

Chapter 2

Definition of Flow Patterns

2.1 Vertical Upward Gas-Water Flow Patterns

The vertical upward gas-water two-phase flow patterns in a pipe of inner diameter 125 mm can be categorized into five classes on the basis of the visual and video observations and still photography. According to Hewitt [1], the five flow patterns, observed in our experiment, can be defined as follows (Fig. 2.1).

Bubble flow (Fig. 2.1a): This flow pattern occurs at low gas flow rates where the gas phase is approximately uniformly distributed in the form of discrete bubbles in a continuum of liquid phase.

Bubble-slug transitional flow (Fig. 2.1b): This flow pattern is characterized by the non-uniform distribution of the concentration of small bubbles in the flow direction. Small bubble coalescence occasionally arises in the part of high bubble concentration, and as a result, a spherically capped bubble is formed.

Slug flow (Fig. 2.1c): Most of the gas appears in large bullet shaped bubbles, also known as Taylor bubbles, whose diameters almost equal the pipe diameter. The liquid slug area between two Taylor bubbles is filled with small bubbles that are quite similar to those in bubble flow.

Slug-churn transitional flow (Fig. 2.1d): As the gas flow rate increases, for example, the gas-water interface of the larger gas bubble becomes distorted near the nose, but still comparatively smooth in the bottom part of a cylindrical gas bubble.

Churn flow (Fig. 2.1e): Because of instabilities in the slugs, churn flow is a highly disordered flow that arises at high gas flow rates. Churn flow can be interpreted as an irregular, chaotic and disordered slug flow. It is also characterized by an oscillatory flow, associated with the moving of liquid phase alternately upward and downward in the channel.

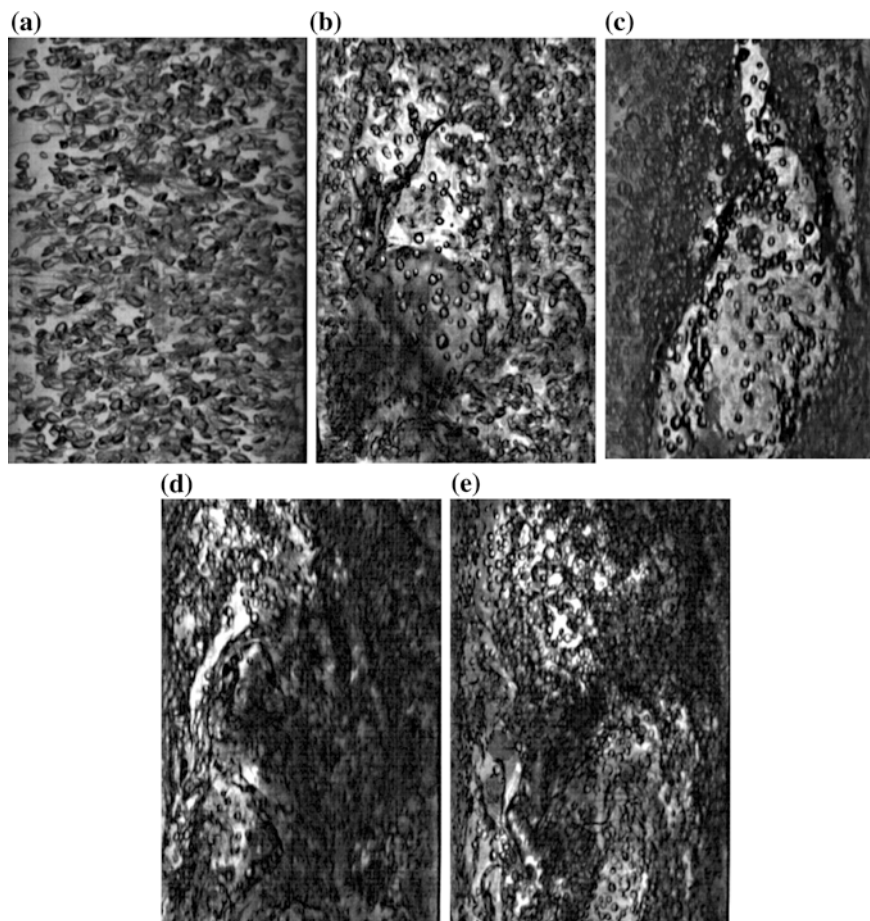


Fig. 2.1 The five vertical upward gas-water two-phase flow patterns recorded by high speed VCR system. **a** Bubble flow; **b** Bubble-slug transitional flow; **c** Slug flow; **d** Slug-churn transitional flow; **e** Churn flow

2.2 Horizontal Gas-Water Flow Patterns

Horizontal gas-liquid stratified flow occurs at very low flow rate. The flow structure of stratified flow is relative stable, the upper part of the pipe is gas phase and the bottom part of the pipe is the water phase. Due to the influence of gravity, there exists a smooth interface between gas and water phase, as shown in Fig. 2.2a-b.

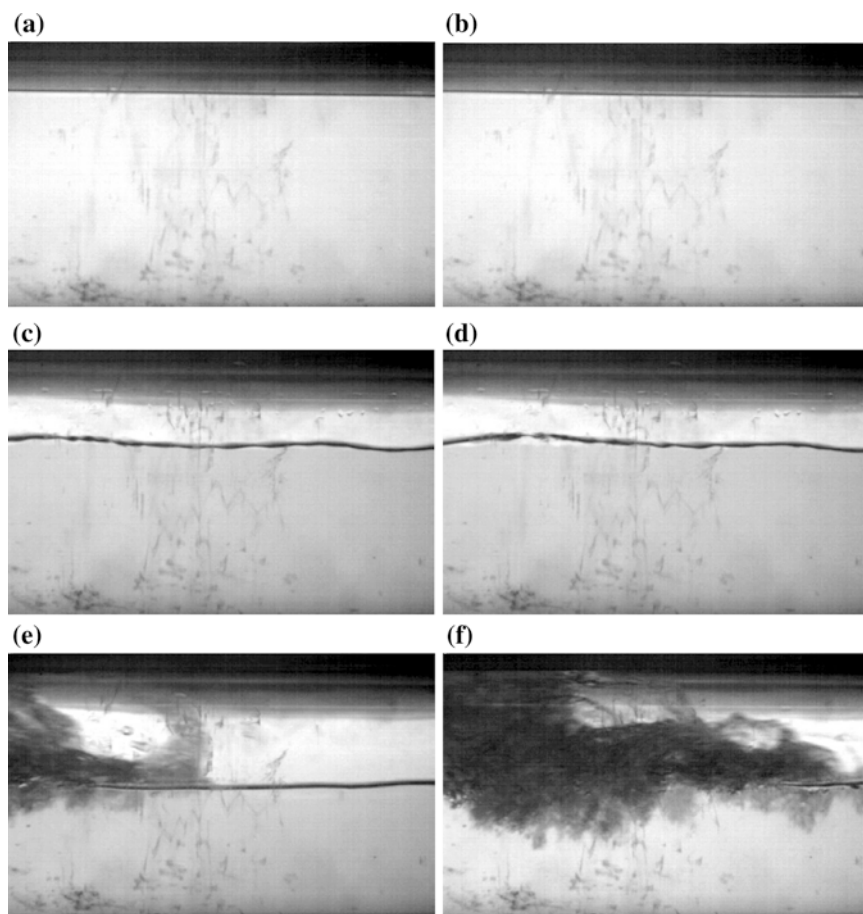


Fig. 2.2 Snapshots for three typical horizontal gas-liquid flow patterns: **a–b** Stratified flow; **c–d** Stratified wavy flow; **e–f** Slug flow

With the increase of gas flow rate, the interface becomes unstable and stratified wavy flow gradually appears with the phenomenon of interface fluctuations, as shown in Fig. 2.2c–d. In this flow pattern transition, due to the increase of flow rate, the turbulence energy will increase. Consequently, the flow structure of stratified wavy flow become unstable gradually and the fluctuations appear in the interface between gas phase and water phase, as shown in Fig. 2.2c–d.

When the gas superficial velocity is high, horizontal slug flow appears. Because of the influence of the turbulence effect, the flow structure of slug flow is very unstable, and compared with that of stratified wavy flow, the interface fluctuations of slug flow become strengthened, as shown in Fig. 2.2e–f.

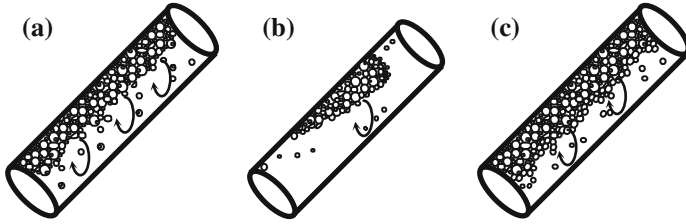


Fig. 2.3 Three water-dominated inclined oil-water flow patterns: **a** Dispersion oil in water-countercurrent flow (D O/W CT); **b** Dispersion oil in water-pseudoslugs flow (D O/W PS); **c** Transitional flow (TF)

2.3 Inclined Oil-Water Flow Patterns

The observed inclined oil-water flow patterns are water-dominated flows and transitional flow. The water-dominated flows include the dispersion of oil in water countercurrent flow and dispersion of oil in water pseudoslug flow. Based on the research of Flores et al. [2], the three typical flow patterns of inclined oil-water two-phase flow, observed in our experiment, can be categorized as follows (Fig. 2.3).

Dispersion Oil in Water-Countercurrent (D O/W CT) flow: The dispersion of oil in water countercurrent flow occurs between low and moderate superficial oil and water velocities. In this flow pattern, the oil disperses in the continuous water as discrete, well rounded, droplets of mostly small to mediums size (see Fig. 2.3a).

Dispersion Oil in Water-Pseudoslugs (D O/W PS) flow: The dispersion of oil in water pseudoslug flow occurs at slightly higher superficial water velocities and from low to moderate superficial oil velocities. In this flow pattern, the sequence of oil droplets observed in the countercurrent flow pattern is interrupted by water breaks, associated with the aggregation and packing of oil droplets at the top of the pipe (see Fig 2.3b).

Transitional flow (TF): The transitional flow occurs at moderate superficial oil velocities and from low to moderate superficial water velocities, in which oil stays at the topline region of the pipe, while at the bottom of the pipe, exist just water containing a few recirculating oil droplets; in the middle region, oil phase and water phase alternately switch (see Fig. 2.3c).

2.4 Vertical Upward Oil-in-Water Flow Patterns

Vertical upward oil-in-water slug flow occurs at low oil-water mixture flowrate, where the small oil bubbles in water continuous phase coalesce to form oil slugs in different sizes. With the coalescence of small oil bubbles becomes more and more, a large number of oil slugs appear.

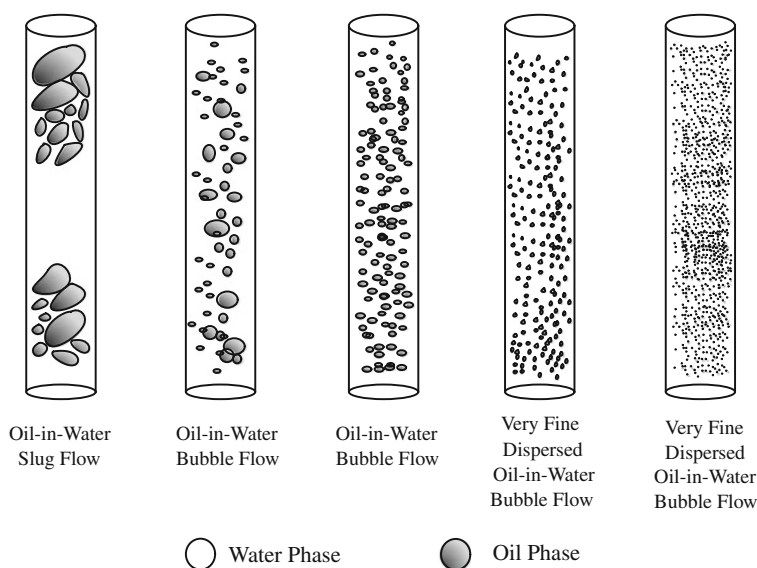


Fig. 2.4 Three types of vertical upward oil-in-water flow patterns in a small diameter pipe. The size of the oil bubble in the five flow conditions from left to right is approximate 10, 5, 2, 1, 0.5 mm, respectively

With the increase of total velocity of the oil-water mixture flow, the turbulent kinetic energy is strengthened and the oil slugs are dispersed into small oil bubbles, i.e., oil-in-water bubble flow occurs. In this flow pattern, the oil phase exists in the form of discrete bubbles in water continuous phase.

When the total velocity of the oil-water mixture flow is high, very fine dispersed oil-in-water bubble flow gradually occurs. Due to the influence of high turbulent kinetic energy, the oil bubbles are broken into smaller oil droplets in the transition from oil-in-water bubble flow to very fine dispersed oil-in-water bubble flow. The motions of large numbers of smaller oil droplets become rather stochastic (Fig. 2.4).

References

1. G.F. Hewitt, *Measurement of Two-phase Flow Parameters* (Academic Press, London, 1978)
2. J.G. Flores, X.T. Chen, C. Sarica, J.P. Brill, Characterization of oil-water flow patterns in vertical and deviated wells. *SPE Prod. Facil.* **14**, 102–109 (1999)

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