A Pool Boiling Experiment using a Fiber Optic Sensing Wire for Direct Measurement of Local Temperatures on a Heating Surface

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1. Introduction

Observing surface temperature during boiling phenomena is crucial because it provides valuable information on heat transfer and various boiling aspects through the boiling curve [1]. Surface temperature observations allow for understanding the heat transfer mechanism, predicting Critical Heat Flux (CHF), and assessing safety and reliability. Current boiling experiments measure surface temperature using resistance methods, infrared thermometry with IR cameras for temperature distribution, and using temperature sensor with thermocouple.

The method of measuring the temperature of a surface where boiling occurs using resistance measures the average temperature of the surface, and it cannot measure the local temperature of the surface [2]. Using an infrared camera allows confirmation of the temperature distribution of the surface [3]. And it is limited in environments where it is difficult to determine emissivity. Temperature sensor with thermocouples measures the temperature of the fluid near the surface rather than the direct temperature of the surface, so it cannot confirm the surface temperature.

The optical fiber sensor employs Rayleigh scattering via OFDR technology, enabling high-resolution analysis of optical paths and reflection characteristics with superior signal-to-noise ratios. By scanning specific wavelength ranges and measuring reflected light distribution, it monitors temperature changes. This sensor used in this study is capable of precise local temperature measurements with a spatial resolution of less than 1mm. This sensor is coated with gold externally. Utilizing it as a wire heater, we aim to measure the local temperature on the surface where boiling occurs, which was difficult to measure in previous experiments.

2. Experiments

Fig.1 depicts the setup of a pool boiling facility using an optical fiber sensor (OFS) as a wire heater. Luna's ODiSI 6000 model was utilized as the OFS data system. TC-1 is used to check the water temperature at the top, and TC-2 is used to check the water temperature at the bottom. The OFS is connected as shown in Fig.1. To reduce contact resistance, the sensor was connected using silver paste, as shown in Fig. 1, resulting in a measured resistance of 0.96 Ω.

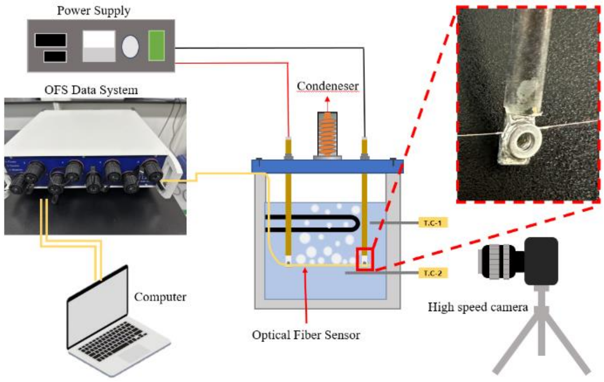

Fig. 1. Facility of wire pool boiling

The diameter of the sensor was confirmed to be 0.155 mm through SEM imaging, as shown in Fig .2. Based on this, experiments were conducted by applying joule heating. In this experiment, 700 mL of deionized water (DI water) was used. The water temperature was increased to approximately 100°C using a cartridge heater. The experiment started with a heat flux of 50 kW/m^2 applied to the wire, and every 10 minutes, the heat flux was increased by 50 kW/m^2. The sensor's gage pitch was set to 0.65 mm and it measures from a maximum of 62.5 Hz down to 15.625 Hz. A high-speed camera was used to visualize the boiling phenomenon occurring on the wire surface, operating under conditions of 1000 fps.

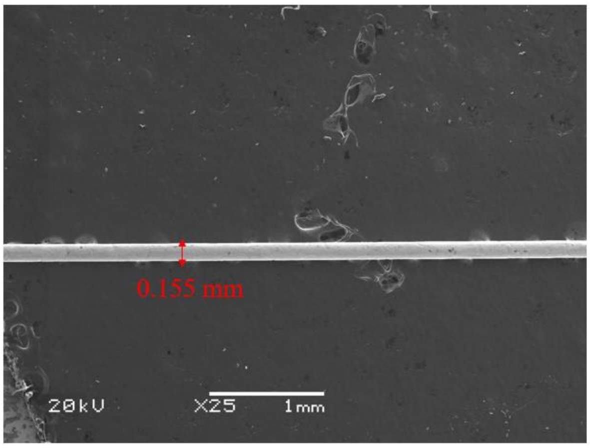

Fig.2. SEM pictures for diameter of OFS

3. Results

The experiment proceeded until 850 kW/m^2, where the wire was broken. Analysis was performed on half of wire.

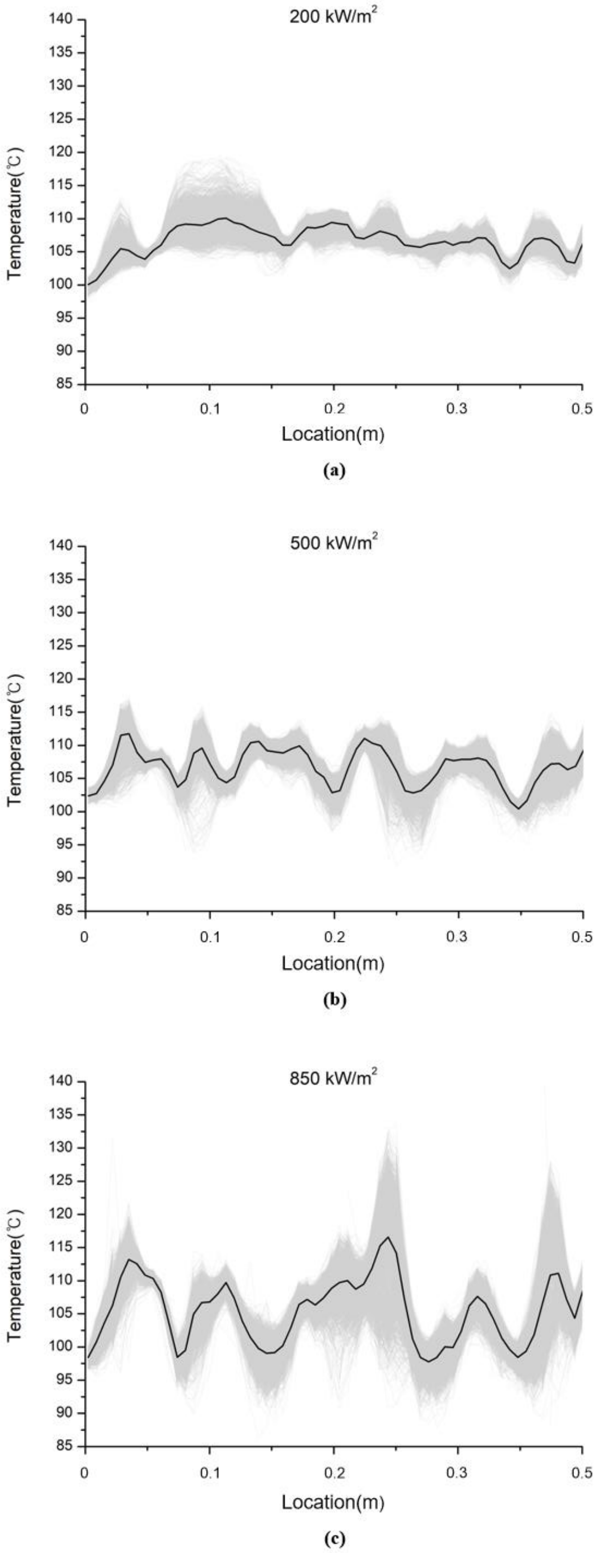

Fig. 3. Graph of temperature deviation on local of surface : (a); 200 kW/m^2, (b); 500 kW/m^2, (c); 850 kW/m^2

Fig. 3 shows the temperature variation on the surface where boiling occurs. In this graph, the gray background behind the black data lines represents the temperature changes over 10 minutes at each location on the surface, and the black data lines represent the average temperature at each surface location. Observing the graph in Fig. 3 (a), at a heat flux of 200 kW/m^2, a relatively stable temperature distribution is shown with slight temperature deviations from the average temperature. As the heat flux increases up to 850 kW/m^2, it can be observed that the deviation from the average temperature increase. This indicates the intensification of boiling phenomena, leading to increased temperature differences at each local surface where boiling occurs.

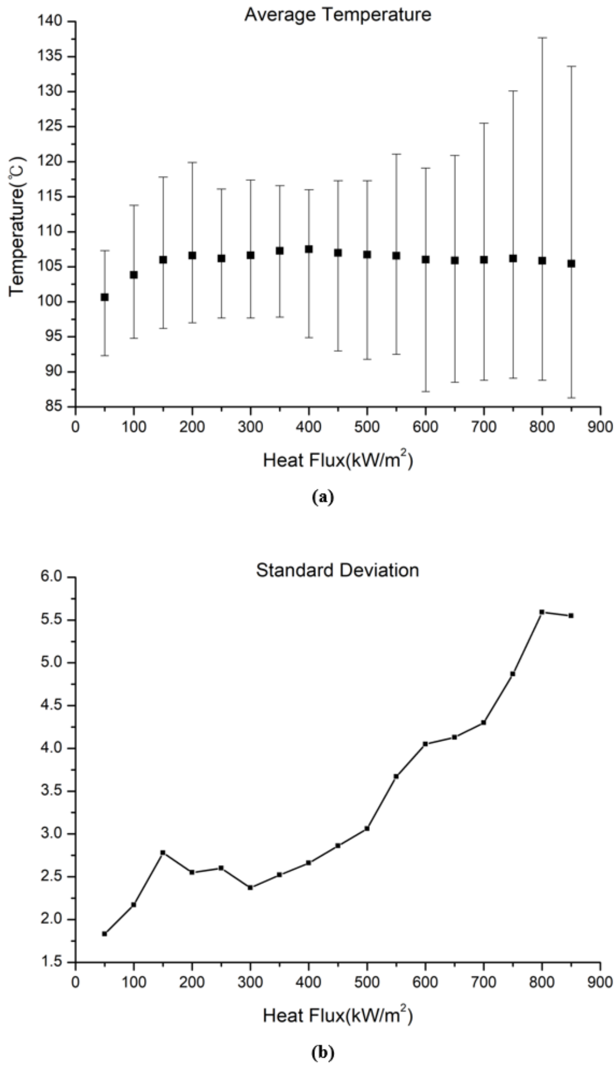

Fig. 4. Graph of average temperature and standard deviation : (a); average temperature, (b); standard deviation

Fig .4 shows the average temperature at different heat flux levels and allows for the observation of the maximum and minimum temperature values at each heat flux. It can be observed from this graph that as the heat flux increases, the deviation from the average temperature also increases. This is further illustrated using the standard deviation graph in Fig .4 (b). Based on this graph, it can be checked that as the heat flux increases, the temperature deviation also increases.

Fig .5 shows images of boiling phenomena at heat flux levels of 200 kW/m^2, 500 kW/m^2, 850 kW/m^2. Fig .5 shows the bubble departure diameter, bubble coalescence, number of bubbles and bubble growth as the heat flux increases. At low heat flux levels, bubbles appear with small and uniform diameters. This suggests that such phenomena occur due to the relatively small temperature differences causing boiling. As the heat flux increases to 500 kW/m^2, it can be observed that the bubble diameter becomes larger compared to the previous heat flux level, and bubble coalescence begins to occur, resulting in an increased number of bubbles.

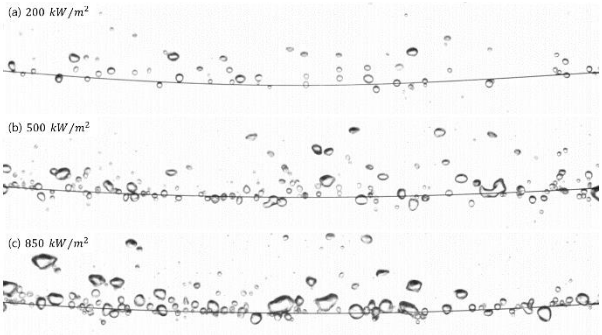

Fig. 5. Photographs of pool boiling on OFS

4. Conclusion

This study shows the measurement method of using a gold coated OFS for direct and precise measurement of local surface temperatures during boiling phenomena. The experimental setup, incorporating the OFS as a wire heater, allowed for detailed observation of temperature variations and boiling phenomena across different heat flux levels, up to the point of wire failure at 850 kW/m^2.

The results show local surface temperature during boiling experiment and shows the identification of increased temperature deviations and the impact on bubble diameter, coalescence, and number of bubbles with rising heat flux, contributing valuable insights into the complex nature of boiling heat transfer.

Future work could study the relationship between surface temperature variations and bubble dynamics and application of OFS in different boiling configurations and fluids, further solidifying its role in the advancement of heat transfer research and applications.

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