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Evaluation of the PASCAL Experiment for Quasi-Steady State and Decrease of PCCT water level using RELAP5

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1. Introduction

In the field of nuclear engineering, there have been many researches to develop the passive safety system to enhance safety and reliability of nuclear power plant. In South Korea, the development of PAFS (Passive Auxiliary Feedwater System)[1] is ongoing to be applied to the advanced power reactor plus (APR+). It can replace completely a conventional auxiliary feedwater system. KAERI (Korea Atomic Energy Research Institute) constructed the test facility named PASCAL (PAFS Condensing Heat Removal Assessment Loop) to validate the cooling and operational performance of the PAFS. Its dimension and material are same as the proto-type U-tube of the PAFS[2].

In this study, the RELAP5 calculations for PASCAL experiment were performed to evaluate its cooling performance under quasi-steady state and long term cooling condition. From the comparison between the RELAP5 analysis results and PASCAL experiment, the improvement of the RELAP5 input model for PASCAL was performed.

2. Modeling of PASCAL Test Facility

Figure 1 is the RELAP5 nodalization of the PASCAL facility. The facility is consist of steam generator, PCHX (Passive Cooling Heat Exchanger), steam line pipes, return line pipes, and PCCT (Passive Condensation Cooling Tank). The nodalization of RELAP5 model is same as the its APR+ PAFS to avoid distortion by change of nodalization.

Described above, the facility simulates a single heat exchanger U-tube of the PAFS then only a single tube is modeled. The dimension and length of the tube is same as the proto-type of PAFS. Major design and scaling parameters of the PASCAL facility are compared with those of the proto-type in Table 1[2].

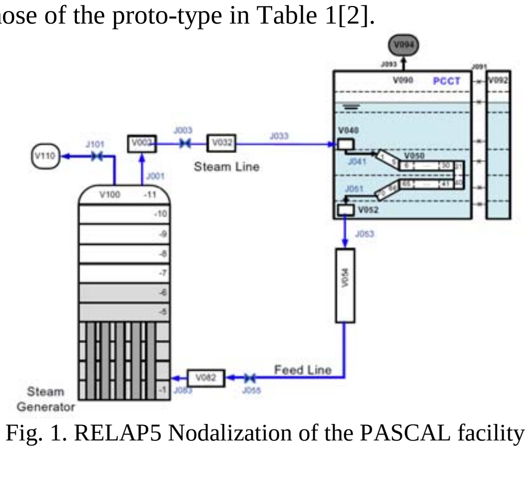


Fig. 1. RELAP5 Nodalization of the PASCAL facility

Table 1 Geometry and scaling parameters

Parameter		PAFS	PASCAL	Ratio
PCHX tube	I.D/O.D	44.8/50.8 mm	44.8 mm / 50.8 mm	1/1
	Length	8.4m	8.4 m	1/1
	No. of tubes	240	1	1/240
	Material	SS304	SS304	-
	Operating Condition	7.4 MPa	7.4 MPa	-
		290 °C	290 °C	
PCCT	Pool height	8.9 m	8.9 m	1/1
	Pool length	18.29 m	6.7 m	1/2.7
	Pool width	13.56 m	0.112 m	1/121

3. Analysis and results

3.1 Quasi-Steady State

KAERI carried out a quasi-steady state experiment for three types of thermal power level, 300, 540, 750 kW according to the volumetric scaling methodology. The test is to find the cooling performance of PCHX under steady state. Table 2 shows the result of the test for three types of power level. 540 kW of heat removal rate is calculated design value to be removed through a single tube under PAFS operation. The results show that the PCHX has enough cooling performance beyond heat removal rate of 540 kW. Because the system pressure in case of 750kW was not more increase and but maintained a steady pressure.

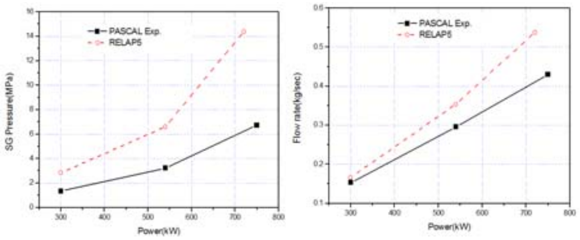
Table 2 Quasi-steady state condition in PASCAL tests

ID	SS/PL-300-P1	SS/PL-540-P1	SS/PL-750-P1
Power(kW)	299.8	540	750.2
Steam Pressure(MPa)	1.342	3.22	6.736
Steam Flow(kg/s)	0.1469	0.2953	0.4302
Return Water Flow (kg/s)	0.1532	0.2958	0.43
Return Line Water Level (m)	12.19	18.28	18.31
Steam Generator Water Level (m)	3.773	3.747	3.491

Table 3 shows the RELAP5 analysis results for a various power level. Generally the system pressure increased as the power rose. But as shown in Figure 2, the analysis results are different from the experiment. At the same power, the system pressure was predicted higher than the result of the experiment. It means that the RELAP5 model underestimates the cooling performance of PASCAL when the fouling factor is not applied. So the system flow rate was also smaller because the condensate flow decreased. The analysis results show that the RELAP5 original model is more conservative in heat removal performance.

Table 3 RELAP5 analysis results of quasi-steady state

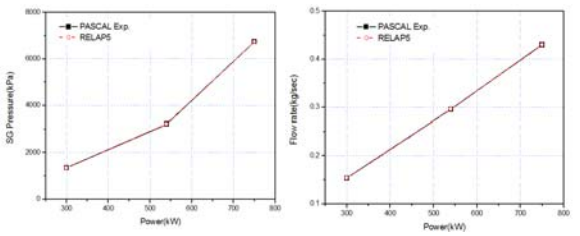
Case	Power (kW)	Steam Pressure (MPa)	Flow (kg/s)	Return Line Water Level (m)
R01	341.94	3.38	0.195	10.52
R02	362.56	3.664	0.210	11.01
R03	410.54	4.381	0.246	12.25
R04	478.13	5.478	0.300	14.29
R05	551.29	6.789	0.366	16.07



(a) System pressure (b) Flow rate

Fig. 2. Comparing results of steady state condition according to the power between the PASCAL experiment and the original RELAP5 model analysis

To make up for the difference, the RELAP5 model was modified with its optional heat transfer characteristics of the PCHX tube as it called a fouling factor. Figure 3 shows the analysis results of the modified model. The modified model predicts well in the system pressure and flow for the each power case. The modified RELAP5 model is adequate to simulate the phenomena occurring in the PASCAL under quasi-steady state condition.



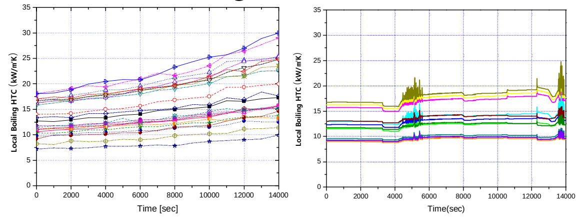
(a) System pressure (b) Flow rate

Fig. 3. Comparing results of steady state condition according to the power between the PASCAL experiment and the modified RELAP5 model analysis

3.2 Decrease of the PCCT Water Level

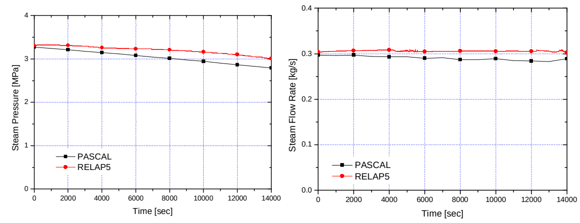
Experiment of the PCCT water level decrease is for evaluating the long term effect in PCHX. If the PAFS is operating for a long time, the PCCT water level continuously decreases by boiling. The lower water level of the PCCT makes the saturation pressure and temperature of the pool water around the PCHX tube to be lower. So the nucleate boiling on the tube surface occurs more actively as the level decrease.

As shown in Figure 4, the boiling heat transfer coefficient (HTC) at the outer wall of the tube increased in the PASCAL test. But the heat transfer coefficient in RELAP5 model had a slight increase relatively. And due to the difference of HTC, the transient tendency of system pressure and flow according to time was also different as shown in Figure 5.



(a) Experiment (b) RELAP5

Fig. 4. Comparing results in local boiling HTC between the PASCAL experiment and the RELAP5 analysis



(a) Steam pressure (b) Steam flow

Fig. 5. Comparing results of long term cooling between the PASCAL experiment and the RELAP5 analysis

4. Conclusions

In this study, the RELAP5 calculations for PASCAL experiment were performed to evaluate its cooling performance under quasi-steady state and long term cooling condition. It was found that the original RELAP5 model underestimated in the cooling performance of the PCHX under quasi-steady state and long term cooling condition. The RELAP5 model modified with the fouling factor can be used for safety and performance analysis of APR+ PAFS.

REFERENCES

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[2] Quick look report on the cooling performance of the passive auxiliary feedwater system with the PASCAL, KAERI, 2011

[3] RELAP5 Mod 3.3 Code Manual, INEEL