Localization of the Hot Spot in the Gap of Pebble Bed of Very High Temperature Gas Cooled Reactor(VHTGR)

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1. Introduction

Pebble Bed Reactor(PBR) has been investigated intensively due to its benefits in management, but its complicated flow geometry requests reliable analytical methods. Hassan[1] and Lee et al.[2] have been made three dimensional computational methods. Hassan[3] also measured local velocity fields with Particle Tracking Velocimetry(PTV), in small sized packed bed using liquid coolant, and Lee et al.[4] measured flow field in the 2-dimensional wind tunnel with a hot wire system. In the present study, we develop the scaled up wind tunnel of pebble bed to use air as coolant in the same Reynolds number condition, as 21614, of the PBMR-250MWth. In order to measure the local surface temperature, the heating system and temperature measurement system were installed and heat transfer analogy was performed. The local surface temperature data shows that the predicted hot spots by Lee et al.[3,6] at the top and bottom of the pebble by the velocity field measurement are reasonable, but the heat conduction is prior than contact effect at contact points.

2. Scaling method.

In this study we adopted the scaled up pebbles from 60mm diameter to 120mm in the gas medium. Physical properties of PBMR are on the Table 1.

Table 1: Specification of PBMR-250MWth

Core Height / Diameter	9.0 / 3.7	m
Helium Inlet / Outlet temperature	500 / 900	^oC
Total Inlet Mass Flow Rate	120	Kg/s
Primary System Pressure	8.5	MPa
Helium Gas Density	5.36	Kg/m^3
Helium Gas Viscosity	3.69×10^{-5}	$N\cdot s/m^2$

For the heat transfer analogy, Nusselt number of Blas Melissari et al.[5] was used as below and parameters for determining heater power are on the Table 2.

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$$Nu = 2 + 0.47 Re^{1/2} Pr^{0.36}$$
$$(3\times10^{-3} \le Pr \le 10^1 ;\ 10^2 \le Re \le 5\times10^4) \quad (1)$$

Table 2: Heat transfer analogy condition

PBMR-250MWth : Helium 500°C / 8.5MPa			Experiment : Air 25°C / 0.1MPa		
ΔT_{He}	L_{He}	k_{He}	ΔT_{Air}	L_{Air}	k_{Air}
12 °C	0.06 m	0.3 W/m·K	12 °C	0.12 m	0.026 W/m·K

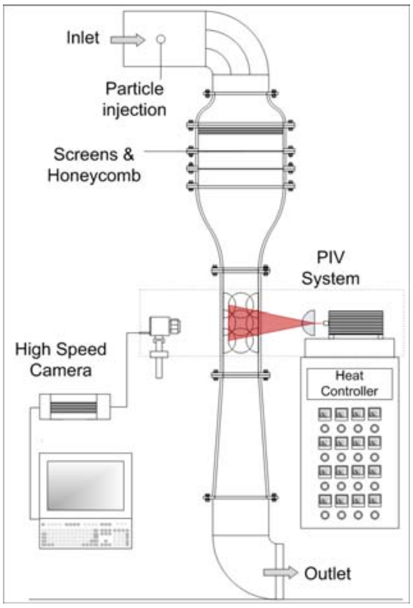

Fig. 1. Experiment system schematic diagram

Heat flux for experiment was calculated as below,

$$q''_{Air} \approx \frac{q''_{He}}{\Delta T_{He}} \frac{L_{He}}{k_{He}} \times \frac{k_{Air}}{L_{Air}} \times \Delta T_{Air} \quad (2)$$
$$\approx 2522.87 (W/m^2)$$

A pebble has 4.52×10^{-2}(m^2) surface area. The heater power for each pebble was obtained by multiplying by the surface area.

$$q_{Heater} \approx 2522.87 \times 4.52\times10^{-2} = 114.03\ (W) \quad (3)$$

3. Experiment Equipment

The wind tunnel system was built as shown in Fig. 1. The maximum nonuniformity was measured as 2.49%. Brass pebbles are installed as Fig. 2. Thermal conductivity of graphite used in PBMR(NBG-10) is about 140($W\cdot m^{-1}\cdot K^{-1}$) and brass(6:4) is 123($W\cdot m^{-1}\cdot K^{-1}$).

Fig. 2. Brass test section for temperature measurement

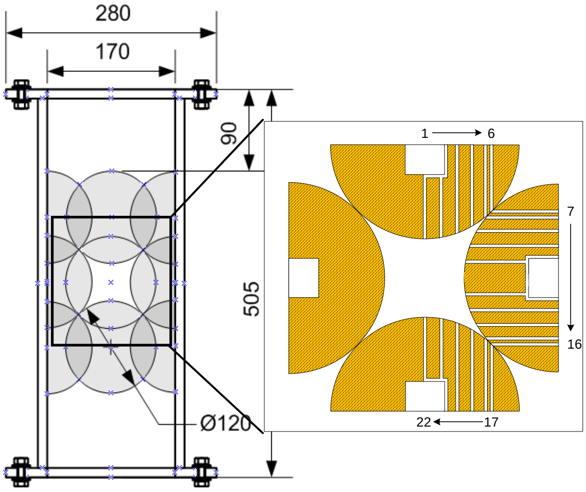

Fig. 3. Surface temperature measurement points

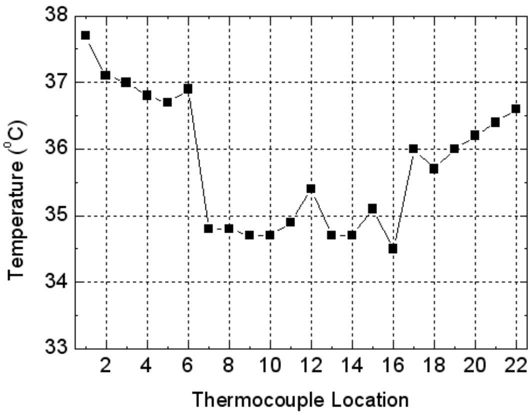

Fig. 4. Surface temperature

4. Results and Analysis

Fig. 3 shows thermocouple locations on the pebble surface. The system was heated for 5 hours to make all pebbles reach steady state temperature. After heating up, it was cooled with 20°C air for 3 hours. The temperature distribution results are shown in Fig. 4. The top pebble showed the highest temperature, and the side pebble had the lowest temperature. The maximum temperature difference was 4°C and this is smaller than predicted values of other researchers. This can be due to the thermal conduction in pebbles. In those simulations, thermal conduction of graphite layer was not considered. Actually, thermal conductivity is temperature dependent. In the case of H-451, the mean thermal conductivity was 145.2(W·m-1·K-1) at 293K, decreases to 80.9(W·m-1·K-1) at 1625K. Thus, it is required to measure temperature differences according to thermal conductivity. However, the experiment result still shows that, especially near the contact point, the conduction effect is very important.

5. Conclusions

In the present study, the local surface temperature was measured. It was found that near the pebble surface, there are stagnation regions at top and bottom of the pebble. Also, we found that the maximum local temperature difference was measured as 4°C with brass test section with 123$W \cdot m^{-1} \cdot K^{-1}$ thermal conductivity. Temperature at the bottom of the pebble was higher than near the contact point. It can be due to the heat conduction in the pebble. Many CFD simulation results are not including the solid mesh part and the heat conduction in the pebble. For this reason, the temperature differences of the simulations seem to be larger than the measured result of this study. In conclusion, for accurate prediction, solid domains must be considered.

Future works will be continued to obtain the other stack structures thermal hydraulic data including the random stack structure. Also, experiments for diverse thermal conductivities will be performed and the results will be compared with the CFD simulation.

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