Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2011

Optimization of Heat Transfer Mode Determination in TASS/SMR-S Core Heat Transfer Model

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1. Introduction

TASS/SMR-S [1] is a system analysis code for safety and performance analysis of SMART. In the core heat transfer model of TASS/SMR-S, the surface heat flux and the surface temperature on the fuel rod are calculated using the following equations [2].

$$q'' = K_I\left(T_I - T_{surf}\right) \quad (1)$$

$$q'' = h\left(T_{surf} - T_{coolant}\right) \quad (2)$$

where K_I is the conductivity per unit length at the outer surface(W/mK), T_I is the volume averaged temperature of the outermost mesh(K), T_{surf} is the surface temperature of the fuel rod(K), h is heat transfer coefficient(W/m^{2}K) and $T_{coolant}$ is the coolant average temperature(K).

In the previous code logics critical heat flux (CHF) location and minimum film boiling (MFB) location must be calculated to determine the heat convection mode on the surface of the fuel rod. The calculation of CHF and MFB locations takes much time-consuming work because of many iterative calculations. To reduce the calculation time occupied by the core heat transfer model, new method to determine the heat convection mode is required. In this study the logics without calculation of CHF and MFB locations are introduced and applied to the analysis.

2. Change of view point

In the previous logics, the heat transfer mode on the surface of a fuel rod was determined in the view point of coolant. All interest was focused on how much heat can be transferred to the coolant at the specified condition. In this study, the view point is changed from coolant to conductor.

If CHF (q''_{CHF}) is known - CHF can be calculated easily because it is a function of coolant properties - the surface temperature of CHF ($T_{CHF,w}$) in the view point of wall can be calculated using eqn. (1).

$$T_{CHF,w} = T_I - q''_{CHF} / K_I \quad (3)$$

If q''_{CHF} and a heat flux ($q''_{CHF,c}$) which is calculated with nucleate boiling heat transfer coefficient and temperature difference between $T_{CHF,w}$ and $T_{coolant}$ are compared, it is easy to determine whether current heat transfer mode is nucleate boiling or not. If $q''_{CHF} < q''_{CHF,c}$, nucleate boiling mode cannot exist. Because q''_{CHF} is the maximum heat transfer rate that can be transferred in nucleate boiling mode.

Similar method can be applied to distinguish the transition boiling and film boiling mode. In the following chapter, it is explained how to determine the heat transfer mode without finding a CHF location and a MFB location in the boiling curve.

3. Logics for heat transfer mode determination

With the assumption that heat can only be transferred from fuel rods to coolant, the maximum surface temperature ($T_{surf,\max}$) is T_I and the minimum surface temperature ($T_{surf,\min}$) is $T_{coolant}$. If the surface temperature changes from $T_{surf,\max}$ to $T_{surf,\min}$, heat flux through fuel rod (q''_w) is increase, but heat flux through coolant (q''_c) is decreased. To find the surface heat flux and the surface temperature of the fuel rod is to find a balanced location of q''_w and q''_c . At a specified surface temperature, by comparing q''_w and q''_c , we can determine whether the surface temperature should be increased or decreased to get the balanced surface temperature. In the following section, the conditions to determine each heat transfer mode are summarized.

3.1 Single phase steam

- Quality (x) = 1.0

3.2 Single phase liquid

- Not single phase steam heat transfer mode, and
- $T_{surf,\max} < T_{coolant,sat}$ (saturation temperature)
- Else, x = 0.0 and $q''_w < q''_c$ when $T_{surf} = T_{coolant,sat}$

3.3 Nucleate boiling

- Not single phase liquid heat transfer mode, and
- $T_{CHF,w} < T_{surf,\min}$
- Else, $q''_{CHF} > q''_{CHF,c}$

If x = 0.0, it is sub-cooled nucleate boiling mode, or else saturated nucleate boiling mode.

3.4 Film boiling

Before proceeding a surface temperature and heat flux of transition boiling ($T_{surf,tr}$, q''_{tr}) should be found by using eqn. (1) and (2) at which transition boiling heat transfer coefficient is applied.

- Not nucleate boiling heat transfer mode, and
- $T_{surf,\min} > T_{surf,tr}$, or $T_{surf,tr} > T_{surf,\max}$
- Else, $q''_{tr} < h_{film\_boiling}\left(T_{surf,tr} - T_{coolant}\right)$

3.5 Transition boiling

- Not film boiling heat transfer mode

4. Application results of new method

The previous logics and the new logics have been tested. A same code input which is one of the THTF input for validation of the core heat transfer model of TASS/SMR-S has been used to compare the calculation result. The calculation results by the new logic have shown good agreement with the results by the previous logics (Fig. 1, 2).

Calculation time also has been checked. Total CPU time of core heat transfer model of TASS/SMR-S is changed from 12.4 seconds to 3.74 seconds. New method is able to calculate the event about 3.3 times faster than the previous method with producing the same results.

5. Conclusions

To improve the core heat transfer model, which is one of the bottlenecks in the overall calculation time, of TASS/SMR-S, a new method has been developed which be able to determine the heat transfer mode of fuel rod surface without the time-consuming calculation of CHF and MFB locations.

The calculation results of the new method have shown good agreement with the result of the previous method, while calculation speed has improved about 3.3 times.

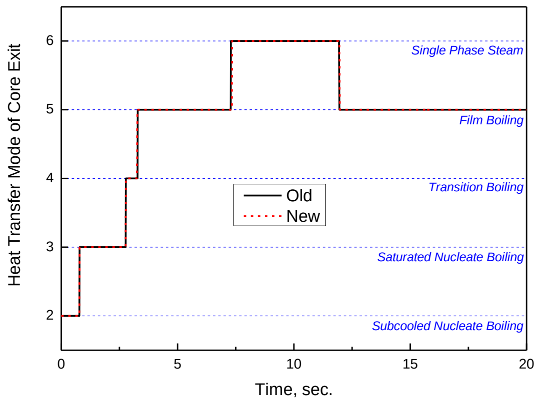

Fig. 1 Heat transfer mode of core exit

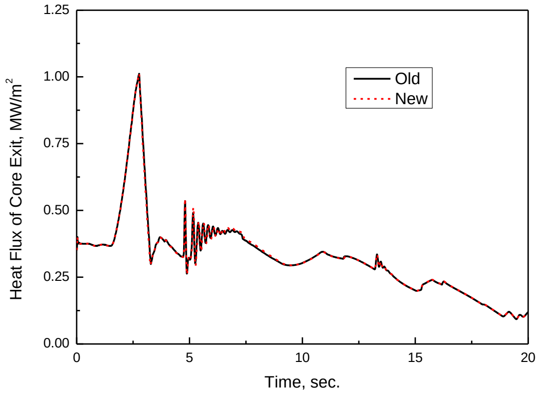

Fig. 2 Calculated heat flux of core exit

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[2] S.W. Lee, S.H. Kim and Y.J. Chung, "Development and steady state level experimental validation of TASS/SMR core heat transfer model for the integral reactor SMART," Annals of Nuclear Energy, Vol. 36, pp. 1039-1048, 2009.