CHAPTER 2 FUNDAMENTAL DEFINITION OF THE FLOW PARAMETERS

This chapter introduces the primary variables which are used throughout this study and derives some simple relationships between them for the case of one-dimensional two-phase flow. In order to categorize between the liquid and vapor phase of the fluid, the subscripts 'l' and 'v' are used for liquid and vapor, respectively.

2.1 Two-phase flow

In flow boiling processes, the vapor and liquid are in simultaneous motion inside the tube. The resulting two-phase flow is generally more complicated physically than single-phase flow. The important variables, including the non-dimensional numbers used to investigate the heat transfer and pressure drop are presented as follows.

2.1.1 Mass flux

The mass flux (G) is defined to be the ratio of the mass flow rate to the cross-section area:

$$G = \frac{\dot{m}}{A} \tag{2.1}$$

2.1.2 Vapor quality

The vapor quality (x) is defined to be the ratio of the vapor mass flow rate to the total mass flow rate:

$$x = \frac{\dot{m}_v}{\dot{m}_v + \dot{m}_l} \tag{2.2}$$

2.1.3 Reynolds number

The first important non-dimensional number is the Reynolds number. It represents the ratio of inertia forces to viscous forces. In the case of convection inside a circular channel, the general form of the Reynolds number can be expressed in the following form:

$$\mathrm{Re} = \frac{\rho u D_h}{\mu} \tag{2.3}$$

Where D_h is the hydraulic diameter, which is defined as the ratio of 4 times cross-sectional area of fluid, *A*, to the wetted perimeter, *P*.

$$D_h = \frac{4A}{P} \tag{2.4}$$

In two-phase flow, the Reynolds of liquid phase can be expressed as:

$$\mathrm{Re}_l = \frac{G D_h \left(1 - x\right)}{\mu_l} \tag{2.5}$$

The same approach can be used for vapor phase, which is defined as:

$$\mathrm{Re}_v = \frac{G D_h x}{\mu_v} \tag{2.6}$$

In that situation, each phase flows alone completely in the cross-section of the channel. Another type of Reynolds number may be calculated:

$$\mathrm{Re}_{lo} = \frac{G D_h}{\mu_l} \tag{2.7}$$

$$\mathrm{Re}_{vo} = \frac{G D_h}{\mu_v} \tag{2.8}$$

2.1.4 Nusselt number

The Nusselt number is one of the dimensionless representations of the heat transfer coefficient. It is defined for an internal flow as the ratio of the convective heat transfer to conduction heat transfer as shown in the following equation:

$$\mathrm{Nu} = \frac{hD_h}{k} \tag{2.9}$$

2.1.5 Weber number

The Weber number expresses the ratio of the inertia to surface tension forces, which is expressed in the following form:

$$\mathrm{We} = \frac{\rho u^2 D_h}{\sigma} \tag{2.10}$$

Generally, in two-phase flow boiling experiments, the liquid and the vapor Weber number can be expressed in the following form:

$$\mathrm{We}_l = \frac{G^2 D_h (1-x)}{\rho_l \sigma} \tag{2.11}$$

And

$$\mathrm{We}_v = \frac{G^2 D_h x}{\rho_v \sigma} \tag{2.12}$$

When the liquid and vapor phase only flows alone in the complete cross-section of the channel, another type of Webber number can be calculated:

$$\mathrm{We}_{lo} = \frac{G^2 D_h}{\rho_l \sigma} \tag{2.13}$$

And

$$\mathrm{We}_{vo} = \frac{G^2 D_h}{\rho_v \sigma} \tag{2.14}$$

2.1.6 Prandtl number

The Prandtl number is defined as the ratio of momentum diffusivity to the thermal diffusivity of the fluid which is expressed as follows:

$$\mathrm{Pr} = \frac{\mu c_p}{k} \tag{2.15}$$

Both the liquid Prandtl number, Pr_l ,and the vapor Prandtl number, Pr_v ,are used in two-phase heat transfer, using the respective properties of each phase.

2.1.7 Froude number

The Froude number represents the ratio of inertia forces of gravitational forces. The general expression is:

$$\mathrm{Fr} = \frac{G^2}{\rho^2 g D_h} \tag{2.16}$$

Similarly, the Froude number of the liquid and vapor phase can be defined by replacing ρ with ρ_l and ρ_v , respectively.

2.1.8 Boiling number

The boiling number expresses the ratio between the heat flux and the potential heat flux that would have been applied for complete evaporation:

$$\mathrm{Bo} = \frac{q}{h_{fg} G} \tag{2.17}$$

2.1.9 Martinelli parameter

The Martinelli parameter is the ratio of theoretical frictional pressure drop that would occur if each phase could flow separately in the cross-section of the channel. In general the Martinelli parameter is calculated as:

$$X = \left[\frac{(dP/dz)_l}{(dP/dz)_v} \right]^{0.5} \tag{2.18}$$

where

$$\left(\frac{dP}{dz} \right)_l = \frac{G^2 f_l}{2D_h \rho_l} (1-x)^2 \tag{2.19}$$

and

$$\left(\frac{dP}{dz} \right)_v = \frac{G^2 f_v}{2D_h \rho_v} x^2 \tag{2.20}$$

The friction factor for phase α (which denotes f for liquid phase or v for vapor phase) in Eqs. (2.1) and (2.1) is given by

$$f_\alpha = 64 \mathrm{Re}_\alpha^{-1} \text{ for } \mathrm{Re}_\alpha < 2000 \tag{2.21}$$

$$f_\alpha = 0.3164 \mathrm{Re}_\alpha^{-0.25} \text{ for } \mathrm{Re}_\alpha \geq 2000 \tag{2.21}$$

$$\mathrm{Re}_\alpha = \mathrm{Re}_l \text{ for liquid phase} \tag{2.23}$$

$$\mathrm{Re}_\alpha = \mathrm{Re}_v \text{ for vapor phase} \tag{2.24}$$