Experimental study on flow boiling heat transfer characteristics in a helically coiled tube

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1. Introduction

Helically coiled tube heat exchangers are widely used for steam generators, refrigerators, and chemical plants. For the System-integrated Modular Advanced ReacTor (SMART), helically coiled tubes are used in the steam generators. The prediction of flow boiling heat transfer characteristics is very important for the design of the steam generators. However, there is a paucity of studies on flow boiling heat transfer characteristics in helically coiled tubes.

2. Experiments and Results

Experiments on flow boiling in a helically coiled tube were conducted to investigate heat transfer characteristics in the coiled tube. Detailed descriptions of the experimental facilities, test section, and results are provided in the following sections.

2.1 Experimental setup

This study's test loop of two-phase steam-water flow is schematically illustrated in Fig. 1. The major parameters which needed to be controlled and measured were the mass flow rate of the working fluid (water), the temperature of the working fluid at the inlet of the test section, the system pressure, and the wall heat flux applied to the working fluid. The loop consists of a water tank, a diaphragm pump to flow working fluids, a coriolis mass flow meter, two pre-heaters, a test section, a condenser, a sub cooler, and a back pressure regulator to maintain and control the system pressure.

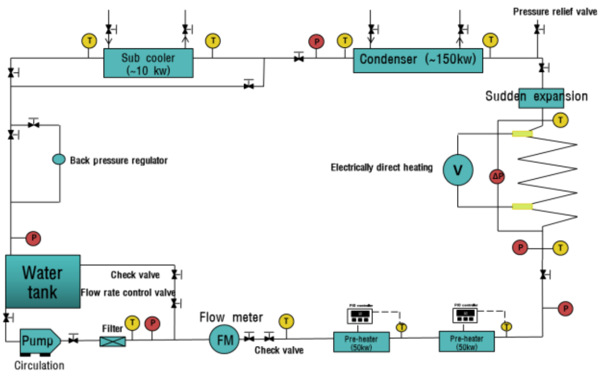

Fig. 1. Schematic image of experimental loop

The three test sections were made of a 2000 mm long Inconel tube of Ø 17 × 2.5 mm with helical diameters of 606, 977, and 1290 mm and helical angles of 8.89, 8.6, and 8.75°, respectively. To measure the local wall temperature, 76 K-type thermocouples were installed at 19 thermocouple stations along the tube. The longitudinal thermocouple stations were installed at intervals of 100 mm. There were four thermocouples at each station. The location of thermocouples around the tube cross section and along the tube is shown in Fig. 2. The test section was heated electrically by DC power supply to supply a uniform heat generation rate to the test section. Experimental conditions are listed in Table I.

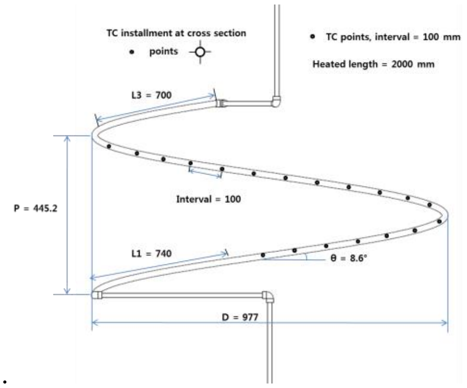

Fig. 2. Schematic image of the test section with helical diameter of 977 mm

Table I: Experimental conditions

Pressure (MPa)	Mass flux (kg/m^2s)	Heat flux (kW/m^2)
1.0-6.0	88.4-530.5	61-1130

2.2 Results and discussion

Nucleate boiling and convective boiling mechanisms take part in the flow boiling heat transfer process [1]. Thus, it is necessary to know whether nucleate boiling or convective boiling dominates in the local regions of flow boiling. The variations of the measured heat transfer coefficient at four heat fluxes for $P_{sat} \approx$ 2 MPa and G ≈ 350 kg/m^2s are shown in Fig. 3 to illustrate the influence of heat flux on heat transfer coefficients. Fig. 3 shows that the heat transfer coefficients increase with the increase of heat flux. Because heat flux is a major parameter which dominates nucleate boiling heat transfer, this result indicates that the effects of nucleate boiling on heat transfer coefficients is important in this experimental range.

Fig. 4 shows the variations of the heat transfer coefficients at three mass fluxes for $P_{sat} \approx$ 3.9 MPa and $q'' \approx$ 450 kW/m^{2}s. The figure indicates that there is no systematic dependence of local heat transfer coefficients on mass flux at a given heat flux. In fully developed nucleate boiling, the heat transfer coefficients are virtually independent of mass flux [2].

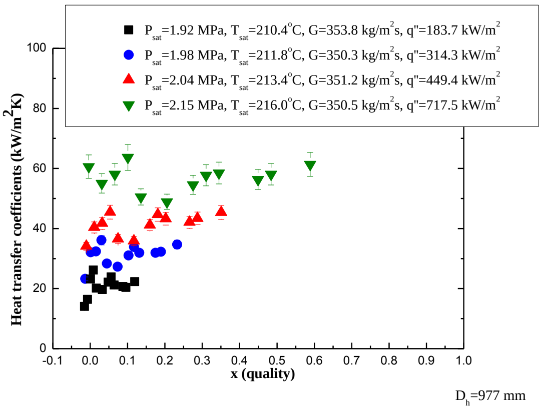

Fig. 3. Effect of heat flux on heat transfer coefficients.

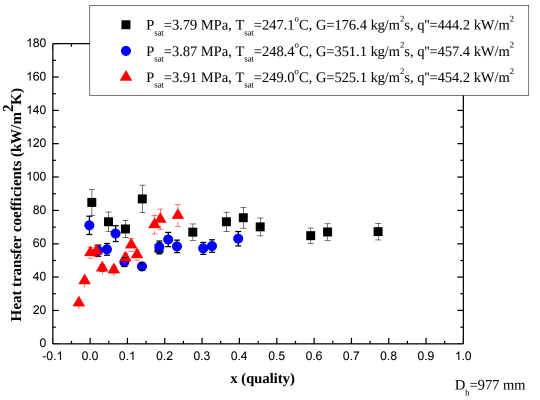

Fig. 4. Effect of mass flux on heat transfer coefficients.

The variations of the measured heat transfer coefficients at four pressures for G $\approx$ 350 kg/m^{2}s and $q'' \approx$ 720 kW/m^{2}s are shown in Fig. 5. The figure shows that the heat transfer coefficients increase with the increase of the system pressure.

Fig. 6 shows the effect of helical diameter (606, 977, and 1290 mm) on heat transfer coefficients for $P_{sat} \approx$ 2 MPa, G $\approx$ 180 kg/m^{2}s, and $q'' \approx$ 450 kW/m^{2}s. As shown in Fig. 6, the effect of helical diameter is not obvious. The effect of helical diameter is consistent with Owhadi et al. [3].

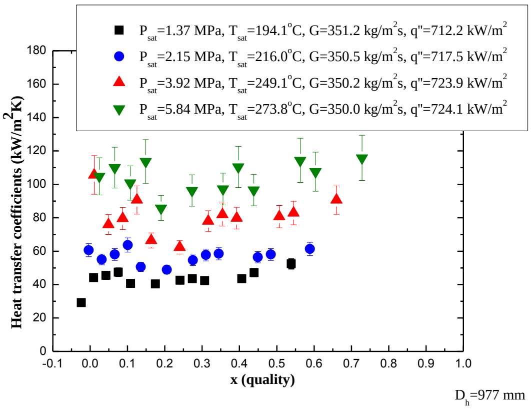

Fig. 5. Effect of system pressure on heat transfer coefficients.

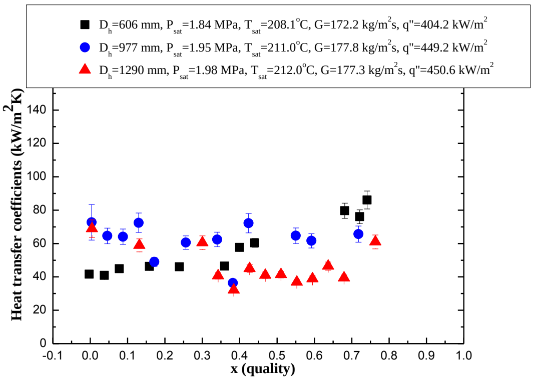

Fig. 6. Effect of helical diameter on heat transfer coefficients.

3. Conclusions

An experimental investigation of flow boiling heat transfer to water was conducted in three helically coiled tubes (D_h = 606, 977, 1290 mm). From the experimental results, it was found that heat transfer coefficients are dependent on heat flux and system pressure, but independent on mass flux and helical diameter.

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