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STUDIES ON MASS AND MOMENTUM TRANSFER AT THE OUTER WALL OF A CIRCULAR CONDUIT WITH ENTRY REGION SPIRAL TAPE WOUND ON ROD AS TURBULENCE PROMOTER

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ABSTRACT

An experimental investigation has been carried out to study the enhancement in mass transfer coefficient by entry region spiral tape wound on rod promoter inserted in a circular conduit. Friction factor, augmentation ratio, energy factor and performance index characteristics are also investigated. The effects of geometric parameters pitch, Height and width of the spiral tape wound on rod on mass transfer and momentum transfer are studied. The experiments are conducted with fourty eight promoters having different Height, Width, Pitch over the Reynolds number range of 4,853 – 14,533. The results obtained are compared with the smooth tube data to assess the improvement in mass transfer. Correlations are developed for mass and momentum transfer as a function ofpitch, length and width of the twisted tape, mass transfer performance index as a function of Reynolds number and pitch and length of the spiral tape wound on rod promoter.

Keywords: Augmentation Factor, Energy Factor, Performance Index, Spiral Tape Wound On Rod, Entry Region Promoter.

I INTRODUCTION

The Process intensification brings paradigm change in process design. It improves the performance of the process equipment. Process intensification offers cost effective process design for sustainable development. Process intensification offers debottlenecking in selected operations. Sometimes it may leads to safer design. Many augmentation techniques are envisaged and tested for their efficiency. Augmentation or process intensification techniques are of great interest in engineering designs to increase the performance of processes. In general, enhancing the heat and mass transfer by the use of passive method is more popular and applied to many engineering applications. One of the earliest works on augmentation is Lin et al[1] studied mass transfer rates in diffusion controlled electrochemical reactions in order to obtain design information for electrochemical processes in circular and annular flow device. These passive methods do not require the extra external power sources. Some of the examples of these turbulence promoter devices are rough surfaces, extended surfaces, wire coil and the swirl flow generating devices like twisted tape, helical tape, snail entry, etc are prominent.Performance of the systems can also be increased by active methods like rotation, vibration and application of electro-static field but complexity in construction and operation involved with make them not viable. Swirl generators with varying geometry enhance heat mass transfer. Extensive work has been reported in literature[2-8]. The advantage of these types of promoters is harnessed with coaxially placed twisted tape insert promoters [9-14] and studies on these are found extensively in literature. Entry region twisted tapes, spiral coils offered efficient transfer processes. Earlier investigations in heat and mass transfer motivated the author to pursue mass transfer in circular conduits with entry region spiral tapes wound on rod. The promoter element is very simple to manufacture with less cost and easy to maintain the systems. The entry region spiral tape wound on rod promoters or other swirl generating devices inserted in the conduit provide swirling flow and the swirl propagates further along the length of the column. Present study is confined to a test section length of 44 cm only but its influence is much longer with some decay in augmentation. It enhances intensity of the turbulence in the conduit.The swirl induces tangential component of velocity and causes improved mixing in the core and extend to wall region thereby enhanced in attractive forces resulting in higher augmentation. Insertion of the entry region spiraltape wound on rodis anticipated to augment transfer coefficient with relatively lower pressure losses. The study of mass transfer in developing flows is of special importance for the design of electrochemical reactors. The analysis of heat and mass development in the entrance region in ducts or annuli has been widely considered. In most of these studies, it is assumed that the velocity and temperature or concentration distributions at the entrance are uniform and the axial distribution of both momentum and heat and mass can be neglected. The heat and mass transfer problems are analogous except for the simplifying assumptions for the development of the equations. Due to the high values of the Schmidt number in electrolytic medium, the heat and mass boundary layer thicknesses are very different. The use of swirl generators has long been recognized [19-25] as a means of enhancing mass transfer in electrochemical cells.Turbulent swirling flows are encountered in many chemical engineering applications. For example swirl is commonly employed in combustion systems and chemical processing plants, in order to increase fluid mixing thereby enhanced heat and mass transfer rates, and subsequently improve the efficiency or the degree of stability of a process. The objective of the present work is to suggest mass and momentum transfer models by conducting experiments with entry region spiral tape wound on rod as the entry region swirl generator. The present work reports the experimental results of mass and momentum transfer in homogeneous flow electrolyte provided with spiral tape wound on rod promoter placed at the entry region of the tube.Hence the present investigation was carried out using entry region spiral tape wound on rodpromoter in circular conduit. It deals with the study on mass transfer at electrodes fixed flush with the inside surface of the wall in the presence of spiral tape and pressure drop in homogeneous flow of fluid. The electrochemical diffusion controlled redox reactions for potassium ferricyanide and potassium ferrocyanide couple are used to measure mass transfer coefficient. It has the advantage of reproducibility of limiting current data with simple instrumentation, acquisition of precise data and reacting surface unaltered. The effect of pitch, height, width of the entry region spiral tapewound on rod promoter was studied in homogeneous flow of the electrolyte. Various geometric and dynamic parameters together with their ranges covered in the present study are presented.

II EXPERIMENTAL SET UP

The schematic diagram of the experimental set up is shown in figure 1. The layout is similar to that used in earlier studies [26-32]. It essentially consisted of a recirculation tank (T), an entrance calming section (A), a test section(B), an exit calming section (C), thermo wells (E_1, E_2), flanges (F_1,F_2), gland nuts (G_1 to G_4), coiled copper tube (H), pump (P), rotameters (R_1, R_2), recirculation tank (T), U tube manometer (UM) and valves (V_1 to V_6). The recirculation tank was a cylindrical copper vessel of 100 liter capacity with a drain pipe and a gate valve (V_1) for periodical cleaning of the tank. A copper coiled tube (H) with perforations was provided to bubble nitrogen through the electrolyte. The tank was connected to the pump with a 0.025 m diameter copper pipe on the suction line of the centrifugal pump. The suction line was also provided with a gate valve (V_2). The discharge line from the pump was divided into two. One served as a bypass line and controlled by valve (V_3). The other line connected the pump to the entrance calming section (A) through rotameter. The rotameter was connected to a valve (V_4) for adjusting the flow rate at the desired rate. The rotameter has a range of 0 to 9.3×10^{-4} m^3/s. The entrance calming section was circular copper pipe of 0.05 m ID provided with a flange and closed at the bottom provided with a gland nut (G_1). The entrance calming section was filled with capillary tubes to damp the flow fluctuations and to facilitate steady flow of the electrolyte through the test section. The details of the test section are shown in figure 2. It was made of a graduated perspex tube of 0.44 m length provided with point electrodes fixed flush with the inner surface of the tube. The point electrodes were made out of a copper rod and machined to the size. The electrodes were fixed flush with the inner surface of the test section at equal spacing of 0.02m. The diameter of the exit calming section was also of the same diameter of the entrance calming section made of copper tube of 0.05 m, and it was provided with a flange on the upstream side for assembling the test section. It has gland nuts (G_2, G_3) at the top and bottom ends. The 0.05 m ID column through which the electrolyte was pumped was constructed by assembling the three sections the entrance calming section, the test section and the exit calming section with the flanges F_1, F_2 and the gland nuts G_1 to G_4. Two thermo wells (E_1, E_2) were provided, one at upstream side of the entrance calming section and the other at the downstream side of exit calming section to measure the temperature of the electrolyte.

The spiral tape wound on rod is fixed at the entrance of the test section with the help of flanges. It served as turbulence promoter in the present study. The entry region spiral tape wound on rod was made from a copper tape of 0.003 m thickness. The copper tape of varying height and width was spiral tape wound on rod such that it gives the desired pitch values. The promoter thus made provided several tape promoters with different values of pitch, height and width. The promoter was welded to a flange and placed concentrically in the test section with the help of flanges attached to the test section and the entrance calming section.

Details of the entry region spiral tape wound on rod promoters used in the study are compiled in the Table 2. Motwane make multimeter of 0.01 mA accuracy and vacuum tube voltmeter were used for measuring the

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limiting current and potential measurements. The electrical circuit consisted of 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 changing the polarity, while the selector switch facilitated the measurements of limiting currents at any desired electrode.

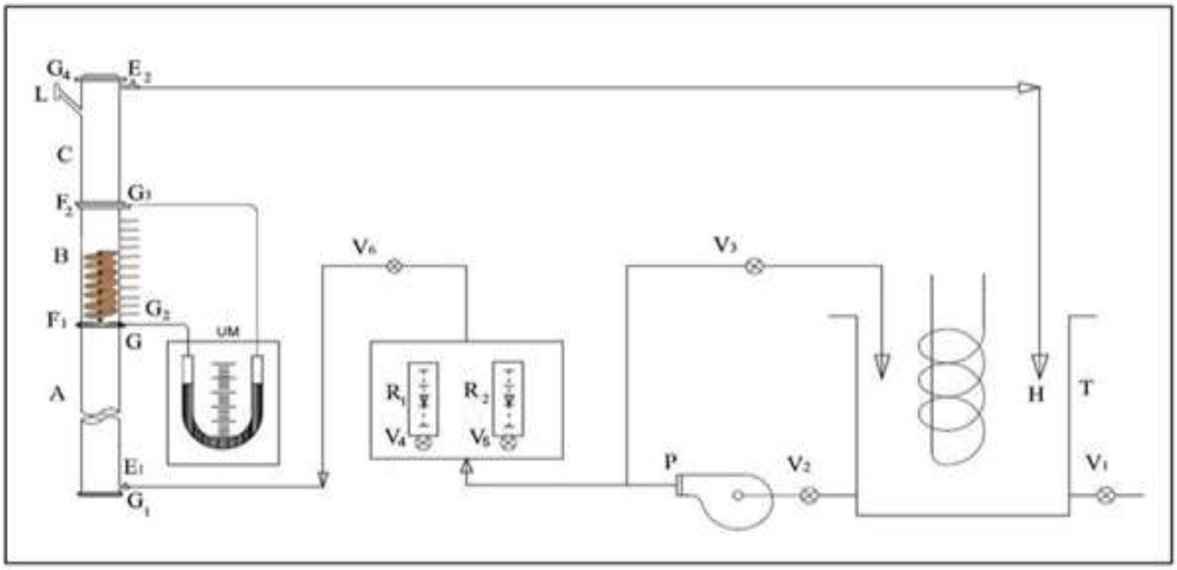

Figure 1 : Schematic Diagram of the Equipment

A : Entrance calming section; B : Test section;C : Exit calming section; F : Flanges; G_1, G_2, G_3, G_4 : Gland nuts; H : Coiled copper tubes; P : Centrifugal pump; R_1, R_2 : Rotameters; T:Recirculation tank; V_1-V_6: Valves; E_1-E_2 : Thermowell; G: Grid; L: Solid inlet port UM : U Tube Mano Meter

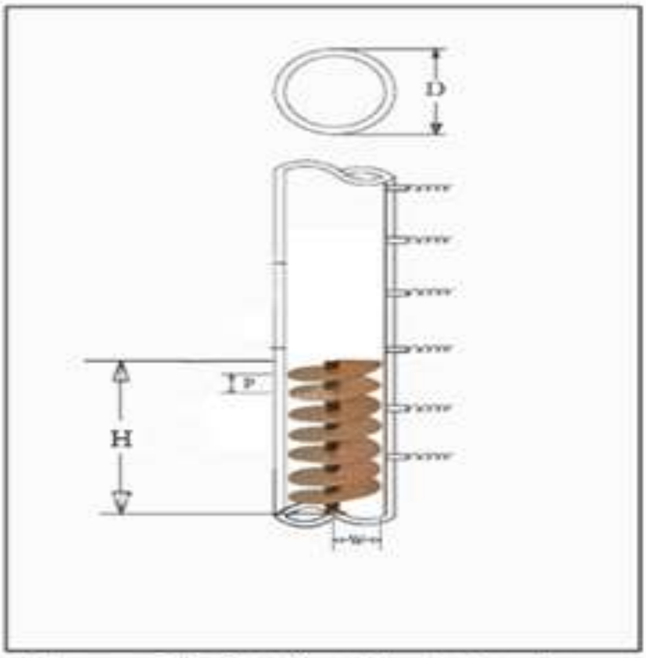

Figure .2 : Details of the test section

Table:1 Range of variables

Variable	Minimum	Maximum
Volumetric flow rate, $Q \times 10^5$ m^3/s	17.3	51.7
Pitch of the promoter,(P) m	0.01	0.04
Height of the promoter,(H) m	0.03	0.07
Width of the promoter,(W) m	0.02	0.04
Schmidt number, Sc	715.9	1054
Reynolds number, Re 4853	14533	

Table.2.Details of entry region spiral tape wound on rod promoters used in the present study

S.No	Height of the promoter, m	Width of the promoter, m	Pitch of the promoter, m
1	0.07	0.04	0.01
2	0.07	0.04	0.02
3	0.07	0.04	0.03
4	0.07	0.04	0.04
5	0.07	0.035	0.01
6	0.07	0.035	0.02
7	0.07	0.035	0.03
8	0.07	0.035	0.04
9	0.07	0.03	0.01
10	0.07	0.03	0.02
11	0.07	0.03	0.03
12	0.07	0.03	0.04
13	0.07	0.02	0.01
14	0.07	0.02	0.02
15	0.07	0.02	0.03
16	0.07	0.02	0.04
17	0.05	0.04	0.01
18	0.05	0.04	0.02

19	0.05	0.04	0.03
20	0.05	0.04	0.04
21	0.05	0.035	0.01
22	0.05	0.035	0.02
23	0.05	0.035	0.03
24	0.05	0.035	0.04
25	0.05	0.03	0.01
26	0.05	0.03	0.02
27	0.05	0.03	0.03
28	0.05	0.03	0.04
29	0.05	0.02	0.01
30	0.05	0.02	0.02
31	0.05	0.02	0.03
32	0.05	0.02	0.04
33	0.03	0.04	0.01
34	0.03	0.04	0.02
35	0.03	0.04	0.03
36	0.03	0.04	0.04
37	0.03	0.035	0.01
38	0.03	0.035	0.02
39	0.03	0.035	0.03
40	0.03	0.035	0.04
41	0.03	0.03	0.01
42	0.03	0.03	0.02
43	0.03	0.03	0.03
44	0.03	0.03	0.04
45	0.03	0.02	0.01
46	0.03	0.02	0.02
47	0.03	0.02	0.03
48	0.03	0.02	0.04

The limiting current data were obtained for the case of reduction of ferricyanide ion at the outer wall of a circular conduit with entry region spiral tape wound on rod as turbulence promoter in homogeneous flow.
Reduction of ferricyanide ion at cathode as presented below

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

Eighty liters of equimolal solutions of 0.01 N Potassium ferricyanide and 0.01N Potassium ferrocyanide with 0.5 N NaOH as excess indifferent electrolyte was prepared. Ferrocyanide ion concentration in the electrolyte was estimated by volumetric method using standard potassium permanganate solution[26] while the concentration of ferricyanide ion was estimated using idometric method [27]. The viscosity and density of the solution at different temperatures were measured with Ostwald Viscometer and specific gravity bottle respectively.The point electrodes in the test section were polished with four zero emery to get a smooth surface followed by degreasing with trichloroethylene solution. The size of the electrode was measured with a traveling microscope. After fixing the promoter in position, blank runs were conducted with only sodium hydroxide solution to ensure that the limiting currents obtained were due to diffusion of reacting ions (Ferricyanide ion) only.

The electrolyte was pumped at a desired flow rate (through the test section) by operating the control and by-pass valves. After the attainment of steady state, potential was applied across the test electrode and wall electrode in small increments of potential (100mV) and the corresponding current values were measured for each increment. As the area of the wall electrode was relatively large in comparison with the area of the test electrode, nearly constant potential was obtained at the test electrode. Since the potential values are not of criteria in the present study, the limiting currents were only measured from the current and potential data. The measurement of limiting current in the present study was adopted as in the earlier works [28-32]. The experiment was repeated by changing the flow rate of the electrolyte and the limiting currents were taken for each flow rate.

III MEASUREMENT OF LIMITING CURRENT

The plot of current versus potential data shows that the increase in potential increased the current up to certain value and further increase in potential maintained nearly the constant current value. This shows that for a sharp increase in potential a small increase in current was noted, which is the limiting current. Mass transfer coefficient was computed from the measured limiting current by the following equation:

$$k_L = \frac{i_L}{nF\,AC_o}$$

Pressure drop for each flow rate was measured simultaneously by using a U–tube manometer with Carbon tetrachloride as manometer liquid.

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IV RESULTS AND DISCUSSION

The experimental results shown in this section are mass transfer coefficient (k_L), friction factor(f), augmentation factor (k_L/k_{L0}), energy factor (E/E_0) and the performance index $\eta = (k_L/k_{L0})/(E/E_0)$ characteristics in a circular conduit equipped withentry region spiral tape on rod promoter as swirl generator. The experiment was done for a total number of fourty eight spiral tape wound on rod promoters having varying Heights pitches and widths. Prior to the experiments with promoters, the empty cell in the absence of spiral tape wound on rod promoter both momentum and mass transfer data were recorded for comparison. The data covered a wide range of Reynolds number (Re) between 4,853 and 14,533.

4.1 Effect of height of the promoter

A graph drawn for k_L versus velocity with height of the promoters as parameter is shown inFigure 1.The figureindicated that insertion of spiral tapewound on rod promoter at the entry region imparts swirl flow to the fluid. The swirl causes thorough mixing. As the fluid passes along the column reduces the thickness of the boundary layer by tractive shearing forces. The figure revealed mass transfer coefficient increase with the increase in velocity of the electrolyte for H values of 0.03 m and 0.07 m. Highest mass transfer coefficient was obtained for the promoter with the height (H) 0.07m, width(W) 0.04m and pitch(P) 0.04m and the enhancement in mass transfer coefficient is 13 fold at a velocity of 0.088m/s and that enhances to 11 fold at the velocity 0.2638m/s.

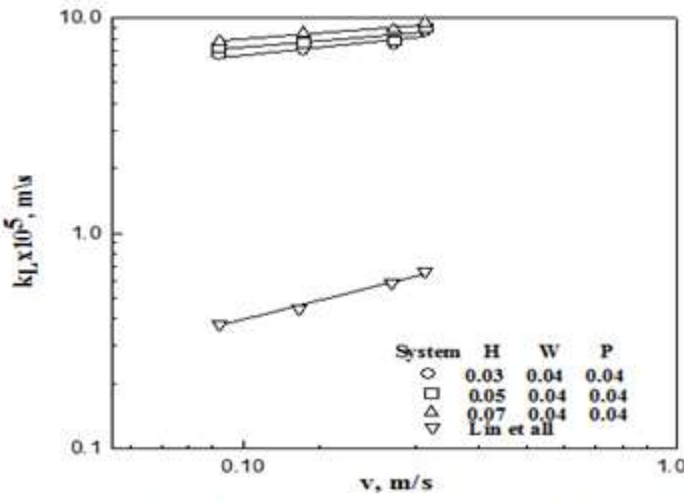

Fig. 3 . Effect of height on mass transfer coefficient

4.2 Effect of pitch of the promoter

The effect of pitch of the promoter on mass transfer coefficient is presented below. The mass transfer coefficients obtained for three different promoters with pitch values 0.01, 0.02, 0.03, 0.04m per turn are shown in figure 4. The figure depicts that the mass transfer coefficient values increased with decrease in pitch of the promoter but the increase is marginal. As the pitch decreases number of turns per meter increases resulting in more number of turns the fluid that passes imparts more swirl to the flow. The swirl in turn increases the mass transfer coefficient. If the pitch further decreases the distance between the turns become narrow at one point it becomes difficult to the flow pass through it because of high resistance due to the skin friction, consequently low turbulence and hence lower mass transfer rates result. The earlier workers [3-4] also reported such observations. Mass transfer values increased 8 to 13 times as the velocity varied from 0.2638m/s to 0.088 m/s. Maximum enhancement was observed for the promoter with the geometric parameters 0.07m height, 0.04m width, 0.04 m pitch while minimum augmentation was obtained for the tape with the geometry H = 0.07m, W = 0.04 m and P = 0.01 m pitch.

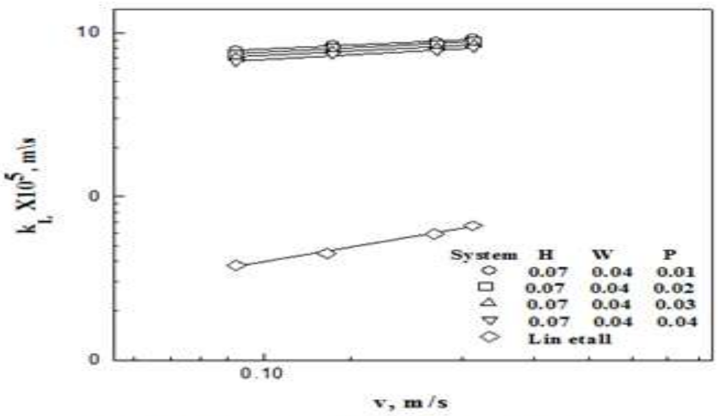

Fig. 4 . Effect of pitch on mass transfer coefficient

4.3Effect of width of promoter

A graph drawn for k_L versus velocity is presented as figure 5. The figure reveals the following information. Mass transfer coefficient is increased with velocity. The figure revealed the mass transfer coefficient increased with increase in width of the promoter. It is due to the drag offered by the promoter by which the axial flow of the fluid transforms into swirl flow. The swirl is largely responsible for the augmentation of mass transfer. Enhancement in mass transfer coefficient is ranged from 14 to 8 fold as the velocity increased from 0.088 m/s to 0.2638 m/s. Effect Pitch of pitch on mass transfer coefficient is presented as inset in fig. 5.4. As width of the tape varies from 0.02 m/turn to 0.04 m/turn, $k_L$values are enhanced to 0.4fold. Exponent on W is found to be 0.13.

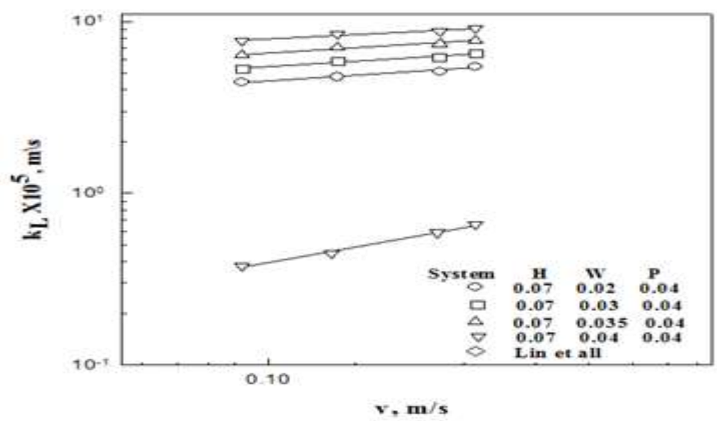

Fig.5. Effect of width on mass transfer coefficient

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4.4 Augmentation factor

The capacity of a promoter in enhancing the mass transfer coefficient can be evaluated using the augmentation factor (k_L/k_{L0}). It is the ratio of the mass transfer coefficient obtained due to the presence of the promoter to that of the mass transfer coefficient obtained in the absence of the promoter under the same flow conditions. The augmentation factor versus Reynolds number plots are drawn in figure 6. Plot A is the data for the promoter that has shown minimum augmentation in the present study. The turbulence promoter that has shown maximum augmentation within the range of variables covered is drawn as plot B. The augmentation factor ranges from 9 to 18folds at lower Reynolds number.

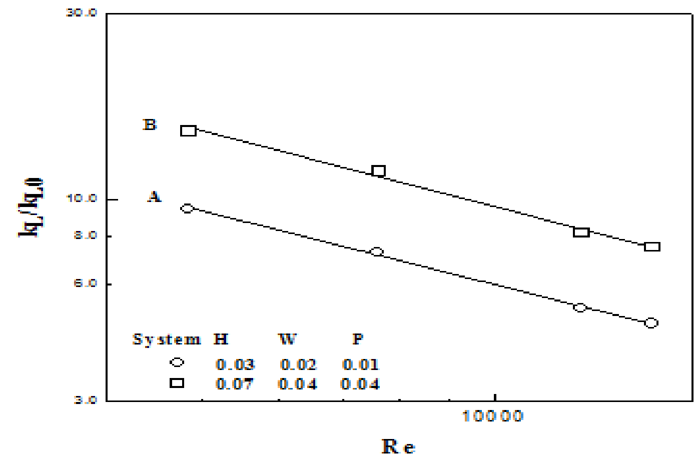

Fig. 6 . Augmentation factor versus Reynolds number

4.5 Comparison

The data of present study were compared with similar works of Prof. P. Rajendra Prasad[19] using spiral coil inserts in circular conduits, K.NagamalleswaraRao [17] twisted tape promoter in circular conduits as shown in figure 7. The results, when plotted as k_L/k_{L0} against Re for similar geometrical conditions, present study shown higher augmentation in mass transfer coefficients over others.

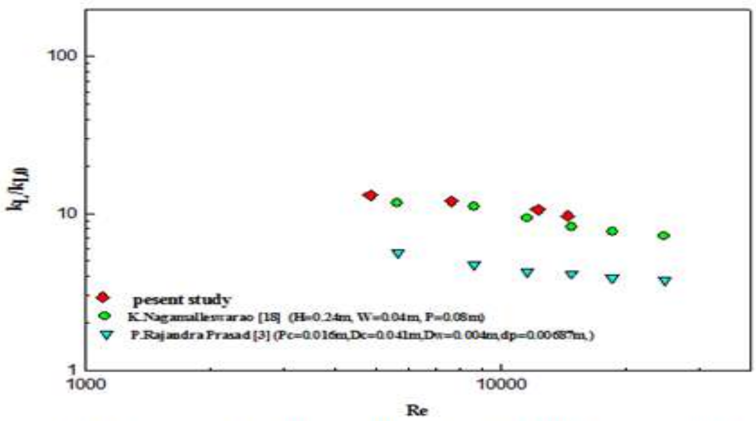

Fig. 7 . Comparision plot for augmentation for homogeneous flow

4.6 Effect of the Height on friction factor

The variation of friction factor with Reynolds number is shown in figure 5.8. The figure reveals friction factor values increasing with the increase in height of the promoter. The increase is low at lower velocities while is higher at higher velocities. As the length increases fluid elements gain intense swirl increasing centrifugal forces and the intensity of swirl becomes dominant resulting in higher frictional losses. Exponent on Re varies with height but marginal when height beyond 0.05 cm indicating the generation of intense turbulence.

Enhancements in friction rise to 19 to 24 folds for a Re of 4853 as height increases from 0.03 m to 0.07 m while that reduces to 13 to 26 folds at when Re reaches a value of 14533.

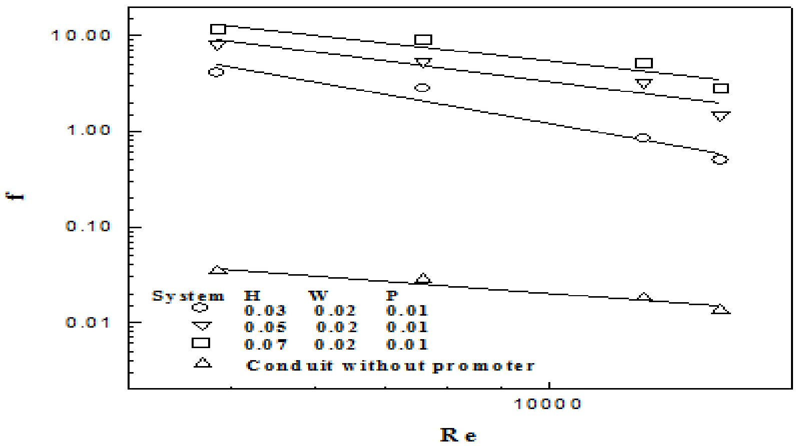

Fig. 8. . Effect of height on of friction factor

4.7 Effect of pitch on friction factor

The effect of pitch on friction factor is shown in figure 9. The figure reveals that the friction factor decreased with increasing Reynolds number and increased with decreased pitch of the promoter. As the pitch decreases the swirl component of the velocity increases resulting in increased skin friction and sliding friction between the fluid layers. The enhancement in friction factor is 18.5 to 22 folds at a Reynolds number of 4853 while tapered off to 11 to 22 as Reynolds number attains 14533. Exponent on Re decreasing with increase in pitch but the decrease become marginal as the pitch reaches 0.03 cm.

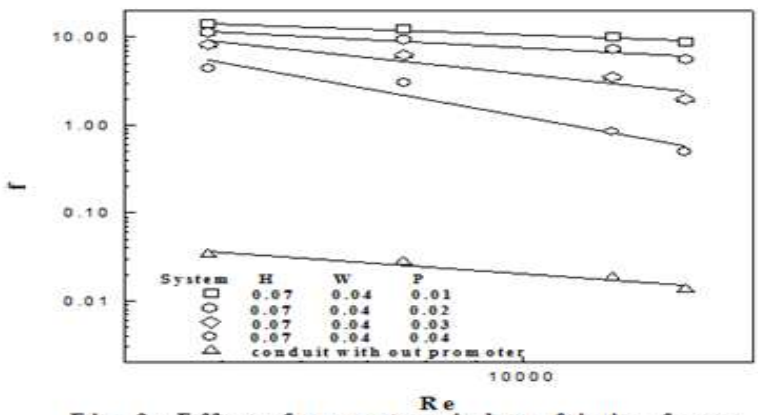

Fig 9 . Effect of promoter pitch on friction factor

4.8 Effect of width on friction factor

A graph is drawn for f versus Re and shown in figure 10. The figure reveal there is a decrease in friction with width, the decrease not uniform up to a width of 0.3 beyond which a marginal influence is observed. Enhancements of friction factor values range from 17 to 19 fold at a Reynolds number of 4853 while that tapered of 15 to 20 fold at a Reynolds number of 14533.

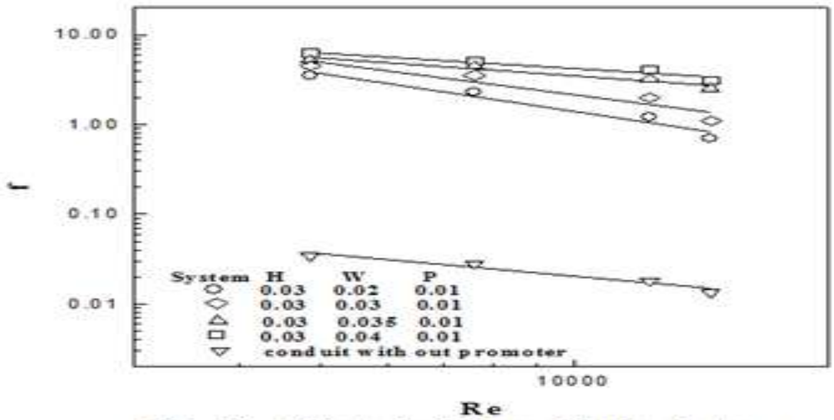

Fig. 10 . Effect of width on friction factor

4.9 Performance evaluation

Performance analysis is essential for the evaluation of net energy gain to ascertain whether the spiral tape wound on rod promoter chosen is efficient from the energy point of view. The comparison is made based on the same pumping power with a view of net gain.Performance index or efficiency of the promoter is defined as follows.

$$\eta = (k_L / k_{L0}) / (E / E_0)$$. or

$$\eta = (k_L / k_{L0}) / (f / f_0)^{1/3}$$

Figure 11. is a plot of performance index versus Reynolds number for two different promoters that shows maximum and minimum augmentation. The performance decreased with increase in Reynolds number. It is also increasing with width, pitch and height of the column.

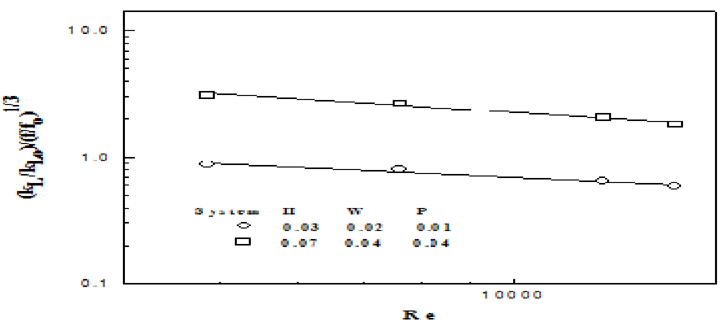

Fig.11 . Variation of performance index with Reynolds number

4.10 Mass and momentum transfer correlation

Present mass transfer and momentum transfer data is obtained for the various spiral tape wound on rod promoters, shown in table 2. The entire experimental data is correlated using regression analysis in terms of $\bar{g}$ (modified mass transferfunction), Re_m^+(modified Reynolds number), $R(h^+)$(Roughness function), The regression analysis of the data yielded the following equations.

Mass transfer correlations.

$$\bar{g} = 14315\left(Re_m^+\right)^{0.528}(P/D)^{-0.122}(H/D)^{-0.092}(W/D)^{-1.487}$$

Standard deviation of 7.72, while the average deviation of 6.21

Momentum transfer correlations.

$$R(h^+) = 0.2049\left(Re_m^+\right)^{0.412}(P/D)^{0.014}(H/D)^{-0.053}(W/D)^{0.128}$$

Average deviation = 3.35, Standard deviation = 4.39

V CONCLUSIONS

Mass transfer coefficients are increasing with velocity. Mass transfer coefficients are increased with increase in height (H), width (W) of the promoter and decreased with increase in pitch (P) of the spiral tape wound on rod promoter.The spiral tape wound of rod with geometric parameters 0.07m height, 0.04m width and 0.04m pitch given maximum augmentation within the range of variables covered in the present study. A maximum augmentation of 15 fold.Friction factor values are decreasing with Reynolds number. The enhancements in friction factors are up to maximum of 26folds over a tube flow with no promoter at low Reynolds number.Performance index decreased with increase in Reynolds number. Maximum performance index is obtained for the promoter with geometric parameters 0.07m height, 0.04m width, 0.04m pitch.Correlations were developed based on semi theoretical considerations. Wall similarity concept is used in the development of correlations.Within the range of variables covered in the present study a maximum efficiency obtained in 3.1.

Nomenclature for Tables

$\mu x10^4$ = Viscosity of the fluid, Kg/m-s

Sc = Schmidt number

P = Twisted tape pitch, m

H = Height of the promoter, m

W = Width of the promoter, m

P = Pitch of the promoter, m.

l = Length of the conduit, 0.044 m

C_0 = Concentration of the electrolyte, kg mol/m^3

g = gravity constant, m/s^2

V = Velocity of the fluid, m/s

k_L = Mass transfer coefficient, m/s

ΔP = Pressure drop, N/m^2

Re_m^+ = modified Reynolds number

$R(h^+)$ = Roughness function for Momentum Transfer

$\bar{g}$ = Mass Transfer function

Y_1 to Y_2= Correlation factors

REFERENCES

[1] C.S. Lin, E.B. Denton, H.S. Gaskill, G.L. "Putnam, Diffusion controlled electrode reactions", *Ind.Eng. Chem. 43/9 (1951) 2136-2143.*

[2] S. Yapici, G. Yazici, C. Ozmetin and H. Ersahan"Mass transfer to local electrodes at wall and wall friction factor in decaying turbulent swirl flow",*International journal of Heat and MassTransfer, 40(1997) 2775-2783.*

[3] Smith Eiamsa-ard, SarawutRattanawong, Pongjet Promvonge "Turbulent Convection in round tube equipped with propeller type swirl generators", *International Communications in Heat and Mass Transfer 36 (2009) 357–364.*

[4] H. Gul, D. Evin, "Heat transfer enhancement in circular tubes using helical swirl generator insert at the entrance", *International Journal of Thermal Sciences 46 (2007) 1297–1303.*

[5] Chinaruk Thianpong , Petpices Eiamsa-ard, Khwanchit Wongcharee, Smith Eiamsa-ard, "Compound heat transfer enhancement of a dimpled tube with a swirl generator", *International Communications in Heat and Mass Transfer 36 (2009) 698–704.*

[6] Sibel Gunes, Veysel Ozceyhan, Orhan Buyukalaca, "Heat transfer enhancement in a tube with equilateral triangle cross sectioned coiled wire inserts", *Experimental Thermal and Fluid Science 34(2010) 684-691.*

[7] Ponget Promvonge, Smith Eiamsa-ard, "Heat transfer augmentation in circular tube using V-nozzle turbulator inserts and snail entry", *Experimental Thermal and Fluid Science 32(2007)332-340.*

[8] P. Sivashanmugam , S. Suresh, "Experimental studies on heat transfer and friction factor characteristics of laminar flow through circular tube fitted with helical screw-tape inserts", *Applied Thermal Engineering 26 (2006) 1990–1997.*

[9] Siva Rama Krishna, Govardhan Pathipaka, P. Sivashanmugam, "Heat transfer and pressure drop studies in a circular tube fitted with straight full twist", *Experimental Thermal and Fluid Science 33(2009) 431-438.*

[10] P. Bharadwaj, A.D. Khondge, A.W.Date, "Heat transfer and pressure drop in a spirally grooved tube with twisted tape insert", *International Journal of Heat and Mass Transfer 52(2009)1938-1944.*

[11] Smith Eiamsa-ard, Panida Seemawute, Khwanchit Wongcharee, "Influences of peripherally-cut twisted tape insert on heat transfer and thermal performance characteristics in laminar and turbulenttube flows", *Experimental Thermal and Fluid Science 34 (2010) 711–719.*

[12] S.Eiamsa-ard, K.Wongcharee, P.Eiamsa-ard, C.Thianpong, “Heat transfer enhancement in a tube using delta-winglet twisted tape inserts”, *Applied Thermal Engineering 30 (2010) 310–318.*

[13] Smith Eiamsa-ard, Chinaruk Thianpong, Petpices Eiamsa-ard, Pongjet Promvonge, “Thermal characteristics in a heat exchanger tube fitted with dual twisted tape elements in tandem”, *International Communications in Heat and Mass Transfer 37 (2010) 39–46.*

[14] Shyy Woei Chang, Tsun Lirng Yang, Jin Shuen Liou, “Heat transfer and pressure drop in tube with broken twisted tape insert”, *Experimental Thermal and Fluid Science 32 (2007) 489–501.*

[15] Murali Mohan Vaka, “Studies on mass and momentum transfer with coaxially placed entry region coil,disc and coil-disc assembly as turbulence promoters in circular conduit”, *Ph.D., Thesis, Andhra University, Visakhapatnam, INDIA, 2008*

[16] Vaka Murali Mohan, C. Srinivasa Kumar, V. Sujatha, P. Rajendra Prasad, S. Sarveswarao, “Mass transfer correlation development for the presence of entry region coilas swirl promoter in tube”, *International Journal of Thermal Sciences 49 (2010) 356–364.*

[17] K. Nagamalleswara Rao, “Studies on mass transfer at the outer wall of a circular conduit with entry region twisted tape as turbulence promoter in homogeneous flow and in fluidized beds”, Ph. D., Thesis, *Andhra University, Visakhapatnam, INDIA, 2011*.

[18] Changal Raju, D “Augmentation of mass transfer at the outer wall of concentric annuli in absence and presence of fluidizing solids effect of wires wound on central rod”.*Ph.D. Thesis, Andhra University, Visakhapatnam, INDIA 1984.*

[19] Rajendra Prasad, P “Studies on ionic mass transfer with coaxially placed spiral coils as turbulence promoter in homogenous flow and in fluidized beds” *Ph.D Thesis, Andhra University, Visakhapatnam, INDIA. 1993.*

[20] Sujatha, V “Studies on ionic mass transfer with coaxially placed helical tapes on a rod in homo fluidized beds”*Ph.D. Thesis, Andhra University , Visakhapatnam, India, 1991.*

[21] Sujatha, V., Bhaskara Sarma, C and Jagannadha Raju, G, J, V “Studies on ionic mass transfer with coaxially placed helical tapes on a rod in forced convection flow” *Chemical Engineering and Processing J, Vol 36/1, Feb 1997, pp 67-73.*

[22] Rajendra Prasad, P., Sujatha,V., Sarma, C, B and Raju, G, J, V, J“Studies on ionic mass transfer with coaxially placed spiral coils as turbulence promoter in homogenous flow and in fluidized beds” *Chemical Engineering and Processing J, vol 43, 2004, pp 1055 -1062.*

[23] K.V.Ramesh, G.M.J.Raju, M.S.N.Murthy, C.Bhaskara Sarma, “ Wall to bed mass transfer in three phase fluidized beds in the absence and presence of a composite promoter”, *Chemical engineering journal 152(20090207-211.*

[24] T.Ravi, B.Srinivasa Rao, P.Gopala Krishna, P.Venkateswarlu, “Ionoic mass transfer studies in fluidized beds with coaxially placed discs on rod as internal”, *Chemical engineering and processing, vol35(1996)pp187-193.*

[25] P. Ravi, N. Ravan, P. Gopala Krishna, P. Venkateswarlu, “Ionic mass transfer at a vibrating electrode support in an electro winning cell”, *Hydrometallurgy 60,2001.69–79.*

[26] Rajendra Prasad, P., Sujatha,V., Bhaskar Sarma, C and Raju, G, J, V, J "Studies on ionic mass transfer with coaxially placed spiral coils as turbulence promoter in homogenous flow and in fluidized beds"Chemical Engineering and Processing Journal, vol 43, 2004, pp 1055 -1062.

[27] Venkateswarlu, P. "Studies on ionic mass transfer with co axially placed discs on a rod as turbulencepromoter" Ph.D., Thesis, Andhra University, Visakhapatnam, INDIA, 1987.

[28] Sujatha, V "Studies on ionic mass transfer with coaxially placed helical tapes on a rod in homo fluidized beds"Ph.D. Thesis, Andhra University , Visakhapatnam, India, 1991.

[29] Sujatha, V., Bhaskara Sarma, C and Jagannadha Raju, G, J, V "Studies on ionic mass transfer with coaxially placed helical tapes on a rod in forced convection flow" Chemical Engineering and Processing Journal, Vol 36, Iss1, 1997, pp 67-73.

[30] Nageswara Rao, V. "Studies on ionic mass and momentum transfer with co axially placed Twisted tape-discassembly as turbulence promoter in circular conduits' Ph.D.,Thesis, AndhraUniversity, Visakhapatnam, INDIA, 2004.

[31] MuraliMohanVaka"Studies on mass and momentum transfer with coaxially placed entry region coil,disc and coil-disc assembly as turbulence promoters in circular conduit" Ph.D., Thesis, AndhraUniversity, Visakhapatnam, INDIA, 2008.

[32] K. Nagamalleswara Rao, "Studies on mass at the outer wall of a circular conduit with entry region twisted tape as turbulence promoter in homogeneous flow and in fluidized beds", Ph. D., Thesis, *Andhra University, Visakhapatnam, INDIA, 2011*.