Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 24-25, 2024

Steam codensation modelling by ECC water in SPACE code

Kwi Seok Ha[a], Seungwook Lee[a]
Korea Atomic Energy Research Institute, Deadeok-daero, 989-111, Yuseong-gu, Deajeon, 34057, Rep. of Korea
Corresponding author: ksha@kaeri.re.kr

***Keywords**:* SPACE, condensation, interfacial heat transfer

1. Introduction

During a loss of coolant accident in pressurized water reactor(PWR), the system pressure is decreased to the setpoint of discharge of ECC of a safety injection tank(SIT) and the cold water is injected into the cold legs where the flow in a horizontal pipe is generally stratified. At that point condensation of steam is occurred on the ECC water itself, on the free surface in the vicinity of ECC impact with enhanced mixing due to jet induced turbulent, and on the free surface far from the jet influence. The system transient analysis codes have a separate flow regime for emergency core coolant (ECC) flow regime map because the general flow regime would not treat appropriately the above condensation process. The special model for direct contact codensation by ECCW in SPACE code[1] is as follows;

$$hi_f = 0.0344 Re_g^{0.58} Re_f^{0.42} Pr_g^{0.33} \frac{k_f}{D_h} \quad (1)$$

where hi_f is the interfacial heat transfer coefficient, *Re* is the Reynolds number, k_f is liquid conductivity, D_h is the hydraulic diameter of cold leg and *Pr* is the Prandtl number.

In recent, the validation calculation of SPACE code for UPTF test 8b[2] showed some disagreement in the liquid temperature between experiment and calculation. In this paper more appropriate model for condensation for ECC component of SPACE is proposed.

2. UPTF test 8b[2]

UPTF (Upper Plenum Test Facility) is a full scale test facility of a 4-loop 1300 MWe PWR which includes the pressure vessel, downcomer, lower plenum, core simulator, upper plenum, 4-loop piping system, and steam generator simulator.

The goal of the test was to investigate the loop flow pattern and to quantify the thermohydraulic boundary conditions which lead to pressure and flow oscillations in the loop when ECC water be injected into the cold leg. Of special interest were the flow parameters which determine water plug formation and oscillation in the loop. The system configuration is as follows;

- The loop 1 was closed by blocking of pump 1 and the form's loss coefficient of pump 3 was adjusted to have 18 in order to establish a nearly constant diffenential pressure of about 0.25 bar between upper plenum and downcomer.
- The break valves of hot leg and cold leg in broken loop were fully open.
- Steam is injected by the core simulator.
- The form's loss coefficient at the pump 2 was set to 18 to simulate the maximum value of the pressure drop during reflood.

The initial system pressure and temperature are 380 kPa and 418 K, respectively. The figure 1 shows ECC water injection rate into the cold leg of loop 2 and steam injection rate from the core simulator. The ECC injection rate is initially 600 kg/s from the 23 seconds and is decreased to 400 kg/s, 250 kg/s, 200 kg/s, 150 kg/s, 85 kg/s, and 20 kg/s in phases. The steam injection rate is constantly injected by 114 kg/s.

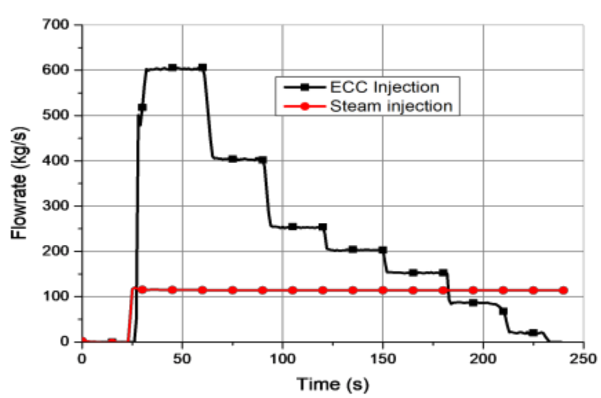

Fig. 1 Injection rates for ECC and steam

3. Analysis of Test 8b

In the SPACE code the mixing and condensation between system coolant and ECC water is modeled in the component of 'ECCX' in which the interfacial heat transfer from the interface to bulk liquid phase is calculated separately calculated by equation (1). However the equation (1) does not consider the condensation due to the ECC water column itself and jet impact.

The correlation in which these kind of condensation processes were taken into account was proposed in the reference [3]. The main idea of the correlation is to consider the turbulence due to the ECC water injection velocity. The final equation form has the form as follows;

$$Nu = K Re_t^a Pr^b Fr^c \alpha^d \left(\frac{d_{ecc}}{D_h}\right)^e \quad (2)$$

where K is the adjustable constant, Fr is the Froud number, α is the void fraction, and d_{ecc} is the diameter of ECC injection pipe.

Adjustable parameters such as, a~e and K should be set through experimental validation. The sensitivity calculations for the UPTF Test 8b were carried out and finally the interfacial heat transfer correlation of equation (3) was derived;

$$Nu = Re_g^{0.36} Re_f^{0.6} Pr_g^{0.33} Fr^{0.4} \frac{d_{ecc}}{D_h} \quad (3)$$

$$Fr = v_f / \sqrt{g L_t} \quad (4)$$

where v_f is the liquid velocity in the cold leg and L_t is the turbunent length which means the liquid height in the pipe of $D_h(1-\alpha)$.

Figure 2 shows the liquid temperatures in the cell into which ECC water injected. Thin dotted lines represent the experimental temperatures at the different heights in the pipe. In the phases with more 250 kg/s of ECC injection rate the all temperature sensors indicate the wetting of liquid and the plug flow regime was observed. While in the phases with less than 250 kg/s of ECC injection rate the stratified flow regime was observed.

The SPACE code calculation using equation (1) shows the very low temperature behaviors compared to the experimental results. It means the interfacial heat transfer rate from the interface to the liquid phase is very low in all phases. However calculations using equation (3) show good agreement with the experimental data.

Figure 3 shows the void fraction in the ECC injected cell. The void fraction using equation (1) is higher than 0.8. In normal cell this corresponds to the void fraction of annular flow regime. On the other hand, in the calculation using equation (3) the void fraction is decreased to about 0.3 which corresponds to the void fraction of plug flow regime.

Conclusively, the flow pattern and thermohydrualic phenomena in the ECC injected pipe is well predicted by equation (3).

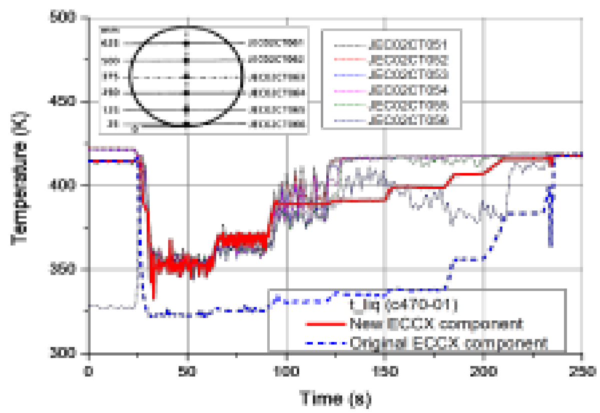

Fig. 2 Liquid Temperatures at ECC injection point

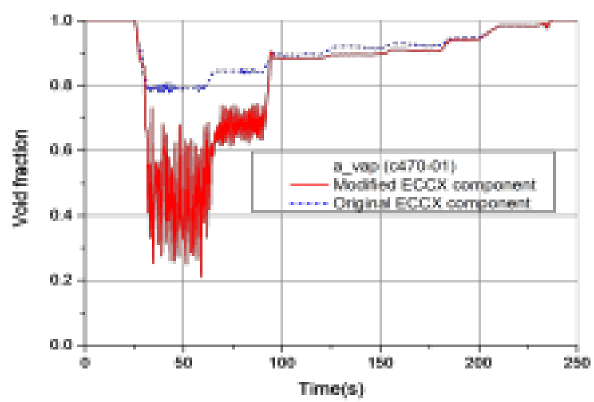

Fig. 3 void fractions at ECC injection point

5. Conclusion

To validate the flow pattern and interfacial heat transfer in the ECC mixing component of SPACE code the UPTF Test 8b was simulated. The calculation using the original interfacial heat transfer correlation shows big difference in the liquid temperature from the experimental data. Finally The new correlation for the interfacial heat transfer correlation was proposed through the simulation and the results are good agreement with the experimental data.

ACKNOWLEDGMENT

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No.20224B10200020).

Reference

[1] S.J. Ha, et al., "Development of the SPACE code for nuclear power plants," Nuclear Engineering and Technology, 43(1), pp. 45-62 (2011)

[2] Siemens AG, Experimental Data Report, UPTF Test No. 8 Cold/Hot leg Flow Pattern Test, U9 316/88/12 (1988)

[3] P. Gaillard, et.al., "The CATHARE code Condensation Modelling Confronted th the TOPFLOW-PTS Steady-state Experiments", NURETH-16 (2015)