CHAPTER 4 DATA REDUCTION

Data reduction from the measured results was done using the methods outlined below.

4.1 Heat transfer data reduction

In this present study, all thermophysical properties of the refrigerant R134a were evaluated using REFPROP, Version 6.01. The data reduction for the measured results is summarized in the following procedures.

The boiling heat transfer coefficient from the heating surface to the refrigerant can be defined as:

$$h_{\mathrm{ave}} = \frac{q''_{\mathrm{w}}}{\left(T_{\mathrm{w}} - T_{\mathrm{sat}}\right)} \qquad (4.1)$$

where T_{sat} is the liquid saturation temperature in the two-phase region. T_{w} is the local wall temperature that is evaluated from the thermocouple reading (T_{tc}) by assuming one-dimensional heat conduction between the thermocouple location and the channel's bottom wall.

$$T_{\mathrm{w}} = T_{\mathrm{tc}} - \frac{q''_{\mathrm{b}}\delta_{\mathrm{tc}}}{k_{\mathrm{s}}} \qquad (4.2)$$

In the above, δ_{tc} is the distance from the microchannel's base to the thermocouple's installed position. k_{s} is the thermal conductivity of copper, and q''_{b} is the base heat flux, which is obtained as follows:

$$q''_{\mathrm{b}} = \frac{\dot{Q}_{\mathrm{TS}}}{A_{\mathrm{b}}} \qquad (4.3)$$

where $\dot{Q}_{\mathrm{TS}}$ is a total electrical power input supplied to the test section, which is controllable using a DC power supply controller and measured with aClamp-On power meter. $A_{\rm b}$ is the cross-sectional base area of the heat sink, $A_{\rm b} = 22 \times 40\ {\rm mm}^2$. In equation1, q''_w is the heat flux on the channel wall of the microchannel. Following the notations of Fig. 6, q''_w is obtained from the following relation:

$$q''_{\rm w} = \frac{q''_{\rm b}(W_{\rm ch} + W_{\rm fin})}{W_{\rm ch} + 2\eta H_{\rm fin}} \tag{4.4}$$

where $W_{\rm ch}$, $W_{\rm fin}$, $H_{\rm fin}$ and η are the channel width, the fin width, the fin height and the fin efficiency, respectively. By assuming an adiabatic fin tip condition, the fin efficiency is given by Incopera (1996)

$$\eta = \frac{\tanh(m \cdot H_{\rm ch})}{m \cdot H_{\rm ch}} \tag{4.5}$$

where m is the fin parameter, which is defined as:

$$m = \sqrt{\frac{h \cdot 2\left(W_{\rm f} + L\right)}{k_{\rm s}\left(W_{\rm f} L\right)}} \tag{4.6}$$

in which L is the fin length. As is seen, Eq. (4.1) and Eqs. (4.3–4.5) are coupled. To obtain the heat transfer coefficient, an initial value for the fin efficiency was assumed; then, by iteration, the corrected value of efficiency was obtained. The vapor quality of the refrigerant R134a at the test section inlet and outlet were determined as follows:

$$x_{\rm TS,in} = \frac{i_{\rm TS,in} - i_{\rm l@TS,in}}{i_{\rm lv@TS,in}} \tag{4.7}$$

and

$$x_{\rm TS,out} = \frac{i_{\rm TS,out} - i_{\rm l@TS,out}}{i_{\rm lv@TS,out}} \tag{4.8}$$

where $i_{\rm l@TS,in}$ and $i_{\rm l@TS,out}$ are the enthalpy of the saturated liquid of the refrigerant, which was estimated based on the measured temperature at the inlet and outlet of the test section. $i_{\text{lv@TS,in}}$ and $i_{\text{lv@TS,out}}$ are the enthalpy of the vaporization of the refrigerant, which depend on the fluid temperature measured at the test section inlet and outlet, respectively. In equation (4.7), $i_{\text{TS,in}}$ is the refrigerant enthalpy at the test section inlet, which is given by:

$$i_{\text{TS,in}} = i_{\text{PH,in}} + \frac{\dot{Q}_{\text{PH,lat}}}{\dot{m}_{\text{ref}}} \tag{4.9}$$

where $i_{\text{PH,in}}$ is the enthalpy of the liquid phase refrigerant at the preheater inlet, $\dot{m}_{\text{ref}}$ is the refrigerant mass flow rate, and $\dot{Q}_{\text{PH,lat}}$ is the latent heat transfer rate in the pre-heater, which is defined as:

$$\dot{Q}_{\text{PH,lat}} = \dot{Q}_{\text{PH}} - \dot{Q}_{\text{PH,sen}} \tag{4.10}$$

where $\dot{Q}_{\text{PH}}$ is the total electrical power supplied to the pre-heater, which is controlled by a DC power supply controller, and $\dot{Q}_{\text{PH,sen}}$ is the sensible heat transfer rate in the pre-heater, which is calculated from

$$\dot{Q}_{\text{sen}} = \dot{m}_{\text{ref}} c_{p,\text{ref}} (T_{\text{PH,out}} - T_{\text{PH,in}}) \tag{4.11}$$

In equation (4.8), $i_{\text{TS,out}}$ is the refrigerant enthalpy at the test section outlet, which can be determined from:

$$i_{\text{TS,out}} = i_{\text{TS,in}} + \frac{\dot{Q}_{\text{TS}}}{\dot{m}_{\text{ref}}} \tag{4.12}$$

4.2 Pressure drop data reduction

The total boiling pressure drop was measured by the differential pressure transducer which is installed between the inlet and outlet of the test section. The total pressure drop includes the sudden contraction loss at the microchannel inlet and the sudden expansion loss at the outlet. Within the microchannel, the two-phase pressure drop consists of frictional and accelerational component. Therefore, the total pressure drop between the upstream and downstream plenums of the test section can be expressed as follows:

$$\Delta P_{\mathrm{total}} = \Delta P_{\mathrm{c}} + \Delta P_{\mathrm{f}} + \Delta P_{\mathrm{a}} + \Delta P_{\mathrm{e}} \tag{4.13}$$

The contraction and expansion pressure drop is the loss due to the abrupt geometry variations in the fluid flow path, which can be calculated from the following correlation, as proposed by Collier and Thome (1994).

$$\Delta P_{\mathrm{c}} = \frac{G^2}{2\rho_{\mathrm{l}}}\left[\left(C_{\mathrm{c}}^{-1} - 1\right)^2 + \left(1 - \sigma^2\right)\right]\left[1 + x_{\mathrm{in}}\left(\frac{\rho_{\mathrm{l}}}{\rho_{\mathrm{v}}} - 1\right)\right] \tag{4.14}$$

and

$$\Delta P_{\mathrm{e}} = \frac{G^2}{\rho_{\mathrm{l}}}\sigma\left(1 - \sigma\right)\left[1 + x_{\mathrm{out}}\left(\frac{\rho_{\mathrm{l}}}{\rho_{\mathrm{v}}} - 1\right)\right] \tag{4.15}$$

In Eqs. (4.14) and (4.15), G represent the mass flux that is calculated based on the smaller cross-section area, σ is the cross-section area ratio and, ρ_{l} and ρ_{v} are the liquid and vapor density and C_{c} is the coefficient of contraction which can be given by Chisholm (1983) as shown in Eq. (4.16).

$$C_{\mathrm{c}} = \frac{1}{0.639\left(1 - \sigma\right)^{0.5} + 1} \tag{4.16}$$

Finally, the the accelerational pressure drop, which is the loss due to change in vapor quality along the channel, is calculated as:

$$\Delta P_{\mathrm{a}} = \left[\frac{G^2 x^2}{\rho_{\mathrm{v}} \alpha} + \frac{G^2 \left(1 - x^2\right)}{\rho_{\mathrm{l}} \left(1 - \alpha\right)} \right]_{out} - \left[\frac{G^2 x^2}{\rho_{\mathrm{v}} \alpha} + \frac{G^2 \left(1 - x^2\right)}{\rho_{\mathrm{l}} \left(1 - \alpha\right)} \right]_{in} \qquad (4.16)$$

where the void fraction, α, can be determined using any of the several correlations suggested in the literature. In this study, it is calculated using Zivi (1964)’s void fraction correlation

$$\alpha = \left[1 + \frac{\left(1 - x\right)}{x} \left(\frac{\rho_{\mathrm{v}}}{\rho_{\mathrm{l}}} \right)^{\frac{2}{3}} \right]^{-1} \qquad (4.17)$$