# Shape Optimization of Outlet Plenum of the PBMR

Jae-Woo Ju , Sang-Moon Lee, and Kwang-Yong Kim *
*Mechanical Engineering Department, INHA Univ., Korea*
**Corresponding author: kykim@inha.ac.kr*

## 1. Introduction

The pebble-bed modular reactor (PBMR) is a typical type of the high temperature gas-cooled reactor (HTGR). At ordinary operating condition, the coolant enters into the reactor core at a temperature of about $540^{0}$C 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 $900^{0}$C.

Different reports have been published by different researchers on the theme of PBMR. Koster et al. [1] have proposed on the design aim 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 [2]. For a very high temperature reactor (VHTR), flow and heat transfer analysis have been carried out by Kim et al. [3]. A relationship between the height of the upper plenum and flow distribution was established by them to decrease the maximum fuel temperature and to increase the fuel performance for the PBMR. Boer et al. [4] optimized the core fuel management.

In this study, design optimization of an outlet plenum of the PBMR has been performed by using three-dimensional RANS analysis and RSA modeling technique [5]. The purpose of the present optimization is to minimize the pressure drop in the outlet plenum of the PBMR of which computational domain and geometrical parameters are shown in Fig.1. Two design variables have been employed for the optimization.

## 2. Numerical Analysis and Optimization Methods

A commercial code ANSYS CFX 11.0 [6] is used for the analysis in PBMR. For the prediction of turbulent flows in the outlet plenum The SST (Shear stress Transport) model [7] has been used.

To reduce the calculation time, only half of the geometry is composed of the computational domain because the geometry is symmetric about y-z plane.

As a preliminary step for the optimization, the objective function and design variables are selected. The design space is then decided for improved system performance. Latin-hypercube sampling [8] is employed to select the design points. At these design points, the objective function is calculated using RANS analysis. RSA model together with the optimal point search algorithm is used to search the optimal design points.

In the present study, dimensionless displacement on the horizontal line ($l/r$) of x-axis and angle of rotation ($\alpha$) about the center of gravity of the roof support block are selected as the design variables for the optimization.

The objective 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. $\rho$ indicates fluid density of Helium. $V_{inletavg}$ indicates average velocity at the inlet.

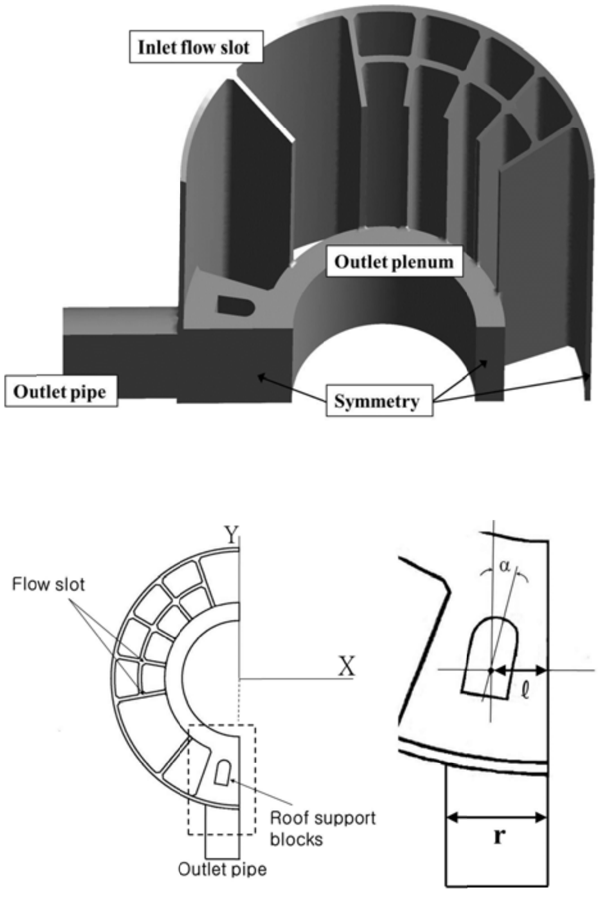
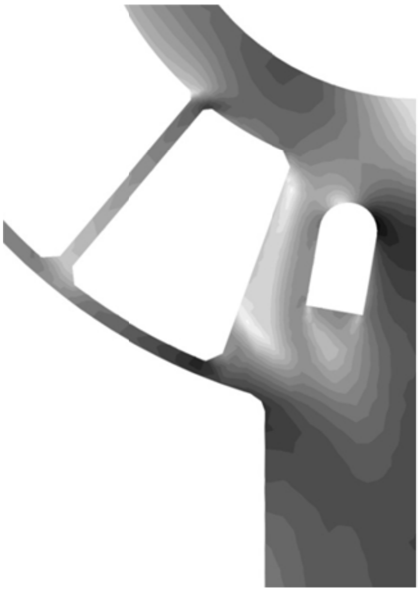
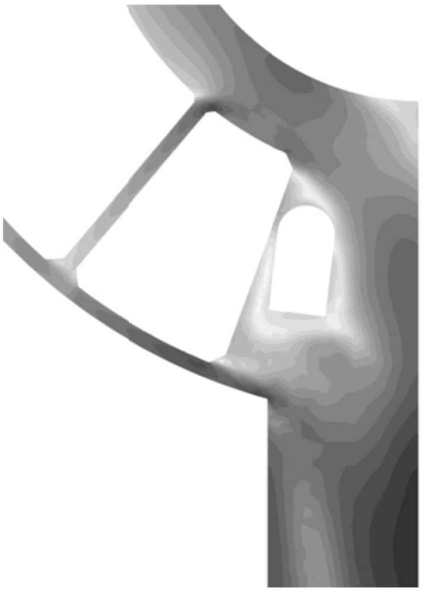



Fig. 1. Computation domain and geometrical parameters in outlet plenum of PBMR; Dimensionless displacement on the horizontal line ($l/r$) and angle of rotation angle ($\alpha$) about the center of gravity of the roof support block.



(a) Reference shape



(b) Optimum shape

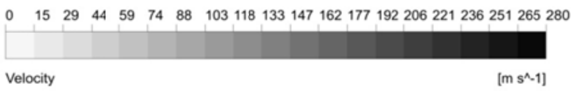



Fig. 2. Velocity distributions around the roof support block for the reference and optimum shape

Table I: Results of optimization

| | Reference | Optimum | |
|---|---|---|---|
| | | RANS | RSA |
| $F_p$ | 5.956 | 5.272 | 5.254 |

## 3. Results

Fig. 2 shows the velocity distributions around the roof support block for the reference and the optimum shape. The optimum design shows uniform velocity profile in comparison with the reference shape.

The results of the optimization are shown in Table I. The objective function has been reduced by 11.8 % in comparison with the reference shape, and 0.34 % relative error has been found between RSA model prediction and RANS analysis result at the same point.

## 4. Conclusions

In this work, three-dimensional RANS has been used for design optimization of the roof support blocks in the outlet plenum of the PBMR. As a result, the optimized shape shows more velocity uniformity than the reference shape and the optimal design gives the decrease of the objective function value as much as 11.8 % in comparison with the reference shape.

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