HYDRODYNAMICS OF COLUMNS WITH PLANE PACKINGS MADE OF EXPANDED METAL SHEETS

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Basic hydrodynamic parameters are measured and evaluated at the two-phase film flow on the vertical plane internals made of expanded metal sheets. Pressure drop, liquid holdup and flooding were measured in dependence on flow rates of both phases and on the geometry of the packing and correlation relations for their calculation were determined.

Experimental results obtained earlier in columns with internals made of vertical plane plates situated in parallel have demonstrated that these internals had very small pressure drop. This resulted in high flow rates of both phases related to the unit of cross-sectional area of the column, but their efficiency was considerably worse in comparison to those already used packings. A large number of experiments performed in recent years in absorption and rectification at normal and reduced pressure (vacuum) have proved that by a suitable choice of the sheets their efficiency can be significantly increased.

The aim was to obtain data on pressure drop, liquid holdup and state of flooding on the vertical plane packing made of expanded metal sheets.

EXPERIMENTAL

Equipment. The measurement was performed in a circular column of ID 108 mm 1·1 m long, made of metylmetacrylate. Into the column were successively hanged nine various packings which differed by the type of expanded metal (size of perforations) and by the distance of individual sheets. The liquid and gas flow rates were measured by orifices. Liquid holdup was measured by weighing: the column was suspended on the two-lever connected with the balance. From the difference of masses needed for equilibrating the two-lever arms *i.e.* of the column into the equilibrium position in dry state and at the liquid flow rate the liquid holdup can be determined. The dynamic effects of the falling liquid on the distributor were eliminated (subtracted) by measurements on the shortened packing. Pressure drops were measured by U-manometers and micromanometers with pressure taps situated below the column (total pressure) and by the tap situated in the wall of the column (static pressure). The head of the column was open into the atmosphere. The measurements were performed with the water–air system and solution of glycerol

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air with the viscosity 4·56 and 10·51 mPas. The measurements were performed so that the gas flow rate was increased successively at the in advance selected constant liquid flow rate up to the state of flooding accompanied by a sudden increase and pulsations in pressure drop and in liquid holdup.

RESULTS

Pressure Drop

For correlation of pressure drop the Fanning equation was used for Δp at the liquid flow rate through the duct

$$\Delta p = \xi \frac{L}{d_e} \cdot \frac{u_g^2}{2} \cdot \varrho_g \,. \tag{1}$$

For the two-phase flow on the plane packing was introduced the relative gas velocity u_r instead of the absolute gas velocity u_g which should better express the actual mutual interaction of the gas and liquid phases. The relative velocity is introduced by the relation

$$u_r = u_g + u_1 \,. \tag{2}$$

The liquid velocity u_1 is at the assumption of constant thickness of the liquid film on the whole plane given by the ratio

$$u_1 = \Gamma / Z \,. \tag{3}$$

Introduction of the relative velocity has really simplified the following mathematical evaluation of experimental data as the graphical plot of $\log \Delta p \sim f(\log u_r)$ gives a linear dependence for the given constant liquid flow rate in the whole range of measured velocities (Fig. 1) unlike in the plot $\log \Delta p \sim f(\log u_g)$ where a system of broken lines is obtained – Fig. 2.

The straight lines in Fig. 1 can be described with regard to the shape of Eq. (*1*) by an analogous relation

$$\Delta p = \xi_r \frac{L \cdot \varrho_g}{2 d_e} u_r^B \,. \tag{4}$$

From Fig. 1 results that the slope B is varying with the wetting intensity Γ.

Similarly, also ξ_r is proportional to the intercept cut by the straight line Γ = const on the axis $\log \Delta p$ for u_r = 1 m/s. Data on packings differing by the width in between the sheets could be correlated according to Eq. (*4*), if for d_e the relation

$$d_e = 4F/O = 2d_d \quad (5)$$

was substituted. For calculation of B and ξ_r the following functional dependences were determined on basis of the experimental data:

$$\xi_r = C_1 + C_2\Gamma \quad (6a) \qquad B = C_3 \,.\, Q_1^{C_4} \,. \quad (6b)$$

The constants C_1 to C_4 for the used expanded metal sheets[2] were determined by the least square method and are given in Table I.

LIQUID HOLDUP

The correlation relation for liquid holdup was derived on basis of the modified Nusselt[1] theory. The modification was made through expansion of the balance equation for a term respecting the mutual effect of gas and liquid – the interphase

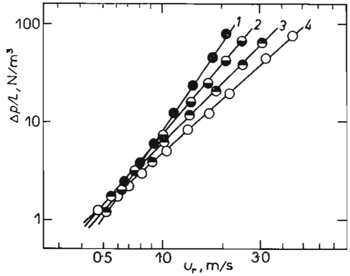

FIG. 1

Pressure Drop in Dependence on Relative Velocity u_r for Expanded Metal Sheets of Type II with the Distance of Sheets $d_d = 0{\cdot}01$ m

1 $\Gamma = 0{\cdot}94$ kg/m s, *2* $\Gamma = 0{\cdot}52$ kg/m s, *3* $\Gamma = 0{\cdot}24$ kg/m s, *4* $\Gamma = 0$ kg/m s.

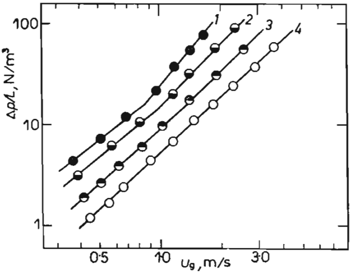

FIG. 2

Pressure Drop in Dependence on Gas Velocity u_g for Expanded Metal Sheets of Type II with the Distance of Sheets $d_d = 0{\cdot}01$ m

1 $\Gamma = 0{\cdot}94$ kg/m s, *2* $\Gamma = 0{\cdot}52$ kg/m s, *3* $\Gamma = 0{\cdot}24$ kg/m s, *4* $\Gamma = 0$ kg/m s.

friction τ_{g1}. After arrangement of the balance equation the relation (7) was obtained

$$\Gamma = \frac{\varrho_1^2 g}{\mu_1} \cdot \frac{h^3}{3} - \frac{\tau_{g1} h^2}{\mu_1 2} \varrho_1 . \quad (7)$$

If the interphase friction τ_{g1} is expressed in the first approach by use of pressure drop of the gas in its passage through the column

$$\tau_{g1} \, 2 l_n L = \Delta p A , \quad (8)$$

and, simultaneously

$$Z = \varrho_1 h . \quad (9)$$

then Eq. (7) can be arranged in the following form (*10*)

$$\Gamma \varrho_1 \mu_1 = \frac{g}{3} Z^3 - \frac{A}{4L} \frac{\Delta p Z^2}{l_n} , \quad (10)$$

TABLE I
Constants of Eq. (*6*)

Type of sheets	x_1	x_2	C_1	C_2	C_3 ($Q_1 < 30$)	C_4 ($Q_1 < 30$)	C_3 ($Q_1 \geqq 30$)	C_4 ($Q_1 \geqq 30$)
I	4	10	0·128	−0·036	1·72	0·033	0·43	0·44
II	6	16	0·163	0·002	1·61	0·084	0·32	0·54
III	8	26	0·152	0·158	1·77	0·060	0·43	0·48

TABLE II
Constants of Eq. (*13*)

Type of sheets	φ	$b_1 \cdot 10^2$	b_2
I	0·27	0·532	1·34
II	0·57	1·330	1·20
III	1·05	1·240	1·32

or (*11*)

$$\Gamma \varrho_1 \mu_1 = \varphi Z^3 - \psi \frac{\Delta p' Z^2}{l'_n} . \qquad (11)$$

The term $2l_nL$ in Eq. (*8*) represents the magnitude of the interfacial area (geometrical area of sheets) and values φ and ψ in Eq. (*11*) are substituting the numerical constants in Eq. (*10*).

For the case of zero gas flow rate, Eq. (*11*) is simplified to the form

$$\Gamma \varrho_1 \mu_1 = \varphi Z_0^3 , \qquad (12)$$

in the log–log coordinates Eq. (*12*) represents a straight line with the slope equal to three. In graphical form of our experimental holdup data Z_0, at the zero gas flow rate in dependence on the term $\Gamma \varrho_1 \mu_1$ in logarithmic coordinates, three mutually parallel straight lines were obtained – for each type of the expanded metal sheets – Fig. 3. These straight lines have confirmed the theoretically derived power with the liquid holdup Z_0 and have determined the magnitude of φ in dependence on the type of expanded metal sheets.

With regard to interfacial area which is not constant but varies primarily with varying wetting intensity and gas flow rate, Eq. (*11*) was for the case of the two-phase

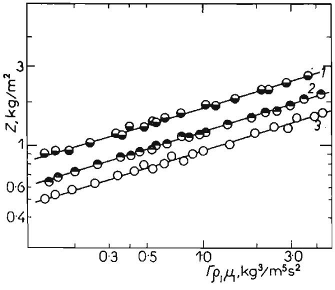

FIG. 3

Liquid Holdup in Dependence on Parameter $\Gamma \varrho_1 \mu_c$

Expanded metal sheets of Type I, *1*; Type II, *2*; Type III; *3*.

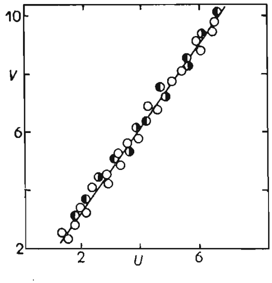

FIG. 4

Correlation of the Flooding State, Eq. (*16*) μ, kg/m s, ϱ, kg/m^3, ◑ 10·51 . 10^{-3} 1160, ◐ 4·56 . 10^{-3} 1120, ○ 1·005 . 10^{-3} 997.

flow arranged into the form

$$\Gamma \varrho_1 \mu_l = \varphi Z^3 - b_1 \left(\frac{\Delta' p Z^2}{l'_n} \right)^{b_2} . \qquad (13)$$

Constants b_1, b_2 or φ for individual types of expanded metal sheets were determined by the optimization method so that for all measurements they should fit at best Eq. (*13*). Relative error in the holdup found experimentally in comparison with that calculated from Eq. (*13*) is not larger than 10%.

FLOODING

In evaluation of data on flooding the correlation relation (*14*) was applied, derived[2] earlier for packed columns

$$1 = [2ge^3 \varrho_1 d_e / \vartheta Q_1^2]^{1/4} - (\tau/\vartheta (Q_g/Q_1)_z^2 (\varrho_1/\varrho_g)]^{1/4} . \qquad (14)$$

The derivation was based on the condition

$$(\mathrm{d}Q_g/\mathrm{d}Z)_z = 0 , \qquad (15)$$

which was proposed and used by Dell and Pratt[3].

Dimensionless parameters defined by Eq. (*14*) were supplemented, on basis of our analysis of the experimental data with regard to various physical properties of the system, with the term of dynamic viscosity which resulted in obtaining criteria similar to those derived by Sherwood and Holloway[4]. This way, the correlation relation for the flooding state was obtained in the form

$$V = 1{\cdot}37U + 0{\cdot}70 , \qquad (16)$$

where

$$V = [2ge^3 \varrho_1 \mathrm{d}_e / Q_1^2 (\mu_1/\mu_w)^{0,2}]^{1/4} ,$$
$$U = [(Q_g/Q_1)_z^2 (\varrho_1/\varrho_g)]^{1/4} .$$

In Fig. 4 are demonstrated in coordinates U and V the experimental data on the state of flooding regardless of the type of expanded metal sheets and physical properties of the system.

LIST OF SYMBOLS

A	cross-sectional area of the column, m^2
B	power in Eq. (*4*)
b_1, b_2	constants in Eq. (*13*)
$C_1 - C_4$	constants in Eq. (*6*)
e	porosity of the packing, m^3/m^3
d_e	equivalent diameter, m
d_d	distance of neighbouring sheets, m
F	free area of the cross section, m^2
g	gravitational acceleration, m/s^2
h	thickness of the film, m
L	length of the packing, m
l_n, l'_n	length of the inlet edge-total or per unit of cross-sectional area, m, 1/m
O	wetted perimeter, m
$\Delta p, \Delta' p$	pressure drop total or per unit of column length, N/m^2, N/m^3
u	velocity in the direction of column axis, m/s
x_1, x_2	dimensions of perforations of the expanded metal sheets, mm
Q	mass flow rate related to the unit of cross-sectional area of the column, $kg/m^2 s$
Z	liquid holdup related to the unit of area of metal sheets, kg/m^2
ϑ	coefficient in Eq. (*14*)
η	coefficient in Eq. (*14*)
μ	dynamic viscosity, kg/ms
ξ	friction factor defined by Eq. (*1*)
ξ_r	friction factor defined by Eq. (*4*), $(m/s)^{2-B}$
ϱ	density, kg/m^3
τ	shear stress, $kg/s^2 m$
φ	constant in Eq. (*11*), m/s^2
ψ	constant in Eq. (*11*)
Γ	mass flow rate of liquid related to unit of length of inlet edge, kg/ms

Subscripts

l	liquid
g	gas
r	relative
gl	on the phase boundary (on the interface)
0	related to the zero gas flow rate
z	flooding
w	water at 20 °C

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