Absorption of VOCs in Rotating Packed Bed

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0.28   0.51

K_Ga

(keyword: Absorption, VOC, Rotating Packed Bed, Higee, Mass Transfer Coefficient)

A Higee absorption process was developed for removing VOCs (Volatile Organic Compounds) from air into aqueous phase under a centrifugal field. A rotating packed bed, which replaces gravity with centrifugal force, was adopted in this study. Under a centrifugal field, the operating range can be covered in higher gas and liquid flow rates due to the reduced tendency to flood, and mass transfer was also enhanced. The experimental results showed that the mass transfer coefficient was increased with increasing rotor speed, to the power ranging from 0.28 to 0.51. Comparing with the model-predicted values and the experimental data of conventional packed beds, K_Ga obtained from our experiment was approximately an order of magnitude higher.

INTRODUCTION

In recent years, there have been many studies on mass transfer intensification of various systems in the high gravity system (i.e. Higee), such as absorption, stripping, adsorption, distillation, and extraction. The higee system, developed by Ranshaw and Mallinson (1981), basically is a rotating packed bed that replaced gravity with centrifugal force. Under a centrifugal field, the liquid film and the mass transfer boundary layer may become thinner. Consequently, the effective wetted surface area of the packing may be increased. Moreover, the system may be operated in higher ratio of gas and liquid rates due to the reduced tendency of flooding. These features would contribute to process intensification; mainly by enhancing mass transfer dramatically and reducing the equipment size significantly.

Absorption, a separation technique to remove VOCs, is to transfer gaseous pollutants to liquid absorbent in a packed column or a bubble

column. Several literatures have been published about the adoption of centrifugal field in the packed bed for absorption. Ramshaw and Mallinson (1981) performed an experiment of absorbing NH_3 into water, and found that the gas phase mass transfer coefficients were 4-9 times higher than those conventional packed beds. Keyvani and Gardner (1989) investigated an air-CO_2-H_2O system. The liquid phase volumetric mass transfer coefficient increased with rotational speed to the power of 0.6-0.7. And an average height of transfer unit could be reduced to 1.5-4.0 cm, which means a reduction of the packed tower height up to two orders of magnitude. Kumer and Rao (1990) also adopted a CO_2-NaOH solution system and found that the overall liquid phase volumetric mass transfer coefficients were an order of magnitude higher than those in conventional packed beds. Guo et al. (1997) constructed a cross-flow rotating packed bed. They performed experiments of absorption of NH_3 in water and absorption of SO_2 in ammonium sulfite solution. Their results showed that the overall gas phase volumetric mass transfer coefficients were not influenced by rotational speed when centrifugal acceleration was above 15g. However, there is no literature concerning absorbing VOCs in a rotating packed bed. Thus, the purpose of this study is to evaluate the centrifugal force on the efficiency of VOCs removal by absorption.

EXPERIMENT

Fig. 1 shows the diagram of the experimental setup. Fresh water at 25   was pumped into the rotating packed bed. An air stream was introduced to a bubbler containing liquid VOCs, and was diluted by another air stream to the desired VOC concentration. The buffer flask in fact is an empty flask to maintain stable gas concentration. Then the water and the gas stream contacted countercurrently in a rotating packed bed. Two VOCs, i.e. isopropyl alcohol and acetone, were used in this study. The concentration of inlet and outlet gas streams were measured by a gas chromatography. In the rotating packed bed, the packings used in this study were 2-mm diameter plastic beads, whose total specific surface area, a_t, was 1200 m^2/m^3, and porosity,   , was 0.4. The axial height of the bed was 2 cm. The inner and outer radiuses of the bed were 2 and 4 cm, respectively. The bed can be operated from 150 to 2100 rpm.

RESULTS AND DISSCUSION

Fig. 2 shows the dependence of VOC removal efficiency on rotor speed. It is obvious that the removal efficiency increases as rotor speed increases within less than 1 second contact time (Guo et al., 2000). This characteristic implies better mass transfer under a high centrifugal field.

The design equation, similar to the one derived by Liu et al. (1996), can be also obtained using mass balance and the transfer unit concept:

$$K_G a = \frac{G_m}{z p_t \delta (r_2{}^2 - r_1{}^2)} \frac{\ln \left[\left(1 - \frac{1}{A}\right) \frac{Y_1 - H_y X_2}{Y_2 - H_y X_2} + \frac{1}{A} \right]}{\frac{1}{A} - 1} \quad (1)$$

where A is the absorption factor defined as

$$A = \frac{L_m}{H_y G_m} \quad (2)$$

Fig. 3 shows the dependence of $K_G a$ on rotor speed. The mass transfer coefficient could be increased by increasing rotor speed. In other words, the centrifugal force reduces mass transfer resistance. If $K_G a$ is expressed as a power law of the rotor speed,   , that is,

$$K_G a \propto \grave{u}^{\,x} \qquad (3)$$

The values of x generally increase with the increase of liquid and gas flow rates and ranges from 0.28 to 0.51.

For conventional packed beds, there have been many correlations to predict a mass transfer coefficient. Eq. (4) is the correlation for the gas phase mass transfer coefficient provided by Onda et al. (1968).

$$\frac{k_G}{a_t D_G} = 2Re_G^{\,0.7} Sc_G^{\,1/3} (a_t d_P)^{-2} \qquad (4)$$

The gas-liquid interfacial area, a, was also provided by Onda et al. (1968).

$$\frac{a}{a_t} = 1 - \exp\left(-1.45\left(\frac{\acute{o}_c}{\acute{o}}\right)^{0.75} Re_L^{\,0.1} Fr_L^{\,-0.05} We_L^{\,0.2}\right) \qquad (5)$$

An overall gas phase volume mass transfer coefficient, $K_G a$, may be expressed in terms of the two film coefficients as follows:

$$\frac{1}{K_G a} = \frac{1}{k_G a} + \frac{H}{k_L a} \qquad (6)$$

where k_L is given by Onda et al. (1968).

$$k_L \left(\frac{\tilde{n}_L}{\grave{i}_L g}\right)^{1/3} = 0.005 \left(\frac{L'}{a\grave{i}_L}\right)^{2/3} \left(\frac{\grave{i}_L}{\tilde{n}_L D_L}\right)^{-0.5} (a_t d_p)^{0.4} \qquad (7)$$

With Eq. (4) to Eq. (7), the model-predicted value for conventional packed beds, $(K_G a)_c$, can be calculated. The comparison of $K_G a$ vs. $(K_G a)_c$ is shown in Fig. 4. It is obvious that these calculated values for conventional packed beds are lower than our higee results. The ratio of the higee experimental values to conventional correlations ranges from 1.15 to 7. This indicates that centrifugal force did enhance the mass transfer of the VOC absorption.

Houston and Walker (1950) performed an experiment of absorbing acetone by water in a conventional packed bed. The height and diameter of the bed were 2 ft and 12 inch. The packings were 1-inch Raschig rings. Their results are shown in Fig. 5. The $K_G a$ obtained from Houston and Walker is approximately an order magnitude lower than this higee experimental results.

CONCLUSION

According to the results of our experiment, it is clear that centrifugal force can intensify the mass transfer during VOC absorption in a rotating packed bed. The concentration of the outlet VOC would be reduced to very low level with aid of a centrifugal force during very short contact time. Compared with conventional packed beds, $K_G a$ of our experimental rotating packed bed can be up to several folds higher than the model-predicted values, and is an order magnitude higher than the experimental data for a conventional bed. This result is confirmed to Ramshaw's (1981) higee experiment, which showed the gas phase mass transfer coefficients were 4-9 times higher than the conventional ones. Therefore, a rotating packed bed indeed is a potential process intensification apparatus for absorption of VOCs.

REFERENCE

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Onda, K., H. Takeuchi, and Y. Okumoto, "Mass Transfer Coefficient between Gas and Liquid Phases in Packed Columns", *J. Chem. Eng. of Japan*, **1**, 56 (1968)

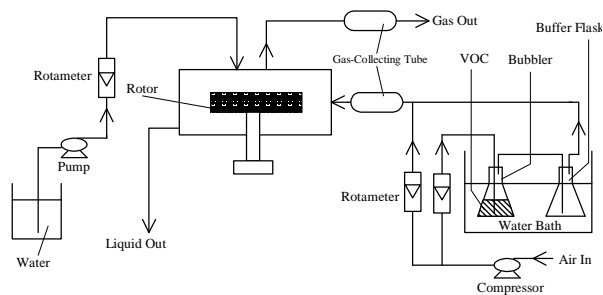Ramshaw, C. and R. H. Mallison, "Mass Transfer Process", United States Patent 4383255 (1981).

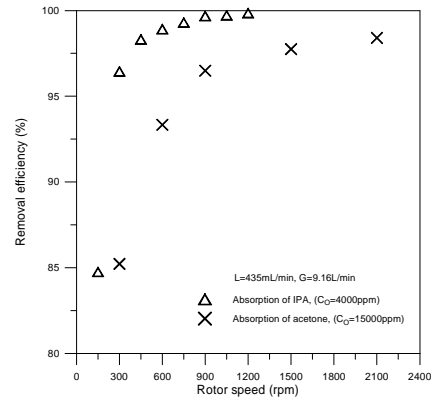Fig. 1. The diagram of the experimental setup.

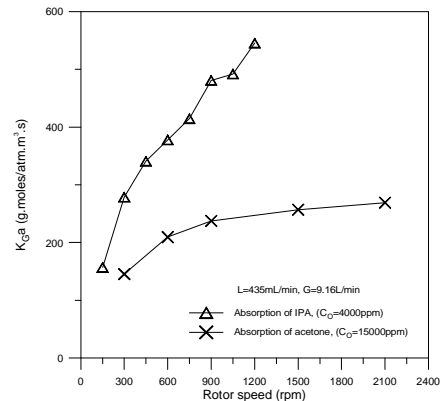Fig. 2. The dependence of VOC removal efficiency on rotor speed.

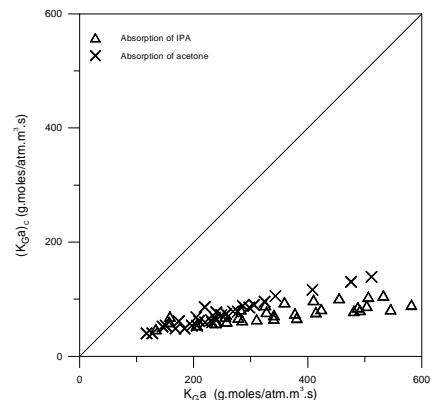Fig. 3. The dependence of K_Ga on rotor speed.

Fig. 4. Comparison of K_Ga of the experimental higee values with the calculated values for conventional packed beds.
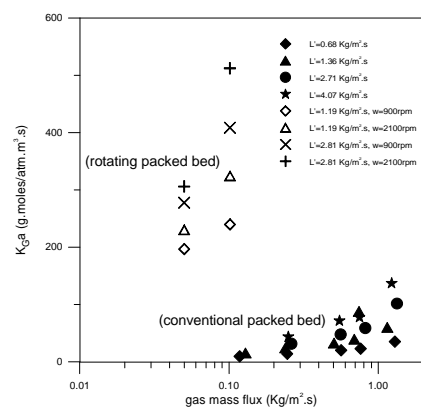

Fig. 5. The mass transfer coefficient of absorption of acetone in a rotating packed bed and in a conventional packed bed.