An experimental setup for thermal oscillation near the dryout front in the single semi-circular channel

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1. Introduction

Recently, a compact heat exchanger technology has received attention for Small Modular Reactors (SMRs) application. A printed circuit steam generators (PCSG) is a kind of compact heat exchangers, which was the potential candidate for the steam generator in SMART [1]. The profound structural integrity and high compactness are main advantages of a PCSG. This is because PCSGs typically have 2 mm semi-circular channel diameter.

Due to the nature of a once-through steam generator, various boiling regimes occur in a PCSG; nucleate boiling, dryout, and dispersed flow film boiling regimes. In the dryout region, the wall is covered by the steam and dispersed flow film boiling occurs in the wall. The unstable nature of dryout front leads to the thermal oscillation in the tube wall temperature. It induces thermal stresses, and thus thermal fatigue failure may occur [2]. It is essential to characterize the thermal oscillation induced by dryout in the view of component service lifetime.

Aforementioned oscillation was mainly investigated in a circular tube in the past [3, 4]. Previous studies focus on a large-size tube having diameter greater than 8 mm. Therefore, an experimental study for the semi-circular channel with mini-sized diameter is crucial to understand the dryout front behavior. The objective of this study is to design the test section reflecting characteristics of PCSG channel geometry.

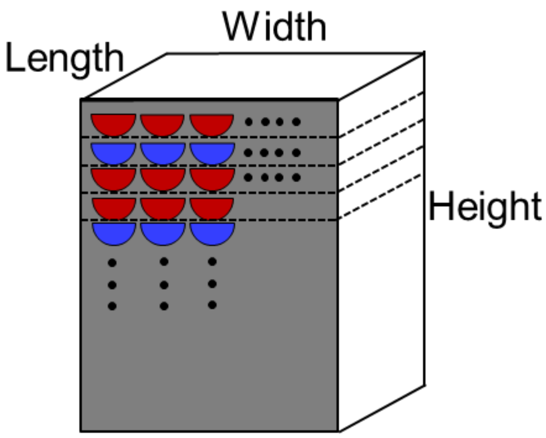

Figure 1. Schematic diagram of the PCHE

2. Setup for the thermal oscillation experiments

2.1 Test section

The test section is fabricated by stacking two plates and welding the joint as shown in Figure 2. Bolting between two plates was performed first to prevent the structural deformation during welding process. Another purpose of bolting is to give well defined geometry to the semi-circular flow channel by adhering two plates completely. The threaded bolt is also welded after the test section welding to maintain the hermiticity. The width and length are determined as 30 and 20 mm, respectively, considering many factors such as the heat loss, material buckling, and electrical resistance adequate for rectifier conditions held in the laboratory. The height is set to 1500 mm to reduce the wall temperature when dryout takes place. There is a 2 mm-wide groove with a depth of 9.5 mm in the middle of the upper plate. This is the space where the temperature sensors including the optical fiber and thermocouple are positioned. An optical fiber sensor with the diameter of 0.16 mm is located at the deepest place of the groove to measure the wall temperature directly. The thickness of 0.5 mm between the flow channel and the groove minimizes the temperature damping effect by sensitively tracking the temperature change of the inner wall.

The test section has single semi-circular channel with the diameter of 2 mm to focus on the thermal oscillation behavior for the thermal-hydraulic parameters without multi-channel effects as shown in Figure 3. The inlet and outlet of the flow channel, which is welded with outer diameter 0.25-inch tubes, is located in a perpendicular direction to the flow path. To generate the superheated steam in the flow channel, the rectifier transfers direct current to the test section through copper electrodes, which is placed on top and bottom of the test section by bolts and on the other side of the inlet and outlet.

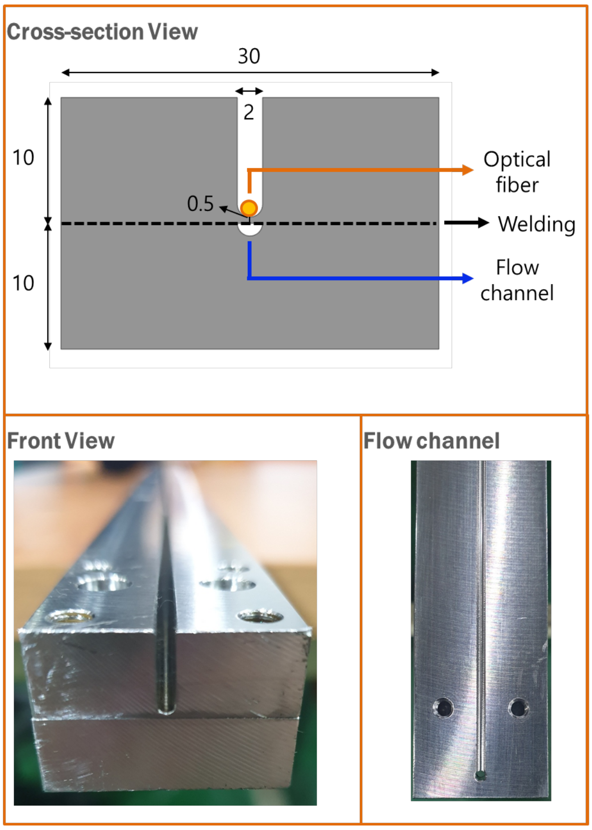

Figure 2. Cross section and front view of the test section

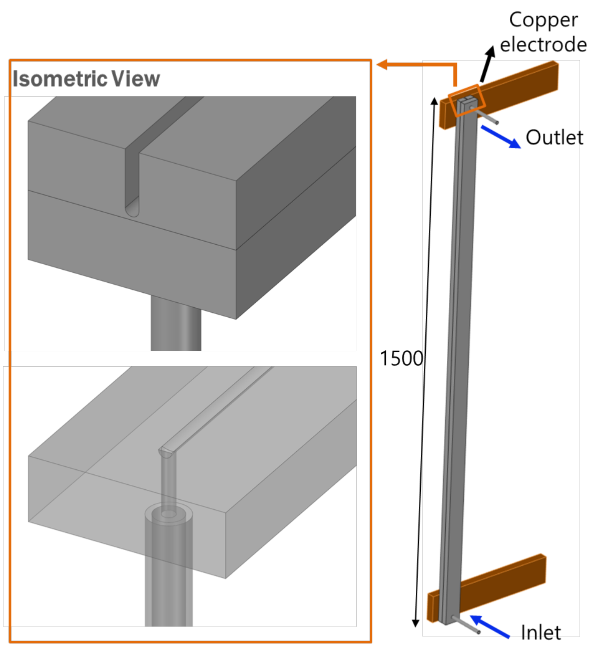

Figure 3. Isometric view of the test section

2.2 Test section analysis

A preliminary thermal-hydraulic analysis of the test section is conducted to check the test section design with one-dimensional analysis. The heat transfer rate in the control volume is determined by the electrical resistance heating. In the initial stage, the constant electrical resistance and current are assumed for every control volume, and then, an FDM analysis is conducted sequentially from the inlet to the outlet. An iterative scheme is adopted for converging the results since the electrical resistivity changes with respect to the temperature.

The maximum wall temperature is set to 400 °C considering the mechanical properties of stainless steel. The other constraint is the pressure drop of 30 kPa. It is assumed that the axial heat conduction is negligible in this study to conservatively design the test section.

Figures 4 and 5 present the temperature distribution of wall and bulk along the axial distance for the semi-circular channel diameter of 2 and 4 mm, respectively. The inlet and outlet temperatures are assumed at 40 °C and the superheat 30 °C, respectively. Thus, the range of outlet temperatures is from 141 °C to 182 °C, which corresponds to 1 bar to 5 bar pressure variation. The dryout can be recognized from the wall temperature distribution (near 1.4 m from the inlet). Since the heat transfer regime changes from nucleate boiling to dispersed flow film boiling after the dryout, the wall temperature rapidly increases. The magnitude of the temperature rise is significant compared to that of the PCSG design. This is because the rectifier supplies the same current along the axial direction of the test section, which means the test section has almost the same heat flux values in the flow channel wall. The heat transfer coefficient of working fluid is decreased at the downstream of dryout, and thus, a large temperature difference at the dryout point occurs to maintain the same heat flux condition.

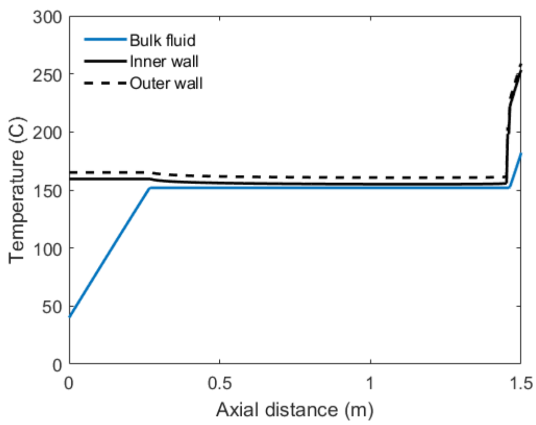

Figure 5. Temperature distribution versus the axial distance (2 mm of semi-circular diameter)

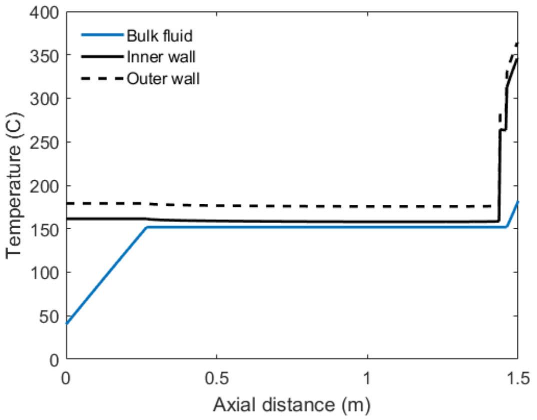

Figure 6. Temperature distribution versus the axial distance (4 mm of semi-circular diameter)

3. Summary and Further Works

A printed circuit steam generator is potential candidate for the future PWR type SMRs. Due to the nature of once-through type steam generator, dryout is always accompanied in PCSGs. The thermal oscillation induced by dryout has not studied for a mini-size flow channel previously, and hence, an experiment was planned to investigate the relation with thermal-hydraulic variables. For the first step, the test section was designed and manufactured while a preliminary numerical analysis was conducted to predict the experimental result. For the future works, experiments will be performed and analyzed and the data will be compared to the numerical modeling results.

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