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Effect of heat source shape on the thermal field in the pebble bed core of High Temperature Gas-cooled Reactor (HTGR)

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1. Introduction

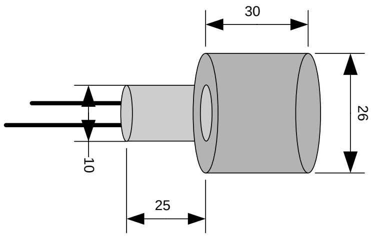
The HTGR design concept exhibits excellent safety features due to the low power density and the large amount of graphite present in the core which gives a large thermal inertia in an accident such as loss of coolant. However, the possible appearance of hot spots in the pebble bed cores of HTGR may affect the integrity of the pebbles, which has drawn the attention of many scientists to investigate the thermal field and to predict the maximum temperature locations in the pebbles using CFD method [1,2], Lee et.al [3] has also done some experimental work on measuring the surface temperature of the pebbles as well as visualizing flow patterns of the coolant gas, and it was found that the temperature near the contacting points between pebbles was not higher than the flow stagnation points due to the higher thermal conductivity of the pebble. Certain error of temperature measurement might occur because of not very uniform heat flux in the pebbles since heater in cylindrical shape was utilized as heat source in previous experiment. In this study, in order to minimize the error brought by non-uniform heat flux, the spherical heaters are employed as heat source; subsequently, thermal field and heat transfer characteristics of the pebbles are investigated.

2. Experiments

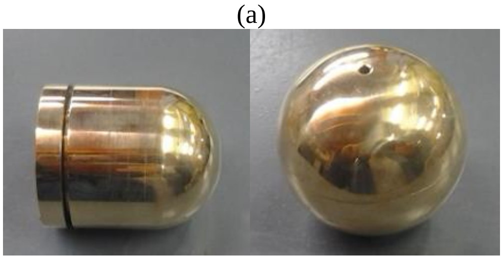
In the present study, the scaled up wind tunnel, through which air as coolant flows, under the same Reynolds number condition as of the PBMR-250MWth was developed. The pebbles stacked in FCC structured are made of brass (60% Cu, 40% Zn) with the diameter of 12cm, and the air of 25^{o}C is used as coolant. According to the calculation [3], heat flux of 2522.87W/m^{2} should be transferred outward from the pebble's surface, which means heat power of 114.03W, 57W and 28.5W is supposed to be generated by the heaters respectively held by the full spheres, half spheres and 1/4 spheres. Fig.1 shows geometry of a cylindrical heater and the spherical heaters fabricated by ourselves.

Since it is inevitable to block the heat convection to a certain degree by attaching thermocouples to the outside surface to measure the temperature, the method of measuring it from inside is carried out and that would allow to get more appropriate results, therefore holes as shown in Fig.2 are drilled. Due to the symmetric structure of the array of pebbles in the PBR core, temperature measuring points are designed to contain respective 6 points both in the upper sphere and in the lower sphere, and 11 points in the side sphere.

Fig.3 shows the vertical cross-section of 4 pebbles contacting each other and it displays clearly the locations of all the measurement points. Moreover, the schematic of wind channel and the structured test section are respectively designed and presented according to Fig.4.



(a)



(b)

Fig.1. (a) Geometry of cylindrical heater (unit mm)
(b) heaters used in the present experiments

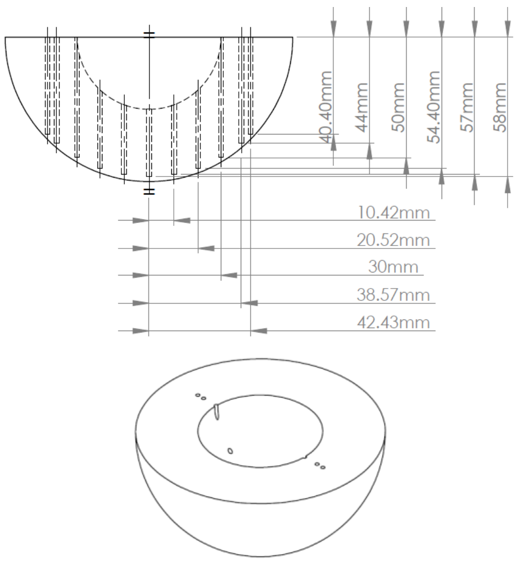


Fig.2. Schematic of the fabrication of temperature measuring point

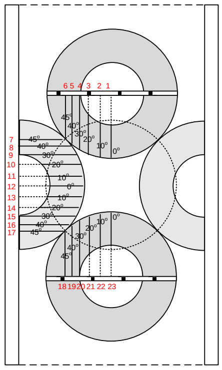


Fig.3. Schematic of locations of temperature measuring point

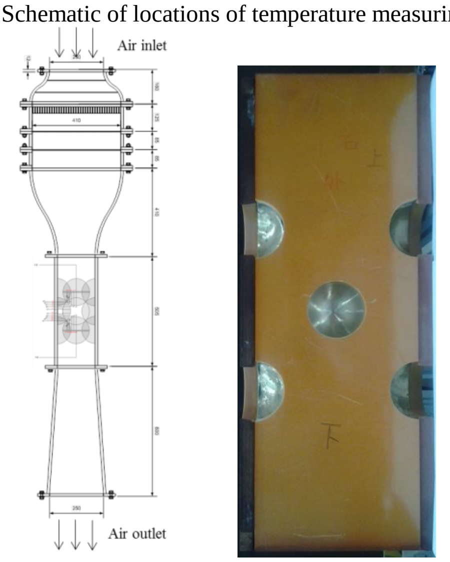


Fig.4. Schematic of wind channel (left) and test section (right)

3. Results and discussion

The thermal field measured in this study according to 23 surface spots shown in Fig.3 is presented by solid circles in Fig.5, and the open circles are previous experiment result.

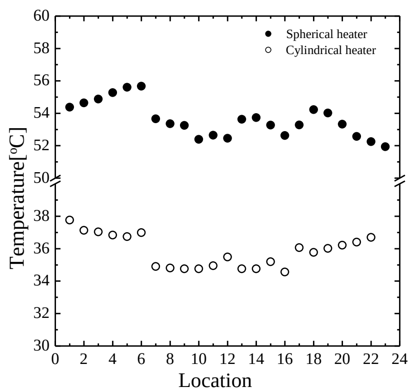


Fig.5. Comparison of the thermal field in terms of using different shapes of heater

The following features can be found from Fig.5: 1) the maximum temperature difference among these measuring points is 3.7^{o}C; 2) from the contact point (point 6 & 18) to the top point (point 1 & 23) of the sphere, temperature continues to decrease for both upper and lower spheres; 3) surface thermal field of the side sphere is relatively complicated, it has 3 turning points (point 12 & 14 & 16). The temperature decreases from the contact point (point 7) to the top point (point 12), and then it does not simply increase until another contact point 17 but decreases again from point 14 to point 16. In addition, the phenomena found in side pebble still cannot be well explained so far, more experimental works should be conducted to find out what the reason is, however, it surely can be confirmed that the result is reasonable and reliable through analyzing the velocity field measured by previous experiment [4].

The spherical heater generates more uniform heat flux than cylindrical one does, as a result, the thermal field of pebble surface shows different characteristic between the previous and the present experiment results: 1) mean equilibrium temperature obtained this time is about 15^{o}C higher because the coolant is 5^{o}C higher than last time, which was 20^{o}C. 2) more importantly, different from temperature increasing from top points to contact points in present study, the previous result shows opposite property because top points are nearer to the cylindrical heater than contact points are.

4. Conclusions

The thermal field of the pebble surface in PBR is measured with heat source in different shapes. More uniform heat flux and more complicated thermal profile are found in the result obtained using spherical heaters. The result shows that the temperature in contact point is higher than that in the top point, which is different from the previous results. The complex thermal phenomena observed in the lower-half side-sphere can be explained by the flow pattern near the surface. However, 3.7^{o}C, the maximum local temperature difference measured in the present experiment is almost same as previous time.

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