# Heat transfer characteristics in a pebble bed reactor core

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## 1. Introduction

In the process of investigating the local hot spots that might appear in individual pebbles of a pebble bed reactor, especially when serious accident such as loss of coolant suddenly happens, it was found that there was a solid difference between experiment and simulation results in terms of pebbles' surface thermal field [1]. Measurement error, unreliable experiment tool, and wrong experiment method, all are possible reasons. Attention was mostly paid to improve the reliability of thermocouples and geometry generation in a simulation model in this study. Heat flux sensor instead of one single thermocouple is used to measure temperatures and heat flux flowing out of each selected position, the results are compared with simulation results obtained from a modified model and good agreement is observed. Heat transfer among the pebbles shows certain pattern. It is believed that this study helps to understand thermal-hydraulic phenomena inside a reactor core and instructs a safer pebble bed reactor design as well.

## 2. Experiment

Experiment facilities and methods were presented in our previous study [2]. Heat powers generated by heat sources are supposed to be 114W, 57W and 28.5W respectively with spherical, cylindrical heaters. Air at 25$^{o}$C with inlet velocity of 2.8m/s is used to be coolant fluid. Yet, there are modified points including heat flux sensor (HFS) and measurement positions, which are shown in Fig. 1.

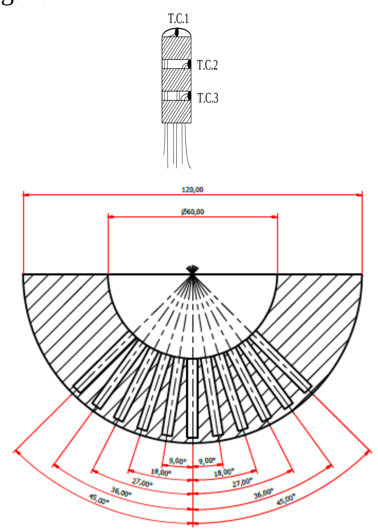



Fig.1 Schematics of a heat flux sensor (up) and channels to hold heat flux sensors (bottom).

The heat flux sensor with a total length of 15mm is of a cylindrical shape (O.D. 3mm) with a spherical head, and distance between two inner thermocouples is 5mm. In an experiment, they are put in the channels which are 9$^{o}$ apart from each other as shown in Fig.1.

## 3. Results

### *3.1 Pebble surface temperature comparison*

The temperatures measured by HFS are shown in Fig.2. The upper pebble has the highest temperatures and the middle pebble lowest temperatures, and the maximum difference is around 10.5$^{o}$C. Unlike the results presented in previous studies [1, 2], surface temperatures in one certain pebble exhibit a very small fluctuation, which is more reasonable and more in accordance with the characteristics of brass whose thermal conductivity is as high as 109 W/m/K.

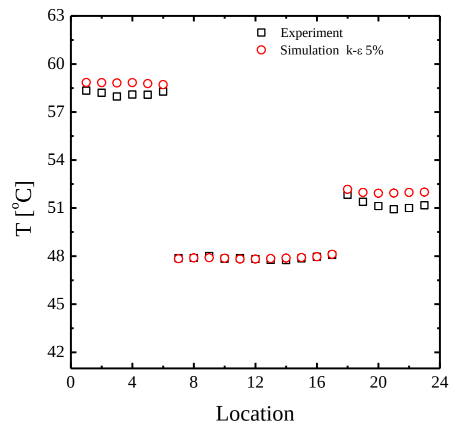


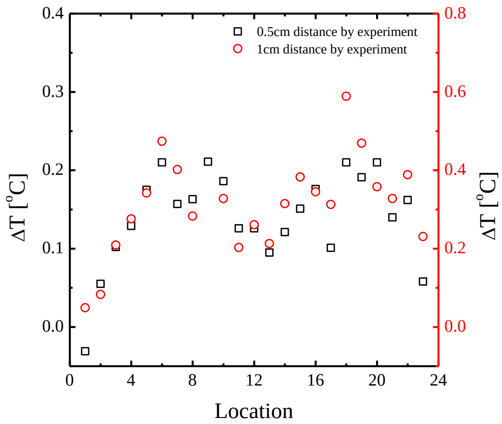

Fig. 2 Surface temperature comparison between experiment and simulation

Simulation is conducted under k-ε turbulence model and intensity of 5%, obtained pebble surface temperatures are compared with experiment ones. They perfectly accord with each other at the positions of middle pebble; however, maximum deviations of 0.5$^{o}$C and 0.9$^{o}$C are found respectively in the upper and lower pebble.

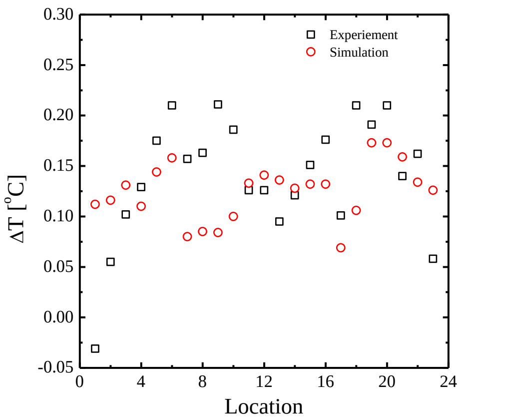
### *3.2 Heat transfer analysis*

Temperatures of positions of 7.5mm and 12.5mm beneath the surface are also analyzed and the temperature differences between positions of 7.5mm and 12.5mm with position of 2.5mm beneath the surface are plotted in Fig. 3a. It shows relatively small temperature difference which indicates relatively weak heat transfer in the areas of lower vertex of upper pebble and higher vertex of lower pebble, and those are stagnation areas as presented before [3,4]. In addition, a relatively weak heat transfer is also found in the vertex of middle pebble. Contrarily, in the contact areas of upper-middle pebble and middle-lower pebble is found strong heat transfer.

The temperature difference is pretty small as can be seen from Fig.3a; therefore, it can be possibly influenced by measurement uncertainty caused by HFS fabrication or installation. In order to avoid such a bad effect on the accuracy of result analysis, comparison with simulation results is performed and shown in Fig. 3b.




(a)




(b)

Fig. 3 (a) Temperature difference beneath surface by experiment and (b) compared with simulation

The pattern exhibited by simulation results is quite complex and different from the experiment one. Such a disagreement cannot be clearly explained so far based on what we know. The simulation results can be trusted only if they've got validated, however, the obtained experiment results have uncertainties, not known how much it is, which may make the measurement worthless. A method to break out this dilemma is trying to be figured out.

## 4. Conclusions

A test rig scaled up from a packing unit of a pebble bed reactor core was constructed, which was treated as an ideal face-centered-cubic (FCC) structure. Heat flux sensors were used to measure the surface temperatures and heat fluxes flowing out of the pebbles. The fluctuation of surface temperatures of each pebble is as small as 0.3°C for the upper pebble, 0.2°C the middle pebble and 0.9°C the lower pebble. The upper pebble shows the highest temperature profile and the middle pebble the lowest temperature profile among the pebbles, and the maximum temperature difference is 10.5°C. The simulation results show a good agreement with experiment ones in terms of surface temperatures, although the largest deviation of 2% can be found at the lower pebble.

Heat transfer is found very weak at three areas, one is the lower vertex of upper pebble, one is the left vertex of middle pebble and another one is the upper vertex of lower pebble. The reason is air rarely flowing by those areas and stagnation zones are formed consequently. However, simulation result shows a different profile. Reasons need to be clarified in the future work.

## ACKNOWLEDGEMENT

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KOFONS), granted financial resource from the Nuclear Safety and Security Commission(NSSC), Republic of Korea (No. 1305008-0416-SB130)

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