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Effect of packing ratio on the flow field and heat transfer characteristics of an FCC pebble-bed

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1. Introduction

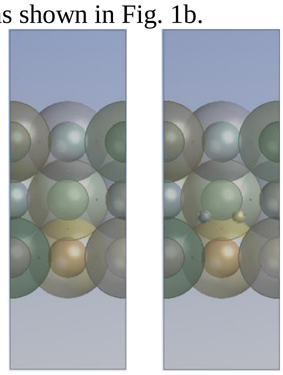
The flow field and heat transfer characteristics of a pebble bed packed in a face-centered-cubic (FCC) structure have been discussed in other studies [1, 2], and the hot spots were partly identified and the stagnation areas observed. However, that is not the finishing line because to design a safer pebble bed reactor only marking where the hot spots are is far less than enough, it is better to find a method by which the hot spots can be reduced or controlled. Toward this end, on the basis of our present experimental setup, a method of filling the space between pebbles with a specific type of objects came to our mind. Since the objects will have influences on the flow regime of fluid, which mostly determines the localizations of hot spots, through adjusting the shape, the size, and the position of the objects it is believed that control the appearance of hot spots is practical. This paper presents corresponding simulation results obtained through CFX, even though it just shows the first-stage output, hopefully, insights on how to finally achieve that goal can still be found in this paper and in the following reports.

2. Computational Methods

A numerical method was firstly deployed before any experimental work would be done. CFX 18.0 was used as the tool to observe the expected results.

2.1 Geometry

Comparison between two models was performed in order to achieve the goal more easily. The geometries used in each model are shown in Fig. 1, and the only difference between them is that two spheres (diameter, 10 mm) are located right above the bottom pebble in the second model, as shown in Fig. 1b.



(a) (b)

Fig. 1. (a) FCC structured pebble bed (b) FCC structured pebble bed with two spheres filled in

Parameters of the model are listed in Table 1.

Table 1 Parameters of each component

Components	Materials	Geometry (mm)
Duct	Bakelite	500 × 170 ×170 (mm^3)
Pebble	Brass	Dia. 120
Heater	Brass	Dia. 60
Object	Brass	Dia. 10

2.2 Meshing

The total number of elements is around 250 million, and the meshing details of each component will not be put up here. However, it is worth noting that boundary layers (5 layers) on both outside and inside the pebble surfaces were created in order to clearly see the flow field near the surfaces.

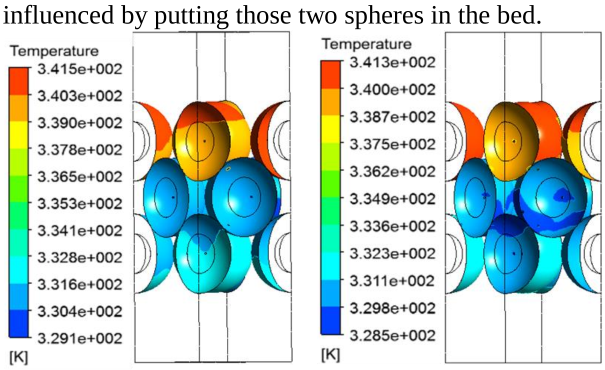
2.3 Boundary conditions

As for the boundary conditions, SST with an intensity of 5% was used as the turbulence model; heat source density was set as 1×10^6 W/m^3. The air was taken as the fluid and its temperature at the inlet kept at 298.15K. The mass flow rate was 0.07158 Kg/s. At the outlet, constant pressure (1 atm.) was set.

3. Results

3.1 Surface temperature profile

As can be seen in Fig.2, both the highest and lowest temperatures are almost same between two cases, which means that the surface temperature is not severely influenced by putting those two spheres in the bed.



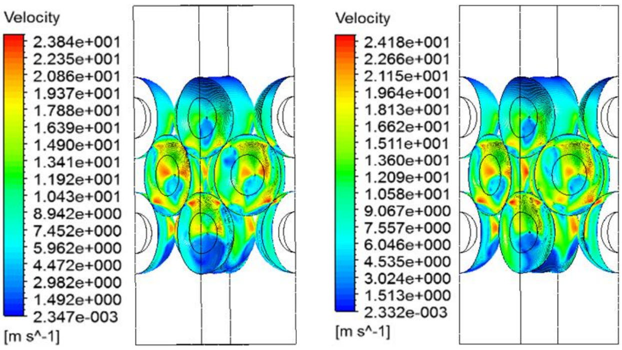
(a) (b)

Fig. 2. Temperature profile of (a) bed without objects (b) with objects in

One possible reason is the objects are too small to be influential. The evidence can be found from local temperature profile of the middle pebble, in Fig. 2b, because of the contact between the pebble and the object, the surface area near contact point shows a bit lower temperature profile. Therefore, it is believed that the variation of surface temperature could be seen more clearly through adjusting the size of the objects.

3.2 Flow velocity profile

Similarly, the overall flow velocity does not show too much difference either. That was possibly caused by the small size of the object, also. However, it is believed that the local flow, especially the area near the objects, will be influenced no matter how small the objects are. Therefore, it is necessary and meaningful to observe that.

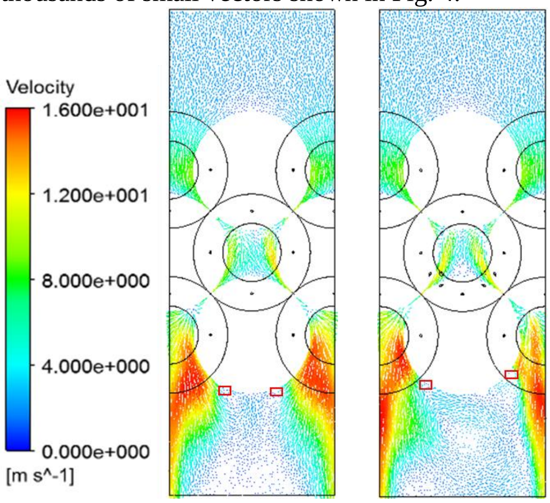


(a) (b)

Fig. 3. Flow velocity of (a) bed without objects (b) with objects in

3.3 Flow separation observation

To observe the local flow field more clearly, a vertical plane was inserted right in the middle of the edge of the y-axis. Flow velocity in this plane is represented by thousands of small vectors shown in Fig. 4.



(a) (b)

Fig. 4. Flow velocity of the mid-plane in the bed (a) without objects (b) with objects in

It is found that the flow does have variation between two cases even though the highest velocity keeps the same. As marked in Fig. 4a and 4b by red squares, the flow separation points are clearly influenced by putting objects in the bed, under that condition the flow separates from the solid surface earlier. The other difference is the distribution of high-velocity flow in the area of under the bottom pebble. More simulations are needed to know its regular pattern.

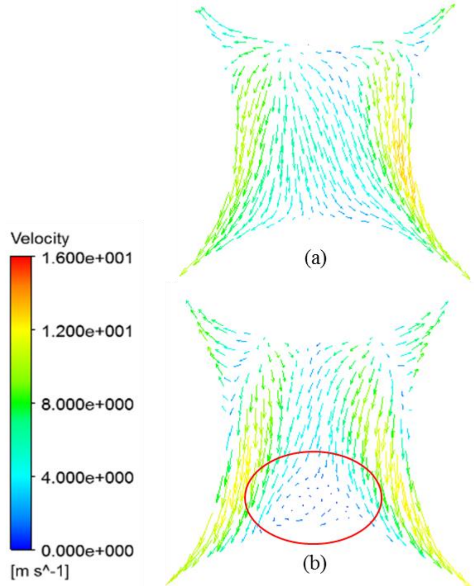


Fig. 5. Flow velocity of the gap area in the mid-plane (a) without objects (b) with objects in

The flow pattern in the gap, formed by four middle pebbles, also shows differently. The most obvious part is that turbulence is formed in the area right above the bottom pebble as marked by a red circle in Fig. 5b. Whether it will benefit lowering the possibility of hot spots appearance or not needs to be verified.

4. Conclusions

Objects were put in an FCC structured pebble bed to see their influences on the thermal and flow fields. It was found that the overall influence was pretty small; however, the flow separation points moved their positions clearly. Also, turbulence was found formed above the bottom pebble. More simulations need to be conducted in order to actualize the control of hot spots.

ACKNOWLEDGEMENT

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