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Calculation of Natural Convection in Sloped Channel for Validation Facility of Core Catcher

Byeonghee Lee*, Joon-Young Kang, Seok-Gyu Jeong
Korea Atomic Energy Research Institute, Daedeokdaero 989-111, Yuseong, Daejeon, Korea 34057
*Corresponding author: leebh@kaeri.re.kr

1. Introduction

A core catcher is the facility which cools down the molten corium safely when it is ejected from the reactor vessel during a severe accident. There are various kinds of core catchers depending on the reactor design, however, they have common characteristic that the main cooling mechanism is natural convection because the active component such as pump is not expected to be available during severe accident.

Korean nuclear power plants (NPPs) have used in-vessel retention external reactor vessel cooling (IVR-ERVC) for the molten corium cooling strategy, which does not allow the molten corium escape from the vessel. The IVR-ERVC meets the requirement of European regulation for licensing, however, the European utilities prefer the core catcher than the IVR-ERVC, therefore the core catcher design, PECS, has been developed for the exporting NPP to Europe.

The PECS cools down the molten corium by the natural convection with wide sloped surface whereas the other core catchers generally have a channel design for the cooling. The cooling capability of the sloped surface need to be validated for the expected licensing procedure of the NPPs.

For the design of the validation facility for PECS, the design of variable channel test facility (V-PECS) is modeled using RELAP5 code, and the thermal-hydraulic behaviors are presented.

2. PECS core catcher

Figure 1 shows the schematic of PECS (passive ex-vessel corium retaining and cooling system) [1]. The PECS is composed of the V-shape steel structure body for retaining of molten corium, and the sloped cooling surface below the structure. The PECS body is supported with the studs installed under it, and the coolant can flow between the body and the basement. Multiple downcomers are installed in the concrete structure, which provides the flow path for the natural circulation. On the steel structure, the sacrificial layer is installed to absorb and spread the heat from the corium until the coolant is supplied.

When the molten corium is ejected from the reactor vessel by a severe accident, the corium is initially hit the upper surface of the PECS body, and starts to spread over the upper body and to react with the sacrificial layer. Before the sacrificial layer is penetrated by the reaction, the coolant is supplied from the IRWST (in-containment

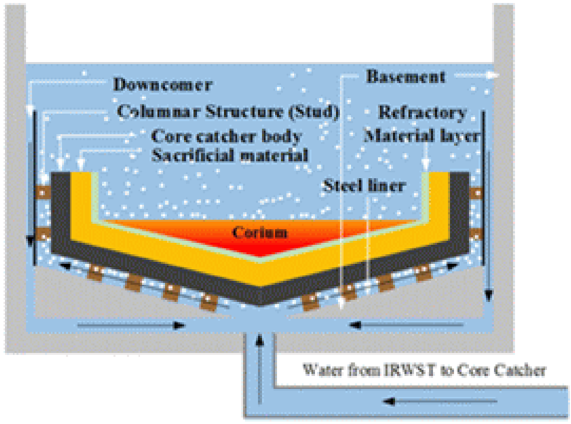

Fig. 1 Schematic of Korean Core Catcher

refueling water storage tank) through the pipe connected to the bottom of the core catcher, the water box. When the water is filled the reactor cavity, the bottom surface of the PECS body transfers the heat to the coolant by the natural convection, and at the same time, the top surface of the corium on the PECS is also transfer the heat to the coolant by pool boiling. At the sloped bottom surface of the PECS body, the coolant flows upward by the natural convection, and then the coolant suppled to the bottom water box via the downcomers, enabling the natural circulation.

2. Validation facility

Figure 2 shows the schematic of V-PECS (Variable PECS) test facility. The V-PECS is the test facility for the validation of the cooling performance of PECS. The V-PECS is currently under the detailed design stage before the installation, and therefore the calculation of expected thermal hydraulic behavior is undergoing.

The V- PECS has the scaled down facility of PECS, with the same length but the different width of the cooling channel compared to the PECS. The PECS has wide cooling surface of 16 m, which is one large surface rather than channels. On the other hand, the V-PECS has about 0.7 m wide channel which can be converted into two 0.3 m channels. The variable channel can examine the effect of the channel width on the cooling performance, and also can examine the flow instability at the multi-channel system. The facility has two downcomers and two raw of heaters for multi-channel cooling test of PECS. Figure 3 shows the inside of V-PECS channel, which shows the variable center walls.

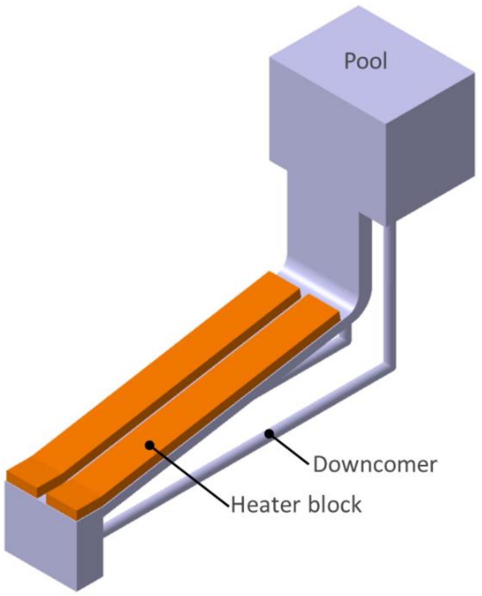

Fig. 2 Schematic of Validation Facility

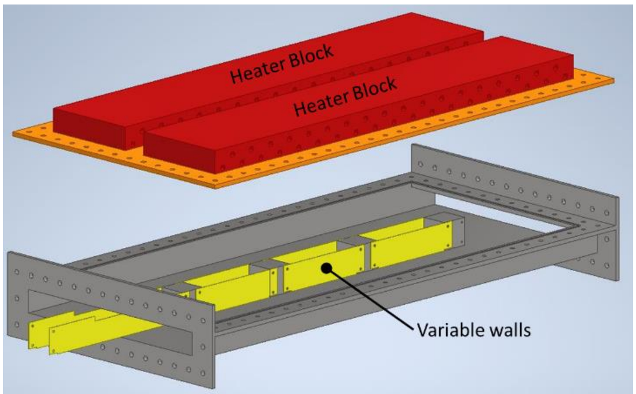

Fig. 3 V-PECS Channel

3. Model and Condition

Figure 4 shows the nodalization of V-PECS for RELAP5 calculation. The model has two channels and two downcomers, and the channels are connected each other using crossflow junctions. The area of the crossflow junctions can be changed, which means the channel can behave either as a single channel or as multi channels. The width and the length of the channel is the same as the designed V-PECS.

Table 1 shows the boundary condition of the calculation. The reference heat flux was calculated from the total decay power of APR1400 divided by the surface area of PECS. The pool level of the calculation was set much lower than that actually expected in PECS condition for conservative analysis. The system is modeled such that the water is supplied to the waterbox when the coolant evaporates by the heat flux, maintaining constant pool level.

Table 1 Boundary condition of calculation

Conditions	Value
Reference heat flux (kW/m^2)	184
Pool level (m)	2.35
Subcooling of supplied water (K)	0
Pressure above pool (bar)	1.0

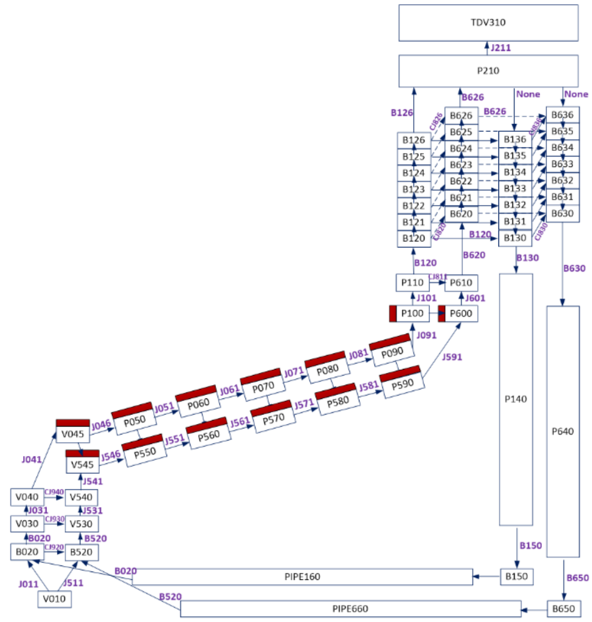

Fig. 4 V-PECS model for RELAP5

4. Calculation Results

Table 2 shows the different cases of the calculations. The variables are the pool water level, heat flux, and the area of the cross flow junction. The heat flux is directly connected to the mass flow of the natural circulation, and the area of the cross flow junction represents whether the two channels are modeled as the independent two channel or a single wide channel. The subcooling of the supplied water does not affect the results, because the amount of the supplied water is too small to change the overall system temperature.

Figure 5 shows the mass flow rate of the referece case, the L1C100P100. After the initial heat-up stage, the mass flow rate seems constant, with occasional fluctuation.

Table 2 Calculation cases

Test #	Condition
L1, L2, L3	Water level 2.35, 3.5, 4.5 (m)
C0, C10, C100	Area of cross flow junction (%)
P30, P50, P70, P100	Heat flux 30~100% of Reference

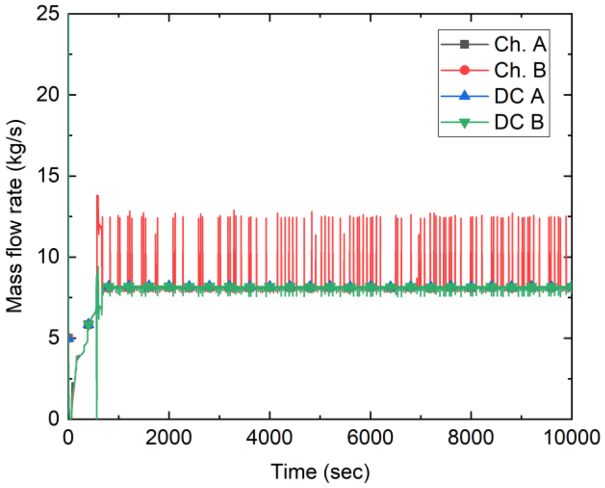

Fig. 5 Mass flow (Ref. case: L1C100P100)

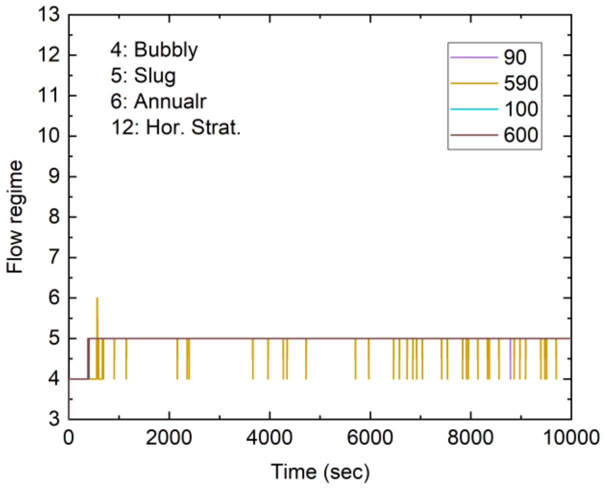

Fig. 6 Flow regime at outlet (Ref. case: L1C100P100)

The flow regime at the outside of the channel fluctuate between bubbly and slug regime as in Fig. 6, which results in the abrupt flow change.

On the other hand, when the area of the cross flow junction is set to 0, which means the two channels behaves as independent channels, the flow fluctuation becomes larger and more frequent as in Fig. 7. The cause of the fluctuation seems still originated from the flow regime change, however, there are possibilities of the other causes such as geysering, pressure difference oscillation (PDO), or density wave oscillation (DWO) [2].

Figure 8 shows the total mass flow of the natural circulation with respect to the relative heat flux. The reference boundary conditions are as in Table 1. The mass flow rate increases as the heat flux increases because the more voids generate higher buoyancy force. The influence of the pool level on the mass flow rate was also examined for the different cases of L1 to L3, however, the influence was very small compared to the heat flux.

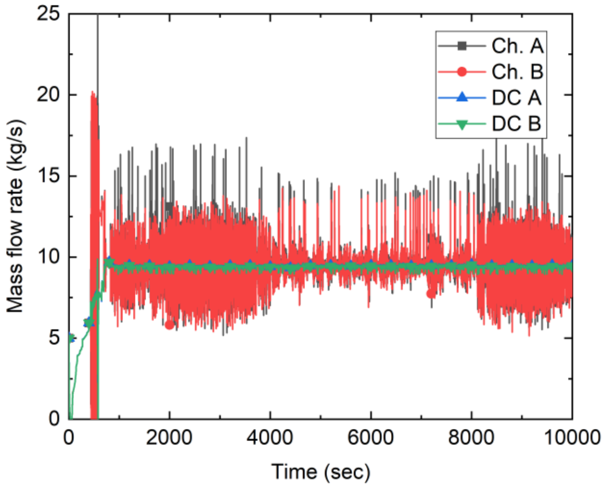

Fig. 7 Mass flow (Case: L1C0P100)

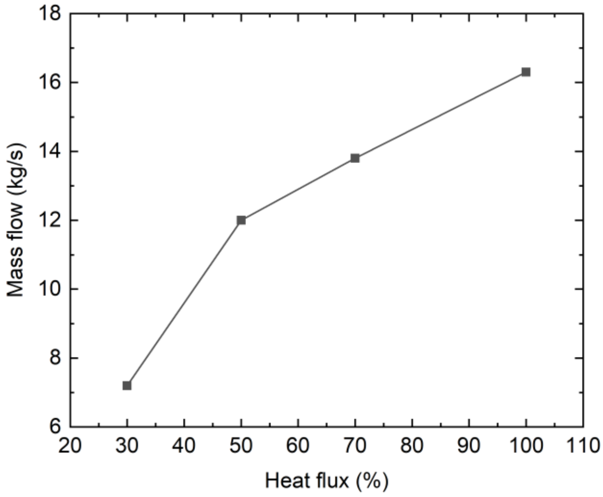

Fig. 8 Mass flow versus heat flux

6. Summary

The V-PECS, the scaled down facility to validate the cooling performance of PECS core catcher was designed and the thermal-hydraulic calculation to estimate the mass flow rate was performed using RELAP5 code.

The V-PECS is composed of variable channel and the two downcomers, to estimate the effect of channel width on the cooling performance and the behaviors of multi-channels. The calculation results show the mass flow rate with respect to the heat flux and the water level. Also the fluctuation of the mass flow was shown due to the flow regime change. The fluctuation was more significant in the multi-channel rather than single large channel. The reason still seems by the flow regime change, however, the other reasons of instabilities are under examination.

The calculation results in this article are expected to be used for the detailed design of the test facility, and also will be used for the validation data after the actual tests.

Acknowledgement

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