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SHORTER COMMUNICATION

EXPERIMENTAL STUDY OF EFFECT OF GAS INJECTION ON RATE OF MASS TRANSFER FROM SOLID TO LIQUID

LIANG-TSENG FAN
Department of Chemical Engineering, Kansas State University, Manhattan, Kansas

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LIST OF SYMBOLS

D_p, diameter of pellet, ft;
G_v, volumetric flow rate of gas, $ft^3/h\ ft^2$;
J_d, mass transfer factor based on liquid flow in two phase flow, dimensionless;
J_{d0}, mass transfer factor in single phase flow, dimensionless;
k_1, mass transfer coefficients based on water flow in two phase flow, $lb/ft^2\ h$;
k_{10}, mass transfer coefficients of single phase flow, $lb/ft^2\ h$;
L_m, mass velocity of water, $lb/h\ ft^2$;
L_v, volumetric flow rate of water, $ft^3/h\ ft^2$;
N_{sh}, Sherwood number, dimensionless;
R, G_v/L_v, dimensionless;
T, temperature, °F;
ϵ, void fraction, dimensionless;
μ, viscosity of liquid.

INTRODUCTION

It is known that the mechanical agitation of the fluid increases the rates of transfer process from a solid to the fluid [1]. When the fluid is a liquid, injection of a gas produces agitation of the liquid. The injection of a gas into the flowing liquid also reduces the space available for the flow of the liquid past the solid surface, thus increasing the linear velocity of the liquid. This intensifies the turbulence and reduces the thickness of the laminar boundary layers around the solid. This should promote the rate of mass transfer. The agitating action of the gas also increases the back-mixing of the fluid in the axial direction of fluid flow. Also the effective transfer area between solid and liquid may be reduced by the presence of the gas. The last two effects should retard the mass transfer.

It can be expected that the first two effects, i.e. the breaking up of the boundary layer and the increased linear velocity of liquid, will predominate when the quantity of injected gas is relatively small; and the last two effects, i.e. increased back-mixing of the liquid and the reduction of the effective transfer area, will be increased as the rate of gas injection is increased. This can be observed in a number of published papers [2, 3] on the effect of gases on the rate of heat transfer between the wall of circular pipes and liquid. Few published data, however, are available concerning the effect of gas injection on mass transfer.

EXPERIMENTAL PROCEDURE

The liquid and gas used in this work were water and nitrogen respectively. The solid used was cylindrical pellets of benzoic acid, with 0·224 in diameter and height.

The test section consisted of a 2 in i.d. by 6 in high cylindrical glass column which was placed above a 14-in section of 2 in i.d. pipe which served as a mixing and calming section. First, 2½ in of inert clay pellets were packed in the column. The clay pellets were of approximately the same size and shape as the acid pellets. The acid pellets were packed into a bed above the inert clay packing. The pellets were then confined by a coarse screen and spring mechanism to reduce the movement of pellets.

Each series of experimental runs consisted of one run without gas injection and several runs with various rates of gas injection. The concentration of benzoic acid in samples obtained from each series of runs was determined by titration.

The degree of randomness of the beds was checked by comparison of single phase (water) flow data with a generalized correlation of solid–fluid mass transfer [4], which was obtained for randomly packed beds.

DISCUSSION AND CONCLUSION

The increase of the mass transfer coefficients due to the injection of inert gas is represented in Fig. 1 as ratios of mass transfer coefficients with gas injection to those under single phase flow.

Figure 1 indicates that the mass transfer rate is accelerated appreciably by injection of relatively small quantities of gas to the flowing liquid. Unlike most of the heat transfer data published, the curves in Fig. 1 do not tend to decline after reaching a maximum point in spite of the fact that the gas injection rate was increased almost five fold in comparison to that used in heat transfer work [2]. This may be explained as follows:

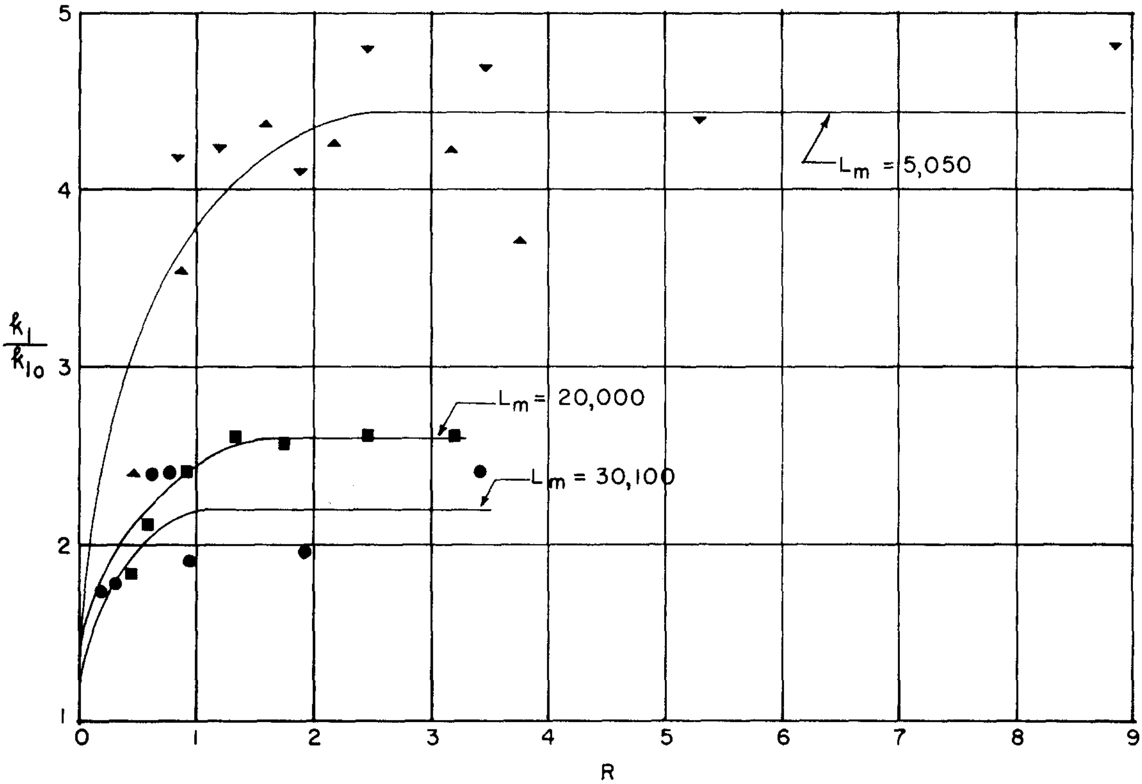

FIG. 1. Effect of inert gas injection on rate of mass transfer.

While the data presented here were obtained in a column packed with particles of benzoic acid, the heat transfer data [2] were obtained in an unpacked plain circular tube. The contact area between the solid and liquid is usually much larger in a packed column than in an unpacked column. A 2 in diameter by 3 in height glass tube packed with 627 benzoic acid particles with a total surface area of 1·06 ft^2 was used in these experiments. The ratio of the surface area of benzoic acid particles to that of the tube inside was roughly eight. Therefore, it might be expected that more than an eight fold increase in the gas quantity over that used in the heat transfer work [2] would be needed to produce decreased mass transfer rates due to the cover-up of transfer area by the gas.

In a manner similar to the results of heat transfer studies, the effect of gas injection in increasing the mass transfer rate becomes smaller as the liquid flow rate increases. Simple reasoning leads to the conclusion that as the liquid flow rate approaches infinity the injection of finite quantity of inert gas will not produce any effect.

In the range of this work, the following empirical equation approximates the $(k_1/k_{10})_{\max}$ or, in term of mass transfer factor, $(J_d/J_{d0})_{\max}$.

$$\left(\frac{J_d}{J_{d0}}\right)_{\max} = 5{\cdot}0 \exp\left[-1{\cdot}76 \times 10^{-3} \frac{D_p L_m}{\mu(1-\epsilon)}\right]. \quad (1)$$

Since, in general [4]:

$$J_{d0} = 1{\cdot}77 \left[\frac{D_p L_m}{\mu(1-\epsilon)}\right]^{-0{\cdot}44} \quad (2)$$

$$(J_d)_{\max} = 8{\cdot}85 \left[\frac{D_p L_m}{\mu(1-\epsilon)}\right]^{-0{\cdot}44} \times \exp\left[-1{\cdot}76 \times 10^{-3} \frac{D_p L_m}{\mu(1-\epsilon)}\right]. \quad (3)$$

From the results of this experimental investigation, the following conclusions could reasonably be drawn:

(1) Injection of gas is a very effective means of accelerating the mass transfer rate from solid to liquid.
(2) When the injection rate of the gas is relatively small, the effect of intensified turbulence due to increased linear velocity of the liquid and mechanical agitation of gas bubbles predominates.

(3) When the gas velocity is increased further, the effect is partially nullified by the reduction of effective transfer area and by the increased back-mixing of liquid in the direction of flow.

(4) The magnitude of the increase of solid–liquid mass transfer rates due to the injection of gas is comparable to that effected by mechanical pulsation of the liquid [5]. It appears, however, that a much less complicated mechanism is required to inject the gas into the liquid than to induce the pulsation of the flowing liquid [5].

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