PRESSURE DROP THROUGH BEVELLED MULTIHOLE ORIFICES IN SERIES

(PWR Blanket Design)

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Summary

This report describes the continuation of a study of pressure drop across various combinations of staggered multihole orifice plates in series. Plates used in this test contained bevelled leading edge holes and were of the general design proposed for flow control in the PWR blanket region. Variables examined in this test were orifice diameters of 0.375, 0.3437, and 0.2812 in., plate spacings of 0.160, 0.300, and 0.625 in., one to six plates in series, and flow rates corresponding to orifice Reynold's numbers ranging from 15,000 to 140,000. The orifice plates and experimental methods employed in this test were similar to those described in the preceding orifice plate report, WAPD-TH-241 (41 holes on a 0.436 in. square pitch located in a 4.195 in. diameter pipe), with the exception that the present plates had a 30° bevel around the leading edge of each hole sufficient in depth to make the bevelled diameter 1/16 in. larger than the hole diameter.

Results are given as pressure loss coefficients (number of orifice velocity heads), and were found to be about 50% less than comparable values for square edge orifices. In general, Reynold's number had no effect upon the loss coefficients. The loss coefficients are estimated to be accurate within $\pm 10\%$ over the range investigated.

Introduction

As stated in WAPD-TH-241, for PWR Core 1, it is necessary to obtain lower coolant velocities in the blanket than in the seed. In order to produce these decreased flow rates under the condition of equal pressure drop across both the seed and the blanket, it is proposed to put one or more orifice plates in series with the blanket rod bundles.

Preceding studies were concerned primarily with square edge orifices. If the water velocity through the orifices is high, the danger of inlet edge erosion exists with square edged orifices. Therefore, the water velocity must be limited, or bevelled or rounded inlet orifices used. Therefore, the tests described herein were made to determine the effect of bevelled inlet edges on pressure drop for various configurations of specific interest to PWR.

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Procedure

Pressure drop tests were performed in the 4" Bettis Low Pressure Hydraulic Loop, No. 26. The orifice plate adaptor housing and spacer rings used in the square edge orifice tests were also employed in the test. Each plate contained 41 holes located on a 0.486 in. square pitch; the distance from the nearest pitch line to the plate center was one-quarter of the pitch. This was done to permit offsetting the holes from one another in multiple plate tests by merely rotating each successive plate through 180°. All multiple plate runs were made with the holes in each plate staggered with respect to the adjacent plates. Flow was always into the bevelled edge.

Sixteen orifice plates were provided for testing, with the following hole size distribution: 6 plates of 0.375 in. diameter, 4 plates of 0.3437 in. diameter, and 6 plates of 0.2812 in. diameter. All plates were 3/16 in. thick. The bevelling detail is illustrated below:

The configurations tested were those shown in the block diagram of Table I. Only those conditions marked with an x were investigated.

Table I

Configurations Tested

Spacing, inches	0.160					0.300		0.625
No. of Plates	1	2	3	4	6	4	6	4
Hole Size, inches								
0.375	x		x		x		x	x
0.3437	x	x		x		x		x
0.2812	x		x		x		x	x

Overall pressure drop across the test section was measured by two pressure taps located approximately 16 inches upstream and downstream from the plates. The drop was indicated on a well type manometer in either inches of carbon tetrachloride or mercury. The loop flow rate was varied from 50 to 450 gpm or up to the maximum measurable pressure drop. Flow rates were measured as the pressure difference across a calibrated Foster Flow Tube. The loop was operated at ambient temperature and 180°F, yielding orifice Reynolds' Numbers ranging from 15,000 to 140,000.

Equation (1) was used to determine the pressure loss coefficient and is shown in measurable terms in Equation (1a),

$$\frac{\Delta P}{\rho} = NK \frac{V_o^2}{2g} \quad (1)$$

$$NK = \frac{2g \Delta P A_o^2}{\rho W^2} \quad (1a)$$

Orifice Reynold's numbers were computed for each test condition using Equation (2),

$$Re = \frac{D_o V_o \rho}{\mu} \quad (2)$$

Results

Values of NK were calculated from equation (1a). A plot of NK vs. Reynold's Number is shown in Figure 1 for the 0.3437 in. diameter orifice plate tests. Little variation with Re is apparent, and similar results were observed from data for the other hole diameters. Therefore, the loss coefficients are generally independent of Re, and may be expressed as an average over the range. The observed values of NK were averaged to obtain $\overline{NK}$ for each configuration, which are presented in Table II.

TABLE II

Observed $\overline{NK}$ Values

Spacing, inches	0.160						0.300		0.625
No. of Plates	1	2	3	4	6		4	6	4
Hole Diameter									
0.375 in.	0.581		1.96		3.96		3.00		1.95
0.3437 in.	0.642	1.81		3.58		2.54			2.44
0.2312 in.	0.825		3.41		6.69		5.43		3.18

As stated in WAPD-TH-241, the observed $\overline{NK}$ may be broken down into two components, i.e., the loss due to the first plate, and that due to each subsequent plate. This division is indicated in Equation (3).

$$\overline{NK} = K_1 + (N - 1) K_2 \quad (3)$$

In this investigation, both K_1 and K_2 were evaluated using equation 3 in order to determine how each varied with plate configuration and for comparison with the square edged data. K_1 was determined from the single plate tests, and assumed not to vary for the same flow rates as other plates were added in series. These results are presented in Table III and Figure 3 as average K_1 and K_2 values for each orifice hole size (or area ratio).

TABLE III

Variation of Orifice Coefficients with Hole Diameter and Plate Spacing

Area Ratio		0.328	0.275	0.185
Orifice Hole Size, inches		0.375	0.3437	0.2812
K_1	(or K_2 @ $S = \infty$)	0.58	0.64	0.82
K_2	($S = 0.160"$)	0.68	1.08	1.23
K_2	($S = 0.300"$)	0.48	0.63	0.92
K_2	($S = 0.625"$)	0.46	0.60	0.78

The graphical representation of equation (3) is shown in Figure 2. It is noted that for some plate spacings it is possible to obtain a lower total coefficient than for the same number of plates at a very large spacing, (K_2 may be less than K_1).

It was suggested in WAPD-TH-241 that K_2 should always be greater than K_1 because an additional turning loss is involved for subsequent plates in bending the fluid through the staggered hole arrangement. This turning loss is no doubt present in a staggered configuration; however, the loss in pressure through an orifice is primarily a function of the

$\Delta(\frac{v^2}{2g})$ for the system. It is reasonable to assume that for certain geometries

the high velocity stream produced at the preceding plate is not entirely dissipated, but a portion continues into the following orifice hole. Therefore, this "channeling" would produce a lower

$\Delta(\frac{v^2}{2g})$ across subsequent plates and a lower pressure loss as observed.

Figure 3 shows the variation of K_2 with spacing for the orifice hole diameters tested and for square edge orifices of the same hole size. It is evident that the bevelled edges are more conducive to the "channeling" effect and that K_2 does approach K_1 at large spacings.

Figures 4 and 5 provide design information for the variation of $\overline{NK}$ with area ratios at bevelled edge orifice plate spacings of 0.160, 0.300, and 0.625 in. respectively. The curves plotted are calculated from equation (3) and the data of Table III, with the experimental points shown for comparison.

It should be mentioned that the results of WAPD-TH-241 showed a similar variation of $\overline{NK}$ with area ratio (Figure 2). However, $\overline{NK}$ did not continue to increase, as might be concluded from Figures 4 and 5, but dropped off as the area ratio decreased. Therefore, extrapolation of this data to smaller area ratios is not recommended.

Conclusions .

Bevelled edge orifice plate pressure drop coefficients average 50 percent of those for comparable square edge orifice plates.

Pressure drop coefficients K_2 may be less than K_1 , for certain bevelled edge orifice plate combinations.

Coefficients are independent of orifice Reynold's number over the range investigated.

The correlations presented are estimated to be accurate within 10 percent and should not be extrapolated to dissimilar geometries or otherwise out of the range for which they were evaluated.

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TABLE C SYMBOLS

(consistent units)

A_o	=	Total flow area of 41 orifice holes
A_T	=	Flow area of housing bore
D_o	=	Orifice hole diameter
g	=	Acceleration of gravity
K	=	Orifice pressure loss coefficient for individual plate (or average for a series of plates)
		(K_1 for single plate or for first of a series of plates)
		(K_2 for subsequent plates of a series)
N	=	Number of orifice plates in a series
$\overline{NK}$	=	Average observed values of NK
ΔP	=	Overall static pressure loss across orifices
Re_o	=	Reynolds number in orifice
S	=	Spacing between orifice plates
V_o	=	Velocity of flow in orifice holes
W	=	Loop volumetric flow rate
ρ	=	Density of fluid
μ	=	Viscosity of fluid

FIGURE 1
TOTAL LOSS COEFFICIENT VS. REYNOLDS NUMBER
(FOR PWA BLANKET FLOW CONTROL ORIFICES)

FIGURE 2

TOTAL LOSS COEFFICIENT VS. NUMBER OF PLATES
(FOR PWR BLANKET FLOW CONTROL ORIFICES)

DATA SHOWN IS FOR 0.375" DIA.
BEVELLED EDGE PLATES

FIGURE 3

SUBSEQUENT ORIFICE LOSS COEFFICIENTS VS. SPACING (FOR PWR BLANKET FLOW CONTROL ORIFICES)

FIGURE 4

TOTAL COEFFICIENT VS. FLOW AREA RATIO
(FOR PWR BLANKET FLOW CONTROL ORIFICES)

ALL PLATES WITH AN 0.160" SPACING

FIGURE 5

TOTAL COEFFICIENT VS. FLOW AREA RATIO
(FOR PWR BLANKET FLOW CONTROL ORIFICES)

ALL PLATES WITH BEVELLED EDGES

TOTAL COEFFICIENT - K_T

8

7

6

5

4

3

2

1

0

0.1

0.2

0.3

0.4

0.5

FLOW AREA RATIO A_2/A_1

5 PLATES

A - 0.125" SPACING

B - 0.25" SPACING

4 PLATES

3 PLATES

2 PLATES

1 PLATE