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# Heat Transfer Distribution for Reactor Cavity Cooling System Riser Considering Thermal Conduction

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## 1. Introduction

The reactor cavity cooling system (RCCS) is the safety grade system for a very high temperature reactor (VHTR). The main role of the RCCS is the heat removal from the reactor vessel. The verification of the performance of the passive RCCS is a key objective for the construction of demonstration plant. Korea Atomic Energy Research Institute (KAERI) is considering the air-cooled RCCS under natural convection operation for a PMR200.

Bae et al. studied scaling of PMR200 RCCS prior to the experimental verification of the RCCS [1]. The cavity radiation number and temperature ratio number were selected as controlling non-dimensional group. KAERI is operating a natural cooling experimental facility (NACEF), which is a ¼ down scaled RCCS experimental facility, under the scaling analysis. The heat transfer in the riser is one of the key phenomena to predict the performance of the prototype RCCS. The riser absorbs heat from the reactor vessel, through radiative heat transfer, and from the reactor cavity, through convective heat transfer. The absorbed heat is removed by convective heat transfer in the riser.

Cho designed the PMR 200 RCCS [2] and analyzed heat transfer in the RCCS [3]. It has been considered that the effect of thermal conduction through riser duct material, which is carbon steel, is negligible because the thickness of the riser duct is small. It is about 5 mm. If the effect of conduction is underestimated, the surface temperature of a RCCS tube is calculated, inaccurately. Therefore, it is necessary to quantify the heat transfer distribution for the outer and inner surface of the riser duct. The quantified result will help to model the heat removal by convective heat transfer in the riser.

The heat transfer distribution for the riser duct was calculated with CFD considering the thermal conduction in present study.

## 2. Method and Results

FLUENT was utilized to simulate the RCCS riser. The riser duct was just modeled. The modeled thickness of the riser duct was 5 mm. the dimension of the riser was 0.26 × 0.03 (symmetry) × 4 m. RNG k-ε model with standard wall functions was selected. FLUENT recommend that a $y^+$ value close to the lower bound ($y^+ \approx 30$) is desirable for standard wall function.

The $y^+$ value for the distance of the first grid point off the wall was about 29. The heat flux boundary conditions at the outer surface in the riser were set by using UDF. The heat fluxes were coming from a CFX calculation which simulated not only riser but all RCCS components. The CFX calculation did not consider the thickness of RCCS duct. The inlet boundary condition was mass flow rate of 0.0145kg/s and the temperature of 300 K. Fig. 1 shows a schematic of the riser.

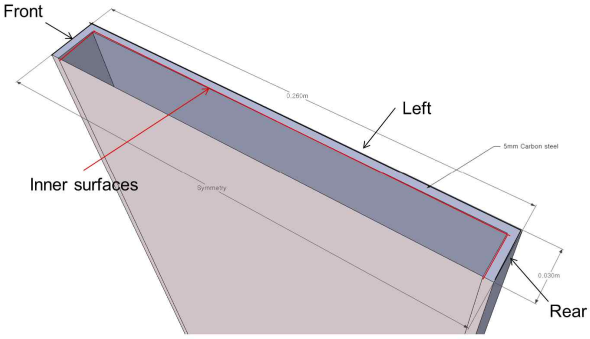
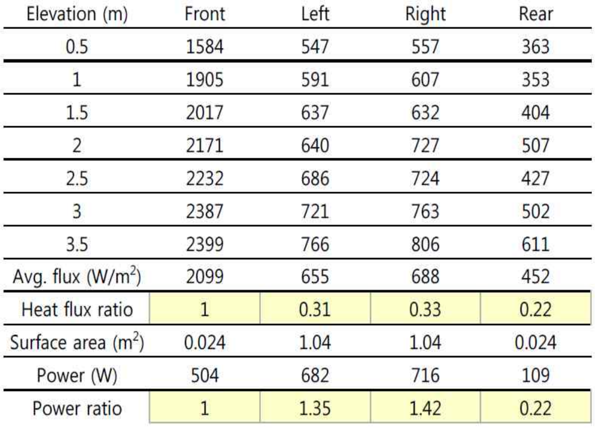


Fig. 1 A schematic of the riser

## 3. Results and discussion

Table I summarizes the heat transfer distribution through the outer surface. As a result of radiative heat transfer from the heater surface, total surface heat flux at the front surface of a RCCS tube is higher than that of other surfaces.

**Table I Heat transfer distribution through the outer surface**



| Elevation (m) | Front | Left | Right | Rear |
|---|---|---|---|---|
| 0.5 | 1584 | 547 | 557 | 363 |
| 1 | 1905 | 591 | 607 | 353 |
| 1.5 | 2017 | 637 | 632 | 404 |
| 2 | 2171 | 640 | 727 | 507 |
| 2.5 | 2232 | 686 | 724 | 427 |
| 3 | 2387 | 721 | 763 | 502 |
| 3.5 | 2399 | 766 | 806 | 611 |
| Avg. flux (W/m$^2$) | 2099 | 655 | 688 | 452 |
| Heat flux ratio | 1 | 0.31 | 0.33 | 0.22 |
| Surface area (m$^2$) | 0.024 | 1.04 | 1.04 | 0.024 |
| Power (W) | 504 | 682 | 716 | 109 |
| Power ratio | 1 | 1.35 | 1.42 | 0.22 |

Table II shows comparisons of the heat flux distribution through the inner and outer surfaces. By the effect of thermal conduction, average heat fluxes through the inner surfaces were almost same. The heat flux through a lateral surface has highest value. By the effect of thermal conduction the average surface temperature at each surface shows a little difference.

Fig. 2 shows velocity magnitudes with the elevations following z-direction. Near the inlet the velocity profile is flat. The velocity profile shows double hump shapes as the air is heated and accelerated.

**Table II Comparisons of the heat flux distribution through the inner and outer surfaces**

| | Inner surface | | | Outer surface | | |
|---|---|---|---|---|---|---|
| Face | Front | Left | Rear | Front | Left | Rear |
| Avg. Heat flux (W/m$^2$) | 798.4 | 848.3 | 666.3 | 2069 | 664 | 464 |
| Heat flux ratio | 1.0 | 1.1 | 0.8 | 1 | 0.3 | 0.2 |
| Surface area (m$^2$) | 0.1 | 1.0 | 0.1 | 0.12 | 1.04 | 0.12 |
| Average power (W) | 79.8 | 848.3 | 66.6 | 248.3 | 691 | 55.7 |
| Power ratio | 1.0 | 10.6 | 0.8 | 1 | 2.8 | 0.2 |
| Average temperature (K) | 415.6 | 400.9 | 395.5 | 415.7 | 401.3 | 395.6 |
| Bulk temperature (K) | 335.4 | | | | | |

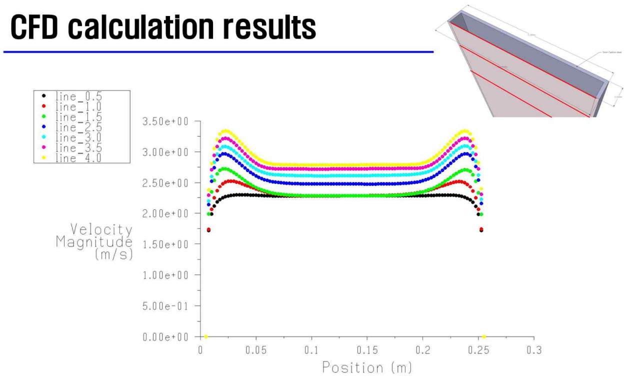


Fig. 2 Velocity magnitudes with the elevations

## 4. Conclusions

CFD results showed that thermal conduction through the RCCS riser was not negligible. Because the material of the riser duct was carbon steel, the thermal conduction effect was comparable even with a small duct thickness to the convective heat transfer by air flow. It is strongly recommended that the heat transfer in RCCS should go with consideration on the thermal conduction of the RCCS riser duct.

## Acknowledgement

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## REFERENCES

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