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Wall-To-Bed Mass Transfer in Three-Phase Fluidized Beds in The Presence of Hourglass Promoter

U.S.N. Babu Bheemisetti[1], M. Vijay[2]*, G.V.S. Sarma[1] and K.V. Ramesh[1]

[1]Department of Chemical Engineering, Andhra University, Visakhapatnam-530003, India.
[2]Centurion University of Technology and Management, Odisha, India

ABSTRACT

Three phase fluidized beds are widely employed in process industries. The ongoing examination is conducted to detect the improvement in coefficients of ionic mass transfer in the presence of an hourglass promoter element in a three phase fluidized bed. Data on coefficient of mass transfer is obtained by employing a diffusion-controlled electrode reaction—reduction of ferricyanide ion. Coefficients of mass transfer are estimated using the measured data on limiting current data for several combinations of flow rates of liquid and gas, pitch, bed porosity, characteristic length, promoter rod diameter and particle diameter. Correlations are also developed for coefficient of mass transfer by regression analysis with the use of proper dimensional groups relating geometrical parameters and flow variables.

Key words: **Gas holdup, liquid holdup, turbulent promoter, fluidization, three-phase fluidized bed, bed porosity**

1. INTRODUCTION

Most chemical processes make use of three phase contacting strategy. Three-phase fluidized bed reactors discover extensive use in the process industries as they have numerous advantages over conventional reactors, such as improved contact among the phases, intimate mixing, a relatively low pressure drop across the bed, temperature evenness inside the bed, higher rates of heat and mass transfer and the comfortable adding up and removal of particles from the process equipment [1]. Bergles[2] reported a complete analysis of studies with different kinds of internal promoters which are turbulence augmenters for the case of homogeneous flow. Efforts were kept to use compound augmentation also to achieve throughputs to the maximum extent possible for least pumping costs and power loss. The fluidization on its own had become an inventive method to achieve elevated magnitudes of augmentations in coefficients. The enhancements in the coefficients were reported to be more than eight to ten times by solids alone. Additional enhancements can be attained by employing a gas as in gas–liquid-solid fluidization. Very few studies [3-12] were attempted so far on the improvements by inserting an active or passive turbulent promoter internals in a three phase fluidized bed.

Experiments had been conducted by using hourglass promoter as an internal to enhance mass transfer from wall to liquid for the case of homogenous flow[13], for the case of liquid solid fluidized beds[14] as well as for the case of gas liquid up flow bubble columns[15]. Coefficients of mass transfer had improved when the hourglass promoter was used as an internal as revealed by the above studies. To the best knowledge of the author, no other investigation had been carried out for mass transfer and on hydrodynamics in three-phase fluidized beds by using hourglass promoter as internal.

Keeping the above in mind, the authors had carried out an investigation to explore the impact of relevant geometric and dynamic variables on coefficient of mass transfer in a three-phase fluidized bed by using hourglass promoter as an internal. Attempts were also made for developing empirical correlations for coefficient of mass transfer by regression analysis with the use of proper dimensional groups relating geometrical parameters and flow variables. The electrodes set flush at inside surface of the exterior cylinder in the test section had been connected to electrical circuit in order to facilitate the limiting current measurement.

The chosen system is:

$[Fe(CN)_6]^{3-} + e \rightarrow [Fe(CN)_6]^{4-}$ (reduction) … (1)

$[Fe(CN)_6]^{4-} \rightarrow [Fe(CN)_6]^{3-} + e$ (oxidation) … (2)

The coefficient of mass transfer is computed from the calculated limiting current utilizing the equation

$$K_L = i_L / nAFC_o \qquad \text{---------} \ (3)$$

2. EXPERIMENTAL PROCEDURE

The present investigation aims at obtaining the transfer of mass from wall to bed in a fluidized bed consisting of three phases by using an array of coaxially placed hourglasses prearranged concentrically on a central rod as a turbulent promoter. The schematic of the test unit had been presented in Fig. 1.

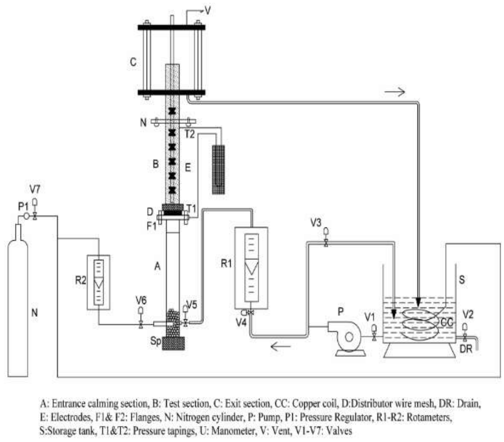

Fig. 1. Schematic diagram of the Experimental setup

Three sub sections namely an entry section or calming section(A), a test section(B) and exit section(C) constitute the main experimental column as illustrated in Fig. 1. The entrance section is made of copper having 6.73cm internal diameter, 7.62cm external diameter and 1.07m length. Randomly sized marble stones were used to fill the bottom part of entrance section to curtail the flow fluctuations and to eradicate tangential entrance effects. Uniform distribution of gas was attained by connecting the gas inlet to a stainless steel made sparger (SP). The flange (F_1) was used to bring connection between the entrance section and test section. A perspex electrochemical cell with 6.73 cm internal diameter and with 0.6 m tall was the test section (B). Thirty-four numbers of copper micro electrodes with 0.00342 m diameter were provided to the test section. One end of those electrodes had set flush to the inside surface of the test section whereas the remaining end was extended outside and behaved as the terminal that acted as a connector between electrical circuit and the electrodes. The bottom part of the test section had been make avaialbel with a stainless steel make wire mesh. Wire mesh served as distributor (D) for fluids as well as a supporter of solid bed. It also had facilitated the electrolyte distribution and gas distribution with uniformity and had helped holding the promoter element. The bottom and top flanges of the test section were provided with two pressure tappings to gauge the difference of pressure across the test section. Those pressure taps had been linked to a 'U' tube manometer in which carbon tetra chloride was used as manometric liquid. Weighed glass beads had been placed as bed material in the test section.

3. RESULTS AND DISCUSSION

The variables that are found to be influencing the mass transfer are superficial velocities of liquid and gas, the particle diameter, promoter rod diameter, characteristic length of the hourglass element and pitch of the promoter. Apart from that the bed porosity and axial length also could show some effect. In this connection, initially the impact of axial length on limiting current and mass transfer is examined.

In the present case, the reason for not exhibiting any significant fluctuations along the longitudinal direction has been explained by Bheemisetti[16]. In the dense bed zone, there is turbulence resulting mainly from scouring action of particles. In the lean bed zone, the flow velocity of the liquid is very high that the resistance film upon the electrode surface is scrapped out to be minimum. Therefore, nearly uniform values for coefficient of mass transfer are attained.

Velocity of liquid showed tremendous effect on coefficient of mass transfer in homogeneous flow with hourglass as an internal[13]. Liquid velocity is also found to be very important especially at lower velocities of liquid and gas in gas–liquid bubble columns as testified by Ramesh et al[6]. Fig. 2 displays the coefficients of mass transfer plotted against superficial velocity of liquid for three different gas velocities. Gas velocities of 0.0140, 0.0234 and 0.0374 meters per second were considered in the present study. Plot A links to a gas velocity of 0.014 meters per second, plot B links to the gas velocity of 0.234 meters per second and plot C links to the gas velocity of 0.0374 meters per second. From these plots, it can be noticed that varying gas velocity did not affect noticeably the mass transfer coefficient.

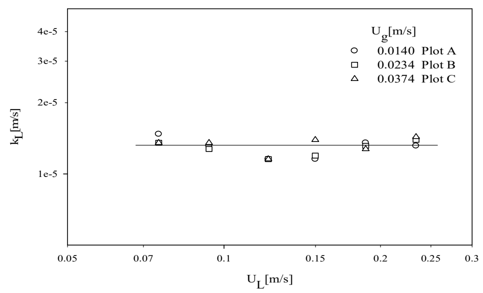

Fig. 2 Effect of velocity of liquid on mass transfer coefficient

Earlier studies[13-15] revealed that the pitch was one among the key parameters which may affect the flow pattern in homogenous flow and fluidized beds. Pitch of the hourglass promoter is an essential geometric parameter that affects the flow pattern at the wall hence appreciably influencing the resistance film thickness. Fig. 3 represents the graph that show how the coefficients of mass transfer are being affected by the variations in pitch for the pitch values of 5 centimeters, 7 centimeters and 10 centimeters.

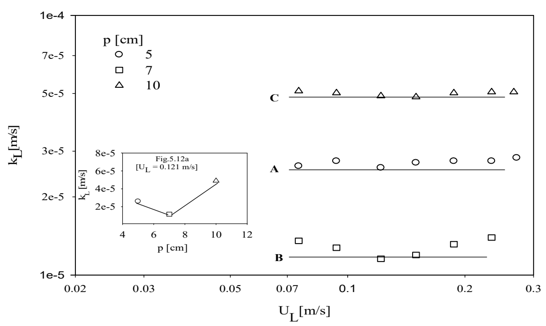

Fig. 3 Effect of pitch on coefficient of mass transfer

It is discovered from both the above figures that the coefficients of mass transfer decreased firstly from a pitch value of five centimeters to seven centimeters (Plots A and B) and then increased for further enhancement in pitch value from seven centimeters to ten centimeters (Plots B and C). The two inset graphs also display the same trend. For a pitch of five centimeters, a free space of one centimeter was there between two consecutive hourglass elements along the axial direction which was engaged by sluggish liquid and solids only. Therefore, the turbulence caused due to their presence would not account for the value of coefficient of mass transfer. But for a pitch of seven centimeters, the free space was three centimeters which favored the formation of wakes due to sudden contractions and sudden expansions. These wakes were without overlapping therefore it results in low values for coefficients of mass transfer. In contrast, for a pitch of ten centimeters, free space was more for the wake formation. Gas phase along with the overlapping of wakes formed, generated severe turbulence resulting in high values for mass transfer coefficients.

The characteristic length is the base diameter of a hemisphere. Area available for fluid flow is decreased with the increase of characteristic length of hourglass leading to the increase of liquid velocity at such regions in the test section when the hourglass element is present. The formation of wakes is predicted due to the sudden contractions and expansions at the edges of hourglass when it is placed transverse to the flow of liquid leading to rigorous turbulence. Hence, increased mass transfer coefficients can be predicted. Fig. 4 shows the graph of coefficients of mass transfer drawn against velocity of liquid for characteristic lengths of three centimeters, four centimeters and five centimeters. Plot A corresponds to a characteristic length of three centimeters, Plot B links to the characteristic length of four centimeters and Plot C links to the characteristic length of five centimeters in both these graphs.

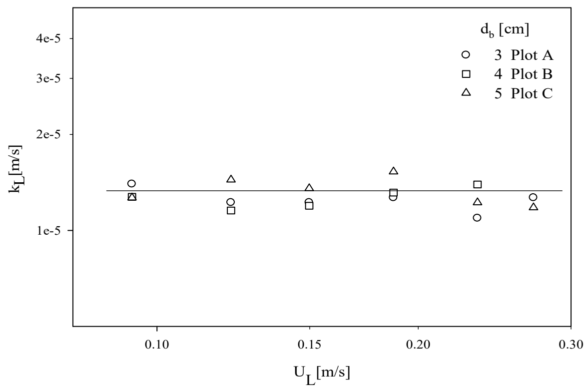

Fig. 4 Effect of characteristic length on mass transfer coefficient

The plots reveal that, values for coefficients of mass transfer are not affected by changing the values of characteristic length. Employing promoter, gas velocity and liquid velocity are the reasons for causing severe turbulence. Nevertheless, the turbulence caused by the gas is supposed to be very high. As a result, a marginal addition is resulted in turbulence because of variations in the characteristic length when compared to that of total turbulence. Hence, characteristic length did not show any clear impact on coefficients of mass transfer.

The effect of three promoter rod diameters viz., 0.6, 1.0 and 1.3 centimeters are investigated in the present study. The presence of hourglass is expected to lead to the formation of sudden expansions and contractions when the flow is taking place, ensuing viscous turbulence. An increase in the diameter of this central rod d_r causes an improvement in obstruction to the flow hence lessening the available cross-sectional area. In the present study, the impact of diameter of rod on k_L has been revealed in Fig. 5. A careful investigation of the plots of this figure reveals that there is no perceptible parametric influence of promoter rod diameter on mass transfer coefficient. The diameter of promoter rod being very little when compared to the column diameter, the variation in velocities of local fluid because of the presence of the promoter rod is very small. Thus, the average coefficient of mass transfer is not likely to be influenced by the diameter of promoter rod.

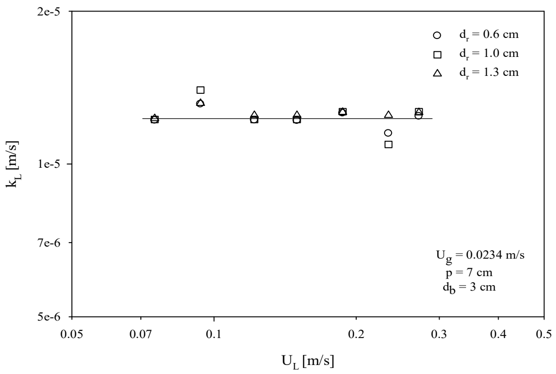

Fig. 5 Effect of rod diameter on coefficient of mass transfer

The additional factor contributing to the decrease in film thickness is the circulation of solids triggering vigorous turbulence in the bulk of the electrolyte as well as at the reacting surface i.e. column wall in the present case. When the diameter of particle is more, its momentum would be forcing the particle to strike the transfer surface more severely hence added scouring away the resistance film. Thus improved coefficients of mass transfer would be appreciated.

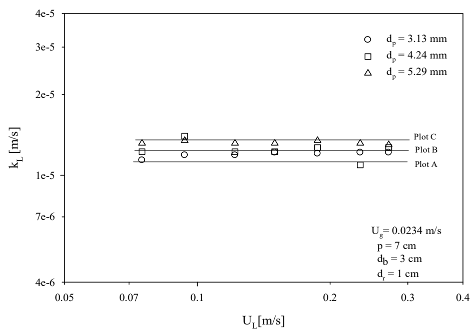

Fig. 6 Effect of particle diameter on coefficient of mass transfer coefficient

Fig. 6 shows the coefficient of mass transfer data obtained when the velocity of gas was kept constant at 0.0234 meters per second and the liquid velocity was varied. The pitch of the promoter taken is 7 centimeters, the hourglass characteristic length is 3 centimeters and the promoter rod diameter is one centimeter. Three different sizes of the particles were chosen. These are 3.13, 4.23 and 5.29 millimeters. The plots corresponding to these particles were exposed as A, B and C correspondingly. However, in the present system, the plots revealed that the effect of particle diameter was not very significant with increase in liquid velocity.

Development of generalized correlation

Earlier investigators[17,6] on two-phase or three-phase fluidized beds had correlated their data using the format of equations involving the dimensionless groups such as j_D-Re. the entire data are segregated into two parts based on the pitch value.

For 5≤ p ≤ 7, the following correlation equation is obtained.

$$j_D = 10.56\left(\mathrm{Re}_p\right)^{-1.06}\left(\frac{d_b}{D_c}\right)^{0.22}\left(\frac{p}{D_c}\right)^{2.25} \quad \ldots (4)$$

Average deviation = 6.310 percent

Standard deviation = 7.667 percent.

For 7≤p≤10, the following correlation equation is obtained.

$$j_D = 8.805\left(\mathrm{Re}_p\right)^{-1.07}\left(\frac{d_b}{D_c}\right)^{0.22}\left(\frac{p}{D_c}\right)^{3.86} \quad \ldots (5)$$

Average deviation = 6.283 percent

Standard deviation = 7.627 percent.

4. CONCLUSIONS

The enhancements in the limiting current because of the introduction of the hourglass promoter internal in a three-phase fluidized bed were up to a maximum of 70 percent at lesser liquid velocity end and 20 percent at upper liquid velocity end. The impact of axial length on coefficient of mass transfer is almost trivial. The velocity of gas has marginal influence only on coefficient of mass transfer. The liquid velocity had no noticeable influence on coefficient of mass transfer. The coefficient of mass transfer decreased initially with increasing pitch value and then increased with additional improvement in pitch value. The characteristic length had not exhibited any impact on coefficient of mass transfer. There is no perceptible parametric influence of promoter rod diameter on mass transfer coefficient. The effect of particle diameter was not very significant with increase in liquid velocity. The coefficient of mass transfer was almost unaltered by varying gas holdup. The coefficient of mass transfer is unaltered by the varying liquid holdup. The influence of bed porosity on mass transfer coefficient is nearly absent.

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