Design of the Perforated Plate Improving Flow Uniformity in the SFR Steam Generator

V.T. Nguyen[a], S. Im[b*], J. Jung[c], S.R. Choi[c], and B.J. Kim[a*]

[a]*School of Mechanical Engineering, Chungnam National University, Daejeon 34134, Korea*
[b]*Department of Mechanical and Control Engineering, Seoul Cyber University, Seoul 01333, Korea*
[c]*Versatile Reactor Technology Development Division, Korea Atomic Energy Research Institute, Daejeon, Korea*

[*]*Corresponding author: bjkim@cnu.ac.kr, sunghyuk@iscu.ac.kr*

1. Introduction

Recently, Korea Atomic Energy Research Institute (KAERI) has proposed the Copper Bonded Steam Generator (CBSG) which consists of heat exchanger modules with cross flow type arrangement: vertical circular tubes for water side and square horizontal channels for sodium side [1]. In this arrangement, uniform sodium flows are required to improve the heat transfer efficiency. The purpose of this study is to optimize a perforated plate leading to uniform sodium flow by the help of numerical simulations (ANSYS FLUENT) [2]. The flow maldistribution and pressure drop are the main evaluation parameters.

2. Numerical methods

Figure 1 shows the heat exchanger for the sodium flow. The pipe diameter is 130 mm. The sodium enters the header and is distributed into 66x33 horizontal channels. Therefore, it is important to obtain uniform sodium flow throughout the 66x33 channels. Each channel is of 4.5 mm x 4.5 mm and the distance between two adjacent channels is 1.2 mm.

Based on the Reynolds number similarity, water is used instead of sodium for simulation with following parameters: temperature 25^{o}C at atmospheric pressure 1 bar; inlet velocity is 4.73 m/s.

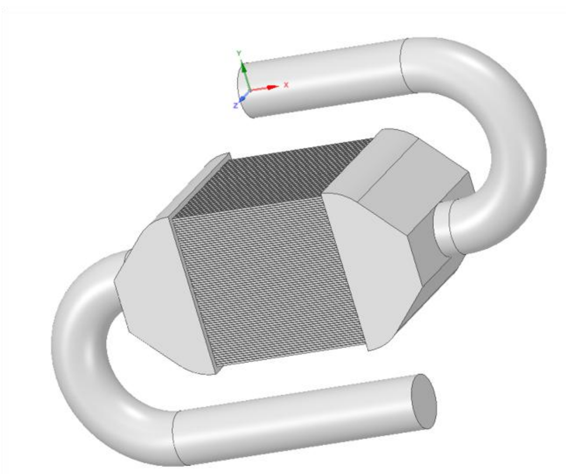

Fig. 1. The geometric model for simulation

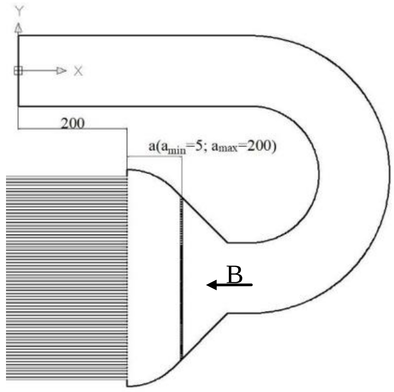

Fig.2. The perforated plate installed in the sodium channel inlet header

2D simulations were performed for preliminary design of the perforated plate. Based on that design, 3D simulations were performed for flow analysis in detail.

A measure of flow maldistribution is evaluated in terms of Coefficient of Variation (CoV) [6]:

$$CoV = \frac{\text{standard deviation } (\sigma)}{\text{average } (\mu)} = \frac{\sqrt{\frac{\sum_{i=1}^{N}(\dot{m}_i - \bar{\dot{m}}_i)^2}{N}}}{\bar{\dot{m}}_i},$$

where, $\dot{m}_i$ is the mass flow rate in the channel i, $\bar{\dot{m}}_i$ is the average mass flow rate throughout all channels, and N is the number of channels (N=66x33=2178). The smaller the CoV and pressure drop, the better.

3. Results and discussion

3.1 2D simulations

The 2D simulation was performed without any perforated plates to capture the flow pattern. The mass flow rate for each channel is shown in Figure 3. An obvious maldistribution is seen along the vertical position. The values of the CoV and pressure drop are $\mathrm{CoV}_0 = 0.3567$ and $\Delta p_0 = 2.269\mathrm{kPa}$.

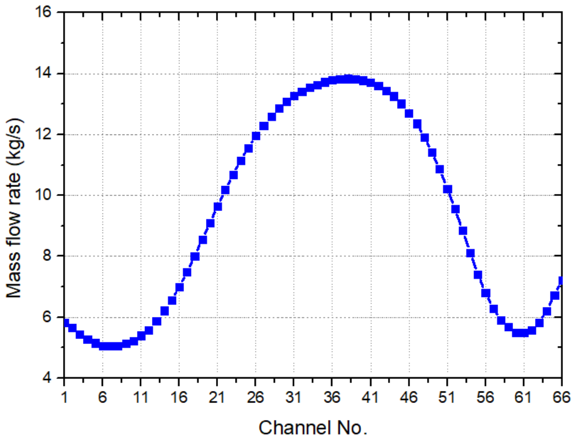

Fig. 3. Mass flow rate for each channel when no plate is added.

Then, the perforated plates with uniform holes (diameter=4.5mm) were installed in the inlet header or both the inlet header and outlet header. The effect of the plate distance from the channel on the CoV and pressure are plotted in Figure 4. There is the optimal position of the perforated plate in terms of CoV, which is the smallest when the plate is placed in the middle of the inlet or outlet headers. This result is consistent with J. Wen et al. [4]. The plate distance of 100 mm is used for 3D simulation.

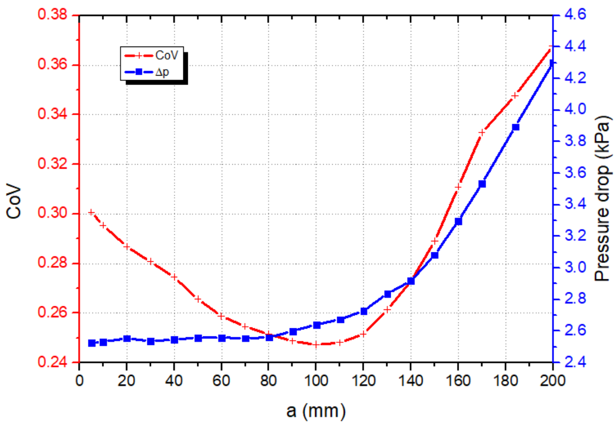

Fig. 4. The change of CoV and pressure according to distance a.

3.2 3D simulations

A 3D simulation without any plates was conducted to obtain the velocity contour in the position where the perforated plates will be placed. Figure 5 shows the velocity magnitude divided into 6 levels.

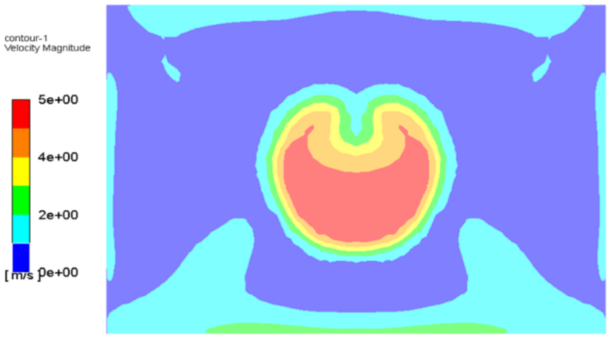

Fig. 5. Velocity contour at distance a=100mm (B view in Figure 2)

The hole diameters are calculated according to the proposed formula:

$$d_i = \sqrt{\frac{v_5}{v_i}} d_5$$

where, d_i is the hole diameter for i-th level velociy magnitude.

d_5 is the smallest diameter corresponding to the maximum velocity magnitude (d_5 = 2.5 mm).

v_i is average value of velocity magnitude of i-th level.

The thickness of the plate is 5 mm and the distance between the holes is 2 mm. The design of the perforated plate is shown in Figure 6.

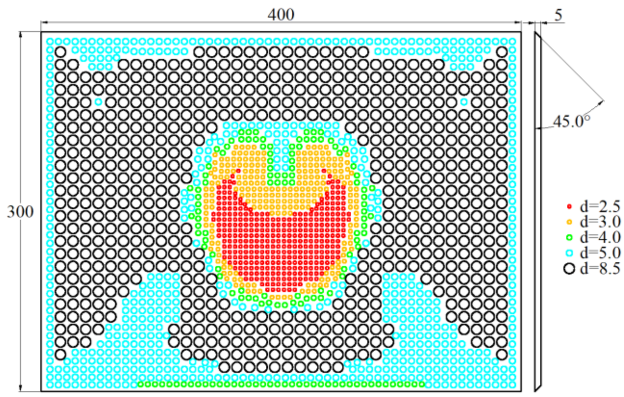

Fig. 6. The design of the perforated plate.

Simulation results are given in the Table I. One can see clear favorable effects of the plates. CoV is significantly decreased at a little cost of the pressure drop.

Table I: Values of CoV and pressure drop

Case	CoV	Reduction in CoV (%)	Δp (kPa)	Increase in pressure drop (%)
No plate	0.3094	-	2.7408	-
Adding 1 plate	0.0751	75.73	2.9462	7.49
Adding 2 plates	0.0706	77.18	3.1852	16.21

4. Conclusions

This paper has presented the numerical simulation to determine the optimal design of the perforated plate to improve the flow uniformity throughout the sodium channels. The proposed design was shown to be excellent to improve heat transfer efficiency in the Copper Bonded Steam Generator.

Acknowledgements

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