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Fractal Theory Analysis of SO_2 Mass Transfer Characteristics in the Modified Packed Absorption Tower

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Abstract: The functions of hydromechanics and volumetric mass transfer coefficient K_{Xa} of cross flow packed tower were studied by setting baffle plates, The influence of different plate spacing (ratio of baffle spacing H to column diameter D) on height of mass transfer unit and mass transfer characteristics were observed and compared in an ordinary packed tower and a cross flow packed tower. Furthermore, using STATISTICA software, the corresponding K_{Xa} correlations were proposed and discussed.

Keywords: fractal theory; modified packed tower; baffle plate; mass transfer characteristics

1 Introduction

The packed tower is one of the most common equipment items in chemical processing. Owning to the easiness in fabrication and replacement, wide range of material selection, strong adaptability, small pressure drop and liquid hold-up as well as efficient mass transfer, great process has been made in the packed tower in the past twenty-odd years. It is mainly applied in the petrochemical, fine chemical, pharmaceutical, foodstuff and environmental protection fields [1–4]. Recently, the operation conditions of the packed tower [5, 6] and the influence of column internals on the absorption effect [7–10] has been received great attention. Nevertheless, it is rare to come across the enhancement of the turbulivity by changing the contact mode of the gaseous and liquid phases, and then improving absorbility. In this paper, baffles are installed inside the staggered packed tower at a certain interval along the height, with neighboring baffles laid out in a manner in the horizontal direction to change the flowing mode of the gaseous and liquid phases from the conventional counter flow to cross flow. The mass transfer transfer characteristics of the modified packed tower and the ordinary packed tower are comparatively investigated.

2 Experimental conditions vs. overall volume absorption coefficient

The experiment was conducted at atmospheric pressure and a temperature of 25°C, and fresh water was used to absorb SO_2 in the mixture of air and SO_2. When the experimental conditions were not changed, the phase equilibrium coefficient was a constant. The inlet and outlet concentrations of the gaseous phase were measured by gas phase chromatography SP6801, and the flow rate of the gaseous and liquid phases was read from rotameters. The concentration X_1 of outlet liquid was calculated with expression (1) according to the law of conservation of mass. Based on the experimental data, the overall volume absorption coefficient K_{Xa} of the liquid phase could be calculated according to expressions (2)∼(4).

$$V(Y_1 - Y_2) = L(X_1 - X_2). \tag{1}$$

$$Z = H_{OL}N_{OL}. \tag{2}$$

$$N_{OL} = (X_1 - X_2)/\triangle X_m. \tag{3}$$

$$H_{OL} = L/K_{Xa}\Omega. \tag{4}$$

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3 Data processing, results and discussions

3.1 Influence of flow rates of gaseous and liquid phases on K_{Xa}

Figure 1 shows the influence of flow rates of the gaseous and liquid phases on the overall volume absorption coefficient K_{Xa} respectively for the ordinary packed tower and the cross flow packed tower. The liquid phase had the same performance for the ordinary packed tower and the cross flow packed tower; in both cases the coefficient K_{Xa} increased with the increase of the liquid phase flow rate. In the ordinary packed tower, with the increase of the gaseous phase flow rate,

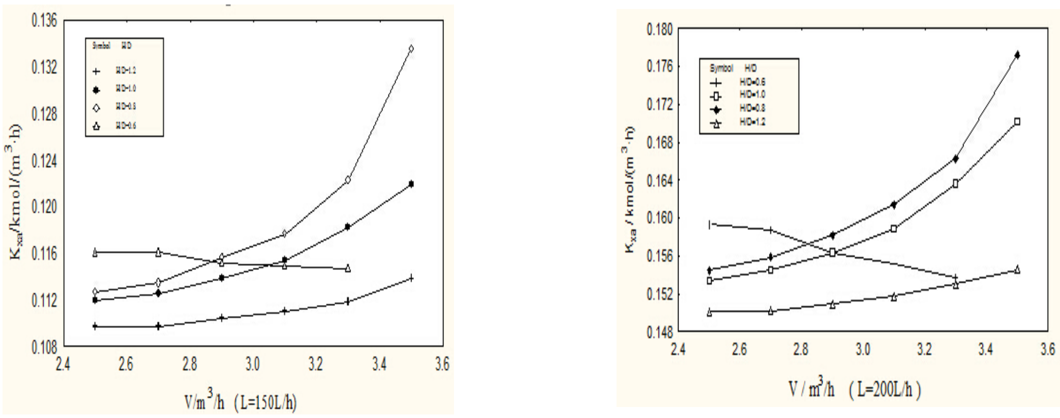

Figure 1: The influence of flow rates and baffle plate spacing H/D on the K_{Xa}.

K_{Xa} essentially remained a fixed value. As the process of SO_2 absorption by water is a liquid film controlling process, and the resistance of liquid film determines the overall resistance of the absorption process, the gaseous phase has hardly any influence on the absorption, whereas in the cross flow packed tower, K_{Xa} increased with the increase of the gaseous phase flow rate. The reason is that the provision of baffles has increased the agitation of gas to the liquid film, thus fractal more irregular and quickly renewing the liquid film surface and decreasing the resistance of the liquid film to intensify the mass transfer process.

3.2 Influence of baffle plate spacing on K_{Xa}

The influence of baffle plate spacing on K_{Xa} was studied for the cross flow packed tower by changing the spacing between two baffle plates. Figure 1 shows when H/D was definite $(1.2 \sim 0.8)$, K_{Xa} increased with the increase of the gas flow; when the flow rates of the gaseous and liquid phases were definite, K_{Xa} increased with the decrease of $H/D(1.2 \sim 0.8)$; when $H/D < 0.8$, K_{Xa} decreased with the increase of the gas flow instead. This is because the increase of velocity of the gas with the same flow rate flowing between the baffles increased agitation to the liquid film and expedited renewal of the liquid film surface, hence the increase of K_{Xa}; when $H/D < 0.8$, the increase of the gas flow caused the increase of the gas velocity flowing between the baffles or even some carryover of liquid to the upper layer tray to influence the mass transfer of gas and liquid, so K_{Xa} decreased with the increase of the gas flow instead. When the gas flow was greater than $3.3m^{-3} \cdot h^{-1}$, as the pressure drop of the gaseous phase was too large, normal operation was not possible. This shows that an optimal $H/D = 0.8$ exists inside the packed tower.

3.3 Influence of baffle plate spacing on the height of mass transfer unit H_{OL}

The height of mass transfer unit reflects the mass transfer performance of the packed tower. The higher the height of mass transfer unit is, the better the mass transfer performance of the packed tower will be. The influence of the baffle plate spacing on H_{OL} is shown in Figure 2. It is shown that installing baffle plates inside the packed tower will decrease the height of mass transfer unit of the packed tower and thus improve the mass transfer performance of the packed tower.

Figure 2 shows that when $H/D < 0.8$, at a low gas velocity, the height of mass transfer unit was small; the height of mass transfer unit increased with the increase of the gas velocity, and when the gas flow exceeded $3.3m^3 \cdot h^{-1}$, mass

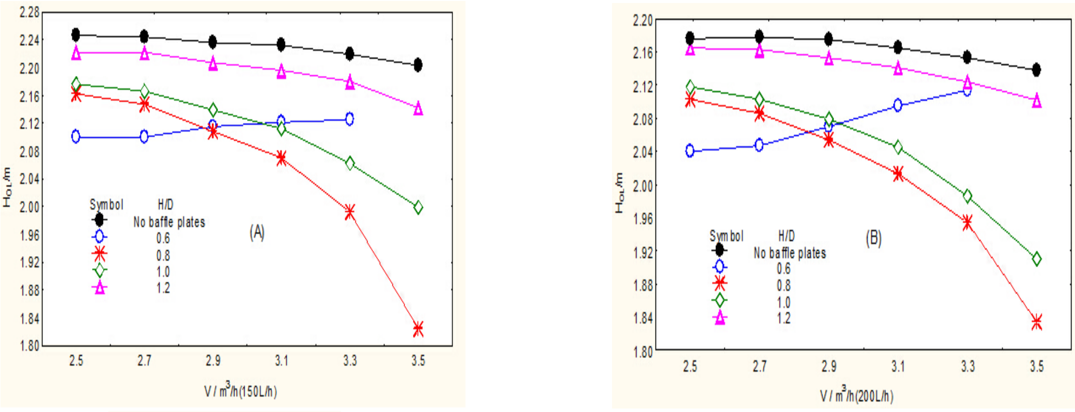

Figure 2: Height of mass transfer unit vs. baffles.

transfer was not possible due to excessively large pressure drop. When $H/D = 0.8 \sim 1.2$, the height of mass transfer unit increased gradually with the increase of H/D, and decreased gradually with the increase of the gas velocity. So when $H/D = 0.8$, the packed tower presented the best mass transfer performance, and the influence of the gaseous phase flow rate on it was significant. This shows the mass transfer performance of the packed tower can by improved by installing baffle plates at suitable plate spacing inside the packed tower.

3.4 Experimental correlations for K_{Xa}

As the influence of the flow rates of the gaseous and liquid phases and the influence of the baffle plate spacing on K_{Xa} are correlated, K_{Xa} is expressed by multiplication of exponential forms of the gaseous phase flow rate and the liquid phase flow rate. The correlations for K_{Xa} under different conditions are worked out by the STATISTIC software based on the above experimental data.

The results of ordinary packed tower are:

$K_{Xa} = 0.7726V_G^{0.064}V_L^{1.062}$ Correlation coefficient *R*$= 0.9997$

The results of cross flow packed tower are shown in Table 1:

Table 1: The results of cross flow packed tower:$(2.5m^3 \cdot h^{-1} \leq V_G \leq 3.5m^3 \cdot h^{-1} \quad 150L/h \leq V_L \leq 200L/h)$

$K_{Xa} = 0.786V_G^{0.095}V_L^{1.086}$	Correlation coefficient *R*$= 0.9996$	$H/D = 1.2$
$K_{Xa} = 0.707V_G^{0.283}V_L^{1.117}$	Correlation coefficient *R*$= 0.9974$	$H/D = 1.0$
$K_{Xa} = 0.574V_G^{0.418}V_L^{1.069}$	Correlation coefficient *R*$= 0.9906$	$H/D = 0.8$
$K_{Xa} = 0.968V_G^{-0.105}V_L^{1.062}$	Correlation coefficient *R*$= 0.9995$	$H/D = 0.6$

For the ordinary packed tower, K_{xa} is in direct proportion to ${V_G}^{0.064}$ and ${V_L}^{1.062}$, and as for the coefficient of the exponent, the coefficient for the liquid phase is far greater than that for the gaseous phase, indicating that the liquid phase flow rate of the determines the absorption resistance. For the cross flow packed tower, although the absorption resistance is still mainly determined by the liquid phase flow rate, the provision of baffles has caused the fact that the gaseous phase flow rate has also imposed some influence on the absorption resistance, and with the decrease of $H/D(1.2 \sim 0.6)$, the increase of the gaseous phase flow rate may lower the absorption resistance. When $H/D = 0.8$, the influence of the gaseous phase flow rate on the absorption resistance is the largest, and with the increase of the gaseous phase flow rate, the absorption resistance decreases gradually; when $H/D < 0.8$, the influence of the gaseous phase flow rate on the absorption resistance weakens, and with the increase of the gas flow, the absorption resistance increases slightly. This might be because the plate spacing is too small, with the result of reduced passage for gas flowing and increased pressure drop, thus influencing the mass transfer of the gaseous and liquid phases. It is thus seen that mass transfer can be intensified by installing baffles with suitable plate spacing in the packed tower.

4 Conclusions

When $H/D = 0.8 \sim 1.2$, the height of mass transfer unit decreases with the increase of the gas flow and increases with the increase of H/D; when $H/D < 0.8$, the height of mass transfer unit increases with the increase of the gas flow.

The liquid phase flow rate has the same performance on K_{Xa} of the ordinary packed tower and the cross flow packed tower, and in both cases K_{Xa} increases with the increase of the liquid phase flow rate.

K_{Xa} of the ordinary packed tower has almost nothing to do with the gaseous phase flow rate, whereas in the cross flow packed tower ($H/D = 1.2 \sim 0.8$), the increase of the gaseous phase flow rate may cause K_{Xa} to increase, and when $H/D = 0.8$, the mass transfer effect of the gaseous and liquid phases is the best; when $H/D < 0.8$, with the increase of the gaseous phase flow rate, the mass transfer effect of the gaseous and liquid phases is weakened instead. When the gas flow is greater than $3.3m^3 \cdot h^{-1}$, as the pressure drop of the gaseous phase is too large, normal operation is not possible.

The provision of baffles in the cross flow packed tower has changed the flow behavior of the gaseous and liquid phases and weakened the wall flow effect; therefore it is not necessary to install liquid redistribution devices inside the tower.

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Appendix: Nomenclature

V kilo molar flow rate of inert gas (kmol/h)
L kilo molar flow rate of clean water (kmol/h)
Y_1 mol ratio of CO_2 in gas entering the column(mol/mol)
Y_2 mol ratio of CO_2 in gas exiting the column(mol/mol)
X_1 mol ratio of CO_2 in liquid exiting the column(mol/mol)
X_2 mol ratio of CO_2 in liquid entering the column(mol/mol)
K_{Xa} overall volumetric coefficient of liquid phase volumetric absorption(kmol/$m^3 \cdot$ h)
Z height of packing layer(m)
H_{OL} height of liquid phase mass transfer unit(m)

N_{OL} number of liquid phase mass transfer units
Ω sectional area of column(m^2)
V_G volumetric flow rate of gaseous phase(m^3/h)
V_L volumetric flow rate of liquid phase(m^3/h)
$\triangle X_m$ logarithmic mean driving force of liquid phase(mol/mol)