A Preliminary Study on ERVC Performance Depending on Insulation Conditions

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1. Introduction

In-Vessel Retention (IVR) researches have been performed for preparation of severe accidents in Nuclear Power Plants (NPPs). External Reactor Vessel Cooling (ERVC) was adopted as an IVR strategy for huge commercial NPPs and System-integrated Modular ReacTor (SMART) in Korea.

In previous studies, several opinions were suggested to strengthen the IVR strategy. For pressurized water reactor, a concept design was proposed to enhance the ERVC natural circulation by installing insulation in reactor cavity [1]. In case of European Union – Advanced Power Reactor (EU-APR), it passed European Utility Requirements certification through a passive ex-vessel cooling system of so called core catcher type [2].

In this study, Computational Fluid Dynamics (CFD) analyses were conducted to evaluate natural circulation depending on insulation conditions. Through this research, the IVR strategy can be strengthened by improving the ERVC cooling performance.

2. Analysis models and method

2.1. Severe accident scenario

When a severe accident occurs and sufficient cooling is not executed successfully, materials in core melt down to lower plenum of the reactor vessel. ERVC is performed by flooding reactor cavity to maintain the integrity of the reactor vessel. Fig. 1 illustrates a concept of IVR-ERVC when the core melt is relocated. In this paper, it is assumed that two-layered molten corium formation consisting of metallic layer and oxide pool occurs at 0 s and simultaneously, the reactor cavity is filled with ERVC water.

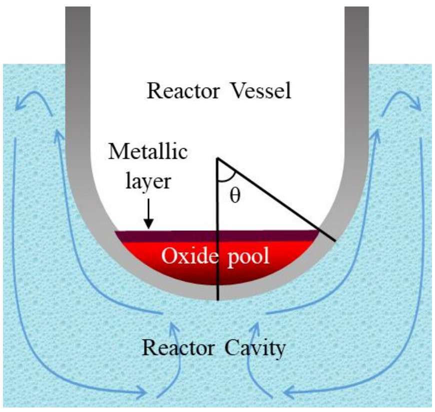


Fig. 1. Schematic of IVR-ERVC natural circulation

2.2. Boundary conditions

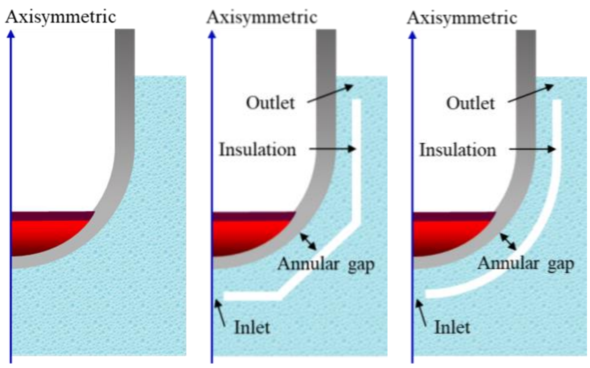
A simple thermal analysis was proceeded by applying boundary conditions used in the IVR situation of a previous study for reactor vessel integrity evaluation [3]. It was considered that the molten corium filled up to 43.3˚ from the bottom center of the reactor vessel [4].

The values obtained from the thermal analysis were applied to the outer wall of the reactor vessel lower head to perform CFD analysis. Temperature of both wall and insulation was maintained at 50 ˚C, same as initial water temperature, for adiabatic effect. Containment pressure was set to 250 kPa, which is equivalent to atmospheric pressure acting on the reactor cavity [5]. Additionally, gravitational acceleration was presupposed to form the natural circulation. Since the purpose of this preliminary study is to compare analysis results under the same conditions, phase change due to water boiling was not considered.

2.3. Analysis conditions

Analysis was conducted for assessment of ERVC cooling capability to maintain the reactor vessel integrity. It was carried out in ANSYS Fluent using a k-ε model. Cases are determined based on the insulation shape and the width of the annular gap between the insulation and the reactor vessel. Fig. 2 shows 2-D axisymmetric models with shape of insulation. And CFD analysis cases are depicted in Table I.

Case 1 was proceeded without insulation and case 2 to case 4 were evaluated with an angular type. Case 5 to case 7 were arranged in a round form. The annular gap was set to have a width corresponding to 50%, 40% and 30% of flow area in the reactor cavity. Both inlet and outlet widths were fixed at the same value as the annular gap of 40%.



(a) None (b) Angular (c) Round

Fig. 2. Insulation types considered in this study

Table I: CFD analysis cases

Case	Insulation type	Annular gap (%)
1	None	-
2	Angular	50
3	Angular	40
4	Angular	30
5	Round	50
6	Round	40
7	Round	30

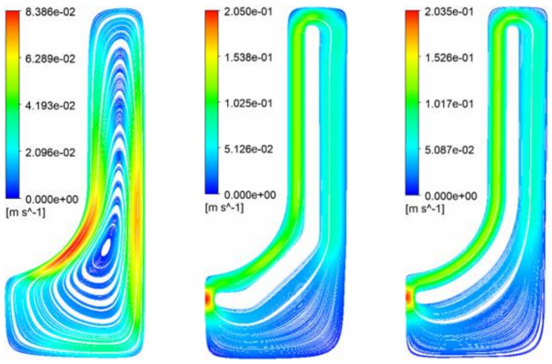
3. Analysis results

CFD analysis was proceeded to evaluate the natural circulation cooling performance of ERVC according to the shape of insulation. Table II shows relative mass flow rates which is divided by the mass flow rate value of case 1 for convenience of comparison. Most of the cases showed better flow rate than case 1, which is without adiabatic, but cases 4 and 5 were not. The smallest case is 4 and the largest case is 6, which are 29% and 235% of the case 1, respectively.

Flow velocity streamlines are depicted in Fig. 3. First, the natural circulation in the absence of adiabatic was evaluated. Next, velocity results of the angular and the round shape are shown. Fig. 4 indicates flow velocity between the reactor vessel outer wall and the insulation at the 43.3˚ from the bottom center of the reactor vessel position. This location is where the focusing effect occurs. When the annular gap is narrow, the angular type exhibits higher maximum flow velocity, while the round type exhibits higher maximum flow velocity when the annular gap is wider.

Table II: Relative mass flow rates based on case 1

Case	Ratio
1	1
2	1.05
3	1.95
4	0.29
5	0.35
6	2.35
7	2.09



(a) Case 1 non-adiabatic (b) Case 3 angular shape (c) Case 6 round shape

Fig. 3. Velocity streamlines of each insulation type

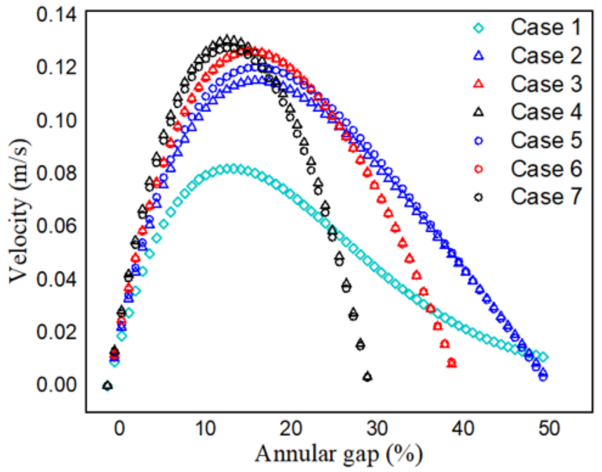


Fig. 4. Flow velocities at the angle of 43.3˚ between reactor vessel outer wall and insulation

4. Conclusions

In this study, a comparison was conducted according to the shape of the insulation and the width of the annular gap in the reactor cavity to enhance the natural circulation in the IVR-ERVC. The conclusions of this research are as follows:

(1) It was confirmed that employing an appropriate adiabatic design led to a significant improvement in the efficiency of system compared to that without insulation.

(2) While there was no significant variance observed in the flow velocity based on insulation shape, variation in the maximum flow velocity was found to be dependent on the shape and gap.

(3) The largest mass flow rate was found at the intermediate annular gap size with no clear trend. Therefore, further sensitivity assessments are needed to determine the optimal size.

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