A Periodic Instability in Horizontal Air-Water Flow Related to Continuity Waves

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Flow instabilities are generally undesirable in two-phase flow processes, they may induce forced mechanical vibrations or affect the local heat transfer characteristics. Among the main mechanisms responsible for these phenomena (Boure et al., 1973), dynamic instabilities caused by the propagation of disturbances are frequently observed. Roughly, these disturbances are transported by two kinds of waves: acoustic and continuity waves.

The following study deals with an instability occurring in air-water, two-phase flow, when the horizontal channel terminates in a diaphragm. This instability is probably related to the propagation of a continuity wave. Such waves in two-component, two-phase flow have been previously investigated (Wallis, 1961; Zuber and Hench, 1962; Wallis, 1969), but the experimental situation is rather different here.

In our case, the instability gives rise to large pressure fluctuations, the frequency of which is measured. Variations in local void fraction are revealed by local measurements. Detailed results are given in Adler (1975).

EXPERIMENTAL

The same apparatus (except the diaphragm) has already been described (Adler, 1977); a diagram is given in Figure 1. The injection device consists of two rectangular perforated plates (120×200 mm^2) through which air at equal flow rates is introduced into the water; circular holes (diameter 0.8 mm) are arranged in a hexagonal pattern in these plates. Two intermediate perforated plates are provided to diffuse the air. The channel (rectangular section 120×24 mm^2) terminates in a diaphragm. Mass flow rates of air and water are constant at the inlet of the injection device.

Local void fraction measurements are described in Adler (1977). Pressure is measured by strain gauges placed flush to a vertical wall in order to prevent the fluctuations from being filtered by bubbles in the pressure tap. The resonance frequency is given by the power density spectrum of the pressure fluctuations.

The influence of D, L, $\bar{u}_G$, $\bar{u}_L$ on the resonance frequency was studied.

RESULTS

The pressure fluctuations at $x = 1.75$ m, (Figure 2) are large, regular, and characterized by the existence of two plateaus, with very quick transitions. The signal at $x = 0.35$ m is filtered with respect to signal at $x = 1.75$ m, but pressure is almost in phase in the whole setup.

Local void fraction was measured during each plateau (at $x = 1.55$ m and in the vertical symmetry plane of the channel). Measured profiles were found to be slightly different. Hence, it was assumed that successive slices of mixtures with different void fractions were flowing within the channel and that the pressure plateaus were induced by the passage of the slices through the diaphragm. Vertical void fraction profiles within the two slices can be obtained from data and are presented in Figure 3. They are quite different, but the spatial mean void fractions are shown to be nearly equal when the pressure variations are taken into account (Adler, 1975).

With respect to these variations in the void fraction profiles, it was assumed that the observed resonance frequency was related to the propagation velocity of continuity waves along the setup. A simple model, that is, continuity wave without slip between phases (Wallis, 1969), leads to a resonance frequency given by

$$\frac{NL}{\bar{u}_G} = 1 + \frac{\bar{u}_L}{\bar{u}_G} \tag{1}$$

Thus, data nondimensionalized by $\bar{u}_{G,m}/L$ were plotted against $\bar{u}_L/\bar{u}_{G,m}$ (Figure 4). Equation (1) gives a correct order of magnitude, but Figure 4 mainly suggests that this nondimensional representation of the results is convenient. The following expression can be derived for the whole set of data:

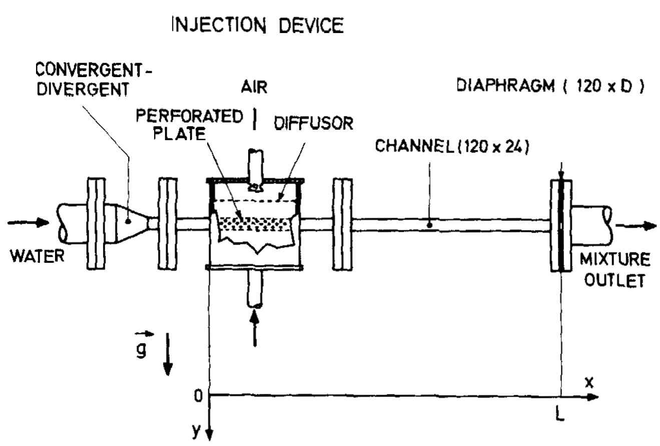

Fig. 1. Schematic diagram of apparatus.

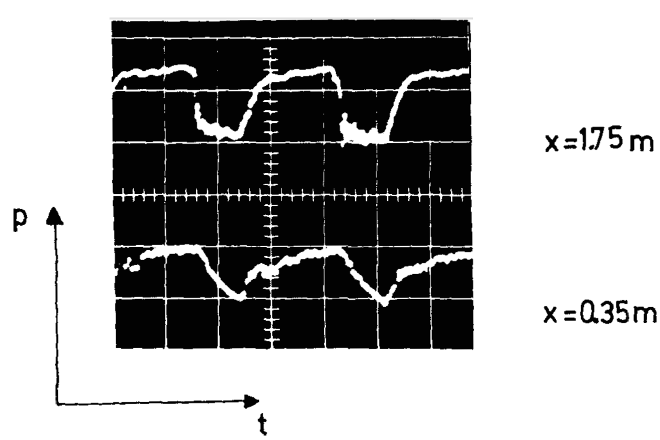

Fig. 2. Characteristic pressure fluctuations (arbitrary origins for time and pressure). Data are for $L = 1.8$ m, $D = 12$ mm.

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TABLE 1. STATISTICAL ANALYSIS OF THE RESULTS. S IS THE RATIO (EXPRESSED IN %) OF THE STANDARD DEVIATION TO THE STATISTICAL MEAN N_*. THE INJECTION DEVICE WITHOUT DIFFUSOR IS DENOTED BY (1). THE EXPERIMENTAL VALUES OF $\overline{u}_{G,A}$ AND $\overline{u}_L$ FOR EACH SET OF D AND L ARE $\overline{u}_{G,A}$ = 3.92, 4.71, 5.5, 6.28, 7.05, 7.95 m/s; $\overline{u}_L$ = 0.96, 1.35, 1.74, 2.12 m/s

L m	D mm	$\tilde{\tilde{N}}_*$	$\tilde{\tilde{S}}$
1.8	12	2.20	8
	16	2.18	9
1.3	12	2.20	5
	12 (1)	2.22	6
	16	2.08	8
0.8	12	2.30	3
	16	2.20	3
Recapitulation		2.20	7

$$N_* = \frac{NL}{(\overline{u}_{G,m}\overline{u}_L)^{1/2}} = 2.2 \qquad (2)$$

Detailed statistical results are given in Table 1. The influence of D and L on N_* is seen to be very weak.

Finally, in order to show that the resonance frequency was not imposed by the injection device, the diffusor was eliminated, N_* is not influenced by this modification (Table 1).

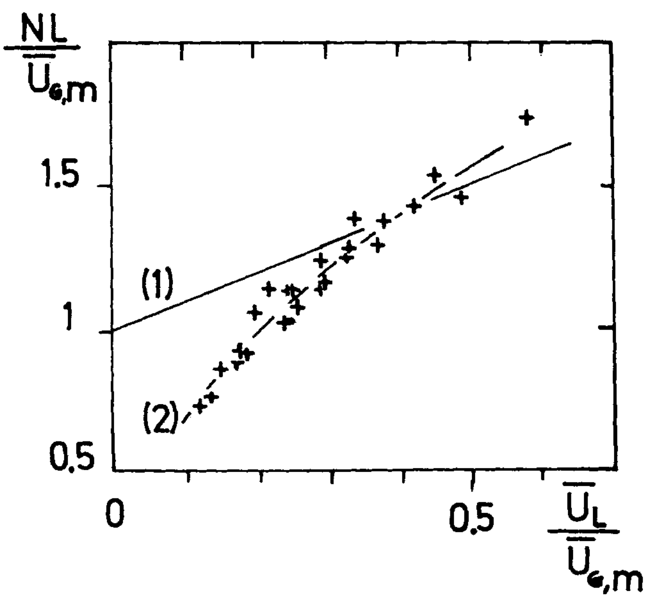

Fig. 4. Nondimensional resonance frequency as a function of the ratio of the mean superficial velocities. Solid line (1) and broken (2): Equations (1) and (2).

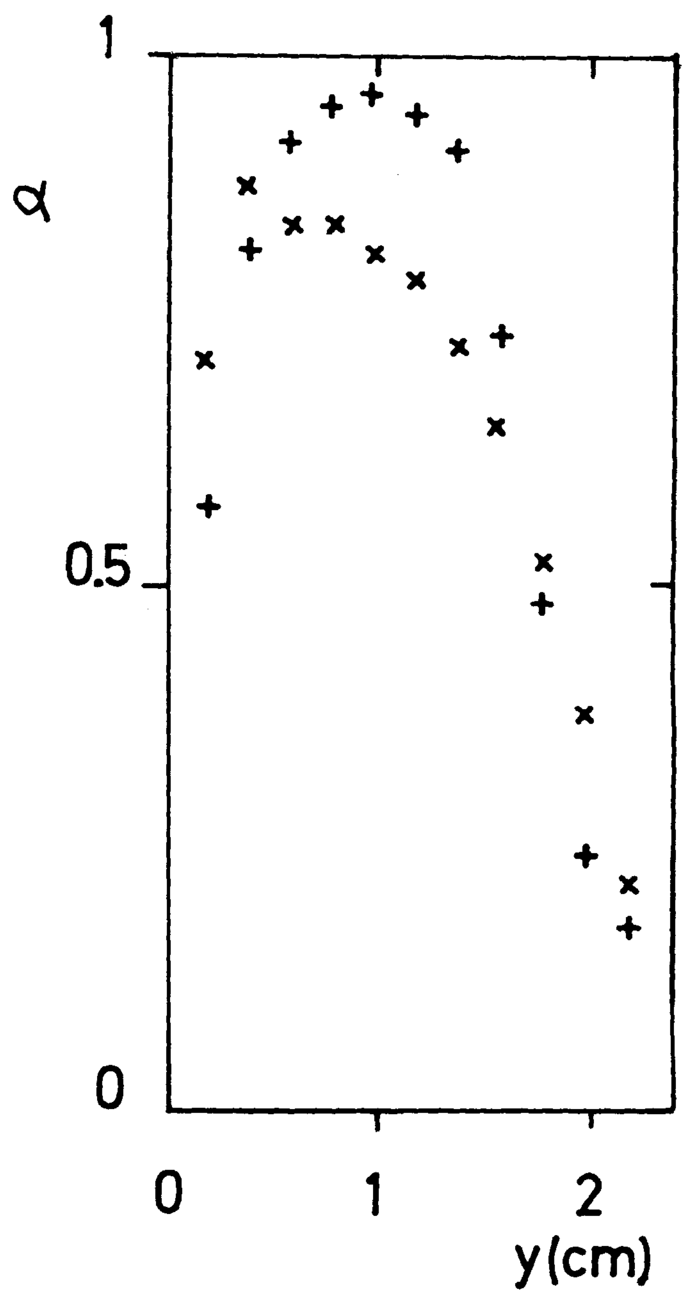

Fig. 3. Void fraction vs. vertical coordinate y for low (+) and high (×) pressure plateaus at x = 1.55 m. Data are for L = 1.8 m, D = 12 mm, $\overline{u}_L$ = 1.74 m/s, $\overline{u}_{G,A}$ = 5.96 m/s.

DISCUSSION

An overall view of the phenomenon can now be exposed. Successive slices of mixtures with different void fraction profiles are flowing in the channel. The pressure plateaus are induced by the passage of the slices through the diaphragm. No local void fraction measurements were performed within the diaphragm; thus it is only suspected that the flow pattern of one slice changes in the diaphragm. The velocity of the front between two successive slices is equal to the velocity of a continuity wave and determines the period of the pressure oscillations.

Since the spatial mean void fraction is the same in two successive slices, pressure must be in phase within the setup, as actually observed.

Gravity can play a role in the phenomenon, but it does not determine the wave velocity, as shown by Equation (2). This is consistent with the fact that the characteristic velocity associated with gravity (Wallis, 1969)

$\sqrt{gH} = 0.5$ m/s is small when compared with the smallest observed velocity which is equal to 4.7 m/s.

Finally, N_* is not influenced by the geometric parameters (D, L, internal structure of the injection device). But D and L influence the onset of oscillations. It should be only noticed that a disturbance induced by a transition of the flow pattern is larger when the diaphragm aperture is smaller and that the frictional pressure drop is nearly proportional to the length of the channel. Hence, a disturbance is easily amplified when D and L are small. Detailed results (Adler, 1975) are shown to follow these trends.

CONCLUSIONS

An oscillatory phenomenon induced by the introduction of a diaphragm in a horizontal air-water, two-phase flow was analyzed.

The experimental frequency is of the same order of magnitude as the frequency of a continuity wave. However, in our case, the void fraction profiles vary through the wave, while the spatial mean void fraction is constant.

The experimental frequency was shown to be given by an empirical formula in which only the mean superficial velocities of each phase and the length of the setup have an effect. This is thought to be characteristic of this type of instability.

NOTATION

α = local void fraction
D = aperture of diaphragm
g = acceleration of gravity
H = height of channel (= 24 mm)
L = length of setup
N, N_* = dimensional, nondimensional resonance frequency
p = pressure
t = time
$\bar{u}_G, \bar{u}_{G,m}, \bar{u}_{G,A}$ = mean superficial velocity of the gas phase for an arbitrary pressure, mean pressure of the setup, atmospheric pressure
$\bar{u}_L$ = mean superficial velocity of the liquid phase
x, y = Cartesian coordinate system (Figure 1), the origin 0 is at the beginning of the injection device, within the vertical symmetric plane of the channel and at the upper wall

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BOOKS

Gas-Solid Reactions, J. Szekely, J. W. Evans and H. Y. Sohn, Academic Press, 1976. 400 pages. price: $39.50.

This a textbook intended for graduate students majoring in metallurgy or chemical engineering with specific interest in gas-solid reactions. Of the eight chapters, the first five chapters (half the book) are devoted to the derivation of rate equations based on several idealized models of gas-solid reactions, with appropriate mathematical problems for exercise. In fact, the major emphasis in the book is on the mathematical treatment of heat and mass transfer accompanying various types of idealized gas-solid reactions with perhaps a biased slant to their grain model. Although the authors do caution the student that good judgment should be exercised in the application of theoretical rate equations to experimental data, they do not give adequate examples of departures from idealized reaction models that are often encountered even in well-thought out experiments. A conceptual analysis of a reaction to be studied is, of course, a priori requisite to the design of a particular experimental method, and the interpretation of the results, however, greater emphasis should have been made on frequently observed departures from idealized reaction models. However, the authors' mathematical treatment of the idealized gas-solid reactions is clearly stated, and the equations given for numerous types of reaction models will be of much value to those who study the gas-solid reactions. The review of past work on oxidation of metals and reduction of metal oxide is highly condensed. In fact, no mention is made of internal oxidation, sulfidation, nitriding, etc. of alloys which is a subject of some importance to the students of metallurgy. In Chapter 6 the authors give a broad outline of experimental techniques used in the study of gas-solid reactions. The principles of gas-solid reactions in multiparticle systems are adequately presented in Chapter 7. Some examples are given in Chapter 8 of gas-solid reactions of industrial importance, such as iron oxide reduction, roasting of sulfides, SO_2 absorption by solids, coal gasification and incineration of solid waste. These examples are intended for the student's orientation and not for detailed discussion of, for example, heat and mass transfer in the blast furnace stack. Graduate students and those in research laboratories investigating gas-solid reactions will find the book helpful in their endeavors.

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Heat Transfer, 4th Ed., J. P. Holman, McGraw Hill Book Company. 530 pages, price: $17.00.

This is a fine elementary treatment, excellent for a strong first course in heat transfer. Analytical, numerical, and em-