The Results of the Second NACEF Test

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1. Introduction

Natural convection tests have been performed at KAERI by using the NACEF (Natural Cooling Experimental Facility) which is a 1/4-scale RCCS (Reactor Cavity Cooling System) test facility to convince inherent passive natural cooling of the reactor cavity in the PMR200, a demonstration plant of the VHTR under development by the institute. The RCCS is the only ex-vessel passive safety system that will ensure the safety of the PMR200, and its performance needs to be verified [1, 2]. For the difficulty of the full-scale test, a 1/4-scale RCCS facility, NACEF, was constructed at KAERI and a few tests have satisfactorily been performed [3, 4]. Here described are the results of the second main test which aimed at the evaluation of heat transfer with the scaled air velocity in the risers and the scaled air temperature increment during passing through the risers.

2. Description of Test Facility

Fig. 1 shows the natural cooling phenomena in the RCCS. The decay heat during an accident transfers from the fuels by conduction to the graphite block and in turn to the reactor vessel by radiation. The reactor vessel needs to be cooled down below the design temperature to prevent its failure by the RCCS through the radiation heat transfer.

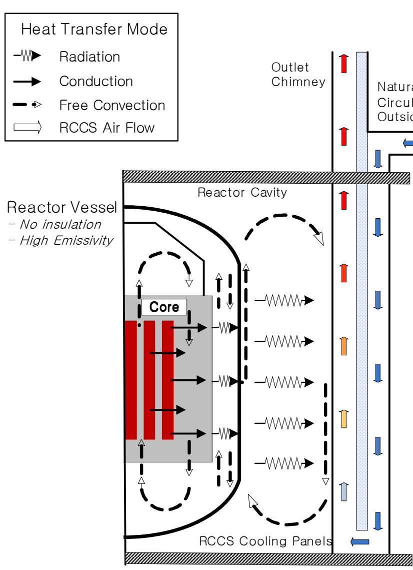

Fig. 1. Natural cooling phenomena in the RCCS

A 1/4-scale mockup of the RCCS (NACEF) was designed and constructed at KAERI, the height of which is 1/4 and the distance from the reactor vessel to the RCCS risers remains the same as the prototype [3, 4]. Figs. 2 & 3 show the 3-D figure of the NACEF and the plan view of its test section, respectively.

Fig. 2. 3-D figure of the NACEF

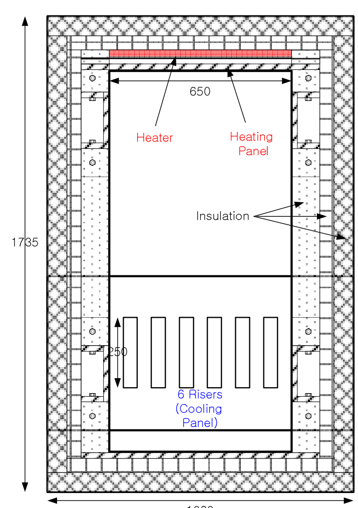

Fig. 3. Plan view of the NACEF test section

The hot panel, the mockup of the reactor vessel, is 4 m high, and two chimneys are 8 m high. The ceramic mold heaters of 52 kW are equipped on the hot plate. Two flow meters of 0 ~ 1500 Nm^3/hr are installed in the downstream of the two chimneys of 0.4 m in diameter. Table 1 shows the instrumentations installed in the NACEF.

Table I: Instrumentations in the NACEF

Sensor	Spec.	Manufac-turer	Model	No.
Flow meter	0 ~ 1500 Nm^3/hr	SAGE	SRP-07	2
Diff. P	0 ~ 625 Pa	Rosemount	3051S	2
TC	0 ~ 1200 °C	OMEGA	0.5 mm K-type	174
Static P.	-1 ~ 1 barg	KELLER	PR-23RY	1
Velocity (Pitot tube)	0 ~ 44 m/s	DWYER	160F	1
Diff. P	0 ~ 25 Pa	DWYER	MS-121	1

3. Results of the Second Test

The second natural cooling test was performed in the NACEF. The purpose of this test is the evaluation of the scaling effect of the PMR200 RCCS. The scaled factors are first the buoyancy driven natural cooling air velocity in the risers and second the air temperature increment during passing the risers. The buoyancy driven air velocity in the riser and the air temperature increment during passing the riser were calculated by using the GAMMA+ code for the prototypic PMR200 [5]. However, these values would be distorted in the NACEF which is 1/4-scale of the PMR200 RCCS due to the difference in the height. The air velocity estimated in the 1/4-scale NACEF from a scaling analysis [3] is a half of the prototype, $l^{\frac{1}{2}} = (1/4)^{\frac{1}{2}} = 1/2$ (the square root of the scale) when the Richardson number remains the same in both scales and the air temperature increment is the same as the prototype. When the ratio of the Richardson number between this mockup and the prototype is unity, the heat flux in the mockup needs to be twice of the prototype, $q'' = l^{-\frac{1}{2}} = (1/4)^{-\frac{1}{2}} = 2$.

Fig. 4 shows the applied electrical power input (P-PS) and the removed power (P-FM) by risers measured by a flow meter. In the early stage, the power input was increased to 25 kW in stepwise manner. At 30,000 s, the power input was decreased to 21 kW and then to 19.6 kW at 42,500 s. The power input was controlled to keep the same air temperature increment in the riser as the prototype. Along with the power input, a damper opening was adjusted to obtain appropriate test conditions, such as the air temperature increase and the scaled air velocity. When the damper opening was adjusted more after 42,500 s with the power input remaining the same, the desired test conditions were obtained as the scaling analysis. The removed power by natural convection was estimated to be 12.3 kW.

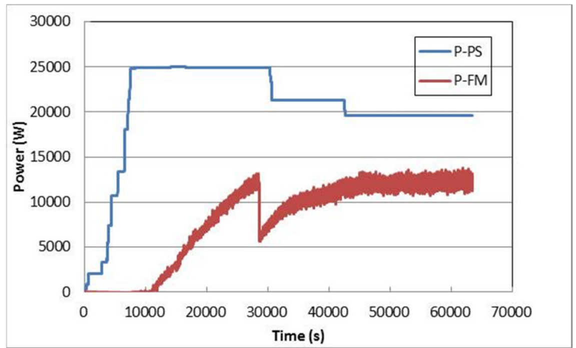

Fig. 4. Applied power (P-PS) and removed power (P-FM)

Fig. 5 shows the temperature distribution in the hot and cold panels and in the riser walls facing the hot and cold panels at 63,400 s. The dip of the hot panel temperature at 2 m elevation is caused by heat loss to the flanges which has no heaters equipped.

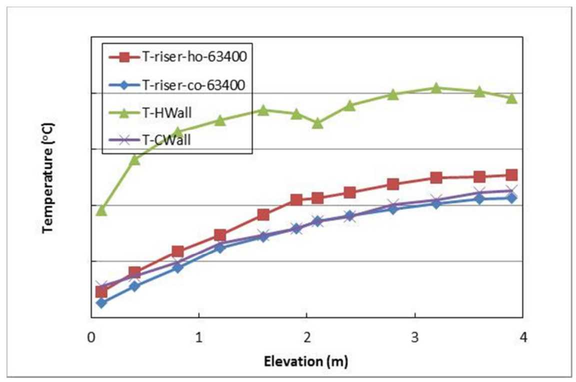

Fig. 5. Temperature distribution in test walls

Fig. 6 shows mass flow rate measured in the north chimney by a flow meter. In the previous test [4], the air flow was found to have entered from the north chimney and escaped to the south chimney along with the air flow induced by natural convection in the test section. Therefore, the south chimney was closed and only the north chimney was opened from the beginning of the test in order to prevent the flow reversal from a chimney. Mass flow rate was measured by natural convection. At 30,000 s, the damper in the north chimney was adjusted to obtain the required air velocity. Then the flow rate was abruptly decreased.

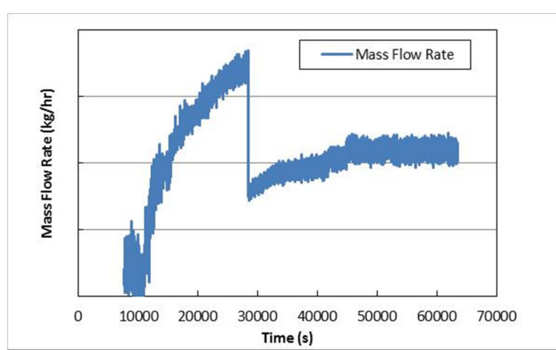

Fig. 6. Mass flow rate in the north chimney

Fig. 7 shows the air velocity induced by natural convection. The velocity measured by a Pitot tube installed in the lower section of a riser (V-PT(100)) is in a good agreement with that calculated from flow rate (V-FM(100)). After 30,000 s, the air velocity evaluated at 100°C was maintained at the required test condition.

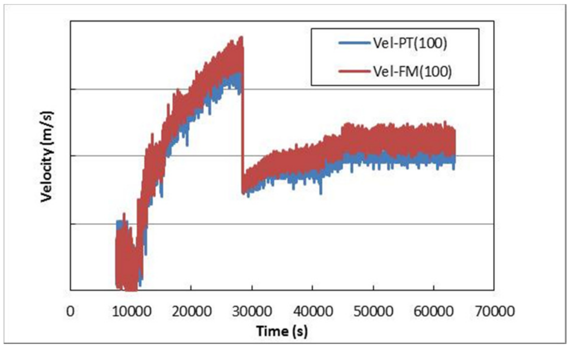

Fig. 7. Air velocity induced by natural convection

Fig. 8 shows the air temperature increment in a riser tube. The air temperature increased with an increase in the input power. After 30,000 s, the time of an abrupt decrease in the damper opening, the temperature increment suddenly increased. After 40,000 s, the temperature increment reached the required test condition with a minor adjustment of the damper.

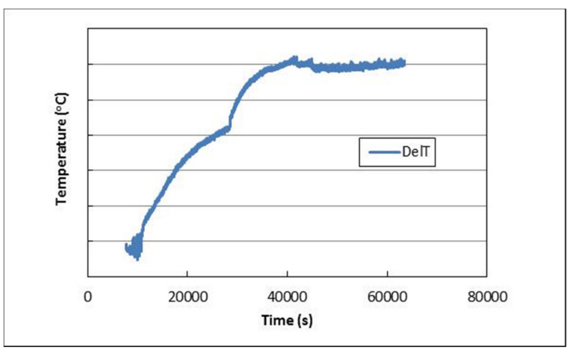

Fig. 8. Air temperature increment in a riser tube

Fig. 9 shows heat transfer coefficients of natural convection in a riser at a quasi-steady state with the scaled air velocity and air temperature increment (t = 63,400 s).

The heat transfer coefficients were estimated based on the area-averaged riser wall temperature since each wall temperature is different from each other.

$$\bar{h} = \frac{\dot{m} c_p \Delta T_z}{\Delta z \sum_{i=1}^{4} P_i \Delta T_{w,i}} \tag{1}$$

where, $\dot{m}$: mass flow rate, c_p : specific heat of air, ΔT_z : air temperature difference between a certain height (Δz), P_i : width of i-th side of a riser, $\Delta T_{w,i}$: temperature difference between i-th wall of a riser and air temperature at the riser center

These heat transfer coefficients (hexp) are compared with two existing correlations. One is the Dittus-Boelter correlation (h-DB) and the other is the Symolon correlation (h-Sym) which is known to be a well-predicting mixed convection correlation [6].

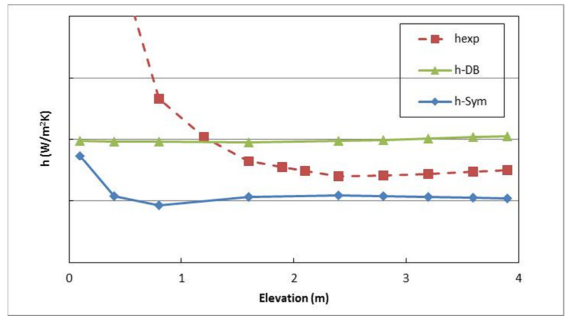

Fig. 9. Heat transfer coefficients along a riser (t = 63,400 s)

In the fairly well developed region (above 2 m), the heat transfer coefficients from the experiment appear a little lower than the Dittus-Boelter correlation, but are higher than the Symolon correlation. This indicates that the heat transfer phenomena are in between the mixed convection and the forced convection. It means that the flow is developing from the mixed convection to the forced convection. In the lower elevation than 2 m, the heat transfer coefficients from the experiment are very much affected by the entrance effect and appear very high.

4. Conclusions

The second main test was performed in the NACEF facility, the 1/4-scale RCCS mockup of PMR200. Natural convection cooling by buoyant force formed in the risers for a scaled condition. The RCCS in the prototypic PMR200 is expected to perform well. The heat transfer regime is in between the mixed convection and the forced convection. More experiments will be performed to confirm natural cooling phenomena by varying test conditions obtained from precedent scaling analyses such as loss coefficient in the system, mass flow rate and/or input power, etc. The experimental data obtained from these tests will be used for the validation of system codes which will be in turn used for the reactor design.

ACKNOWLEDGEMENTS

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