Improvement of the MELCOR code to Simulate the Plate-out Phenomena in a VHTGR.

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1. Introduction

KAERI has a plan to apply the MELCOR code to simulate the plateout/dust/H3 in a HTGR. However MELCOR is designed to calculate a FP vapor condensation under the severe accident condition in a PWR. But from a previous work [1], the phenomena to be implemented or improved in MELCOR were identified to simulate FP plate-out phenomena over a primary circuit under VHTGR conditions.

In this study, three improvement works were performed to improve the FP vapor condensation model in MELCOR for a VHTR. The first work was to evaluate the effect of a mass transfer coefficient for a plate-out. The mass transfer coefficient values from the three different cases were compared. The first one was the default mass transfer coefficient value from MELCOR. The second one was on updated mass transfer coefficient based on the VICTORIA code. The last one was the mass transfer coefficient calculated by using the correlation for predicting the mass transfer coefficient under a helium condition in the PADLOC code [2].

The second work was to evaluate the effect of a temperature boundary condition by using a multi-nodalization for a plate-out. The last work was to evaluate the effect of considering the decay phenomena for a plate-out. The objective of this study was to extend the FP vapor condensation model in MELCOR by using the OGL-1 experiment so that this model can be applied to not only a PWR but also a VHTGR.

2. Description of the Actual Work

2.1 Re-calculation of the mass transfer coefficient

In MELCOR, the mass transfer coefficient for a FP vapor to a surface is calculated based on a mass diffusivity of steam through air. Therefore, in order to apply it to a VHTGR system using helium as a coolant, the mass diffusivity value for steam through air has to be replaced by that of FP species through a helium gases. The binary mass diffusivity of a non-polar gas at a low density can be predicted by using 'Chapman-Enskog' equations. In the first case, default MELCOR mass transfer coefficient values were used. But in the second case, the Lennard-Jones potential parameter values were replaced by that of the VICTORIA code [3].

In the third case, the following correlation from the PADLOC code by GA was adopted for the mass diffusivity of FP through helium gas.

$$D_{k,g} = 0.1682\left(\frac{Tc}{1000}\right)^{1.65}\left(\frac{23.83}{P_g}\right)\sqrt{\frac{\frac{1}{M_k}+0.25}{0.257}}$$

where $D_{k,g}$= FP diffusion coefficent [cm^2/s]
T_c = He gas temperature [k]
P_g = He gas pressure [atm]
M_k = FP k molecular weight [g/mole]

The surface activities being predicted by three cases were compared by using the OGL-1 test. For Cesium-137, the three cases showed a similarity but in the case of the MELCOR with the PADLOC model, I-131 did not plate-out on the cooler.

2.2 Effect of the circuit temperature input when using a multi-nodalization approach

In the OGL-1 test, the gas temperature was changed from 1000°C to 300°C. But the gradient of the temperature change from the inlet to the outlet for the components such as the heat exchanger, cooler or long pipe is too steep to represent it with one control volume.

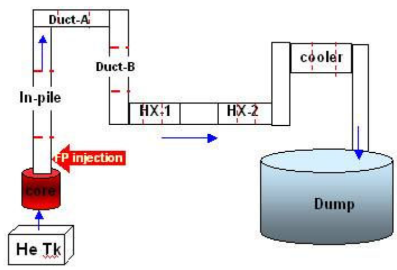

Fig. 1 The nodalization of the OGL-1 test facility

A plate-out depends on a mass transfer coefficient and a difference in the FP concentration in the atmosphere. The temperature can have an effect on these two parameters.

Figure 2 shows a comparison of the amount of plate-out for the Cs-137 between a one nodalization and a multi-nodalization. The distributions of the plate-out were similar but the amount of plate-out for the multi-nodalization was larger than that of the single case.

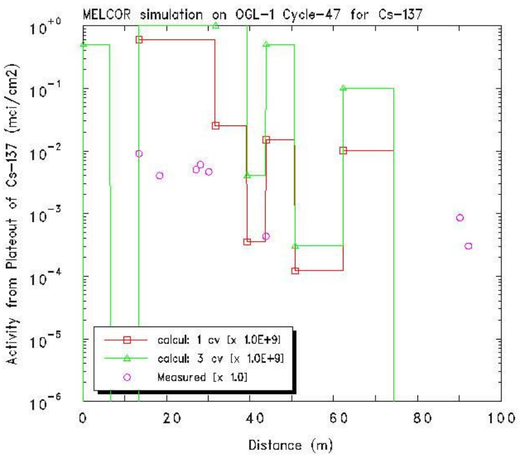

Figure. 2 The comparison of the plate-out for Cs-137 between single and multi-nodalization for OGL-1 test.

But the predicted amount of the plate-out was considerably over-predicted when compared with the experimental data. Therefore, it is necessary to estimate whether the current MELCOR model is proper or not for simulating a plate-out in a HTGR.

2.3 Effect of decay phenomena on a plate-out

By considering an operation time of about 30 years in a VHTR, its decay phenomena or its precursor effect should be taken into account when calculating a plate-out. The important FP species to be considered when calculating a plate-out are Cs-137, Iodine-131 and Ag-110m. The I^{131} has a half-life of 8 day and the Cs^{137} has a half-life of 12.05 years. The governing equations for considering the its decay can be set-up as below;

$$\frac{dM_{a,k}}{dt} + \sum_i \frac{A_i k_i}{V}(M_{a,k} - M^s_{i,k}) + \lambda_k M_{a,k} = 0 \quad ---(1)$$

$$\frac{dM_{i,k}}{dt} = \frac{A_i k_i}{V}(M_{a,k} - M^s_{i,k}) - \lambda_k M_{i,k} \quad ---(2)$$

where $M_{a,k}$ = mass of FP, k in bulk space
$M_{i,k}$ = mass of condensed FP, k on surface i
$M^s_{i,k}$ = saturation concentration of F,P k based on surface i temperature
K_i = mass transfer coefficient of FP k for surface i
λ_k = decay constant for FP, k
A_i = surface i area, V= space volume

The following analytical solutions were obtained by applying the "*Laplace transformation*" to the governing equations (1), (2).

$$M_{a,k}(t) = \frac{\beta}{\xi} - \left(\frac{\beta}{\xi} - M_{a,k}(0)\right)e^{-\xi t} \quad ---(3)$$

$$M_{i,k}(t) = M_{i,k}(0)e^{-\lambda_k t} + \frac{A_i k_i}{V}\left[\left(\frac{\beta}{\xi} - M^s_{i,k}\right)\frac{(1-e^{-\lambda_k t})}{\lambda_k}\right] - \frac{A_i k_i}{V}\left[\left(\frac{\beta}{\xi} - M_{a,k}(0)\right)\frac{(e^{-\lambda_k t} - e^{-\xi t})}{\alpha}\right] \quad ---(4)$$

where $\alpha = \sum_i \frac{A_i k_i}{V}$ $\quad \beta = \sum_i \frac{A_i k_i M^s_{i,k}}{V}$
$\xi = \alpha + \lambda_k$

The above solutions (3),(4) were implemented into MELCOR and the effect of the decay phenomena was evaluated using OGL-1 data. But its effect was negligible. This is because the circuit was modeled as a "once-through" and the resultant gas velocity was so fast that the FP residence time was less then 10 sec along the circuit.

3. Conclusion

KAERI has a plan to apply the MELCOR code to simulate a plateout/dust/H3 in a VHTGR. The MELCOR was applied to simulate the OGL-1 test (cy-47) and the effect of the diffusion coefficient between He/air/steam revealed no large difference except for iodine-131.

The plate-out predicted by MELCOR revealed a large over-prediction. Therefore, we need to establish whether MELCOR is proper or not for simulating the plate-out phenomena in a VHTGR. The analytical solutions by considering the decay phenomena were derived and implemented into MELCOR for a VHTGR.

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