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Measurement of Liquid Temperature Using Micro-thermocouple in Subcooled Flow Boiling

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1. Introduction

In this paper, algorithm is applied, which can discriminate the local liquid temperature in the two-phase flow measured by the self-designed micro-thermocouple. The algorithm used to calculate the temperature of each phase is based on the response time of micro-thermocouple and the exponential regression method. This algorithm is verified by the experiments with an optical chopper and a laser. In addition, this algorithm is applied to the measurement of the liquid temperature. The liquid temperature is measured by micro-thermocouple, which is made of alumel-chromel wire (K-type) with the outer diameter of 12.7 μm and the response time of several milliseconds. Finally, the liquid temperatures estimated by the developed algorithm in the subcooled boiling is used to assess the capability of CFX-4.2 code.

2. Applied Algorithm and Experimental Results

2.1 Micro-thermocouple

The measurements of phase temperatures have an important role to constitute the governing equation for energy. Thus, the sensor and algorithm to measure the fast changes in temperature, caused by phase transfer, accurately have been developed using the micro-sized sensor to measure temperatures[1,2]. The micro-thermocouple manufactured in this study has an outer diameter of 12.7 μm and is shaped like a hot-wire type. The micro-thermocouple is fabricated with a couple of alumel-chromel wire (K-type). The hot junction is twisted and the each wire is electrically insulated by ceramic tube. Each wire is supported by needle against the fluctuation of water and bubble. The wire with an outer diameter of 12.7 μm is extended with the read wire of 127 μm O.D. by pressing in the needle and is sealed up by an epoxy. Each wire adjacent to the junction in the needle is fixed with an epoxy.

2.2 Description of the Algorithm

The algorithm developed by S. J. Kim[3] is applied, using the characteristic curve of the micro-thermocouple. It has the exponential form dependent on time constant and consists of two steps.

In the first step of the applied algorithm, the phase between vapor and liquid in raw data from the micro-thermocouple is discriminated to find characteristic temperature curve piece by piece. The major parameter to discriminate the phases is applied as ATD(averaged temperature displacement) defined as follow.

$$ATD_{i+\frac{S}{2}} = \frac{\sum_{k=(i+S)}^{k=(i+S)+L} T_k - \sum_{k=i}^{k=i+L} T_k}{L} \qquad (1)$$

where L means the time interval between two averaged time-positions to calculate an averaged temperature. S means the time interval to calculate the displacement of the averaging temperature at the each time-position, where l and s mean $L\Delta f$ and $S\Delta f$, respectively. $1/\Delta f$ is the sampling rate of data acquisition system. These two parameters reduce noise effects of an actual micro-thermocouple signal. If a single bubble passes through the junction of the micro-thermocouple, ATD has the maximum value at time when the bubble starts to pass through the junction and the minimum value at time when the bubble passes through the junction completely. The phases are discriminated using characteristics of ATD.

In the second step of the algorithm, the temperature is calculated. It is assumed that temperature change is formed along the exponential curve. If the residence time in the hot junction of the micro-thermocouple is smaller than the time constant or similar magnitude orders, the hot-junction will not reach the temperature of exponential curve. Thus, temperature data is just a part of the whole of exponential curve. That is, the convergent temperature can be determined by exponential regression method, which was proposed by Stefan F.J. Langer[4]. The each calculated temperature becomes to build probabilities of temperature and to form PDF.

(1.1)

2.3 Experimental Results

The fabricated micro-thermocouple and the algorithm are applied to measure liquid temperature in the subcooled flow boiling. The inner tube of a 19 mm outer diameter is composed of a heated section and silver-soldered copper electrodes at both ends of the heated section. The heated section is a 1,870 mm long inconel 625 tube with a 1.5 mm wall thickness. This heated section is preceded and followed by 500 mm long and by 690 mm long, copper tubes, respectively. The visual observation and taking a photograph is possible because the outer tube is composed of Pyrex tube and stainless tubes with 32 mm inner diameter. The micro-thermocouple was installed at the position of and the temperature was measured at 0.6, 0.7, 0.9, 1.3, 1.8, 2.4, 3.1 and 3.8 mm from the heated wall, radially. Experiment conditions are located in Table 1.

In the subcooled flow boiling, there are various phenomena to be caused by bubbles and wakes which bubbles invoke. Thus, the liquid in subcooled flow boiling fluctuates due to liquid mixing by convection and vapor condensation. The temperatures of raw data are divided into two temperatures, which are high and low temperature, when the algorithm is applied. These divisions are to extract major temperatures in fluctuations of raw data. The high temperatures abstracted from the algorithm, mean major temperatures to increase liquid, and the low temperatures abstracted from algorithm mean major temperatures to decrease liquid. The vapor temperatures are filtered using the difference of the time constants between the vapor and the liquid. The liquid temperature can be determined as the expectation value of the high and low temperatures.

The algorithm was applied to the measured temperature using micro-thermocouple and the results were compared with CFX-4.2 as shown in Fig 1 and 2. The estimated temperatures using the developed algorithm make a good agreement with the results of CFX-4.2.

Table 1. Experimental cases of the subcooled flow boiling

Case	Flow Rate (LPM)	Liquid Velocity (m/s)	Heat Flux (kW/m^2)	Inlet Subcooled Degree(K)	Inlet Pressure (MPa)
G1Q1	17.9	0.5729	96.695	20.655	0.11823
G2Q1	13.9	0.4449	96.695	23.320	0.12216
G2Q2	13.9	0.4449	81.125	23.410	0.11875
G3Q3	10.0	0.3201	67.377	23.680	0.12473
G3Q2	10.0	0.3201	80.978	22.843	0.12430

3. Conclusion

The fabricated micro-thermocouple was used to measure liquid temperature in subcooled flow boiling. The fluctuation and phase change can be measured using the fabricated micro-thermocouple in this study. The temperature could be classified into major temperatures to be compensated except for the vapor temperature. The estimated liquid temperature to be the expectation value for the extracted temperatures applying the algorithm compared with the CFX-4.2 code. The results showed the CFX-4.2 made a good agreement with the estimated liquid temperature, comparatively.

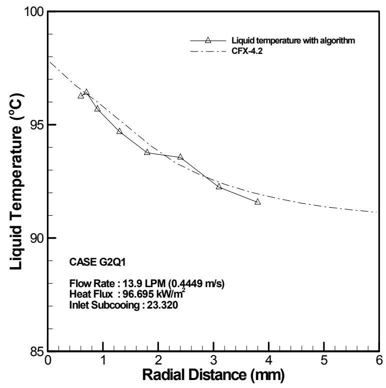

Figure 1. Comparison of liquid temperature (Case : G2Q1)

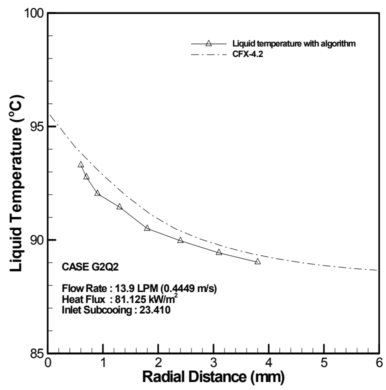

Figure 2. Comparison of liquid temperature (Case : G2Q2)

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