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HDC-1584

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Richland, Washington
January 11, 1950

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FROM: George M. Roy

SUBJECT: MAXIMUM TEMPERATURE OF ALUMINUM END CAP

REFERENCES: (1) CP 1580 (3) CP 2071
(2) CP 1989 (4) HDC 1176

This document consists of

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Introduction:

The addition of the aluminum end cap disturbs both the distribution of thermal neutrons and the temperature distribution. Neutron density at the end of the slug is increased appreciably and therefore the heat production in the end of the slug is also increased. The end result is increased heat flow into the cap with correspondingly higher temperatures.

The combined results and conclusions of documents CP-1580, CP-1989, and CP-2071 afford a means of calculating the aluminum end cap temperatures with consideration being given to the above mentioned "Wilkins effect", i.e., that the heat production near the end of a slug with an aluminum end cap is greater than the heat production at the middle (axially) of a slug.

Conclusion:

The maximum temperature in the aluminum end cap is calculated to be about 278° F. for the "G" Pile. This temperature occurs at the center of the maximum performance process tube.

Discussion:

It is believed that the maximum temperature of the aluminum end cap would occur near the center of the process tube as T_{co} (water film temperature drop) has its maximum value in this region. Although the maximum bulk water temperature occurs at the outlet end of the active zone and is

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Discussion (cont'd)

about 54° F. greater than the bulk water temperature at the center, the water film temperature drop is only 5.9° F. as compared to 42.3° F. used in the calculation of the maximum end cap temperature. Admittedly, the value of "h" at this point is appreciably different from that used in the calculations ("h" at this section is 8890 as compared to 7373 used in CP-1580), but the effect is not likely to result in a higher value of end cap temperature in view of the much smaller T_{∞} . The effect of "h" on the ratio of T_1/T_{∞} is not at all obvious from inspection of the equations used in obtaining the resulting T_1/T_{∞} of 3.64. To calculate the effect would require a numerical solution to the equation for the temperature at the point 1; which is:

$$T = \frac{2q}{k\alpha} \sum C_n \left(e^{-2\lambda_n^2 L} + 1 \right)$$

$$\text{where } C_n = \frac{2}{\alpha} \left(H_1 - H_2 \right) \frac{1}{\mu_n} \frac{1}{(1 - e^{-2\mu_n L})} \frac{\left(1 - e^{-2\lambda_n L} \right) \lambda_n}{\lambda_n^3 J_1(\lambda_n a) [C + 1 - (C-1) e^{-2\lambda_n L}]}$$

$$\left(\frac{\mu_n^2}{\mu_n^2 + H_2^2} \right) \left(\frac{J_0 \lambda_n a / J_0(\mu_n a)}{\lambda_n^2 - \mu_n^2} \right)$$

$$\begin{aligned} \text{where } \mu_n \text{ is determined from: } \mu_n J_1(\mu_n a) &= H_2 J_0(\mu_n a) \\ \text{and } \lambda_n \text{ from: } \lambda_n J_1(\lambda_n a) &= H_1 J_0(\lambda_n a) \\ \alpha &= k/K \end{aligned}$$

It is thought that such a calculation and critical review of the derived equations are not warranted in view of the time involved and the fact that the calculated value of 278° F. is not at all critical. (The maximum axial slug temperature is 745° F.)

The assumption of intimate contact between slug and cap was made for all equations.

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ANALYSIS AND CALCULATIONS

T_1 = Temp. of point 1 in the sketch

T_{∞} = Temp. drop across water film

t_{f-c} = Bulk water temp. at center of process tube

a = Radius of the slug

L = Length of aluminum end cap

h = Coefficient of heat transfer between water and surface

k = Thermal conductivity of Uranium

$H_1 = h/k$ and $H_2 = h/K$

K = Thermal conductivity of aluminum

W = Length (cm) determined by equating the quantity of heat produced per second in a length w of the slug (some distance away from Al cap) to that flowing across the junction per second.

The results given in CP-1580 and CP-2071 were calculated for the following conditions:

$a = 1.7$ cm.
 $h = 1$ calories/(sec.) (sq cm) (Deg. C.) or 7373 Btu/(hr) (sq. ft.) (Deg. F.)
 $k = .06$ calories/(sec.) (cm) (Deg. C.) or 14.514 Btu/(hr.) (ft.) (Deg. F.)
 $K = .5$ calories/(sec.) (cm) (Deg. C.) or 120.95 Btu/(hr) (ft.) (Deg. F.)

Calculations were made for several values of L .

The maximum temperature in the Aluminum Cap is desired for the conditions listed below:

$a = 1.83$ cm
 $h = 7232$ Btu/(hr.) (sq. ft.) (Deg. F.)
 $k = 14.514$ Btu/(hr.) (ft.) (Deg. F.)
 $K = 120.95$ Btu/(hr) (ft.) (Deg. F.)
 $L = 0.47$ cms (i.e. 0.85 inches)

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The value of 7232 given for h was calculated using equation (13) given in Section F of HDC-1176. This is the heat transfer coefficient at the center of the maximum performance tube which is the position of maximum heat generation.

The effect on temperature due to the slight discrepancy between the two values of h was neglected.

From the results of method I of CP-1580, the ratio of T_1/T_∞ is found to be 3.4. The Wilkins effect (reference 2) is $(1 + L/6)$ or 1.0783. Thus, $T_1/T_\infty = (3.4)(1.0783) = 3.64$

The effect of using a radius of 1.83 cm instead of the value of 1.7 cm would alter the results a negligible amount, as can be seen from the following comparison: Figure 1 of reference (1) gives a plot of w/a as a function of L/a for two methods of calculations. Choose the ratio of L/a as 0.4/1.7 or 0.235. Figure (1) gives the values of w/a corresponding to 0.235 which were calculated by methods I and II. These values are .24 and .262, respectively. The corresponding temperatures calculated from the two methods are $T_1/T_\infty = 3.8$ and $T_1/T_\infty = 3.95$, respectively. Thus, increasing the heat flow into the end cap by a factor of 2.62/2.4 or 1.09, increases the temperature at point 1 by an amount 3.95/3.8 or 1.04. For a value of L/a of about .47 the corresponding values of w/a for methods I and II are equal and the calculated temperatures by the two methods are also equal. This comparison gives a good idea of the effect of w/a on the temperature at the point in question. Now, for the actual case of $L/a = .47/1.83$ the corresponding ratio (from curve I) of w/a is 0.248. As the value of T_1/T_∞ being used is for L/a of .47/1.7 which corresponds to a w/a of 0.252, the increase of w/a is .252/.248 or 1.014 which results in a negligible temperature increase.

Thus, using the value of T_1/T_∞ of 3.64 along with previously calculated values of temperature drop across the water film and the bulk water temperature at the center of the process tube, the temperature at point 1 can be found.

From the equations given in HDC-1176 the values h , T_∞ , and t_{f-o} for the maximum performance tube operating at 552 KW and a water flow rate of 34.6 gpm are as follows:

$$\begin{aligned} h &= 7232 \text{ Btu/(hr) (sq. ft.) (Deg. F.)} \\ T &= 42.3^\circ \text{ F.} \\ t_{f-o} &= 124.4^\circ \text{ F.} \end{aligned}$$

$$\begin{aligned} \text{Thus } T_1 &= (42.3)(3.64) + 124.4 \\ T_1 &= 278.4^\circ \text{ F.} \end{aligned}$$

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