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Effect of a Central Graphite Column on a Pebble Flow in a Pebble Bed Core

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1. Introduction

A pebble bed reactor(PBR) uses coated fuel particles embedded in spherical graphite fuel pebbles. The fuel pebbles flow down through the core during an operation. The pebble bed core is configured as cylindrical or annular depending on the reactor power. It is well known that an annular core can increase a cores' thermal power. The annular inner core zone is typically filled with movable graphite balls or a fixed graphite column. The first problem with this conventional annular core is that it is difficult to maintain a boundary between the central graphite ball zone and the outer fuel zone. The second problem is that it is expensive to replace the central fixed graphite column after several tens of years of reactor operation. In order to resolve these problems, a PBR with a central graphite column in a low core is invented[1].

This paper presents the effect of the central graphite column on a pebble flow by using the computational fluid dynamics(CFD) code, CFX-10.

2. Numerical Methods

2.1 CFD Model

The PBR core consists of numerous fuel and graphite pebbles that are stacked in a graphite reflector structure. Figure 1 shows the pebble bed core with the central graphite column(130) in a low core and its CFD model. Only 1/3 of the PBR core is modeled by using the symmetry of the core geometry.

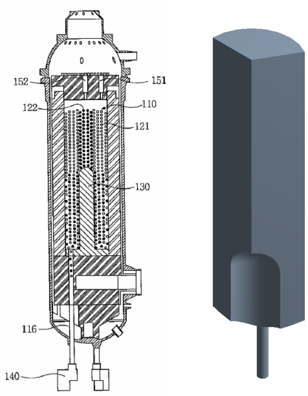

Figure 1. Pebble bed core with a central graphite column and CFD model.

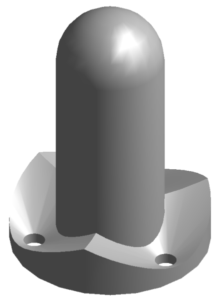

Figure 2. Defule cone of PBR with a central graphite column.

Figure 2 shows a schematic of a defule cone and the central graphite column in a low PBR core. The pebbles will flow down to the defule chute(116 in Fig. 1) though the three holes in the annular region. Diameter of the PBR core is 3.7 m and its height is assumed to be 12 m. The length of the defule chute is 4 m. Diameter of the central graphite column is 2 m and its height(H) changes to 4 m and 8 m. The PBR core without the central column is also modeled as a reference case. Total number of nodes used in this study is 193,200.

2.2 Numerical Analysis and Boundary Conditions

The pebble flow is assumed to be a fluid flow since it is reasonable to evaluate the effect of the central column. A high viscosity fluid, Glyserol is chosen as a working fluid. The flow is assumed as laminar because the pebble velocity(~2.9 mm/hr) inside the core is very slow (Re << 1). It is noted that approximately 2900 pebbles out of 450000 pebbles in PBMR400 are extracted from the core everyday. The CFD solver execution is terminated when all the RMS residual is below its target criteria of 10^{-10}.

A uniform flow condition and constant pressure are applied respectively at the inlet and outlet boundaries. Symmetric conditions are used at the side boundaries. No-slip condition is applied to the reactor shroud and defule-chute wall.

3. Results and Discussions

Figure 3 compares the streamlines at various radial locations starting from the top of the core(i.e., inlet boundary) with the central graphite column of 4 m. It can be seen that the pebbles in the central core region move

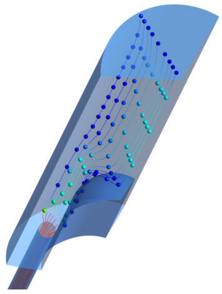

Figure 3. Pebble flow streamlines with the central graphite column (H=4 m).

down fast initially and slow down near the central column. The pebbles in the intermediate region are decelerated as they approach the central column and are accelerated in the low core region due to a narrow pebble path.

Figure 4 shows the pebble velocity distributions at various radial and circumferential positions for two different central columns, i.e., H=4 m and H=8 m. The pebbles in the central region (r < 0.5) and the peripheral region (r > 1.6) move slower than those in the other regions due to the friction between the central column and the reactor shroud. Their velocity also significantly decreases as the height of the central column increases.

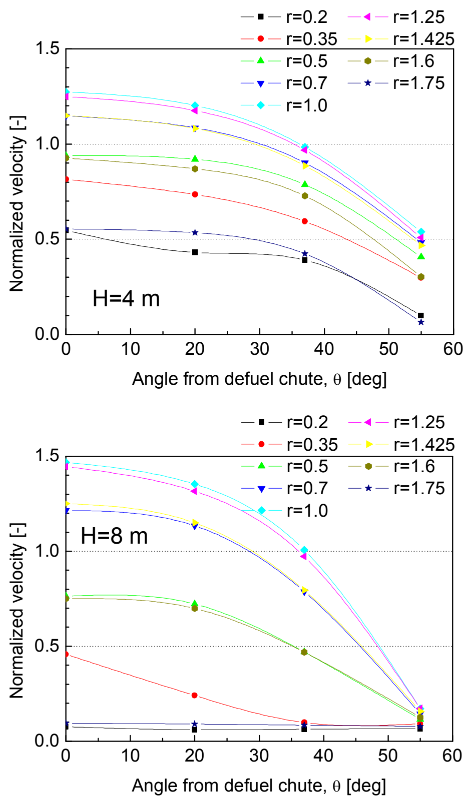

Figure 4. Pebble velocity distributions depending on the pebble location

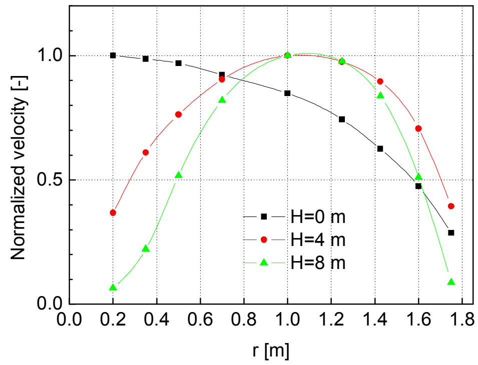

Figure 5. Effect of the central graphite column on pebble velocity

The velocity distributions also show a noticeable decrease of the velocity of the pebbles in the region more than 30^{o} away from the center of the defule chute.

Figure 5 compares the pebble velocity depending on the height of the central column. The velocity of the pebbles in the central region (r < 0.5) is much lower than that for the case without the central column (H=0 m). It also shows that the central and peripheral pebbles move slowly and the velocity difference increases as the height of the central column increases.

4. Conclusion

A CFD simulation is performed to support a conceptual PBR design with a central graphite column in a low core. The pebble velocity is predicted by assuming that the pebble flow is a highly viscous fluid flow. The CFD analysis showed a large dependency of the pebble velocity on the height of the central column. Particularly, the pebbles in the central core region flow down very slowly as the height of the central column increases. Hence, this study has proven that the central graphite column in a low pebble bed core could effectively control the pebble velocity. It is however necessary to optimize the central column for its application in the future.

Acknowledgement

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REFERENCES

[1] J. H. Chang, W. K. In and W. J. Lee, "A Pebble-Bed Gas Cooled Reactor with a Central Graphite Column in Low Core," Korea Patent, Application No. 10-2006-0082164, 2006.