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3-D Analysis of Natural Circulation in PCCT of PAFS using the CUPID Code

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1. Introduction

A three–dimensional thermal-hydraulic code, CUPID [1], which has been developed for the component scale analysis of a nuclear reactor, is used for the analysis of PAFS (Passive Auxiliary Feedwater System). PAFS is one of the safety features of APR+ (Advanced Power Reactor Plus), which intended to completely replace the conventional active feedwater system. The physical phenomena in PAFS include various thermal hydraulic issues such as flashing, subcoolled boiling, single- and two-phase natural circulation, swelling and boil-off. Moreover, all those thermal hydraulic phenomena happen in multi-dimensional way due to the geometrical features of PAFS. A preliminary study was done for a secondary system of the real scale PAFS with CUPID.

2. PAFS

Fig. 1 shows the schematic diagram of a quarter of PAFS PCCT. For passive cooling, PAFS has a condensate cooling tank called PCCT (Passive Condensate Cooling Tank) and heat exchanger tubes. Heat is fed from a steam generator into heat exchanger tubes and transferred to the secondary cooling water in PCCT. PAFS has 240 heat exchanger tubes, and the tubes are arranged by 4 bundles. Each bundle has 60 heat exchanger tubes, and the one bundle is plotted in Fig. 1.

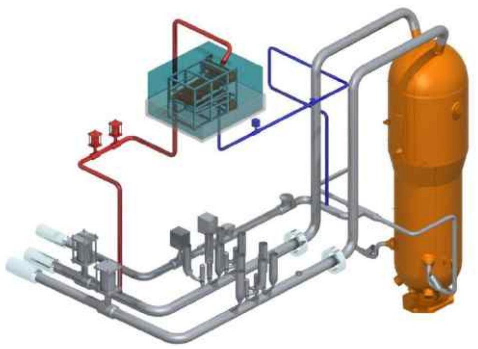


Fig. 1. Schematic diagram of PAFS.

3. PAFS Model for CUPID Simulation

Fig. 2 shows the top view of PCCT to define a problem for CUPID calculations. The pool is divided into 4 volumes for the computational efficiency. Among the 4 volumes, the right-bottom volume is defined as the computational domain. A quarter of the pool has 1.082 unit in width, 0.802 unit in depth, and 1.25 unit in height. Water fills the pool up to 0.09 unit in height. Table 1 shows the geometrical specification of the heat exchanger tubes. The unit refers to the normalization by the heat exchanger tube length.

Table 1 Heat exchanger tube information of PAFS

Name	Value	Unit
Outer/Inner diameter	0.0060/0.0053	Normalized
Heater Tube Length	1.00	Normalized
Power	15.36	MW/m

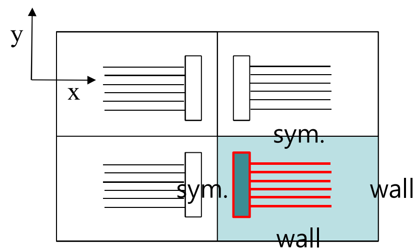


Fig. 2. Top view of PCCT.

For initial condition, the cooling water is 60 °C and at rest initially.

For boundary conditions, there is an outlet opened to the atmosphere. The wall condition covers all the outer boundaries except two vertical contacting to the other volumes. They were set to be symmetry.

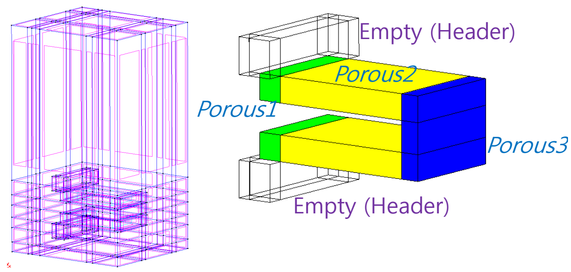


Fig. 3. CAD modeling using GiD and the division of volume porosity for the bundle of 60 heat exchanger tubes.

Fig. 3 shows the CAD modeling for the computational domain and the division of volume porosities for the heat exchanger tube bundle. The heat exchanger tubes are defined as three sections. Porous 1 region for elbow configurations, porous 2 region for straight tube configurations, and porous 3 region for U type configurations. Furthermore, headers are modeled as presented in Fig. 3. It is assumed that the header is a non-heating object and hollow. Thus, the header is defined to have a wall boundary condition.

The CAD model is divided by 27962 cells (41×31×22). The grid scale is 0.254 m~0.349 m.

4. Analysis Using CUPID

To analyze PAFS, CUPID v1.7 [2] is used. CUPID v1.7 uses MPI method to accelerate the computational speed. The computer used in this calculation has Intel(R) Core(TM) i7-3790X CPU (64 bit and 6 cores) and 32482 MB shared memory. The computational domain is decomposed by 6 regions vertically.

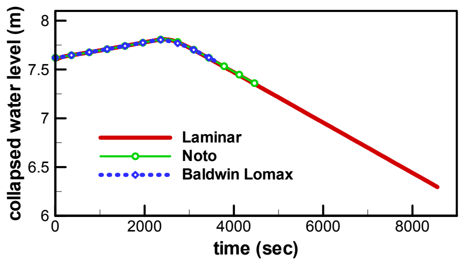
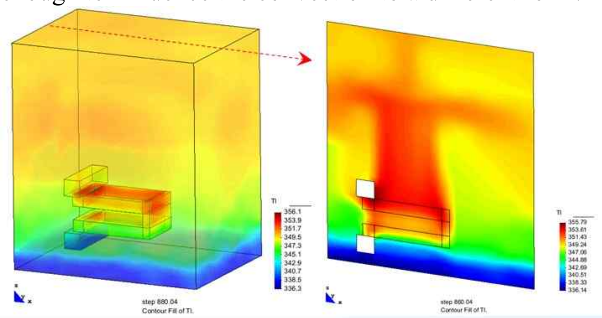


Fig. 4. Calculated collapsed water level of PAFS.

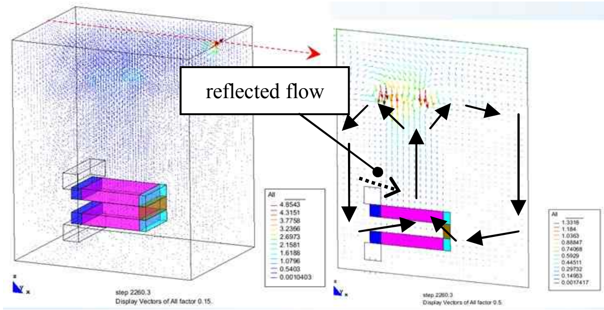
Fig. 4 shows the calculated collapsed water level using CUPID v1.7. To compare the results in turbulence point of view, Noto & Matsmoto model [3] and Baldwin Lomax [4] model are tested against the Laminar condition. The collapsed water level shows the highest swelling point is at around t=2300 s. It is a reasonable when it is compared to the expected saturation time, t=2351 s.

Fig. 5 shows the fluid properties at t=250 s. At t=250 s, single-phase natural circulation occurs. As presented in Fig. 5, liquid temperature and liquid velocity field is circulating in two directions of rotation. Furthermore, unlike the PASCAL test, the circulations are somewhat complicated in depth direction. On the free surface, the velocity is dispersed to all directions. Finally, a thermally stratified region is observed below the lowest part of the bundle.

Fig. 6 shows the void fractions before and after the saturation. From the interface, the upper part is filled with air and steam, the lower part is filled with water. As the heat exchanger bundle is heated, swelling starts. When the temperature is almost saturated at around t=2350 s, flashing appears as shown in Fig 6(b). In this simulation, flashing phenomena is observed asymmetrically in depth direction. It can cause unsteady natural circulation in two-phase. Moreover, the sudden velocity increase in two-phase natural circulation makes the reflected flow (the dotted arrow in Fig. 5) strong enough to influence the convection to a different form.

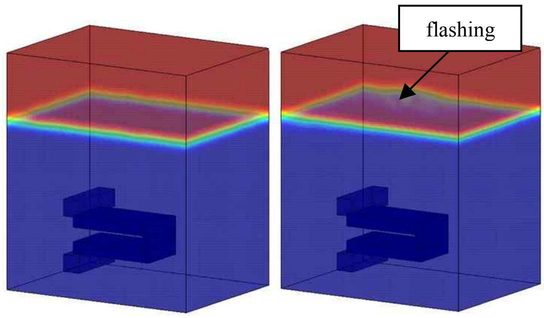


(a) Liquid temperature



(b) Liquid velocity

Fig. 5. Liquid temperature and liquid velocity at t=250 s.



(a) 250 s (b) 2540 s

Fig. 6. Void fraction at t=250s and 2540 s.

5. Conclusions

A preliminary analysis for the real scale PAFS PCCT was performed. The collapsed water level coincides with the expected results. The temperature and velocity field showed the single-phase natural circulation mode as shown in previous PASCAL simulations [5]. Finally, void fraction is appeared to be asymmetric in flashing so that it may affect strongly the convection form after saturation.

ACKNOWLEDGEMENT

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