Effect of Redistoributor for Absorption in Packed Beds

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By

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Abstract

Redistributor was made of a improved stainless screen and this redistributor was applied to absorption equipment of packed bed type. Absorption experiments for water and air-carbon dioxide system were carried out in packed bed filling up packing of every kind; 1/2, 1, 3/2 and 2 inch Ceramic Raschig rings, Teraret S and Plastic net Raschig ring in the range of about 2000 [kg/m^2hr] to 6500 [kg/m^2hr] under constant gas flow rates condition. The results were that liquid distribution in cross section of the bed was very unified by redistributor and N.T.U. with redistributor was 1.5 times higher than that of without one.

Introduction

The liquid which was supplied over the packing from the top of bed gathers to the wall and it becomes a wall flow. This tendency is remarkably in high packed bed[1]. For a wall flow, it is reported that the ratio of a wall flow to total liquid flow (wall flow ratio) has no connection with the liquid flow rates[4,10] and wall flow ratio much depends on the liquid flow rates[9,11]. Under the assumption that lowering of tower efficiency by reason of liquid distribution was mainly caused by only on a wall flow, *i.e.*, wall effect, dependence of wall flow ratio on height of bed was investigated. And the results were shown that the wall effect was not observed in the region over 1 feet depth at 20,000 [kg/m^2hr], over 2 feet depth at 2,500 [kg/m^2hr] liquid flow rate by Porter[11,18], and over 1.5 meter depth at 2,500 [kg/m^2hr] liquid flow rate by Dutkai[1]. If lowering of tower efficiency because of liquid distribution depends not only on the effect of a wall flow but also on the difference of uniformity, it is expected that using suitable redistributor leads to inprovement in tower efficiency. As the tower efficiency is affected by uniformity of liquid distribution at the top of bed, Gildenbrat et al.[19] investigated the number of feed points.

Let us suppose that liquid in the bed doesn't flow with keeping maximum interfacial area, but flows with decreasing interfacial area as flowing downward. The absorption experiment of using special redistributor was carried out and pressure drop and holdup in the bed were measured. The main purpose is to know:

(1) How degree absorption efficiency is incleased by using successful redistributor in the optimum position of bed.

(2) For what reason this distributor is utilized for absorption in packed beds.

Apparatus and procedure

A schematic diagram of the apparatus used for the determination of number of transfer units (N.T.U.) is shown in Fig. 1. The bed was made of poly-meta-acrylate resin, having an inside diameter of 190 *mm* and 1200 *mm* height. Redistributor consisted of space 50 *mm* in height and 9 *mm* opening special stainless screen. In order to flow the liquid uniformly the special screen

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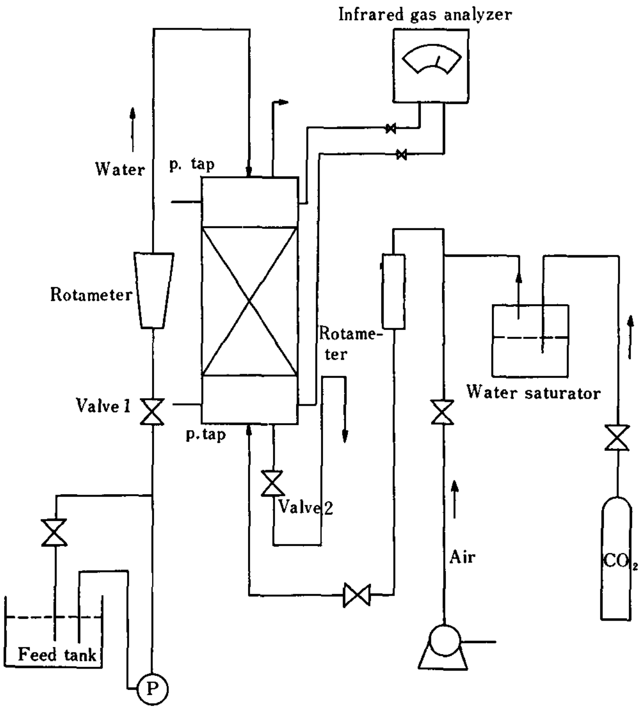

Fig. 1 Schematic flow diagram of apparatus

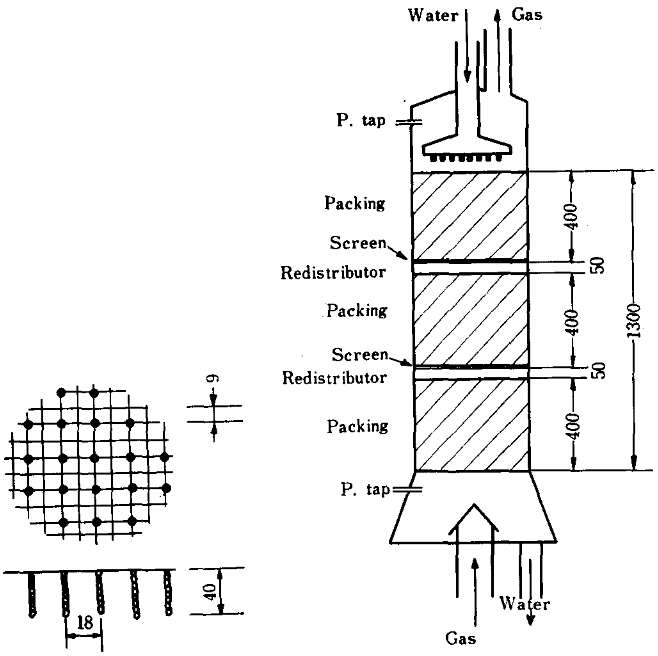

Fig. 2(a) Details of redistributor **Fig. 2(b)** Position of redistributor in packed bed was set up guide bars every other cross point of screen as shown in Fig. 2(a). The guide bars were 40 *mm* in length and moved flexibly by liquid flowing. The positions of which the redistributor were inserted were shown schematically in Fig. 2(b). Experiments were carried out with two redistributors which devided a bed into three parts. To neglect the affection of not uniformity of liquid distribution on absorption efficiency, 50 liquid feed points at the top of bed are required at least per m^2 of bed cross-section and uniform liquid distribution is accomplished by 113 feed points. The number of feed points in this experiment were about 5600 per m^2 of bed crosssection. Three different type of packing materials were employed in this work; Plastic net Raschig ring, Teraret S and 1/2 inch, 1 inch, 3/2 inch and 2 inch Raschig rings. The void fraction was computed from the volume of bed and the volume of packing. The pressure drop across the bed was measured by a calibrated water manometer connected to the pressure taps which located top and bottom of the test section.

The system of water and air-carbon dioxide (8–10[%] by volume) mixtures was employed to mass transfer. Compressed gas was supplied to bottom of the bed through a water saturator. The water maintained at 25 ± 1°C and the gas flowed counter-currentry. The liquid at entrance and exit never differed in temperature by more than 1°C. The liquid and gas flow rates were measured by rotameters and controlled by a valve arrangement. The liquid flow rate varried, over the range of 2000 [kg/m^2hr] to 6500 [kg/m^2hr], while the gas flow rate was maintained constantly at 1200 [kg/m^2hr]. During experiments, flow rate were held constantly by manual control.

The runs were made under the steady state condition. In order to check up being steady state, it is confirmed that the concentration of carbon dioxide in liquid phase is constant at the bottom of bed. At the discharge end of the bed, liquid was kept at a constant level by adjusting the flow rate through valve $V-3$ to prevent gas bubbles from leaving with the exit liquid. For each measurement, a set of samples was drawn periodically from the feed and from the base of the packing. The N.T.U. of this experiments were calculated by Equation (5). Samples were analyzed for acidity by back titration with 0.1N barium hydroxide solution and 0.1N hydrochloric acid. Carbon dioxide gas concentration was measured on a Infrared Gas Analyzer (TYPE IRP2, Fuji electric Co L.T.D.). Liquid holdup in the packing was determined by the following procedure. After steady state had been attained for a given flow rate, valve $V-1$ was closed. The volume of liquid from the packing was measured. This procedure was repeated for different liquid rates.

Theory

If the gas carring the solute is considered to be in soluble in the liquid phase, and if the solvent is considered to be nonvolatile, the rate of absorption which is accomplished in the differential section of height dZ may be written as follows by material balance

$$VdY = LdX \qquad \cdots\cdots(1)$$

in addition, the rate of absorption may be expressed as follows

$$\text{Rate of absorption} = K_xaS\,dZ(X^*-X) \qquad \cdots\cdots(2)$$

The changing rate of a component within a phase must be equal to the rate of transfer to the phase. Thus Eq. (1) may be combined with Eq. (2) to give

$$LdX = K_xaS\,dZ(X^*-X) \qquad \cdots\cdots(3)$$

Eq. (3) may be used to being solve for the required height of bed by integrating over the total alteration in concentration between the bed terminals.

$$dZ = \frac{L}{K_x aS}\int_{X_1}^{X_2}\frac{dX}{X^*-X} \qquad \cdots\cdots\cdots\cdots\cdots(4)$$

Both equiribrium curve and operating-line are regard as linear over the range of this experiments. N.T.U. is described as follows

Equiribrium Relation $Y^* = mX+b$

Operating Line $Y-Y_2 = \frac{L}{V}(X-X_2)$

$$\text{N.T.U.} = \frac{(X_2-X_1)\ln[(X_2^*-X_2)/(X_1^*-X_1)]}{(X_2^*-X_2)-(X_1^*-X_1)} \qquad \cdots\cdots\cdots\cdots\cdots(5)$$

Results and discussion

1. The effect of redistributor

Fig. 3(a) and Fig. 3(b) show the relationship between the number of transfer unit and the liquid flow rate in 190 *mm* diameter bed packed with 1/2 inch and 1 inch Raschig rings under atomospheric conditions, respectively. In Fig. 3(a), experimental results of both cases setting up two redistributors and without one were shown full lines, moreover the previous data[7] is indicated broken line. The results of without redistributor were deviated to the lower parts than previous data. It may be considered that end effects and flow patten were slightly different

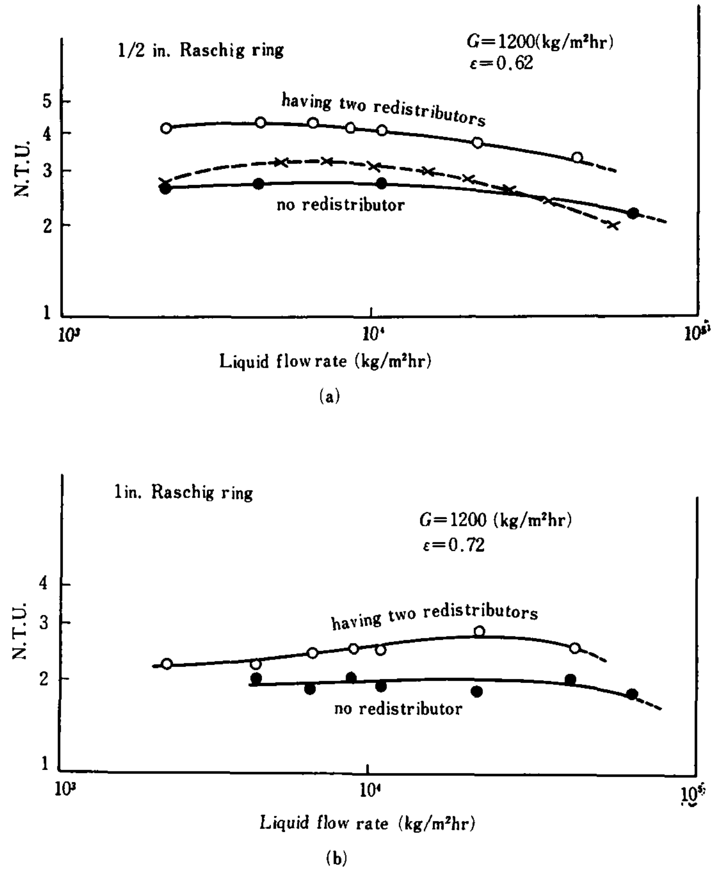

Fig. 3 Effect of redistributor on N.T.U. ; packed with Ceramic Raschig ring

because of previous data were obtained in 66 *mm* diameter bed packed into 1500 *mm* height, results of this work were measured in a 190 *mm* diameter bed packed into 1200 *mm* height. As shown cleary in this figure, the value of N.T.U. with redistributor is found to be 1.5 times higher than that of without redistributor. Further, maximum absorption efficiency attained to 97% of saturation. It is one of the reason is as follows: as wetting distribution was uniformalized by using redistributor, gas-liquid effective interfacial area increased. Moreover liquid mixing in radial direction which is caused by redistributor make to increase the driving force.

By comparison between Fig. 3(a) and 3(b), it is known that the value of N.T.U. with two redistributors for the 1/2 inch Raschig ring packing was about 1.5 times higher than for the 1 inch Raschig ring over the liquid flow rates range of 10^3 $[kg/m^2hr]$ to 10^4 $[kg/m^2hr]$. In this flow region, redistributor is more useful in the case of the 1/2 inch Raschig ring packing compare with 1 inch Raschig ring packing. Redistributor doesn't effect on absorption efficiency in the case of more than 3/2 inch Raschig ring in the range of this work. Fig. 4 shows the results packed Teraret S. The effect of redistributor on N.T.U. is appeared clearly in this figure. And the value of N.T.U. increases gradually to 10^4 $[kg/m^2hr]$ liquid flow rate and over this flow rate the valve decreases gradually; there is an optimum operational region in Teraret S packing. The results in plastic net Raschig ring packing were similar to that of Teraret S packing. The maximum value corresponds to the case of the same size Ceramic Raschig ring packing.

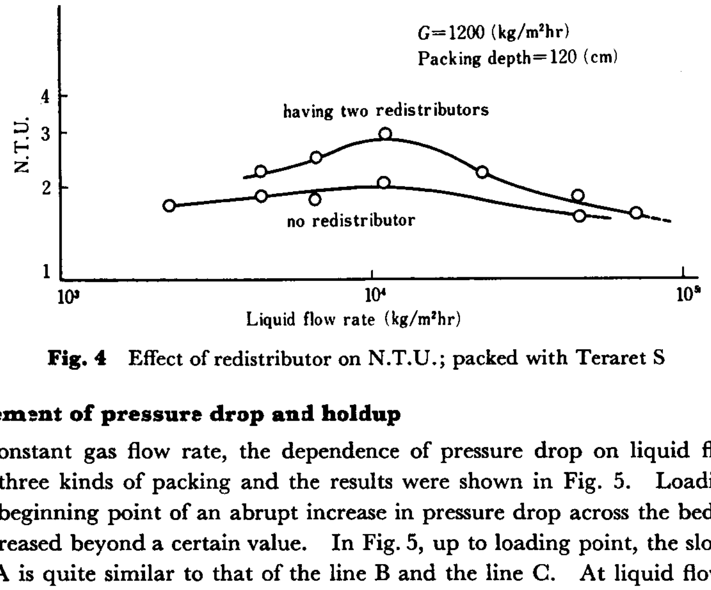

Fig. 4 Effect of redistributor on N.T.U.; packed with Teraret S

2. **Measurement of pressure drop and holdup**

Under constant gas flow rate, the dependence of pressure drop on liquid flow rates was measured in three kinds of packing and the results were shown in Fig. 5. Loading point was indicated by beginning point of an abrupt increase in pressure drop across the bed as the liquid flow rates increased beyond a certain value. In Fig. 5, up to loading point, the slope of pressure drop line of A is quite similar to that of the line B and the line C. At liquid flow rates above 2.0×10^4 $[kg/m^2hr]$, the pressure drop of 1/2 inch Raschig ring increase rapidly than others. However, in the case packed with 1 inch Raschig ring and Teraret S, even if liquid rates was made above $6.0\times 10^4[kg/m^2hr]$ an abrupt increase is not observed. As the pressure drop decreases with increasing in size of packing, it is profitable in view of pressure drop to operate in large size of packing at high flow rate region. In practice, N.T.U. decreases in most cases so that to use large size of packing under high flow region does not always give a good results on absorption efficiency.

Holdup is plotted against liquid flow rates as shown in Fig. 6. Liquid holdup rises in inverse proportion to packing size. N.T.U. increased with residence time which was calculated by liquid holdup/liquid flow rate. N.T.U. of using small size packing is higher than that of large packing. Accordingly, it is considered that one of the reason for increasing N.T.U. is caused by rising of the liquid holdup, that is, increasing the residence time over the range of

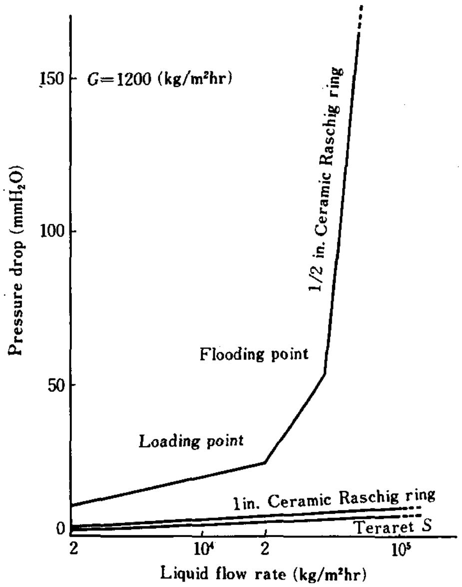

Fig. 5 Pressure drop vs. Liquid flow rate
A : ½ in. Rasching ring
B : 1 in. Rasching ring
C : Teraret S

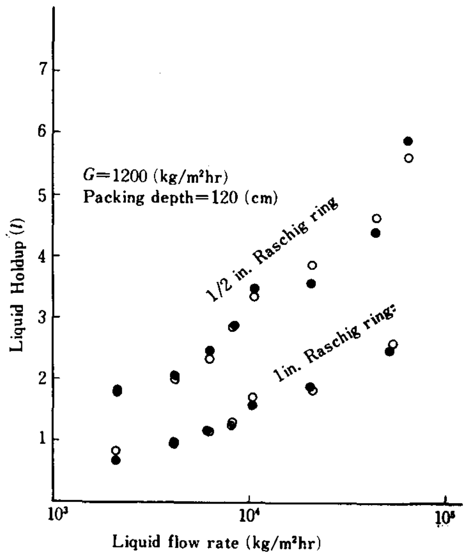

Fig. 6 Holdup vs. liquid flow rate; Ceramic Raschig ring

this experiment. By the comparison Fig. 5 and Fig. 6, the pressure drop and liquid holdup increase linearly with liquid flow rates. From this fact, liquid distributions are similar over the range of this experimental flow rates. This fact indicate that increasing N.T.U. is not caused by the holdup increment, that is, the residence time increment on account of redistributor, but caused by uniform liquid distribution. To uniform of liquid distribution raises up the wetting area.

The relation between N.T.U. and void fraction

As one step for considering N.T.U. in relation to pressure drop or liquid holdup, the connection N.T.U. and void fraction is examined and its results were shown in Fig. 7. The

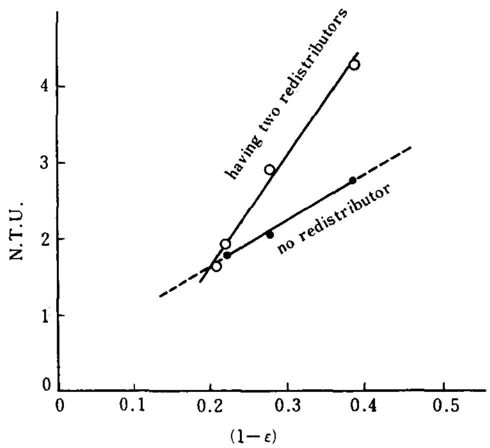

Fig. 7 The relation between N.T.U. in optimum operation and void fraction

relation between holdup and pressure drop were studied by Sato et al.[12,13,14] and Suzuki[17]. Susskind and Becker[16], Eugun[6] and Cozeny, Carmman[15] reported for pressure drop in packed bed and confirmed that pressure drop and $(1-\varepsilon)^2/\varepsilon^3$, pressure drop and $(1-\varepsilon)/\varepsilon^3$ bear a linear relationship to each other.

In this work, N.T.U. vs. $(1-\varepsilon)^2/\varepsilon^3$, N.T.U. vs. $(1-\varepsilon)/\varepsilon^3$, N.T.U. vs. $(1-\varepsilon)$ and N.T.U. vs. ε were plotted, only corelation of N.T.U. vs. $(1-\varepsilon)$ became straight lines in both cases with redistributor and without one. There is a discrepancy in the slope of the lines.

Conclusion

Utilizing a packed bed with special redistributor in various packing, gas absorption experiments with water and air-carbon dioxide system are undertaken. Moreover liquid holdup and pressure drop are measured. Its results are as follows;

(1) Redistributor is useful for rising up absorption efficiency, its efficiency is attained about 1.5 times higher than without redistributor.

(2) Above mentioned is not caused by residence time increment, but caused by uniform liquid distribution as a result of redistributor.

(3) As one step for considering N.T.U. in relation to pressure drop or holdup, the relation N.T.U. to void fraction is examined. It is found that N.T.U. becomes linear with $(1-\varepsilon)$ in the case of without redistributor and similar relation is obtained in the case of with redistributor.

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Literature cited

1) Dutkai, E. and E. Ruckenstein: Chem. Eng. Sci., **23**, 365 (1968)
2) Fujita, Kuwabara and Wakida: Paper presented at the meeting of Soc. Chem. Engrs. (Japan) (1953)
3) Hoftyzer, P.J.: Trans. Inst. Chem. Engrs., **42**, T109 (1964)
4) Jameson, G.J.: *ibid.*, **44**, 198 (1966)
5) Jameson, G.J.: *ibid.*, **45**, 74 (1967)
6) Kamei, S.: "Kagaku kikai no riron to keisan", 2nd ed, Sangyo Tosyo
7) Kataoka, T.: Thesis of Master, University of Osaka prfeecture (1957)
8) Kubo, K. and S. Odajima: Bulletin of Osaka prefectural tecnical college Vol. 3, 53, (1969)
9) Onda et al.: Kagaku kogaku, **33**, No. 5, 50 (1969)
10) Porter, K.E. and M.C. Jones: Trans. Inst. Chem. Engrs., **41**, 240, (1963)
11) Porter, K.E. and J.J. Templeman: *ibid.*, **46**, T86 (1968)
12) Sato et al.: Preprint of the 2nd autumnal meeting of the Soc. of Chem. Engrs., Japan at Nagoya, E202 (1968)
13) Sato et al.: *ibid.*, E202, (1968)
14) Sato et al.: Preprint for 34th Annual Meeting of The Soc. of Chem. Eng., Japan at Tokyo, C206 (1969)
15) Schlichting, H.: "Boundary Layer Theory" translated by J. Kistin, 4th ed, Mcgraw-Hill (1960)
16) Susskind, H. and Walter, B.: A. I. Ch. E. Journal, Vol. 13, No. 6, 1155 (1967)
17) Suzuki, Y. et al.: Preprints for 36th Annual Meeting of The Soc. of Chem. Eng , Japan, No. 312, Tokyo (1971)
18) Templeman, J.J. and K.E. Porter: Chem. Eng. Sci., **20**, 1139 (1965)
19) Gil'denblat, I.A., N.M. Gurova and V.M. Ramm: Int. Chem. Eng., **7**, 149 (1967)

Nomenclature

a	=interfacial area per unit volume of packing	$[m^2/m^3]$
K_x	=over all mass transfer coefficient based on the liquid phase)	$[kg\text{-}mol/m^2hr\ \Delta x]$
L and V	=rate of flow of liquid and gas, respectively	$[kg\text{-}mol/hr\ m^2]$
m	=slope of equilibrium curve	[—]
$N.T.U.$	=number of transfer units (based on the liquid phase)	[—]
S	=empty tower cross sectional area	$[m^2]$
X	=solute concentration in gas phase	[—]
Y	=solute concentration in liquid phase	[—]
Z	=height of packing of tower	$[m]$
ε	=void fraction in bed	[—]

Subscript

*	=equilibrium state
1	=condition at top of tower
2	=condition at bottom of tower