The Test Results of the NACEF RCCS Test Facility

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1. Introduction

The NACEF (Natural Cooling Experimental Facility) is under operation at KAERI as a 1/4-scale RCCS test facility to convince inherent passive natural cooling of the reactor cavity in the PMR200, a demonstration plant of the VHTR under development by KAERI. The Reactor Cavity Cooling System (RCCS) is the only ex-vessel passive safety system that will ensure the safety of the PMR200, and its performance needs to be verified [1-3]. For the difficulty of the full-scale test, a 1/4-scale RCCS facility, NACEF, was constructed at KAERI and shakedown tests were satisfactorily performed [4]. Here described are the results of the first main test which aimed at the evaluation of the effects of the scaled air velocity in the risers and of 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.

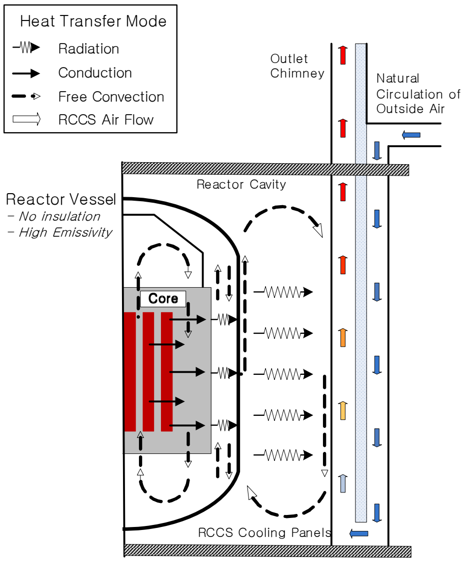

Fig. 1. Natural cooling phenomena in the RCCS

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 [4]. Figs. 2 & 3 show the 3-D illustration of the NACEF and the plan view of its test section, respectively.

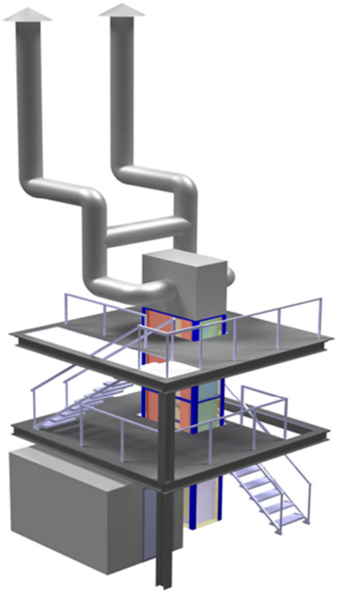

Fig. 2. 3-D illustration of the NACEF

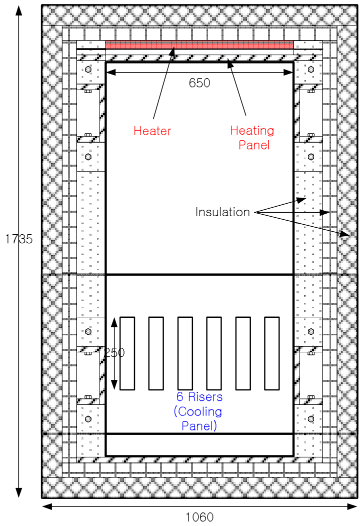

Fig. 3. Plan view of the NACEF test section

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 1500 Nm^3/hr are installed in the downstream of the two chimneys of 0.4 m in diameter. Table 1 shows the instrumentations 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. First Test Results

The first 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 was calculated to be ~ 4 m/s in the prototypic PMR200 and the air temperature increment during passing the riser was 100°C [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 ~ 2 m/s which is $l^{\frac{1}{2}} = (1/4)^{\frac{1}{2}} = 1/2$ of the prototype (the square root of the scale) when the Richardson number remains the same in both scales and the air temperature increment is 100°C same as the prototype. The other conditions in the NACEF test remain the same as the prototype, such as the maximum temperature of the reactor outer vessel wall of 404°C and that of the riser wall of 253°C.

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 27 kW in stepwise manner. At 25,000 s, the power input was decreased to 25 kW to keep the same maximum temperature for the vessel wall and riser wall as the prototype. Afterwards, the power input was controlled to keep the same vessel wall and riser wall temperature as a damper opening was manipulated to obtain appropriate test conditions. About 35,000 s, the damper opening and the power input were controlled to obtain a scaled air velocity of ~ 2 m/s. At 42,200 s, the power input and the damper opening was also controlled to obtain the scaled air temperature increment of 100°C with other conditions remaining the same.

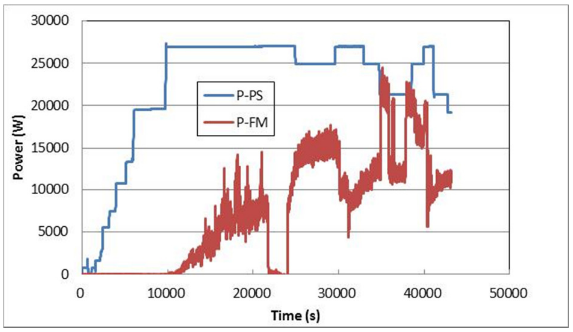

Fig. 4. Applied power (P-PS) and removed power (P-FM)

Fig. 5 shows the temperature distribution in the hot and cold panels and in the riser walls facing the hot and cold panels at 42,500 s. The temperature maintained the required conditions for the test. The sink of the hot panel temperature at 2 m elevation is caused by heat loss to the flanges which has no heaters equipped.

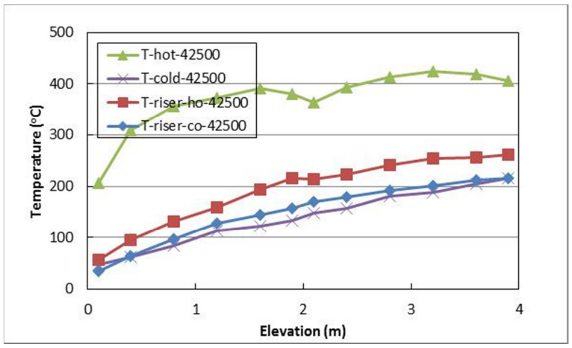

Fig. 5. Temperature distribution in several walls

Fig. 6 shows nominal volume flow rate measured in the both chimneys by flow meter. In early stage, both chimneys were open and the air flow came in from the north chimney and went out to the south chimney along with the air flow induced by natural convection in the test section. Therefore, the south chimney was closed at 24,000 s and the air flow induced by pure natural convection was measured in the north chimney. Then the flow rate was varied by opening and closing actions of the damper to achieve proper test conditions.

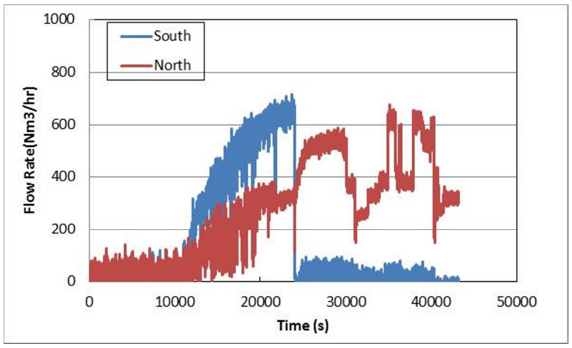

Fig. 6. Nominal volume flow rate in both chimneys

Fig. 7 shows mass flow rate in the north chimney calculated from the volume flow rate. This mass flow rate was used for the evaluation of heat removal rate and air velocity, etc.

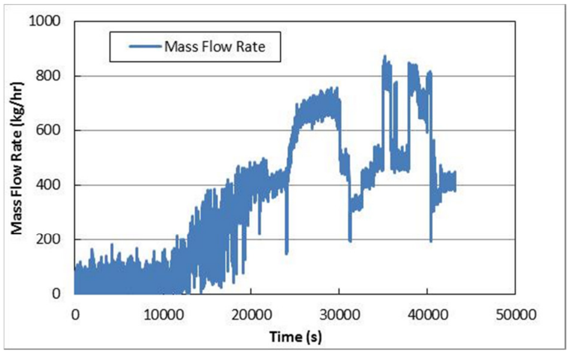

Fig. 7. Mass flow rate in the north chimney

Fig. 8 shows air velocity induced by natural convection. The velocity measured by a Pitot tube installed in the lower section of a riser (V-PT) is in a good agreement with that calculated from flow rate (V-FM). During 36,000 ~ 37,700 s, the air velocity was maintained the required test condition of ~ 2 m/s.

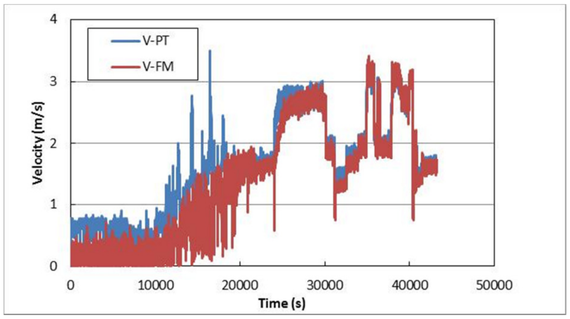

Fig. 8. Air velocity induced by natural convection

Fig. 9 shows the average air temperature at a riser inlet (TL-3) and outlet (TU-6). Although the air temperature was varied with controlling of a damper, at 42,500 s, the temperature increment during passing the riser reached the required test condition of 100°C.

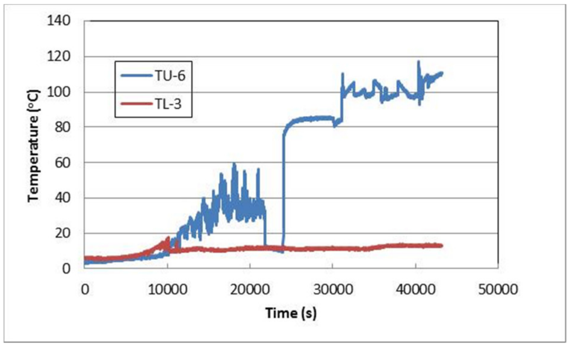

Fig. 9. Air temperature at riser inlet and outlet

Fig. 10 & 11 show heat transfer coefficients of natural convection in a riser at air velocity of ~ 2 m/s (t = 37, 600 s) and air temperature increment of 100°C (t = 42,500 s), respectively. 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].

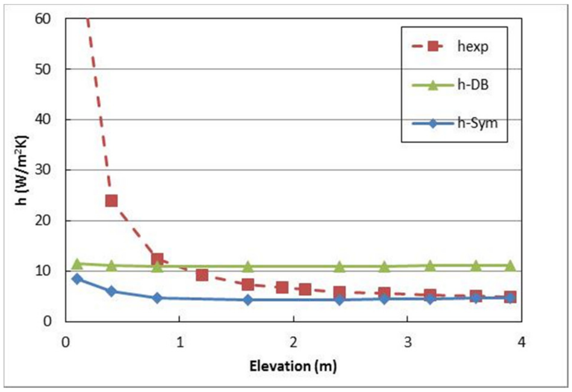

Fig. 10. Heat transfer coefficient (t = 37,600 s)

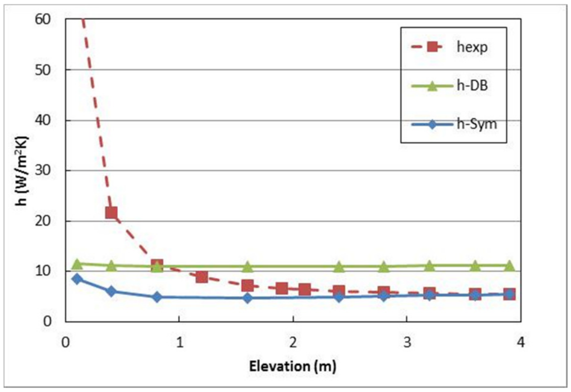

Fig. 11. Heat transfer coefficient (t = 42,500 s)

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 do a good agreement with the Symolon correlation. This indicates that the heat transfer phenomena are more likely mixed convection rather than 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 first 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. The RCCS in the prototypic PMR200 is expected to perform well. The heat transfer mode seems to be more likely to be mixed convection than 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 and/or input power, etc. The experimental data obtained from these tests will be used for system code validation and in turn reactor design.

ACKNOWLEDGEMENTS

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