Development of a two-dimensional heat structure model in SPACE code

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1. Introduction

The SPACE (Safety and Performance Analysis CodE) code is currently developing as the nuclear safety analysis code, sponsored by Korean government for a licensing purpose of pressurized water reactors in Korea. Several research and industrial organizations such as KAERI, KHNP, KOPEC, KNF and KEPRI have participated in the SPACE development. One of the main features of the SPACE code is that it is based on a multi-dimensional two-fluid, three-field models [1, 2]. KAERI is in charge of developing physical models and correlation packages. Among them are i) a flow regime selection, ii) wall and interfacial frictions, iii) interfacial heat and mass transfers, iv) a wall heat transfer, and so on.

Also, KAERI is developing heat structure models for calculation of the heat transferred across solid boundaries of hydrodynamic volumes. Modeling capabilities of heat structures are general and include fuel pins or plates with nuclear or electrical heating, heat transfer across steam generator tubes, and heat transfer from pipe and vessel walls. Temperatures and heat transfer rates from one-dimensional of the transient heat conduction equation. However, for reflood situation, two-dimensional form of the heat conduction equation is considered. To efficiently use the two-dimensional conduction solution, a fine mesh-rezoning scheme may be required. This paper is focused on the two-dimensional heat structure model.

2. Methods and Results

2.1 Two-dimensional heat structure model

A two-dimensional conduction scheme is used in the reflood model for cylindrical heat structures. The integral form of the two-dimensional heat conduction equations is

$$\iiint_V \rho C_p \frac{\partial T(\vec{x},t)}{\partial t} dV = \iint_S k \nabla T(\vec{x},t)\cdot dS + \iiint_V Q(\vec{x},t) dV \quad (1)$$

where k is thermal conductivity, Q heat source, S surface, t time, T temperature, V volume, $\vec{x}$ space coordinates, ρC_p volumetric heat capacity.

Integration of the heat conduction equation yields the following form of finite difference equation

$$G_{ij}\frac{T_{i,j}^{n+1}-T_{i,j}^{n}}{\Delta t} = a_{ij}^{L}T_{i-1,j} + a_{ij}^{R}T_{i+1,j} + a_{ij}^{T}T_{i,j+1} + a_{ij}^{B}T_{i,j-1} - (a_{ij}^{L}+a_{ij}^{R}+a_{ij}^{T}+a_{ij}^{B})T_{i,j} + Q_{i,j} \quad (2)$$

The above difference equation is solved using the alternative direction implicit (ADI) method. The scheme is represented by two steps as follows.

$$G_{ij}\frac{T_{i,j}^{n+1/2}-T_{i,j}^{n}}{\Delta t/2} = a_{ij}^{L}T_{i-1,j}^{n} + a_{ij}^{R}T_{i+1,j}^{n} + a_{ij}^{T}T_{i,j+1}^{n+1/2} + a_{ij}^{B}T_{i,j-1}^{n+1/2} - (a_{ij}^{L}+a_{ij}^{R})T_{i,j}^{n} + (a_{ij}^{T}+a_{ij}^{B})T_{i,j}^{n+1/2} + Q_{i,j} \quad (3)$$

$$G_{ij}\frac{T_{i,j}^{n+1}-T_{i,j}^{n+1/2}}{\Delta t/2} = a_{ij}^{L}T_{i-1,j}^{n+1} + a_{ij}^{R}T_{i+1,j}^{n+1} + a_{ij}^{T}T_{i,j+1}^{n+1/2} + a_{ij}^{B}T_{i,j-1}^{n+1/2} - (a_{ij}^{L}+a_{ij}^{R})T_{i,j}^{n+1} + (a_{ij}^{T}+a_{ij}^{B})T_{i,j}^{n+1/2} + Q_{i,j} \quad (4)$$

Here, the superscripts n, $n+\frac{1}{2}$, and $n+1$ denote the values at times t, $t+\frac{\Delta t}{2}$, $t+\Delta t$, respectively.

Commonly, when two-dimensional heat structure model is considered, the given numbers of axial nodes are not sufficient. So, in system code, fine mesh rezoning scheme is developed to overcome the problem. At each time step, all heat structures in a heat-structure geometry are searched to fine the positions of the quenching points. Then, for certain numbers of axial nodes near the quenching point in each heat structure, a fine-mesh rezoning is applied as shown in figure 1. The number of axial mesh intervals is determined by user input.

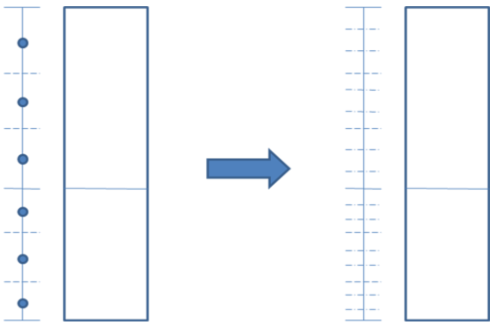
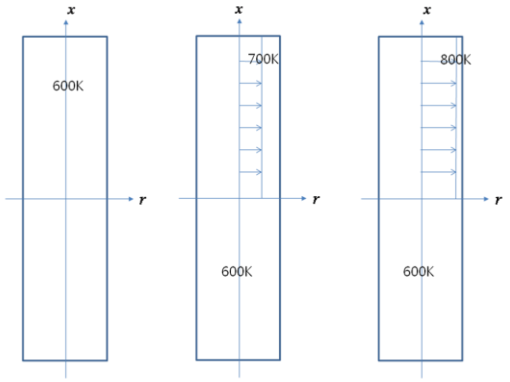


Figure 1. Fine mesh rezoning scheme adopted in SPACE code.

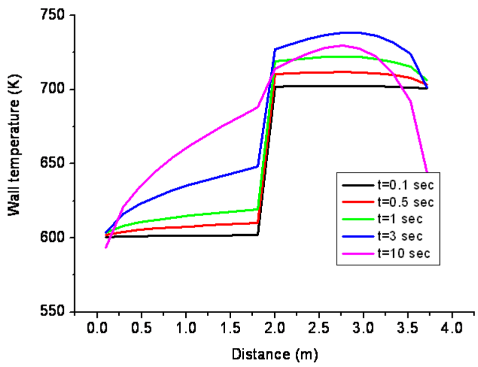
2.2 Assessment of two-dimensional heat structure model

As a first step of assessment, the conceptual problems shown in figure 2 are considered. As shown in figure 2, three different situations of initial temperature distribution in a given heat structure are considered. Then, the transitional behavior of the temperature distribution in each situation is compared against that from MARS. As shown in figure 3, the SPACE gives similar transitional behavior of the temperature distribution to that obtained in MARS, which means that the two-dimensional heat structure model is well implemented in SPACE.

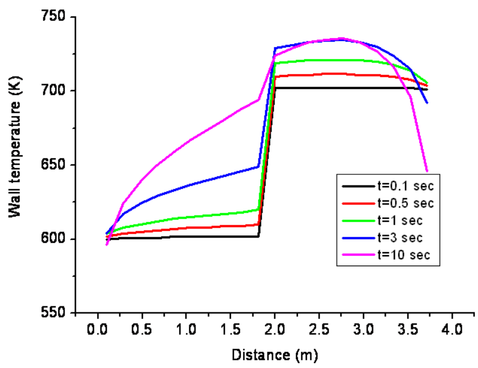


(a) (b) (c)

Figure 2. Description of conceptual problem used for validation: (a) case 1; (b) case 2; (c) case 3.



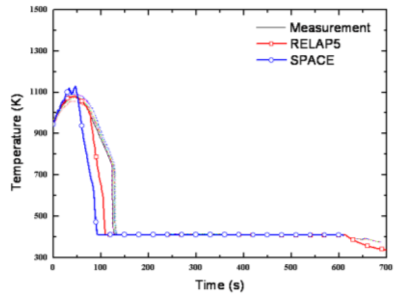
(a)



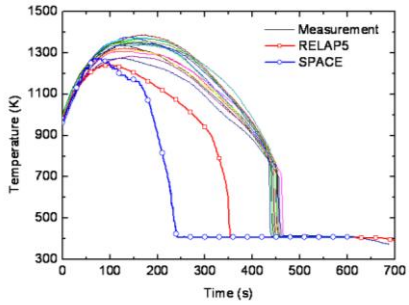
(b)

Figure 3. Transitional behavior of temperature distribution in a heat structure in case (2).

To assess further the performance of the two-dimensional heat structure implemented in SPACE, one case of FLECHT-SEASET reflood tests (FS-31504) is considered as shown in figure 4. As shown in figure 4, in lower height, the SPACE result is quite similar to the RELAP5 result and measurement data. However, in higher height, the wall temperature from SPACE decreases more rapidly as compared to the RELAP5 and experiment. The difference may be attributed to the different wall heat models adopted in SPACE and RELAP5 under the reflood condition. To resolve the issue, a further study would be required.



(a)



(b)

Figure 4. Temporal behavior of wall temperature: (a) 3.9ft; (b) 8.1ft.

3. Conclusion

In this paper, the development and assessment of the two-dimensional heat structure model in SPACE code was described. In SPACE code, the two-dimensional heat structure model is considered to predict more accurately the behavior of the heat structure under the reflood condition. To assess the performance of the two-dimensional heat structure model, the conceptual problem was considered and the results from SPACE were compared against those from MARS. As further step of validation, one case of FLECHT-SEASET tests (FS-31504 condition) was used to assess the performance of the two-dimensional heat structure model.

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