Development of COCAT code to simulate the corium cooling phenomena from the bottom injection

Jong-Hwa. Park[a], Hwan-Yeol Kim[a], Jong-Tae Kim[a], Seong Wan Hong[a]
a KAERI, 150 Dukjin-dong,Yusong., Taejon, 305-353, jhpark3@kaeri.re.kr

1. Introduction

In the severe accident, for the containment integrity, it is necessary to develop the method that can make the molten corium in the cavity cool quickly without any interaction between the molten corium and the concrete. KAERI has developed a new corium cooling concept by simultaneously injecting the water and the non-condensable gas through the nozzles from the bottom. But no tools are available to predict the corium cooling phenomena in the cavity with the concept of the bottom injection. Therefore, KAERI developed the COCAT code that can simulate the complex cooling phenomena being expected by the injection of water from the bottom with as simple as possible. But the current status of COCAT is primitive. Therefore, it is imperative to perform the validation works against the available experimental data.

2. Description of the Actual Work

2.1 Analysis Scope and Features of COCAT

The figure 1 shows the cavity and the molten corium to be simulated. The heat transfer with the cavity wall was not considered for the conservative analysis.

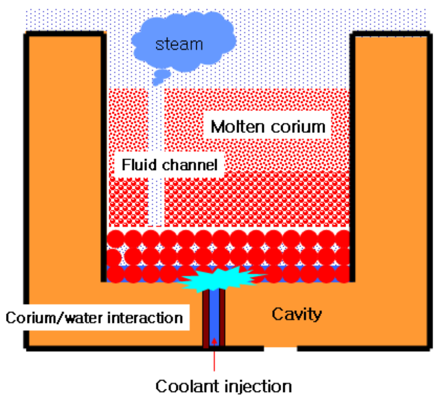

Figure 1. Conceptual Picture for modeling the corium-catcher cooling phenomena

2.2 Governing heat transfer equations

To predict the average temperature for the each layer of the relocated corium and the cavity, the number of layers for the corium (=4) and the cavity basement were assumed as 8. Therefore, the heat transfer governing equations were set-up for these 9 nodes.

For the concrete & air component i=1

$$\frac{A\Delta Z\rho_{c1}C_{p1}}{2}(T_1^{t+\Delta t}-T_1^t)=[K_{c1}A\frac{(T_2^{t+\Delta t}-T_1^{t+\Delta t})}{\Delta Z}+h_aA(T_{air}-T_1^{t+\Delta t})]\Delta t$$

For the concrete component i (2≤i ≤4)

$$\frac{(A\Delta Z\rho_{ci\text{-}1}C_{pi\text{-}1}+A\Delta Z\rho_{ci}C_{pi})}{2}(T_i^{t+\Delta t}-T_i^t)=[K_{ci}A\frac{(T_{i+1}^{t+\Delta t}-T_i^{t+\Delta t})}{\Delta Z}+ K_{ci\text{-}1}A\frac{(T_{i\text{-}1}^{t+\Delta t}-T_i^{t+\Delta t})}{\Delta Z}]\Delta t$$

For the molten corium component i=5

$$\frac{(A\Delta Z\rho_{c4}C_{p4}+A\Delta Z(1\text{-}\varepsilon_5)\rho_{d5}C_{p5})}{2}(T_5^{t+\Delta t}-T_5^t)=[K_{c4}A\frac{(T_4^{t+\Delta t}-T_5^t)}{\Delta Z}+ h_dA(1\text{-}\varepsilon_5)(T_6^{t+\Delta t}-T_5^{t+\Delta t})-h_{boil}^5\frac{(6A\Delta Z(1\text{-}\varepsilon_5))}{D_5}(\frac{(T_5^{t+\Delta t}-T_6^{t+\Delta t})}{2}-T_{sat})]\Delta t$$

For the molten corium component 6≤i ≤8)

$$\frac{(A\Delta Z(1\text{-}\varepsilon_{i\text{-}1})\rho_{di\text{-}1}C_{pi\text{-}1}+A\Delta Z(1\text{-}\varepsilon_i)\rho_{di}C_{pi})}{2}(T_i^{t+\Delta t}-T_i^t)=[h_dA(1\text{-}\varepsilon_{i\text{-}1})(T_{i\text{-}1}^{t+\Delta t}-T_i^{t+\Delta t})+ h_dA(1\text{-}\varepsilon_i)(T_{i+1}^{t+\Delta t}-T_i^{t+\Delta t})-h_{boil}^{i\text{-}1}\frac{(6A\Delta Z(1\text{-}\varepsilon_{i\text{-}1}))}{D_{i\text{-}1}}(\frac{(T_{i\text{-}1}^{t+\Delta t}-T_i^{t+\Delta t})}{2}-T_{sat}) -h_{boil}^i\frac{(6A\Delta Z(1\text{-}\varepsilon_i))}{D_i}(\frac{(T_i^{t+\Delta t}-T_{i+1}^{t+\Delta t})}{2}-T_{sat})]\Delta t$$

For the molten corium & air component 9

$$\frac{A\Delta Z(1\text{-}\varepsilon_8)\rho_{d8}C_{p8}}{2}(T_9^{t+\Delta t}-T_9^t)=[h_dA(1\text{-}\varepsilon_8)(T_8^{t+\Delta t}-T_9^{t+\Delta t})+ h_dA(1\text{-}\varepsilon_8)(T_{air}-T_9^{t+\Delta t})-h_{boil}^8\frac{(6A\Delta Z(1\text{-}\varepsilon_8))}{D_8}(\frac{(T_8^{t+\Delta t}-T_9^{t+\Delta t})}{2}-T_{sat}) -Q_{rad}]\Delta t$$

All these equations can be expressed as the matrix form.

$$\begin{bmatrix} A_{11} & A_{12} & 0.0 & \ldots\ldots & 0.0\ldots\ldots & & & & 0.0 \\ A_{21} & A_{22} & A_{23} & 0.0 & 0.0\ldots\ldots & & & & 0.0 \\ 0.0 & A_{32} & A_{33} & A_{34} & 0.0\ldots.0.0 & & & \bullet & 0.0 \\ \bullet & & & & & & & & \\ \bullet & & \bullet & & & & & & 0.0 \\ \bullet & & & \bullet & & & & & \\ \bullet & & & & & & \bullet & & \\ 0.0\ldots & & 0.0.. & 0.0 & A_{86} & A_{87} & A_{88} & & 0.0 \\ 0.0 & 0.0\ldots\ldots & & \bullet & \ldots. & 0.0 & A_{98} & & A_{99} \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \\ T_7 \\ T_8 \\ T_9 \end{bmatrix} = \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \\ C_9 \end{bmatrix}$$

The above matrix equation can solve with "Crout reduction" method for the tri-diagonal linear system.

2.3 Model for the porosity and the steam generation

To form the porous structure, it was assumed that the local porous value (ε=porosity) can be changed by the local pressure build-up. The local steaming rate was modeled as below;

$$\dot{m}_i = h^i_{boil} A \varepsilon_i (T^i_m - T_{sat})/h_{fg}$$

where i = layer number ($1 \le i \le 8$)
h_{boil}= boiling heat transfer coefficient
T_m= average temperature of corium
h_{fg}= latent heat of vaporization

The local pressure build-up by steaming can calculate based on the above steaming rate.

$$P_i = \frac{\dot{m}\, RT_{sat}}{V_i M_{stm}} dt + P_{inj}$$

where V_i = sum of the void space in layer i
R= gas constant
M_{stm} = molecular weight of steam
P_{inj} = back pressure for the bottom inject

The porosity generation rate was modeled with the same correlation as WABE [1], which was developed by FZK.

$$\frac{d\varepsilon}{dt} = \frac{A}{\nu \rho} f(T_m)\,(P_i - P_m)\varepsilon^{2/3}$$

where Pi= local pressure, A=0.2
P_m=corium hydrostatic pressure
If $T_m < T_{solidus}$ $f(T_m)=0$, not $f(T_m)=1$
ρ, ν= corium density/viscosity

2.4 Heat transfer model between debris and coolant

The heat transfer phenomena between the molten corium (=porous debris) and the ingress coolant were assumed as the pool boiling phenomena. The simulation of pool boiling phenomena was performed based on the three representative boiling regimes such as "nucleate boiling", "transition boiling"" and "film boiling" under the condition of changing the surface temperature, pressure and material properties.

2.5 Sample calculation results

Table.1 showed the summary of the input data for COCAT code.

Table 1. summary of the important input for COCAT

Input parameters	Value [unit]
Cross sectional area of cavity	0.04908 [m2]
Axial layer thickness (constant over 8 layers)	0.0652 [m]
Initial coolant temperature (air)	293 (303) [k]
Fundamental particle size	9.0x10-3 [m]
Corium solidus temperature	2326 [k]
Radiative HT from corium to air	10 [W/m2-k]
Back pressure from bottom inject	2.0x105 [Pa]
Initial corium temperature	3000 [k]
Initial concrete temperature	303 [k]
Initial concrete conductivity	0.9344 [W/m^2-k]
Initial corium conductivity	2.38 [W/m^2-k]

Figure 2 showed the calculation results for the concrete and the corium temperature for the each layers during the 500 sec.

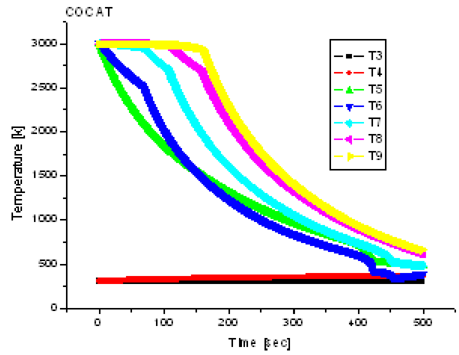

Figure 2. Layer temperature

3. Conclusion

KAERI developed the COCAT code that can simulate the complex cooling phenomena being expected by the injection of water from the bottom with as simple as possible. But the current status is primitive. Therefore, it is imperative to perform the validation works against the available data. For the later, the axial heat transfer model had better extend to two dimensions and the corium properties should be updated. Also it is necessary to validate the 'porosity increase model' against the experimental data under the various conditions.

REFERENCES

1. Walter Widmann, Manfred Burger," Experimental and theoretical investigation on the COMET concept for ex-vessel core melt retention",, Nuclear engineering & design,2006, 236, 2304-2327.