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# Momentum Transfer In Square-Grooved Serrated Disc Inserted Tube

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**ABSTRACT**

Results are presented from experimental investigation on the effect of coaxially placed entry region square grooved serrated disc as turbulence promoter on momentum transfer rates in circular tubes. The study covered a wide range of variables such as flow rate of electrolyte, 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 friction factor increased with increase in 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). A similarity law approach was attempted to interpret the friction results and correlate them in terms of *momentum transfer roughness function* $R(h^+)$ and *roughness Reynolds number*($Re^+$). The correlation which was developed could be extended to a wider range of variables by virtue of law of wall similarity. The following correlation was reported out of the study. $R(h^+)=0.1046 \times 10^{-10}(Re^+)^{2.9320} (\phi_1)^{-4.478} (\phi_2)^{-0.3066} (\phi_3)^{-0.7725}$

**KEYWORDS:** Fluid friction, momentum transfer, square grooved serrated disc, insert promoter

## 1. INTRODUCTION

The role played by rough surfaces in fluid mechanics and mass transfer has been of interest for a long time. On the other hand this interest has been for practical reasons because of the increase in friction and mass transfer rate associated with rough surfaces. In earlier studies effect of roughness on friction factor and velocity distribution was done by Nikuradse [1] for sand grain roughness. Cope [2] studied heat and momentum transfer for roughness elements. Nunner [3]studied heat and momentum transfer in rough pipes. Friction and heat transfer measurements for repeated rib roughness in tube flow was done by Sams [4], Burnett[5], Koch[6]. Webb, Eckert and Goldstein [7] conducted experiments using tube with internal pins and correlated their data in terms of *roughness Reynolds number* ($Re^+$) and *roughness momentum transfer function* $R(h^+)$. Dipprey and Sabersky[8] analyzed their data in terms of *roughness function* for their experimental study. Sethumadhavan and Raja Rao[9] conducted experiments for heat and momentum transfer for the tubes with tightly fitted helical wire coils.

Most of the works mentioned above utilized wall similarity concept and correlated their data in terms of *roughness function* and *roughness Reynolds* number by assuming two regions namely viscous region close to the wall of the tube and turbulent region which existed in the turbulent core away from the surface of tube. The same two-region flow assumed in this study due to the presence of disc across the flow in the tube which generated turbulent core flow and viscous flow at the wall. The bluff bodies like co-axially placed serrated discs would augment mass and momentum transfer rates considerably. This was due to wakes and eddies generated by them. An attempt was made to correlate the data in terms of $R(h^+)$ and $Re^+$ using the following type of analysis. Range of variables covered in this study were presented in the table 1

**Table:1**

| Variable Minimum | maximum | Max/Min |
|---|---|---|
| Diameter of 0. 025 the disc, ($d_d$), m | 0. 045 | 1. 8 |
| Disc thickness, 0. 001 ($d_t$), m | 0. 005 | 5 |
| Distance of the 0. 10 disc from the entrance of the test section, (h), m | 0. 26 | 2. 6 |
| Velocity, V, m/s 0. 03289 | 0. 3289 | 10 |
| Reynolds number, Re | 1933 | 19337 |

## 2. EXPERIMENTAL PROGRAMME:

The experimental setup used for the study was similar to those used in earlier studies[10, 11, 12]. Schematic diagram of experimental set up was shown in figure 1. It was 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 was 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 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(V2). The discharge line from the pump was split into two. One served as a bypass line and controlled by valve (V3). The other connected the pump to the entrance calming section (E1) through Rotameter. The Rotameter was connected to a valve (V4) for adjusting the flow at the desired value. The Rotameter had a range of 0 to $475x10^{-6}$ m3/s. The entrance calming section consisted of 0. 05 m ID circular copper pipe with a flange and was closed at the bottom with a gland nut(G). The up-stream side of the entrance calming section was filled with capillary tubes to dampen the flow fluctuations and to facilitate steady flow of the electrolyte through the test section. The test section was made of a graduated perplex tube of 0. 64m length 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. They were fixed flush with the inner surface of the test section at equal spacing of 0. 01m. Exit calming section was also of the same diameter copper tube of 0. 5 m long and it was provided with a flange on the upstream side for assembling the test section. It had gland nuts ($G_{4,}$ $G_3$) 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. Square grooved serrated disc serving as turbulence promoter was made of copper of various sizes with a provision to fix it rigidly within the test section. The limiting current measuring equipment consisted of multimeter of Motwane make which had 0. 01 mA accuracy and vacuum tube voltmeter was used for potential measurements. The other equipment used in circuit were 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.

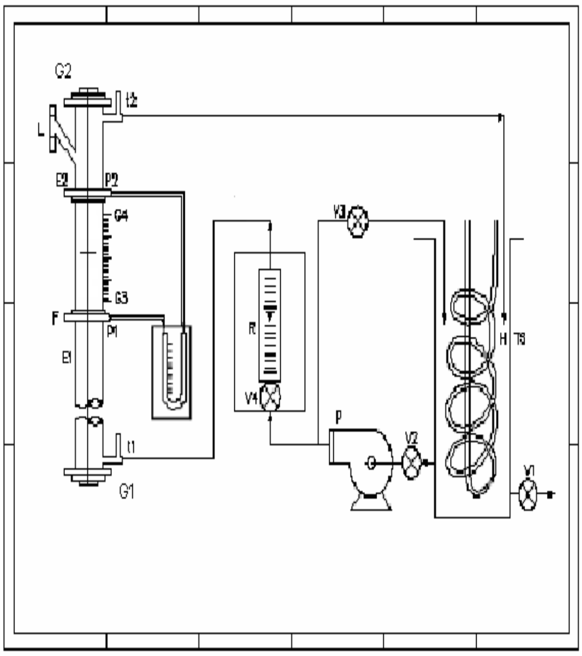



**Figure 1: Schematic Diagram of Experimental Setup**

The following electrode reaction was involved in the study.
Cathodic reduction of ferricyanide ion:

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

Equimolal solution of 0. 01 M Potassium ferri-ferrocyanide couple was chosen along with 0. 5N NaOH were prepared. The point electrodes fixed flush with surface of the wall of the cell were used to obtain limiting currents. Initially blank runs were conducted with 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. On attainment of steady state, potentials were 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 wall electrode in relation to the test electrode nearly constant potential was maintained at the test electrode. The limiting currents were obtained from the measurements of
applied potential and current as had been done in several earlier works[10, 11, 12]. The attainment of limiting current was indicated by the constancy of current with a large increase in the potential.
Pressure drop measurements were taken using an U-tube manometer with Carbon tetrachloride as manometric liquid.

## 3. RESULTS

An attempt is made to know momentum transfer data which is derived by measuring pressure level by U-tube manometer with pressure taps placed on either side of the test section. For the measured pressure level, effective friction losses are calculated by the following equation.

$$\Delta P = (\rho_{ccl\,4} - \rho_{electrolyte})(g/g_c)\, h \qquad (2)$$

$$F = \Delta P d.\ g_c / 2.\ L.\ \rho.\ V^2 \qquad (3)$$

In the present study energy losses are due to skin friction offered by the wall in addition to from friction offered by disc.
Table 2 indicated the friction factor obtained in this study together with the other works. The friction factors obtained were comparable to other studies with different turbulence generating systems.

**Table 2**

| Author | Promoter | Friction factor | Range of Re |
|---|---|---|---|
| T. S. Sitaraman [11 ] | String of spheres | 0. 333-0. 131 | 1000-34000 |
| Yapici et al [14 ] | Swirl generators angles with duct axis | | 8900-27000<br>8900-27000 |

| | | | |
|---|---|---|---|
| This work | $15^0$-$45^0$<br>$60^0$-$70^0$<br>square-grooved serrated disc | 0. 042-0. 031<br>0. 243-0. 117<br>0. 284-0. 168 | 1933-19337 |

***EFFECT OF PARAMETERS***

**Effect of disc diameter ($d_d$):**

A graph is drawn for the friction factor versus Reynolds number and is shown in figure 2. Disc diameter is varied from 0. 025m, 0. 030m, 0. 035m, 0. 040m and 0. 045m and the corresponding pressure drop and friction factor values are calculated. As the disc diameter increased, friction factor is also increased. Disc diameter has strong influence on friction factor because of form friction generated in the column together with the skin friction.

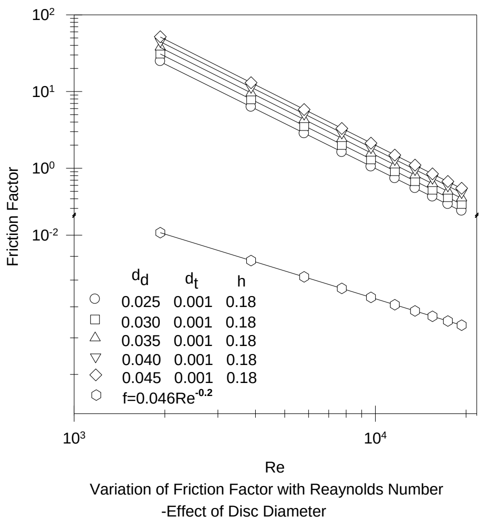
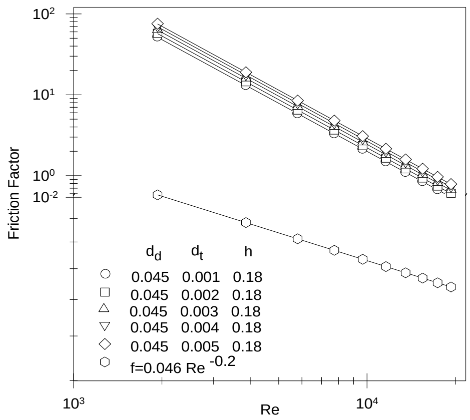



**Figure 2:**

**Effect of disc thickness ($d_t$):**

The variation of friction factor with Reynolds number for studying the effect of thickness of the disc ($d_t$) is shown in figure 3. The friction factor increases with increase in thickness of the disc. The increase in friction factor is from 85. 82 times to 123. 20 times over smooth tube values of [13] as the thickness of the disc increases from 0. 001 to 0. 005m at the velocity of 0. 3289m/s.

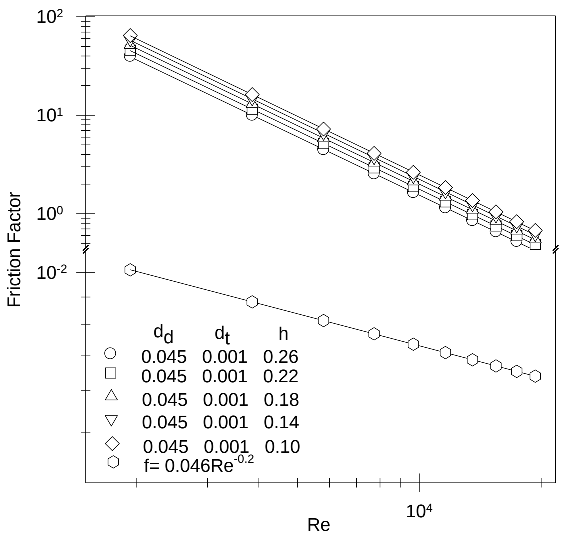
Effect of distance of the serrated disc from the entrance of the test section(h)**:**




Variation of Friction Factor with Reaynolds Number
-Effect of Disc Thickness

**Figure 3:**

A graph is drawn for friction factor ‘f’ against Reynolds number (Re) for the set of geometric parameters $d_d$=0. 045m, $d_t$=0. 001, for various ‘h’ values and is shown in figure 4. The graph reveals that the friction factor increases as ‘h’ decreases. The enhancement in friction factor from 66. 86 times to 105. 83 times over smooth tube values[13] as the ‘h’ decreases from 0. 26m to 0. 10m. it is observed that 0. 10m distance is suitable for better performance




Variation of Friction Factor with Reynolds Number
-Effect of Distance of the Disc from Entrance of the Test Section

**Figure 4:**

**4. CORRELATION DEVELOPMENT:**

Flow of electrolyte through a conduit with square-grooved serrated disc placed across the flow of fluid generated eddies and wakes caused turbulence in the vicinity of the disc and extends to the wall, to the upstream section of flow and also to the downstream section of disc. As a result of these flow fields, the flow was fully turbulent causing a turbulent core, the central region of tube and viscous flow, very near the wall of tube. From the measured pressure drop data, friction factor f was calculated using the equation (3).

An attempt was made as per the conventional procedure of [10, 12] to correlate friction factor with Reynolds number including dimensionless geometrical groups,

$f=0.1899\times10^{9}\ Re^{-1.9722}(\phi_1)^{1.2864}(\phi_2)^{0.1996}(\phi_3)^{0.5025}$ (4)

Average Deviation =22. 18

Standard Deviation=22. 79

But this showed large deviation. So an attempt was made to correlate the data in terms of $R(h^+)$ and $Re^+$ using the following type of analysis. The basic similarity concept assumed the existence of two regions mentioned earlier, namely, (i) the inner region near wall where the velocity distribution depended exclusively on the local conditions like y, $\tau_w$, $\mu$ and (ii) the outer region away from the wall where direct effect of viscosity on mean flow was negligible. For the inner region near the wall, the dimensionless velocity was given as

$u^+ = y^+$

where $u^+ = u/u^*$, $y^+ = y\,u^*/\nu$ (5)

For the outer wall region where the dependency of velocity distribution on molecular viscosity ceased to exist, the velocity distribution would follow the relationship

$u^+=1/k.\ \ln y^+ + c_1$ (6)

By the application of boundary conditions u=0, $y=y_0$ where $y_0$ was the thickness of laminar sub layer that would depend on the turbulence generated, equation (5) reduced to

$u^+ =1/k\ \ln(y/y_o)$ (7)

The turbulence in the core and at the wall was significantly affected by the geometric parameters of the promoters employed in addition to the fluid velocity. In this case, length of tape ($T_L$) was the major characteristic geometric parameter as this was expected to be significantly effect the thickness of the laminar sub layer. In this study the parameter $d_d$ was chosen while computing $u^+$

therefore, $y_o \propto d_d$ (8)

Equation (7) could be modified as

$(u_{max}-u)/u^* =1/k\ \ln(y/d_d)$ (9)

Combination of equations (6) and (9) would give the velocity distribution equation for the turbulent dominated part of the wall region

$u^+=2.5\ln(y/d_d) + R(h^+)$ (10)

The above equation presented modified velocity profile for the case of two regions in the presence of promoters. Assuming that equation (9) held good for the entire cross section of the tube, the friction factor for the turbulent flow inside tube with twisted tape could be given by integration of equation (9). Thus the friction similarity law for rough surfaces could be represented by

$R(h^+) = 2.5\ln[2\, d_d/d)] + \sqrt{(2/f)} + 3.75$ (11)

Where $R(h^+)$ is *roughness momentum transfer function*

The turbulent flow induced by the promoter was also found to be affected by geometrical parameters of serrated disc. The resulting format of equation for correlating the momentum transfer data with square grooved serrated disc as promoter could now be written as

$R(h^+) = c_1 . (Re^+)^{b1}$ (12)

Here, $c_1$, $b_1$ were proportional constant and exponent respectively

$Re^+$ was *roughness Reynolds number* defined by the following equation

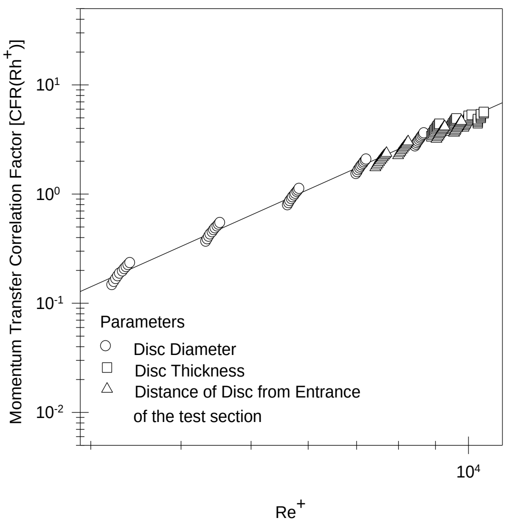
$Re^+ = (d_d/d) . Re . (\sqrt{f/2})$ (13)

By using *roughness momentum transfer function*($R(h^+)$) in place of friction factor and *roughness Reynolds number* ($Re^+$) in place of Reynolds number, the following correlation was obtained by regression analysis.

$R(h^+) = 0.1046 x 10^{-10} (Re^+)^{2.9320} (\phi_1)^{-4.478} (\phi_2)^{-0.3066} (\phi_3)^{-0.7725}$ (14)

Average deviation =13. 186, Standard deviation =14. 759

Figure 5 indicated the correlation plot for equation (14)




Correlation plot for equation 14

**Figure 5**
**:**

**Comparison of correlations:**

For a selected set of geometric parameters correlation factor for momentum transfer ($Y_1$) is plotted against Re+. For comparison of data with the other studies, Nageswara Rao [15]data having comparable geometric parameters, is computed with the present method is shown and plotted as figure6. The data falls close to the present study indicating correlation presented in the present work is comparable and better correlating.

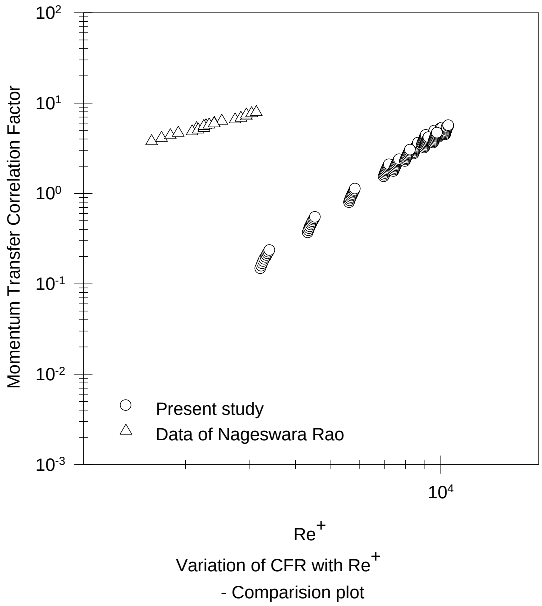



**Figure 6:**

**Figure7:Turbulence Promoters**

## 5. CONCLUSIONS:

Based on data of friction factor against Reynolds number, one can carefully analyze frictional losses with geometric parameters. Correlation presented in the this study is developed by empirical approach. This is valid for the range of variables covered in this study, but probably capable of predicting data at higher ranges. The data generated and correlation developed are helpful in the design of efficient electrolytic cells which are used for various applications like organic synthesis etc.

**Nomenclature:**

| | | |
|---|---|---|
| Re | = | Reynolds number = $dV\rho/\mu$ |
| $Re^+$ | = | Roughness Reynolds number = $(d_d/ d). Re. \sqrt{f/2}$ |
| $R (h^+)$ | = | Roughness momentum transfer function = $2. 5\ln(2d_d/d)+\sqrt{(2/f)}+3. 75$ |
| $u^+$ | = | dimensionless velocity, $u/u^*$ |
| $y^+$ | = | dimensionless radial distance from the wall, $y u^*/\nu$ |
| d | = | Diameter of test section, m |
| $D_L$ | = | Diffusivity of reacting ion, $m^2$/sec |
| f | = | Friction factor, $\Delta p\, d\, g_c /2LV^2 \rho$ |
| $\Delta P$ | = | Pressure difference, $N/m^2$ |
| g | = | Acceleration due to gravity, $m/sec^2$ |
| $g_c$ | = | Gravitational constant. |
| L | = | Length of Test section, m |
| 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 |
| $Y_1$ | = | $R(h^+) / (d_d/d)^{-4. 478} (d_t/d)^{-0. 3066} (h/d)^{-0. 7725}$ |

**Greek letters:**

| | | |
|---|---|---|
| $\phi_1$ | = | $(d_d/d)$ =Dimensionless group |
| $\phi_2$ | = | $(d_t/d)$ =Dimensionless group |
| $\phi_3$ | = | $(h/d)$ =Dimensionless group |
| $\mu$ | = | Viscosity of fluid, Kg/m. sec |
| $\nu$ | = | Kinematic viscosity, $m^2/s$ |
| $\rho_c$ | = | Density of manometer fluid, $Kg/m^3$ |
| $\rho$ | = | Density of fluid, $Kg/m^3$ |
| $\tau_w$ | = | Shear stress, $N/m^2$ |

**REFERENCES:**


[1] Nikuradse, J. Laws of Flow in Rough Pipes. 1933, VDI FORSCH-Heft 361(1933)

[2] Cope, W. F. The friction and heat-transmission coefficients of rough pipes,

Proc. Inst. Mech. Engrs., 145, vol. 99(1941)

[3] Nunner, W. Heat transfer and pressure drop in rough tubes, UKAEA Translation AERE Lib /Trans,, 786, (1956)

[4] Sams, E. W. Heat transfer and pressure drop characteristics of wire-coil type turbulence promoters, USAEC Reactor Heat Transfer Conference, (1956)

[5] Burgoyne, I. B., Burnett, P. and Wilkie, D. Forced convection heat transfer data from surfaces roughened by transverse ribs, UKAEA, TRG Report 781 (W) (1964)

[6] Koch, R. VDI-Forscht, Series B, 241(1958)

[7] Webb, R. L., Eckert, E. R. G. and Goldstein, R. J. Int. J. Heat and Mass Transfer, vol. 14, pp601-617(1971)

[8] Dipprey, D. P. and Sabersky, R. H. Heat and Momentum Transfer in smooth and rough tubes at various Prandtl numbers Int. J. Heat and Mass Transfer, vol. 6, pp329-353(1963)

[9] Sethumadhavan, R. and Raja Rao, M. Turbulent flow heat transfer and fluid friction in helical wire coil inserted tubes, Int. J. Heat and Mass Transfer, vol. 26, pp 1833-1845(1983)

[10] P. Venkateswarlu, T. Gopichand, G. J. V. J. R ajuIncreased mass transfer in a circular column in the presence of disc promoter" J. Energy Heat Mass Transfer, 22, pp195-203(2000)

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

[12] S. Sarveswara Rao, G. J. V. J. Raju Studies on Ionic Mass Transfer with co-axially placed cones on a rod in homogeneous fluid and fluidized beds" Paper presented at World Congress III of Chemical Engineers, Tokyo, p481, (1986)

[13] Warren L. MacCabe, JulianCSmith, Peter Harriot, Unit Operations of Chemical Engineering, 5thed., McGrawHill, NewYork, p-100(1993)

[14] S. Yapici, G. Yazici, C. Ozmetin, H. Esahan andO. Comakli Mass transfer to local electrodes at wall and wall friction factor behavior in decaying decaying turbulent swirl flow Int. J. Heat Mass Transfer, Vo. l40, pp. 2775-2783, (1997)

[15] Nageswara Rao V. and Chitti Babu, N. Analysis of momentum transfer with coaxially placed disc as turbulence promoter in circular conduits, IUP Journal of Chemical Engg., (2008)