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Localization of the hot spots in a pebble bed reactor

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1. Introduction

The pebble bed reactor (PBR) is a candidate reactor type for the very high temperature reactor (VHTR), which is one of the Generation-IV reactor types. 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 and cause serious accident like fission products releasing from the fuel to the reactor coolant system, which has drawn the attention of many scientists to investigate flow patterns of the coolant [1, 2] and to observe the temperature profile of the PBR core by simulation [3]. However, systematically experimental analysis on the temperature of pebbles' surfaces and of the fluid near them has never been done before. In this present study, the temperature profile of 23 designated positions in the upper, side and lower pebbles is observed and the results obtained are evaluated by CFX simulation results. The conclusions are made and may contribute to a better design of a PBR core and a closer inspection of the local hot spots to avoid destruction of pebbles from happening.

2. Simulation

The geometries of the fluid part and solid part consisting of the pebbles and the heaters are shown in Fig. 1. Because it is very hard to know the real size of the contact area, the diameter of pebbles contacting area in the following case is set as 6mm. Other than that, a contact diameter of 3.5mm is also considered and simulated to make the results comparable and the conclusion more solid.

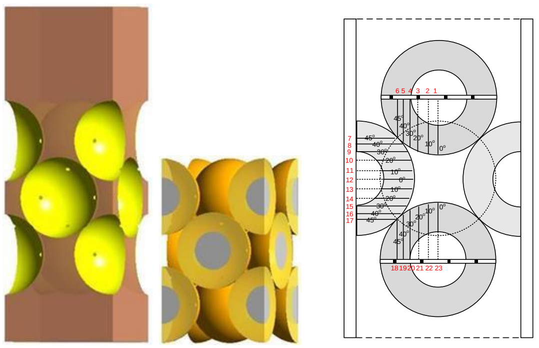


Fig. 1 The fluid part (left) and solid part (middle) and locations of temperature measuring point in plane 1(right).

In order to clearly observe the temperature field in the PBR core, plane 1 is inserted which vertically crosses the test section in the center and includes all the designated spots.

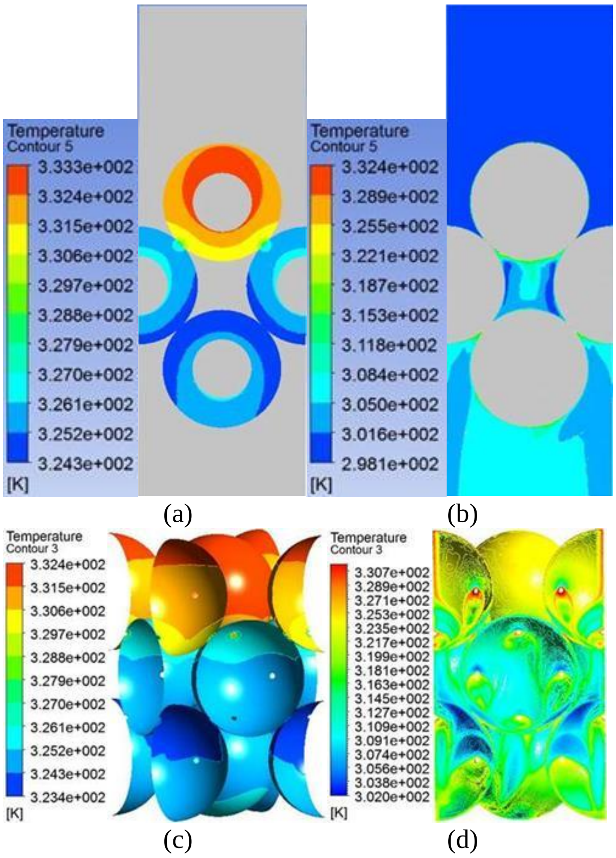


Fig. 2 (a) the pebbles' temperature profile in plane 1
(b) the fluid temperature profile in plane 1
(c) the full view of the pebbles' surface temperature profile
(d) the full view of near-wall fluid temperature

The profile of plane 1 shows the temperature of pebbles (Fig. 2a) and of the fluid (Fig. 2b). The upper pebble reveals generally higher temperature than the side and lower pebbles, on the one hand, it is because of the quasi-laminar fluid flow and low velocity around it; on the other hand, due to the array of the pebbles when the fluid is flowing over the side pebbles complexed turbulence will occur and increase the flowing velocity which correspondingly decreases pebbles' surface temperature. The temperature of upper-side pebble contact area is lower than the upper pebble but higher than the side pebble, which shows the evidence that heat transferred from the upper pebble to the side ones through contact areas. However, the same phenomena does not take place between the side pebble and the lower pebble because of almost same temperature on both sides. The temperature of fluid near a contact area is generally higher than that of other areas for the reason of low fluid velocity in that area, which finally results in low local heat transfer coefficient and may affect the integrity of the pebble.

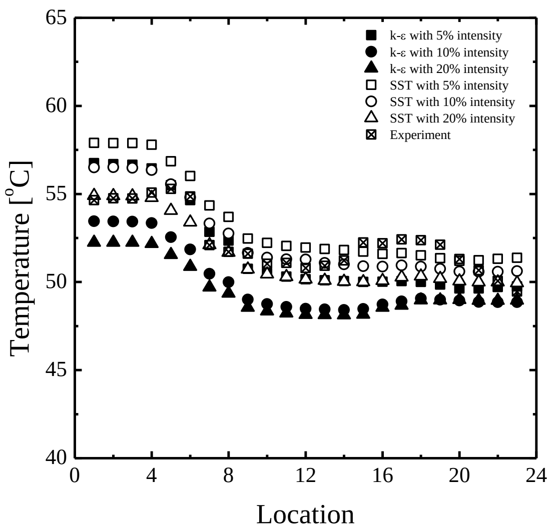
Full views on temperature field of the pebbles' surfaces and of the fluid nearby are shown in Fig. 2c and Fig. 2d, respectively. The temperature profile of pebbles is not as complicated as that of the fluid.

3. Experiment

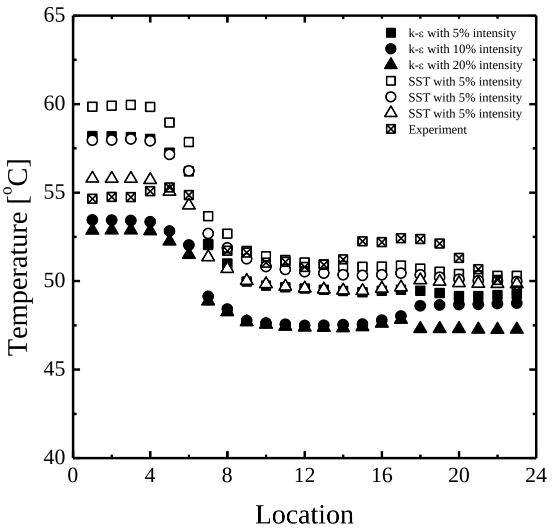
The experiments are designed to use air at 25°C instead of helium as a coolant. . In order to actualize it, scaling law is used to transform operation parameters of the real PBMR-250MWth condition to the parameters of the practical experiment condition. The feasibility has been presented in our previous study [4].

4. Results and discussions

The results are shown in Fig.3. It is found that the six selected locations in the upper pebble had nearly same temperature; the temperatures variation trend show a concave form in the side pebble; the surface temperature keeps decreasing from the contact point to the vertex in the lower pebble; the maximum temperature difference among these points is 5.83°C. The stagnation zones found below the upper pebble and above the lower pebble in simulations seem not particularly increase the solid surface temperature, to the contrary, the vertex of the lower pebble showed an even lower temperature than surroundings. To ensure the results are reliable, CFX simulations under many conditions are conducted according to the diameter of contact area and turbulence model.



(a)



(b)

Fig. 3 (a) comparison of simulation and experiment results with pebbles contact diameter of 6mm and (b) of 3.5mm

The temperature values of those specifically chosen positions obtained in simulations of all cases are marked in Fig. 3a and Fig. 3b, cases with the same contact diameter are drawn in one figure in order to keep the its clarity. All simulation cases show similar trend of thermal temperature starting from the upper pebble to the lower pebble, specifically, position 1 to 4 have the same highest temperatures while position 12 and 13 have the lowest for cases of k-e turbulence intensity higher than 10% in both Fig. 3a and Fig. 3b. The temperatures of position 18 to 23 shows three variation trends in general; one is a concave form, the second one to keep constant and the third one to keep decreasing. However, the total variation is so small that it cannot be clearly seen from the figures. But the temperature trends of position 7 to 23 of all cases are listed in other places, only results are presented here. By contrasting experiment with simulation it is not difficult to find out SST with 20% turbulence intensity could predict the thermal field more accurately among these models.

5. Conclusions

Thermal field of a PBR core is investigated in this study. Specifically, experiments on measuring the pebbles' surface temperature are performed. It is found that the upper pebble has an overall higher temperature profile than the other pebbles and the stagnation zone under does not increase its surface's temperature. In addition, the temperature profile of the side pebble shows a concave form and it keeps decreasing from the contact point to the vertex in the lower pebble. Lastly, the maximum temperature difference among these points is 5.83°C. These findings above are validated by CFX simulations under two different turbulence models (k-e, SST) and two contact areas (diameter of 6mm and 3.5mm). By contrasting the temperature variation trends of all simulation cases, it is concluded that SST turbulence model with 20% intensity shows a better agreement with the experiment result, nevertheless, slightly deviation is also found in terms of total temperature difference and the peak appears in position 17~19 in experiments. Therefore, in order to present convincible thermal field of a PBR core, firstly, more work needs to be done to exclude the possibility of measurement error; secondly, a different surface temperature measuring method might be taken; thirdly, CFX simulations should be conducted under other conditions. These findings may contribute to a closer inspection of the local hot spots to avoid destruction of pebbles from happening.

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