Velocity Field Measurement of Pebble Bed for HTGR Using PIV

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1. Introduction

Pebble Bed Reactor(PBR) Very High Temperature Reactor(VHTR) has hundreds of thousand pebbles which induce the narrow and complicated flow channel. Due to its complicated geometry of flow channel, numerical analysis has been intensively made rather than the experimental observation. Hassan[1] measured local velocity field with Particle Tracking Velocimetry(PTV), in small sized packed bed using refractive index matching liquid and Lee et al.[2] measured flow field in the 2-dimensional wind tunnel by Hot-wire system. In the present study, we develop the scaled up wind tunnel of pebble bed to visualize its flow field in the air media. As an instrument, we develop the Particle Image Velocimetry(PIV) and the data were compared with the CFD result.

2. Scaling method.

In this study we adopted the scaled up pebbles from 60mm diameter to 120mm in the gas medium. The key scaling parameter is determined as the Reynolds number and the physical properties on the Table 1.

Table 1: Specification of PBMR-250MWth

Core Height / Diameter	9.0 / 3.7	m
Helium Inlet / Outlet temperature	500 / 900	^{o}C
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}	$N{\cdot}s/m^2$

The velocity of the air can be determined as:

$$Re = \frac{5.36\times 2.48\times D_{h(He)}}{3.69\times10^{-5}} = \frac{1.20\times V_{Air}\times D_{h(Air)}}{1.80\times10^{-5}} \quad (1)$$

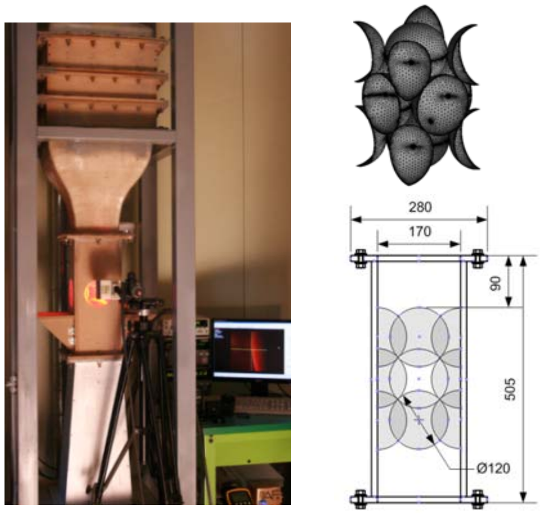
Helium gas inlet speed is calculated as 2.48m/s. By applying the result to Equation 1, we can obtain the air inlet speed as 2.7m/s for a double sized system. The result of dimensional analysis is shown in Table 2.

Table 2: Result of dimensional analysis for air

Pressure	0.1	MPa
Temperature	25	^{o}C
Density	1.20	Kg/m^3
Viscosity	1.80×10^{-5}	$N{\cdot}s/m^2$
Inlet Velocity	2.7	m/s

3. Experimental test rig

The wind tunnel and PIV system were built as shown in Figure 1(a). The maximum nonuniformity was measured of 2.49%. The PIV system test data was taken from Okamoto et al.[3] and the error was less than 5%.



(a) (b)

Fig. 1. Experiment system. Wind tunnel and PIV system(a), Test section geometry (b)

The test section consists of 170×170× 505(mm) duct and FCC stacks as shown in Figure 1(b). As listed in Table 3, we employed high speed camera with 4000fps to measure the mean velocity of 1.3m/s which is 50% of the desired velocity.

Table 3: Velocity measurement condition

Inlet Velocity	1.3	m/s
Shutter Speed	1/8000	s
Frame per second	4000	fps
Image Resolution	256×512	pixel×pixel

4. Results and Analysis

Due to the fluctuation of the flow field and the nonuniform distribution of the pebbles, we produce velocity field by average 40 pictures. Figure 2 represent to the average velocity field. Figure 3 shows the velocity graph at 1.5mm away from the pebble surface. The velocity increases from 1, then decreases at 5 rapidly and increases from 6 to 13. The 1.0m/s velocity point on 1 is the error caused by the boundary limitation of PIV system and it was eliminated in Figure 2. The velocity rapidly decreases at 14 and reaches very low level at 15. After this point, flow is getting faster and loses the speed at the point 19. The velocity difference between point 5 and 15 is caused by the contact point.

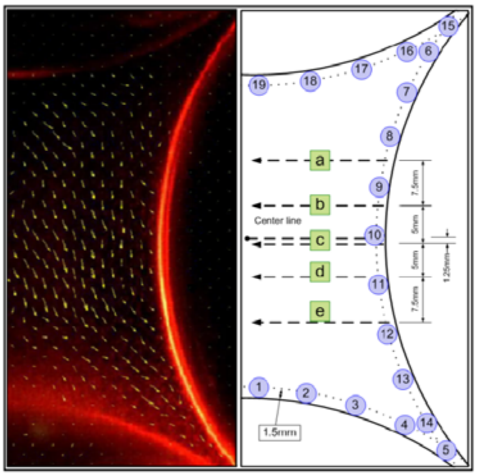


Fig. 2. Average velocity field

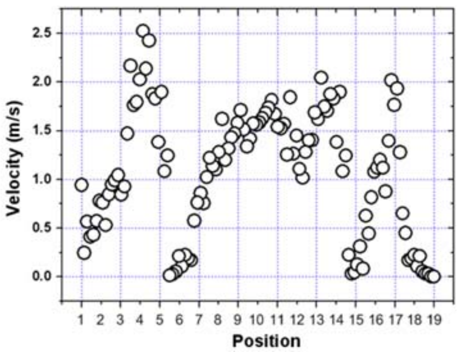


Fig. 3. Velocity graph 1.5mm away from the pebble surface.

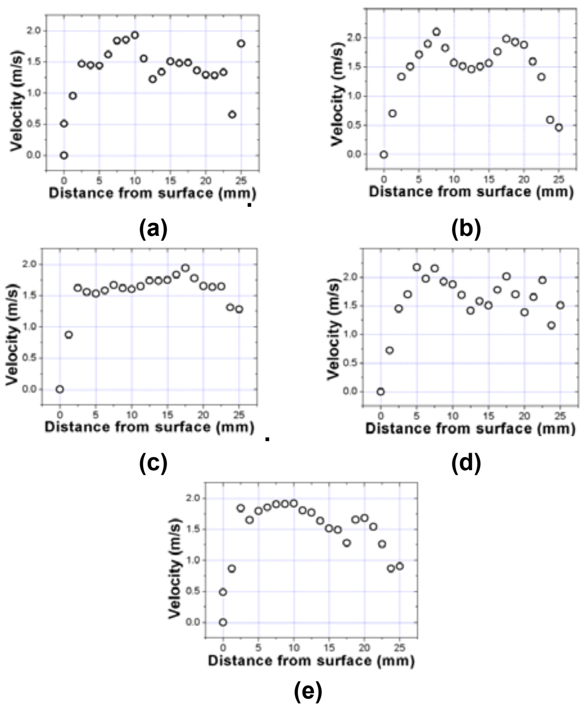


Fig. 4. Velocity distribution from the pebble surface center along the line a, b, c, d and e of Figure 2.

Before the contact point, the vortex is not found, but after the point, three dimensional vortex makes the stagnation region. This low speed region is also found in the simulation result of Lee[2]. In this observation we can easily identify the suspected points as the stagnation points. Also, we can see the effect of the contacting point of the pebbles and the effect of the back flow between the points of 18 and 19. As considering that the cooling efficiency is proportional to the flow velocity, pebble surface temperature will be highest at the contact point and average temperature will be high at 15~19 region.

For five lines in Figure 2, the velocity distributions are plotted in Figure 4 according to the lines. The velocity increases from surface to the 5~10mm region and decreases after 15~20mm region. Except c, based on 12mm from the surface, the velocity near pebble surface is faster than near center and this is caused by FCC geometry. Flow comes from upper corners and flows out to lower corners. It makes the center velocity slow.

5. Conclusions

In the present study, it was found that there are stagnation regions at top and bottom of the pebble, and the average velocity at bottom surface is shown to be the lowest. Also, we found that the contact point makes the back flow and slow region. The present data will be useful for the evaluation of the conventional CFD code in the adiabatic condition to know the best grid structure and turbulent model.

Future works will be continued to attain the complete thermal hydraulics data including the flow velocity, pressure, and temperature.

ACKNOWLDGEMENTS

The present work is supported by program of the Basic Atomic Energy Research Institute (BAERI) of the Ministry of Education and Science and Technology (MEST) of Korea.

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