Computation of the Temperature Distribution in a Fuel Particle Bed in Single and Two Phase Conditions

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1. Introduction

A hypothetical core disruptive accident in an LMR could result in the settling of fragmented fuel debris on the horizontal support plate below the core. The generated heat in the debris bed due to decay heat source is transported partially upwards to the overlying coolant layer of pool and partially downward via the plate to an underlying fluid. The temperatures in the plate are important because they are related to the mechanical integrity of the retention plate [1, 2]. To predict the temperature distribution, a programming for a computation of the temperature profile in the fuel bed in single and two phase conditions has been developed, and illustrative results of the calculations are presented.

2. Methods and Results

The geometry to be considered is shown in Fig.1, where the bed is cooled by the overlying and underlying pool of fluid. The temperature field and phase condition within the bed depend on the ability of heat transfer to the pool of sodium and a given condition in the bed.

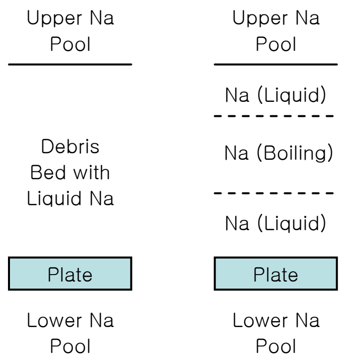

Fig. 1.Characteristic of a debris bed.

For a given particle bed height at increasing values of decay heat source, the following situations may be attained [3]:

- the sodium in the bed is of single phase condition, where maximum bed temperature is below the sodium saturation temperature.
- the sodium in the bed is of two phase condition, where the temperature exceeds the sodium saturation temperature.
- dryout layer is formed at heat generation values beyond dryout inception.
- a molten layer is formed, where temperatures exceed the melting point of the particles.

It is assumed that beds are of infinite radial extent, and heat source density, the temperatures of overlying and underlying coolant and the corresponding top and bottom heat transfer coefficients are time- invariant. With regard to the composition of the particle bed it is assumed that the bed is homogeneous. But in this paper a computation tool for single phase and two phase conditions has been developed.

2.1 Mathematical Method of solving the problem

Using above assumptions, the problem can be treated as a boundary value one-dimensional heat conduction problem. The following are the governing equations with different thermal conductivities and boundary conditions.

$$\frac{d}{dx}\left(k_1\frac{dT_1}{dx}\right)+g_1(x)=0, \qquad 0<x<a$$

$$\frac{d}{dx}\left(k_2\frac{dT_2}{dx}\right)+g_2(x)=0, \qquad a<x<b$$

$$-k_1\frac{dT_1}{dx}+h_0T_1=h_0T_{\infty 0}, \qquad x=0$$

$$k_2\frac{dT_2}{dx}+h_LT_2=h_LT_{\infty L}, \qquad x=L$$

$$k_2\frac{dT_2}{dx}=k_1\frac{dT_1}{dx}, \qquad x=a$$

$$T_1=T_2, \qquad x=a$$

To make system of equations, the finite-difference method using the control volume approach is used. Thomas algorithm is used to solve the equations.

If we assume that the axial heat flux is zero at the boundary of boiling layer and the lower liquid sodium layer, heat transport inside the boiling layer is upward due to convective effects. Then we can separate analyses of the upper sodium layer region and the lower region which is made of a lower sodium layer and the support plate.

The temperature of the upper boundary of the lower sodium layer is the sodium saturation temperature. The thickness of the lower sodium layer becomes [3]:

$$h_{Na1}=-\frac{\lambda_b}{\alpha_{eff}}+\lambda_b\left[\left(\frac{1}{\alpha_{eff}}\right)^2+\frac{2\left(T_{sat}-T_{c,1}\right)}{\lambda_b q'''}\right]^{0.5}$$

, where $T_{c,1}$, λ_b are the lower coolant temperature below the support plate and the bed conductivity. The effective heat transfer coefficient α_{eff} is given by

$$\frac{1}{\alpha_{eff}} = \frac{1}{\alpha_{c,1}} + \frac{d_p}{\lambda_p}$$

, where $\alpha_{c,1}$, λ_p, d_p are the convection heat transfer coefficient of the lower pool, the plate conductivity and the plate thickness. The thickness of the upper sodium layer becomes:

$$h_{Na2} = \frac{q''_{0,2}}{q'''} - \frac{\lambda_b}{q'''}\left[\left(\frac{q''_{0,2}}{\lambda_b}\right)^2 - \frac{2q'''(T_{sat} - T_{b,2})}{\lambda_b}\right]^{0.5}$$

, where $T_{b,2}$, $q''_{0,2}$ are the upper boundary temperature of the upper sodium layer and the upward heat flux. Then the thickness of the boiling layer can be derived from the total height.

$$h_{boil} = h_{bed} - h_{Na1} - h_{Na2}$$

2.2 Results

Data for illustrative computations is following:

bed height :18.87 cm
plate thickness : 2 cm
upper convection heat transfer coefficient : 10^4 W/m^2-C
lower convection heat transfer coefficient : 10^5 W/m^2-C
thermal conductivity of the plate : 20 W/m-C
sodium-filled bed thermal conductivity : 22 W/m-C
upper and lower coolant temperature : 500 C
sodium saturation temperature : 900 C

Fig. 2 shows the axial temperature distributions in the debris bed with the different power densities (1x10^6, 2x10^6, 3x10^6 W/m^3). When bed power density is increased the bed condition is changing from the single phase to two phase, and the boiling region in the two phase condition is increasing. At the single phase condition about half of total generated heat is removed from bottom cooling. But the downward heat removal fraction is decreasing with the power density since the generated heat of the boiling region is removed upwards. In spite of the reduction of the fraction the temperature drop in the steel plate is increasing, hence thermal stress increases.

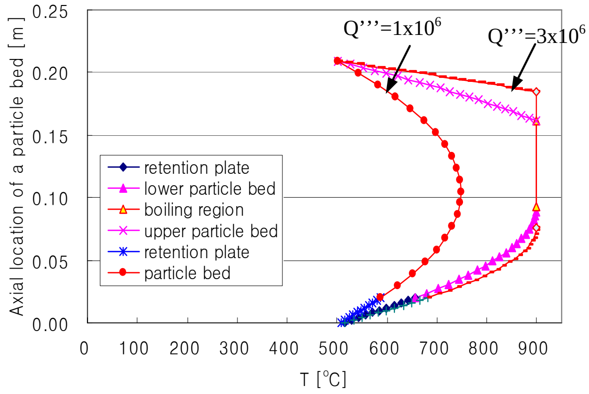

Fig. 2. Temperature distribution of the debris bed in single and two phase condition.

3. Conclusions

A computation tool to predict the temperature distribution of the debris bed in single and two phase conditions has been developed. It can be used to estimate the thermal load of a steel support plate and to perform parameter studies.

REFERENCES

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