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Comparison between CUPID and CTF for Subchannel Scale Thermal-Hydraulic Analysis of Single Fuel Assembly Problem

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1. Introduction

Recently, high-fidelity and multi-physics thermal hydraulic analysis methods have been developed for the safety analysis of nuclear power plants. Among the various types of thermal hydraulic analysis codes, the subchannel scale analyses are attracting attention as the computing power develops.

The subchannel scale thermal hydraulic code, COBRA-TF was developed by PNNL(Pacific Northwest National Laboratory) in 1980, and CTF is improved version of COBRA-TF by PSU(Pennsylvania State University) [1]. CTF is used for full core subchannel thermal hydraulic analysis in CASL(Consortium for Advanced Simulation of Light water reactors) project recently.

In Korea, KAERI(Korea Atomic Energy Research Institute) has developed the in-house code CUPID [2]. In subchannel scale analysis using CUPID, scalar variables and vector variables are stored at the center of the mesh cells, which means collocated grid. Besides, CTF uses different meshing scheme named staggered grid as Fig. 1. In CTF, scalar variables are stored in scalar mesh cells and vector variables are stored in momentum mesh cells.

In this study, calculation results of subchannel scale analysis using CUPID would be compared with CTF which uses different meshing scheme, in order to verify the subchannel scale analysis capability of CUPID code.

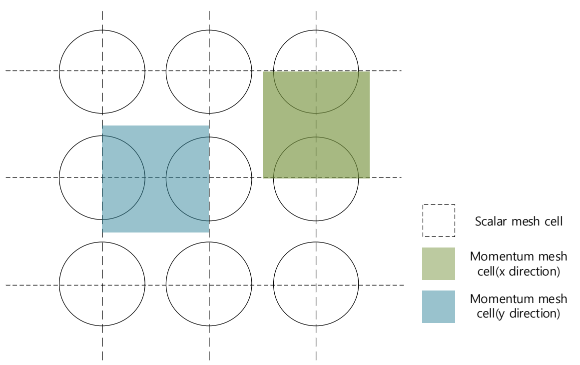


Fig. 1. Schematic view of staggered grid in CTF

2. Single Assembly Modelling

In this study, single assembly from APR1400 is used for verification. As shown in Fig. 2, the single assembly has 236 fuel rods and 5 guide tubes, with 9 spacer grids. The active length of the assembly is 3.810m. Outer diameter of fuel rod and guide tube is 9.5mm and 25.704mm. Initial pressure is 155.13bar and inlet velocity is 4.69m/s while inlet temperature is 291℃, at the initial state. The power distribution used in this calculation is from nTRACER calculation result [3] of assembly number 23, which is located as in Fig. 3.

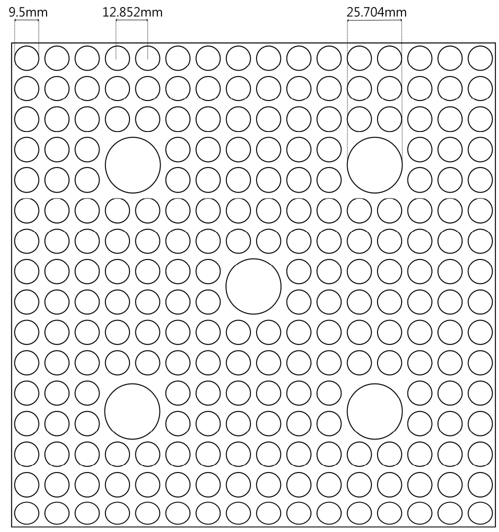


Fig. 2. Schematic view of APR1400 single assembly geometry

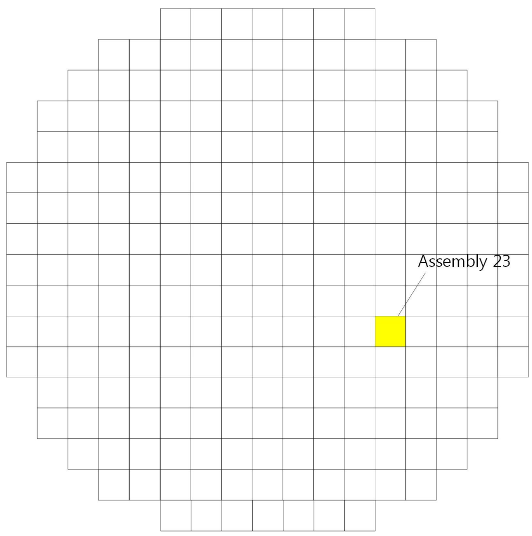


Fig. 3. Location of assembly number 23 in APR1400

2.1 Modelling of Single Assembly Using CUPID

CUPID uses porous media model for subchannel scale analysis [2]. The porosity at the center of the guide tube is defined as 0.05. The pressure loss coefficients at the location of spacer grids are defined as 0.57, and the turbulent mixing coefficient is 0.05 in this calculation. There are 34 axial meshes including one ghost cell, and the total number of cell is 9826.

2.2 Modelling of Single Assembly Using CTF

Same pressure loss coefficients and turbulent mixing coefficient were defined in CTF as CUPID. At the location of guide tubes, the subchannel is not defined, and wall model is applied at the boundary of guide tube. As in Fig. 4, subchannel number, rod number, and gap number is re-defined for absence of the subchannel named 'guide tube' in Fig. 4. In Fig. 4, numbers in square boxes represent rod numbers and numbers in rectangular boxes represent gap numbers. Boundaries of subchannel named 'guide tube' are considered as wall. Therefore, 236 rods and 284 subchannels at a single axial location is used in CTF, while the number of axial mesh is 35 including two ghost cells and total number of cells is 9940.

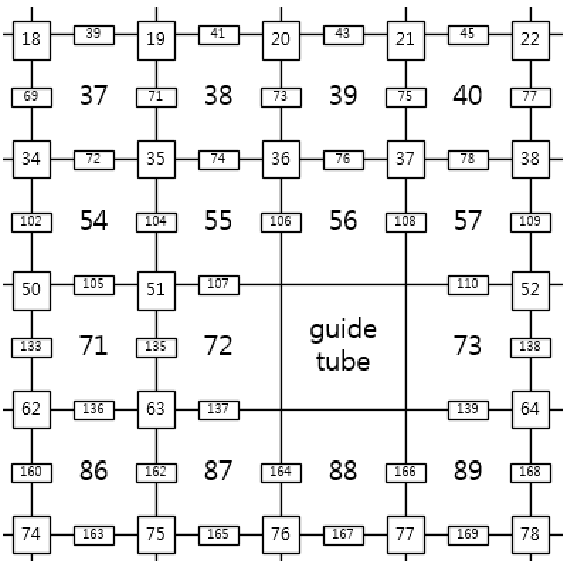
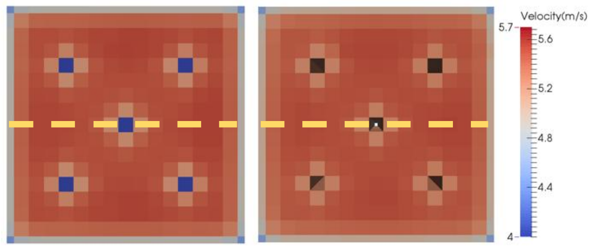


Fig. 4. Schematic view of numbering near the guide tube in CTF

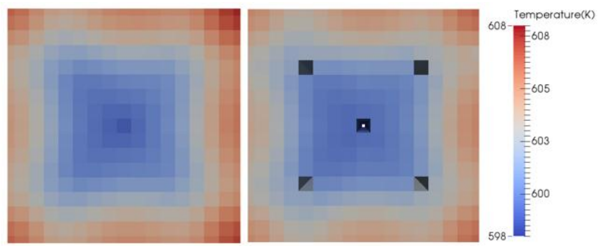
3. Calculation results

Fig. 5 and 6 illustrate the outlet velocity distribution and temperature distribution of the calculation result using CUPID and CTF. Fig. 7 shows the line extraction result which means velocity and temperature profiles along the yellow line in Fig. 5. According to Fig. 5 and 6, velocity and temperature distribution at the outlet are well matched with CUPID and CTF results. In Fig. 7, at the values near the boundary and guide tube, visible differences are observed both temperature and velocity profile. Since CTF uses staggered grid, velocity is stored at the boundary of subchannels. So velocity values at the center of the subchannels are the average values at its boundaries. So minimal values, where at boundaries of assembly and near the guide tubes, can be flatten and become bigger than CUPID calculation results.



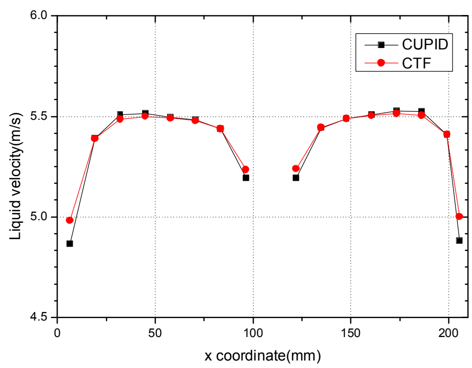
(a) (b)

Fig. 5. Outlet velocity distribution calculated by (a)CUPID and (b)CTF

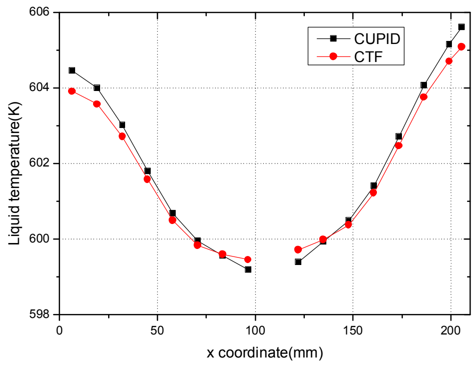


(a) (b)

Fig. 6. Outlet temperature distribution calculated by (a)CUPID and (b)CTF



(a) Liquid velocity profile



(b) Temperature profile

Fig. 7. Comparison of calculation results with line extraction

4. Conclusion

In this study, the capability of subchannel scale analysis using CUPID code is verified by comparing the calculation results using CTF code which is using staggered grid. For the verification, single assembly problem from APR1400 reactor core was modelled and simulated. As a result of calculation, it was confirmed that the velocity and temperature distributions at the outlet of the assembly were well matched with each other.

For the future study, code-to-code verification with two-phase flow problem is needed.

ACKNOWLEDGEMENT

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