THE PRESSURE DROP OF PERFORATED PLATES OF EXTREMELY LOW FREE AREA AND OPENING DIAMETER

M. ŘEHÁKOVÁ and F. KAŠTÁNEK

Institute of Chemical Process Fundamentals, Czechoslovak Academy of Sciences, 165 02 Prague 6 - Suchdol

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The paper deals with pressure drops of perforated plates with circular openings. Experimental measurement of pressure drops covered the following ranges of geometrical parameters of the plates: $\varphi = 0{\cdot}1-1\%$, $d = 0{\cdot}7-1$ mm, $T/d = 2{\cdot}7-16$. The Reynolds number ranged between $4 \cdot 10^3$ and $11 \cdot 10^3$. Assuming that the maximum energy dissipation occurs due to expansion of the gas emerging from plate openings the data were correlated using a relation for adiabatic expansion. The relation was modified by two correction parameters accounting for the differences due to the interference of the flows through a plate containing many openings. These empirical correction parameters were correlated.

The efficiency of mass transfer in multiphase systems is markedly affected by the properties of the heterogeneous mixture. The most common way of continuous feeding of the lighter phase into the mixture is based on the use of one or more plates (grids) arranged in a vertical sequence. The plate is required in the first place to distribute the lighter phase uniformly over the column cross section and to form a stable constant bed. In practice the required function of the grid can often be met only at the expense of a drastic cut of the free area of the grid. This is particularly so in case of fluidized-bed reactor operating with very fine, usually polydispersed cohesive particles the diameter of which does not exceed tens of micrometers. Uniform aeration and formation of stable fluidized layer are feasible in these cases only with the aid of the grids of free area less than 1%. As another example may serve the bubble-bed reactors for gas–liquid systems where, moreover, the grid must satisfy the requirement of minimum seepage of the heavier phase. The necessary reduction of the free area causes on the other hand increased energy losses and the pressure drop of the plate thus becomes an important parameter for optimizing these reactors.

While pressure drops of conventional types of grids ("dry" plates) with the free area exceeding 3% can be calculated with a good accuracy and correlated (*e.g.* the review of Červenka[1]), the experimental data and calculation procedures for plates of extremely low free area (*i.e.* below 1% where standard published procedures fail) seem to be completely missing in the literature. This paper presents results of an experimental study of pressure drops of perforated plates with circular openings characterized by parameters $\varphi = 0{\cdot}001-0{\cdot}01$, $d = 0{\cdot}7-1$ mm and $T/d = 2{\cdot}7-16$ for the Reynolds numbers based on opening diameter covering the technically important range between 4000–11000. A correlation is presented for Δp derived on the basis of a critical analysis of present theories.

EXPERIMENTAL

The study covers 16 plates with circular openings. The plates were manufactured of brass with the edges of the openings left unchamfered. The openings were arranged in a triangular pitch. The ranges of geometrical parameters of the plates were as follows: $D = 33$ mm, $d = 0{\cdot}7-1$ mm, $T = 2-14{\cdot}4$ mm, $T/d = 2{\cdot}7-16$ mm, $\varphi = 0{\cdot}1-1\%$, $n = 4-19$, $P = 6{\cdot}6-11$. The pressure drops of the above plates were measured on an experimental set-up consisting of a distributing chamber for feeding the air below the grid, a perspex glass cylinder and the grid proper mounted to the chamber by a flange. Two 4 mm pressure taps were mounted in the column. One in the wall of the distributing chamber just below the grid, the other in the wall of the perspex cylinder just above the grid. All grids were investigated experimentally within the range of the Reynolds number between $4 \cdot 10^3 - 11 \cdot 10^3$. Air was brought into the distributing chamber from a compressor *via* pressure reducing valve and oil separator. The flow rate of air was metered by short Venturi tube made to meet the VDI standards[2] ensuring accuracy of $1{\cdot}5\%$. The pressure drop was measured by mercury U-manometers. Each value of the pressure drop was read three times and the arithmetic mean was taken for processing.

RESULTS AND DISCUSSION

The experimentally found values of the pressure drop in the investigated interval of the Reynolds number are quite high for the given geometry and reach values close to one atmosphere. The pressure drop data were used to calculate the coefficient of resistance of the plate, ξ, from the relation

$$\xi = 2\,\Delta p/\varrho_1 v_0^2\,. \tag{1}$$

Fig. 1 shows a typical plot of ξ *versus* Re_0. In the given range of geometrical parameters this course is for all plates analogous. The values of the resistance coefficient for a given Re_0, however, are different and depend on plate geometry. The latter dependence is very complex and judging from the graph not quite clear.

As the most important observation for plates of low free area we regard the fact that given a plate free area ξ increases at constant Re_0 with the simplex T/d up to a certain limiting value reached at about $T/d \approx 6$. With T/d increasing above this limit the resistance coefficient for the given plate no longer varies.

For the correlation of our experimental data we tried first procedures recommended for pressure drop calculation of the perforated plates of rectification columns[1]. Unfortunately, in the derivation of existing procedures based on various concepts of the mechanism of the process, the authors ultimately resorted to purely empirical correlations without any physical background. In view of the number and the character of the variables affecting pressure drop across the perforated plate it seems that a theoretical analysis is virtually impossible.

For thick plates Červenka[1] recommended the correlation of Kolodzie[3] and Smith Van Winkle[4]

$$\xi = [(1 - \varphi^2)(P/d)^{0.2}]/K^2\,, \tag{2}$$

where the dependence of the coefficients K on T/d and Re_0 is expressed graphically. According to these authors the coefficient K remains essentially independent of T/d in the range Re_0 between $4 . 10^3 - 20 \cdot 10^3$ and T/d ranging between 2 and 3. This is completely at odds with our measurements when K computed from Eq. (2) depends strongly on Re_0 even for $T/d = 2{\cdot}7$. Our course of K *versus* Re is essentially a straight line (K decreases with increasing Re) and the average values of K differs from those published in the above paper. Moreover, K computed for a given Re_0 and T/d depends also on the free area of the grid and the number of openings.

The correlation of Kneule and Zelfel[5], recommended[1] for thick plates up to $T/d = 4$, is not suitable either. According to these authors (see Fig. 8 of their paper) the resistance coefficient decreases with Re_0 which is in complete disagreement with our findings (Fig. 1). McAllister and coworkers[6] have derived the following expression for the resistance coefficient of the plate

$$\xi = K'[0{\cdot}4(1{\cdot}25 - \varphi) + (1 - \varphi)^2 + 4fT/d]\,. \tag{3}$$

This relation indicates that the sum of the resistance coefficients: $\xi_{\text{contraction}} + \xi_{\text{expansion}}$ (the first two terms in the bracket of Eq. (3)) is a constant identical for all out investigated grids owing to the very low free area. The difference of the experimental results from the computed values would then be accounted for only by the coefficient $\xi_{\text{friction}} = 4fT/d$. This conclusion is of course incorrect because the contribution corresponding to a given T/d, d and Re_0 would be the same for all grids of different free area (identical friction coefficients f). Moreover, it turns out that the correction coefficient K', which according to McAllister should be only

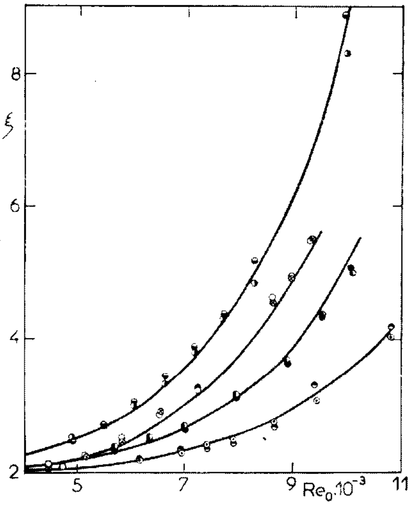

FIG. 1

Plate Resistance Coeficient as a Function of Re_0 for Selected Plates

◒ φ 0·0018, $T/d = 16$, T 11·2 mm, d 0·7 mm, n 4; ◑ φ 0·0018, $T/d = 8$, T 5·6, d 0·7, n 4; ◐ φ 0·00315, $T/d = 8$, T 5·6, d 0·7, n 7; ● φ 0·00315, $T/d = 16$, T 11·2, d 0·7, n 7; ⊙ φ 0·0052, $T/d = 8$, T 7·2, d 0·9, n 7; ◓ φ 0·0052, $T/d = 16$, T 14·4, d 0·9, n 7; ⊗ φ 0·0085, $T/d = 8$, d 0·7, n 19; ○ φ 0·0085, $T/d = 16$, d 0·7, n 19. The curves indicate the course of ξ *versus* Re_0 according to the proposed correlation.

function of T/d, appears to depend under our experimental conditions strongly on Re_0. As we have already established the independence of the resistance coefficient on T/d starting from a certain limiting value of this simplex, it is apparent that in comparison with the values of the resistance coefficient for contraction and expansion, the friction coefficient cannot be important. Consequently, Eq. (3) must be also regarded as unsuitable for our geometry.

This finding, as well as the fact that the pressure drops across the grids of used geometry are unusually high, suggest that the energy of gas passing through plate openings is dissipated predominantly by expansion from the pressure prevailing below the plate to that above the plate, *i.e.* the openings function as jets. The independence of ξ on T/d at high values of this parameter may be explained by formation of a steady velocity profile in these relatively long tubes. Accordingly, the expression used for correlating Δp under our experimental conditions was that of adiabatic expansion in the form used *e.g.* in the calculation of the flow rates in the Venturi tubes and jets[7]

$$w = CYA[2\,\Delta p\varrho_1/(1 - \beta^4)]^{1/2}\,. \tag{4}$$

The expansion factor is given by

$$Y = \left[r^{2/\varkappa}\left(\frac{\varkappa}{\varkappa - 1}\right)\left(\frac{1 - r^{(\varkappa-1)/\varkappa}}{1 - r}\right)\left(\frac{1 - \beta^4}{1 - \beta^4 r^{2/\varkappa}}\right)\right]^{1/2}. \tag{5}$$

On combining Eqs (1) and (4) one obtains

$$\xi = 1/[(C/\sqrt{1 - \beta^4})^2\, Y^2]\,. \tag{6}$$

The foregoing considerations concerned the flow through an isolated opening. The effect of mutual interference of individual parallel streams emerging from the plate has been incorporated into two correction parameters. One of these parameters corrects the discharge coefficient C, the other, the expansion factor Y. With the used plate geometry and experimental arrangement the quantity β may be regarded as negligibly small. The resulting working expressions then take the form

$$\xi = K_2/Y^2\,, \tag{7}$$

$$Y = \text{const.}\,.\left[r^{2/\varkappa}\left(\frac{\varkappa}{\varkappa - 1}\right)\left(\frac{1 - r^{(\varkappa-1)/\varkappa}}{1 - r}\right)\right]^{1/2}. \tag{8}$$

In the experimental range of pressure drops (and corresponding Re_0 numbers) and the parameter $(1 - r)/\varkappa$, where

$$r = p_2/p_1 = p_2/(p_2 + \Delta p)\,, \tag{9}$$

ranges between 0–0·4, Eq. (*8*) may be approximated by

$$Y = K_1[(1 - r)/\varkappa]\,. \tag{10}$$

The optimum values of the parameters K_1 and K_2 were evaluated from the experimental values of Δp for the corresponding values of the Reynolds number, Re_0, by non-linear regression.

Eqs (*7*) and (*10*) follow the course of the ξ *versus* Re_0 dependence with a very good accuracy (the maximum relative deviation amount to 6%) for all combinations of T/d, n and φ. It was established that for thick plates ($T/d \geqq 6$) the parameter K_1 of the expansion factor may be regarded in the whole investigated range as a constant, namely $K_1 = 1{\cdot}446$.

The correction factor K_2 of the discharge coefficient was correlated as a function of plate free area and the number of plate openings by

$$K_2 = [3{\cdot}85 + 48{\cdot}316/n^{2.3}]\,\varphi^{0.179}\,. \tag{11}$$

Combining Eqs (*1*), (*7*) and (*9*)–(*11*) one obtains a relation for the total pressure drop of the plates of extremely low free area in the form of a polynomial.

LIST OF SYMBOLS

C discharge coefficient
d opening diameter
D diameter of grid
f friction factor
K coefficient, Eq. (*2*)
K' coefficient, Eq. (*3*)
K_1 correction parameter, Eq. (*10*)
K_2 correction parameter, Eq. (*7*)
n number of plate openings
p_1 pressure below the grid
p_2 pressure above the grid
Δp pressure drop
P pitch
r $= p_2/p_1$
$\mathrm{Re}_0 = v_0 d \varrho_1/\mu$
T thickness of grid
v_1 superficial velocity below grid
v_0 $= v_1/\varphi$ velocity within opening
w mass flow rate
Y expansion factor, Eq. (*5*)
β $= d/D$ parameter
φ relative free area of grid
$\varkappa$ coefficient of adiabatic expansion
μ viscosity of gas
ϱ_1 density of gas entering the grid
ξ resistance coefficient of grid

REFERENCES

1. Červenka J.: *Thesis*. Czechoslovak Academy of Sciences, Prague 1972.
2. VDI — *Durchfluß Meßregeln*. DIN, 1952.
3. Kolodzie P. A., Van Winkle M.: AIChE J. *3*, 305 (1957).
4. Smith P. L., Van Winkle M.: AIChE J. *4*, 266 (1958).
5. Kneule F., Zelfel E.: Chem.-Ing.-Tech. *38*, 260 (1966).
6. McAllister R. A., McGinnis P. H., Plank C. A.: Chem. Eng. Sci. *9*, 25 (1958).
7. A.S.M.E. Research Committee on Fluid Meters Report: *Fluid Meters — Their Theory and Application*, 5. Ed., 1959.

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