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Measurement of the Minimum Film Boiling Temperature Using a Hot-Patch Technique

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1. Introduction

The minimum film boiling temperature (T_{MFB}) is of vital importance in nuclear safety analysis since it plays a major role in judging whether the heat transfer is in the film-boiling regime or not. Some system codes [1, 2] use this temperature as a decision parameter for film-boiling. For example, in TRACE code [1], the minimum film boiling temperature is set to the maximum of that given by the Groeneveld-Stewart correlation and a value of 725 K to improve the predictive capability for reflood simulations based on data from FLECHT-SEASET and THTF reflood tests. However, to our experience, the minimum film boiling temperature predicted by the existing correlations [2] is usually lower than 725 K.

Literature survey reveals that in general the existing correlations were developed for high pressures and high flow rates. On the other hand, the pressure and flow rates are relatively low under the reflood circumstance during a large break loss-of-coolant accident. Hence, as a matter of fact, the existing correlations are out of the applicability to predict the thermal-hydraulics in reflood. Lack of experimental data for low pressures and low flow rates stimulated this study. In the present study, the minimum film boiling temperatures were measured using a hot-patch technique [3] in order to assess the conventional correlations.

2. Experimental setup and procedures

Figure 1 delineates the test section. The test section of a circular tube has an inner diameter of 14 mm and an outer diameter of 20 mm, and a length of 2000 mm. The test section is electrically heated by applying a DC power between bus-bars. Two hot-patches made of copper are attached to the test section, in order to form film boiling. Each hot patch was heated by eight 250 W cartridge heaters. A total of 44 thermocouples are attached on the outer surface of the tube to measure the axial wall temperature distribution.

Initially, the tube was empty and hot patches were heated up to 800 °C. The test section was theated to about 700 °C by DC power of about 7 kW. When the maximum wall temperature reaches 700 °C, subcooled water is then injected from the bottom of the test section. The power applied to each hot-patch is automatically controlled to maintain the hot patch temperature at 800 °C during the experiment. Due to high wall temperatures, water cannot contact the wall and thus the film boiling is maintained through the test section. After a steady-state is attained, the DC power applied to the tube was reduced stepwise by approximately 5% each time. Sufficient time was allowed for the flow to stabilize between steps. The process was repeated until the first detection of abrupt decrease of one of the wall temperatures.

Table 1 compares the typical reflood conditions with the present experimental conditions. The flow rate was measured by a mass flowmeter. The pressure and fluid temperature were measured at the inlet and exit of the test section. The inner wall temperatures were calculated using steady-state thermal conduction equation and the measured outer wall temperatures. The temperature difference between the outer and inner surface was estimated 10^{o}C for a typical condition.

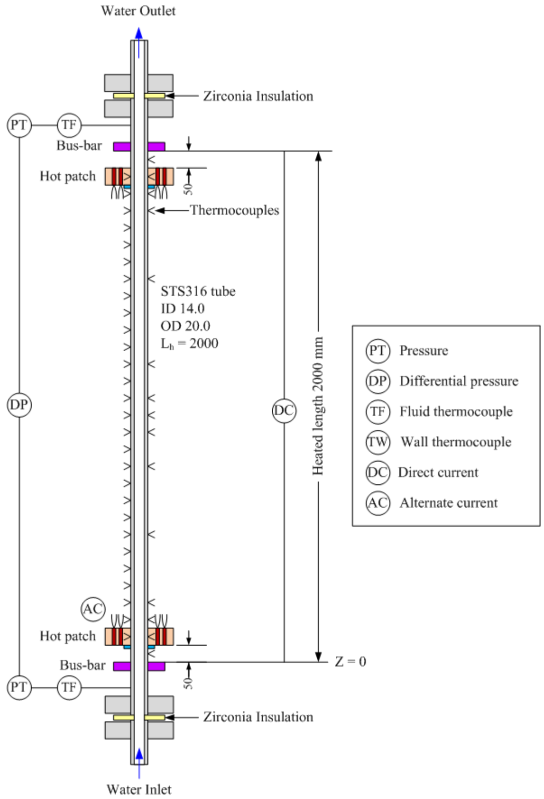

Fig. 1 Test section equipped with two hot patches

Table 1: Experimental Conditions

	Reflood conditions	Experiment
Pressure, p [MPa]	0.1~0.3	0.1, 0.2, 0.4
Max. wall temperature [^{o}C]	300~1204	<800
Mass flux, G [kg/m^{2}s]	20~250	50, 100
Inlet subcooling, ΔT [^{o}C]	<50	10, 20

3. Experimental Results

Preliminary experimental results were obtained. Figure 2 shows the temperature distribution along the test section before and after the first quenching at a point (z = 300 mm) between hot-patches for the inlet pressure of 0.1 MPa, the mass flux of 50 kg/m^{2}s, and inlet subcooling of 15 ^{o}C. The first quench appears at about 2683 seconds. The first quench temperature is considered as the minimum film boiling temperature, T_{MFB} (= 255^{o}C). Table 2 summarizes the experimental results. The quenching locations for three cases are the same. The values in the fourth and fifth columns are the applied powers between the inlet and the quenching location and the equilibrium equalities at the quenching location.

The Groeneveld & Stewart correlation is a function of pressure and equilibrium quality. Hence, for the first and second cases, the predicted minimum film boiling temperatures are the same. However, from a physical point of view, the minimum film boiling temperature is expected to increases with increasing mass flux. The present experiment shows this behavior. It is also observed that the minimum film boiling temperature increases with increasing the inlet subcooled temperature. One can say that the experiment seems physical. However, the measured temperatures are relatively deviated from the values obtained by the correlation, since the correlation was not developed based on the experimental database for reflooding conditions.

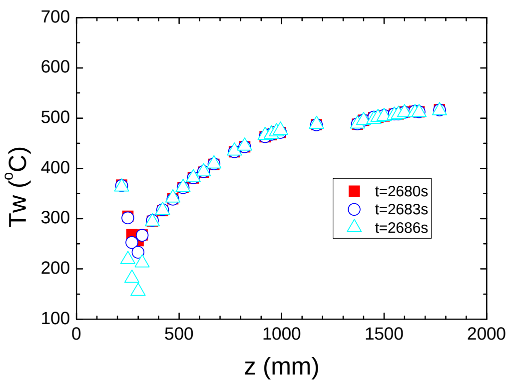

Fig. 2 Temperature distributions before/after first quench (p = 0.1 MPa, G = 50 kg/m^{2}s, ΔT = 15 ^{o}C)

Table 2 Comparison with Groeneveld-Stewart Correlation

p (MPa)	G (kg/m^{2}s)	T_{sub} (^{o}C)	Q [kW]	x	$T_{MFB,GS}$ (°C)	$T_{MFB,exp}$ (°C)
0.12	50	15	0.997	-0.028	384	255
0.12	100	15	1.145	-0.028	384	305
0.12	100	25	1.654	-0.047	448	321

4. Conclusions

Experiments were made to measure the minimum film boiling temperature for low pressure and low flow rate by using a hot-patch technique. The measured temperatures were somewhat deviated from the values obtained by the correlation. It is necessary to improve the conventional correlations at low pressure and low mass flux conditions. We are going to do additional experiment, in order to investigate the effects of pressure, mass flux, and inlet temperature.

Acknowledgements

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