Numerical Study of Thermal Hydraulics for Secondary side of Steam Generator by CUPID/MARS Coupled Simulation

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1. Introduction

Numerous efforts to investigate the thermal hydraulics of secondary side of steam generators have been performed. Since a thermal-hydraulic behavior in the secondary side of steam generator such as two-phase boiling flow, flow-induce vibration of U-tubes is quite complicated, the importance to numerically investigate the flow behavior has been arisen. Recently, multi-scale analyses have been developed to take into account the primary side as well.

In this study, the coupled CUPID and MARS code was used for the simulation of boiler side of the PWR steam generator. Calculation results are compared with the existing code quantitatively.

2. Numerical Methodology

2.1 Governing equation

The formulation of the thermal hydraulic models of the CUPID code [1] is based on the three-dimensional description of transient two-fluid/three-field model. Two solution methods (Energy coupled and decoupled methods) are available. The pressure correction equation is set up by coupling the momentum equation with all the scalar equations or the mass equation.

2.2 Physical models and correlations

For the porous media approach such as rod bundle in reactor core or tube bundle in steam generator, the CUPID code provides a special package such as flow regime map, interfacial drag and heat transfer and wall friction to capture two-phase thermal hydraulics, which are widely used in system-scale codes and existing steam generator design code, ATHOS3. Table 1 summarizes the physical models and correlation implemented in CUPID code.

Table 1. Physical models for SG calculation

Model	Implementation
Flow regime map	MARS [2]
Interfacial model (drag, HTC)	MARS + SPACE [3]
Wall friction	ATHOS3 [4]
Wall HTC	Simplified SPACE + ATHOS3

2.3 Coupling strategy between CUPID and MARS

The coupling between two codes was conducted by sharing the heat structure surface temperatures and the outmost solid temperatures at every time step by using the interactive control function of the MARS. By using the function, designated pointer variables can be exchanged between MARS and CUPID when the latter calls the dynamic linked library (DLL) of the former. At first, MARS solves the hydrodynamic equations and the conduction equations with given boundary conditions, including the U-tube outer wall temperatures. Then, the outmost temperature of the heat structure (T_{sol}) in Fig. 1, is transferred from MARS to CUPID. With this solid temperature, CUPID solves the heat balance equation in order to obtain the outer wall temperature (T_{wall}). In this step, CUPID uses flow variables inside the secondary side (for example, the fluid temperature (T_f), liquid velocity, etc.) calculated by itself.

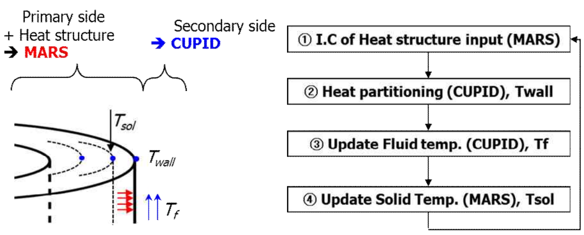

Fig. 1 Coupling strategy and data transfer between CUPID and MARS.

2.4 Node mapping of steam generator

For CUPID/MARS coupled simulation, the APR1400 steam generator is taken into account. Fig. 2 shows the one-dimensional nodalization for MARS calculation. The CUPID code handles the secondary side of the steam generator, whereas the MARS code covers the primary side of RCS. For the riser region of steam generator, the CUPID code focuses not on the whole geometry but only U-tube region. Since the upper plenum is not taken into consideration, the recirculation ratio is assumed to be a steady state value. In respect to the computational geometry for CUPID, the tube bundle is modeled as a porous media.

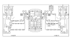

Fig. 2 APR1400 nodalization for CUPID/MARS coupled simulation

3. Results and Discussion

3.1 Simulation results

The coupled code is run from an initial state, and the physical time is 200 sec. Since both codes have their own subroutine to calculate the time step size, the less one is chosen. Normally the time step size of the CUPID code is less than one of MARS due to relatively small size of the computational grid. The MARS code is updated using the time step size from the CUPID code. Since the CUPID code is parallelized based on the domain decomposition technique, a real calculation time can be shortened as much as the processors are involved. About an hour takes to calculate the case in Fig.3 with 6 processors in PC.

Fig. 3 shows the qualitative results of coupled simulation. The configuration for CUPID calculation, three different flow inlets: hot side from bottom, cold side from bottom, and economizer from downcomer. A top surface is assumed to be flow outlet. The heat from the MARS fluid cell is successfully transferred to the CUPID fluid cell with having satisfied the energy balance at the tube surface. As time goes by, the fluid temperature in secondary side increases beyond the saturation temperature, and then the gas phase occurs at upper region.

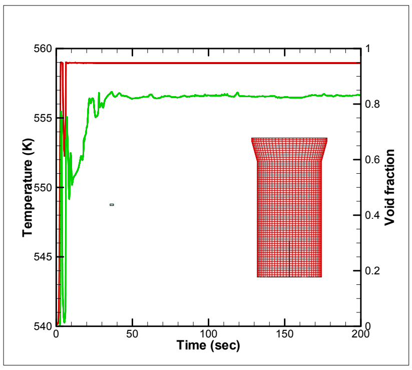

Fig. 3 Liquid temperature and void fraction at the top region of the riser

4. Conclusions

Coupled CUPID/MARS code was applied for the simulation of the steam generator. The primary side of the steam generator and other RCS was simulated by MARS and the secondary side was calculated by CUPID with porous media approach. For coupled simulation, the porous medium was applied in order to take into account the effect of the U-tube bundle and other supporting structure which play a role to be a flow resistance.

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