CHAPTER 2 BACKGROUND KNOWLEDGE

2.1 Two-phase flow patterns

The main characterizing feature of two-phase flows is the fact that an interface exists between the two phases and, in gas-liquid flow, this interface takes a wide variety of forms. There is an almost infinite range of possibilities, but, in general, the surface-tension effects tend to create curved interfaces leading to spherical shapes (droplets or bubbles). The bigger occlusion of the discontinuous phases in the continuous phase causes the bigger the departure from a spherical shape. Thus, small droplets tend to be spherical whereas bigger ones are often deformed in the gas flow, and so do bubbles. The description of two-phase flow can be simplified by classifying types of interfacial distribution and calling these ‘flow regimes’ or ‘flow patterns’. It should be stressed at the outset that classification of types of flow, though extremely useful, is still highly qualitative and often very subjective. Many different regimes have been defined and wide varieties of names have been used. The flow patterns encountered in vertical upwards co-current flows are illustrated in Fig. 2.1 together with actual photographs of each pattern. Regimes are defined as follows (Collier and Thome 1994).

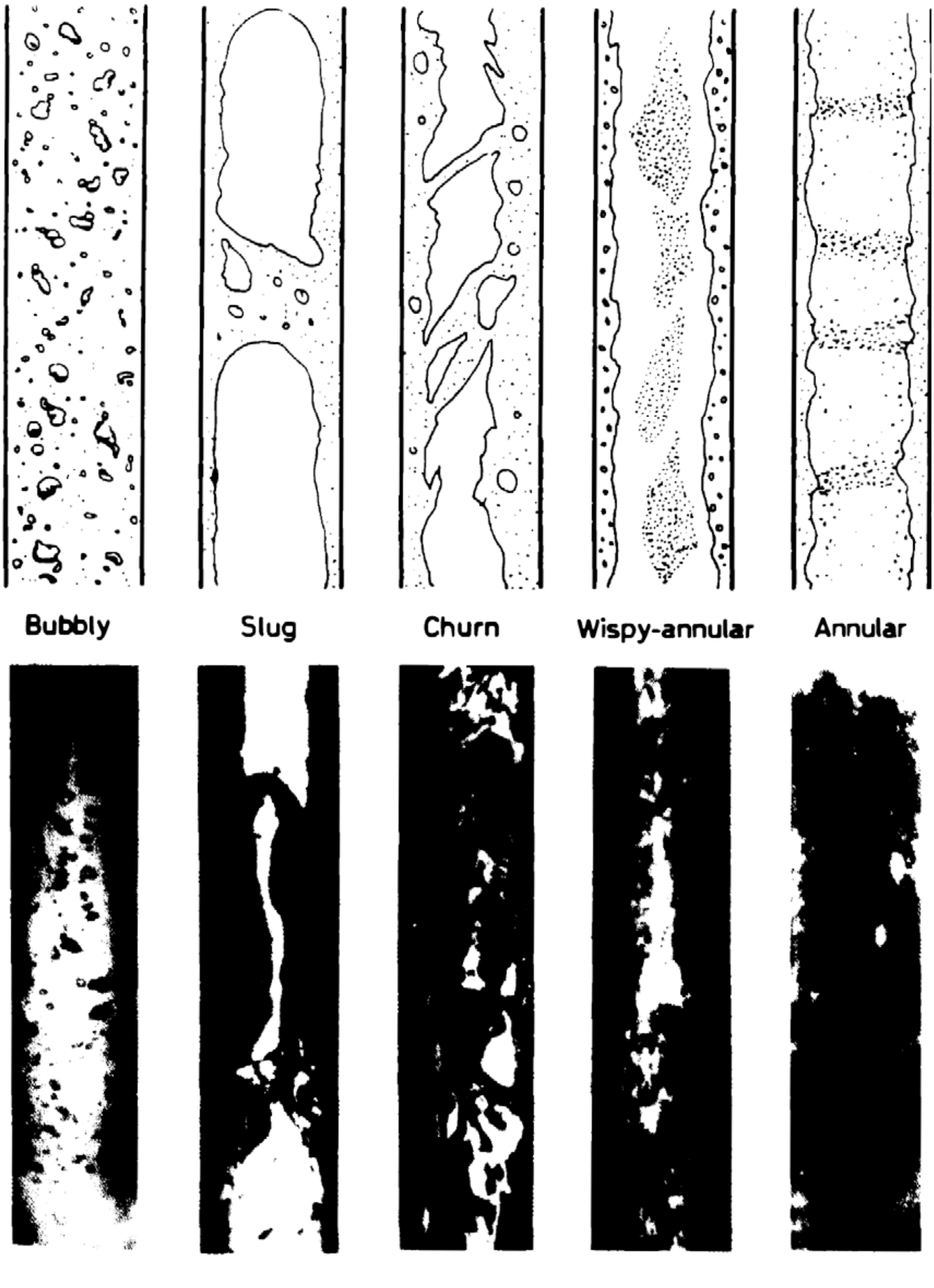

Figure 2.1 Flow pattern in vertical co-current flow (Collier and Thome 1994).

2.1.1 Bubbly flow

In bubbly flow the gas or vapor phase is distributed as discrete bubbles in a continuous liquid phase. At one extreme the bubbles may be small and spherical and at the other extreme the bubbles may be large with a spherical cap and a flat tail. In this latter state, although the size of bubbles does not approach the diameter of the pipe, there may be some confusion with slug flow.

2.1.2 Slug flow

In slug flow the sizes of the gas or vapor bubbles are approximately the diameter of the pipe. The nose of the bubble has a characteristic spherical cap and the gas in the bubble is separated from the pipe wall by a slowly descending film of liquid. The liquid flow is contained in liquid slugs which separate successive gas bubbles. These slugs may or may not contain smaller entrained gas bubbles carried in the wake of a large bubble. The length of the main gas bubble can vary considerably.

2.1.3 Churn flow

Churn flow is formed by the breakdown of the large vapor bubbles in the slug flow. The gas or vapor flows in a more or less chaotic manner through the liquid which is mainly displaced to the channel wall. The flow has an oscillatory or time varying character, hence, the descriptive name ‘churn’ flow. This region is also sometimes referred to as semi-annular or slug-annular flow.

2.1.4 Wispy-annular flow

The flow in this region takes the form of a relatively thick liquid film on the wall of the pipe together with a considerable amount of liquid entrained in a central gas or vapor core. The liquid in the film is aerated by small gas bubbles and the entrained liquid phase appears as large droplets which have agglomerated into long irregular filaments or wisps. This region occurs at high mass velocities and because of the aerated nature of the liquid film could be confused with high velocity bubbly flow.

2.1.5 Annular flow

In annular flow a liquid film forms at the pipe wall with a continuous central gas or vapor core. Large amplitude coherent waves are usually present on the surface of the film and the continuous break up of these waves forms a source for droplet entrainment which occurs in varying amounts in the central gas core. In this case, as distinct from the wispy-annular pattern, the droplets are separate rather than agglomerated.

2.2 Heat transfer enhancement techniques

There are different techniques used for heat transfer enhancement, which are classified into two groups: (1) active and (2) passive methods. Active methods are those that require external power such as surface vibration, fluid vibration and electrostatic field to facilitate the desired flow modification and concomitant improvement in the rate of heat transfer. The second group is passive methods which do not require direct input of external power such as treated surfaces, extended surfaces and coiled tube. The classification of various heat transfer enhancement techniques are shown in Table 2.1.

2.2.1 Passive methods

- Treated surfaces involve fine-scale alternation of the surface finish or coating (continuous or discontinuous) as shown in Fig 2.2. They are widely used for boiling and condensation, while, they have slight effects on the single-phase heat transfer.

Table 2.1 Classification of various heat transfer enhancement techniques

Active Methods	**Passive Methods**
Mechanical aids	Treated surfaces
Surface vibration	Extended surfaces
Fluid vibration	Displaced enhancement devices
Electrostatic field	Swirl flow devices
Injection	Coiled tube
Suction	Surface tension devices
Jet impingement	Additive for liquids
	Additive for gases
	Rough surfaces

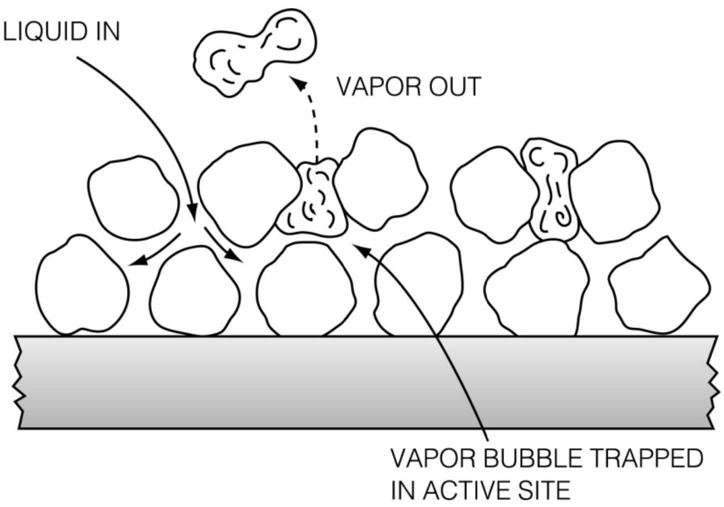

Figure 2.2 Treated surfaces

- Rough surfaces are produced in many configurations ranging from random sand-grain type roughness to discrete protuberances. As shown in Fig. 2.3, the configuration is generally chosen to disturb the viscous sub-layer rather than to increase the heat transfer surface area. Application of rough surfaces is directed primarily toward single-phase flow.

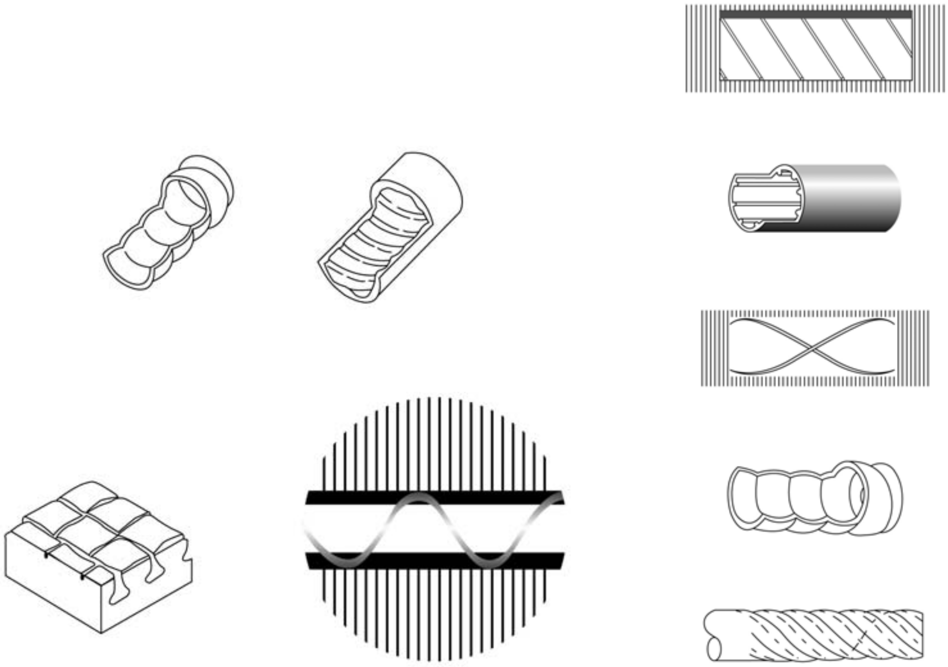

Figure 2.3 Rough surfaces

- Extended surfaces are routinely employed in many heat exchangers. Fig. 2.4 shows a variety of enhanced extended surfaces. Work of special interest to enhancements is directed toward improvement of heat transfer coefficients on extended surfaces by shaping or perforating the surfaces.

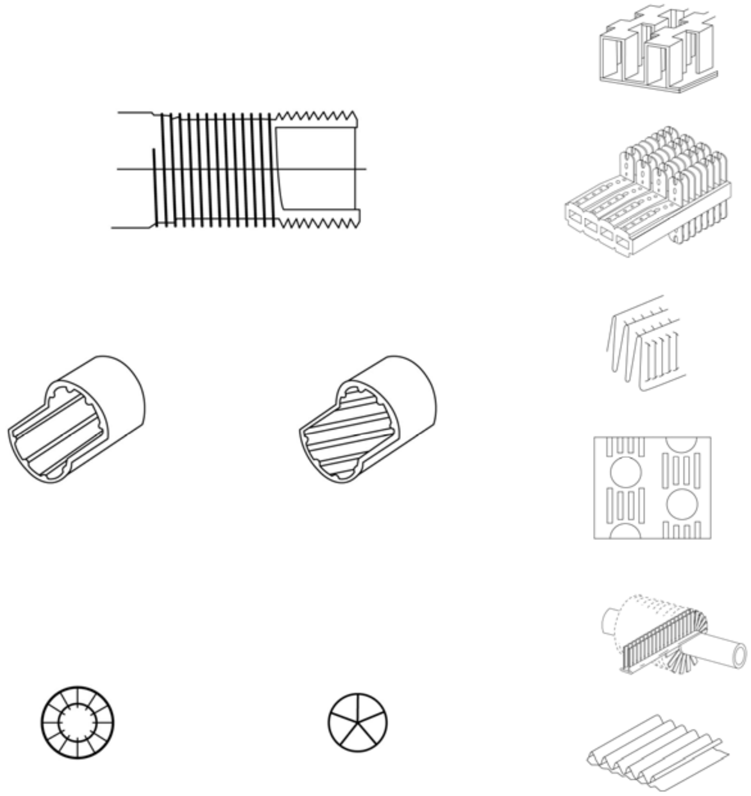

Figure 2.4 Extended surfaces

- Displaced enhancement devices are inserted into the flow channel so as indirectly to improve energy transport at the heated surface. They are used with forced flow. The devices are shown in Fig. 2.5.

- Swirl-flow devices include a number of geometric arrangements tube inserts for forced flow that create rotating and/or secondary flow: coiled tubes, inlet vortex generators, twisted-tape inserts, and axial-core inserts with a screw-type winding as shown in Fig. 2.6.

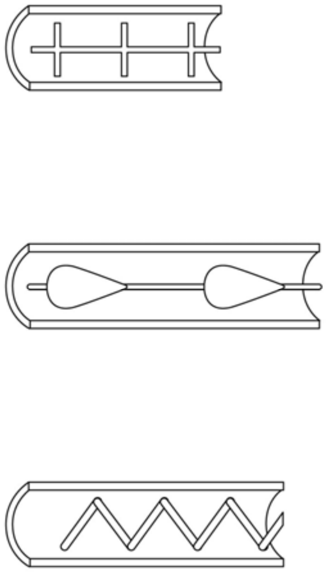

Figure 2.5 Displaced enhancements

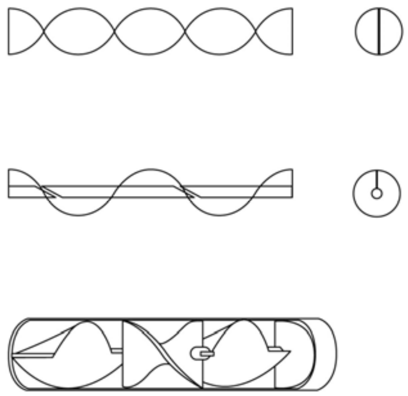

Figure 2.6 Swirl-flow devices

- Surface-tension devices consist of wicking or groove surfaces to direct the flow of liquid in boiling and condensing.

- Additives for liquids include solid particles and gas bubbles in single-phase flows and liquid trace additives for boiling systems.

- Additives for gases are liquid droplets or solid particles, either dilute-phase (gas-solid suspensions) or dense-phase (fluidized beds).

2.2.2 Active methods

- Mechanical aids involve stirring the fluid by mechanical means or by rotating the surface. Surface scraping, widely used for batch processing of viscous liquids in the chemical process industry, is applied to the flow of such diverse fluids as high viscosity plastics and air. Equipment with rotating heat exchanger ducts is found in commercial practice.

- Surface vibration at either low or high frequency has been used primarily to improve single-phase heat transfer.

- Fluid vibration is the practical type of vibration enhancement because of the mass of most heat exchangers. The vibrations range from pulsations of about 1 Hz to ultrasound. Single-phase fluids are of primary concern.

- Electrostatic fields (DC or AC) are applied in many different ways to dielectric fluids. Generally speaking, electrostatic fields can be directed to cause greater bulk mixing of fluid or disruption of fluid flow in the vicinity of the heat transfer surface, which enhances heat transfer.

- Injection is utilized by supplying gas to stagnant or flowing liquid through a porous heat transfer surface or by injecting similar fluid upstream of the heat transfer section. Surface degassing of liquids can produce enhancement similar to gas injection. Only single-phase flow is of interest.

- Suction involves vapor removal, in nucleate or film boiling or fluid withdrawal, in single-phase flow, through a porous heated surface.

- Jet impingement forces a single-phase fluid normally or obliquely toward the surface. Single or multiple jets may be used, and boiling is possible with liquids.