Transactions of the Korean Nuclear Society Autumn Meeting
Taebaek, Korea, May 26-27, 2011

Design Optimization of A PCHE Using RSA Model

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1. Introduction

Nuclear power generation based on gas turbine cycle is recently considered as a nuclear power generation concept for the future due to the advantages in terms of simplicity and efficiency in comparison with steam turbine cycle [1]. However, durability of each component of this cycle should be guaranteed due to high temperature and high pressure environment. In addition, since gas is used as working fluid, inefficiency due to the large volume is inevitable in the case that a heat exchanger is used as a recuperator and pre-cooler. In this respect, as the alternative type of heat exchanger, printed circuit heat exchanger (PCHE) developed by HEATRIC [2], which has excellent heat transfer performance, is the heat exchanger suitable for the high temperature gas cooled reactors.

In this work, PCHE channels have been optimized to enhance heat transfer and friction performances using three-dimensional Reynolds-Averaged Navier-Stokes (RANS) analysis and response surface approximation (RSA) [3].

2. Flow Analysis and Optimization Methods

The computational work in this study is performed with the commercial CFD code, ANSYS CFX-11.0 [4], which employs an unstructured grid to solve governing equations for three-dimensional steady turbulent flow and heat transfer in the PCHE. Reynolds number based on hydraulic diameter of the channel is 152,000 in this calculation and the working fluid used in the calculation was supercritical carbon-dioxide. Shear Stress Transport (SST) model [5] with automatic wall treatment is used as turbulence closure.

Fig. 1 shows grid system and calculation domain of PCHE. Counter flow PCHE is used for this work. Boundary conditions are shown in Table I. Periodic conditions are used on upper and lower boundaries (z-x plane) and on each side boundary (z-y plane).

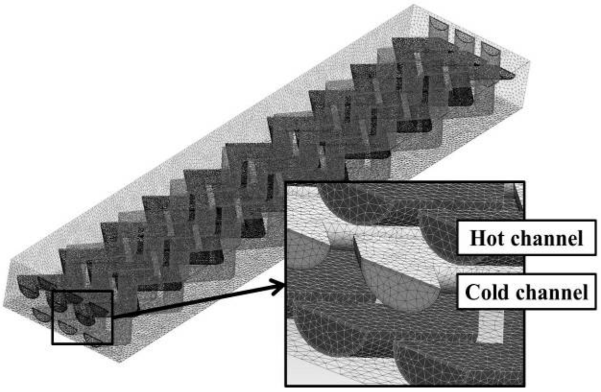


Fig. 1. Grid system and calculation domain of PCHE

For the first step of the optimization procedure, the objective function and design variables are selected. The design space is then decided for improved system performance. Design points are selected through Latin-hypercube sampling [6]. The objective function is calculated using RANS analysis at these design points. Finally, the RSA model is constructed, and then optimal points are searched by the optimal point search algorithm.

The objective function (F) is defined as a linear combination of two different functions representing friction factor in the cold channels of PCHE (F_p) and heat transfer effectiveness (F_f) with a weighing factor, β as follows:

$$F = F_t + \beta F_p \tag{1}$$

F_t is defined as the reciprocal of effectiveness (η);

$$F_t = \frac{1}{\eta} = \frac{T_{hot,in} - T_{cold,in}}{T_{hot,in} - T_{hot,out}}. \tag{2}$$

Table I: Boundary Conditions

Conditions	Values
Cold inlet flow rate (kg/s)	0.0009456
Cold inlet temperature (°C)	123
Cold outlet pressure (kPa)	8312
Hot inlet flow rate (kg/s)	0.0008670
Hot inlet temperature (°C)	138.2
Hot outlet pressure (kPa)	2528

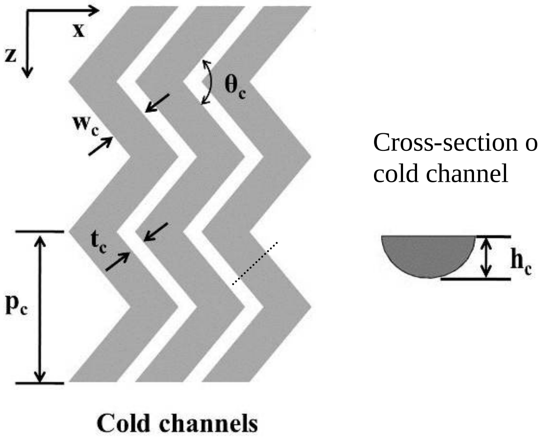


Fig. 2. Geometry of the cold channels of PCHE

F_p, friction factor is defined as follow;

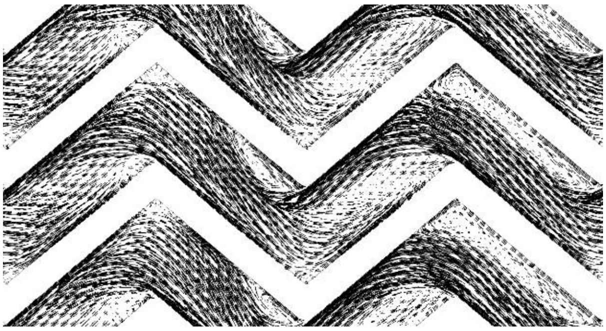
$$F_p = \frac{p_{inlet} - p_{outlet}}{0.5\rho_{avg} v_{avg}^{\ 2}}. \tag{3}$$

The cold channel angle (θ_c) and ellipse aspect ratio of the cold channel ($w_c/2h_c$) are employed as non-dimensional design variables. These variables are represented in Fig.2

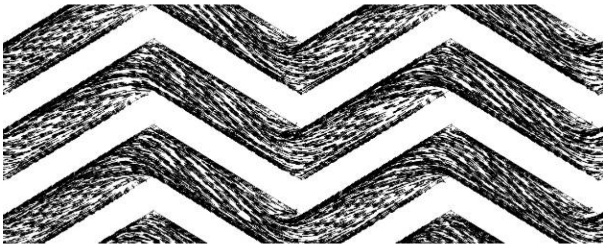
3. Results

The optimization results are shown in Table II. As shown in this table, the objective function value in the optimum shape is finally reduced by 4.5% in comparison with the reference shape. Prediction for the objective function at the optimum shape by RSA model shows only 0.43% relative error compared to that calculated by RANS analysis.

Fig. 3 represents the comparison of the velocity vector fields in the cold channels between the reference and optimum shapes. In the optimum shape, the separation zone is reduced remarkably near bending part, while it is widely observed in the reference shape. Consequently, the separation zone induces the decrease of the heat flux on flat wall of the cold channel with the increase of the pressure drop [7].



(a) Reference shape



(b) Optimum shape

Fig. 3. Velocity vector fields in the cold channels (0.2h_c away from the flat wall)

Table II: Results of Optimization

	Ref.	Opt.	
		RANS	RSA
F	2.466	2.355	2.365
F_t	2.049	2.131	-
F_p	19.87	10.65	-

4. Conclusions

In the present study, PCHE channel has been optimized to enhance the effectiveness and friction performance by numerical optimization techniques based on RSA method combined with RANS analysis. Two design variables, viz., the cold channel angle and ellipse aspect ratio of the cold channel, have been selected for the optimization. The objective function values were evaluated by RANS analysis at each design point selected by LHS. The results showed that the optimum shape has the enhanced effectiveness and friction performance than reference shape. And predicted value using through RSA model had a good agreement with the RANS analysis result. Therefore, the optimization procedure presented in this work can be used economically for the design of PCHE channel.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant No.20090083510 funded by the Korean government (MEST) through Multi-phenomena CFD Engineering Research Center.

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