Preliminary Sizing of Printed Circuit Steam Generators with Zigzag Channels

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1. Introduction

A PCSG (Printed Circuit Steam Generator) is expected to be substituted for conventional steam generators in SMRs (Small Modular Reactors) due to its compactness. Thus, it is important to optimize the size of the PCSG for designing the SMR.

Kim and Kim [1] investigated effects of a channel diameter on thermal sizing of a PCSG with micro straight semicircular channels connected by cross bridges. They showed that a decrease in the channel diameter gives an increase in the thermal power and a decrease in the volume of the PCSG.

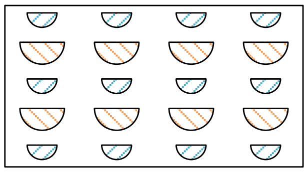
Kim and Kim [2] found the optimum channel length for minimizing the volume of a PCSG with zigzag channels in its secondary side. However, their results were only for a single case for a channel diameter.

In this study, preliminary sizing of a PCSG with zigzag channels was conducted. The optimum channel length for several channel diameters was investigated, and pressure drops in primary and secondary sides were predicted. (This study is an expanded study based on the results by Kim and Kim [2].)

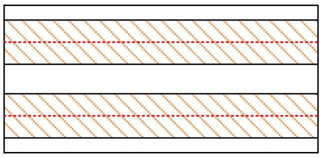
2. Calculation method & PCSG geometries

The calculation methodology for calculating thermal performance of the PCSGs in this study was proposed by Kim et al. [3]. In their paper, the channels had a square cross-section, and they are straight. However, in this study, channels are semicircular shapes as shown in Fig. 1(a). Also, the primary-side channels are straight as in Fig. 1(b), but the secondary-side channels are zigzag channels with cross bridges, which are connecting adjacent channels, as depicted in Fig. 1(c). Therefore, the correlations for the heat transfer coefficient and for the friction factor used in this study were newly developed, and they are different from those used in the original methodology [3].

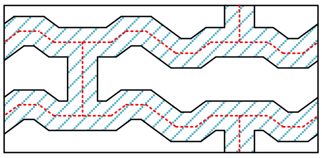
The cases for various channel diameters tested in this study are tabulated in Table 1. (Here, the channel diameter means the diameter of the semicircular cross-section of the channel, but not the hydraulic dimeter. Also, the cross-section is perpendicular to the centerline of the channel, which is the red and dotted line in Figs. 1(b) and 1(c).) For the reference case, the primary- and the secondary-side channel diameters were set to be 3.0 mm and 2.0 mm, respectively, and the distance between centerlines of adjacent channels was 5.0 mm. For the cases of the reduced channel size, as well as the channel diameters, all geometrical parameters related to the channel arrangement are scaled down by the same rate, except for the channel length, which is an independent parameter along with the channel diameter. For each channel size, the calculations for the PCSGs with 0.4 ~ 1.2 m-long channel length were carried out. The boundary conditions are listed in Table 2, and they are based on the design data of SMART [4].



(a) Cross-sectional view



(b) Primary-side top view



(c) Secondary-side top view

Fig. 1 Channel arrangement

Table 1. Channel diameters

Channel size	Channel diameter	
	Primary side	Secondary side
60%	1.8 mm	1.2 mm
80%	2.4 mm	1.6 mm
100% (Reference)	3.0 mm	2.0 mm

Table 2. Flow boundary conditions

Parameter	Primary side	Secondary side
Total flow rate	2356.6 kg/s	190.4 kg/s
Temperature	320.9°C (inlet)	230.0°C (inlet)
Pressure	15.0 MPa (inlet)	5.76 MPa (outlet)

3. Calculation results

For all of the calculation results, the PCSGs perform the heat transfer duty of 365 MWt. The calculation results for various channel sizes and lengths are shown in Figs. 2 ~ 4. Fig. 2 presents the PCSG volume, and Figs. 3 and 4 give the primary- and the secondary-side pressure drops, respectively. In Fig. 2, decreasing the channel size results in the smaller PCSG volume, since the heat transfer becomes enhanced and the wall thermal conductive resistance is reduced as the channel size is scaled down. However, the flow velocity in each channel increases due to a decrease in the channel size as in Table 3, hence the pressure drop increases as the channel size decreases as shown in Figs. 3 and 4.

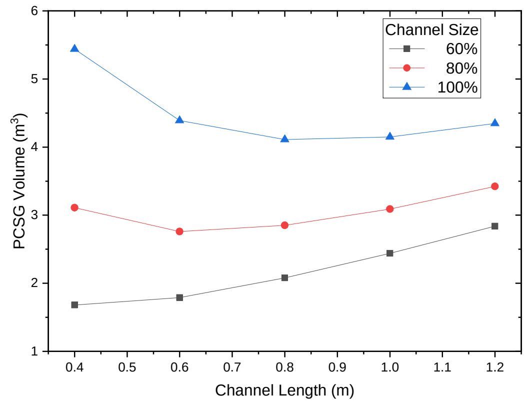


Fig. 2 PCSG volume

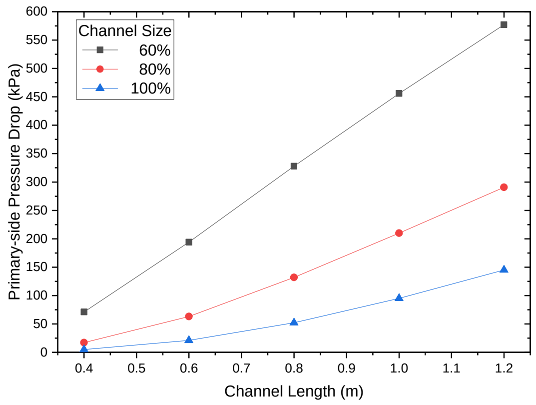


Fig. 3 Primary-side pressure drop

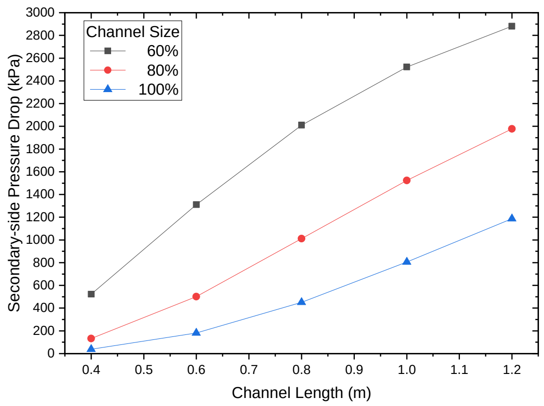


Fig. 4 Secondary-side pressure drop

Table 3. Flow velocities (channel length: 0.8 m)

Channel size	Flow velocity at inlet	
	Primary side	Secondary side
60%	7.83 m/s	1.26 m/s
80%	5.72 m/s	0.92 m/s
100% (Reference)	3.95 m/s	0.64 m/s

The optimum channel length minimizing the PCSG volume becomes shorter as the channel size decreases as shown in Fig. 2. However, since the optimum channel length does not guarantee a minimum of the pressure drop, the designer should determine the channel size and the channel length of the PCSG considering the operating conditions and the components, such as reactor coolant pumps and/or feedwater pumps.

4. Conclusions

In this study, preliminary sizing of the PCSG with zigzag channels in its secondary side was carried out. A volume change of the PCSG for various channel sizes and lengths was estimated, and pressure drops was also predicted. The optimum channel length for each channel size was found. It will be useful to design the PCSG under the limitations of primary- and secondary-side pressure drops.

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