Discharge Coefficients Through Perforated Plates at Reynolds Numbers of 400 to 3,000

P. L. SMITH, JR., and MATTHEW VAN WINKLE

University of Texas, Austin, Texas

The correlation of Kolodzie and Van Winkle (*3*) for predicting dry plate orifice coefficients through perforated plates originally covering a Reynolds number range of 2000 to 20,000 has been extended to apply to Reynolds numbers as low as 400. The correlation applies to column diameters ranging from 3 to 15 in.

Kolodzie and Van Winkle (*3*) reported experimental data and a correlation derived therefrom based on a study of perforated plate dry pressure drop with air as a fluid and the Reynolds numbers range of 2000 to 20,000. Because of possible interest in discharge coefficients and pressure drop through perforated plates at lower Reynolds numbers than those covered in the original work, this investigation was initiated to extend the data over the range down to Reynolds numbers of 400. Essentially, Reynolds numbers ranging from 400 to 3000 were studied in this work.

EQUIPMENT

The equipment arrangement was the same as that used by Kolodzie (*3*) and consisted mainly of flanged sections of 3-in. I.D. Pyrex glass pipe arranged horizontally so that perforated plates of various characteristics could be placed between the flanges. Details of the setup are given in (*3*).

The perforated plates studied were the same as those in the original work and the range of variables included in their design are shown in Table 1.

TABLE 1

RANGE OF PLATE DESIGN VARIABLES

Hole diameter, in.	1/16, 3/32, 1/8, 5/32, 3/16, 1/4
Hole pitch to diameter ratio	2, 3, 4
Plate thickness, in.	0.081, 0.125, 0.1875, 0.25
Plate thickness to hole diameter ratio	0.33 to 4.0
Plate free area, % of pipe cross-sectional area	2.33 to 15.8

All holes were drilled on a triangular pitch.

PROCEDURE

The experimental procedure was essentially that followed by Kolodzie but slightly modified to obtain greater accuracy in reading pressure drop data at the lower flow rates. These modifications included use of a more sensitive draft gauge with optical magnification of the scale and meniscus in the tube. Also the runs were started at the high flow rates and readings taken at decreasingly lower rates until the pressure drop was too small to be measured. This procedure enabled duplicate determinations to be made with a maximum absolute error of 5% and an average absolute error of approximately 2%.

P. L. Smith, Jr., is at present with C. F. Braun Co., Alhambra, California.

ORIFICE COEFFICIENTS

The orifice coefficients shown on the figures were calculated by means of Equation (1)

$$w = CA_f Y \sqrt{\frac{2g_c \rho_1 \Delta P}{1 - \left(\frac{A_f}{A_D}\right)^2}} \qquad (1)$$

EXPERIMENTAL RESULTS

For each pitch to diameter ratio a plot was prepared showing the orifice coefficient as a function of Reynolds number with the thickness to diameter ratio as a parameter. Figures 1, 2, 3, and 4 present these data.

Sudden sharp decreases in pressure drop as the flow rate was gradually decreased were encountered in testing plates having a plate thickness to hole diameter of 0.75 to 0.80. Because of this, the experimental points were not as reproducible as in other situations. A number of points were taken and averaged to give the points from which the dashed curves shown on the figures were drawn.

Such instability in a study of a single orifice in approximately the same range of thickness-to-diameter ratio was reported by Lesem, *et al.* (*4*). They explained the phenomenon by postulating that for thick-plate orifices, the vena contracta lies between the upstream and downstream surfaces of the plate; for thin plate orifices the vena lies beyond the downstream surface of the plate; and that for orifices for intermediate plate thicknesses, the vena lies between the surfaces. In the

TABLE 2

COMPARISON OF EXPERIMENTAL AND PREDICTED DRY-PLATE PRESSURE DROP

Fluid	Reynolds No.	t/d Ratio	P/d Ratio	ΔP, exp. in H_2O	ΔP, calc. in H_2O	% Difference
			Arnold, *et al.* (*1*) 15-in. column			
Air	1760	0.35	1.085	0.51	0.66	−16.6
	880			0.15	0.15	0.0
	400			0.04	0.04	0.0
	2500	0.49	1.14	2.80	2.70	0.4
	1880			1.70	1.66	0.2
	1252			0.70	0.68	0.3
	1096			0.50	0.50	0.0
	985	0.49	1.06	0.30	0.31	−0.1
	657			0.12	0.14	−0.2
	494			0.082	0.083	−0.2
			Mayfield, *et al.* (*5*) 6-in. column			
	2570	1.00	4.00	0.45	0.48	−6.2
	2380			0.40	0.42	−4.8
	1925			0.25*	0.28	−10.1
	1475			0.15*	0.17	−7.1
			Hunt *et al.* (*2*) 6-in. column			
Air	2820	1.00	4.00	0.166	0.162	4.9
	2000			0.083	0.082	1.2
	1260			0.033	0.033	0.0
	1395			0.166	0.164	2.4
	982			0.083	0.082	1.2
	624			0.033	0.033	0.0
Carbon Dioxide	2360	1.00	4.00	0.50	0.49	2.0
	1665			0.025	0.025	0.0
Methane	1835	1.00	4.00	0.046	0.045	2.1
	1160			0.0184	0.0183	0.0
Argon	2230	1.00	4.00	0.115	0.112	2.6
	1310			0.046	0.046	0.0

*extrapolated

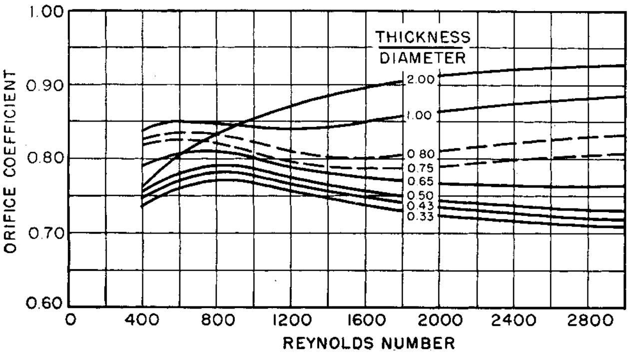

Fig. 1. Plot of orifice coefficient vs. Reynolds number for a pitch to hole diameter ratio of 2.0.

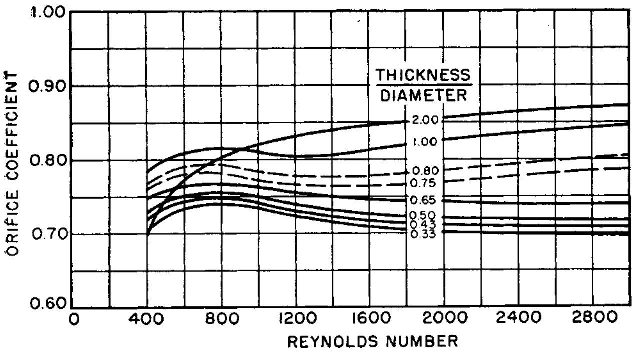

Fig. 2. Plot of orifice coefficient vs. Reynolds number for a pitch to hole diameter ratio of 3.0.

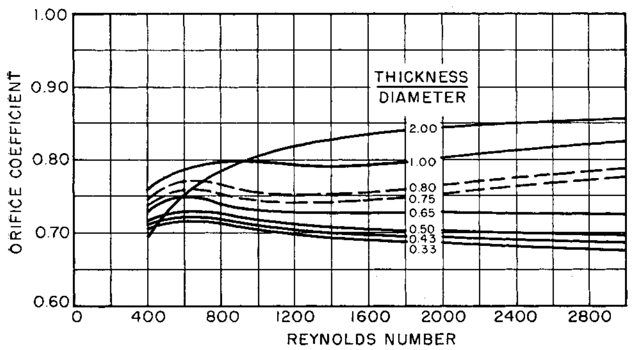

Fig. 3. Plot of orifice coefficient vs. Reynolds number for a pitch to hole diameter ratio of 4.0.

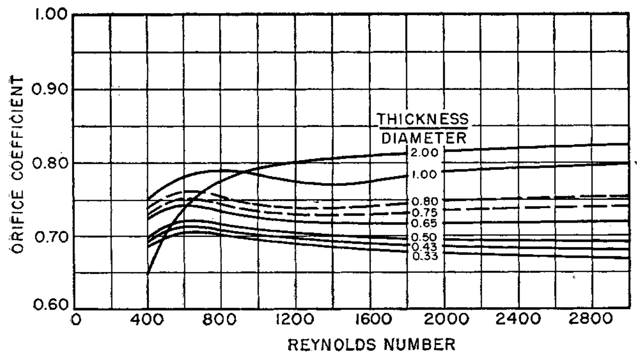

Fig. 4. Plot of orifice coefficient vs. Reynolds number for a pitch to hole diameter ratio of 5.0.

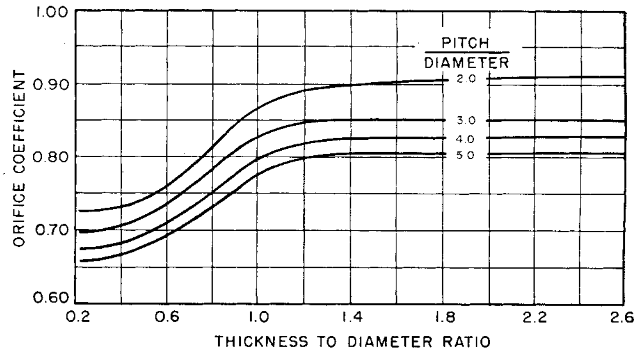

Fig. 5. Cross plot of Figures 1, 2, 3, and 4 at a Reynolds number of 2000.

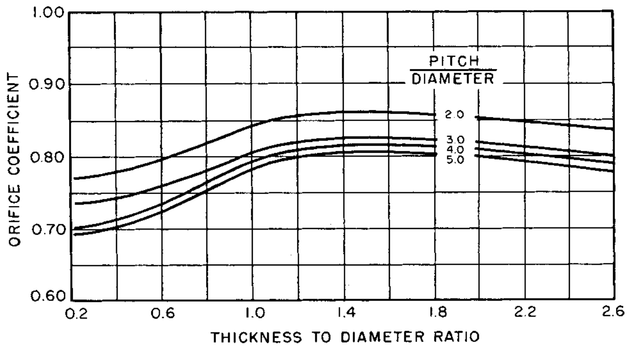

Fig. 6. Cross plot of Figures 1, 2, 3, and 4 at a Reynolds number of 1000.

first case, the jet is attached to the downstream edge. In the second, it is not attached to the surface. In the third case, the jet moves downstream as flow is increased or upstream as it is decreased; thus the jet attaches itself to or detaches itself from the surface and causes sharp changes in pressure drop. In all probability where perforated plates are concerned, this mechanism is intensified by interference action between adjacent holes at their downstream edges.

Figures 5, 6, and 7 are cross plots of Figures 1, 2, 3, and 4 at Reynolds numbers of 2000, 1000, and 600; these plots relate orifice coefficients to plate-thickness-to-hole-diameter ratio with parameters of hole-pitch-to-diameter ratio.

From these curves a plot of orifice coefficient vs. hole diameter-to-pitch ratio on log-log paper, Figure 8, indicated a series of parallel straight lines at each thickness-to-diameter-ratio. The average slope of the lines was 0.10. Equation (2) represents this family of lines.

$$\log C = \log k + 0.10 \log \frac{d}{P} \qquad (2)$$

Equation (2) may be rearranged in the form of Equation (3):

$$K = C\left(\frac{P}{d}\right)^{0.10} \qquad (3)$$

The curves in Figures 1 through 4 may be represented by one curve when K is plotted vs. the thickness-to-diameter ratio. K is a constant for any given thickness-to-diameter ratio.

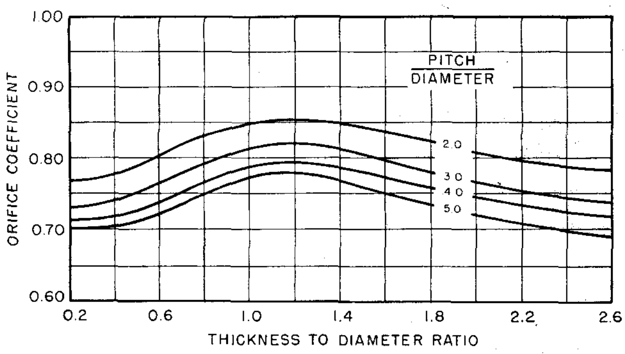

Fig. 7. Cross plot of Figures 1, 2, 3, and 4 at a Reynolds number of 600.

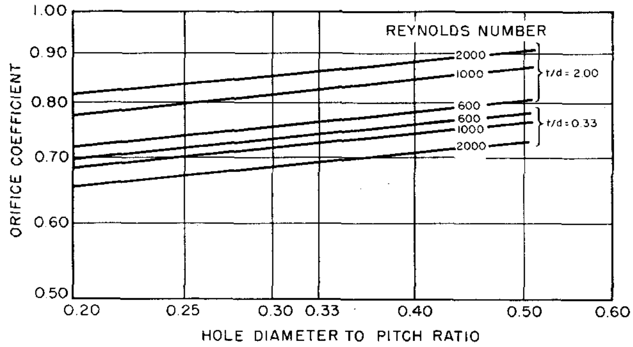

Fig. 8. Cross plot of Figures 5, 6, and 7 at two thickness to hole diameter ratios.

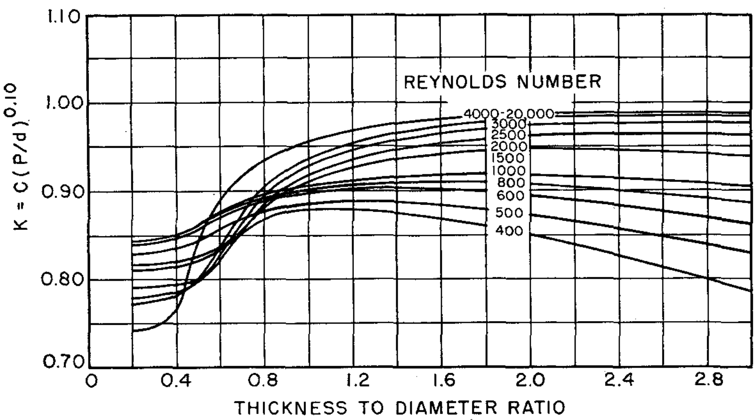

Fig. 9. A correlation relating perforated plate orifice coefficient with the physical characteristics of the plate and fluid.

Figure 9 is a plot of K vs. thickness-to-diameter ratio for the range of Reynolds numbers at parameters from 400 to 20,000. The single curve for Reynolds numbers of 4000 to 20,000 was taken directly from Kolodzie and Van Winkle (*3*).

DISCUSSION

The correlation shown in Figure 9 indicates that for Reynolds numbers above 4000 the orifice coefficient increases with increasing thickness-to-diameter ratio until the ratio reaches approximately 1.7. For t/d ratios greater than 1.7, the coefficient is practically independent of the t/d ratio. At Reynolds numbers below 2000 the coefficient increases with increasing t/d ratio to a maximum value at around $t/d = 1.0$. It then decreases. At the lower Reynolds numbers, the rate of decrease relative to t/d ratio is more rapid. The coefficient also decreases with increasing pitch-to-diameter ratio.

Figure 9 indicates that orifice coefficients increase with increasing Reynolds numbers only when the thickness-to-diameter ratio is above approximately 1.0. Below this value the orifice coefficient increases with increase in Reynolds number up to approximately 1000 and then decreases sharply until the minimum is reached for Reynolds numbers of 4000 to 20,000 at a thickness-to-diameter ratio below 0.4.

APPLICABILITY OF CORRELATION

Kolodzie (*3*) showed that the original correlation, based on Reynolds numbers of 2000 to 20,000, could predict other dry-plate pressure drop data reported in the literature (*1, 2, 5*) within an accuracy of 5%. The correlation, extended in Reynolds number range to 400 by this work, also predicts the available data to within an accuracy of 5% at the lower Reynolds numbers. Table 2 includes comparison of experimental pressure drop and predicted pressure drop selected at random.

Table 3 gives a summary of the range of variables in which this correlation has been shown to be accurate within 5%.

TABLE 3
EFFECTIVE RANGE OF CORRELATION

Variable	Minimum	Maximum
P/d ratio	2.0	5.0
t/d ratio	0.25	3.0
A_f/A_t ratio	0.60	1.00
Reynolds number	400	20,000
Column diameter	3 in.	15 in.

It applies to air, carbon dioxide, methane, and argon and covers a gas molecular weight range from 16 to 44.

Maximum orifice coefficients were obtained under the following conditions:

Reynolds number	1000 and greater	Less than 1000
t/d ratio	1.0 or greater	2.0 or less
P/d ratio	2.0 or less	2.0 or less

The correlation therefore has been shown to apply to dry-plate pressure drop through perforated plates at Reynolds numbers down to 400.

NOTATION

A_D = free cross-sectional area of duct, sq. ft.
A_f = total free area of holes on the plate, sq. ft.
A_t = maximum total free area of holes on the plate, sq. ft.
C = orifice coefficient
d = hole diameter, ft.
g_c = 32.2 (lb. force-ft.)/(lb. mass-sec.^{2})
K = constant
P = hole pitch (center to center distance), when used in ratio (P/d)
P = pressure drop across plate, lb./sq. ft.
ΔP = pressure drop, lb./sq. ft.
Re = Reynolds number
t = plate thickness
w = mass flow rate, lb./sec.
Y = expansion factor
ρ = density of fluid (air), lb./cu. ft.

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