CFD Analysis of Flow Characteristics in the PAFS PCCT for APR +

Mun Soo Kim*, Jong Chun
Korea Hydro and Nuclear Power Co., Ltd(KHNP), 25-1 Jang-Dong, Yuseong-gu, Daejeon, Korea
**Corresponding author: nikollao@khnp.co.kr*

1. Introduction

The passive auxiliary feedwater system (PAFS) is one of the passive safety features adopted in the APR+. The PAFS has two independent high-pressure closed loops; each loop has a heat exchanger (U-tube bundles) submerged in a PCCT water pool [1]. The PAFS cools the secondary system by heat transfer in a horizontal U-tube in the PCCT. The cooling water in the PCCT is maintained at atmospheric pressure, so that boiling heat transfers at the surface of the U-tube and natural convection occurs in the PCCT water pool [2]. The conventional system codes, such as the RELAP5 /Mod3.3 and the MARS codes, are inadequate for flow pattern analysis of this system.

The purpose of this study is to analyze the flow characteristics in the PAFS PCCT for APR + utilizing a CFD code, CFX.

2. Basic design of PAFS PCCT

The PAFS is composed of two independent trains; each train has a PCCT used as an ultimate heat sink of the PAFS. This heat sink is a rectangular shaped steel lined concrete tank located at an elevation of 200 feet from the auxiliary building. A schematic diagram is given in Fig. 1.

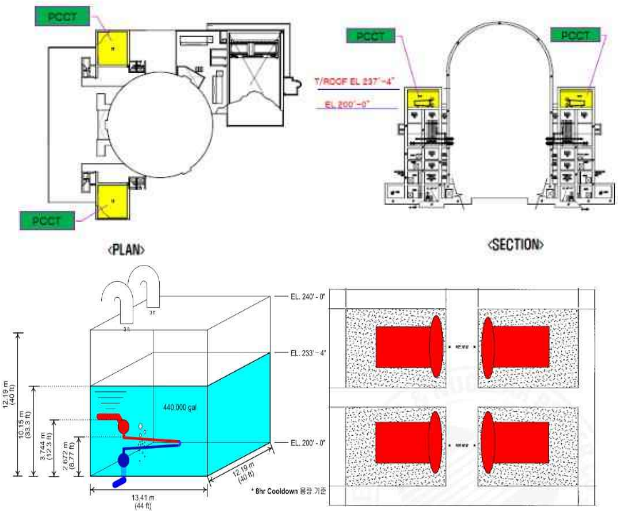

Fig. 1. Location of PCCT & Schematic diagram of PCCT in PAFS

The PCCT capacity has to be determined based on the mission time of the PAFS, which is defined by the duration of the cooling of the RCS from the initial conditions by PAFS actuation to the shut down cooling entry condition for all design basis accidents. The PCCT preliminary capacity including dead volume has been determined to be 440,000 gallons. This means that the PAFS can be operated for eight hours without refill. The PCCT level will be controlled by the makeup water system operated by the PCCT level controller during normal operating conditions.

The heat exchanger consists of slightly inclined stainless steel U-tubes [3, 4]. Fig. 2 shows the modeling of the U-tube bundle in the PCCT using CFX design modeler for flow analysis. The geometry of the tube is summarized in Table I. A total of four heat exchangers are installed in one PCCT. The tube bundles are shaped to minimize thermal stress during their operation.

Table I: Geometry of U-tube bundle

Parameter	Design
Horizontal U-tubes per bundle	60ea
Inner / Outer Diameter	44.8mm / 50.8mm
U-tube Length	8.1m
Incline angle	3 °
Upper and Lower header diameter	762mm
Height (Maximum)	3,200mm
Tube pitch (Minimum)	114mm

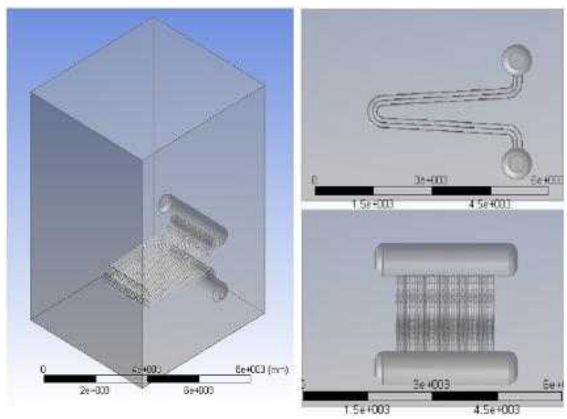

Fig. 2. CFX analysis modeling of U-tube bundle

The heat exchanger tubes are filled with condensate water during normal operation. The heat exchanger tubes start to remove heat from the SG after the PAFS actuation signal occurs. The cooling water in the PCCT is heated through convection heat transfer at the outside of the heat exchanger tubes. In PCCT, pool boiling begins when the PCCT pool temperature reaches the saturation temperature at the PCCT pressure.

3. Analysis and Results

The geometric details of the U-tube bundle are represented by three parts: for the top & bottom headers, three layers and twenty tubes, respectively. In order to get the boundary conditions for CFD analysis of PCCT, RELAP5/Mod3.3 codes are used. The thermal-hydraulic conditions inside U-tubes are evaluated using RELAP5/Mod3.3. For the CFD analysis, to reduce the numerical effort, all parts are divided into quarter-values about the y-axis, which division allows application of the periodicity interface to their fluid domain. The U-tube bundle and the PCCT are discretized with hexahedral cells and tetrahedral cells.

3.1 RELAP5/Mod3.3 analysis results

The PAFS model, including nodding for piping, heat exchanger (U-tube bundle), and PCCT, is attached to the current APR1400 model. To predict the temperature profiles at the U-tube surface and at the PCCT water pool, U-tube bundle has been divided into fifteen volumes. Steady-state analysis is performed using the APR 1400 conditions because the system configuration of the APR+ is very similar to that of the APR1400. Fig. 3 shows the temperature of each part of the U-tube and the PCCT. These results are used in boundary conditions of CFD analysis.

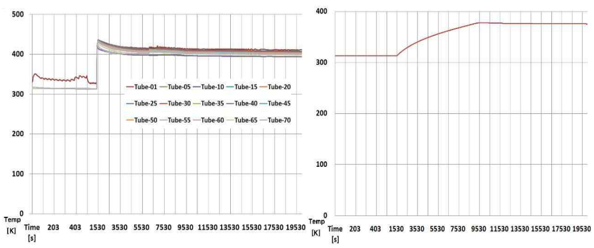

Fig. 3. Temperature at PCCT & surface of U-tubes

3.2 CFD analysis

The outlet boundary condition is set for opening at 1 atm, which enables the fluid to cross the boundary surface in either direction. No-slip wall condition and automatic near-wall treatment are used for the wall boundary layer. To take buoyancy effects into account, y-axis gravity is applied in the fluid domain and the buoyancy reference temperature is set at 25 ◦C. Mesh match tolerance is set at 0.005. A fully implicit second-order backward Euler scheme is used for the transient calculation with a time step of 0.1 s until all RMS residual values are below a convergence limit of 1.0E−4.

Fig. 4 shows the CFX Post processing results of the streamline and density variation in a quarter volume for the PCCT. The behavior of density variation is caused by the heat transfer of the tube bending part, which is higher than the headers in the PCCT.

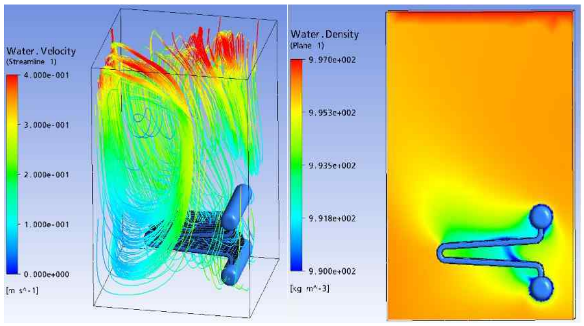

Fig. 4. CFX analysis Post processing: Stream line in PCCT (L), Density variation (R).

4. Conclusions

A three-dimensional flow analysis of the PAFS PCCT using the CFX model has been performed. The temperature of each part of the U-tube was estimated using the RELAP5/Mod3.3code, which has been developed for the preliminary analyses of PAFS IET and SET. Natural circulation streamlines in the PCCT were verified. These streamlines are due to the density variation caused by different heat fluxes for each part of the U-tubes.

In future studies, the flow analysis results will be compared with assessments of the RELAP5/Mod3.3 codes and the SET natural circulation.

ACKNOWLEDGMENTS

This work was supported by the Nuclear Research & Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy

(*No. R-2007-1-005-02*)

REFERENCES

[1] The Feasibility Study Report on Development of the Core Technologies for APR+, S07NJ06-K-TR-001, 2008

[2] The Conceptual Design Report for PAFS, 07NJ06-E-TR-006, 2009

[3] A Review Report on manufacturing probability for Heat Exchanger for PAFS, S07NJ06-D-TR-002, 2009

[4] Schaffrath A. et.al., Modeling of Condensation In Horizontal Tubes, Nuclear Engineering and Design, Vol. 204, 2001