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Augmentation of Mass Transfer Coefficient in Decaying Swirl Flow

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The enhancements in mass transfer coefficients due to the presence of helical tape promoter is presented in this paper. The variables studied are the flow rate of the electrolyte, rotational speed, Reynolds number, rotational Reynolds number and Scmidt number. It is found that the mass transfer coefficient increased with increased flow rate and also increased with increase in the rotational speed. Rotation improved the mass transfer coefficient from 5-107 %. Mass transfer coefficient in the rotation of helical tape swirl generator is enhanced from 0.5 fold to 13 fold over the mass transfer coefficient in forced convection flow.

Key Words: Mass transfer coefficients, Augmentation, Helical coil, Swirl flow, Ionic mass transfer.

INTRODUCTION

The intensification of mass or heat transfer at low-pressure losses is of great importance in many industrial processes. The use of augmentation technique has been well recognized for economic operations, reduced equipment size and increased outputs. Basic feature of any augmentation technique is to enhance the transfer rate by increasing turbulence in the flow[1,2]. In recent years several theoretical and experimental studies are continuously being carried out to identify an appropriate augmentation technique suitable to a given system[3-6]. The enhancement of convective heat or mass transfer in process equipment has been of vital importance because of the necessity of energy and material savings.

Swirl flow devices form an important group of passive augmentation techniques[7-11]. In swirl flow, the tangential velocity component due to imposed concentric circular motion about the duct axis is of comparable magnitude with the mean axial flow velocity. Swirl flow has a wide range of application in various engineering areas including heat and mass transfer separation and classification in cyclones, nuclear propulsion system, agricultural spray machines, industrial furnaces and internal combustion engines to enhance convective transport properties in circular ducts in addition to obtain clean and efficient combustion and to control flame size and shape[12]. External rotation of the swirl generator makes it an active technique and further enhances the heat/mass transfer rates. A number of studies have been carried out to determine the heat or mass transfer in rotating flows[13-16]. Because of the complex nature of rotating flow fields and the attendant difficulty in determining the heat and mass transfer, there has been an emphasis on studies of comparatively simple configuration *viz.*, disks, cylinders, cones *etc.*, rotating about their own axis. In earlier investigations helical tape swirl generators were employed as entry region swirl generator and significant augmentation in heat and mass transfer rates were reported[17-19]. However the use of rotation of helical tape at the entry region by an external force has a greater potential to achieve higher transfer rates. But the research is meager in this direction.

Present investigation is therefore undertaken to obtain the effect of rotating helical tape swirl generator at the entry region on mass transfer rates in circular conduits in case of forced convection flow of electrolyte. It essentially deals with the evaluation of mass transfer rates at the wall of the conduit.

EXPERIMENTAL

The schematic diagram of the experimental unit used in the present study was shown in Fig. 1. Limiting current measurements were taken at copper microelectrodes fixed flush to the inner surface of the wall of the test section for the reduction of ferri cyanide ion. Prior to the assembly of the main unit, the microelectrodes were polished with four zero emery to get a smooth surface. Subsequently degreasing operation with trichloro ethylene solution was carried out.

After fixing the helical tape swirl generator in the slot of the brass rod, blank runs were conducted with indifferent electrolyte (sodium hydroxide solution) alone to ensure that the limiting currents obtained in the subsequent runs were due to diffusion of reacting ions only. 90 L of electrolyte consisting of 0.01 N potassium ferri cyanide, 0.01 N potassium ferro

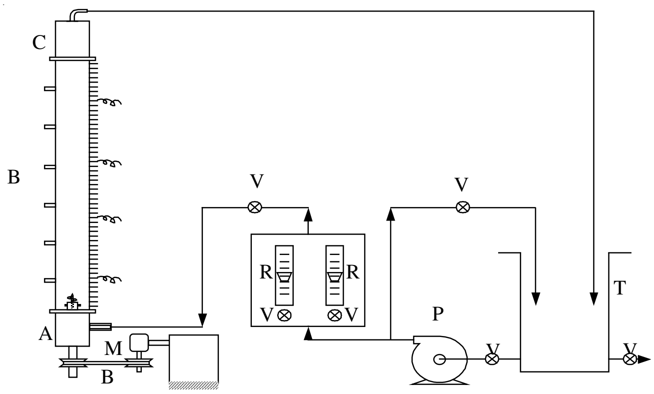

Fig. 1. Experimental setup

cyanide and 0.5 N sodium hydroxide was prepared in the storage tank. Excess sodium hydroxide was used as a supporting electrolyte to suppress migration of the reacting ion and to make the reaction diffusion controlled.

The electrolyte was pumped through the test section at a desired flow rate by operating the control and by-pass valves. The helical tape swirl generator was rotated to the desired speed. The speed of rotation was measured with a stroboscope. After the flow rate and the rotation speed were stabilized, limiting currents were measured for reduction of ferricyanide ion by applying the electric potential across the electrode and the wall of the main unit. The attainment of limiting current was observed by a small increase in current for a sharp rise in potential.

To evaluate the effect of height from the swirl; the limiting current data were measured at different microelectrodes for different flow rates of the electrolyte at constant rotation speed. The data were then measured at varying speeds of rotation. The limiting current data were also measured for no external rotation of the helical tape swirl generator. The mass transfer coefficients were calculated from the limiting current[20].

RESULTS AND DISCUSSION

In an effort to study the effect of the rotating helical tape swirl generator on mass transfer rate, 1980 limiting current data are obtained. These data are measured using electrochemical method reduction of ferri cyanide ion. The reaction-taking place at the test electrode is as follows:

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

Limiting current data are obtained at 30 test electrodes on the wall of the column. The parameters studied in this investigation are flow rate of the electrolyte and speed of rotation of the swirl generator.

Longitudinal variation of mass transfer coefficient: Fig. 2 show the variation of local mass transfer coefficient with the height of the electrode for the rotating helical tape swirl generator at different velocities. The plots indicate maximum coefficient values against the swirl generator and limiting coefficient values decrease with an increase in height from the helical tape swirl generator. Beyond certain height from the swirl generator, the limiting current density values are more or less constant. The rotation of the swirl generator situated at the entrance region leads to decay swirl flow. The intensity of the swirl decreases with increase in height from the swirl

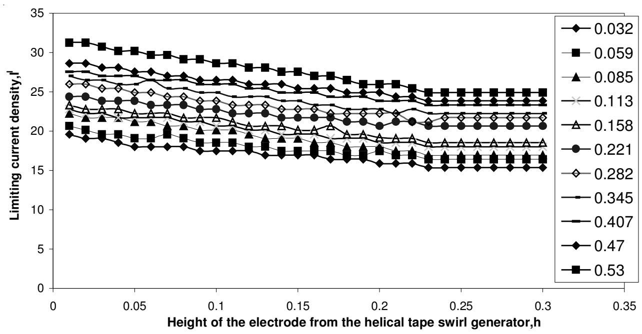

Fig. 2. Effect of height of the electrode from the helical tape swirl generator on limiting current density for rotation speed 500 rpm

generator. This results in lowering of the mass transfer coefficient with height. Beyond certain height, indicated in the figure, the effect of the swirl becomes negligible and hence mass transfer coefficient are more or less constant.

Effects of velocity and speed of rotation: To find out the effects of velocity and rotation speed, the average mass transfer coefficients are calculated by taking simple arithmatic mean of the local mass transfer coefficients obtained at different electrodes till the electrode beyond which mass transfer coefficient value is a constant, for a given velocity. Fig. 3 indicates the effects of velocity and rotation speed on average mass transfer coefficient ($k_{Lr,av}$). It is found that average mass transfer coefficient increases as the velocity is increased from 0.032-0.53 m/s. These plots also confirm that the average mass transfer coefficient increases with an increase in rotation speed from 500-3000 rpm. It is obvious that increase in speed of rotation results in higher average mass transfer coefficients.

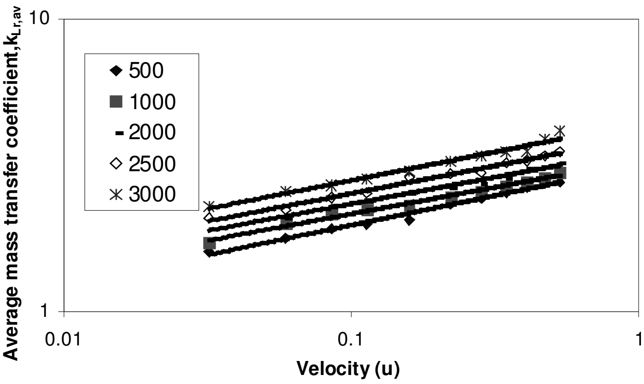

Fig. 3. Effect of velocity and speed of rotation on average mass transfer coefficient

Enhancement of mass transfer coefficient: The mass transfer coefficients obtained in the present case with the rotation of the helical tape swirl generator are compared with the mass transfer coefficient obtained on forced convection flow of the electrolyte in the absence of helical tape swirl generator. The data for forced convection of the electrolyte are predicted from the equations $J_{Df} = 2.023\ Re^{-0.2}$ for turbulent flow and J_{Df} = f/2 for laminar flow. Values of friction factor are evaluated from f *versus* Re graph. The data are presented in Fig. 4 with ($k_{Lrav}/k_{Lf,av}$) - 1 as a function of velocity (u). It is observed that the mass transfer coefficients in the present case are augmented from 0.5 fold to 13 fold.

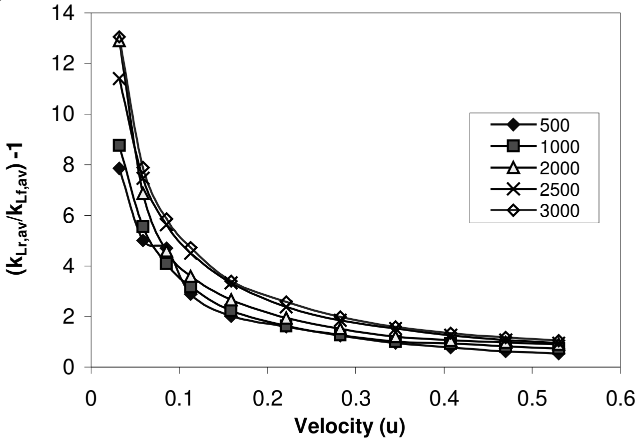

Fig. 4. Enhancement of mass transfer data with rotating helical tape swirl generator over the mass transfer coefficient in a forced convection flow

Correlation of the data: J_{Dr} and Re values are calculated for the present data to account on the variation in physical properties of the electrolyte. The effect of Reynolds number on mass transfer parameter J_{Dr}-factor is shown in Fig. 5 for different values of u_r. The plots clearly indicate the effect of rotation velocity (u_r). Generally mass transfer data are correlated with J_{Dr} or $Sh/Sc^{2/3}$ as a function of Re and other parameters studied. Based on the above observations the present data can be correlated in the following format

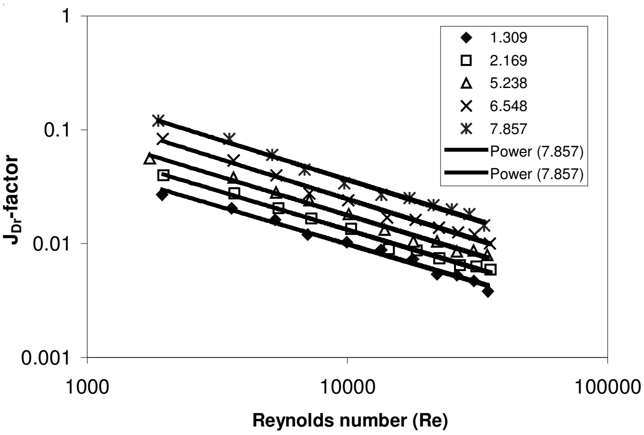

Fig. 5. Effect of Reynolds number on mass transfer parameter

$$J_{Dr} = cRe^{x}Re_{r}^{y} \quad (1)$$

The data, when correlated in the above format, yielded the following equation

$$J_{Dr} = 3.06Re^{-0.84}Re_{r}^{0.19} \quad (2)$$

Average deviation is 4.76 % and standard deviation is 5.1 %.

Conclusion

Present study showed that, the mass transfer coefficient decreases with increase in height of the electrode from the helical tape swirl generator. The swirl effect is negligible beyond certain height of the electrode from the helical tape swirl generator. It is observed that the mass transfer coefficient in a decaying swirl flow decreases from 10-30 % of its initial intensity. The mass transfer coefficient increases with an increase in flow rate. The mass transfer coefficient was enhanced as the speed of rotation was increased. Rotation improved the mass transfer coefficient from 5-107 %. Mass transfer coefficient in the rotation of helical tape swirl generator is enhanced from 0.5 fold to 13 fold over the mass transfer coefficient in forced convection flow.

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