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Mass Transfer Coefficient Enhancement Using Spiral Wound Rod as Turbulence P romoter in an Electrolytic Cell

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Abstract

Objectives: to improve efficiency of process equipment by increasing the mass transfer coefficient with a spirally wound rod as the turbulence promoter. **Methods:**The function of facet promoters, whirl generators, and test sections of different congruous shapes increase the mass transfer coefficients at the reaction surface. Diffusion-controlled redox (ferricyanide - ferrocyanide) reaction has been chosen for the study. Limiting current data from the reduction of ferricyanide is used for mass transfer coefficient calculation. A set of three geometric parameters such as pitch(P), height(H), and width(W) of the promoter were investigated in the current study. **Findings:** An increase in the mass transfer coefficient values with the increment of flow rate of electrolyte from 0.088 m/s to 0.263 m/s was observed. A rise in the promoter height from 0.03 to 0.07m enhanced the mass transfer coefficient by 25.7 fold, while the increase in the width of the promoter from 0.01 to 0.04m resulted in a rise of the mass transfer coefficient by 26.3 fold. On the contrary, the mass transfer coefficient decreased upon increase in the pitch of the promoter from 0.01 to 0.04m, but overall enhancement is 25.7 fold. The increase in the mass transfer coefficient on an average compared to a rectangular turbulence promoter was 5.71 fold. **Novelty:** The spiral wound rod as a promoter increased the mass transfer coefficient several folds compared to other promoters. The spiral wound rod is quite simple to manufacture, has low cost and ease of maintenance. Therefore, the promoter used in the study could be employed for heat and/or mass transfer enhancement in Industrial applications.

Keywords: Limiting current; Promoter; Mass transfer Coefficient; Swirl flow; Redox reaction

1 Introduction

Process equipment is used to produce different types of petroleum and pharmaceutical products using chemical reactions. The performance of the process equipment has a bearing on the final yield of the product. The efficiency of the process equipment has been improved over the years by increasing the mass transfer coefficient. The coefficient depends on the number of moles of reactant converted per unit time. In turn, the conversion of an electrolyte depends on the type of fluid flow in the reactor. Only lateral mixing was studies, the effects of axial mixing were underestimated[(1)]. Both the mixing conditions influence the mass transfer coefficient. Several investigators have studied the enhancement of mass transfer coefficient by employing different techniques/methods viz. twisted tapes, helical coils, snails, helical screws, etc. Of them, the passive method for enhancement of heat and mass transfer is the most prominent and practiced in many engineering applications[(2)]. In the turbulent core, the velocity distribution for mass transfer is controlled by eddy dispersion of momentum and eddy dispersion of mass. In the buffer region, the united action of molecular and eddy diffusion determines the velocity distribution and mass transfer[(3)]. External power sources are not required for passive methods. The vane promoter increases the mass transfer coefficient by creating lateral mixing in an electrolytic cell. The effect of electrolyte rate and the geometric parameters of vanes on mass transfer at the wall were studied[(4)]. The helical screw-tape promoter enhanced the mass transfer coefficient and heat transfer by creating lateral mixing and imperfect axial mixing conditions in the test section[(5)]. The rectangular turbulence promoter increased the mass transfer coefficient by initiating lateral mixing only[(6)]. The spiral coil as promoter enhanced the mass and momentum transfer coefficient by creating lateral mixing of the fluid. The mass, heat and momentum transfer data are required for designing chemical equipment. Momentum transfer studies were conducted using the spiral coil as turbulence promoter in compelled transmission flow of electrolyte and obtained pulse transmissibility on the exterior wall of the electrochemical cell. Limiting currents data was used to develop momentum transfer coefficients[(7)]. Snail and V nozzle promoters enhanced heat transfer and mass transfer coefficient by initiating lateral mixing and negligible axial mixing conditions[(8)]. Earlier studies were mostly confined by creating perfect lateral mixing and negligible axial mixing conditions in the test section. Swirl flow of electrolyte in the test section was not created and hence, not studied. When a spiral wound rod was used as a promoter, it creates swirl flow inside the test section. Hence, swirl flow creates perfect lateral as well as perfect axial mixing of fluid, which enhances the mass transfer coefficient more effectively. This concept motivated us to study the performance of the spiral wound rod as a promoter in an electro-chemical cell.

2 Methodology

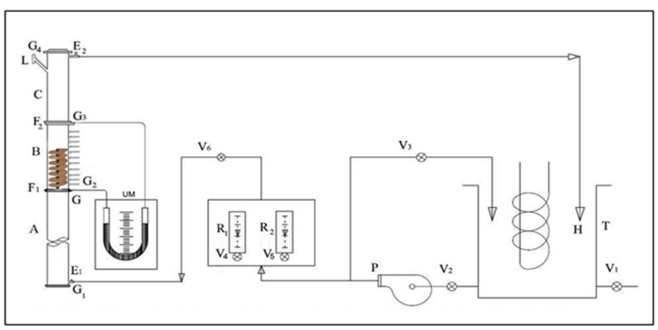

Fig 1. Schematic diagram of the equipment used for experimentation

The experimental setup demonstrated in Figure 1 was used in earlier studies[(4)]. The different components viz. gateway section (A), and experimentation section (B), way out of an enclosed place section (C), nuts (G_1 to G_4), thermal wells (E_1, E_2), Transport (P), rims (F_1,F_2), rotameters (R_1, R_2), copper coiled tube (H), pressure control tank (T), manometer (UM) and faucets (V_1 to V_6) are indicated in the figure. The recirculation copper tank of 100 liter capacity was connected to a drainpipe having a faucet(V_1) for weekly cleaning. The nitrogen is bubbled through a perforated copper coiled tube(H) in the electrolyte. A copper pipe is connected between the intake line of the pump and the pressure control tank with a gate faucet(V2). The pump drain pipe was split into two. One line is used as a bypass and it is restrained by a faucet(V3). The supplementary line was joined to the rotameter, and the outlet of the rotameter was joined to the gateway section(A). The gateway part was a copper circular channel of 0.05 m inside diameter furnished with a backplate at the base with a kernel (G_1). The details of the test section are shown in Figure 2.

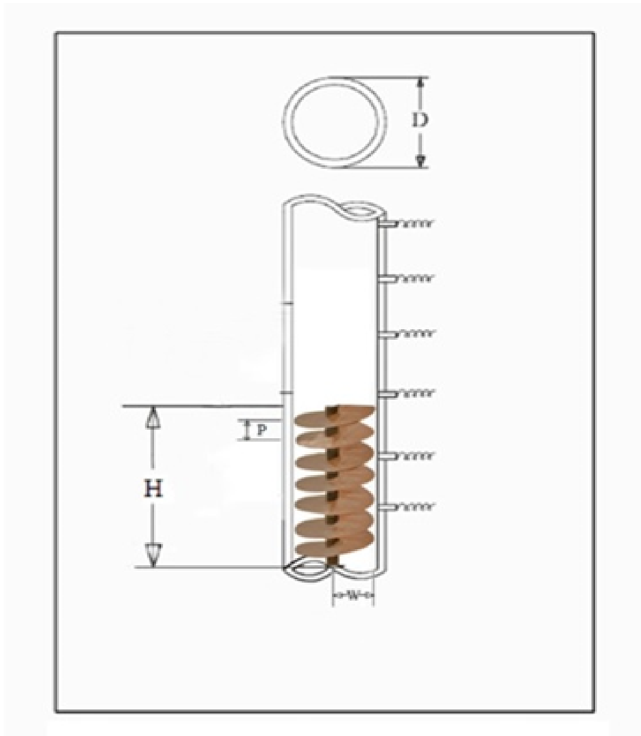

Fig 2. Details of the test section

The Perspex graduated conduit of 0.44 m height was administered with point electrodes hooked at the internal surface. Point electrodes are made with a copper rod. The electrodes were fixed at an equal layout of 0.02 m in the conduit. The size of the wayout section was identical to the size of the gateway section finished with a copper tube. Thermal wells (E_1, E_2) at the gateway section and at the wayout section were used to determine the temperature of the electrolyte. The spiral wound rod was placed at the entry of the analysis section. It acts as a turbulence promoter in the study.

The limiting current and potential measurements are estimated with a multimeter and vacuum tube voltmeter.

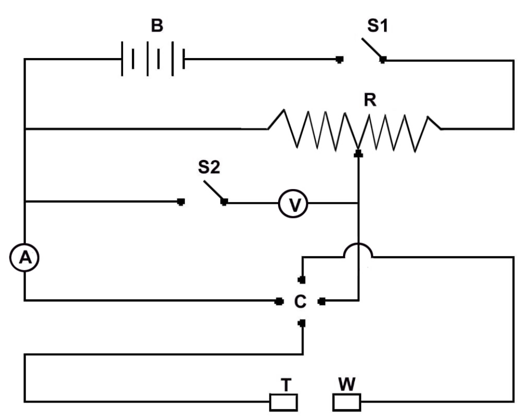

Fig 3. Electric circuit

The electrical circuit contained a rheostat(R), commutator(C), switch(S1 & S2), and a battery(B) as the power source, Milli-Ammeter(A), Wall Electrode(W) and test Electrode(T). The commutator aids the estimation of limiting currents under similar operating conditions for the oxidation and reduction process. The control switch promoted the analysis of limiting currents at one pertinent electrode.

2.1 Experimental procedure

The cathode reaction is presented below.

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

Similar normality solutions of 0.01N Potassium ferricyanide, 0.01N Potassium ferrocyanide of seventy liters with 0.5N NaOH as excess indifferent electrolyte were arranged. The volumetric method was used to assess the concentration of ferrocyanide ions with standard potassium permanganate solution and iodometric method was used to assess the concentration of potassium ferricyanide ions. Ostwald viscometer and specific gravity bottle were used to estimate the viscosity and density of the electrolyte at distinctive temperatures respectively. The electrodes present in the conduit were gleamed and cleaned with trichloroethylene chemical. The electrode area was estimated by the traveling microscope. The promoter was fixed coaxially in the conduit and only sodium hydroxide solution was circulated to assure that the captured currents are limiting currents, as a result of the diffusion of reaction ions. The electrolyte was circulated at a pertinent velocity by directing the by-pass and control valves. After fulfilment of the steady state condition, the potential was enforced across the conduit in meager increments, and the analogous current values were identified [4]. The study potential was captured at the analysis electrode because the wall electrode was moderately large in analogy with the analysis electrode [5]. The limiting currents were only taken for efficiency estimation, therefore potential values were not important in the study.

2.2. Measurement of limiting current

The gain of potential boosts the limiting current towards a pertinent value and with further increment in potential, approximately the consistent current value results. This appears a clear boots of potential resulting in a slight increment in current. The mass transfer coefficient was gauged from the deliberately chosen limiting current from the below equation.

$$K_C = \frac{i_L}{nFAC_0}$$

The results presented are based on nearly 4800 local limiting currents, 240 pressure drop measurements using 48 promoters. The study adopted the use of a spiral wound rod as a turbulence promoter at the entry region, and perhaps the promoter enhances turbulence by generating a swirl to the axial component of the flow. Limiting currents were measured on the outer wall along the test section. The swirl intensifies local turbulence and the augmentation of mass transfer results. The local limiting currents visualize the local variation of i_L(Limiting current)over and above the length of the column, and local average limiting currents were used for the calculation of the average mass transfer coefficient (k_C). The data is useful in the designing of energy efficient transfer operations. The measured data consisted of flow rate Q, temperature T, the concentration of reacting ion C_0, limiting current $i_{L,}$ (from current potential measurements), and pressure drop Δp. The swirl generated by the spiral wound rods at the entry region of the circular conduits propagates along the length of the column. Promoters were inserted coaxially at the entry region of the test section and mass transfer rates were computed at the wall of the analysis section from the measured limiting currents. Simultaneous pressure drop data were also measured which helped in evaluating the promoter for its efficacy. As the turbulence promoter is located at the entrance of the test section, it transforms axial flow into swirl flow.

A graph is drawn with local limiting current (i_L) versus distance along the test sectionis shown in Figure 4. It reveals progressive intensification of turbulence up to a distance of 20 cm from the entrance where the promoter is located. Limiting current values are increasing up to 20 cm, beyond this distance values of limiting currents remained constant, indicating sustenance of turbulence over a certain length. In the present experiment, the maximum length of the test section was 44cm. The generated turbulence was found to sustain up to 44cm. But it may continue for longer lengths and are to be probed. After a certain distance, the turbulence needs to decline and attain that value of a tube with no inserted promoter.

The results presented in Figure 5 reveal the relation between mass transfer coefficient and velocity of electrolyte, with height of the promoter as a variable. The promoter at the entry region creates swirl flow and that provides proper mixing of the fluid. The thickness of the boundary layer decreases as the fluid passes through the column because of tractive shearing forces. When the results are compared with Lin et al [2] without a promoter. k_C values have increased with the increase in the height of the promoter from 0.03 to 0.07m, at constant pitch and width. The promoter of height of 0.07 m, width of 0.04 m and pitch of 0.04 m has a high mass transfer coefficient. Enhancement of k_C is 25.7 fold at a flow rate of 0.088 m/s and 14.3 fold at a 0.263 m/s flow rate when compared to the measured values without a promoter.

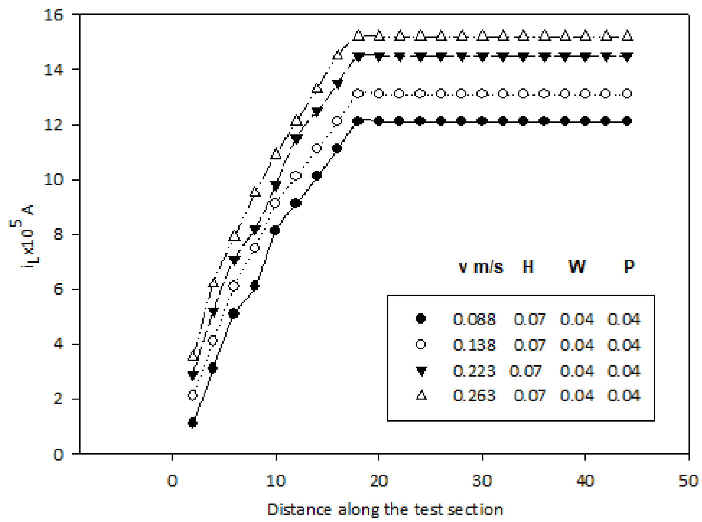

Fig 4. Variation of limiting current for a biggest promoter with different flow rates of electrolyte.

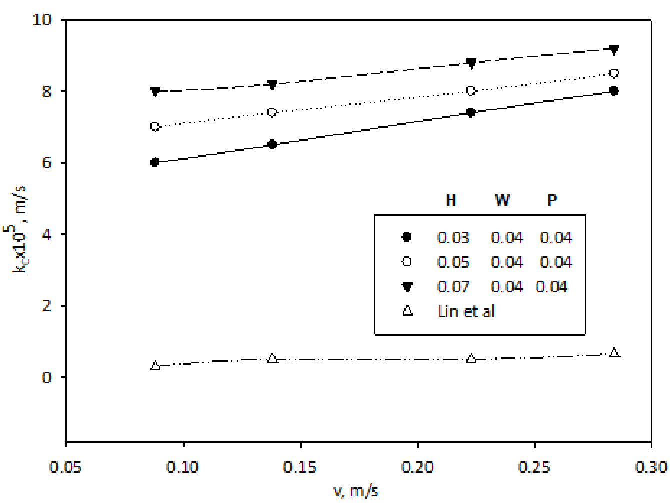

Fig 5. Promoter height effect on mass transfer coefficient

The relation between mass transfer coefficient and pitch of promoter is presented in Figure 6. Mass transfer coefficient values are increased by decreasing the pitch of promoter values from 0.01 m to 0.04 m. The number of turns per meter increases if the pitch is decreased resulting in more swirls in the fluid, which in turn increases the mass transfer coefficient. Fluid flow will obstruct if the pitch is too small and the skin friction results in high resistance. Consequently, a low mass transfer coefficient results as was indicated in earlier reports[(9)]. Values of k_C were 26.3 folds increased and 14.3 folds increased at a flow rate of 0.263 m/s and 0.088 m/s respectively when compared to without promoter[(2)]. Particularly high mass transfer coefficient values were resulted for the promoter of geometry 0.07 m height, 0.04 m width, 0.01 m pitch, while minimum mass transfer coefficient was obtained for the promoter of geometry 0.07 m height, 0.04 m width, 0.01 m pitch.

Figure 7 is the Illustration of the relation between the mass transfer coefficient and velocity of electrolyte with width of the promoter as a variable. The mass transfer coefficient is enhanced with the increment of the width of the promoter. The drag of the promoter converts the axial flow of electrolyte to swirl flow. This enhances the mass transfer coefficient. Improvement of mass transfer coefficient 25.3 folds and 14.3 folds at an electrolyte flow rate of 0.088 m/s and 0.263 m/s respectively with increase of width from 0.02m to 0.04m.

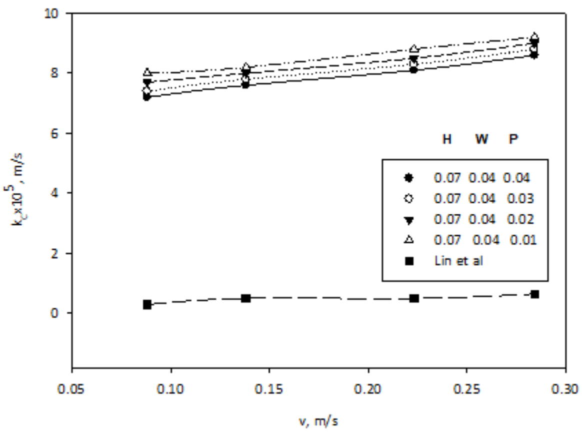

Fig 6. Pitch of promoter effect on mass transfer coefficient

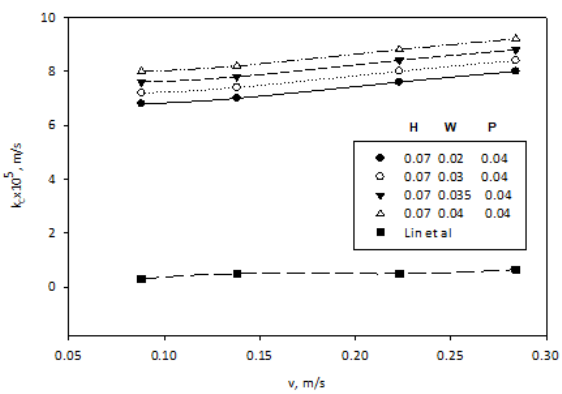

Fig 7. Promoter width effect on mass transfer coefficient

3 Conclusions

In this study, the performance of the spiral wound rod as turbulence promoter was analyzed by creating a swirl flow of fluid. The intensity of the swirl increased from zero at the entrance and reached a maximum value at 20 cm corresponding limiting current increased 0 at the entrance to $15x10^{-5}$A at 20cm of the test section and then it became constant up to 44 cm height. It was found that with the increase in the height of the promoter from 0.03m to 0.07m, the coefficient has enhanced by 14.7 folds and 24.7 folds at a flow rate of 0.088 m/s and at 0.263 m/s respectively, as against the condition of promoter absence. When the pitch of the promoter was changed from 0.01m to 004m, the mass transfer coefficient decreased, due to the skin friction of the promoter. The calculated coefficient differed over by 26.3 and 14.6 folds at a flow rate of 0.088 m/s and 0.263 m/s respectively, as against the condition of promoter absence. In the case of change of the promoter width from 0.02m to 0.04m, the coefficient has increased to 25.3 fold and14.3 fold at a flow rate of 0.088 m/s and 0.263 m/s respectively relative to the condition without the promoter. This study shows that the performance of spiral wound promoter was better than the previouly studied promoters for example mass transfer coefficient compared to rectangle promoter was 5.71 folds. The limitation is that the study was confined to 44 cm of the test section the swirl progresses beyond 44 cm. How far it has progressed and its intensity required to be probed. Further studies can be employed on the efficacy of spiral wound rod promoter in real chemical reactors and heat exchangers of industry

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