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Wetted Area of Packing Materials in a Packed Column

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요 약

Raschig ring, half ring, half square 및 square의 4가지 충전물에 대하여 그들의 wetted area를 측정하였다. 내경이 8cm인 충전탑 내에서 물과 공기가 향류로 접촉되도록한 실험을 통하여 wetted area에 영향을 미칠 수 있다고 생각되는 요인들, 예컨대 기체유속, 액체속유, 점도 및 표면장력등의 영향을 조사하였다. 차원해석법과 실험식에 의하여 실험 결과를 종합하여 관계식을 도출 하였다.

Abstract

Wetted area was measured for four types of packing materials such as Raschig ring, half ring, half square and square. Water and air were contacted countercurrently in an 8-cm I. D. packed column. The effects of several parameters which were thought to affect the wetted area were investigated. Dimensional analysis was undertaken, and correlations were obtained from experimental data.

1. Introduction

Among the variables related to the performance of the packed column the contact area of liquid and gas, provided by packing materials, is very important. Many attempts to measure the contact area have been made and a large number of experimental data have been obtained by verious methods.

Weisman and Bonilla[1] proposed the method of determining the wetted area by measuring the height of a transfer unit. Shulman and Degouff[2] measured the rate of vaporization of rings of pure naphthalene. The ratio of the rate of vaporization of the wetted to the dry packing was taken as the fraction of total surface taking part in the mass transport. Yoshida and Koyanagi[3] used the same technique for vaporization of water into air and absorption of methanol by water from air-methanol mixture, and observed that the ratio of interfacial area to total area was different from the value for vaporization.

Fujita and Sakuma[4] used the dye technique. This technique, one of the earliest methods of the measurements, has been used broadly up to present. Hikita and Kataoka[5] found that the wetted area was independent of viscosity and gas flow rates up to loading point for Raschig rings. Recently Hayashi and Hirai[6] measured the wetted area for the packing materials of eliminator type made of polyvinylchloride in a gas-liquid contacting apparatus of cross flow system.

Results reported by various investigators differ from one another considerably. Packing materials used were Raschig rings and Berl saddles in most of cases.

In this experiment, four types of packing materials were used to investigate the effects of various parameters affecting them. They were Raschig ring, half ring, half square and square. Wetted areas of these packing materials were obtained by using reddish dye, rhodamine, and correlations were obtained for each of these packing materials by dimensional analysis and experimental data.

2. Dimensional Analysis

Wetted area can be affected by various factos. Among them, gas flow rate G, liquid flow rate L, liquid viscosity μ, and surface tension σ, are regarded as important parameters. According to the experimental results, however, it was confirmed that gas flow rate G, had negligible effect on the wetted area. Therefore, the gas flow rate was excluded from the list of parameters in dimensional analysis which aims to obtain a relation for the ratio of the wetted area to the total area of packing material, a_w/a_t. Three new parameters, liquid density ρ, gravitational constant g, and the total surface area of packing material a_t, are included for the dimensional analysis. Listed in *Table* 1 are the parameters and their dimensions used in the analysis.

Table 1. List of parameters.

name	symbol	dimensions (Mlt)
Liquid flow rate	L	M/l^2t
Viscosity	μ	M/lt
Surface tension	σ	M/t^2
Density	ρ	M/l^3
Gravitational constant	g	l/t^2
Total surface area of packing in unit volume	a_t	$1/l$

The procedure to obtain the dimensionless products π_i, is as follows. Three variables of L, σ, and a_t are taken as the basis for analysis.

$$\pi_1 : \mu L^a \sigma^b a_t^c$$

$$\frac{M}{lt}\left(\frac{M}{l^2t}\right)^a\left(\frac{M}{t^2}\right)^b\left(\frac{1}{l}\right)^c$$

condition on l; $-1-2a-c=0$

condition on M; $1+a+b=0$

condition on t; $-1-a-2b=0$

$$a=-1$$
$$b=0$$
$$c=-1$$

Therefore

$$\pi_1=\frac{a_t\mu}{L} \qquad (1)$$

Putting $\pi_2=\rho L^a\ \sigma^b\ a_t^c$ and $\pi_3=gL^a\ \sigma^b\ a_t^c$, then performing the same procedure as in π_1, the π_2 and π_3 become

$$\pi_2=\frac{a_t\sigma\rho}{L_2} \qquad (2)$$

$$\pi_3=\frac{L^2{}_g}{\sigma^2 a_t^3} \qquad (3)$$

Then the dependency of a_w/a_t is expressed as

$$\frac{a_w}{a_t}=f\left(\frac{a_t\mu}{L},\ \frac{a_t\sigma\rho}{L^2},\ \frac{L^2{}_g}{\sigma^2 a_t^3}\right) \qquad (4)$$

The final correlation is expected to be the form of

$$\frac{a_w}{a_t}=K\cdot\pi_1^\alpha\cdot\pi_2^\beta\cdot\pi_3^\gamma \qquad (5)$$

and the constants in the equation will be determined by the experimental results.

3. Experimental Procedure

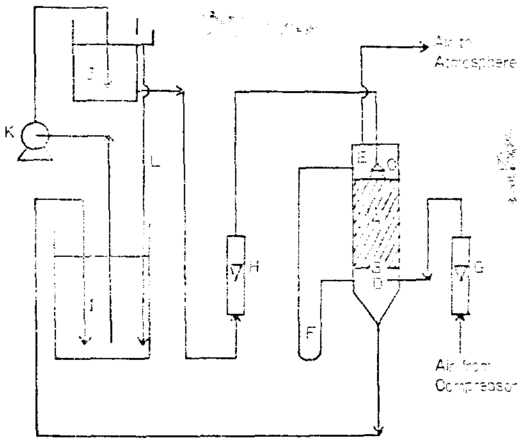
Experiments were undertake nin an 8-cm I. D. packed column made of glass, in which packing materials were packed randomly to a 60 cm height. Pressure drop was checked by a manometer which was connected tothe column. A stainless steel nozzle was used as the liquid distributor. Figure 1 shows a schematic diagram of the experimental apparatus.

Figure. 2 shows the shapes of packing materials used, and their characteristics were listed in *Table* 2.

Table 2. Characteristics of packing materials.

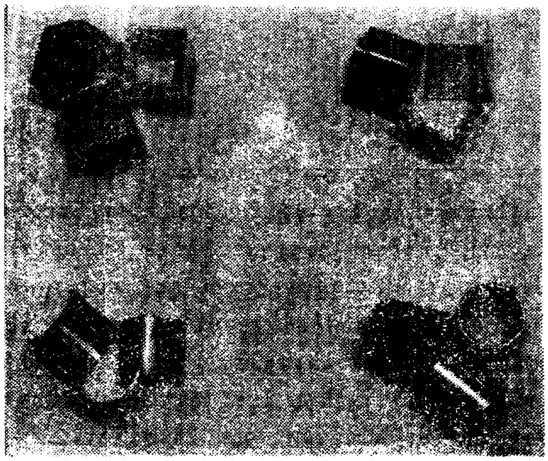
Packing Material	Raschig Ring	Half Ring	Half Square	Square
Material	Carbon steel	Carbon steel	Carbon steel	Carbon steel
Nominal size, in	0. 5	0. 5	0. 5	0. 5
Height, in	0. 5			0. 5
Outside diameter, in	0. 5			
Wall thickness, in	0. 05	0. 05	0. 05	0. 05
Surface area per piece, ft^2	0. 01018	0. 00534	0. 00711	0. 01296
Number of piece/ft^3 (average)	11300	36900	30500	11200
Surfaec area, a_t, ft^2/ft^3	115	197	217	146
Void fraction	0. 85	0. 82	0. 80	0. 88
Equivalent diameter to Raschig ring, in	0. 5000	0. 4034	0. 4568	0. 5973

Water colored by rhodamine (0. 005 wt. %) was used for the flowing liquid. The colored water was stored in the storage tank and pumped to the constant head tank. The overpumped water in the constant head tank was flowed down through the overflow path and recycled to the storage tank. Paper was pasted to the surface of packing materials to identify the dyed area as the wetted area. The paper pasting method which has been used by many other researchers [4,5] does not affect the generalized conclusions from the experimental data, since the main purpose of present investigation is aimed to the effect of the geometrical shapes of the packing material on the wetted area. Air was introduced into the column through a nozzle and a pressure regulator from the one-HP compressor. Air flow rate was controlled by a needle valve and measured with a rotameter. At the same time, water from the constant head tank was introduced into the column through the distributor countercurrently with the rising air.



A=packed column	G=gas rotameter
B=packing support	H=liquid rotameter
C=liquid distributor	I=liquid storage tank
D=air inlet	J=constant head tank
E=air outlet	K=pump
F=manometer	L=overflow path

Fig. 1. Schematic diagram of the experimental apparatus.



Top: square (left), half square (right)
Bottom: half ring (left), Raschig (right)

Fig. 2. Shapes of packing materials.

The paper-pasted packing materials were wetted and dyed during the operation. The water from the column was recycled to the storage tank and the air was discharged into the atmosphere.

After 20 minute's operation, water and air supplies were stopped. Packing materials were taken out from the column, and the pepers were removed and dried. The dyed areas were cutted. By weighing these dyed paper, the ratio of wetted to total area was determined.

First, the effect of gas flow rate was checked for the four types of packing materials by changing its flow rate with the liquid rate fixed. Then by changing the liquid flow rate, its effect was observed. The effect of viscosity was checked by using a glycerine solution for the liquid phase. Finally, adding a surfactant to the water, the effect of surface tension was investigated.

4. Results and Discussions

4-1 Effect of gas flow rate

Figures 3 to 6 show the effect of gas flow rate on wetted area for the four types of packing materials. In *Fig.* 3, it is shown that a_w/a_t is increased slightly at the gas flow rate of 160

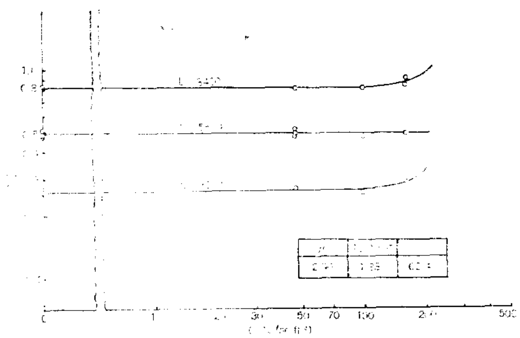


Fig. 3. Effect of gas flow rate to fractional wetted area for Raschig ring.

lb/hr. ft^2, and below that point the values of a_w/a_t are almost constant with the value obtained at $G=0$. Figures 4 and 5 show the effect of G on half ring and half square, respectively.

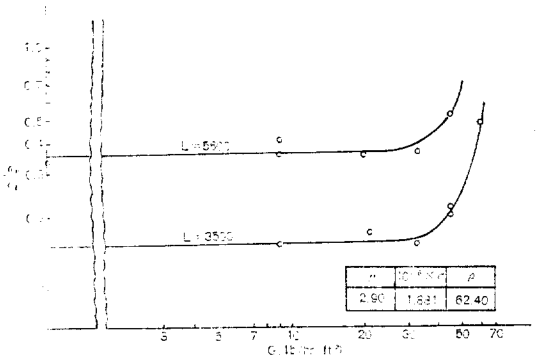


Fig. 4. Effect of gas flow rate to fractional wetted area for half square.

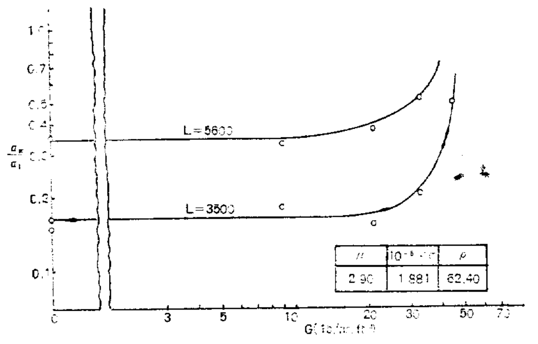


Fig. 5. Effect of gas flow rate to fractional wetted area for half square.

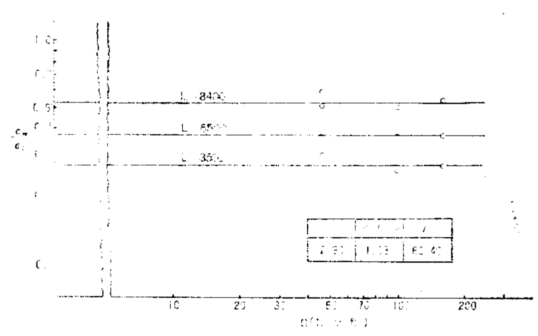


Fig. 6. Effect of gas flow rate to fractional wetted area for square.

Because these two types of packing materials have less void fraction than Raschig ring or square, loading was occurred at relatively low gas flow rate. Figures show the fact that a_w/a_t was increased abruptly above loading point, but up to loading the values of a_w/a_t were almost accorded with that of at $G=0$. The results show that the effect of gas flow rate was independent of wetted area up to loading point.

4-2. Effect of liquid flow rate

Figures 7 to 10 show the relations between the fractional wetted area a_w/a_t and liquid flow rate L. with surface tension σ, and viscosity μ, as parameters. Among straight lines in figures, solid line represents the experimental results with pure water, dotted line represents the data of higher viscosity by adding glycerine to the water while dashed line represents data of lower surface tension by adding Triton X-100, a surfactant, to the water. *Table* 3 shows the physical properties in these three cases.

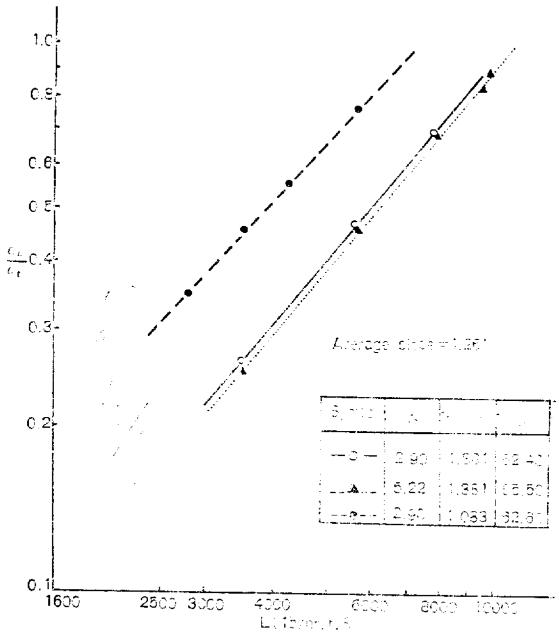


Fig. 7. Effect of liquid rate to fractional wetted area for Raschig ring.

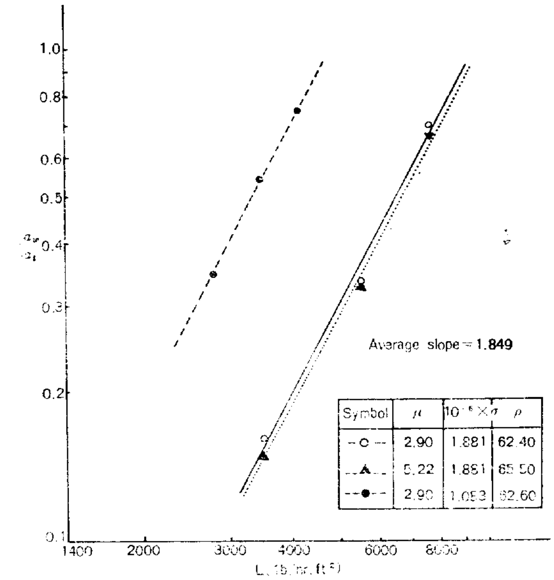


Fig. 8. Effect of liquid rate to fractional wetted area for half ring.

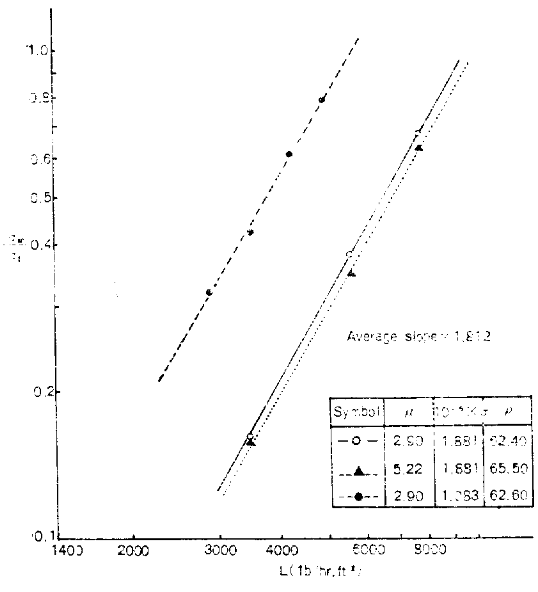


Fig. 9. Effect of liquid rate to fractional wetted area for half square.

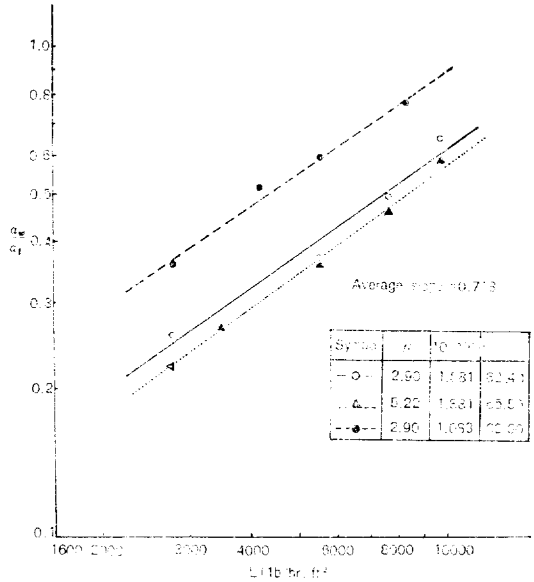


Fig. 10. Effect of liquid rate to fractional wetted area for square.

Table. 3. Physical properties of three flowing liquids.

Liquid type (Symbol)	Surface tension, σ lb/hr^2	Viscosity, μ lb/hrft	Density, ρ lb/ft^3
Liquid 1 (-O-)	1.881×10^6	2.90	62.40
Liquid 2 (-▲-)	1.881×10^6	5.22	65.50
Liquid 3 (-●-)	1.083×10^6	2.90	62.60

In the figures, it shows that the three straight lines under different viscosities and surface tensions are almost parallel. The general relation was expressed as

$$a_w/a_t \propto L^a \qquad (6)$$

and individual values of each packing are listed in *Table* 4.

Table. 4. Numerical values of exponents.

Packing	a in Eq. (6)	b in Eq. (7)	c in Eq. (8)
Raschig ring	1.261	−0.036	−0.930
Half ring	1.849	−0.118	−2.221
Half square	1.812	−0.155	−1.722
Spuare	0.718	−0.171	−0.673

The exponent of the relation obtained for Raschig ring was somewhat higher than those of Shulman and Degouff[2] and coincided with the results of Hikita and Kotaoka[5] at the lower rates of liquid flow.

4-3. Effect of viscosity

To clarify the effect of visocosity, glycerine was mixed into water to increase its viscosity from 2.90 to 5.22 lb/hr. ft. The results were correlated as following equation:

$$a_w/a_t \propto \mu^b \tag{7}$$

The individual values are listed in *Table* 4.

The effect of viscosity on half ring, half square and square was noticed appreciably, but for Raschig ring, the exponent of μ was so small value as −0.036 that the effect of viscosity on Raschig ring could be neglected. These facts state that the effect of viscosity on wetted area was somewhat complicated to obtain the simple relation than the other variables.

4-4. Effect of surface tension

It is anticipated that wetted area of packing material is increased when surface tension, σ, of the liquid is decreased. To confirm the fact, a surfactant was added to water to decrease its surface tension from 1.881×10^6 to 1.083×10^6 lb/hr. ft^2. As the concentration of the surfactant in water was so low, changes in physical properties other than surface tension were negligible. Analysis of the experimental data showed that the effect of surface tension was extremely large compared to that of viscosity. The effect of surface tension was constant for the changes of liquid flow rate. For each packing materials, the following general relation was obtained.

$$a_w/a_t \propto \sigma^c \tag{8}$$

And the c values for each packing were listed in *Table* 4.

5. Dimensionless Froms of Correlations

The experimental data were correlated with dimensionless groups as in Eq. (5). The empirical relations of a_w/a_t were obtained as follows:

For Raschig ring;

$$a_w/a_t=K_1\ (\pi_1)^{0.036}\ (\pi_2)^{0.295}\ (\pi_3)^{0.318} \tag{9}$$

For half ring;

$$a_w/a_t=K_2\ (\pi_1)^{0.118}\ (\pi_2)^{-0.490}\ (\pi_3)^{1.356} \tag{10}$$

For half square;

$$a_w/a_t=K_3\ (\pi_1)^{0.115}\ (\pi_2)^{-0.065}\ (\pi_3)^{0.894} \tag{11}$$

For square;

$$a_w/a_t=K_4\ (\pi_1)^{0.171}\ (\pi_2)^{-0.126}\ (\pi_3)^{0.400} \tag{12}$$

The experimental data were replotted as in *Fig.* 11 through *Fig.* 14. For Raschig ring, results of plotting $(a_w/a_t)\ (L/a_t\mu)^{-0.036}\ (L^2/a_t\sigma\rho)^{-0.295}$ against $(L^2\ g/\sigma^2\ a_t^3)^{0.318}$ was shown in *Fig.* 11.

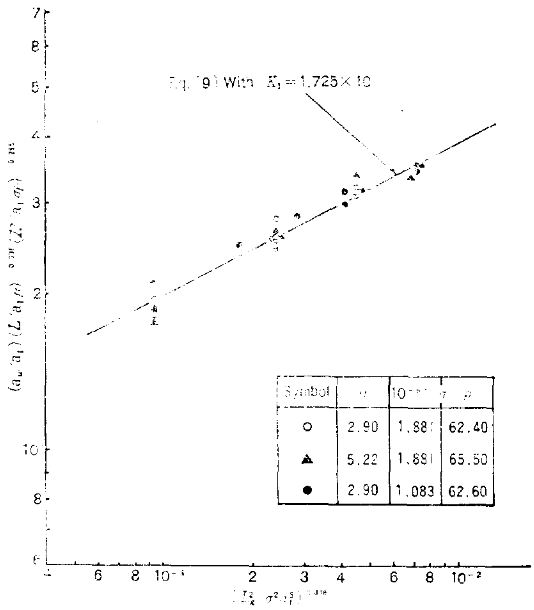


Fig. 11. Correlation of dimensionless groups for Rashig ring.

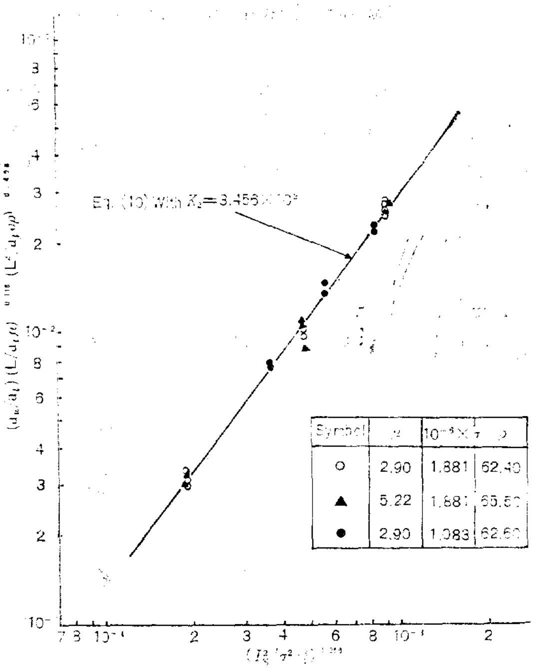


Fig. 12. Correlation of dimensionless groups for half ring.

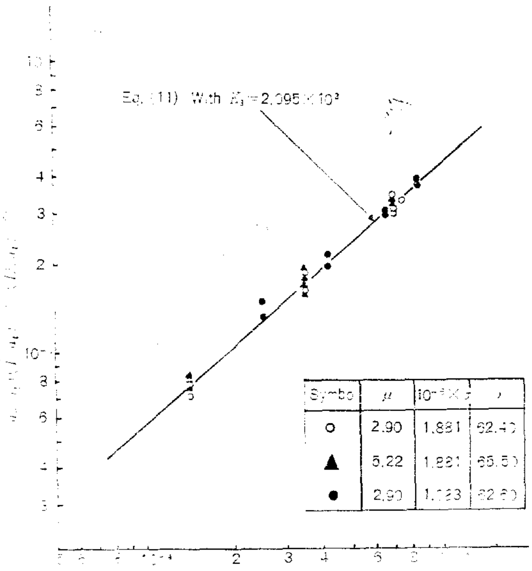


Fig. 13. Correlation of dimensionless groups for half square.

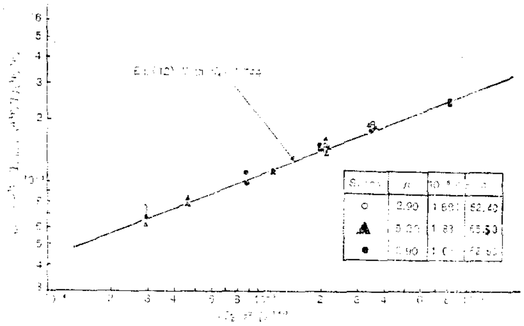


Fig. 14. Correlation of dimensionless groups for square.

From the figure, K_1 was determined as

$$K_1=1.725\times 10 \qquad (13)$$

From *Fig.* 12 through 14,

$$K_2=3.456\times 10^2 \qquad (14)$$

$$K_3=2.095\times 10^2 \qquad (15)$$

$$K_4=1.744 \qquad (16)$$

6. Conclusions

1. Gas flow rate had no effect on the wetted area up to loading point for half ring and half square which experimental result had not been reported.
2. The effect of viscosity on the wetted area appeared to be somewhat complicated than that of the other variables such as liquid flow rate and surface tension.
3. The effects of variables on fractional wetted area were expressed in terms of dimensionless groups as in Eqs. (9) to (12) with K values as in Eqs. (13) to (16).

Nomenclature

a, b, c =exponent (−)

a_w =wetted area of packing (ft^2/ft^3)

a_t =total surface area of packing (ft^2/ft^3)

$f(\ )$ =function of

g	= gravitational constant	(ft/hr^2)
G	= mass velocity of gas	$(lb/hr.\ ft^2)$
K	= constant defined by Eq. (5)	(−)
K_1	= constant defined by Eq. (9)	(−)
K_2	= constant defined by Eq. (10)	(−)
K_3	= constant defined by Eq. (11)	(−)
K_4	= constant defined by Eq. (12)	(−)
L	= mass velocity of liquid	$(lb/hr.\ ft^2)$
l	= length	(ft)
M	= mass	(lbm)
t	= time	(hr)
α, β, γ	= exponent in Eq. (5)	(−)
μ	= viscosity of liquid	(lb/hr. ft)
ρ	= density of liquid	(lb/ft^3)
σ	= surface tension	(lb/hr^2)
π_1, π_2, π_3	= dimensionless products shown in Eq. (1), (2), and (3)	(−)

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