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Experimental study on the mixed convection phenomena in the air-cooled RCCS riser

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1. Introduction

Reactor Cavity Cooling System (RCCS) is a key safety system that enables its inherent safety in cooperation with its low power density and large thermal margin [1]. Therefore, the performance of RCCS is a principle parameter for the safety of the reactor. It depends on the heat removal rate by the RCCS riser that is a kind of heat exchanger of RCCS.

An air-cooled type RCCS is a candidate system for the RCCS of PMR200 that is a prismatic-type VHTR developed by KAERI [2]. Several researches have been conducted for verifying the performance of the air-cooled type RCCS with the scaled-down experimental conditions and facilities; KAERI has constructed a quarter-scale RCCS experimental facility, NACEF [3] and Argonne National Laboratory constructed a half-scale experimental facility, NSTF [4]. Due to the scaled experimental conditions, however, the heat transfer regime inside the riser is guessed to be changed from the forced convection to the mixed convection, which causes large uncertainties in evaluating the RCCS performance. And the mixed convection and the deterioration of the heat transfer could occur not only in the scaled down facility but also in the prototype RCCS in compliance with the certain thermal fluid condition inside the riser. While existing researches on the mixed convection were carried out for the tube geometry, the RCCS riser has rectangular duct geometry. The geometry might affect the heat transfer. Therefore, it is required to investigate heat transfer phenomena inside the riser.

In this study, the experiments for heat transfer phenomena inside the RCCS riser were conducted and its results were analyzed by comparison to the existing correlations.

2. Riser Heat transfer Experimental Facility

To analyze heat transfer phenomena inside the riser, the separate effect experiment for a riser was conducted. Since the existing RCCS experimental facilities contains several risers and cavity region, it is difficult to control thermal and fluid conditions for one riser and to obtain detail information such as heat flux and velocity profiles inside the riser. Therefore, Riser Heat transfer Experimental Facility (RHEF) was constructed in Seoul National University. Schematic diagram of RHEF is depicted in Fig. 1. The height of the riser in the experimental facility is 4 m and its width and depth is

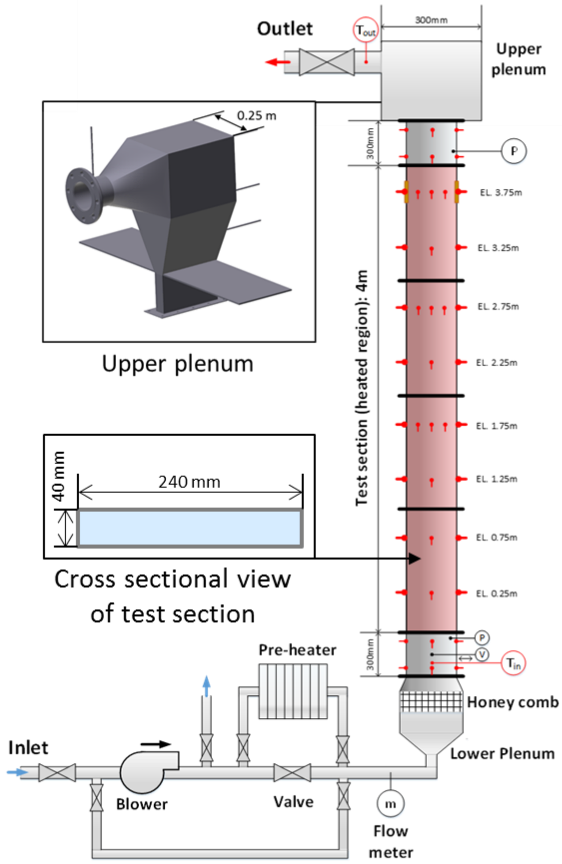

Fig.1. Schematic diagram of the experimental facility

240mm and 40mm, respectively, which are same with those of NACEF. A separate electrical heater was attached on each surface of test section so that the heat flux at each surface could be controlled independently.

A blower at the inlet pipe line inhales the air from the inlet and exhales it to the test section. Before the test section, the multi-hole plate and honeycomb flattens its flow distribution. And then the air is heated up flowing through the test section. Outlet temperature of the air is measured at the exit of the upper plenum. Wall temperature is measured at eight elevations in the test section. Eight temperature measuring points are located at each elevation. By the obtained variables, the heat transfer coefficient could be calculated along the elevation as follows.

$$h(z) = \frac{q''(z)}{T_{wall}(z) - T_{fluid}(z)} \qquad (1)$$

where q'' is the heat flux on the surface and T is temperature. z is the elevation.

3. Experiment result and discussion

With various thermal and fluid conditions, experiments were conducted. Fig. 2 shows the experiment result where Reynold number was 4847 and heat flux was 541.3 W/m^2. As shown in Fig. 2, Average heat transfer coefficient was lowered by 27.8% compared to that of forced convection. Reynolds number of the flow corresponds to forced convection. However, the heat flux on the wall was relatively strong so that the heat transfer regime was converted to the mixed convection.

According to the literature, the heat transfer is hindered due to the buoyancy effect near the heated wall in the mixed convention regime [5]. In this experiment, the information such as the flow structure demonstrating the theory could not be measured though. Further researches on the flow structure in the mixed convection are required.

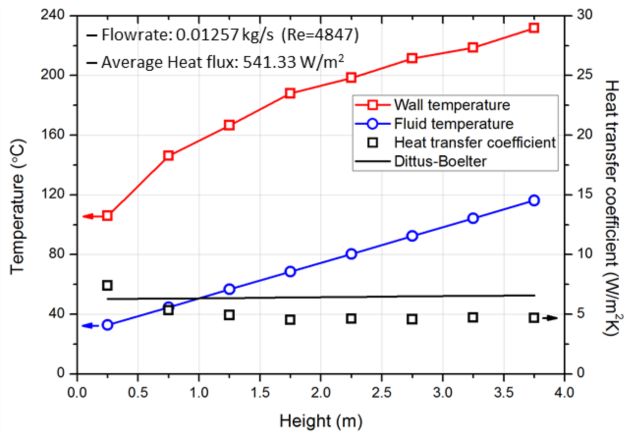

Fig.2. Experiment result for Re4847HF541 case

To search for the heat transfer coefficient correlation accounting for riser heat transfer phenomena, 32 cases of the riser heat transfer experiment were proceeded. The experimental results were compared to existing mixed convection correlations; Jackson's correlations [5] and Symolon's correlation [6]. However, any correlation were not agreed well with the experiment results over the entire region as shown in Fig. 3.

In this study, therefore, a modified Symolon's correlation was suggested. The correlation is as follows.

$$\frac{Nu}{Nu_F}=\left[\left(\left(\frac{6.0\times10^{-6}}{Bo}\right)^{2.0}\Big/\left[1+\left(\frac{6.0\times10^{-6}}{Bo}\right)^{2.0}\right]\right)^{3.564}+\left(30.28Bo^{0.3608}\right)^{3.564}\right]^{0.281} \quad (2)$$

where Bo is buoyancy number that is defined by:

$$Bo=\frac{Gr}{\mathrm{Re}^3\,\mathrm{Pr}^{0.5}}. \quad (3)$$

Fig. 4 shows the experiment results and its comparison to original Symolon's correlation and modified Symolon's correlation. In the low Buoyancy number region below 1000, two correlations rarely shows the difference. Above the buoyancy number, however, modified Symolon's correlation presdicts lower heat transfer coefficients, which matches experimental result well. Based on this fact, it is recommended to adopt the modified Symolon's correlation for the RCCS riser heat transfer.

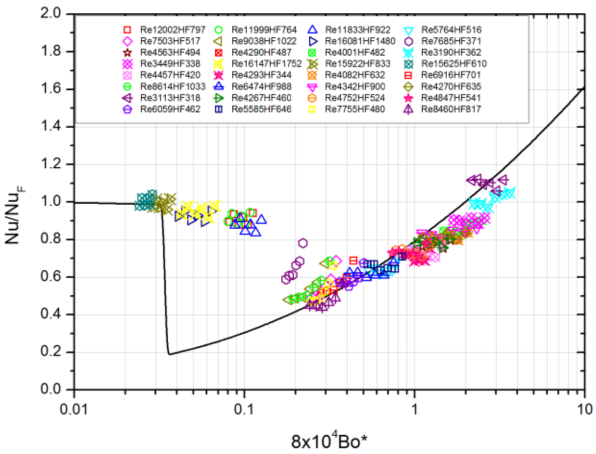

Fig.3. Comparison of experiment results to Jackson's correlation

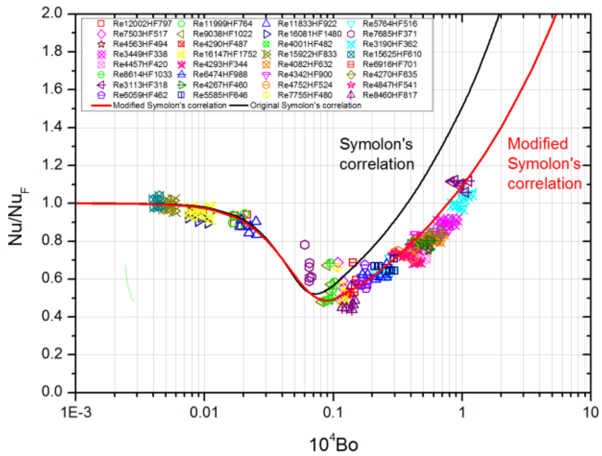

Fig.4. Comparison between experiment results and the correlations

4. Conclusion

Experimental study on the convective phenomena inside the RCCS riser was conducted. An experimental facility for the RCCS riser heat transfer phenomena was constructed in SNU. With the experimental facility, heat transfer experiments were carried out. At the certain experimental condition, it was identified that mixed convection was occurred and heat transfer was deteriorated.

And the existing heat transfer correlations for mixed convection were reviewed and compared to experimental results. A modified correlation was suggested since no existing correlation was appropriate for the riser heat transfer. The modified correlation agreed well with experiment results over the entire Buoyancy number region.

However, further researches on the heat transfer mechanism of the mixed convection are required to analyze the heat transfer phenomena inside the RCCS riser duct.

Acknowledgement

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