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**PRESSURE DROP AND VOLUME FRACTION OF
GRID AND WIRE SPACED SUBASSEMBLIES**

by

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Components Technology Division

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Pressure Drop and Volume Fraction of Grid and Wire Spaced Subassemblies

J. F. de Paz

ABSTRACT

The results of parametric calculations of pressure drop and volume fractions for honeycomb grid spaced fuel rod bundles are given, and a comparison with those of spiral wire spaced subassemblies is presented. The study covered the range of pin diameters from 0.3 to 0.45 inches, with linear heat ratings between 10 and 40 kW/ft. Included is also a brief discussion of the pressure drop predictions by several commonly used correlations.

I. Introduction

The different spacer systems used in fuel rod bundles can be classified into two groups: longitudinal spacers attached to each fuel pin (such as fins or wires) and spacers attached to the subassembly duct at a number of axial planes (such as grids of various types). In order to evaluate the suitability of either concept, a study was made of the performance of one typical design in each class, namely honeycomb grid and spiral wire. It must be emphasized that any extension of the conclusions derived from this study to other geometries in either of the above two classes can only be, at best, qualitative, as will be shown below. It was felt, however, that the study of two typical spacer systems would be valuable as an indication of what can be achieved with either wires or grids.

The study covered a range of pin diameters from 0.3 to 0.45 inches, and linear heat ratings of 10 to 40 kW/ft. The following parameters were kept constant in the calculations:

Total Power	500 MWt
Power in Core	90%
Power in Axial Blanket	8%
Power in Radial Blanket	2%
Radial Power Peaking Factor	1.375
Axial Power Peaking Factor	1.200
Maximum Sodium Velocity	25 ft/sec
Temperature Rise Across Core	300°F
Sodium Outlet Temperature	1050°F
Active Core Height	36 in.
Axial Blanket Thickness	15 in.
Axial Reflector Thickness	5 in.
Plenum Length	30 in.
Pellet Density	95%
Number of Pins Per Assembly	169
Number of Control Rod Positions	36

These values were chosen so as to ensure applicability of the resulting data to the reference cores considered in the ongoing optimization studies.¹

The grids under consideration were of the Westinghouse honeycomb design described in Ref. 2 and shown in Fig. 1. The characteristic dimensions of the grid and support straps were taken to be 0.016 and 2.25 inches for the support strap thickness (t_s) and height (H_s) and 0.009 and 0.55 inches for the grid strap thickness (t_g) and height (H_g) respectively. These values were recommended by Ref. 2 on the basis of in-pile experience, and were maintained constant in the calculations. With honeycomb grids, the fuel elements are kept in position by elastic dimples stamped into the grid straps. There is, of course, a limit to the dimple size that can be achieved for a given design. This limit is a function of the grid geometry and was given by Ref. 3 as 0.1 in. for the above grid dimensions. The rod diameters and spacings considered in this study required dimple sizes which were always smaller than this limit.

Fig. 1. Honeycomb Grid (From Reference 2)

11. Pressure Drop

The pressure drop in the grid spaced subassemblies is computed by adding the pressure drop in the grids

$$N \left(K + \frac{f L_g}{D_g} \right) \frac{\dot{m}^2}{2 \rho A_g^2} \quad (1)$$

to that of the bare rod sections

$$\frac{f_o L_o}{D_o} \frac{\dot{m}^2}{2 \rho A_o^2} \quad (2)$$

where f designates friction coefficient, L length, D equivalent diameter, A area and $\dot{m}$ the mass flow rate. The subindices g and o correspond to the grid and bare rod sections, respectively, and N is the number of grids. The above expression (1) for the pressure drop in the grids is seen to consist of a first term accounting for the form loss in the abrupt section changes, and a second term, proportional to the grid length L_g , corresponding to the friction losses. The friction coefficients were computed using standard correlations for turbulent flow in pipes (of the form $f = 0.316/Re^{0.25}$). The energy loss coefficient was given by Ref. 3 as

$$K = 0.75 \left(1 - \frac{A_g}{A_o} \right) + \left(1 - \frac{A_g}{A_o} \right)^2 \quad (3)$$

and the grid flow area:

$$A_g = A_o - t_s (H - 0.032) 2\sqrt{3} - \frac{t_s P}{\sqrt{3}} (12n^2 - 20n - 13)$$

where P is the rod pitch, n the number of rows of rods (counting the center rod as row one), and H the distance between inside flats of the hex can.

The value of the latter required for a given rod diameter D and pitch is

$$H = (2n - 2)P \cos 30^\circ + 2[0.567D + t_s + 0.016]$$

The pressure drop given by Eqs.(1), (2) and (3) were compared with that occurring in wire spaced subassemblies of the same rod diameter and linear heat rating, and assuming no clearance in the rod bundle. The latter pressure drop was computed, following the approach of reference 4, by distributing the subassembly flow amongst the inner and outer channels according to their equivalent diameters and flow areas, and taking into account the effect of the wire spacer by means of a factor M applied to the standard expression for the pressure drop in a uniform duct. This factor is a function of the Reynolds number, bundle pitch to diameter ratio P/D, and wire pitch to rod diameter ratio H/D:

$$M = \frac{1.034}{(P/D)^{0.124}} + \frac{29.7(P/D)^{6.94} Re^{0.086}}{(H/D)^{2.239}}$$

The results are presented in Figs. 2 and 3. It is seen in Fig. 2 that the pressure drop in gridded assemblies decreases more rapidly with increasing linear heat rating than **that of** wire spaced assemblies, resulting in pressure drops that become significantly lower when the linear heat rate is higher than approximately 20 kW/ft, for the range of pin diameters under consideration. It should be noted, however, that there is a considerable degree of uncertainty in the actual values of pressure drop; namely, $\pm 14\%$ for the wire spaced rod bundles according to Ref. 4, and $\pm 15\%$ for gridded assemblies of less than 217 pins, according to Ref. 5. Figure 3 shows the uncertainty bands for pressure drops for the 0.4 in. pins as a function of the linear heat rating. It is seen that, while there is a significant difference in the nominal pressure drop for gridded and wire-wrapped assemblies at high linear heat rates, the crossover cannot be accurately established. In fact, for linear heat rates lower than 20 kW/ft there seems to be no significant difference in the performance of either type of spacer, as regards pressure drop.

Fig. 2. Subassembly Pressure Drop

Fig. 3. Error Bands of Subassembly Pressure Drops

III. Comparison of Various Pressure Drop Correlations for Grids

In the following, the correlation for the pressure drop in the grid spacer given by expression (1) and equation (3) will be compared, with the results of past studies. The second term in the right hand side of (3) is commonly used to account for the pressure drop in an abrupt expansion, while the first term, which was obtained by Westinghouse from experimental data on their honeycomb grids, agrees quite well with the values presented in Reference 6 for the loss coefficient in a sudden contraction when $A_g/A_o > 0.7$ with $Re > 10^4$. C. Betts, et al. (Ref. 9) compute the pressure drop across grids using a different loss coefficient for the sudden contraction, namely $0.5 (1 - A_g/A_o)$. Their predictions are approximately 16% lower than their experimental data, whereas using WARD's coefficient of $0.75 (1 - A_g/A_o)$ results in computed values of the pressure drop which are approximately 3% higher than Bett's data. This seems to confirm also the validity of Eq. (3). The value of K, which describes the form losses, was found in the present study to be equally important in terms of magnitude to that of the ratio $f_g L_g/D_g$, which is proportional to the friction losses, contrary to the postulations of Ref. 7, where the friction loss is said to be small compared with the form loss. Since the friction losses are proportional to grid length, the total spacer losses would be expected to depend significantly on the latter.

A different approach is followed by de Stordeur⁷ and Rehme.⁸ Instead of computing separately the form and friction losses, they express the grid pressure drop ΔP_g in terms of an overall spacer drag coefficient. Thus reference 7 gives:

$$\Delta P_g = C_s \frac{\dot{m}^2}{2\rho A_g^2} \frac{A_o - A_g}{A_o} \quad (4)$$

where C_s was determined experimentally as a function of Reynolds number and found to be dependent on the type of grid (honeycomb or line-of-sight) but equal for all the different honeycomb grids considered. C_s was also seen to be approximately equal to 1.65 for $Re > 4 \times 10^4$. Rehme⁸ postulates:

$$\Delta P_g = C_v \frac{\dot{m}^2}{2\rho A_o^2} \left(\frac{A_o - A_g}{A_o} \right)^2 \quad (5)$$

Again C_v was found to be almost constant for large Reynolds numbers, tending to a value of ~ 6.5 . Furthermore the same value of C_v was seen to fit data from all the grid types studied (including both line-of-sight and honeycomb).

By equating the right-hand side of Eq. (4) with expression (1), a value of C_s is calculated as:

$$C'_s = 0.75 + \frac{A_o - A_g}{A_o} + \frac{A_o}{A_o - A_g} \times \frac{f L_g}{D_g}$$

Likewise, equating (5) with (1) gives

$$C'_v = \left(\frac{A_o}{A_g} \right)^2 \left[0.75 \frac{A_o}{A_o - A_g} + 1 + \left(\frac{A_o}{A_o - A_g} \right)^2 \frac{f L_g}{D_g} \right]$$

The values of C'_s computed in this way for Reynolds numbers between 0.4×10^5 and 0.8×10^5 , were found to range between 1.7 and 2.14, fairly close to the measured value of ~ 1.7 , while C'_v ranged between 15.7 and 17.8; since the value of C_v measured by Rehme is only ~ 6.5 , his correlation results in pressure loss predictions considerably lower than those of expression (1). Table I shows the values of pressure drop predicted by the three correlations for 0.35" pins and over a range of P/D ratios (all other parameters as listed in section I). The WARD and de Stordeur correlations

Table I. Comparison of Pressure Drop in Grid Spacer Predicted by Different Correlations. (Pin O.D.: 0.35". Average Na velocity: 25 ft/sec. Average temperature: 900°F. Reynolds number based on the equivalent diameter and Na velocity at the grid.)

<u>Pitch</u> Diameter	Pressure drop per grid (psi)			
	Re	WARD (ref. 2)	de Stordeur (ref. 7)	Rehme (ref. 8)
1.097	0.4×10^5	2.9	2.2	1.3
1.162	0.5×10^5	1.7	1.5	0.7
1.224	0.7×10^5	1.1	1.0	0.4
1.283	0.8×10^5	0.94	0.96	0.4

agree quite well, particularly at high Reynolds numbers. Rehme's shows considerable discrepancy. A reason can be postulated for this which also explains the apparent contradiction of formulas (4) and (5), in which the pressure drop is given as independent of grid length, and expression (1), which is a function of L_g . While several honeycomb grids were included in de Stordeur's study, all the high Reynolds number data was taken on Westinghouse grids. It is possible that high Re data taken with other grids might have shown a dependence of C_g with grid geometry (even within the honeycomb type). On the other hand the honeycomb grids studies by Rehme had a length of 0.31" (vs. 0.55" for the reference grids considered here). This shorter length might account for some of the difference found in the pressure drop, with other geometric dissimilarities also contributing to it. It is concluded from the above that the results provided by the pressure drop correlations must be viewed with caution and only qualitative conclusions drawn from them unless experimental data is available for the specific grid geometry being considered. This is particularly true of more general correlations, like (4) and (5), which do not allow for separate computation of the form and friction losses.

IV. Volume Fractions

The spacer volume fractions in the gridded assemblies is determined by the volume of each grid, given by the expression

$$t_s (H - 0.032) 2\sqrt{3} H_s + \frac{t_g P}{\sqrt{3}} (12n^2 - 20n - 13) H_g$$

and the number of grids, which is in turn a function of the grid spans.

The values recommended by Ref. 3 for the span of optimized grids (in inches)

can be expressed as functions of pin diameter by linear equations:

$$\text{core region span} = 18.182 \times D + 3.773$$

$$\text{plenum and blanket region span} = 3.333 * D + 4.333.$$

The resulting volume fraction is compared with that of wire in Figs. 4 and 5. The wire volume fraction is seen to increase with heat rating since, for a given coolant velocity and temperature rise, a higher linear heat rate requires a larger flow area and distance between pins. On the other hand, the grid volume fraction is seen to decrease slightly with increasing power rating. This is due to the fact that the subassembly cross-sectional area increases linearly with heat rate, whereas, for a constant grid strap thickness and height, the grid volume increases only with the square root of the subassembly area. As a result, at high heat rates the spacer volume fraction is much smaller for grids than for wires. The grid volume fraction is seen to be smaller in the blankets, due to the larger span allowable in that region.

The fuel volume fraction for either spacer concept, shown in Fig. 6, reflects the effect of duct thickness and intersubassembly gap, as well as that of the spacer volume fractions themselves. The duct thickness is determined by the subassembly pressure drop and flat-to-flat distance, and its value chosen so as to make the pressure induced stresses in the can equal to 1.5 times the maximum allowable stress intensity for the material under consideration* (20% CW316SS in this study). To allow for the pressure drop downstream of the fuel rod bundle, an extra 30 psi has been added to the pressure losses shown in Fig. 2 when computing the duct thickness. The

*See Reference 1 for further details.

Spacer Volume Fraction in the Core (%)

Fig. 4. Spacer Volume Fraction in the Core

Spacer Volume Fraction in the Axial Blanket (%)

Fig. 5. Spacer Volume Fraction in the Axial Blanket

inter-subassembly gap has been assumed to be proportional to the inside distance between flats and equal to, approximately, one twentieth of the latter.

V. Conclusions

The pressure drops occurring in grid spacers are strongly dependent on the grid geometry (grid strap thickness and height, grid span, etc.). When using the grid dimensions recommended in Ref. 3, the pressure drop produced by honeycomb grid spaced subassemblies is smaller than that of wire spaced bundles for large linear heat ratings. For values of the latter smaller than approximately 20 kW/ft, the difference in the pressure drop produced by either spacer is small and cannot be computed accurately with the available correlations.

The spacer volume fraction for gridded assemblies is relatively insensitive to linear heat rate, while that of wire spacers increases considerable with power rating. As a result, for high values of the latter the grid spacers have volume fractions significantly lower than the spiral wires. The grid spacers result also in higher fuel volume fractions at high linear heat rates.

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