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# The Study of Absorption and Hydraulic Character in Packing Tower

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# 충전탑에서 흡수와 수력학적 특성에 관한 연구

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## 국 문 요 약

산업공정에서 배출되는 대기오염물질 및 유독성가스를 제거하기 위한 방법에는 여러 가지가 적용되고 있으나, 본 연구에서는 충전탑을 이용한 흡수원리로써 오염물질을 처리하는데 수력학적 특성에 대해서 연구하였다. 즉 환경보호와 화학공업에서 에너지 절약 측면에 충전탑의 사용이 증가되고 있으며, 충전물의 재료로는 플라스틱, 금속 및 세라믹 등으로 제작되며 종류로는 VSP-ring, Hiflow-ring, Hackette, Top-packing, Envi-pac 등이 있고 사용 범위는 정류와 증류, 흡수 및 탈착과 액체와 액체의 추출공정 등에 효율적으로 사용되고 있다. 산업현장에서 과거에 주로 사용되어온 Intalox-saddle, Raschig-ring, Pall-ring 등의 재래적 충전물은 압력손실과 물질전달, 에너지 절약 및 효율성이 좋은 격자형 충전물의 개발로 인하여 점점 사용이 감소되고 있는 추세이며, 최근에는 합성수지로 제조된 충전물 NSW-ring, Hiflow-ring, Envi-pac 등은 실험 결과에 의해서 재래적인 충전물 Raschig-ring과 Pall-ring보다 높은 상대적인 공간체적과 충전 높이에 따른 낮은 압력손실과 함께 높은 부하 한계치에 대하여 효율적이고 가벼운 분리작용에 의한 수력학적 특성이 증명되어졌다. 격자형 충전물이 산업에 적용되기 위해서는 압력손실과 액체함량, 부하 한계치 가스상 또는 액상 물질전달의 특성을 규명하는 것이 중요하다. 따라서 본 연구에서는 가스와 액체의 역류흐름에 의한 수력학적 특성과 물질전달 실험결과를 나타내었다.

## I. Introduction

Several methods of the removal of Air Pollution Substance exhausted in industry process are applied, but this research shows the Hydraulic Character to treat pollution substance as absorption by means of packing tower. That is, Packing tower is increasing in terms of *environmental protection and saving energy* in chemical industry, the material as packing tower is plastic, metal and ceramic and the shape is Lattices structure. The main packing tower is VSP-ring, Hiflow-ring, Hackette, Top-packing, Envi-pac and so forth. The ranges of their use are *environmental protection equipment, heat* substance transfer process in chemical industry, *rectification and* distillation, *absorption and* desorption, and other methods of extraction is used efficiently.

The conventional structure packing like Intalox-saddle, Raschig-ring, Pall-ring used at industry scene in the past is less used because of Lattice structure packing good for pressure drop, mass transfer, saving energy and energy efficiency. Recently packing-NSW-ring, Hiflow-ring, Envi-pac-manufactured as composition resin is low pressure drop and more space volume than Raschig-ring and Pall-ring and more efficient in loading limit. Hydraulic character is demonstrated in the light separation. To use Lattice structure packing in industry, it is important to define pressure drop, liquid hold-up, loading-limit, gas phase and liquid phase mass transfer character.

Also scale-up brought about conventional structure packing being used as usual is solved by using Lattice packing material. And long troubled separation technic is rechargeable efficiently thanks to Lattice packing structure. The conventional view is that the diameter of packing tower above the diameter value(1m) can't be used. But it is demonstrated that the diameter of packing tower (from 6m to 11m) can be used. Gas capacity factor(Fv), Liquid hold-up($U_L$), Volume mass transfer coefficient ( $\beta_V \cdot a_e$) to diffusion coefficient was gained by experiment. This research shows that hydraulic character and mass transfer experiment result is on account of gas and liquid back flowing.

## II. Experimental equipment

Each system's factor : $NH_3$-Air/$H_2O$, $NH_3$-Air/$H_2O$-$H_2SO_4$, $SO_2$-Air/$H_2O$-NaOH are mainly selected from pressure drop, gas liquid phase, hydraulic dynamic force, and mass transfer. And the main experimental equipment is shown at Fig. 1, and each diameter of packing tower is 0.22m, 0.30m, and 0.45m. The height of it is from 0.70m to 2.0m. The diameter

Table 1. Investigated packings

| Packing | NOR-PAC PVDF | Hiflow PP | Hiflow Metal |
|---|---|---|---|
| Height | 27mm | 50mm | 28mm |
| Diameter | 27mm | 50mm | 25mm |
| Thickness | 2mm | 1.5mm | 0.4mm |

of packing material are 25mm and 50mm, the many pipe of allowance density in liquid are used. To improve the defect of scale-up accompanied in this experiment, liquid distribution equipment is carried out by using distribution pipe while I was managing to handle the holes of it and is equipped in the top of the packing tower.

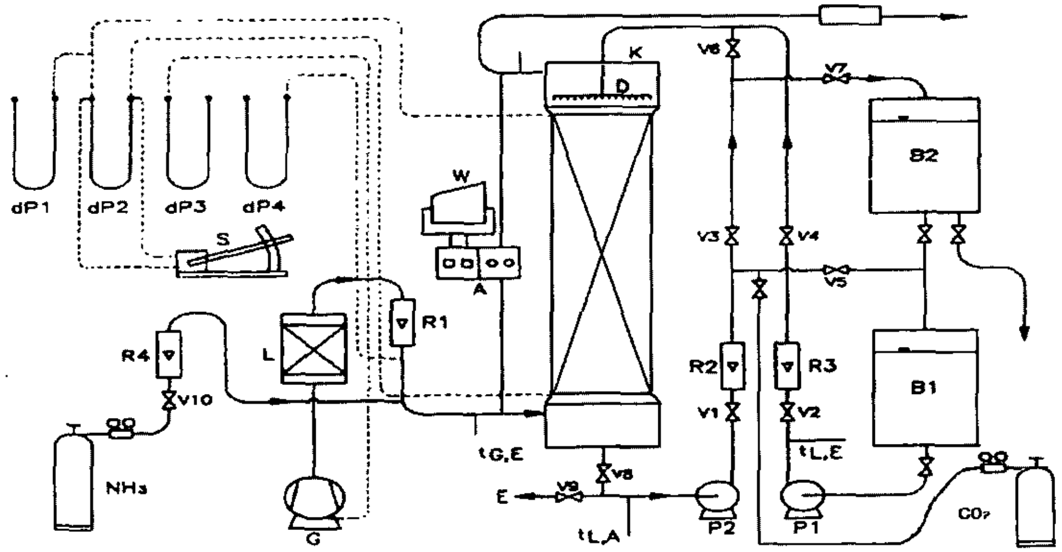
Also the packing material in experiment is shown in the Table 1 and after filling each packing material, different height and diameters in the three experimental equipment are used, and then liquid hold-up, diffusion efficient, specific pressure drop are measured.

## III. Mass Transfer and Hydraulic Character Study

The aim of experiment is one to investigate gas and liquid characters and I adopted other means of system, investigated and analysed hydraulic characters in the condition of $U_G$ (gas velocity) passing into the packing tower and fixed $U_L$(liquid loading). $NH_3$ density absorbed in the water and average gas volume transfer is solved by the Billet experimental equation.

$$\dot{m}_V = \text{const} \rightarrow \dot{m}_{V,BL} = \dot{m}_{V,s} = \rho_{V,BL} \cdot \dot{V}_{V,BL} = \rho_{V,s} \cdot \dot{V}_{V,s}$$

The upper equation is understood by equilibrium model in the $NH_3$-Air system, and




$dP_1 \sim dP_4$ : U-manometer, S : Inclined-manometer, $R_1 \sim R_4$ : Rota-meter, L : Humidifier,
G : Gas blower, W : Recorder, A : Gas analyzer, K : Column(Tower) $V_1 \sim V_{10}$ : Valve,
$P_1$, $P_2$ : Pump, $B_1$, $B_2$ : Liquid storage vessel, D : Distributor

Fig. 1. Schema of absorption investigation plant

diffusion efficient is solved by the Hobler's results.

$$\log m_{pc} = 4.705 - 1922.0/T_V \text{ [bar m}^3\text{/kmol]}$$

$NH_3$ concentration within air flowing into the packing tower, and $NH_3$ amount transferred at the bottom of packing tower are shown in the following.

$$\dot{n}_L = \dot{V}_L \cdot C_L \text{ [kmol NH}_3\text{/S]}$$

$$\dot{n}_V = \dot{V}_V \cdot \rho_V/M_V \, (y_u - y_o) \text{ [kmol NH}_3\text{/S]}$$

$$\dot{n}_m = (\dot{n}_V \cdot \dot{n}_L)/2$$

The *number of transfer unit in the gas* is calculated by the equation (1) and the numerical value transferred an the bottom of packing tower by the equation (2) and the numerical value transferred at the top by the equation (3).

$$NTU_{OV} = \frac{Y_U - Y_O}{\triangle y_u^* - \triangle y_o^*} \ln \frac{\triangle y_u^*}{\triangle y_o^*} \quad (1)$$

$$\triangle y_u^* = y_u - y_u^* \text{ :with } y_u^* = m_{yz} \cdot x_u \quad (2)$$

$$\triangle y_o^* = y_o - y_o^* \text{ :with } y_o^* = m_{yx} \cdot x_o \quad (3)$$

And if the $NH_3$ at the bottom and the top of packing tower is defined as $Y_U$ and $Y_O$ each, the mole concentration of $Y_U^*$ and $Y_O^*$ are represented in the following formula.

$$m_{yz} = \frac{18968.6}{\rho_V \cdot T_V} 10^{(4.705 * 1922/T_V)} \text{ [kmol/kmol]}$$

Accordingly the relative formula of packing tower height and the of transfer unit to the number of transfer unit is this :

$$HTU_{OV} = H/NTU_{OV}, \; HTU_{OV} = u_v / k_v \cdot a_e$$

Next, the relation of gas phase $HTU_V$ is determined as formula (4) and λ in it is explained in formula (5).

$$HTU_V = HTU_{OV} - \lambda \cdot HTU_L \quad (4)$$

$$\lambda = m_{yx} \cdot \dot{V} / \dot{L} \quad (5)$$

The height of transfer unit $HTU_L$ in liquid phase is as follows.

$$HTU_L = U_L / \beta_L \cdot a_e \rightarrow U_L = \frac{1}{3600} \cdot \frac{\dot{L}}{\rho_L \cdot \pi/4 \cdot d_s^2}$$

A liquid loading constant, a filling constant and mass transfer coefficient agree in the following formula.

$$\beta_L \cdot a_e = U_L^n \cdot D_L^{1/2} \; [1/s]$$

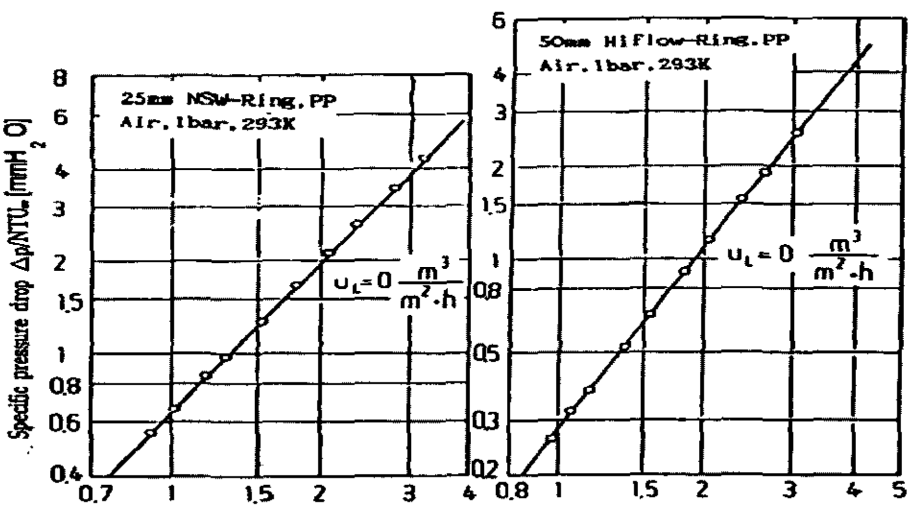
Form $HTU_L$ and $HTU_V$ volume mass transfer coefficient $\beta_V \cdot a_e$ is represented in the following formula.

$$\beta_V \cdot a_e = U_V / HTU_V \; [1/s]$$

The pressure drop $\triangle P/H$, $HTU_V$ per the height of gas is obtained as follows.

$$\triangle P/NTU_V = \triangle P/H \cdot HTU_V$$

In the experiment of this study system, first, mass transfer resistance is less generated in the process of mass transfer as gas phase mass is effectively transferred at the critical concentration where the $NH_3$ concentration is less than 0.05kmol/kmol. $SO_2$ concentration measured in second mass transfer experiment, the critical concentration is influenced by fluid transfer as




Gas capacity factor Fv(Kg$^{1/2}$ m$^{-1/2}$ s$^{-1}$)

Fig. 2. Pressure drop for gas capacity factor unwetted NSW-ring and Hiflow-ring.

diffusion component is not shown when it is stronger than critical concentration.

In short, just as $NH_3$ and $SO_2$ chosen in the mass transfer system is expressed in the sixth and seventh equations, $NH_3$ is absorbed in $H_2SO_4$, $SO_2$ in NaOH. The absorption in these two systems experiences a rapid chemical reaction at phase border on account of solvent being used.

$$2\,NH_3 + H_2SO_4 + H_2O \Rightarrow (NH_4)_2SO_4 + H_2O \quad \text{for } x > x_{kr} \tag{6}$$

$$SO_2 + 2NaOH \Rightarrow Na_2SO_3 + H_2O \tag{7}$$

The mass transfer resistance of liquid phase in this process can be overlooked. In case penetrating only gas capacity factor($F_V$) by filling 25mm NSW-ring and 50mm Hiflow-ring in the form height(1m), pressure drop is gained in the form of the equation(8)

The Reynolds number of as phase is shown in formula (9) and the wall factor K of packing beds in formula (10).

$$\triangle P_0/H = \Psi \frac{1-\varepsilon}{\varepsilon^3} \cdot \frac{F_V^2}{d_p \cdot K} \tag{8}$$

$$Re_V = \frac{u_v \cdot d_p}{(1-\varepsilon)\nu_v} \cdot K \tag{9}$$

$$1/K = 1 + \frac{2}{3}\frac{1}{(1-\varepsilon)}\frac{d_p}{d_s} \tag{10}$$

The part diameter $d_p$ can be obtained in the following formula.

$$d_p = 6 \cdot (1-\varepsilon)/a$$

Accordingly when the extent of the number of Re is over 2100, the value is obtained by using the two formulas different from each other. As liquid is dropped down on packing beds through liquid distributor, water film is formed on the surface of a filling and mass is transferred through this film. As liquid flows down, liquid capacity which forms part of packing beds increases pressure drop by reducing space volume. Fig. 3 shows that the line is parallel form pressure drop of Fv function, and gas capacity factor, to a flow point and it increase rapidly when flooding limit point exceeds 70%.

As liquid phase volume increases at over loading point, it affects mass transfer in packing tower. When liquid is sprayed in packing tower, the pressure drop of packing bed can be represented as the equation (11), and the pressure drop, when not sprayed, is represented

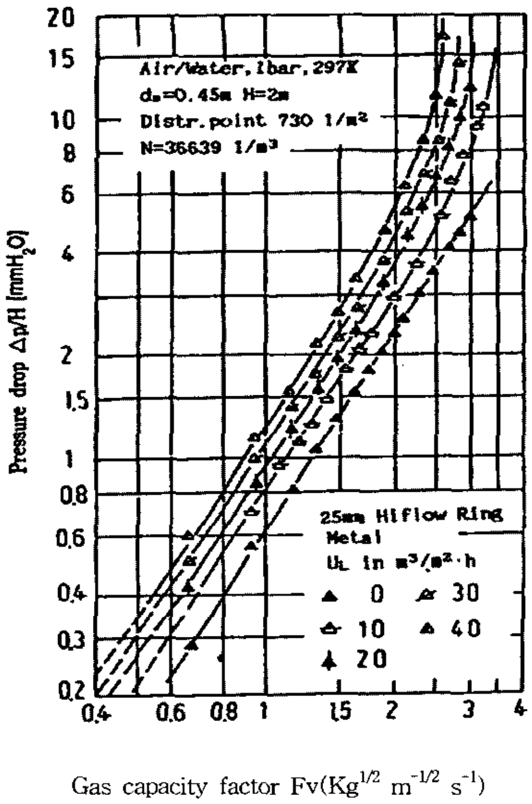



Fig. 3. Pressure drop for unit height of packings as a function gas and Liquid loading

as the equation formula (12), (13).

$$\frac{\triangle P}{H} = \Psi_L \frac{[1-(\varepsilon-h_L)]}{(\varepsilon-h_L)^3} \cdot \frac{F_V^2}{d_p \cdot K} \quad (11)$$

$$\frac{\triangle P/H}{\triangle P_0/H} = \frac{\Psi_L(1-(\varepsilon-h_L)) \cdot \varepsilon^3}{\Psi(\varepsilon-h_L)^3 (1-\varepsilon)} \text{ for } U_L \ll U_V \quad (12)$$

$$\frac{\triangle P}{\triangle P_0} = \frac{\Psi_L}{\Psi}(1+\frac{h_L}{1-\varepsilon}) \cdot (1-\frac{h_L}{\varepsilon})^{-3} \quad (13)$$

Two phase transfer resistance coefficient becomes the function of phase Reynolds number and $\triangle P/\triangle P_0$ can be solved by measuring liquid sprayed pressure drop to space volume of dry packing which is not sprayed. Liquid phase $R_{eL}$ is obtained by formula (14) and to obtain liquid phase resistance coefficient $\Psi$, formula (15) can be used in $R_{e_L}>10$ and formula (16) can be used in $R_{e_L}<10$.

$$R_{eL} = U_L/(a \cdot \nu_L) \quad (14)$$

$$\Psi_L = 2.67 \cdot R_{eL}^{-0.4266} \quad (15)$$

$$\Psi_L = 1.50 \cdot R_{eL}^{-0.1760} \quad (16)$$

$$\Psi_L = 0.865 \text{ for } 10 \le R_{eL} \le 60 \quad (17)$$

The following equation shows pressure drop to packing beds sprayed by liquid.

$$\frac{\triangle P}{H} \Psi_L \frac{1-\varepsilon}{\varepsilon^3} \frac{F_V^2}{d_p \cdot K}(1+\frac{h_L}{1-\varepsilon})(1-\frac{h_L}{\varepsilon})^{-3}$$

The liquid phase resistance coefficient is independent of packing shape and material. Liquid hold-up( $h_L$) within packing tower is determined to the intervention parameter according to equation(18). Surface tension in packing tower is induced by the equation (19), and liquid load factor is driven by the result of a logarithm to viscosity(20).

$$\tau = h_L/U_L \cdot H \quad (18)$$

$$(\frac{W_{eL}}{F_{rL}}) = \frac{\rho_L \cdot g}{\sigma_L} \cdot \frac{\varepsilon^3 d_p^2}{(1-\varepsilon)^2} \quad (19)$$

$$(\frac{F_{rL}^2}{R_{eL}})^{1/3} \equiv B_L = (\frac{\eta_L}{\rho_L \cdot g^2})^{1/3} \cdot \frac{U_L}{\varepsilon} \cdot \frac{1-\varepsilon}{\varepsilon \cdot d_p} \quad (20)$$

The result shows that the result gained by this experiment is one obtained by packing material regardless of volume. Air pressure coefficient exceeded the function of phase transfer coefficient is testified by the equation (22).

$$F_{V,FI}^* = \frac{F_{V,FI}}{\sqrt{\rho_L - \rho_V}} = f\ (x) \quad (21)$$

$$X = \frac{\dot{V}}{\dot{L}} \cdot \sqrt{\frac{\rho_V}{\rho_L}} \quad (22)$$

The following Table 2 shows the condition conducted in this experiment. The result gained by this experiment is that the separation

Table 2. Test conditions for packing studies.

| Symbol | $d_s$ / m | H / m | N / $1/m^3$ | B $1/m^2$ | B TYP |
|---|---|---|---|---|---|
| ▽ | 0.22 | 1.2 | 38,300 | 2,315 | 1 |
| ▼ | 0.3 | 1.4 | 39,917 | 122 | 1 |
| ● | | | | 1,350 | 1 |
| ● | 0.45 | 2.0 | 36,639 | 155 | 1 |
| △ | | | | 400 | 1 |
| △ | | | | 730 | 1 |
| ▲ | | | | 2,400 | 2 |
| ○ | 0.3 | 1.37 | 40,790 | 15 | 1 |

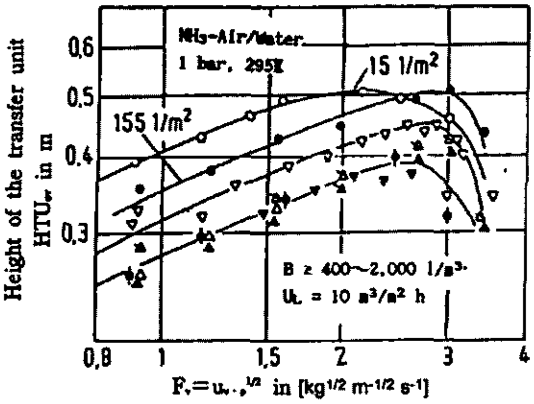



Fig. 4. Height of an overall transfer unit for different number of distribution.

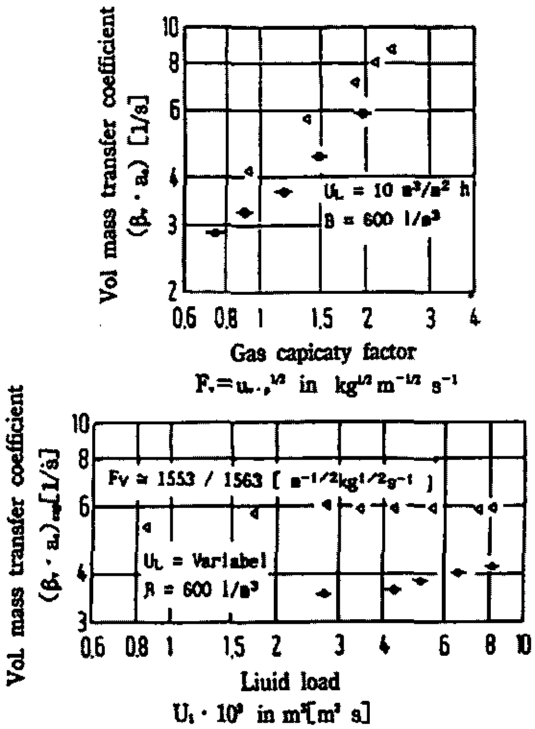



Fig. 5. Vol, mass transfer coefficient for packing showing effect of capacity factor and liquid load.

efficiency in the rectification process is increasing on account of liquid distributor in the packing tower top being unified.

Fig. 4 shows the height of transfer unit acquired in changing gas capacity factor on condition of liquid load being unified. This research can prove to be appropriate in the separation effect of mass transfer if the packing

*Table 3. Parameter for estimating gas phase mass transfer coefficient*

| Packing | $d \cdot 10^3$/m | $C \cdot 10^{-6}$ | n | m | system | number of the measure point | $\delta(\beta_v \cdot a)$ % |
|---|---|---|---|---|---|---|---|
| Hiflow-ring Matel | 27 | 2.41 | 0.833 | 0.25 | $NH_3-Air/H_2O$ | 63 | ±2.6 |
| | | | | | $SO_2-Air/H_2O$ - NaOH | 13 | ±5.4 |
| | | | | | $NH_3-Air/H_2O$ - $H_2SO_4$ | 12 | ±7.2 |
| Hiflow-ring PP | 50 | 5.18 | 0.675 | 0.46 | $NH_3-Air/H_2O$ | 13 | ±10 |
| | | | | | $NH_3-Air/H_2O$ - $H_2SO_4$ | 10 | ±18.9 |
| | | | | | $SO_2-Air/H_2O$ - NaOH | 11 | ±5.6 |
| NSW-ring PVDF | 27 | 2.8 | 0.845 | 0.333 | $NH_3-Air/H_2O$ | 12 | ±8.7 |
| | | | | | $NH_3-Air/H_2O$ - $H_2SO_4$ | 10 | ±22.5 |

tower diameter is $d_s$>0.3m. This conclusion is gained by changing liquid distributor density from 15 ℓ/$m^2$ to 240 ℓ/$m^2$.

Fig. 5 shows that the volume mass transfer coefficient is measured by liquid load factor and gas capacity factor.

Table 3 indicate constant C, n, and m's value gained through the packing material experiment. according to Table 3, the numerical value of mass transfer coefficient and gas capacity factor in large packing material are higher than those in small packing material. The numerical value of mass transfer coefficient ( $\beta_V \cdot a_e$) are determined through this experiment, and induced through these processes, and it is testified that there is interrelation between mass transfer and pressure drop.

$$\beta_V \cdot a_e = C \cdot F_V{}^n \cdot U_L{}^m \cdot D_V{}^{2/3}$$

$$\triangle P/NTU_V \cdot S_{cv}{}^{-2/3} = f\ (F_V)$$

The special character of gas mass transfer are determined by the equation (24) packing volume ( $V_s$ ) to the height of minuteness unit (dH) in the packing tower. The mass transfer from gas side to liquid side is decided by the equation (23).

$$d\,\dot{n}_a = \beta'_v \cdot a_e \cdot (y - y^*) \cdot dV_s \qquad (23)$$

$$dV_s = (d_s{}^2 \cdot \pi/H) \cdot dH \qquad (24)$$

The pressure drop decided by diffusion character of each system.

$$\beta_V \sim D_V{}^{2/3}$$

$$dP/dH = f\ (F_{V,}\, U_{L,} \varepsilon, a)$$

Mole transfer occurs in the height of minuteness unit, and this is determined by the equation (25), and the numerical value of pressure drop(dP) is expressed by the equation (26)

$$d\,\dot{n}_a = \dot{V} \cdot dy \qquad (25)$$

$$dP/d\,\dot{n}_a = \frac{1}{\dot{V}} \cdot \frac{dp}{dy} \qquad (26)$$

Mole transfer dna of component A is concluded by following expression.

$$\frac{dP}{d\,\dot{n}_a} = \frac{1}{(\beta'_V \cdot a_e)\ (y - y^*)} \frac{dP}{dV_s}$$

Final relation can be arrived at the following conclusion.

$$\frac{dP}{dy} \cdot (y - y^*) = \frac{\dot{V}}{(\beta'_V \cdot a_e)} \cdot \frac{dP}{dV_s}$$

$$\frac{dP}{dy} \cdot (y - y^*) = \frac{\dot{V}}{(\beta'_V \cdot a_e) \cdot d_s{}^2 \cdot \pi/4} \cdot \frac{dP}{dH}$$

And number of transfer unit in following expression can be concluded by measuring height of transfer unit.

$$dy/(y - y^*) = d\ (NTU_V)$$

$$\frac{\dot{V}}{(\beta'_V \cdot a_e) \cdot d_s{}^2 \pi/4} = HTU_V$$

And dH pressure drop in this expression are concluded by differential relation (27).

$$\frac{dP}{d\,NTU_V} = (\frac{dP}{dH}) \cdot HTU_V \qquad (27)$$

Pressure drop of two phase transfer is formed by $\triangle P/\triangle P_O$ in terms of pressure drop to one phase flowing, and the equation(28) is induced by changing dP/dH in the equation(27).

$$\frac{dP}{dH}=(\frac{\triangle P}{\triangle P_0})\cdot(\frac{\triangle P_0}{\triangle P})$$

$$\frac{dP}{d\ (NTU_V)} = \frac{\Psi(1-\varepsilon)F_V^2\ (\triangle P/\triangle P_0)}{K^3\cdot\varepsilon^3\cdot dP}\cdot HTU_V \quad (28)$$

In system to have transfer resistance of gas, $HTU_V$ is concluded by schmidt number in following expression, and liquid load scope is regularly arrived like following equation.

$$HTU_V\ \text{prop.}\ Sc_v^{2/3}$$

When the equation mentioned above is induced, the numerical value of $\triangle P/\triangle P_0$ liquid hold-up is regular in the scope of warm as well. By the best satisfied condition, the conclusion in each system is arrived by the equation (29) and complement function is arrived, too. Therefore the equation (30) is caused by this conclusion.

$$\triangle P/NTU_V=C_p\cdot F_V^2\cdot Sc_v^{2/3} \quad (29)$$

$$\frac{(\triangle P/NTU_V)\cdot Sc_v^{-2/3}}{F_V^2}\approx C_p\equiv\text{const} \quad (30)$$

Following equation(31) is needed to express experiment conclusion.

$$\triangle P/NTU_V\cdot Sc_v^{-2/3}=f\ (F_V)=c_p\cdot F_V^2 \quad (31)$$

Fig. 6 is expressed for measuring conclusion of expression (31), and shows n = 2 incline degrees in the log graph under over load.

Height of transfer unit is calculated by adapting the equation(32), and volume mass transfer coefficient is concluded by reflecting

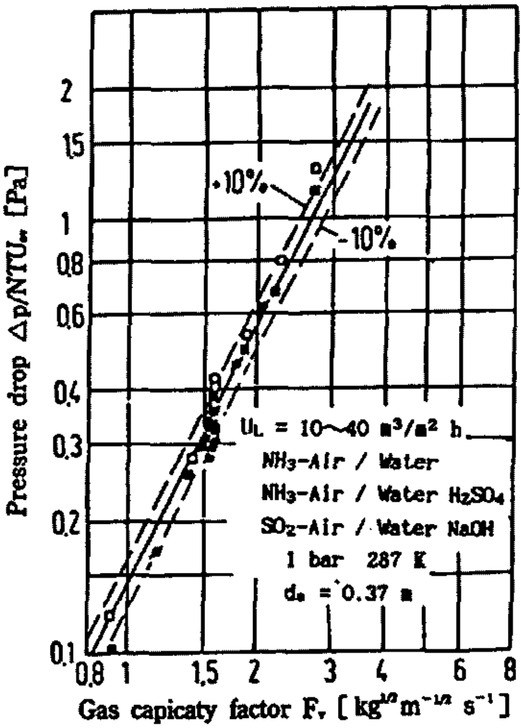



Fig. 6. Specific pressure drop for gas capacity factor in three system

resistance of liquid. In short, total height oftransfer unit can be arrived by conclusion of experiment.

$$HTU_V=(\triangle P/NTU_V)/(\triangle P/H) \quad (32)$$

$$\beta_V\cdot a_e=\frac{\triangle P/H}{\triangle P/\triangle NTU_V}\cdot u_V$$

$$HTU_{OV}=HTU_V+(m_{yx}\cdot\frac{\dot V}{\dot L})\cdot(\frac{u_L}{\beta_V\cdot a_e}) \quad (33)$$

## Ⅳ. Conclusions

Gas phase substances of air pollution substance, especially hazardous gas and malodorous substances are removed by several method by several method but plug tower in this study is used for getting basic material. After a direct road of supplement in filled by different lattice structure, result appeared by three different experimental mass transfer system, and this research result of studying management effect, mass transfer of fluid mechanics and hydraulic character are like as follows.

1) In high load condition, if raising mass transfer, pressure drop rises less and efforts to need for packing tower operating is consumed less.
2) By proper separating a compound sensitive to heat, absorption, desorption, extraction, rectification and distillation process are used effectively.

By conclusion of this studying, it is expected that great effects of packing tower design will be gained in the provinces-construction, equipment operation used in environmental protection, and precision chemical manufacture-by effectively removing air pollution substance.

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