Parametric Study on an Outlet Plenum of the PBMR

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1. Introduction

The problem of exhaust gases from fossil fuels which are playing havoc role in the pollution have caused us to go for an alternative option. The nuclear energy has emerged as an alternative option for it. The nuclear power generation concept was established for the future plan. The pebble-bed modular reactor (PBMR) as a high temperature gas-cooled reactor (HTGR) was planned to generate power. The hydrogen can also be produced by the high temperature of PBMR. The process of generating hydrogen by PBMR is more effective than any other methods [1]. At normal operating condition the coolant enters into the reactor core at a temperature of about 540^0C and at a pressure of 7 MPa and after cooling the pebbles inside the reactor core it comes out through the outlet plenum with a temperature of 900^0C.

Different reports have been published by different researchers on the topic of PBMR. Koster et al. [3] have suggested on the design goals for this type of reactor taking the economy, stability and efficiency into considerations. The optimum shape for the inlet plenum of PBMR has been obtained by using Reynolds averaged Navier-Stokes (RANS) analysis and Kriging modeling by Kim and Lee [4]. For a very high temperature reactor (VHTR), flow and heat transfer analysis have been performed by Kim et al. [5]. A relationship between the height of the upper plenum and flow distribution was established by them to reduce the maximum fuel temperature and to increase the fuel performance for the PBMR. Boer et al.[6] optimized the core fuel management. However, advanced research on the outlet plenum of PBMR has not been carried out, yet.
In this study, a numerical study on an outlet plenum of the PBMR has been done by using three dimensional Reynolds-averaged Navier-Stokes (RANS). Pressure drop in the outlet plenum of the PBMR has been analyzed with the geometrical parameters which are given in Fig.1.

2. Numerical Analysis

To reduce the computational load, only half of the geometry is comprised in the computational domain because the geometry is symmetric about y-z plane as shown in Fig. 1.

To solve continuity and three-dimensional RANS equations for three-dimensional steady flows in the outlet plenum, ANSYS CFX-11.0 [7] has been used.

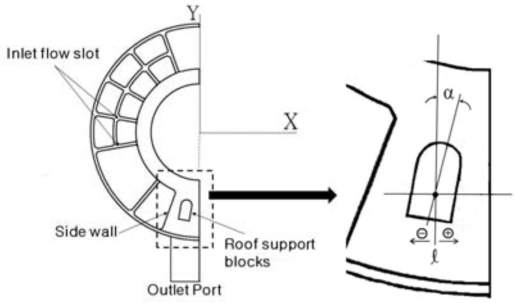

Fig. 1. Geometrical parameters in Outlet Plenum of PBMR; displacement on the horizontal line (ℓ) and angle of rotation (*α)* about the center of gravity of the roof support block.

For the prediction of turbulent flows in the outlet plenum, the SST (Shear stress Transport) model has been employed. Due to the combination of both k-ε and k-ω models with blending function, the SST model is preferred. The k-ω model is used near the wall and k-ε models are used in the region far from the wall. Under adverse pressure gradient, the SST model captures flow recirculation more effectively than the other eddy viscosity models as reported by Bardina, et al. [8]. Unstructured tetrahedral meshes are employed in most of the computational domain to produce the volume meshes, but prism meshes are employed near the walls.

In the present study, displacement on the horizontal line (ℓ) of x-axis and angle of rotation (*α)* about the center of gravity of the roof support block are selected as the parameters for the study.

The performance function, F_P is representing friction performance in the outlet plenum (F_P). F_P is a dimensionless pressure drop in the outlet plenum defined as:

$$F_p = \frac{P_{in} - P_{out}}{0.5\rho v_{inletavg}^2} \qquad (1)$$

where p_{in} and p_{out} are total pressures at inlet and outlet, respectively. ρ indicates fluid density of Helium. $V_{inletavg}$ indicates average velocity at the inlet.

3. Results and Discussion

Fig. 2 shows velocity vectors around the roof support block for the reference case. Low-velocity regions are generally observed downstream of the roof support block and near the sidewall while high-velocity flow is developed between the roof support blocks. It is thought that the flow, which is developed from the center to bottom and becomes fast in the narrow slots, runs into the right side of the outlet plenum.

The velocity vectors with the different displacements and angles of rotation of the roof support block are shown in Figs. 3(a) and (b). The low-velocity regions shown in Fig. 2 merge into a single low-velocity zone, and the high-velocity region between the roof support blocks is enlarged in the case with negative displacement. On the contrary, a new high-velocity region is developed between the roof support block and side wall in case with positive displacement.

Figs. 3(c)-(d) represent the velocity vectors with the different angles of rotation of the roof support block. Area of the low-velocity region near the side wall is affected by the angle of rotation. This area becomes largest when the angle is -10°, and smallest when the angle is +10°.

Table I shows the values of dimensionless pressure drop represented in eq. (1). The pressure drop in the outlet plenum is reduced when block is moved to negative and angle of rotation is rotated to -5°. The pressure drop is more affected by the displacement than the angle of rotation of the roof support block.

3. Conclusions

In this work, three-dimensional RANS has been performed to analyze the effects of the geometric parameters of the roof support blocks on pressure drop in the outlet plenum of the PBMR. The pressure drop in outlet plenum is more sensitive to the displacement of the roof support block than to the angle of rotation of the block. And, the pressure drop is increased with the decrease of the gap between the two roof support blocks.

ACKNOWLEDGEMENT

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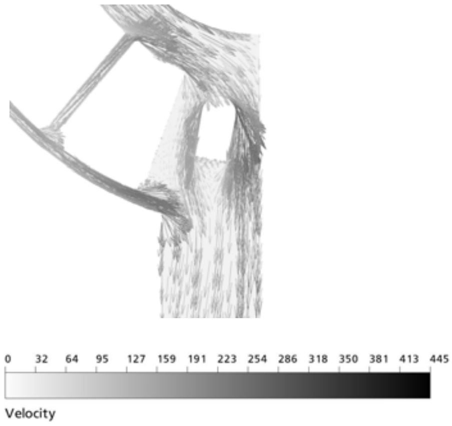
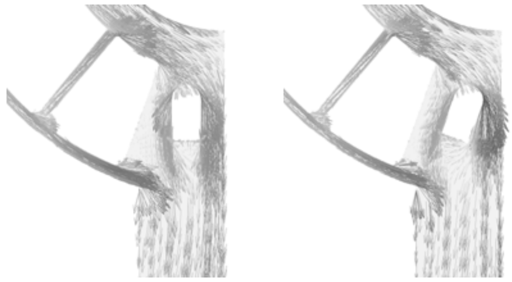


Fig. 2. Velocity vectors around the roof support block for the reference case

(a) -0.1m (b) +0.1m



(c) -10° (d) +10°

Fig. 3. Velocity vectors around the roof support block for different values of ℓ and α

Table I: The values of dimensionless pressure drop

ℓ	-0.1m	-0.05m	Ref	+0.05m	+0.1m
F_p	5.52	5.51	5.85	5.96	7.31
α	-10°	-5°	Ref	+5°	+10°
F_p	5.95	5.68	5.85	5.90	6.13

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