1-D PCSG Model Development for Preliminary Safety Analysis of SMART Plus

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1. Introduction

There is strong interest in small modular reactors (SMRs) for low cost and effective safety in many counties and institutes. Korea Atomic Energy Research Institute (KAERI) develops the SMART Plus, the next generation design of SMART. The Printed Circuit Heat Exchanger (PCHE) is adopted as the steam generator for increasing thermal efficiency in the SMART Plus. The preliminary safety analysis of SMART Plus will be performed using the TASS/SMR-S code. In the TASS/SMR-S code, the PCSG model is developed to simulate the heat transfer of the steam generator adopted the PCHE for the preliminary safety analysis of the SMART Plus.

2. Methods and Results

In this section, the Printed Circuit Steam Generator (PCSG) design, the TASS/SMR-S code and 1-D PCSG model are described.

2.1 PCSG Design

The PCHE is compact heat exchanger, which is formed by the diffusion bonding of stacked plates whose grooved surfaces are the flow paths. Figure 1 shows the general PCHE manufactured by the Heatric [1].

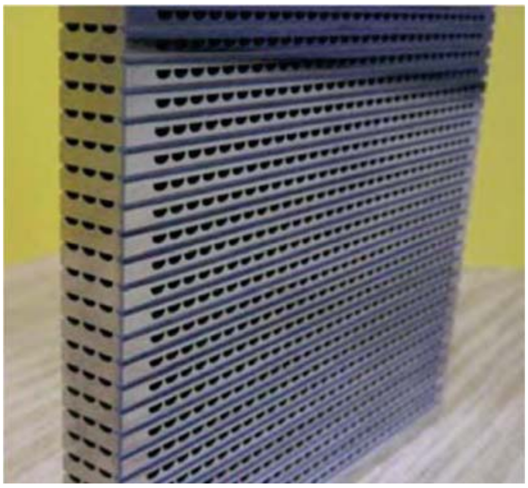

Fig. 1. Section of PCHE [1]

The PCSG is the steam generator that transfers heat from the reactor coolant system to the secondary system through the PCHE. The primary side channels with semicircular cross-section are placed per plate and the secondary side channels are divided into the straight semicircular and rounded partial zigzag. The straight semicircular channels are used in flow paths connecting the main heat transfer region. Thermal hydraulic conditions for SMART Plus PCSG design is developed from SMART.

2.2 TASS/SMR-S

The TASS/SMR-S is a computer code that simulates the thermal-hydraulic behaviors of NSSS using conservation equations on liquid mass, mixture mass, non-condensable gas mass, mixture momentum, gas energy, and mixture energy for non-equilibrium two-phase flow.

There are Core, RCP, Steam Generator (SG), Passive Residual Heat Removal System (PRHRS) models in the TASS/SMR-S code. In the SG model, the primary side gives heat to the secondary side with helical tubes. It is assumed that the geometry of the heat structure is cylinder type and the heat transfer correlation is developed for the helical tube in the SG model.

2.3 PCSG Model

2.3.1 1-D Conduction Model

Figure 2 shows the schematic drawing of the PCSG model. The complex multiple flow paths of the PCSG are simplified to a rectangular heat structure and two paths. The 1-d Finite Volume Method (FVM) is used to solve the temperature of the PCSG structure. The heat fluxes of the primary and secondary system calculated from convection model are boundary conditions.

Figure 3 shows the schematic drawing of the effective heat transfer length of the PCSG model. The effective heat transfer length is calculated from the 3-d Computational Fluid Dynamics (CFD) code. The heat from the hot channel is conducted to the upper and lower cold channels. In the PCSG model, there are only two paths and the generated heat is conducted in one direction from the hot channel to the cold channel. Thus, the effective heat transfer length that is calculated from the 3-d CFD code is twice that of the PCSG model.

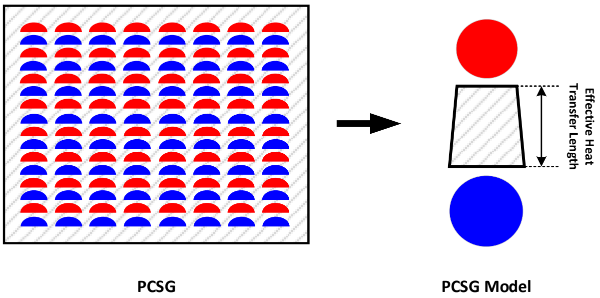

Fig 2. Schematic drawing of the PCSG model

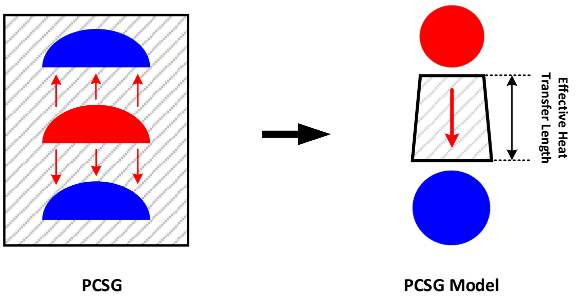

Fig 3. Schematic drawing of the effective heat transfer length for the PCSG model

2.3.2 Convection Model

The heat of the fluid in the PCSG channels is transferred to the wall of the PCSG by the convection. As the channels are micro size, the heat transfer correlations of the general pipe are inaccurate in the PCSG model. The single-phase heat transfer correlation uses the correlation obtained from 3-d CFD calculations. The Chen heat transfer correlation is used for the boiling condition [2].

2.4 PCSG Model Verification

The developed PCSG Model is confirmed for preliminary safety analysis of SMART Plus. Figure 4 shows the PCSG nodalization of SMART Plus. The boundary conditions are inlet conditions of the primary and secondary channels. Two cases are simulated to evaluate the effect of the heat transfer length. The heat transfer length of the Case 2 that is calculated from the 3-d CFD code is twice that of the Case 1.

Figure 5 and Figure 6 show the PCSG area factor and normalized temperature. The PCSG area factor is the heat transfer area of the PCSG model divided by the designed PCSG heat transfer area. After 40 seconds, the PCSG area factor is changed to match the primary outlet temperature to the design value. In the Case 2, the PCSG area factor increases due to the increased heat resistance of the PCSG structure. As mentioned above, the heat is conducted in one direction in the PCSG model and it makes the heat resistance of the conduction increase.

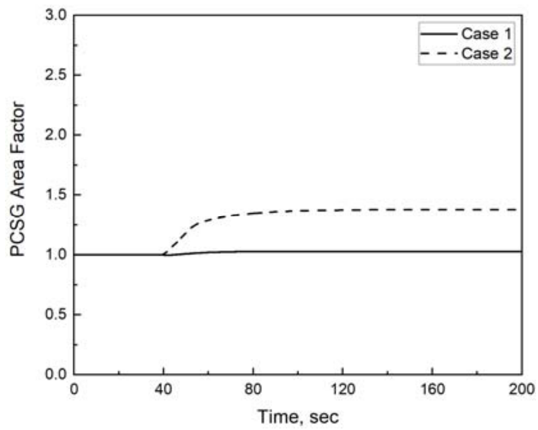

Fig 5. PCSG Area Factor

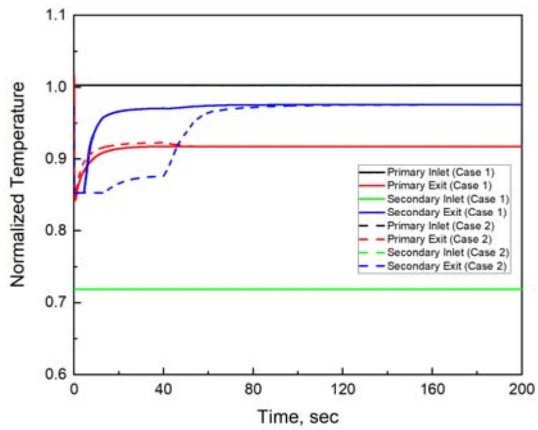

Fig 6. PCSG Normalized Temperature

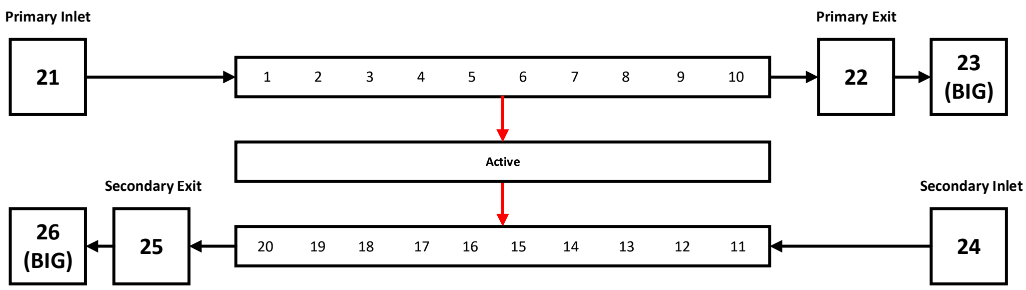

Fig. 4. PCSG Nodalization for Verification

3. Conclusions

The PCSG model is developed for preliminary safety analysis of SMART Plus. The effective heat transfer length and the heat transfer correlation are adjusted in the PCSG model to simulate the heat transfer of the micro channels. In the further studies, the PCSG model will be validated by comparing with the experimental results.

ACKNOWLEDGMENTS

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