Experimental study on ONB, OFI and CHF for Subcooled Flow Boiling through one-side Heated Narrow Rectangular Channel

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1. Introduction

In the past decades, the compact volume systems such as heat exchangers, nuclear research reactors etc. have significantly adopted the use of subcooled flow boiling in narrow rectangular channel owing to high heat transfer capabilities [1, 2]. Subcooled flow boiling involves a boiling liquid whose bulk temperature is below the saturation, flowing over a surface exposed to a high heat flux.

The present work deals with an experimental investigation of the thermal hydraulic parameters of subcooled flow boiling such as onset of nucleate boiling (ONB), onset of flow instability (OFI) and critical heat flux (CHF) for an upward flow of water in a narrow one-side heated rectangular channel. The ONB was identified by using the slope of wall temperature deviation method whereas the OFI was determined using pressure drop and outlet pressure fluctuation.

2. Experimental facility and test condition

The schematic diagram of the experimental facility is shown in Fig. 1. It consists of a test section, water reservoir, heat exchanger, pump, flow meter, thermocouples, pressure transducers and data acquisition system (DAQ). Direct current power supply system is connected to supply the electrical power to the heater. The power supply is connected to the digital power meter by the current sensor input terminal to monitor the exact output power sent to the printed circuit board (PCB) heater.

The test section was made of clear acrylic material with a rectangular cross-section (10 × 35 mm) and a height of 155 mm. The flow channel had a cross-sectional area of 3 x 3 mm and height of 102 mm. A thin flat rectangular copper heater with the length of 102 mm and width of 1.5 mm was fabricated on the PCB and mounted on test section.

Before the experiment, the water in the loop was preheated until it reached the desired temperature and mass flowrate is set up using the manual control of the pump. Once the flow rate and inlet temperature are steady, power is added to the test section. The power is increased gradually step by step until CHF occurs which is evident by breaking up of the PCB heater. The experimental test condition are summarized in Table. I.

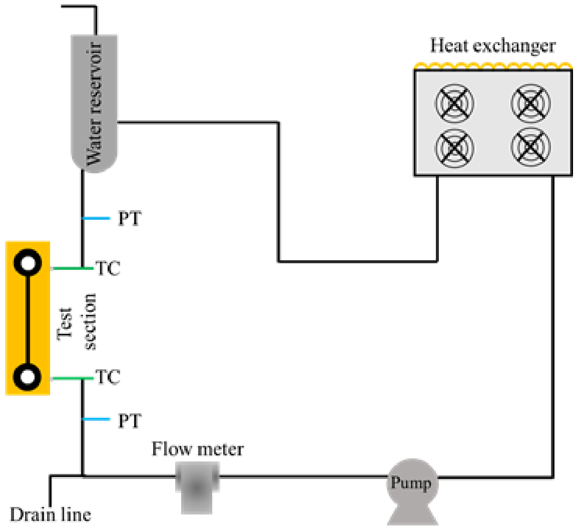

Fig. 1. Experimental apparatus

Table I: Test condition

Parameter	Value
Inlet temperature [°C]	30
Flow rate [kg/s]	0.0028, 0.0056 and 0.007
Inlet pressure [MPa]	0.013 – 0.017
Heat Flux [MW/m^2]	0.02 – 5.5

3. Results and discussion

Experiments were performed to investigate ONB, OFI and CHF for subcooled flow boiling in an upward narrow rectangular channel for three different mass flowrate conditions. The experimental results are summarized in Table II.

Table II: Experimental results

Flow rate [kg/s]	ONB [MW/m^2]	OFI [MW/m^2]	CHF [MW/m^2]
0.0028	0.37	2.33	3.57
0.0056	0.63	2.60	4.56
0.0070	0.90	4.14	5.43

3.1. ONB criteria

As shown in Fig. 2, the ONB incipience was identified using the wall temperature deviation method as the intersection of the single-phase and two-phase lines [3]. The goodness of fit for the single-phase and two-phase lines is measured by evaluating coefficient of determination, R^2 given as:

$$R^2 = 1 - (SS_{resid} / SS_{total}) \qquad (1)$$

where SS_{resid} = sum of squared residuals
and SS_{total} = sum of squared differences from the mean

The R^2 statistic which ranges from 0 to 1 measures how useful the independent variable is predicting values of the dependent variable. An R^2 value near 0 indicates that the fit is not much better than the model whereas an R^2 value near 1 indicates that the independent variable explains most of the variability in the dependent variable. Hence the number of data points to be used for fitting of single-phase and two-phase lines is selected based on the highest value of R^2. Table III explains this criteria for the single-phase line where 8 data points fitting is chosen as it corresponds to highest R^2 value.

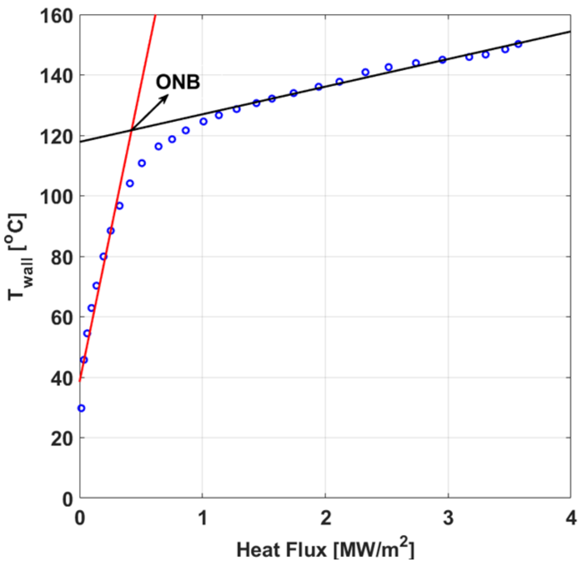

Fig. 2. ONB criteria

Table III: Calculation of R^2

No. of data points	SS_{resid}	SS_{total}	R^2
5	78.3579	991.6784	0.920985
6	124.9030	1612.4870	0.922540
7	171.8721	2451.7450	0.929898
8	242.9546	3526.8300	0.931112
9	355.6619	4816.1500	0.926152
10	522.3510	6295.7620	0.917031
11	842.3345	7901.3830	0.893394

3.2. OFI criteria

The OFI point was identified using the pressure drop and outlet pressure fluctuation [4]. As the heat flux was increased after ONB, more bubbles were generated on the heater surface finally leading to an instability along the flow channel. This point at which the pressure drop increased rapidly simultaneously with an increase in outlet pressure fluctuation was considered as OFI as shown in Fig. 3.

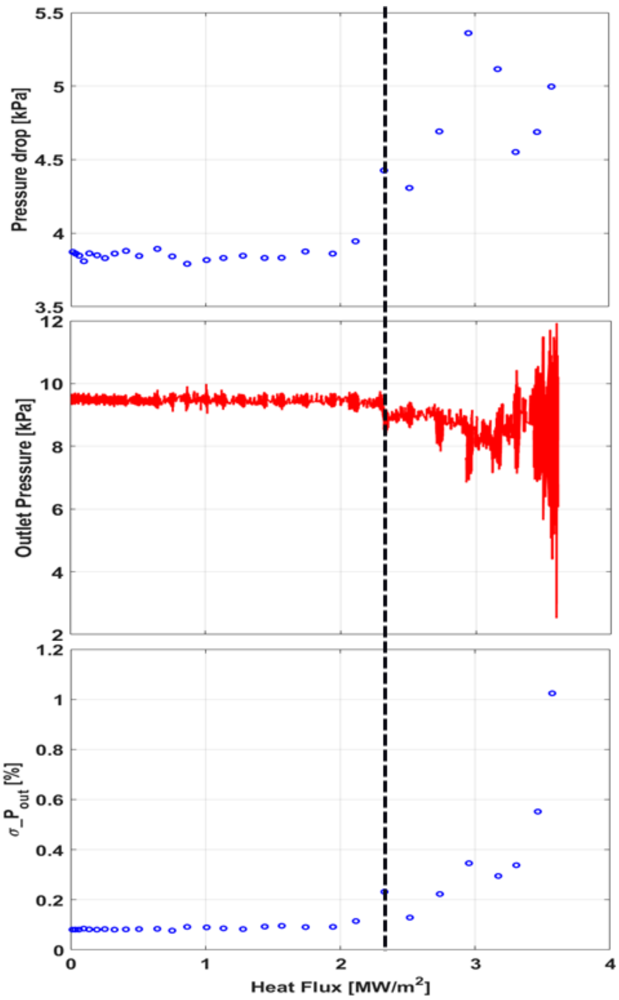

Fig. 3. OFI criteria

3.3. Critical heat flux (CHF)

The occurrence of CHF in subcooled flow boiling with high heat fluxes results in a significant increase in the wall temperature of heating surface which can lead to serious damage of the surface. Hence the CHF must be avoided.

All the three parameters i.e. ONB, OFI and CHF increased with increasing mass flow rate. As the increase in mass flow rate enhanced the heat transfer, more heat was required to achieve a high superheat wall temperature to initiate the ONB and the OFI and hence reach the CHF. However, the ratio of the heat flux required to be added after ONB to reach OFI and CHF differs for each experiment not in a consistent manner. For instance, for the mass flow rates of 0.0028 kg/s and 0.0056 kg/s, 1.96 MW/m^2 and 1.97 MW/m^2 were added respectively after the ONB to reach the OFI whereas 3.24 MW/m^2 were added when the mass flow rate was 0.007 kg/s. On the other hand, the amount of heat flux to be added after the OFI to reach the CHF condition was almost similar for the mass flow rates of 0.0028 kg/s and 0.007 kg/s i.e. 1.24 MW/m^2 and 1.29 MW/m^2 respectively whereas it was comparatively higher i.e. 1.96 MW/m^2 for the mass flow rate of 0.0056 kg/s. Hence, more experiments are required to be performed to further investigate the obvious reasons for these differences.

4. Conclusions

Experimental investigation of the subcooled flow boiling thermal hydraulic parameters i.e. ONB, OFI and CHF for a narrow rectangular channel heated from one side was carried out. The slope of the wall temperature was used to determine the ONB whereas the pressure drop and outlet pressure fluctuation were used to determine the OFI. All three parameters showed an increase in heat flux value as the mass flow rate was increased. The heat flux ratios between ONB and OFI and OFI and CHF were not consistent for the three mass flow rate conditions. Hence, more experiments are planned in future to investigate this inconsistency.

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