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Wall-To-Bed Mass Transfer in an Inverse Fluidized Bed

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Abstract

Mass transfer coefficient data were obtained in an inverse fluidized bed electrochemical reactor between a flowing fluid electrolyte and inner column wall of the reactor. Polypropylene particles of cylindrical shape having a density of 877.6 kg/m3 were used as bed material. From this study it was noticed that there was no radial variation of mass transfer coefficient. Mass transfer coefficient was found to decrease with liquid velocity and reached a minimum and remained constant. When analyzed in the lines of Richardson and Zaki, the bed porosity yielded an exponent of 1.206. An important correlation was obtained for predicting mass transfer coefficient in terms of Colburn j-factor and particle Reynolds number and bed porosity.

Keywords; *Fluidization, inverse fluidization, limiting current, mass transfer coefficient, wall-to-bed mass transfer*

I. INTRODUCTION

In conventional fluidized beds, solid particles having density higher than the flowing fluid are subjected to fluidization in such a way that the fluid flows in upward direction and owing to the momentum of the fluid the particles get suspended. Applications of this kind of conventional fluidization are numerous and spread across the entire spectrum of the process industry. However, in some situations, there is a necessity to fluidize particles that have density lower than the flowing medium. In such cases, the fluid is admitted at the top so that the low dense particles are subjected to fluidization. This kind of operation is known as inverse fluidization and this type of fluidization has also potential applications in process and allied industries. Applications of inverse fluidization are found in biological waste water treatment, biochemical processes, bioprocesses, food processing, environmental engineering, petrochemical engineering, waste water treatment, aerobic fermentation processes, biotreatment of waste water etc. The advantages of inverse fluidization are high mass transfer rates, less solid attrition and minimum carryover of solids. Literature survey revealed that previous studies in inverse fluidization are limited to minimum fluidization velocity[1-5], bed expansion[6-7], axial dispersion[8] and flow patterns[9-10]. Therefore, the present investigation is focused on obtaining rate of mass transfer from flowing electrolyte to the inside surface of the column wall in an inverse fluidized bed. The electrolyte solution was prepared by dissolving potassium ferrocyanide and potassium ferricyanide salts so that the concentration of each of these salts in the resulting electrolyte would be 0.01M. Sodium hydroxide was also dissolved in this electrolyte solution to the extent of 0.5M. The bed material employed consisted of thin cylinders made of poly propylene (2.151 mm dia x 5.0 mm length). These particles had a density of 877.6 kg/m^3. The electrochemical reaction is:

$Fe^{3+} + e \rightarrow Fe^{2+}$ …(1)

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Using eqn.(2) mass transfer coefficient is calculated.

$$k_L = \frac{i_L}{FAC_0} \quad \dots (2)$$

Where

k_L = mass transfer coefficient

i_L = limiting current

A = surface area of electrode

F = Faraday constant

C_0 = Concentration of potassium ferricyanide

II. EXPERIMENTAL

Figure 1 represents the line diagram of the experimental unit. Two tanks are employed: T1 is the feed tank and T2 is the collecting tank. Liquid from T2 is recirculated to T1 using a centrifugal pump P. Valves, 3 in number are used for controlling the flow rate of liquid through the test section. A rotameter R gives the reading of volumetric flow rate. This rotameter is calibrated with the fluid electrolyte. The test section consists of a perspex tube having an inner diameter of 1 inch. Electrodes having a diameter of 2 mm are arranged to the test section in such a way that the surface of the electrode perfectly aligns with inside wall. Four electrodes were arranged at a fixed length from the entry of the fluidized bed on four sides which are helpful in determining the radial variations. Electrodes are also arranged to elicit longitudinal variations. At entry point a wire mesh is placed to support the solid particles. The entry point of the fluid electrolyte is at the top of the test section. The particles have density smaller than the liquid, and hence the liquid flowing downward fluidizes these solid particles. To facilitate the continuum of the liquid, the outlet is provided in the form of a leg along with overflow line. Data on bed height and limiting current are obtained[12].

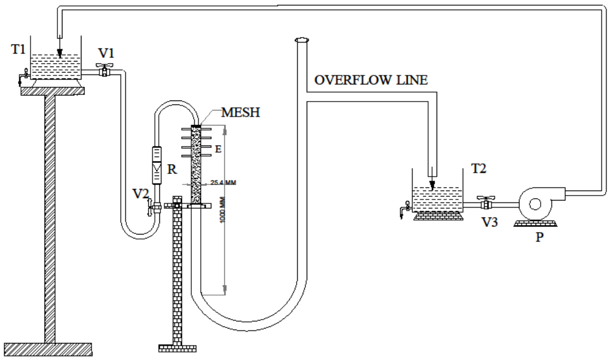

Figure 1. Line diagram of experimental unit

III. RESULTS AND DISCUSSION

In Figure 2, k_L was taken on y-axis and U_L was taken on x-axis. At lower liquid velocity k_L was higher and as the liquid velocity is increased k_L decreased and reached a minimum value. With further increase in U_L, the k_L remained unaffected. At low liquid velocities, dense fluidization occurs, and hence the turbulence is severe. Hence higher values of k_L were obtained. As the velocity of the fluid electrolyte is increased, the bed expanded and hence the number particles present in given volume decreased. Hence turbulence decreased. It resulted in decreasing k_L. As the liquid velocity reaches 2.4 cm/s, there is no further decrease in the turbulence due to solids because of lean bed conditions. Hence the mass transfer coefficient remained constant.

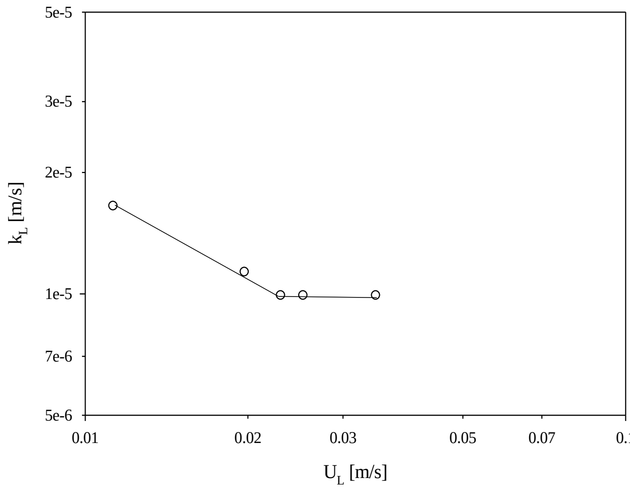

Figure 2. Effect of liquid velocity

Figure 3 presents variation in k_L in radial direction. The plots demonstrate that k_L remained same in the

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radial direction. This means the turbulence generated by the bed is uniform at any given cross section of the bed.

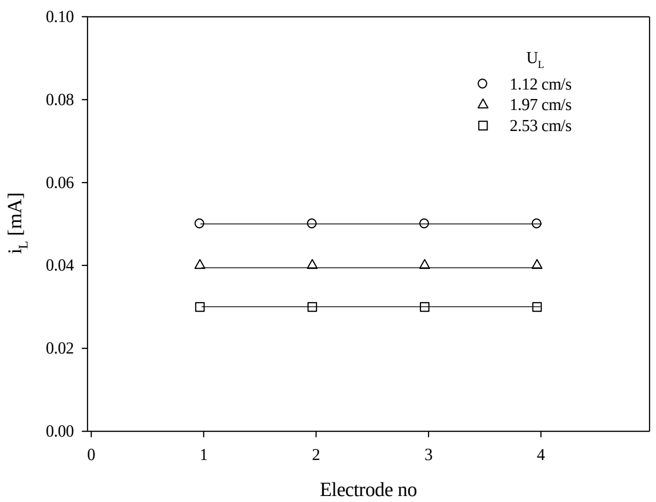

Figure 3. Effect of radial direction

From Figure 4 it can be identified that the bed height increases with liquid velocity. The relation between bed porosity and liquid velocity could be seen from Figure 5 wherein the bed porosity increased with liquid velocity. Figure 6 shows the relation between particle Reynolds number and bed porosity.

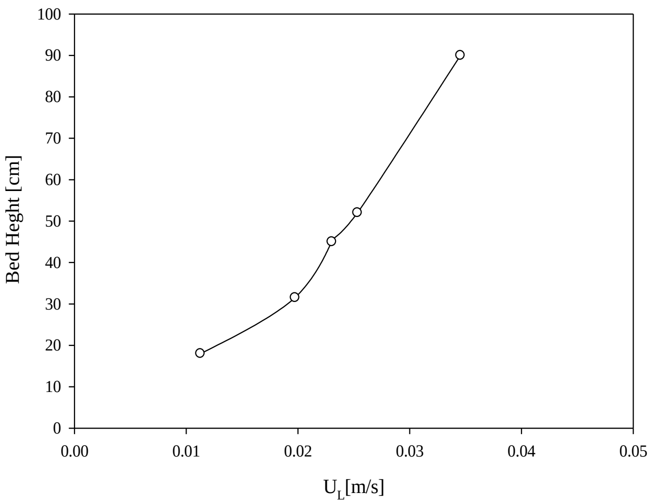

Figure 4. Effect of liquid velocity on bed height

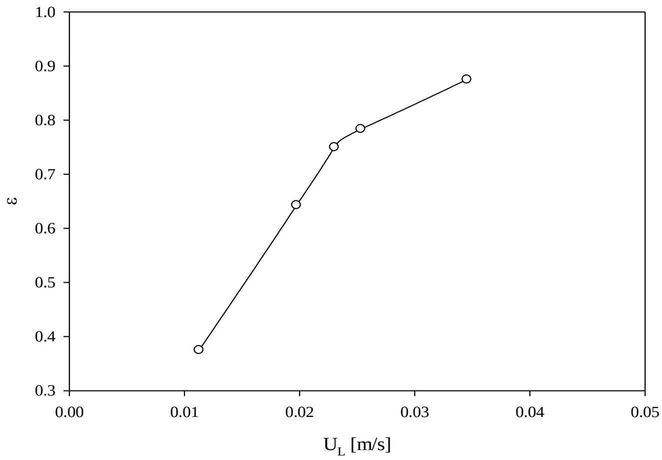

Figure 5. Effect of liquid velocity on bed porosity

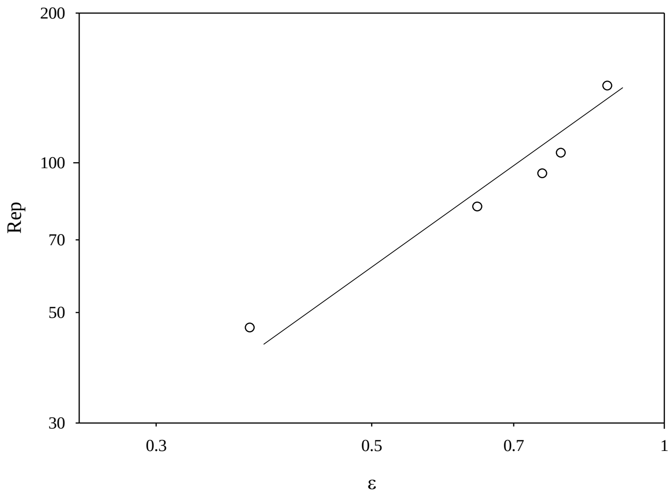

Figure 6. Re_p versus bed porosity

The relation between particle Reynolds number and bed porosity is obtained using least squares regression analysis to obtain the following equation.

$$Re_p = 146.1\varepsilon^{1.206} \qquad \ldots(3)$$

Average and standard deviations were 7.121 and 8.176 percent respectively. Similarly eqn.(4) was obtained for mass transfer with average and standard deviations as 4.148 and 4.806 percent respectively.

$$j_D\varepsilon = 0.18\left(\frac{\mathrm{Re}_p}{1-\varepsilon}\right)^{-0.30} \qquad \ldots(4)$$

IV. CONCLUSIONS

An experimental study has been conducted to obtain mass transfer coefficient in an inverse fluidized bed.

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The following conclusions have been drawn from this study:

- Radial variation of mass transfer coefficient is not noticed.
- Mass transfer coefficient is found to decrease liquid velocity and reached a minimum and remained constant.
- The bed porosity had observed a Richardson-Zaki exponent of 1.206.
- A useful correlation is obtained for predicting mass transfer coefficient in terms of Colburn j-factor and particle Reynolds number and bed porosity.

Nomenclature

D_L = diffusivity [$m^2.s^{-1}$]

d_p = particle diameter [m]

j_D = Colburn j-factor = $\frac{k_L}{U_L} Sc^{2/3}$ [-]

Sc = Schmidt number = $\frac{\mu_L}{\rho_L D_L}$ [-]

Re_p= particle Reynolds number = $\frac{\rho_L d_p U_L}{\mu_L}$ [-]

U_L = superficial liquid velocity [$m.s^{-1}$]

ρ_L = density of electrolyte [$kg.m^{-3}$]

μ_L = viscosity of electrolyte [Pa.s]

ε = bed porosity [-]

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