Chapter 3

DATA REDUCTION

The single-phase liquid convection and two-phase flow boiling heat transfer coefficients of the coolant FC-72 flowing over the small heated plate on the bottom of a horizontal rectangular-channel will be deduced from the measured raw data. The data reduction procedures are described in the following.

3.1 Single-phase Heat Transfer

Before the two-phase experiments, the effective power input Q_e to the coolant flowing over the copper plate is evaluated from the difference between the total power input Q_t to the copper plate and the total heat loss of the test section Q_{loss}. The total power input can be calculated from the measured voltage drop across the electric-heater and the electric current passing through it.

The total power input Q_t and the effective power input Q_e are hence evaluated respectively from the equations:

$$Q_t = V \cdot I \tag{3.1}$$

Where V and I are individually the voltage drop across and current through the electric-heater, and

$$Q_e = Q_t - Q_{loss} \tag{3.2}$$

Here the total heat loss from the copper plate is approximately estimated from the relation

$$Q_{loss} = \frac{2\pi L k_T (T_w - T_{T,s})}{\ln(r_{T,s}/r_w)} + \frac{(T_e - T_{T,b})}{\dfrac{L_{T,b}}{k_T A_{T,b}} + \dfrac{L_M}{k_M A_M}} \tag{3.3}$$

Where k_T and k_M are the thermal conductivities of the Teflon and the mica, respectively; $A_{T,b}$ and A_M are respectively the bottom area of the Teflon block and the bottom area of the mica plate; L, $L_{T,b}$ and L_M are individually total thickness of the plates, the thickness of the Teflon plate, and the thickness of the mica; T_w and T_e are respectively the average temperature of the copper plate and the temperature at the electric-heater, T_T is the temperature of the Teflon block, as schematically shown in Fig. 2.7.

The imposed heat flux at the copper plate surface is defined as

$$q = Q_e / A_{cp} \tag{3.4}$$

where A_{cp} is the surface area of the copper plate. The relative heat loss from the test section is defined as

$$\varepsilon = \frac{Q_{loss}}{Q_t} \times 100\% \tag{3.5}$$

The results from this estimation show that the relative heat losses for all cases investigated here are about 20% at $q=10\ \mathrm{W/cm^2}$. The average single-phase liquid convection heat transfer coefficient over the copper plate is defined as

$$h_{1\phi} = \frac{Q_e}{A_{cp} \cdot (T_c - T_{in})} \tag{3.6}$$

where Q_e is the effective power input to the FC-72, T_{in} is the coolant temperature at the inlet of the test section, and T_c is the average temperature of the upper surface of the copper plate.

3.2 Two-phase Flow Boiling Heat Transfer

In the subcooled flow boiling experiment the state of coolant FC-72 at the inlet of the rectangular flow-channel is evaluated from the energy balance for the pre-heater. The total heat transfer rate in the pre-heater is calculated from the temperature drop on the water side as

$$Q_{w,p} = \dot{m}_{w,p} \cdot c_{p,w} \cdot (T_{w,p,i} - T_{w,p,o}) \tag{3.7}$$

where $\dot{m}_{w,p}$ is the mass flow rate of the hot water in the pre-heater, $c_{p,w}$ is the specific heat of water, and $T_{w,p,i}$ and $T_{w,p,o}$ are respectively the temperatures of the water at the pre-heater inlet and outlet. Note that in the pre-heater the coolant FC-72 is still in liquid state. Hence on the coolant side in the pre-heater

$$Q_{w,p} = \dot{m}_r \cdot c_{p,r} \cdot (T_{r,p,o} - T_{r,p,i}) \tag{3.8}$$

where $\dot{m}_r$ is the mass flow rate of the coolant in the pre-heater, $c_{p,r}$ is the specific heat of coolant, and $T_{r,p,o}$ and $T_{r,p,i}$ are the temperatures of the coolant at the pre-heater outlet and inlet, respectively. Combining the above two equations allows us to calculate $T_{r,p,o}$, which is considered as the temperature of FC-72 at the test section inlet. On the other hand, the average two-phase heat transfer coefficient for the coolant flow over the copper plate is defined as

$$h_{2\phi,sat} = \frac{Q_n}{A_{cp} \cdot (T_c - T_{sat})} \quad \text{for saturated flow boiling,} \tag{3.9}$$

and

$$h_{2\phi,sub} = \frac{Q_n}{A_{cp} \cdot (T_c - T_{r,bulk})} \quad \text{for subcooled flow boiling} \tag{3.10}$$

where T_{sat} is the saturated of the coolant FC-72 and $T_{r,bulk}$ is the bulk liquid temperature which is defined as

$$T_{r,bulk} = \frac{T_{r,i} + T_{r,o}}{2} \tag{3.11}$$

3.3 Uncertainty Analysis

Uncertainties of the single-phase liquid convection and flow boiling heat transfer coefficients and other parameters are estimated by the procedures proposed by Kline and McClintock [38]. The detailed results from this uncertainty analysis are summarized in Table 3.1.

Table 3.1 Summary of the uncertainty analysis

Parameter	**Uncertainty**
Rectangular channel geometry	
Length, width and thickness (%)	±0.5%
Area (%)	±1.0%
Parameter measurement	
Temperature, T (℃)	±0.2
Temperature difference, ΔT (℃)	±0.3
System pressure, P (kPa)	±2
Average mass flux of coolant, $\overline{G}$ (%)	±3
Amplitude of mass flux oscillation (%)	±4.8
Period of mass flux oscillation (sec)	±0.25
Single-phase heat transfer in rectangular channel	
Imposed heat flux, q (%)	±4.2
Heat transfer coefficient, $h_{1\phi}$ (%)	±12.3
Two-phase heat transfer in Rectangular channel	
Imposed heat flux, q (%)	±4.2
Heat transfer coefficient, $h_{2\phi}$ (%)	±12.3