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RESEARCH ARTICLE

MASS TRANSFER IN CIRCULAR PIPE USING SQUARE GROOVED CLEAVED DISC AS TURBULENCE PROMOTER

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ABSTRACT

Stud The present study comprises of the evaluation of mass transfer rates at the outer wall of the electrochemical cell. Mass transfer coefficients were evaluated from the measured limiting currents technique. The study covers the influence of various diameters of the disc (D_d), thickness of disc (T_d) and positions of disc(h). The results have revealed that the mass transfer coefficient increases with increase in velocity, diameter of the disc (D_d), thickness of disc (T_d) and decreases with increase in distance of disc from entrance of the test section(h). Within the range of variables covered, the augmentations achieved in mass transfer coefficients were up to 2.08 fold over the tube flow in absence of a promoter. Mass transfer rates were analyzed with mass transfer roughness function and roughness Reynold`s number. The correlation achieved is $J_D = 128.40(Re^+)^{-0.9753} (\phi_1)^{0.9224}(\phi_2)^{0.1785} (\phi_3)^{0.4109}$

INTRODUCTION

In recent years the process industries 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 exists. Various techniques have been adopted to augment the transfer rates. Use of rough surfaces is one of the several enhancement techniques reported by Bergler (Bergler, 1969), through which it is possible to achieve a two-fold objectives of maximum mass transfer rate with a minimum frictional pressure drop. Considerable work has been reported on the use of surface roughness elements and insert promoter. Augmentation is in mass transfer coefficient was reported with use of string of spheres (Sitaraman, 1997), string or discs (Venkateswarlu and Jagannadha Raju, 1987), spiral coil (Sethumadhavan and Raja Rao, 1983), coaxially placed cones (Sarveswara Rao, 1983) or twisted tapes mounted on a central annual rod (Sujatha, 1991), Discs (Venkateswarlu, 1987) and orifices[8] placed across the flow in conduit generate form friction both in upstream and downstream sides, thus generated friction continuous to show their effect on wall mass transfer coefficient along the cell. In earlier investigation where coaxially placed twisted tape–disc assembly (Sujatha kumara, 2003) employed as turbulence promoters in circular conduit, significant augmentation in mass transfer was reported. Studies on effect of coaxially placed square- grooved serrated disc in circular conduit on mass transfer rates in case of forced convection flow of electrolyte have not been reported.

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Present investigation is therefore undertaken and essentially deals with evaluation of mass transfer rate at the wall through limiting current technique using the above promoters. Pressure drop calculations have been done by using manometer readings.

Parameters covered in the present study are shown below:

Variable	Minimum	Maximum	Max/Min
Diameter of the disc (D_d), m	0.025	0.045	1.8
Disc thickness (T_d), m	0.001	0.005	5
Distance of the disc from the entrance of the test section, (h),m	0.10	0.26	2.6
Velocity (V), m/s	0.03289	0.3289	10
Reynold's number (Re)	1933	19337	10
Schmidt number (Sc)	982.2	1040	1.0588

Experimental setup

A photograph and schematic diagram of experimental set up are shown in figure 1 and figure 2 respectively. It is similar in layout to that used in earlier studies (Krishna *et al.,* 1966; Sudhakhara Rao *et al.,* 1966; Bhaskar Sarma, 1978). 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 0.025 m 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.

Fig. 1. Experimental Setup

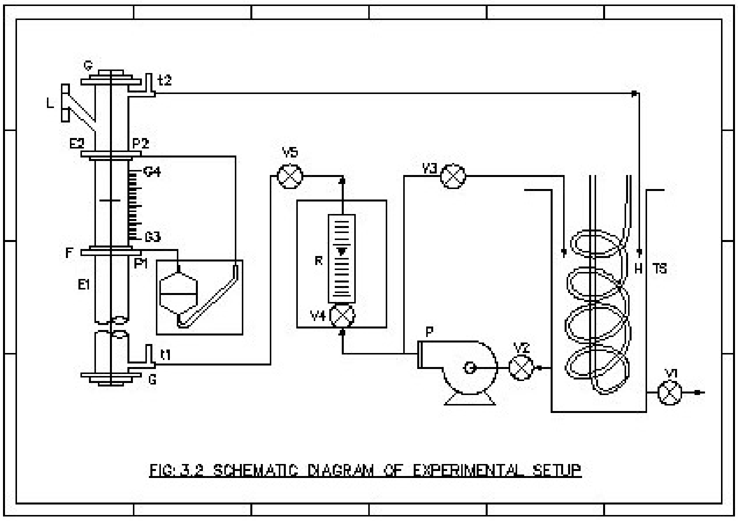

Fig. 2. Schematic Diagram

Fig. 3. Turbulence Promoters

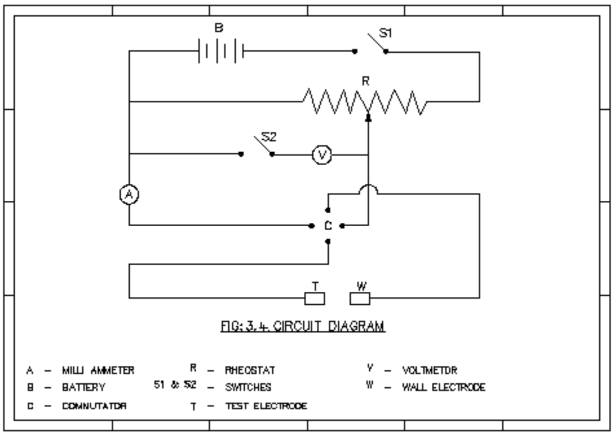

Fig. 4. Circuit Diagram

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 $166x10^{-5}m^3/s$. 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 was 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 downstream side of exit calming section for measurement of temperature of the electrolyte. Serrated disc serving as turbulence promoter is made of copper of various sizes with a provision to fix it rigidly within the test section. The Serrated disc is placed concentrically in the test section.

The promoters used are shown in by photograph in Figure 3. 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 equipment used in circuit is 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 Figure 4.

Experimental procedure

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

Cathodic reduction of ferricyanide ion:

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

The following grades of chemicals have been used for preparing the electrolyte and analytical reagents:

Electrolyte:

Potassium ferrocyanide	AR
Potassium ferricyanide	AR
Sodium hydroxide	GR
Analytical reagents:	
Hypo	AR
Potassium permanganate	AR
Potassium dichromate	AR
Oxalic acid	AR
Starch	AR

Eighty liters of equimolal solution of 0.01M Potassium ferricyanide and Potassium ferrocyanide with 0.5N NaOH as indifferent electrolyte were prepared. The electrolyte is analyzed for ferrocyanide ion concentration by volumetric titration method using standard potassium permanganate solutions and for ferricyanide ion using idometric method. The viscosity of the solutions at different temperatures is measured with Ostwald Viscometer and densities are measured using specific gravity bottle. The point electrodes are polished using four zero emery specific gravity bottle to get a smooth surface without protuberances. Subsequently degreasing operation with trichloro ethylene solution is carried out. The size of the electrode is measured with a traveling microscope. 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 (Krishna *et al.,* 1966; Sudhakhara Rao *et al.,* 1966; Bhaskar Sarma *et al.,* 1978 Venkateswarlu, 1987). 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:

$k_L = i_L/nFAC_o$ ……………..…..……. 2

Pressure drop measurements are also taken simultaneously using an inclined manometer with Carbon tetrachloride as manometric liquid.

RESULTS AND DISCUSSION

Analysis of mass transfer data (Effect of geometric parameters)

Effect of disc diameter: Disc diameter has strong influence on k_L. k_L versus velocity is drawn for different disc diameters and is shown in figure1.various disc diameters used in the present study are D_d=0.025, 0.030, 0.035, 0.040, 0.045 mass transfer coefficient increases with increase in disc diameter. The augmentation in mass transfer coefficient is 1.2451 times over the smooth tube (Lin *et al.,* 1951) for disc diameter 0.025m at a velocity of 0.3289m/s while the augmentation is 2.0843 times over the smooth tube (Lin *et al.,* 1951) for the disc diameter 0.045m at the same velocity 0.3289m/s.

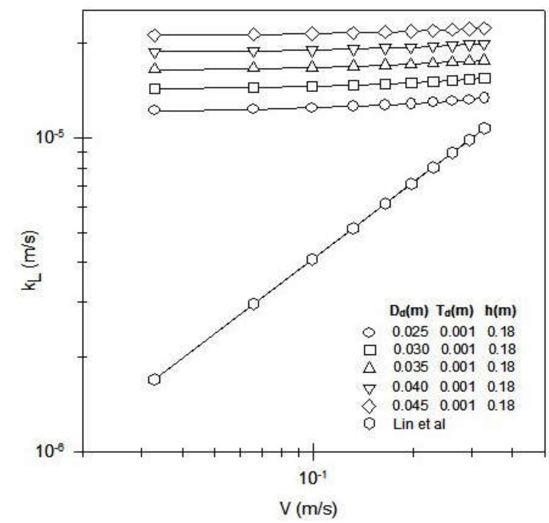

Fig. 5.

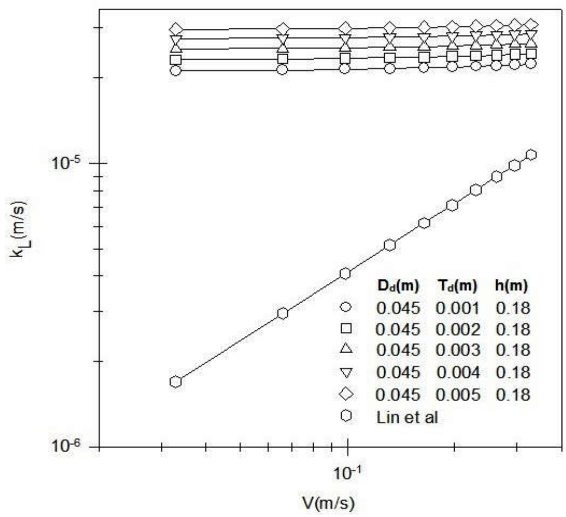

Fig. 6.

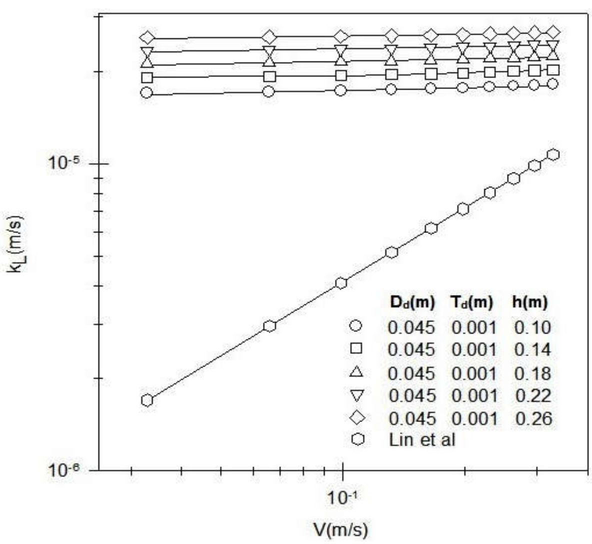

Fig. 7.

In plots k_L vs V, the varying parameters for figure 5, figure 6, figure 7 are disc diameter (D_d), disc thickness (T_d), position of disc (from entrance of the test section) (h) respectively.

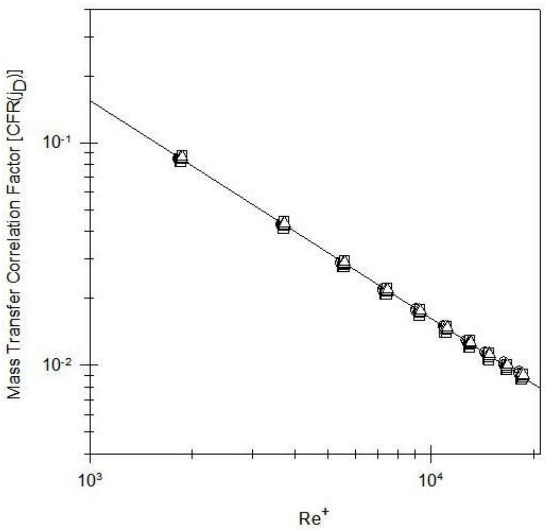

Fig. 8.

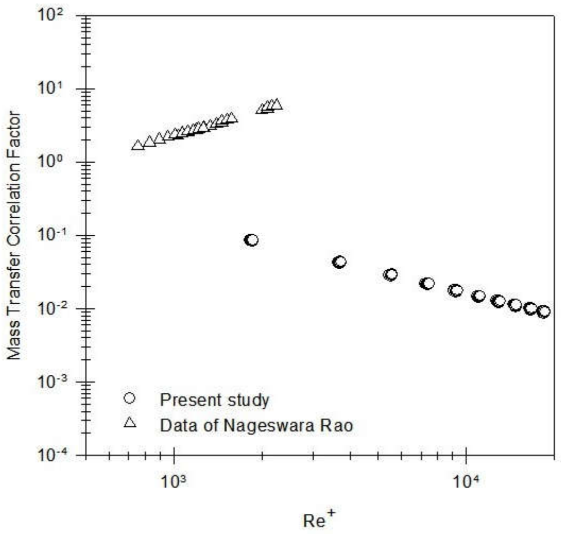

Fig. 9.

Effect of disc thickness: In figure 4, k_L is drawn against velocity 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 T_d= 0.001, 0.002, 0.003, 0.004, 0.005 m. Mass transfer coefficient increases from 2.0843 times to 2.8774 times as the thickness of the disc increases from 0.001m to 0.005m at the velocity of 0.3289 m/s

Effect of spacing inside the test section: As the distance of the promoter 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 serrated disc region versus velocity for different distances of the disc(h) from the entrance of the test section are plotted and is shown in figure 7. Mass transfer coefficients are decreased from 1.6924 to 2.5042 over Lin *et al.,* (1951) for the smooth tube, while the distance of the disc from the entrance of the test section increases from 0.10 m to 0.26m.

Development of correlations for mass transfer

The data on mass transfer with single serrated disc as turbulence promoter could well be calculated in the lines done in earlier studies (Nageswara Rao and Chitti Babu, 2009). Correlation of data using colburn J_D factor with Reynolds number have yielded the following equation

$$J_D = (91.846)\, Re^{-0.9723} \qquad \ldots\ldots\ldots\ldots\ldots 3$$

Average deviation = 20.93
Standard deviation = 24.15

By incorporating dimensionless geometrical groups, the following correlations are yielded

$$J_D = (128.40)\, Re^{-0.9753}(\phi_1)^{0.9224}(\phi_2)^{0.1785}(\phi_3)^{0.4109} \qquad \ldots\ldots\ldots 4$$

Average deviation = 1.6984
Standard deviation = 2.1409

Where $\phi_1=D_d/d$, $\phi_2=T_d/d$, $\phi_3=h/d$, Sc which are dimensionless groups

Correlation graphs for equations and are given in the figures and respectively

Comparison of correlations

For a selected set of geometric parameters correlation factor in mass transfer (Y_1) is plotted against Re^+ i.e., Figure 8, for comparison data of other studies namely Nageswara Rao V (Nageswara Rao and Chitti Babu, 2009) having comparable geometric parameters, are computed with present method are shown and plotted as Figures 9. The data falls close to the present study indicating correlation presented in the present work is comparable and better correlating.

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 $\mu/\rho D_L$

Nomenclature:

D_d	=	Disc diameter, m
T_d	=	Thickness of the disc, m
h	=	location of the disc from the entrance of the test section,
mV	=	Average velocity, m/s
d	=	Diameter of test section, m
D_L	=	Diffusivity of reacting ion, m^2/sec
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	=	Conversion factor (mass & force)
i_L	=	Limiting current, A
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

$Y_1 = J_D / (D_d/d)^{0.9224}(T_d/d)^{0.1785} (h/d)^{0.4109}$

Greek letters

μ = Viscosity of fluid, Kg/m. sec

ρ_c = Density of manometer fluid, Kg/m^3

ρ = Density of fluid, Kg/m^3

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