# Evaluation for External Reactor Vessel Cooling System using CFD Simulation

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## 1. Introduction

To ensure the safety of the nuclear plants, there are lots of safety systems in the nuclear plant. One of them is External Reactor Vessel Cooling system (ERVC) which is operated when a molten corium is relocated in a lower head of a reactor vessel. As ERVC system runs, coolant flows down into a reactor cavity to remove a decay heat from the molten corium. This work simulated the ERVC system which is applied to APR1400 with CFD. To estimate the efficiency of the ERVC system, we designed the reactor cavity of the ERVC system of APR1400 in a full scale. From the designed model, we measured temperature distribution of the reactor vessel outer wall. Two kinds of coolant were used in this computational approach. One is present flooding matter which is water. The other is liquid metal gallium. With varying the area of the inlet and outlet of reactor cavity, we evaluated the importance of each variable.

## 2. Experiments and Results

ERVC system has reactor cavity which is filled with coolant when a severe accident occurs. The ERVC system of APR1400 is applied to this model which has same size and shape. But this simulation only designed coolant inlet, cavity and outlet.

### *2.1 Designed Model*

ERVC system of APR1400 has four major components; coolant inlet, outlet, cavity, and coolant pool. Therefore coolant can circulate through cavity and coolant pool. This simulation designed inlet, cavity, and outlet except coolant pool, to set the variables for factors.

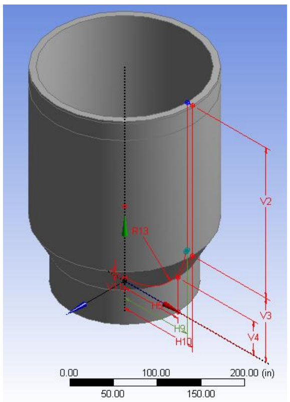


Fig. 1. 3D view for geometry of the ERVC system using CFD.

Table I: Dimensions of geometry (inch)

| | | | |
|---|---|---|---|
| H10 | 109.84 | H5 | 86.34 |
| H9 | 101.34 | R13 | 99.915 |
| V11 | 4.75 | V2 | 210.76 |
| V3 | 90.16 | V4 | 47.79 |

The model is cylindrical shape which has circular inlet in the bottom side of the cylinder and ring-shaped outlet on the wall.

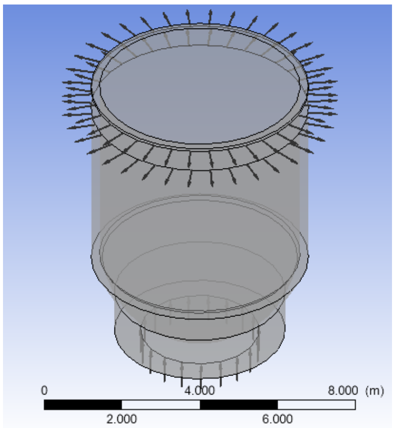


Fig. 2. Coolant flow direction in the system

The coolant flows into bottom and out from top representing natural circulation. The default value for mass flow rate of coolant inlet is 370 kg/s. The pressure of inlet and outlet is atmosphere pressure.

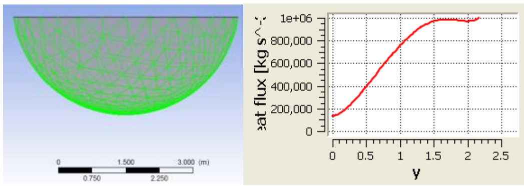


Fig. 3. Heat distribution which represents decay heat from the molten corium.

We only designed reactor cavity so we replaced decay heat from molten corium with distributed heat flux.

*2.2 Coolant variables*

To evaluate the capability of coolant type, we used two different coolants for this simulation. One is single-phase water and the other is gallium. The property of water is that of room temperature and it didn't vary as temperature change. Also the property of the gallium was set from the default value at room temperature. The area of inlet and outlet were 2500 $in^2$, 16218 $in^2$ each.

Table II: Properties of water and gallium

| | Water | Gallium |
|---|---|---|
| Specific heat capacity [J/kgK] | 4181.7 | 381.5 |
| Thermal conductivity [W/mK] | 0.6069 | 29 |
| Density [$kg/m^3$] | 1000 | 5910 |
| Thermal diffusion coefficient [$m^2/s$] | 1.45E-7 | 1.29E-5 |

The thermal diffusion coefficient of the gallium is much larger than the water so it can be expected that gallium can remove the heat more. As expected, maximum temperature for gallium was much less than about 470 K. However we assumed the water as single phase and the temperature of the gallium was too high to evaluate the safety system.

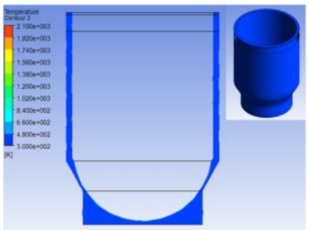

Fig. 4. Temperature distribution of simulated ERVC system for water coolant.

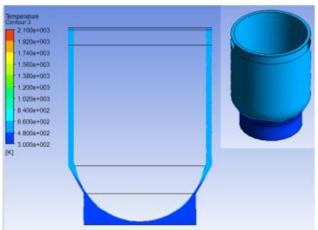

Fig. 5. Temperature distribution of simulated ERVC system for gallium coolant.

*2.3 Inlet variable*

To investigate the impact of inlet area, we simulated 3 different size of inlet area for two coolants. As increasing inlet area about 30% each, maximum temperature decreased for both water and gallium about 8%, 3% each.

Table III: Maximum temperature for different size of inlet.

| Inlet Area [$in^2$] | Water [K] | Gallium [K] |
|---|---|---|
| 2500 | 2066 | 874.4 |
| 3600 | 1900 | 843.7 |
| 4900 | 1311 | 819.9 |

## 3. Conclusions

Maximum temperatures of water cases were higher than expected values for real reactor. Single-phased coolant was one of major reasons because coolant undergoes phase change during the operation in real reactor. Phase change requires much energy so that much of the heat is removed from phase change process. In the case of gallium coolant, the temperatures were much less than that of the water. It is shown that Gallium can remove much heat from the reactor in single phase, because it has higher thermal conductivity.

Inlet and outlet area directly affect to the coolant mass flow rate which is one of major factors for efficient heat removal in ERVC system. However in CFD simulation, effect of inlet area wasn't significant.

Further work with multi-phase computational work using CFD would be needed.

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