Thermal Hydraulic Analysis of PWR Steam Generator using CUPID-SG: Coupling of the Primary and Secondary Coolant Models

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1. Introduction

Steam generator is one of the major component of a PWR (Pressurized Water Reactor), which provides dry steam to the turbine using the heat transferred from the primary coolant system. It also provides a physical barrier to prevent radioactive material release to the secondary coolant system. Thus, reliable analysis models are essential to ensure both the performance and the safety of the steam generator of PWRs.

In the previous study, a 3-dimensional thermal hydraulic analysis code named CUPID-SG [1] has been developed and applied to a simulation of the riser region of the steam generator secondary side.

In this paper, analysis models for the primary coolant and heat exchanger tube have been developed and coupled with the secondary coolant model. The developed models are presented and verification results are discussed.

2. Analysis Models

2.1 Governing Equation and Solution Scheme

CUPID-SG has been developed based on the CUPID code [2] which adopts the two-fluid model. The finite volume method (FVM) is used to discretize the governing equation. Unstructured grid can be used to model complex geometries. Both the semi-implicit and fully-implicit [3] methods can be applied to solve the linearized equation. Domain decomposed parallel computing using the MPI library is allowed for a large scale calculation. Physical models relevant to the U-tube bundle geometry have implemented which include wall and interfacial friction models.

2.2 Downcomer, Steam Separator, and Steam Dome Models

Conventional steam generator thermal hydraulic analysis code such as ATHOS3 [4], models the riser part of the secondary side (Fig.1) and does not include downcomer, steam separator, and steam dome. And the recirculation flow from the steam separator is given as an input and does not change during the calculation. Thus, a transient simulation is not allowed.

In this study all secondary domains including downcomer, steam separator, and steam dome are modeled as shown in Fig.1. The recirculation flow from the steam separator is calculated which enables a transient analysis. Also flow distribution inside the downcomer is calculated for a more realistic simulation.

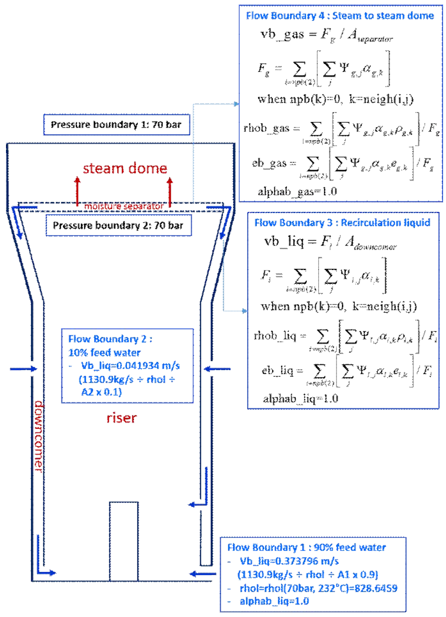

Fig. 1. Boundary conditions for downcomer, separator, and steam dome.

2.3 Primary Coolant and U-tube Models

One-dimensional conservation equations are applied for the thermal hydraulics inside a U-tube and heat conduction of the U-tube. All U-tubes are grouped as the number of hot side cells in the x-y plane. For example, the number of U-tube groups is 640 in Fig.2 and the one-dimensional model is applied to each U-tube group.

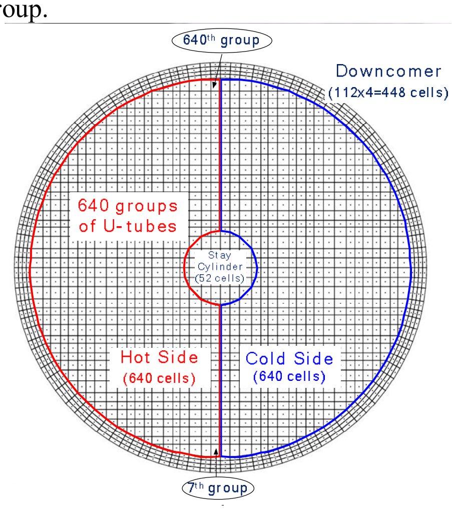

Fig.2 Top view of calculation grid and U-tube groups

2.4 Mapping of the primary and secondary grids

Computational grid has been generated for Shin Kori unit 3&4 as shown in Fig.3. 1780 2-dimensional grids (Fig.2) are extruded along the z-direction resulting total number of 121988 grids. Then, the one-dimensional computational grids for the U-tube primary side is mapped with corresponding secondary grids (Fig.4). The 2-dimensional grid has been configured to make the mapping convenient.

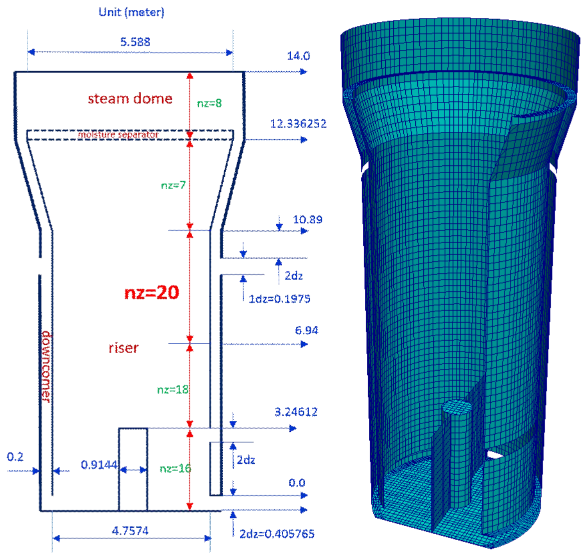

Fig.3 Calculation grid for the SG secondary side

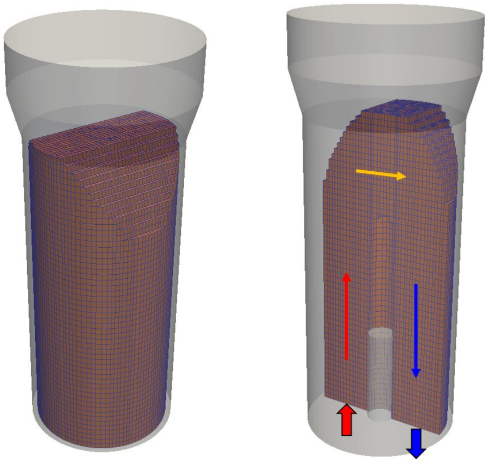

Fig4. Coupling of the primary and secondary sides

3. Analysis Results

CUPID-SG has been applied to the thermal hydraulic analysis of Shin Kori 3&4 steam generator. Steady state at 100% full power condition is simulated. Fig.5 shows the simulation result of void fraction and primary coolant temperature which qualitatively well agree with design values. Also, the calculated recirculation flow ratio to feedwater flow was found to be around 3.0 which is close to the design value.

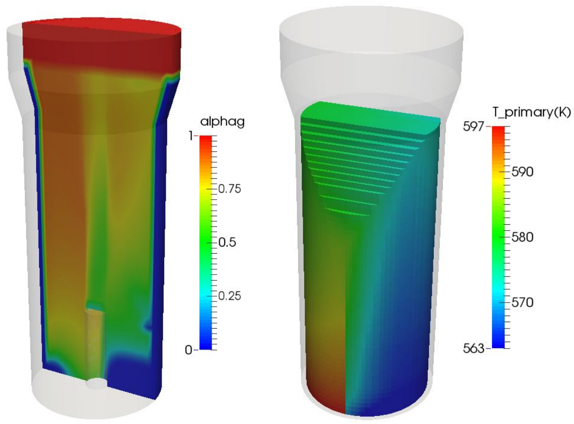

Fig.5 CUPID-SG analysis for Shin Kori 3&4 (Left: void fraction, Right: primary coolant temperature)

4. Conclusions

A PWR steam generator analysis code which can simulate downcomer, steam separator, and steam dome as well as riser has been developed. Also, the primary coolant and heat conduction of U-tube were modeled and coupled with the secondary coolant model. A state of art simulation of a PWR steam generator can be achieved using CUPID-SG since it provides all of the analysis models necessary for a steam generator simulation.

ACKNOWLEGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) and the Korea Foundation of Nuclear Safety (KoFONS) grant funded by the Korean government (MSIP & NSSC)(Nuclear Research and Development Program: 2017M2A8A4015005, Nuclear Safety Research Center Program: 1305011).

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