GAS/LIQUID FLOW RESEARCH IN THE NETHERLANDS†

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Abstract—Two phase flow research is widely spread in The Netherlands among industrial laboratories (process industry) and universities. To summarize everything which is going on would be impossible, and the following is restricted to mentioning those experiments and investigations that are intended to improve the understanding of basic phenomena in gas/liquid flow.

Even with the above mentioned restriction, the following survey is not complete, but it is hoped that the most important current research is included.

1. TECHNICAL UNIVERSITY DELFT

Laboratory for Aero- and Hydrodynamics. Department of Mechanical Engineering

The gas/liquid flow research of this group comprises following studies:

(a) *Similarity criteria for isothermal gas/liquid flow.* Under a number of restrictions (Chesters 1975) dynamic similarity of gas/liquid flows can be achieved when, apart from appropriate scaling of velocity and length, the Morton number

$$M = (\rho_1 \sigma^3)/\mu_1^4 g$$

has the same value for the considered flows.

Here ρ_1 and μ_1 are the density and dynamic viscosity of the liquid, σ is the coefficient of surface tension and g the acceleration of gravity.

The Morton number is entirely composed of liquid properties and a search among numerical values of these properties for various liquids learns that water and trichloroethylene have approximately the same Morton number

$$\text{water at } 20°C, \ M = 3.93 \times 10^{10}$$

$$\text{trichloroethylene at } 20°C, \ M = 3.81 \times 10^{10}.$$

Experiments are in progress employing this to scale water/air vertical pipe flow with a trichloroethylene/gas mixture. The scaling possibilities become significantly larger when g is scaled. For horizontal or nearly horizontal flow large scale down factors for the length can be obtained when, by rotation, g can be increased (Chesters 1977). An experiment in which this is realized has very recently been constructed with the cooperation of the Royal/Shell Laboratories in Amsterdam.

(b) *Bubble coalescence.* Similarity as mentioned under (a) breaks down as soon as coalescence of bubbles is important. A special, analytical and numerical, study is in progress to investigate the thin film between adjacent bubbles during coalescence. The results, obtained so far and valid for low Weber numbers are reported in Chesters & Hofman (1982).

(c) *Stability of a fluid film between a solid wall and an inmiscible liquid flow.* Inspired by the possibility of transporting a viscous liquid like oil in an annulus of a much less viscous liquid, the stability of a thin film has been investigated.

It appears that in the linear case a thin film can be stable, even when the film is one of gas and the liquid is uppermost (Koman & Chesters 1981). Experiments are in progress to test this

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†Survey given at the Meeting of the AGARD fluid Dynamics Panel, Trondheim 1982.

case. This work continues other work by Ooms *et al.* (1982) on the stability of a viscous core flow supported by a liquid film.

(d) *Liquid-bubble flow at a tube branch.* In cooperation with the Faculty of Medicine of the Erasmus University at Rotterdam, research is carried out on the behaviour of small air bubbles in the vicinity of branches (figure 1). This, with in mind the injection of small bubbles in the pulmonary system.

One is particularly interested in those situations in which the bubbles find themselves downstream from the branch in a tube with a diameter equal to the effective bubble diameter or even smaller.

Laboratory for "Fysische Technologie", Department of "Chemische Technologie" and Department of Applied Physics

The studies to be mentioned in the following find their roots in practical cases of gas/liquid flow and their aim is to obtain more insight and, if possible simple, rules of operation for the user of the particular process in which the flow under consideration occurs.

(a) *Bubble column reactor.* The experimental device is a closed loop consisting of two vertical legs with a height of 10.5 m connected by short horizontal legs, in which bubbles and liquid circulate as indicated in figure 2.

The interesting feature here is that circulation of the liquid is maintained by bubbles injected in the leg in which the liquid flows downward. This happens at a depth sufficiently large for stable operation with a liquid circulation velocity of 1–2 m/s. This velocity is large enough to
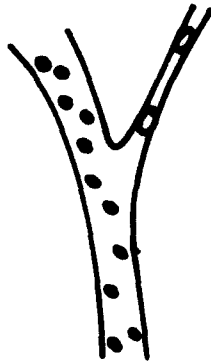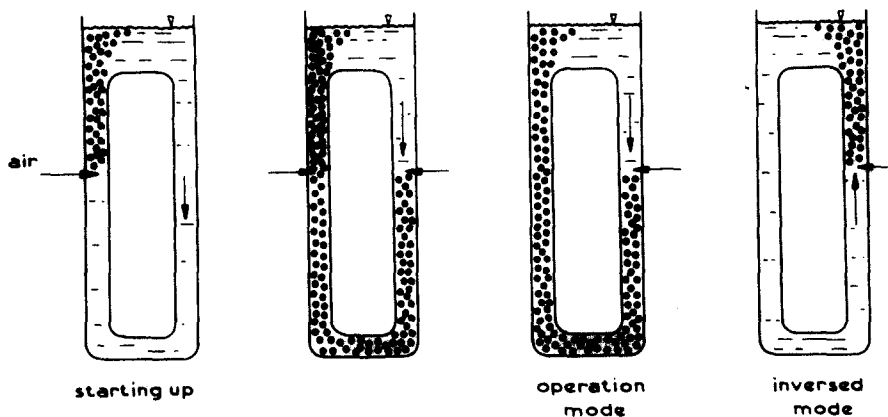

Figure 1. Bubbles in pulmonary systems.

Figure 2. Operation of bubble column (after van der Lans and Smith 1982).

carry the bubbles down to the bottom, at the same time compressing the air to higher pressures (see figure 2). The same air once in the riser is responsible for the air lift effect (van der Lans & Smith 1982). A problem being studied is the stability of the system. Further, the interest here is in the mechanics of the circulation, and the transfer of mass between bubbles and liquid. Practical application of this kind of circulation occurs in fermentation processes and in waste water treatment (see further, e.g. van der Lans & Smith 1982).

(b) *Bubble columns in unconfined regions.* Bubble columns, in laterally unconfined regions, are studied in a project with originated from the idea to use bubble columns to destratify (thermally) stratified reservoirs of drinking water. Destratification is required to prevent excessive blooming of algae. In a first study, which now is finished, the mixing in isothermal water, of depth H, say, has been investigated (figure 3a). It appeared that a region of an extent of about $5H$ is influenced by the bubble column. The flow pattern (figure 3b) in a stratified fluid is quite different. The region of influence is much larger (Goossens 1979). Parameters of interest here are the applied gas flow and the intensity of stratification. The present research involves systematic variation of these parameters, see Chesters, van Doorn & Goosens (1980).

(c) *Plunging air jets.* Just terminated (van de Donk 1981) is a study of the hydrodynamics of plunging air jets in water. This type of liquid/gas flow was studied in connection with the aeration of water and other liquids.

(d) *Dispersion of gas clouds by water sprays.* A water jet in another liquid becomes unstable and forms, when the other liquid is a gas, a waterspray. The hydrodynamics of the flow in which the waterdroplets entrain air which in its turn (by continuity) comes in motion, locally turbulent, is the object of study here. The analysis of the various hydrodynamic processes such as entrainment and turbulent diffusion, is accompanied by experimental research regarding the flow, e.g. with help of LDA measurements (van Doorn 1981). Practical application here is the dilution and dispersion of hazardous gas clouds by water sprays.

Department of Applied Mathematics

Mr. P. van Beek is working on the mathematical study of averaged equations for suspensions of small air bubbles in water (van Beek 1982). This work is very similar to the theoretical work carried out at the Twente Technical University to be discussed in section 4. The differences are in the averaging procedures and techniques.
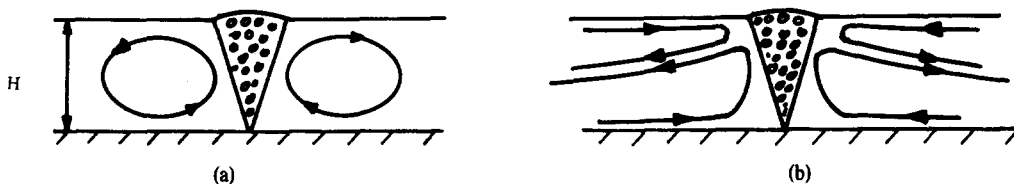

Figure 3(a) and 3(b). 3(a) Bubble column in laterally unconfined isothermal fluid. 3(b) Bubble column in laterally unconfined stratified fluid.
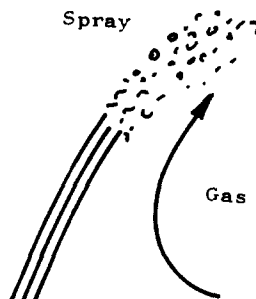

Figure 4. Waterdroplets, entraining gas.

2. ROYAL/SHELL LABORATORIES, AMSTERDAM

Research is motivated here by the desire to use two-phase flow pipelines for the transport of total well head product to shore. Typically, transportation is effected at pressures exceeding 100 bar, using pipes of 0.75 m diameter and larger over distances of several hundred kilometers through hilly terrain.

Two phase flow research at Royal/Shell Laboratories, Amsterdam covers experimental as well as theoretical studies associated herewith. A case study has illustrated the hazards of using standard correlations (based on atmospheric air/water data in small pipes) for pressure loss and liquid holdup outside their validity range (Oliemans 1976). "Phenomenological" rather than empirical models have been developed for the various flow regimes expected in long pipelines through hilly terrain. These models have been validated with field data obtained from controlled conditions in pipelines, operating in two-phase flow. For verification of a number of model aspects, such as flow pattern transitions, an extensive experimental program will be carried out in an 8-inch high-pressure test facility. The recently constructed facility consisting of a 300 m long horizontal pipeline, 150 m of which can be positioned at angles of 1, 3 and 5 degrees, will ᵗ operate at 70 bar. Initially, the fluids will be gas and condensate taken from an existing pipeline. It will be possible to carry out experiments over the full spectrum of conditions: from pure gas flow via two-phase gas/liquid flow to pure liquid flow. At a number of locations, in fully instrumented pipe sections, a large number of two-phase flow parameters will be recorded simultaneously.

3. TECHNICAL UNIVERSITY EINDHOVEN

Laboratory for "Warmtetechniek"

In this laboratory, a two phase flow test rig is in an advanced state of construction. Essentially it consists of a vertical pipe with a length of 8.5 m and a diameter of 0.04 m in which, by addition of heat to a maximum of 2 MW, a vapour water mixture can be generated. It is expected that a wide variety of void fractions and of flow topology can be achieved in this vertical pipe. Detailed and careful measurements with modern techniques are envisaged of such quantities as void fractions, local velocities.

4. TECHNICAL UNIVERSITY TWENTE (ENSCHEDE)

Laboratory for Fluid Mechanics and Heat Transfer

Pressure waves and shock waves in mixtures of water and small air bubbles were studied in the period 1968–78 (van Wijngaarden 1972; Noordzij & van Wijngaarden 1974). In recent years research is aimed at a systematic construction of averaged equations of motion for bubbly suspensions. The initial stimulus for this was the fact, noticed by many people around 1975, that the equations used in existing computer codes to calculate transients in two phase flow, are not hyperbolic but possess complex characteristics. Since both stable acoustic waves and concentration waves have been observed in experiments their description must be by real characteristics. A rigorous application of averaging techniques over the microscale (e.g. inter bubble distance) should lead to equations with real characteristics. Extra terms (with regard to "standard" sets of equations) arise from fluctuations of velocities and of pressure (van Wijngaarden 1982). Results obtained for low void fraction indicate that real characteristics are obtained indeed. At the same time the characteristic speed of concentration waves can be calculated. These results will be published in the near future. At higher void fractions, interactions such as studied in Biesheuvel & van Wijngaarden (1982) have to be taken into account.

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