Thermal Sizing of Printed Circuit Steam Generators with Straight Semicircular Micro Channels Connected by Cross Bridges

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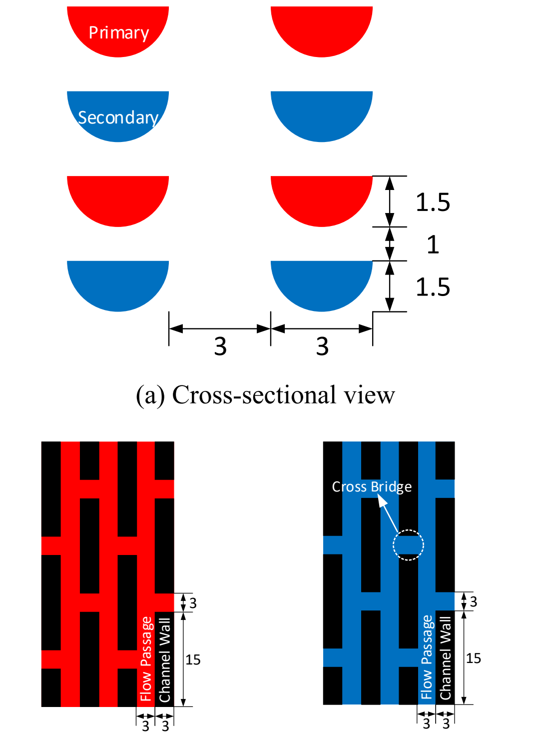
1. Introduction

A Printed Circuit Steam Generator (PCSG) is composed of a lot of micro channels to extremely expand the heat transfer area, thereby it shows the very high compactness for the heat transfer. Hence, Korea Atomic Energy Research Institute (KAERI) has developed the PCSG to substitute a conventional shell-and-tube type steam generator in a small modular reactor [1-4]. They proposed the methodology to analyze the thermal-hydraulic behavior of a unit channel for evaluating the thermal performance of PCSGs [1,3]. Using the methodology, the thermal performance of PCSGs composed of square channels were compared with that of circular channels [2], and the effects of channel wall thickness between primary and secondary channels on the thermal performance was studied [3]. Also, the uncertainty of the two-phase heat transfer coefficient was analyzed [4].

However, square channels and circular channels adopted in the previous studies are difficult to be manufactured through the etching process. Also, an alternative to channel blockage by a loose part or dirt is necessary to prevent degradation of the performance. Therefore, in this study, thermal sizing of the PCSG reflecting the practical design considerations to introduce to a nuclear power plant was conducted.



(a) Cross-sectional view

(b) Primary-side floor (c) Secondary-side floor

Fig. 1 Channel arrangement (unit: mm)

2. Methods and Results

2.1 Numerical Method

The PCSG evaluated in this study is composed of straight and semicircular micro channels connected to adjacent ones by the cross bridges as shown in Fig. 1. The semicircular shape was chosen because an etching process, which creates micro channels on a flat metal plate, gives us their semicircular cross section only. Also, the micro channel is more susceptible to clogging by a loose part and/or dirt than conventional macro tubes. Thus, the cross bridges connecting adjacent channels are introduced to allow fluid to flow to the other path even if one flow path is blocked.

In this study, the methodology to calculate steady-state thermal-hydraulic behavior including two-phase flow and phase-change phenomena in a unit channel of the PCSG [1,3] was used. The methodology adopts the thermal network model, which requires the heat transfer coefficients for calculating the convective thermal resistances. Therefore, Nusselt number in the specific geometry as in Fig. 1 was developed, and also the friction factor for predicting the pressure drop was proposed as follows [5]:

$$\mathrm{Nu} = 0.024\,\mathrm{Re}^{0.794}\,\mathrm{Pr}^{0.555} + 0.198 \quad (1)$$

$$f = 0.493\,\mathrm{Re}^{-0.447} + 0.0046 \quad (2)$$

Boundary conditions of primary and secondary channels are equivalent to those of the shell-and-tube type steam generator of the SMART reactor [6]. Values of their thermal power, primary-side flow rate, inlet temperature, inlet pressure, and secondary-side flow rates, inlet temperature, outlet pressure are equivalent.

2.2 Results

Figure 2 shows the results of thermal sizing of the PCSG with straight semicircular micro channels connected by cross bridges, compared with that of

PCSGs having the circular and square channels [2]. The volume of the PCSG with semicircular channels with cross bridges is similar to that with circular channels. That is, the PCSG with square channels shows the best thermal performance, because its gap between a primary-side channel and a secondary-side channel is thinner than the others. When the PCSG length is short, the quantity of channels should be increased to meet the equivalent thermal power. Thus, the flow velocity decreases, and the flow shows transition from turbulent flow to laminar flow, so that the thermal performance becomes worse, and the size of the PCSG is getting bigger.

Pressure drops of primary and secondary sides of the PCSGs are depicted in Figs. 3 and 4. The PCSG with cross bridges has approximately two times higher than the others. It is expected that the increment in the pressure drop is mainly resulted from the vortices in the cross bridges.

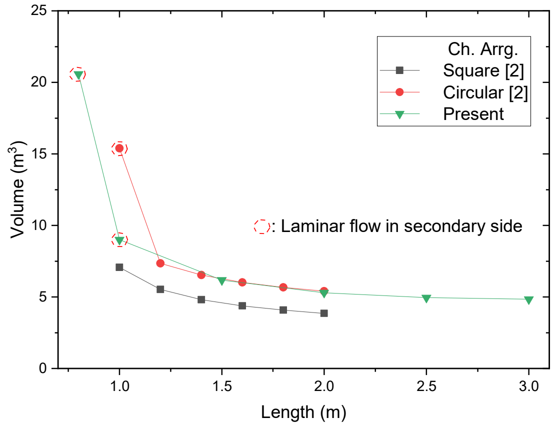


Fig. 2 PCSG volume

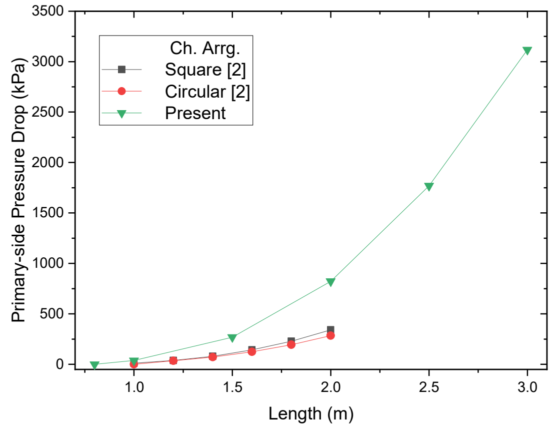


Fig. 3 Primary-side frictional pressure drop

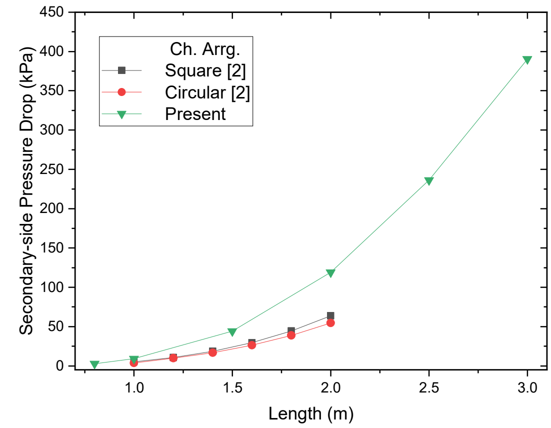


Fig. 4 Secondary-side frictional pressure drop

3. Conclusions

In this study, thermal sizing of the PCSG with straight semicircular micro channels connected by cross bridges was conducted, and compared with that of PCSGs evaluated in the previous study. The present PCSG has the similar thermal performance to the PCSG with circular channels, but shows the higher pressure drops than the others. However, the results of this study will be more useful to design the PCSG because the present PCSG is more practical and manufacturable.

Acknowledgement

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