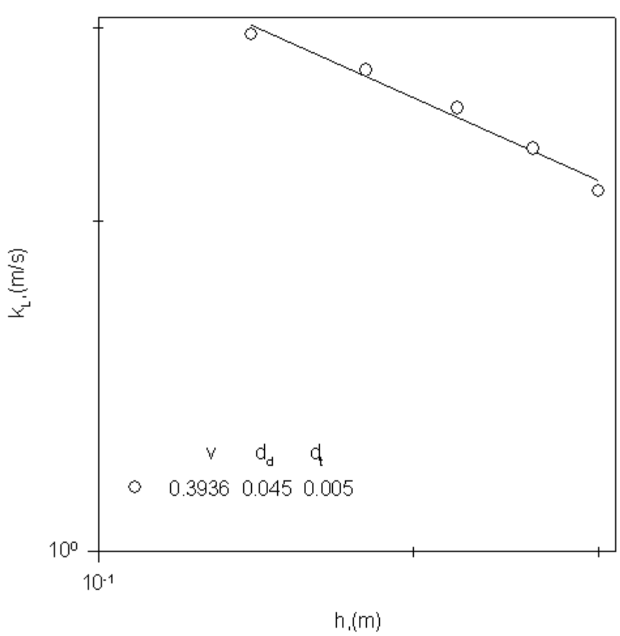

Figure 12: Variation of mass transfer coefficient with distance of disc

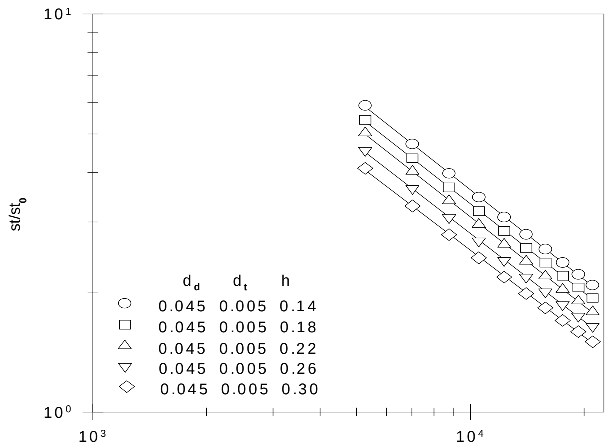

Figure13: Variation of St/St$_0$ with Reynolds number
-Effect of distance of disc from entrance of the test section

DEVELOPMENT OF CORRELATIONS

The data on mass transfer with single perforated disc as turbulence promoter could well be calculated in the lines done in earlier studies [17].Correlation of data using Colburn J_D factor with Reynolds number have yielded the following equations.

Perforated disc region:

$J_D = 83.21x\ (Re)^{-0.9348}$ .... (3).

Average deviation = 44.35,

Standard deviation = 68.98

By incorporating dimensionless geometrical groups, the following correlations are yielded

Perforated disc region:

$J_D=0.155(Re)^{-0.9432}(\phi_1)^{0.641}(\phi_2)^{0.4658}(\phi_3)^{-0.3775}(Sc)^{1.1521}$ ..... (4)

Average deviation = 3.53

Standard deviation = 5.25

Where $\phi_1=d_d/d$, $\phi_2=d_t/d$, $\phi_3=h/d$, S_c which are dimensionless groups

Sc is Schmidt number

Correlation plots for equation (4) is presented in the figure 14.

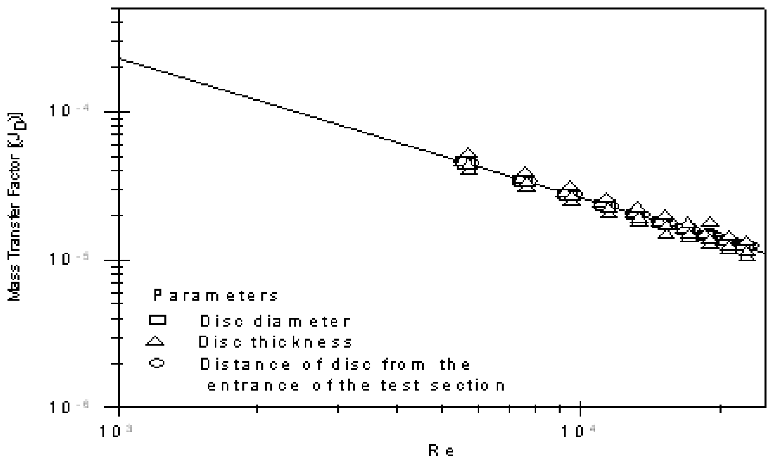

Figure 14: Correlation plot for equation (4)

Comparison of correlations

For a selected set of geometric parameters correlation factor in mass transfer (Y_3) against Re is plotted, compared with the data of Teja Latha [18] is shown in figure 15.

$$Y_3 = J_D / (d_d/d)^{0.641}(d_t/d)^{0.4658} (h/d)^{-0.37750} (Sc)^{1.1521} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

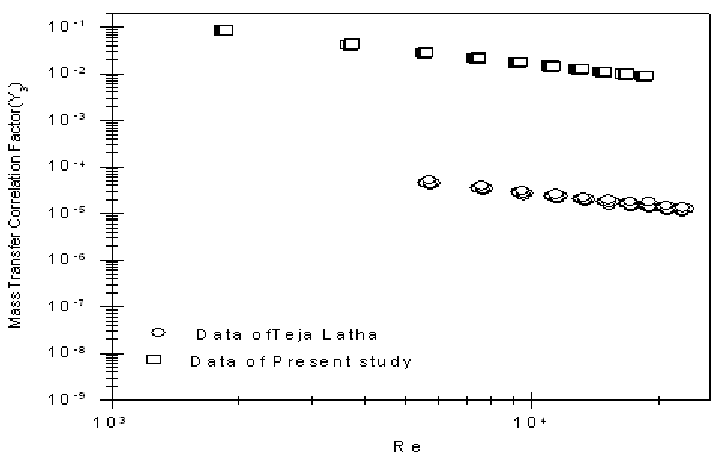

Figure 15: Variation of CFR with Re –Comparison plot

CONCLUSIONS

Mass transfer coefficients are increasing with increase in velocity. Mass transfer coefficients are increasing with increase in disc diameter (d_d), thickness of the disc (d_t) and decreases as distance of the disc (h) from the entrance of the test section increases. In the present study, it is found that disc diameter

(d_d) of 0.045m, disc thickness=0.005, distance of the sic from the entrance of the test section (h) =0.14m, offered maximum augmentation. A maximum augmentation of 5.95 folds is observed over smooth tube flow. Correlations developed based on semi theoretical considerations. Wall similarity concept is applied for the present case.

Correlations developed for mass transfer:

Perforated disc region:

$$J_D=0.155(Re)^{-0.9432}(\phi_1)^{0.641}(\phi_2)^{0.4658}(\phi_3)^{-0.3775}(Sc)^{1.1521}$$

Dimensionless Groups

J_D	=	Mass Transfer Factor $(k_L/V).S_C^{2/3}$
Re	=	Reynolds number = $dV\rho/\mu$
Re^+	=	Roughness Reynolds number = $(d_d / d).Re.\sqrt{(f/2)}$
$R(h^+)$	=	Roughness momentum transfer function = $2.5\ln(2 d_d/d) + \sqrt{(2/f)} + 3.75$
St	=	Stanton number = k_L/V
St_o	=	Stanton number for conduit without internals
Sc	=	Schmidt number $\mu/\rho D_L$
Sh	=	Sherwood number $k_L.d/D_L$
u^+	=	dimensionless velocity, u/u^*
y^+	=	dimensionless radial distance from the wall, $y\,u^*/\nu$

Nomenclature

C_0	=	Concentration of Ferry cyanide, kmol/m^3
d	=	Diameter of test section, m
D_L	=	Diffusivity of reacting ion, m^2/sec
d_d	=	Disc diameter, m
E	=	Energy consumed using perforated disc in the conduit, N/m^2
E_o	=	Energy consumed for empty conduit,N/m^2
f	=	Friction factor, $\Delta p\, d\, g_c /2LV^2 \rho$
ΔP	=	Pressure difference, N/m^2
F	=	Faraday's constant = 96,500 coulombs/g-mol
g	=	Acceleration due to gravity, m/sec^2

g_c = Gravitational constant.

i_L = Limiting current, amp

k_L = Mass Transfer coefficient, m/s

k_o = Mass transfer coefficient of the empty conduit, m/s

L = Length of Test section, m

n = Number of electrons transferred

Q = Volumetric flow rate, m^3/s

d_d = diameter of the disc, m

d_t = thickness of the disc, m

h = location of the disc from the entrance of the test section, m

u = Local velocity, m/s

u^* = Friction velocity = $\sqrt{(\tau_w g_c / \rho)}$, m/s

V = Average velocity, m/s

y = Radial distance from the wall, m

Y_3 = $J_D / (d_d/d)^{0.641}(d_t/d)^{0.4658} (h/d)^{-0.37750} (Sc)^{1.1521}$

REFERENCES

1. Burns, J.R. and Jchuck,R.J.J. (2005), "Determination of liquid – solid mass transfer coefficient for a spinning disc reactor using limiting current technique." Int. J. Heat and Mass Transfer, 48, 2540-2547

2. Ravi,T. , Srinivasa Rao,B. Gopal kishna,p. and Venkateswarlu,P. (1996), "Ionic mass transfer studies in fluidized beds with co-axially placed discs on a rod as internal" Chem. Engg . Process., 35,187-193

3. Sherwood, J.D., and Stone, H.A. (1997), "Added mass of a disc accelerating within a pipe, Phy. Fluids., 9, pp 3141-3148

4. Padesta, J.J., Paus, G.S., and Arvia, A.J. (1974),"Ionic mass transfer at horizontal disc electrode under longitudinal vibration ".Electro Chim. Acta ,19, 583-589

5. Escudie, R., Epstein, N., Grace, R., and Bi, H.T. (2006),"Effect of partical shape on liquid fluidized beds of binary solids mixtures" Chem.Engg. Science., 61, 1528-1539

6. Venkateswarlu, P., Gopichand, T., and Raju, G.J.V.J. (2000), "Increased mass transfer in a circular column in the presence disc promoter" J.Energy Heat Mass Transfer, 22,195-203

7. S.C. Lau , J. Cervantes , J.C. Han , R.J. Rudolph , K. Flannery (2003) Measurements of wall heat (mass) transfer for flow through blockages with round and square holes in a wide rectangular channel International Journal of Heat and Mass Transfer 46 , 3991–4001

Se Kyung Oh, Ary Bachtiar Krishna Putra and Soo Whan Ahn (2009) Heat Transfer and Frictional Characteristics in Rectangular Channel with Inclined Perforated Baffles World Academy of Science, Engineering and Technology 49 , 324-329.

9. Bhaskar Sarma, C. (1978), "Ionic mass transfer at circular and elliptical cylinders in cross flow of homogeneous fluid and in fluidized solids " Ph.D. Thesis, Andhra University, Visakhapatnam

10. Venkateswarlu, P. (1987) "Studies on ionic mass transfer with co axially placed discs on a rod as turbulence promoter" Ph.D., Thesis, Andhra University, Visakhapatnam,

11. Lin C.S.,E.B.Denton,H.S.Gaskill and G.L.Putnam (1951), "Diffusion controlled reaction", Ind.Engg.Chemistry, 43, 2136-2143

12. Sitaraman, T.S (1977), Augmentation of mass transfer with coaxial string of spheres as internals in tubes and fluidized beds, Ph.D. Thesis, University of Madras, India

13. S.Sarveswara Rao, G.J.V.J.Raju(1986), "Studies on Ionic Mass Transfer with co-axially placed cones on a rod in homogeneous fluid and fluidized beds" World Congress III of Chemical Engineers, Tokyo, pp.481

14. D.Changal Raju,C.Bhaskara Sharma,G.J.V.Raju (1992), "Ionic mass transfer at the outer wall of concentric annuli in the presence of fluidizing solids-Effect of wires wound on central rod" J.Energy Heat Masss Transfer, 14,151-156

15. Klaczac,A(1973), Trans. A.S.M.E., J. Heat Transfer, 95,557

16. V.Sujatha,C.Bhaskara Sarma,G.J.V.Jagannadha Raju (1997), "Studies on ionic mass transfer with coaxially placed helical tapes on a rod in forced convection flow", Chem.Engg.Process., 36, 67-73

17. Nageswara Rao, V.and Chitti Babu, N. (2008) "Studies on ionic mass transfer with coaxially placed disc as turbulence promoter in circular conduits" Caledonian journal of Engineering, 4, 26 -32

18. S. Teja Latha, V.Nageswara Rao and M.Gangadhar (2010), "Mass transfer in circular tube with square-grooved serrated disc as turbulence Promoter", Int. J. Chemical Engineering Research, 2, 335-344