## Studies on Momentum Transfer with Coaxially Placed Disc as Turbulence Promoter in Tubes

***Sujatha, V*[3]*., Vaka Murali Mohan*[1]*., C. Srinivasa Kumar*[1]*., Ahmad.J Rusumdar*[2]*., Sarveswara Rao, S*[3] *and Rajendra Prasad, P*[3*]**

*1. RRS College of Engineering and Technology., Mutangi, Patancheru, Hyderabad, A. P, INDIA*

*2.* Leibniz Institute for Tropospheric Research, Permoserstr, Leipzig , Germany

*3. Chemical Engineering Dept., A U College of Engg., Visakhapatnam-03, A P, INDIA.*

**ABSTRACT**

Studies on momentum transfer with coaxially placed disc as turbulence promoter in tubes have been presented in this paper. The electrolyte is equimolal Potassium ferricyanide, Potassium Ferro cyanide and excess sodium hydroxide. The friction correlation is based on law of the wall similarity. The variables covered in this study are the flow rate of the electrolyte, the geometric parameters of the promoter – disc diameter from 0.02 m to 0.04m, height of the disc from 0 to 0.50 m, Reynolds number varies from 1200 to 12,500. The friction factor due to presence of the disc is significant in the fully developed turbulent region and it is 2 to 12 folds over the smooth tube flow. The friction factor decreases with increase in Reynolds number. The friction factor increases with increasing disc diameter. The friction factor increases to a maximum and then decreases with increasing height of the disc. A model was developed for momentum transfer function in terms of geometric parameters and presented.

$$R(h^+) = 7986.4\ [\mathrm{Re}_m]^{-0.85} \left(\frac{d_d}{D}\right)^{-0.29} \left(\frac{H_d}{D}\right)^{0.01} \left(\frac{V^2}{D\,g}\right)^{0.44}$$

**Keywords:** turbulence promoter, circular conduits, friction factor, semi theoretical model, Reynolds number, enhancement.

## 1. Introduction

Several works on heat and mass transfer operations have been conducted for the augmentation process to minimize the equipment size and to maximize profit. The enhancement process invariably associated with increase energy losses which are to be monitored. The data will be useful in design and development of such operations and for the

* Prof. Dr. P. Rajendra Prasad
Department of Chemical Engineering
A U College of Engineering, Visakhapatnam - 03, A P, INDIA
E-mail : murali_vaka@yahoo.com, Tel. Ph no. 91-891- 2844899. Fax no: 91-891-2747969

optimization but the necessary data has not been developed. Therefore the present work has been undertaken to produce the necessary data and to develop model which is based on semi theoretical analysis.

Coaxially placed disc across the flowing fluid in a circular conduit alters the flow pattern due to obstruction. The disc diverts the axial flow to radial as result of creeping flow. The flow after passing the disc stabilizes to axial flow. Wakes and eddies are generated on the rear side of the disc. These wakes generate intense turbulence in the flow. The disc predominantly generates the form friction hence the flow becomes more turbulent.

The following are some investigations which use turbulent promoter for the augmentation of transfer process. Venkateswarlu and Raju [1] obtained momentum transfer data with co-axially placed discs on a central rod. Nageswarao [2] studied mass and momentum transfer with coaxially placed twisted tape–disc assembly as turbulence promoter in circular conduits. Both the investigations [1 and 2] are employed with 0.01 M equimolal Potassium ferricyanide, Potassium Ferro cyanide and 0.5N sodium hydroxide as an electrolyte. Paisarn Naphon [3] investigated the heat transfer characteristics and the pressure drop of the horizontal double pipe with coil-wire insert. Sheriff and Gumley [4] investigated the heat-transfer and friction characteristics of a surface with discrete rough nesses. Lodh et al [5] explains the effect of spiral coils and twisted tapes as augmentators on heat and momentum transfer with gas solid mixtures. Frank Kreith and David Morgolis [6] employed coiled wires and twisted tapes as turbulence generating devices in their heat and momentum transfer studies. Smith Eiamsa-ard et al [7] investigated heat transfer and friction factor characteristics in a double pipe heat exchanger fitted with regularly spaced twisted tape elements. Ventsislav Zimparov [8] predicted the friction factors for the case of a fully developed turbulent flow in a spirally corrugated tube combined with a twisted tape insert. Eiamsa-ard and Promvonge [9] studied the effects of V-nozzle inserts on heat transfer and friction characteristics in a uniform heat flux tube.

Data on momentum transfer in circular conduits coaxially placed disc as turbulence promoter have been taken up since the data on the present system has not been reported in literature. The effect of diameter of the disc and the location of the disc on momentum transfer is envisaged. When the length of the test section is fixed the possible loss of pressure could vary considerably with the location of the disc. The data and model developed in study will be useful in the design of efficient electrochemical cell in particular and any transfer operation in general.

## 2. Experimentation

The schematic diagram of the experimental set up is shown in Fig.1.The equipment essentially consists of a re-circulating tank, a centrifugal pump, a rotameter, an entrance calming section, a test section, and an exit calming section. The pressure tapes at the two ends of the test section and connected to a U tube manometer. The manometric fluid is $CCl_4$. The promoter is mounted in the test section coaxially by means of gland nuts. After inserting the promoter in the column, hundred liter of the electrolyte consisting of 0.01 M potassium ferricyanide, 0.01 M potassium ferrocyanide, and 0.5N sodium hydroxide is prepared in the storage tank. The electrolyte is Newtonian, not so dangerous and it has density of 1023Kg/$m^3$. The required flow rate of the electrolyte is adjusted by operating the control and by pass valves. The experiments are repeated by varying the disc diameter ($d_d$), location of the disc ($H_d$) and corresponding pressure drops are noted down. The experiment is based on 216 pressure drop measurement. Effective friction factor is calculated from measured pressure drops. The information is highly useful in the design and development of energy efficient transfer operations in general mass transfer in particular. The range of variables covered is given in Table 1.

## 3. Results

The momentum transfer with disc inserted in tube flow is merger. Experimental plan is envisaged to observe the effect of disc placed in the conduit with specific attention of process. Disc placed at different position in a conduit of 0.58 m test section is studied. Pressure loss is measured by using U- tube manometer; effective friction factor was computed by the following equation

$$f = \frac{\Delta P D g_c}{2 L V^2 \rho} \tag{1}$$

Based on the data of friction factor versus Reynolds number, frictional losses with geometric parameter are analyzed the $f_0$ value is predicted from $f_0 = 0.046\,\mathrm{Re}^{-0.2}$.

***Effect of disc diameter***

Three different sizes of discs were used for the present work. The variation of the size of the disc is limited by the conduit diameter. Disc of 0.04, 0.03, 0.02 m diameter sizes are placed in the column and the corresponding pressure loss and friction factor values are calculated. The variation of $f/f_0$ versus Reynolds number is drawn and shown in Fig.2. The plots reveal that the $f/f_0$ decreases with increase in Reynolds number. The augmentation achieved is 10 folds when the diameter of the disc is 0.04 m. The effect of friction factor on disc diameter is shown in Fig.3 and the plots reveal that the friction factor increases with increasing disc diameter.

***Effect of location of the disc***

The location of the disc is affecting the pressure loss because of the following region. Pressure loss decays as we move away from the disc on either side of the disc due to decaying turbulence. The turbulence is maximum when the disc is placed in the middle of the test section as it includes more turbulence region on either side where as if the disc is placed on either end of the section which includes only one part of the turbulence decaying section with marginal variation due to change in flow patterns. The location of the disc is the distance between the disc and from the starting of the test section. 0, 0.25, 0.50 m locations are chosen in this study. The variation of $f/f_0$ versus Reynolds number is drawn and shown in Fig.4. The plots reveal that $f/f_0$ decreases with increase in Reynolds number. The augmentation achieved is 10 fold when the location of the disc is 0.25 m. The effect of friction factor on location of the disc is shown in fig.5. The figure reveals friction factor increases to a maximum and then decreases with increasing location of the disc.

**4. Model development**

An important group of passive augmentation methods from the flow devices which coaxially placed disc as turbulent promoter is important. Conventional f– Re type correlations have been attempted to correlate the present data using the following format of equation.

$$f = C\,\mathrm{Re}^{m}(\Phi_1)^{n_1}(\Phi_2)^{n_2}(\Phi_3)^{n_3} \qquad (2)$$

where $\Phi_1$, $\Phi_2$, $\Phi_3$ are the geometric parameters.

correlation for the data of flow through smooth circular conduit.

$$f = 10.9\,\mathrm{Re}^{-0.203}(d_d/D)^{-0.44}(H_d/D)^{0.56} \qquad (3)$$

Average deviation = 18.2, Standard deviation =21.4

In view of these large deviations an alternative approach has been attempted by use of the wall similarity concept proposed by Webb [10, 11], Dippery and Saborsky [12], Nikuradse [13] and Deissler [14]. The similar concept assumes velocity distribution is expected to experience the effect of viscosity and surface roughness. When an object is placed across the flow in a circular conduit, drag is generated and the drag enhances turbulence. Thus generated turbulence exerts tractive force at the wall and makes the boundary layers thinner. The flow is divided into two regions namely inner region and outer region. The inner region constituted with boundary layer whose thickness is δ at $y^+$, where δ is small. The velocity distribution depends on $y^+$, $\tau_0$, μ. For inner region the velocity profile in terms of dimensionless velocity is given by

$$u^+ = y^+ \tag{4}$$

$$where \quad u^+ = \frac{u}{u^*}$$

$$y^+ = \frac{yu^*}{\nu}$$

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

$$u^+ = \frac{1}{k}\ln y^+ + C_1 \tag{5}$$

By the application of boundary conditions u=0,$y=y_0$ where $y_0$ is the thickness of laminar sub layer that depends on the turbulence generated , Equ. 5 reduces to

$$u^+ = \frac{1}{k}\ln(y/y_0) \tag{6}$$

The turbulence in the core and at the wall is significantly affected by the geometric parameters of the promoters employed in addition to the fluid velocity. In the present study the parameter $d_d$ was chosen while computing $u^+$ therefore,

$$y_0 = d_d \tag{7}$$

Equ.7 could be modified as

$$\frac{u_{max} - u}{u^*} = \frac{1}{k}\ln(y/d_d) \tag{8}$$

Combine equ. 5 and 8 gives the velocity distribution equation for the turbulent dominated part of the wall region

$$u^+ = 2.5\ln[y/d_d] + R(h^+) \tag{9}$$

The above equation presents modified velocity profile for the case of two regions in the presence of promoters. Assuming that equ.9 holds good for the entire cross section of the circular conduit, the friction factor for the turbulent flow inside the circular conduit with entry region coil can be given by integration of equ.9. The generated roughness function R ($h^+$) is given by the following equation

$$R(h^+) = 2.5\ln[2(d_d/D)] + \sqrt{2/f} + 3.75 \quad (10)$$

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

The resulting format of equation for correlating the momentum transfer data with disc as promoter can now be written as

$$R(h^+) = C_1 [\mathrm{Re}_m]^{b_1} \quad (11)$$

$Re_m$ is roughness Reynolds number defined by the following equation

$$\mathrm{Re}_m = (d_d/D).\mathrm{Re}.\sqrt{f/2} \quad (12)$$

The data on momentum transfer are therefore similarly analyzed for both inner region and outer region. By using roughness function R ($h^+$) in place of f and Roughness Reynolds number $Re_m$ in place of Re the following correlations were obtained by regression analysis. Correlation without incorporating dimensionless geometrical groups for disc,

$$R(h^+) = 0.601[\mathrm{Re}_m]^{0.297} \quad (13)$$

Average deviation =28.47, Standard deviation = 33.56

Due to large deviations, the dimensionless geometrical groups are introduced. The following correlations were obtained by incorporating dimensionless geometrical groups

$$R(h^+) = 7986.4\,[\mathrm{Re}_m]^{-0.85}\left(\frac{d_d}{D}\right)^{-0.29}\left(\frac{H_d}{D}\right)^{0.01}\left(\frac{V^2}{D g}\right)^{0.44} \quad (14)$$

Average deviation = 1.2414, Standard deviation = 1.4461

Equ. 14 is the relation between the momentum transfer function versus $Re_m^+$ together with geometric parameters of the disc promoter. Correlation plot for equation 14 is presented as figure 6. The relationship is well correlated with the region coefficient of 0.9996. This correlation is useful in the design and optimization of transfer process.

## 5. Conclusions

The friction factor due to presence of the disc is significant in the developed flow. Enhancements in friction factors are 10 folds when the disc diameter is 0.04m and the location of the disc is 0.25 m. The friction factor increases with increasing disc diameter. The friction factor increases to a maximum and then decreases with increasing the location of the disc from starting of the test section. A semi theoretical model was developed for momentum transfer function in terms of geometric parameters and presented.

$$R(h^+) = 7986.4\ [\mathrm{Re}_m]^{-0.85} \left(\frac{d_d}{D}\right)^{-0.29} \left(\frac{H_d}{D}\right)^{0.01} \left(\frac{V^2}{D\,g}\right)^{0.44}$$

**6. List of symbols**

D = diameter of the conduit, m

$d_d$ = diameter of the disc, m

$H_d$= location of the disc, m

L = length of the conduit, m

ΔP = change in pressure

$g_c$ = gravity constant, m/s$^2$

u = local fluid velocity

$u^+$ =dimensionless velocity

u* = friction velocity

$u_{max}$ = average fluid velocity, m/s

$y^+$ = dimensionless distance

$y_0$ = thickness of laminar sub layer

V = velocity of the fluid, m/s

k, $C_1$, $b_1$ = constants

*Dimensionless*

$R(h^+)$ = Roughness momentum transfer function

$Re_m$ = modified Reynolds number

Re =Reynolds number, dVρ/μ

f = Friction factor

$f_0$ = Friction factor for smooth tube flow, $f_0 = 0.046\,\mathrm{Re}^{-0.2}$

f' = Correlation factor

$\Phi_1 = d_d/D$

$\Phi_2 = H_d/D$

$\Phi_3 = V^2/Dg$

*Greek symbols*

$\tau_0$ = wall shear stress, kg/m s$^2$

ρ = density of the fluid, kg/m$^3$

μ = viscosity of the fluid, poise

δ = boundary layer thickness

ν = kinematics viscosity

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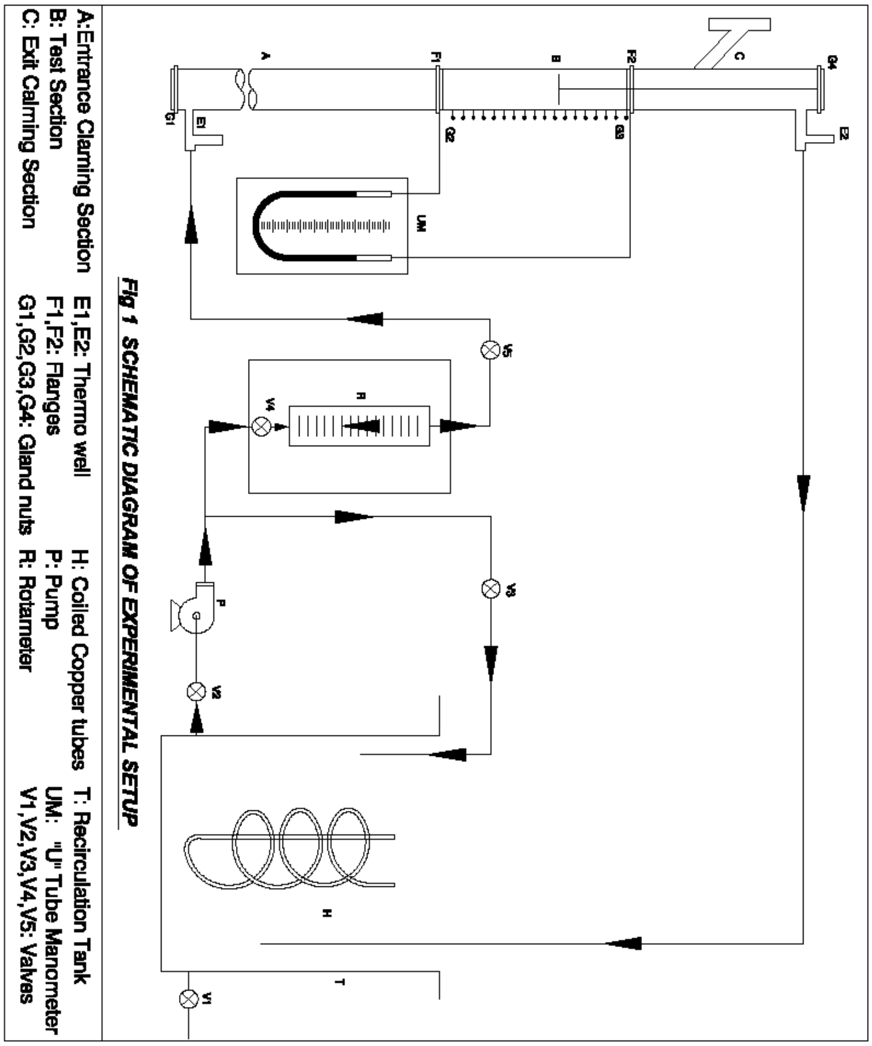


***Fig 1 SCHEMATIC DIAGRAM OF EXPERIMENTAL SETUP***

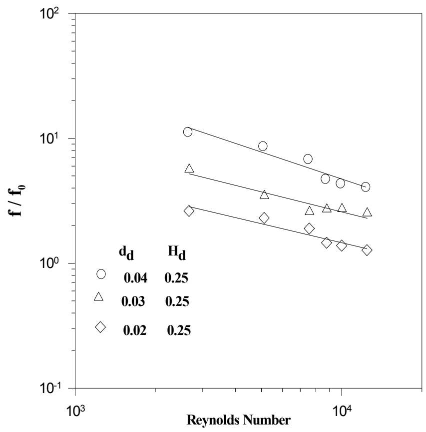

Fig. 2 Variation of friction factor with Reynolds number

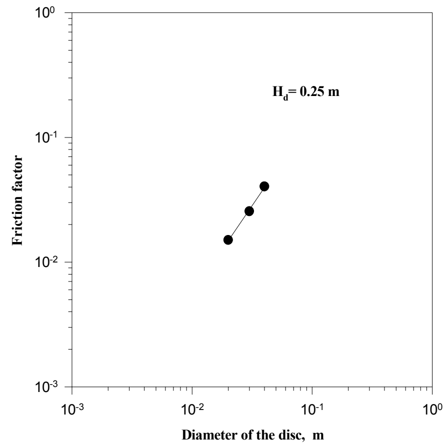

Fig.3 Effect of friction factor on disc diameter

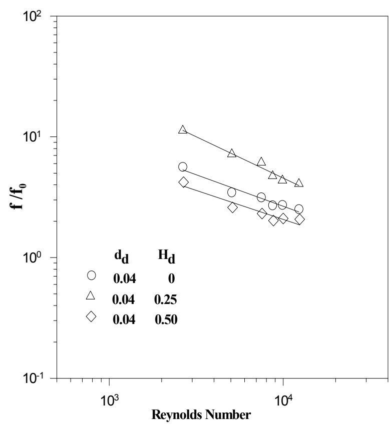

Fig. 4 Variation of friction factor with Reynolds number

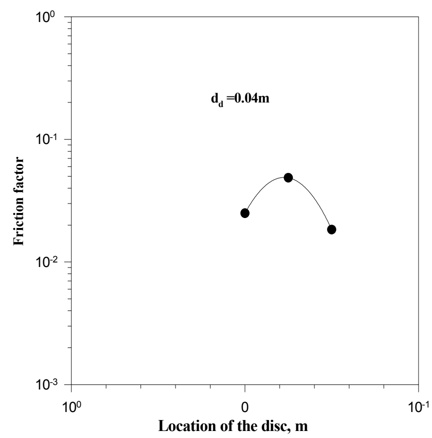

Fig.5 Effect of friction factor on location of the disc

## Table.1 Range of variables covered in the present study

| Disc diameter ($d_d$) m | Location of the disc ($H_d$) m | Velocity (V) m/s |
|---|---|---|
| 0.02 | 0 | 0.0591 |
| 0.03 | 0 | 0.0591 |
| 0.04 | 0 | 0.0591 |
| 0.02 | 0 | 0.1608 |
| 0.03 | 0 | 0.1608 |
| 0.04 | 0 | 0.1608 |
| 0.02 | 0 | 0.2751 |
| 0.03 | 0 | 0.2751 |
| 0.04 | 0 | 0.2751 |
| 0.02 | 0.25 | 0.0591 |

| | | |
|---|---|---|
| 0.03 | 0.25 | 0.0591 |
| 0.04 | 0.25 | 0.0591 |
| 0.02 | 0.25 | 0.1608 |
| 0.03 | 0.25 | 0.1608 |
| 0.04 | 0.25 | 0.1608 |
| 0.02 | 0.25 | 0.2751 |
| 0.03 | 0.25 | 0.2751 |
| 0.04 | 0.25 | 0.2751 |
| 0.02 | 0.50 | 0.0591 |
| 0.03 | 0.50 | 0.0591 |
| 0.04 | 0.50 | 0.0591 |
| 0.02 | 0.50 | 0.1608 |
| 0.03 | 0.50 | 0.1608 |
| 0.04 | 0.50 | 0.1608 |
| 0.02 | 0.50 | 0.2751 |
| 0.03 | 0.50 | 0.2751 |
| 0.04 | 0.50 | 0.2751 |