CHAPTER 4 DATA REDUCTION

The following calculation is employed to determine the vapor quality of the refrigerant entering and exiting test section, heat transfer coefficient, and two-phase friction factor, from the data recorded during each test run at steady state conditions.

4.1 The inlet vapor quality of the test section ($x_{TS,in}$)

$$x_{TS,in} = \frac{i_{TS,in} - i_{lT_{TS,in}}}{i_{fgT_{TS,in}}} \tag{4.1}$$

where $i_{lT_{TS,in}}$ and $i_{fgT_{TS,in}}$ are the enthalpy of the saturated liquid and the enthalpy of vaporization, respectively, based on the temperature at the test section inlet, and $i_{TS,in}$ is the enthalpy of refrigerant at the test section inlet, which is calculated by the following equation:

$$i_{TS,in} = i_{ph,in} + \frac{Q_{ph}}{m_{ref}} \tag{4.2}$$

where $i_{ph,in}$ is the inlet enthalpy of the liquid refrigerant before entering the pre-heater, m_{ref} is the mass flow rate of the refrigerant, and Q_{ph} is the heat transfer rate in the pre-heater:

$$Q_{ph} = m_{w,ph}\, c_{p,w} (T_{w,in} - T_{w,out})_{ph} \tag{4.3}$$

with $m_{w,ph}$ being the mass flow rate of water entering the pre-heater.

4.2 The outlet vapor quality of the test section ($x_{TS,out}$)

$$x_{TS,out} = \frac{i_{TS,out} - i_{lT_{TS,out}}}{i_{fgT_{TS,out}}} \tag{4.4}$$

where $i_{TS,out}$ is the refrigerant enthalpy at the test section outlet, $i_{lT_{TS,out}}$ is the enthalpy of the saturated liquid based on the temperature at the test section outlet, and $i_{fgT_{TS,out}}$ is the enthalpy of vaporization based on the temperature at the test section outlet. As a consequence, the outlet enthalpy of the refrigerant flow is calculated as:

$$i_{TS,out} = i_{TS,in} + \frac{Q_{TS}}{m_{ref}} \qquad \text{for evaporation} \qquad (4.5)$$

$$i_{TS,out} = i_{TS,in} - \frac{Q_{TS}}{m_{ref}} \qquad \text{for condensation} \qquad (4.6)$$

where the heat transfer rate, Q_{TS}, in the test section is obtained from:

$$Q_{TS} = m_{w,TS} c_{p,w} (T_{w,in} - T_{w,out})_{TS} \qquad \text{for evaporation} \qquad (4.7)$$

$$Q_{TS} = m_{w,TS} c_{p,w} (T_{w,out} - T_{w,in})_{TS} \qquad \text{for condensation} \qquad (4.8)$$

where $m_{w,TS}$ is the mass flow rate of the water entering the test section, and $(T_{w,in} - T_{w,out})_{TS}$ is the difference in water temperature between the outlet and inlet positions.

4.3 Average heat transfer coefficient (h_{avg})

The average heat transfer coefficient (h_{avg}) can be calculated using the following equation:

$$h_{avg} = \frac{Q_{TS}}{A_i (T_{i,avg,wi} - T_{avg,sat})} \qquad \text{for evaporation} \qquad (4.9)$$

$$h_{avg} = \frac{Q_{TS}}{A_i (T_{avg,sat} - T_{i,avg,wi})} \qquad \text{for condensation} \qquad (4.10)$$

where $T_{avg,sat}$ is the average temperature of the refrigerant at the test section inlet and outlet, $T_{i,avg,wi}$ is the average temperature of the inner wall, and A_i is the inside surface area of the test section.

4.4 Two-phase friction factor (f_{tp})

The total pressure gradient is the sum of three contributions: the gravitational pressure gradient, the momentum pressure gradient, and the frictional pressure gradient as follows:

$$\left(\frac{dP}{dz}\right)_T = \left(\frac{dP}{dz}\right)_F + \left(\frac{dP}{dz}\right)_G + \left(\frac{dP}{dz}\right)_M \tag{4.11}$$

Pressure drop due to gravity can be determined from:

$$\left(\frac{dP}{dz}\right)_G = -g\left[(1-\alpha)\rho_l + \alpha\rho_g\right] \tag{4.12}$$

where the void fraction, α, can be determined from the Zivi correlation (1975):

$$\alpha = \frac{1}{1+\frac{(1-x)}{x}\left(\frac{\rho_g}{\rho_l}\right)^{2/3}} \tag{4.13}$$

The momentum pressure gradient can be defined as follows:

$$\left(\frac{dP}{dz}\right)_M = G^2\frac{d}{dz}\left[\frac{(1-x)^2}{\rho_l(1-\alpha)} + \frac{x^2}{\rho_g\alpha}\right] \tag{4.14}$$

The two-phase frictional pressure gradient can be obtained by subtracting the gravitational and momentum terms from the total measured pressure drop as follows:

$$\left(\frac{dP}{dz}\right)_F = \left(\frac{dP}{dz}\right)_T - \left(\frac{dP}{dz}\right)_G - \left(\frac{dP}{dz}\right)_M \tag{4.15}$$

The two-phase friction factor is calculated by the following equation based on the equivalent Reynolds number:

$$f_{tp} = \left(\frac{dP}{dz}\right)_F \frac{\rho_l d_i^3}{2\,\mathrm{Re}_{eq}^{\;2}\,\mu_l^{\;2}} \tag{4.16}$$

where the equivalent Reynolds number is determined from:

$$\mathrm{Re}_{eq} = \frac{G_{eq} d_i}{\mu_l} \tag{4.17}$$

and equivalent mass flux is defined as:

$$G_{eq} = G[(1-x) + x\sqrt{\frac{\rho_l}{\rho_g}}] \tag{4.18}$$