

Study on radial dispersion of solid-liquid in catalyst-bundles

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Abstract—Using the fixed bed ($\phi = 72\text{mm}$) packing with micro glass beads to simulate a small sack in the catalyst-bundles. A dispersion model was established at the stable state point source tracing condition, and its analytic and numerical solution were obtained. The stable state point source tracer technique and reducing pressure sampling were used to measure the concentration profile of tracer under different liquid flow rate and different height of fixed bed. The results indicated that the coefficient of radial diffusion decreased with the increasing of the packing height, on the contrary the coefficient of radial diffusion increased with the increasing of the liquid flow rate and the diameter of the micro beads. The influence of axial diffusion coefficient on the radial diffusion coefficient was also discussed and the relationship between Per with $\ln(Re)$ was obtained by data regression.

Key words: catalyst-bundles; dispersion model; concentration distribution; radial dispersion coefficient

I. INTRODUCTION

In the catalytic distillation tower, catalyst bundle is the commonly catalyst packing method, which consists of stainless steel ripple silk screen, catalyst, and small sack of nylon, polypropylene or vinylon. The preparation process of the catalyst-bundles is as follows: a certain amount of catalyst is loaded into a small nylon sack, then, the small nylon sack with loading catalyst is overlapped with a corrugated sheet of stainless steel wire gauze and coiled into circular cylinder, thereby forming a layer of sack and a layer of wire gauze, as shown in Fig.1. The catalyst-bundle is a quite mature and reliable catalyst packing way proved by the industrial practice [1].

In catalytic distillation tower, liquid flow in the catalyst-bundle is especially important because reaction is taking place in the liquid. So, the determination of radial dispersion in the catalyst-bundles is one of the most important study topics in recent years, because the radical dispersion coefficient is not only the key parameter of the catalytic distillation tower design, but also the essential data of the simulation and optimization. However, it is difficult to obtain reliable data on flow in catalyst-bundles because experimental methods are quite difficult and there are no good numerical methods to study the flow in catalyst-bundles.

The studies of the mixed characteristic in catalyst-bundles had been reported in references [2-3], but the researchers took samples directly from the outlet section in order to obtain the concentration profile at different height of the catalyst-bundle. The liquid flow of outlet section might have a distinct disturbance because it may destroy the flow field in the catalyst-bundles when sampling.

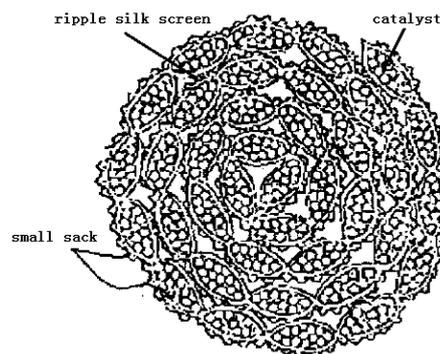


Fig. 1 Schematic of catalyst bundle

Wang et al. used the experiment principle of tracing–response to measure and calculate the mass transfer rate in the catalyst-bundles [4]. The concentration changes of tracer in the outlet of the fixed bed were measured in a 5A molecular sieve fixed bed with the diameter of 267mm in reference [5], in which the stable state point source tracer technique was adopted using methane as the trace gas. The results indicated that the radial diffusion was proportional to the gas flow speed. The mass transfer was studied by Baten [6] in fixed bed with the height of 290mm KATAPAK-SR catalyst-bundles, he found that axial and radial diffusion coefficients increased along with the rising of liquid flow rate and the axial dispersion might be neglected in its experimental scope.

The primary objective of our work is to determine radial diffusion coefficient in the catalyst-bundle. Besides experimental work, we have also established a dispersion model of the catalyst-bundle in order to obtain an insight into the liquid flow.

II. BUILDING AND SOLVING OF THE DISPERSION MODEL

As shown in Fig.1, the catalyst-bundle can be broken down into two sections: the sack section, which is filled with catalyst, and the channel section, which is formed between the sack and the corrugated sheet of wire gauze. During multiphase operation, in the catalytic distillation tower, liquid will flow down under influence of gravity and gas may flow either co- or counter currently, liquid will remain in the sack section due to capillary forces and gas will mainly remain in the channel section due to the lower resistance to flow. And liquid should not enter the channel section because pressure drop will increase significantly and

even flooding may occur. So the gas flowing doesn't affect the liquid flow in the sack section.

The dispersion of the liquid phase in the sack section contains axial and radial diffusions. Because the form of the small sack is circular cylinder, the small sack can be considered as a cylindrical fixed bed. The supposition can be proposed according to the actual situation in the fixed bed:

- The flow rate of tracer and deionized water is stable.
- Neglecting the influence of gas flow on the liquid dispersion in the sack section.
- Adsorption of micro glass beads to tracer is neglected.
- Liquid flow only along the axial.
- The fixed bed is axial symmetry.
- The fixed bed is uniform temperature.

The transfer model of the fixed bed is shown in Fig. 2 and Fig. 3 shows the schematic infinitesimal of the fixed bed. The material balance of tracer is made at the height of H , radius of r , and the partial differential equation (1) was obtained.

$$u_z \frac{\partial C_A}{\partial h} = E_h \frac{\partial^2 C_A}{\partial h^2} + E_r \frac{1}{r} \frac{\partial}{\partial r} \left(\frac{\partial C_A}{\partial r} r \right) \quad (1)$$

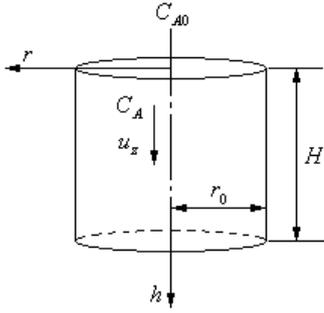


Fig. 2 Model of fixed-bed

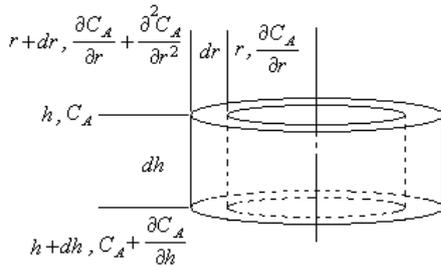


Fig. 3 Infinitesimal unit of the fixed-bed

According to the experimental set-up and the stable state point source, the boundary conditions of (1) are obtained:

$$\left(\frac{\partial C_A}{\partial r} \right)_{r=0} = 0 \quad (2)$$

$$\left(\frac{\partial C_A}{\partial r} \right)_{r=r_0} = 0 \quad (3)$$

$$0 \leq r \leq r_e, C(r,0) = C_{A0} \quad (4)$$

$$r_e < r \leq r_0, C(r,0) = 0 \quad (5)$$

Using separation of variable to solve (1), (6) can be obtained:

$$\frac{C_i}{C_{A0}} = 1 + \sum_{j=1}^{\infty} \frac{u_z}{u_e J_0^2(\alpha_j)} \exp \left[\frac{u_z r_0^2 - \sqrt{u_z^2 r_0^4 + 4NE_r^2 \alpha_j^2} h}{2NE_r} \right] \cdot J_0 \left(\alpha_j \frac{r_i}{r_0} \right) \quad (6)$$

In (6), $N = \frac{E_h}{E_r}$, if neglecting the axial dispersion, namely $N=0$, (1) can be simplified:

$$\frac{C_i}{C_{A0}} = 1 + \sum_{j=2}^{\infty} \frac{u_z}{u_e J_0^2(\alpha_j)} \exp \left[- \left(\frac{\alpha_j}{r_0} \right)^2 h \frac{E_r}{u_z} \right] \cdot J_0 \left(\alpha_j \frac{r_i}{r_0} \right) \quad (7)$$

In order to calculate the radial dispersion coefficient, N was supposed as a constant and the target function can be defined as follows:

$$q = \min \sum_{i=1}^9 \left(\frac{C}{C_{A0}} - \frac{C^*}{C_{A0}} \right)^2 \quad (8)$$

$$2 \sum_{i=1}^9 \left(\frac{C}{C_{A0}} - \frac{C^*}{C_{A0}} \right) d \left(\frac{C}{C_{A0}} \right) / dE_r = 0 \quad (9)$$

When q is very small, $dq/dEr=0$, Er can be obtained from (9) by optimization method.

III. EXPERIMENT

In Fig. 4, a schematic view of the experimental set-up is shown. The diameter of the fixed bed is 72mm and the fixed bed is packed with different diameter of micro beads (0.3-0.6mm, 0.6-0.8mm, 0.8-1.0mm), the voidage ranges from 0.38 to 0.42. The stainless steel wool (50 meshes) was fixed at the bottom of the fixed bed to support the glass micro beads. Along the side of the fixed bed, 9 pores were opened evenly, and the capillaries, being as sampling pipe, were inserted in the side of the fixed bed separately with different distances apart from the axle center, as shown in Fig. 5.

Using deionized water as the main fluid, deionized water was pumped into the head tank, keeping the liquid level of the head tank invariable. Deionized water was sprayed to the surface of the fixed bed through the spray thrower. The solution of 1mol/L KCl is used as the tracer which is pumped to the center of the fixed bed. After 1 hour stabilization, the liquid is sampled from the capillary. The concentration of tracer is determined by the conductivity

meter (115A+) made by Thermo Electron Corporation and the concentration profile of the tracer is obtained.

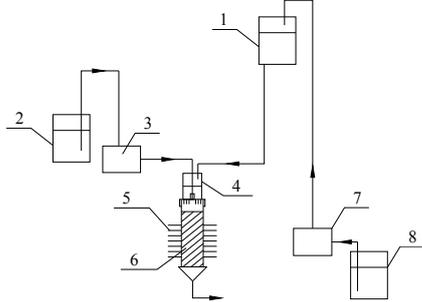


Fig. 4 The flow sheet of experimental set-up. 1- elevated tank; 2- storing cistern of tracer; 3, 7-pump; 4- spray header; 5- capillary; 6-fixed-bed; 8-storing cistern of deionized water

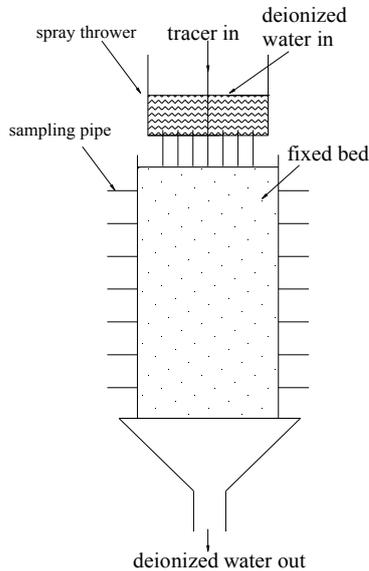


Fig. 5 The schematic of the fixed bed

IV. ANALYSING OF EXPERIMENTAL RESULTS

A. Influence of axial dispersion coefficient to radial dispersion

In order to study the influence of ratio of E_h to E_r , N , on radial dispersion coefficient, (6) is solved with different N ($N=0, 1, 5, 10, 20$), and the results were listed in table I.

TABLE I. THE VALUE OF E_r WITH DIFFERENT NUMBER OF N ($E_r \times 10^7$), M^2/s

u_z m^3/h	$N=0$	$N=1$	$N=5$	$N=10$	$N=20$
0.0144	3.3282	3.3626	3.4677	3.4773	3.4798
0.0180	4.2417	4.4040	4.5285	4.5698	4.6298
0.0216	5.5521	5.6433	5.6677	5.7272	5.9157

0.0252	6.6312	6.7039	6.8111	7.0956	7.2008
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It can be found in table I that the calculated value E_r is increasing slightly with the increasing of N . The deviation of E_r does not surpass 10% ($0 \leq N \leq 20$), which indicates that the influence of axial dispersion coefficient is very small, and the radial dispersion is the dominant factor in fixed bed. Therefore, the axial dispersion is neglected.

B. Influence of the fixed bed height to radial dispersion

The values of radial dispersion coefficient E_r are obtained at different liquid flow rate and different height of the fixed bed with the diameter of the micro beads from 0.8mm to 1.0mm, and the results are shown in Fig. 6.

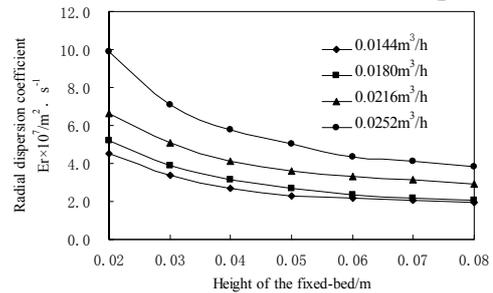


Fig. 6 Values of E_r with different height of the fixed-bed

As shown in Fig. 6 the radial dispersion coefficient gradually reduces with the increasing of the fixed bed height when the flow rate was a constant, and it reduces to a constant gradually. This is because the increasing of the fixed bed height enhances the resistance of mass transfer and reduces the eddy diffusion. But the resistance of mass transfer will not change when the fixed bed height achieves the certain extent, and the radial dispersion coefficient will also tends to a constant.

C. Influence of the liquid flow rate to radial dispersion

The values of radial dispersion coefficient E_r obtained at different liquid flow rate with a diameter of the micro beads is 0.8mm-1.0mm, and the results as shown in Fig. 7.

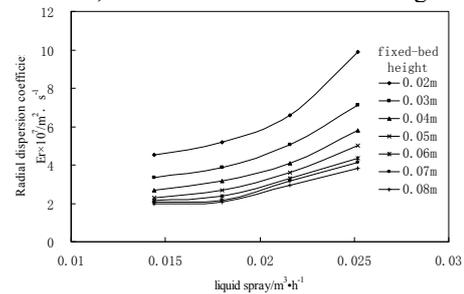


Fig. 7 Values of E_r with different liquid spray

As shown in Fig. 7 the radial dispersion coefficient increases with the increasing of the liquid flow rate when the height of the fixed bed is a constant. This is because in the experimental scope, the eddy diffusion is dominant in the fixed bed. The increasing of the liquid flow rate enhances the

eddy diffusion, and therefore, the radial dispersion is growing.

D. Influence of the micro beads diameter to radial dispersion

The values of radial dispersion coefficient E_r obtained at different diameter of the micro beads with the liquid flow rate of $0.018\text{m}^3/\text{h}$, and the results as shown in Fig. 8.

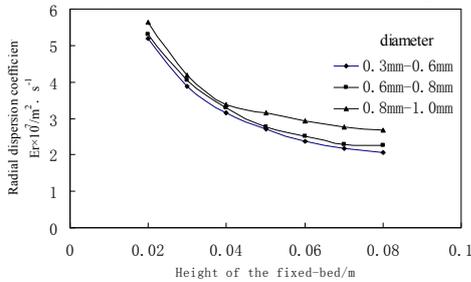


Fig.8 Values of E_r with different diameter of the crystal ball

As shown in Fig. 8 the increasing of the micro beads diameter enhances the radial dispersion coefficient. Because of the voidage increases as the increasing of the micro beads diameter, and the eddy diffusion is enhanced. The dimensionless number Per which indicates the extent of radial diffusion obtained from radial dispersion coefficient by (10).

$$Per = \frac{u_z \times r_0}{Re} \quad (10)$$

The equation of Per and $\ln(Re)$ can be obtained by fitting of the experimental data, and the results as shown in Fig. 9.

$$Per_r = -321.11 \times (\ln Re)^2 + 4410.9 \times \ln Re - 15063 \quad (11)$$

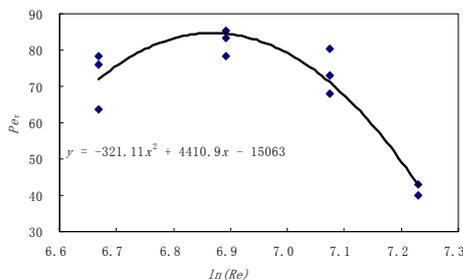


Fig.9 Values of Per with the variety of $\ln(Re)$

IV. CONCLUSIONS

Using the fixed bed loading micro beads to simulate the single catalyst-bundle, the radial dispersion coefficient was obtained by stable state point source tracer technique, and the conclusions are obtained as follows:

- The dispersion model established is in good description to the fixed bed.
- The influence of axial dispersion was studied, and the result indicates that the axial dispersion can be neglected in the experimental scope.

- The radial diffusion coefficient is reduced with the increasing of the packing height, and on the contrary the coefficient of radial diffusion is increased with the increasing of the liquid flow rate and the diameter of micro beads.
- The equation of Per and $\ln(Re)$ obtained by fitting of the experimental data.

NOTATION

a_j —positive root of first-order bessel function;
 C —concentration of tracer, $\text{mol}\cdot\text{L}^{-1}$;
 C_{A0} —original concentration of tracer, $\text{mol}\cdot\text{L}^{-1}$;
 E_r —radial dispersion coefficient, $\text{m}^2\cdot\text{s}^{-1}$;
 E_h —axial dispersion coefficient, $\text{m}^2\cdot\text{s}^{-1}$;
 Per —psect number;
 r —radius of fixed bed, m ;
 r_e — out-let radius of tracer, m ;
 r_i —radial distance, m ;
 Re —reynolds number.
 u_z —liquid flow rate, $\text{m}\cdot\text{s}^{-1}$;
 u_c —flow rate of tracer, $\text{m}\cdot\text{s}^{-1}$;

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