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BRIEF COMMUNICATION

FLOW PATTERNS IN TWO-PHASE DOWNFLOW OF GAS AND VERY VISCOUS LIQUID

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Two-phase flow of gas and very viscous liquid is present in many processes in the chemical and petrochemical industries. Many apparatus run on the basis of two-phase downflow.

Examples of experimental flow-pattern studies carried out in vertical downward flow are those of Golan & Stenning (1969), Oshinowo & Charles (1974), Yamazaki & Yamaguchi (1979), Spedding & Nguyen (1980), Barnea *et al.* (1982) and Crawford *et al.* (1985). Summary reviews of downflow have been published by Delhaye *et al.* (1981). Nearly all of these investigators used air and water. Oshinowo & Charles (1974) also observed the air–glycerine–water system with liquid viscosity μ_L up to 0.012 N s/m^2. These authors identified the six flow patterns shown in figure 1. A different classification has been proposed by Yamazaki & Yamaguchi (1979) for the air–water system. The flow patterns in downflow observed by these authors were bubbly flow, slug flow, wispy annular flow, annular flow and hybrid ones such as bubble–slug flow and slug–annular flow etc. Each was the same as observed in upflow.

The literature is rather lacking in investigations on possible flow patterns in two-phase downward flow with very viscous liquids. The authors' own experimental data were obtained with an air–mineral oil system. The liquid viscosity μ_L was changed from 0.18 to 7.5 N s/m^2 by means of temperature selection. The two-phase mixture flows downward through 2.0 m long glass tubes with

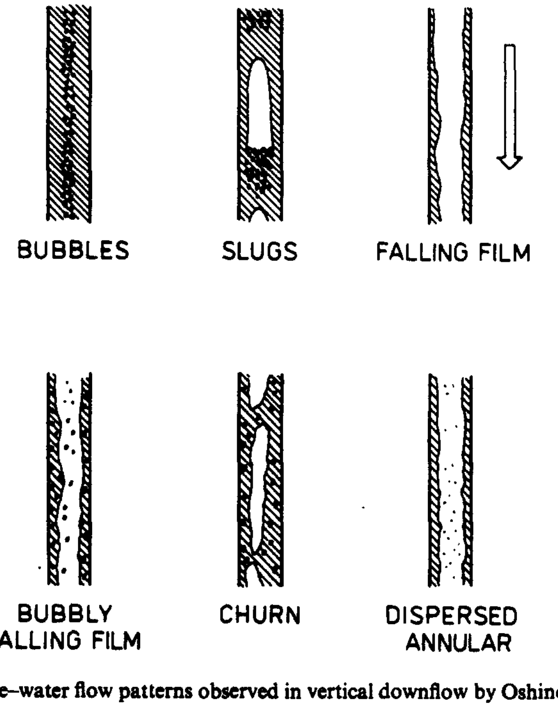

Figure 1. Air–glycerine–water flow patterns observed in vertical downflow by Oshinowo & Charles (1974).

internal diameters (D) of 10, 15 and 25 mm. The gas superficial velocity V_{SG} was changed from 0.01 to 38.0 m/s and the liquid superficial velocity V_{SL} was changed from 0.003 to 1.1 m/s.

The flow pattern in the test section was determined by visual observation in the stream of passing light (it was necessary to use a special lighting system because the oil was very dark). Photographic techniques were also used.

As a result, eight flow patterns were determined (see figure 2). The following pattern descriptions are proposed:

Film smooth flow. This structure occurs on the border between one-phase gravitational liquid flow and two-phase flow. The liquid flows in the form of a thin smooth film; the gas displaces along the tube axis and does not cause wavy motion of the liquid.

Wavy flow. The liquid flows along the tube wall as a wavy film. The gas core contains very few or no liquid droplets.

Froth flow. The liquid and the gas are intermixed forming a highly turbulent mixture.

Annular flow. The liquid flows as a wavy film around the tube wall. The liquid film surrounds a core of high-velocity gas which contains liquid droplets.

Bubble flow. The gas phase is dispersed in the form of individual bubbles in the liquid. The bubbles are hemispherical and they flow along the tube axis one by one.

Plug flow. This flow pattern is similar to bubble flow except that the bubbles are much bigger.

Core flow. The liquid flows in the form of a film which surrounds the gaseous core. The diameter of the gaseous core is comparable to the film thickness.

Stalactite flow. The gas phase is dispersed in the form of individual bubbles in the liquid. An additional liquid flow (a thin streamlet) exists inside the gas bubbles, along their symmetry axis.

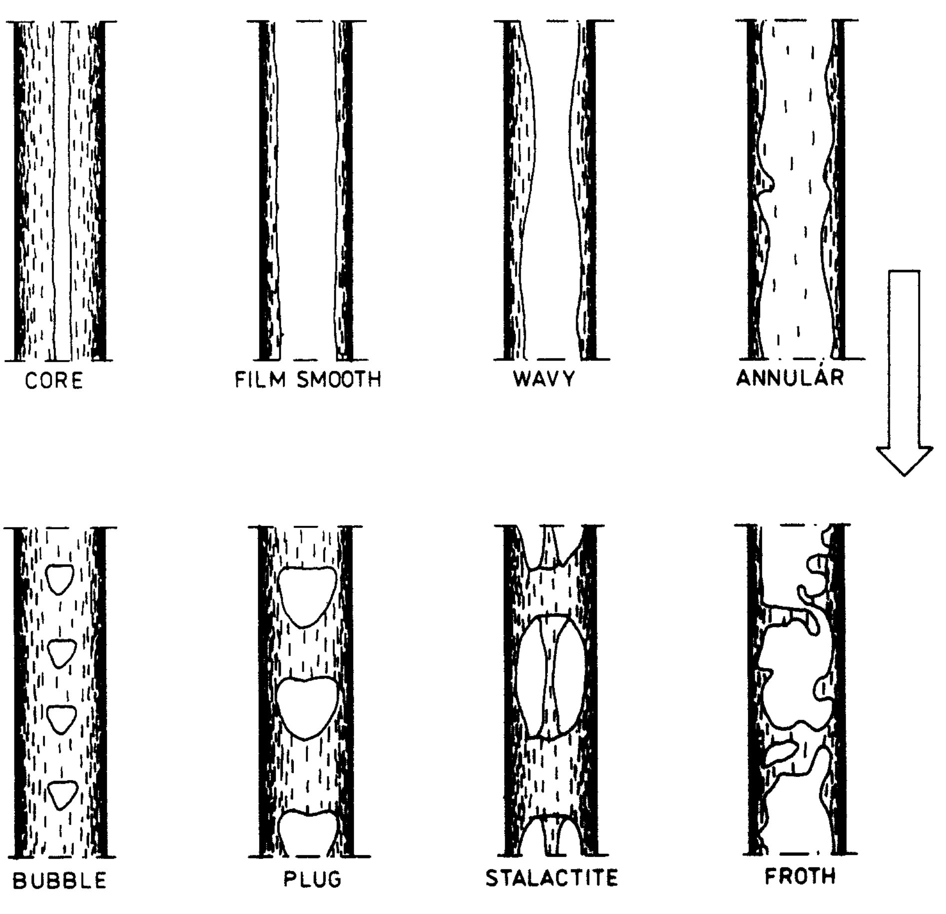

Figure 2. Flow patterns observed in air–very viscous liquid vertical downflow.

Two new patterns were determined and the names "core flow" and "stalactite flow" proposed for them. Figure 3 shows an example of the stalactite structure in a tube with diameter $D = 25$ mm for liquid viscosity $\mu_L = 1.69$ N s/m^2, surface tension $\sigma_L = 0.0363$ N/m and density $\rho_L = 996$ kg/m^3.

An example of the gas–very viscous liquid flow map for vertical downflow in a 15 mm dia tube for liquid viscosity $\mu_L = 1.73$ N s/m^2 is shown in figure 4.

From the investigations carried out so far it appears that the range of occurrence of particular flow patterns depends on the viscosity of the liquid. Ongoing investigations are aimed at determining a new flow-pattern map for two-phase gas–very viscous liquid downflow, including the effect of liquid viscosity and tube diameter on the range of occurrence of particular flow patterns.

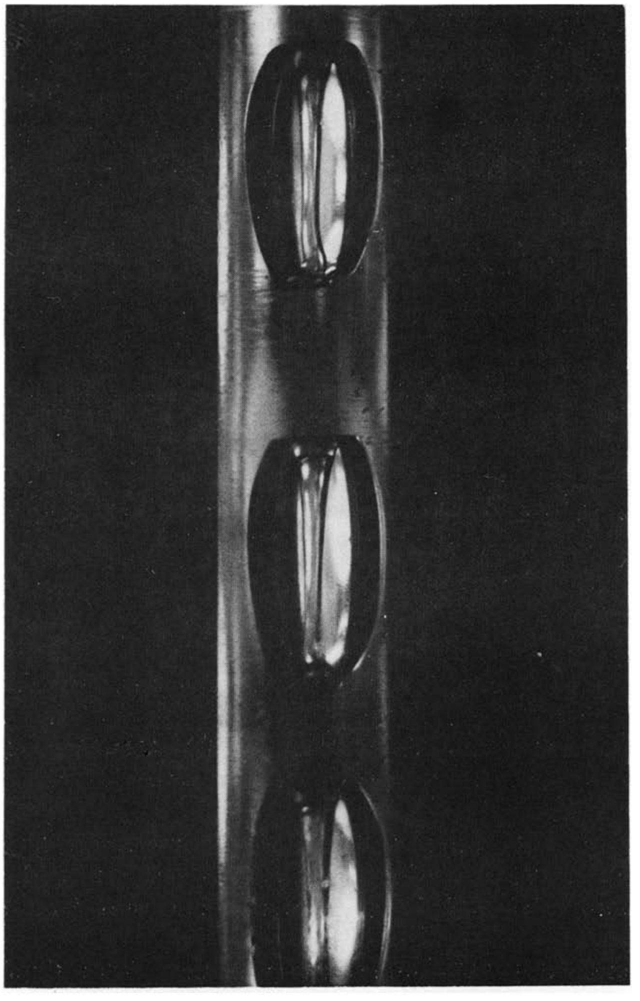

Figure 3. Stalactite structure in a $D = 25$ mm dia tube.

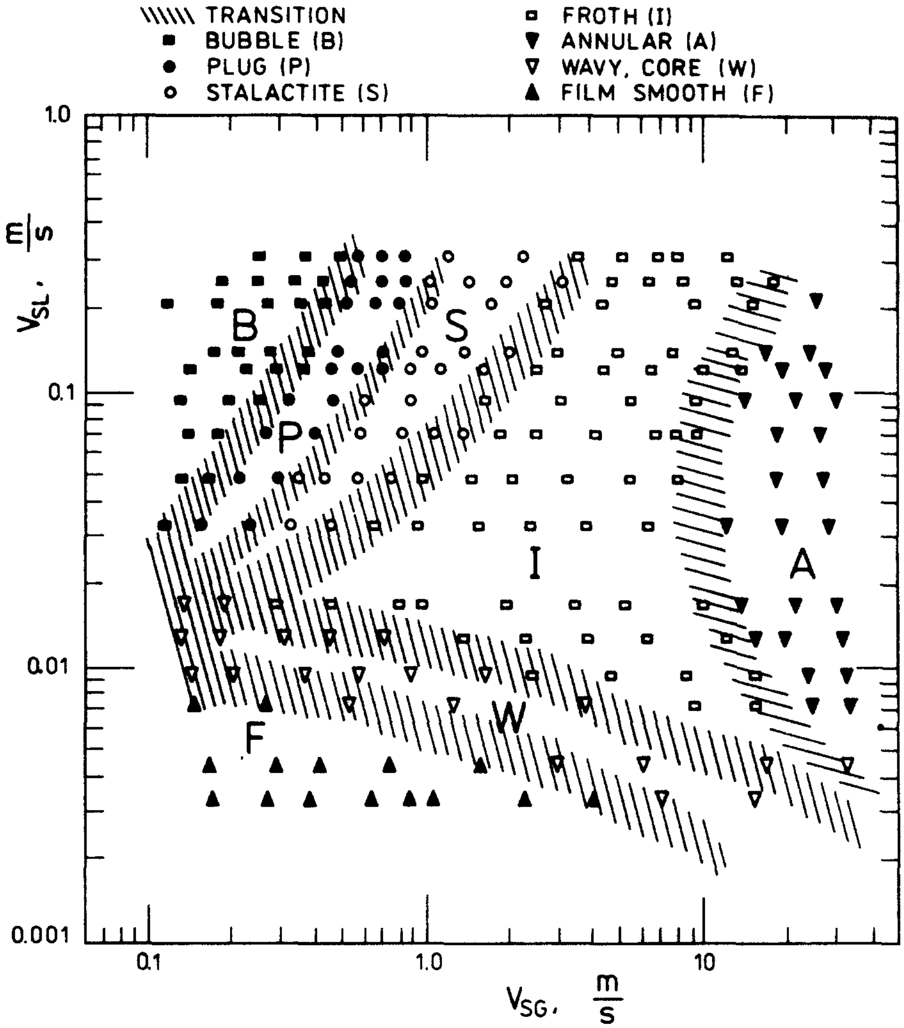

Figure 4. Flow-pattern map for air–very viscous liquid downflow; $D = 15$ mm, $\mu_L = 1.73$ N s/m^2, $\rho_L = 996$ kg/m^3, $\sigma_L = 0.036$ N/m.

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