

Gas-phase Mass Transfer Resistance in Rotational-current Tray*

Teruo TAKAHASHI and Yasuharu AKAGI**

Department of Industrial Chemistry

(Received May 31, 1969)

In this report, the average holding time of gas in foaming layer and the number of transfer units based on gas-phase of the Rotational-current tray were considered experimentally.

The average holding time was determined by water-air system. On the other hand, the number of transfer units was determined by water-ammonia-air system that gas-phase resistance controlled.

The average holding time increases with gas and liquid velocities, and does not change with the tray dimensions clearly. From the experimental results of the number of transfer units, it was found that the tray can be operated at high efficiency up to larger gas and liquid flow rates than that of sieve trays.

§1 Introduction

The Rotational-current tray has many advantages in comparison with sieve trays.

The pressure loss of gas flow through a tray, the liquid holdup on a tray and the mass transfer rates of the liquid-phase resistance controlling system in the Rotational-current tray have already been reported^(1, 2), 3), 4).

In this work, as a fundamental study of mass transfer in the tray, the holding time of gas in foaming layer on the tray was considered by the water-air system and then the absorption tests were carried out by the water-ammonia-air system.

The number of transfer units based on gas-phase was correlated with gas velocity based on hole area of the tray and the average holding time of gas-phase. Moreover the number of transfer units based on gas-phase were compared with the results of several sieve trays.

§2 Experimental apparatus

The dimensions of the tray are shown in **Table 1**. In the table, the equivalent diameter of a hole (D) and the ratio of the hole area to

Table 1 Dimensions of trays

Tray No.	D (cm)	T (cm)	n (-)	A_h/A_c (%)
P-2	0.54	0.08	60	10.3
P-4	0.55	0.16	126	21.3
P-8	0.92	0.08	60	28.6
P-14	0.64	0.08	90	20.7
P-15	1.10	0.08	36	22.5

the tray area in percentage (A_h/A_c) are obtained from the projected area of the hole (S').

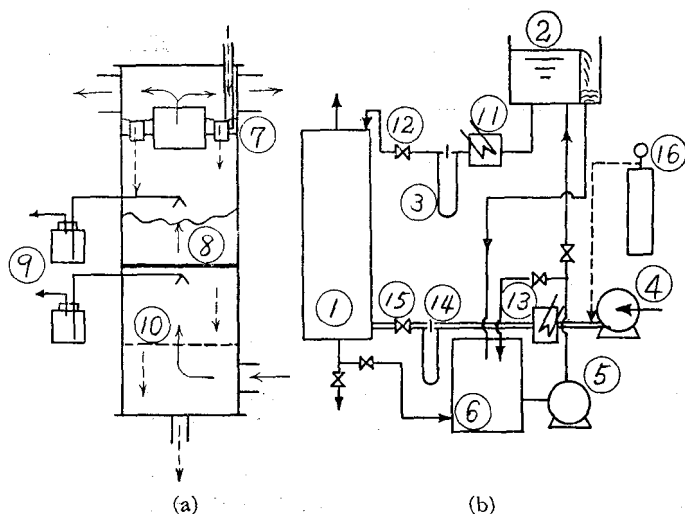
In **Fig. 1 (b)**, the flowsheet of the experimental apparatus is shown. Liquid is stored in the feed tank ⑥ and pumped up the constant head tank ② from there by the circulation pump ⑤, from which it is fed to the column ① after passing through the temperature controlling device ⑪ and the flow meter ③. Flow rates are controlled with the valve ⑫. On the other hand, air from the blower ④ flows into the column after passing through the temperature controlling device ⑬ and the flow meter ⑭. Flow rates of mixed gas are controlled with the valve ⑮.

The structure of the column ① is shown in **Fig. 1 (a)**. The column is 15 cm in diameter and is made of transparent vinyl chloride. Therefore the observation of foaming layer on a tray from outside is possible.

The flow of entering gas is regulated by the

* Presented at the Chugoku-Shikoku meeting of the Chemical Society of Japan, Okayama, October, (1967), 401

** Department of Applied Chemistry, Okayama College of Science



1. tower 2. constant head tank 3. liquid flow meter 4. blower
5. pump 6. feed tank 7. liquid distributor 8. tray 9. sampling device
10. gas distributor 11. liquid temperature control vessel
12. valve 13. gas temperature control vessel 14. gas flow meter
15. valve 16. ammonia gas bomb

Fig. 1 Experimental apparatus

distributor ⑩ and flows through the tray ⑧. The flow of liquid enters at the top of the column, is regulated by the distributor ⑦ and falls on the tray. These liquid and gas form the foaming layer on the tray and contact at there and then come out of the system.

§3 Experimental procedures

Each tray in Table 1 is experimented with conditions that the guides are set upward (upper guide tray, U. G. T.) and downward (down guide tray, D. G. T.). The variables and their ranges investigated are as follows; the hole diameter ($D=0.54-1.10$ cm), the ratio of the total hole area to the tray area ($A_h/A_c=10.3-28.6\%$), gas velocity through the hole of the tray ($u_h=2.5-18$ m/sec) and liquid velocity through the hole of the tray ($w_h=0.0028-0.025$ m/sec).

The average holding time of gas in foaming layer on the tray is measured by the water-air system. The flow mechanism due to the system is similar to that of the water-ammonia-air system used in mass transfer operations, because the concentrations of diffusing component in water and air are small.

The height of foaming layer is measured by a scale at a steady state.

As shown in Fig. 1 (b), ammonia gas from

bomb ⑯ is mixed into air at the outlet of blower. The concentration of ammonia is retained about 1 vol% by the controlling valve. The mixed gas contacts with water on the tray and then the ammonia gas in air is absorbed by water.

Gas sampling device ⑨ for measuring absorption rate of ammonia is shown in Fig. 1 (a). The volume of the sampling vessel is about 500 ml. As the upper sampling tap is possible to lift up and take down, it is always set just over the foaming layer. The down sampling tap is fitted just under a tray. Therefore, the concentrations of sample from these taps can be regarded as those of outlet and in-

let of the foaming layer. As the discharge rate of sampling gas is controlled by a cock and an aspirator, and the rate is small, the flow pattern of fluids on a tray does not change by sampling. The sample is analyzed as follows; the superfluous dilute hydrochloric acid is added to the sample, and the excess of hydrochloric acid is titrated by sodium hydroxide. In the titration, the mixture neutralizes at pH 5 to 6 because the ammonium chloride is created in the mixture, so that the mixed indicator of methyl-red and methylene-blue is used. At the same time, the ammonia concentrations of inlet and outlet water are determined by using the sampling devices of liquid³⁾ and the analytical method as mentioned above. The data that the material balance of ammonia is realized in gas and liquid side, are adopted to correlate the number of transfer units.

§4 Experimental results and discussions

4.1 Theory

Murphree tray efficiency of absorption based on gas-phase is defined as follows (refer to Fig. 2).

$$E_{MV} = (y_i - y_o) / (y_i - y^*) \quad (1)$$

On the other hand, material balance in the

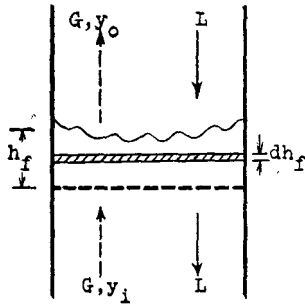


Fig. 2 Flow mechanism of gas and liquid on a tray

microheight of foaming layer (dh_f) is

$$Gdy = K_{OG} a(y - y^*)dh_f \quad (2)$$

In the operation, as the concentration change of ammonia in water is small, y^* is nearly constant. Therefore Eq. (2) can be integrated and Eq. (1) is substituted in it.

$$N_{OG} = \frac{K_{OG} ah_f}{G} = \int_{y_o}^{y_i} \frac{dy}{y - y^*} = -\ln(1 - E_{MV}) \quad (3)$$

The liquid-phase mass transfer resistance can not be negligible in water-ammonia-air system, then the number of transfer units based on gas-phase (N_G) is calculated by next equation.

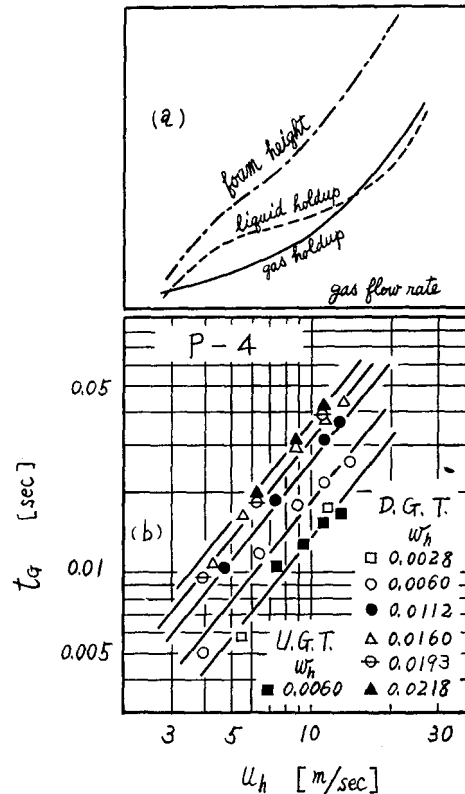
$$\frac{1}{N_G} = \frac{1}{N_{OG}} - \left(\frac{mG}{L}\right) \frac{1}{N_L} \quad (4)$$

4.2 Average holding time of gas

The contact time of gas and liquid is one of the most important variables in mass transfer operations. The average holding time of gas on a tray is closely related with the contact time, and it is an important factor in mass transfer operations of gas-phase resistance controlling system.

The gas holdup on a tray is obtained by subtracting the height of clear liquid from the height of foaming layer. According to the gas holdup is divided by the gas flow rate, the average holding time of gas is obtained. The relation between the foam height, the liquid holdup and the gas holdup is shown in Fig. 3 (a). The liquid holdup (that is, height of clear liquid) is calculated from the equations that have already been reported²⁾,

Fig. 3 (b) shows an example of the relations between the average holding time and gas velocity, using the liquid velocity and the kind

Fig. 3 Relation between t_g and u_n , using w_n as parameter in P-4

of guide as parameters. The average holding time increases with gas velocity. It also increases with liquid velocity because the gas holdup increases with liquid velocity, and it does not systematically change by the tray dimensions.

The results of the experiments for D. G. T. are similar to that for U. G. T.. However, the average holding time on U. G. T. is smaller than that on D. G. T. (refer to Fig. 3 (b)) because the gas holdup on D. G. T. is larger than that on U. G. T..

4.3 Number of transfer units in water-ammonia-air system

In the gas-phase resistance controlling system, it is considered that gas velocity and the average holding time of gas influence strongly the mass transfer rate.

The concentrations of ammonia in gas-phase at the points of inlet and outlet of foaming layer are determined by the methods of sampling and analysis as shown in §3. Then Murphree tray efficiency based on gas-phase (E_{MV})

is calculated by Eq. (1) and the number of transfer units based on gas-phase (N_G) is calculated by Eqs. (3) and (4). The number of transfer units based on liquid-phase (N_L) is calculated by using the equations that have already been reported³⁾. In this study, as the concentration of ammonia is small and its operational range is narrow, m in Eq. (4) is nearly constant, and the value had been reported by Fujita⁵⁾ can be used.

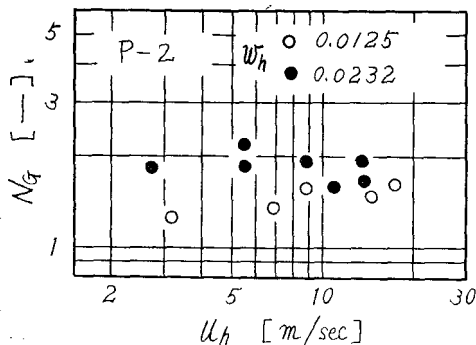


Fig. 4 Relation between N_G and u_h in P-2, D. G. T.

A relation between the number of transfer units based on gas-phase and gas velocity is shown in Fig. 4. N_G changes hardly due to increasing gas velocity because the increase of the holding time and the decrease of the contacting degree of gas and liquid will inversely influence to it. Though in this figure N_G increase slightly with liquid velocity, on the whole the explicit tendencies is not obtained. These tendencies do not change by the kind of guide.

Fig. 5 shows an example of the relation between the number of transfer units based on gas-phase and the average holding time, using the liquid velocity as a parameter. N_G changes hardly due to increasing the holding time of gas.

The relations between N_G and product of gas velocity by the average holding time are shown in Fig. 6 for U. G. T. and in Fig. 7 for D. G. T.. N_G of the trays that A_h/A_c and D are large, are slightly smaller than those of other trays, but on the whole it can be concluded that N_G do not change by

the operating conditions and tray dimensions. N_G of U. G. T. are a little smaller than that of D. G. T..

In Fig. 8, N_G of the Rotational-current tray are compared with those of several sieve trays. In the reports of Walter et al⁶⁾ and Gerster et al⁷⁾, liquid velocity based on the hole area of the tray is unknown because tray dimensions are not detailed. Liquid velocities used by Kamei et al⁸⁾ and Gardner et al⁹⁾ are smaller than those of the Rotational-current tray. All of these are the sieve trays of cross-current type, and the weir height of these trays are shown in the figure. Gas velocity of the Rotational-current tray is equal or slightly larger than that of these sieve trays.

Although A_h/A_c of the sieve trays of cross-current type does not exceed 10%, that of the Rotational-current tray is possible to design up to about 30% as shown in Table 1. In addition the whole area of the Rotational-current

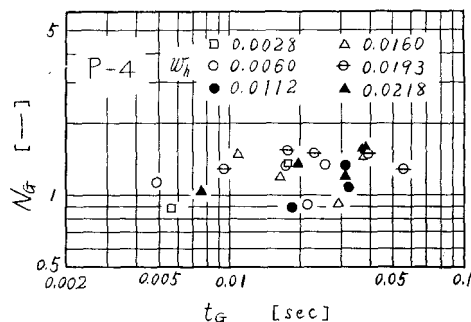


Fig. 5 Relation between N_G and t_G in P-4, D. G. T.

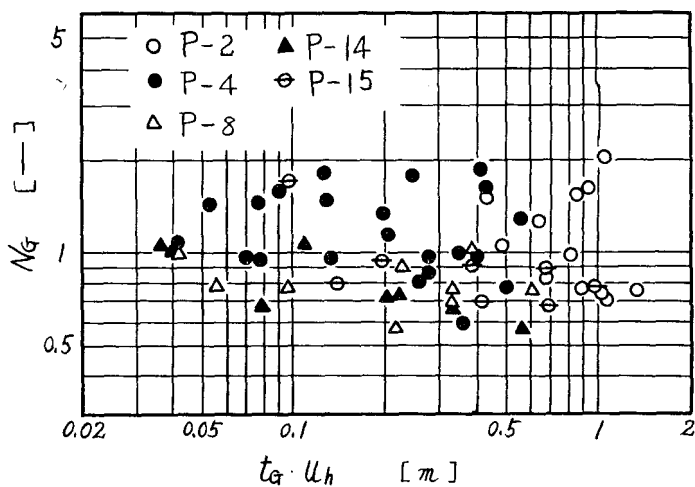


Fig. 6 Correlation of N_G in U. G. T.

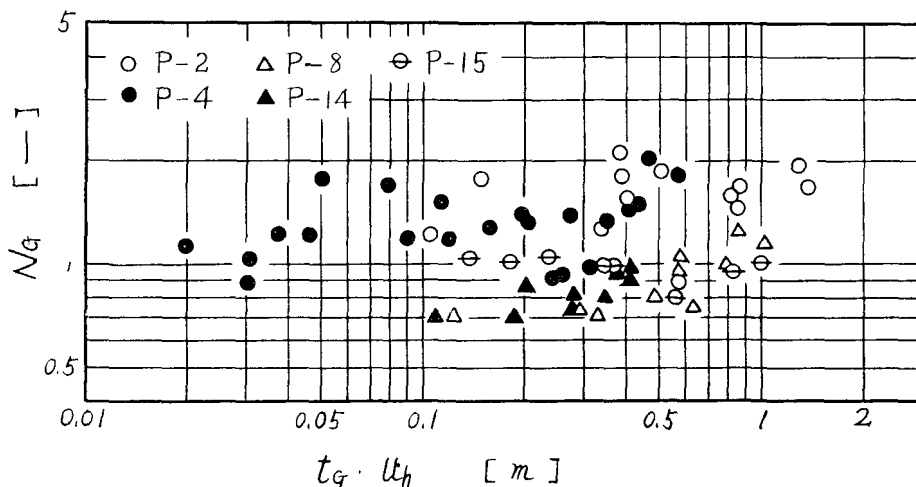


Fig.7 Correlation of N_G in D.G. T.

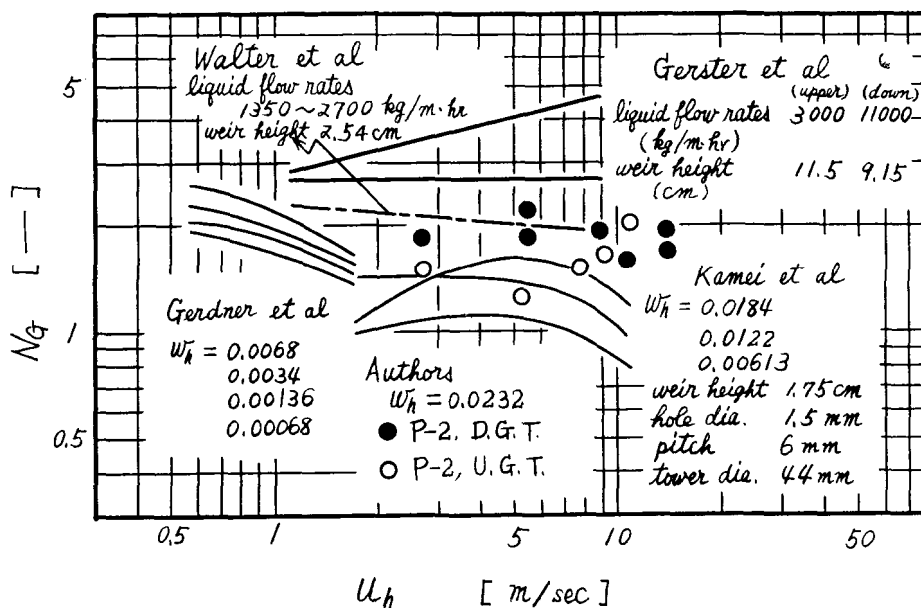


Fig.8 Comparison of N_G with sieve trays

tray can effectively contribute to contact of gas and liquid because the tray has not weir and downcomer. Therefore, it is concluded that the Rotational-current tray deals with several times of gas throughput in sieve tray of cross-current type.

§5 Conclusions

In this work, the average holding time of gas on the tray using water-air system and the number of transfer units based on gas-phase using water-ammonia-air system on the Rotational-current tray have been considered ex-

perimentally. The results obtained are as follows.

1. The average holding time of gas on the tray increases with gas and liquid velocities, and does not systematically change by the tray dimensions. The average holding time of gas on D. G. T. is larger than that on U. G. T.
2. The number of transfer units based on gas-phase differ hardly due to changing gas velocity and tray dimensions. The number of transfer units based on gas-phase of U. G. T. and D. G. T. are represented by Figs. 6 and 7, respectively.
3. It is concluded that the Rotational-

current tray can be operated at high efficiency up to larger gas and liquid flow rates than that of sieve trays.

Nomenclature

a : contact area [cm^2/cm^3]
 A_c : cross-sectional area of column [cm^2]
 A_h : total hole area [cm^2]
 D : equivalent diameter of hole [cm]
 E_{MV} : gas-phase Murphree tray efficiency [fraction]
 G : gas flow rate [$\text{g}/\text{cm}^2 \text{ sec}$]
 h_f : height of foaming layer [cm]
 K_{OG} : over-all gas-phase mass transfer coefficient [$\text{g}/\text{cm}^2 \text{ sec}$]
 L : liquid flow rate [$\text{g}/\text{cm}^2 \text{ sec}$]
 m : slope of equilibrium curve in water-ammonia-air system [—]
 n : number of hole [—]
 N_G : number of transfer units based on gas-phase [—]
 N_L : number of transfer units based on liquid-phase [—]
 N_{OG} : number of over-all transfer units based on gas-phase [—]
 S' : projected hole area, refer to literature (2) [cm]
 T : tray thickness [cm]
 t_G : average holding time of gas in foaming layer on a tray [sec]

u_h : gas velocity based on S' , refer to literature (2) [cm/sec]
 w_h : liquid velocity based on S' [cm/sec]
 y_i, y_o : concentration of transferring component in gas entering and leaving tray [mol-fraction]
 y^* : concentration of transferring component in gas at equilibrium [mol-fraction]

Literature cited

- 1) T. TAKAHASHI and Y. AKAGI : Chem. Eng. (Japan), **31**, (1967) 600
- 2) T. TAKAHASHI and Y. AKAGI : Memoirs School Eng., Okayama Univ., **2**, (1967) 50
- 3) T. TAKAHASHI and Y. AKAGI : *ibid*, **3**, (1968) 51
- 4) T. TAKAHASHI, Y. AKAGI and Z. OHIRA : The Proceeding of 32th Annual Meeting (Society of Chemical Engineers, Japan), (1967) No. 2, 118
- 5) S. FUJITA : Chem. Eng. (Japan), **27**, (1963) 109
- 6) J. E. WALTER and T. K. SHERWOOD : I. E. C., **33**, (1941) 493
- 7) J. A. GERSTER, A. P. COLBURN, W. E. BONNETT and T. W. CORMODY : Chem. Eng. Progr., **45**, (1949) 716
- 8) S. KAMEI, T. TAKAMATSU and S. NAKASAKI : Chem. Eng. (Japan), **20**, (1956) 71
- 9) R. G. GARDNER, D. MOCKAY and D. SMITH : Trans. Instn. Chem. Engrs., **44**, (1966) T62