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Maximum Fuel Temperature With One Coolant Channel Blocked

Discussion:

For the solid heat-generating core with parallel coolant channels the maximum fuel temperature is of paramount interest. This study provides an estimate of the effect of hole blockage on this maximum temperature for a triangular array.

Some temperature distributions have already been derived for a large uniformly heat-generating solid which is cooled internally. Specifically, the solution for round coolant holes with an equilateral-triangular arrangement is available (Ref. 1).

In order to obtain an upper limit on fuel temperature for the case in which a flow hole would become blocked in a triangular array, the temperature distribution for a hexagonal array was derived. This was accomplished by the simple superposition of two triangular array distributions. The maximum temperature in the hex arrangement gives an upper limit for the maximum temperature in the blocked hole triangular array case. This can be seen from Figure 1. The maximum temperature occurring at the blocked hole at "A" would be the same as for the hex array, except that the effect of the X holes on the temperature at "A" would be missing. Therefore, the maximum hexagonal array temperature is a conservative maximum to use for a triangular array with one blocked hole.

Conclusions:

1. Curve 1 gives the upper limit of the maximum fuel temperature in the triangular array with one hole blocked, as given below, and the maximum temperature with no blockage as given by Sparrow (Ref. 1). Curve 2 gives the ratios of the fuel temperature differentials for the blocked and normal case.

2. The expression for the triangular array with one blocked hole is derived as,

$$(1) \frac{(T_m - T_o)}{(Q/\bar{K}) S^2} = \frac{3}{2} \left\{ \frac{\sqrt{3}}{\pi} \ln \frac{0}{1 - \frac{3}{2} \frac{r_o^2}{S^2}} + \frac{1}{2 \phi^2} - \frac{1}{\sqrt{3} \phi} - 0.23446 + .015 \right\}$$

where:

- S = half spacing of holes
- r_o = hole radius
- ϕ = $\sqrt{3} S/r_o$
- Q = volumetric heat generation rate
- $\bar{K}$ = average thermal conductivity (defined in 4 below)
- T_m = maximum fuel temperature
- T_o = coolant hole surface temperature

3. The expression above also gives the maximum temperature in a hexagonal array where S is the half distance between holes.

4. In applying the results of this work and Sparrow's work, the proper exact expression to use for thermal conductivity is given by,

$$\bar{K} = \frac{\int_{T_o}^{T_m} K(T) dT}{T_m - T_o}$$

where:

- T = temperature
- $K(T)$ = thermal conductivity as a function of temperature
- $\bar{K}$ = thermal conductivity to use in determining T_m

Calculation:

As seen by Figure 2, two sets of parallel-triangular arrays form a hexagonal array. Considering the heat generation rate for each triangular set as $1/2 Q$, and noting that the triangular half spacing is $\sqrt{3}S$, then Sparrow's solution (Ref. 1) for triangles can be superimposed.

This superposition, with appropriate adjustment to the proper tube surface temperature, results in the temperature distribution for a hexagonal array. The results are given below for the maximum temperature,

$$(2) \quad \frac{T_m - T_o}{(Q/R)S^2} = \frac{3}{2} \left\{ \frac{\sqrt{3}}{\pi} \ln \left(1 - \frac{0}{\frac{\sqrt{3}}{2\phi}} \right) + \frac{1}{2} \cdot \frac{1}{\phi^2} - \frac{1}{\sqrt{3}\phi} - 0.23446 \right. \\ \left. + \sum_{n=1}^N \Delta_n \frac{(-1)^n}{6^n} \left(\frac{2}{\sqrt{3}} \right)^{6n} \left\{ 1 - \left(1 - \frac{\sqrt{3}}{2\phi} \right)^{6n} \right\} \right\}$$

$$\text{where } \phi = \frac{\sqrt{3}S}{r_o}$$

Δ_n is a constant function of ϕ , given by reference 1.

Equation 2 is considered valid for $\frac{S}{r_o}$ greater than 1.5. The approximation given by equation 1 is accurate to within 2% for $1.5 < \left(\frac{S}{r_o} \right)$.

References:

1. E. M. Sparrow, "Temperature Distribution in Internally-Cooled, Heat Generating Solid", A.S.M.E. publication, 60-SA-15.

Maximum Fuel Temperature Function vs. Spacing - Radius Ratio

T_m = Maximum Fuel Temperature

T_o = Coolant Hole Surface Temperature

Q = Volumetric Heat Generation Rate

$\bar{K}$ = Average Thermal Conductivity

r_o = Hole Radius

S = Hole 1/2 Spacing

$$\frac{T_m - T_o}{(Q/\bar{K}) S^2}$$

**Effect of Blocked Hole on Maximum Fuel Temperature
for Equilateral-Triangular Flow Hole Arrangement**

CURVE 2

EC'ILATERAL-TRIANGULAR ARRANGEMENT

FIGURE 1

SUPERPOSITION OF TWO TRIANGULAR ARRAYS TO FORM
HEXAGONAL ARRAY

FIGURE 2