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PRESSURE FLUCTUATIONS IN A VAPOUR–LIQUID MIXTURE FLOW

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Abstract—This paper presents the results of a series of measurements of unsteady wall pressure fluctuations for the upward flow of a vapour–liquid mixture of freon in a circular pipe. The results show the strong attenuation of incident pressure disturbances by the mixture, the generation of pressure fluctuations by the turbulent two-phase mixture flow and the propagation of pressure disturbances associated with the flow in the direction of flow. The latter pressure disturbances appear to move at a velocity approximately 1·4 times that of the nominal average mixture velocity.

1. INTRODUCTION

THE CO-CURRENT flow of two-phase mixtures generally presents a very complicated flow structure, both in terms of the unsteady formation of the phase boundaries and in terms of the fluctuations of velocity, pressure and other continuous variables within the flow. From the broad classification of flow patterns based on visual observations, such as those carried out by Baker [1], Quandt [2] or Kozlov [3] for example, the flows to be discussed here would be expected to be of the bubble type, the vapour phase being dispersed in the form of relatively small bubbles immersed in a continuous liquid phase. Whilst fairly extensive experimental data are available in regard to the variation of average conditions in the flow, such as the correlation of pressure drop data by Tong [4] or of mean void fraction data by Zuber and Findlay [5], it appears that there is currently only a limited amount of data available concerning the unsteady fluctuations which occur in vapour–liquid or gas–liquid mixture flows. This is partly due to the difficulty of making experimental measurements of unsteady parameters, where the presence of the phase interfaces makes it difficult to investigate fluctuations of flow parameters, such as velocity, in the same detail as has been possible for single-phase turbulent flow. Some experimenters, such as Neal and Bankoff [6], Malnes [7] and Sandervag [8], have used resistance probes to indicate the phase variations in flows where the liquid phase is significantly conducting. However, for flow where the liquid is non-conducting, this method is not applicable and it seems therefore that the study of fluctuating wall pressures may provide one approach to the investigation of instantaneous flow fluctuations which can be applied to any two-phase flow.

The occurrence of pressure fluctuations, due to a two-phase flow, will be determined firstly by the turbulent velocity fluctuations which generate pressure disturbances within the flow and secondly by the manner in which disturbances are propagated through the mixture. Whilst there is little information available concerning the former, due to the difficulty in measuring unsteady velocities, the transmission of fluctuations has been studied analytically in order to determine the drastic reduction in the velocity of propagation of pressure disturbances caused by the introduction of the vapour phase and also to determine the strong attenuation of incident disturbances. The velocity of pressure disturbances has been investigated by Davies [9] amongst others under the assumption that the mixture behaves as a continuum and either achieves thermodynamic equilibrium during the passage of the fluctuations or, alternatively, that no inter-phase mass transfer occurs. For a steam–water mixture it was found that this velocity reduced to less than 100 ft/s at a void fraction of 0·5 and ambient pressure when no mass transfer was considered, the minimum velocity increasing with pressure. The effect of the mixture achieving thermodynamic equilibrium was to reduce the velocity at low void fractions to a fixed value at zero void fraction not equal to the liquid phase sonic velocity. This effect is due to the formation of vapour bubbles required to maintain thermodynamic equilibrium of a small disturbance even at a nominally zero average void fraction. Simpson and Silver [10, 11], in considering critical flow of saturated liquids also described this phenomenon and demonstrated the relatively low critical velocities which apply to the discharge of vapour–liquid mixtures. Rushton and Leslie [12] have given further consideration to the problem of critical flow for the particular case of flow nozzles and show that prediction of critical flow can result from assumptions in the mathematical model used. Whilst there appears to be some uncertainty as regards flows through nozzles, depending upon the way in which the flow is represented mathematically, it may be said that there is more general agreement concerning propagation of disturbances through homogeneous mixtures (as in the approach of Davies [9]). However, the influence of inhomogeneities in a real flow situation, such as that in a circular pipe considered here, cannot immediately be discounted and in this regard the discussion of Rushton and Leslie appears relevant.

The effect of the response of gas or vapour bubbles when the frequency of the imposed disturbances is comparable with the bubble resonance frequency has been discussed by Batchelor [13] and more recently by Van Wijngaarden [14], although this is significant primarily for small bubbles at frequencies higher than the range of frequencies investigated in the present experiments. The last-mentioned authors also showed the variation of attenuation in the mixture, caused in gas–liquid mixtures by viscous dissipation due to the oscillatory bubble motions and the relative motion between bubbles and liquid. For vapour–liquid mixtures, attenuation and velocity under conditions of non-equilibrium mass transfer have been shown by Mecredy and Hamilton [15] to be strongly influenced by the mass transfer coefficient for the bubbles, as well as bubble size, frequency and void fraction.

From the preceding discussion it may be concluded that there are a number of factors which influence the attenuation and propagation velocity of pressure disturbances in two-phase mixtures. In practice, many of the relevant parameters, such as bubble size and mass transfer co-efficient in particular, are not known, in addition to which the flow is likely to contain non-uniform distributions of average void fraction and bubble size. For these reasons the application of the predictions of the theories to practical situations, such as the flow along pipes, would be very difficult, in which case experimental data concerning transmission and attenuation in complex situations of practical interest are of value.

Measurements of fluctuating pressures in gas–liquid mixture flows have been reported by Semenov [16] and by Hubbard and Dukler [17], both using air–water mixtures. The regular pressure pulsations set up by slug flows were discussed by Semenov, the predominant frequencies being relatively low. Variations in the reduced amplitude and frequency were related to the flow speed, a maximum in the reduced frequency being found at a void fraction of approximately 0·25. The amplitude of the pressure fluctuations reached a maximum at a much higher void fraction of approximately 0·9. Whilst the overall trends were shown by these results, the analysis of the fluctuating signals was restricted to evaluation of the two parameters mentioned. This approach is practicable for slug flows but not for bubbly flows where it is no longer possible to identify easily a characteristic pulsation waveform. The maximum flow velocity was of the order of 1 m/s. Hubbard and Dukler carried out experiments at velocities of the order of a few meters per second for slug and annular flows and showed maxima in frequency spectra which could be associated with the flow extending to 6 Hz.

From this discussion it may be seen that only limited information is available concerning the transmission and attenuation of pressure fluctuations by two-phase vapour–liquid mixtures in complex flow situations of practical relevance, such as flow inside a circular pipe. Also, little information is available concerning the generation of turbulent pressure fluctuations by two-phase flows. The purpose of the experiments to be described is to investigate these effects in a vapour–liquid pipe flow situation.

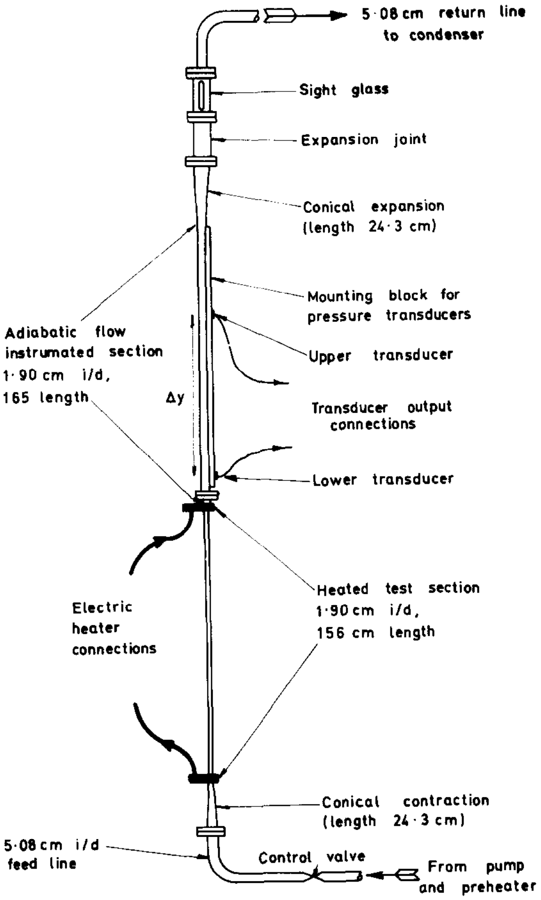

FIG. 1. General arrangement of test section.

2. EXPERIMENTAL FLOW AND INSTRUMENTATION

Measurements were carried out with a flow of Freon 12 through a 1·90 cm i.d. pipe mounted in a vertical position. This test section formed part of a closed loop circulation system, the freon being circulated by a rotary pump operating at 3000 rpm. The freon was passed from the pump, which operated at constant speed, the flow rate being controlled by a by-pass line and valve, through an electric preheater before entering the test section. During the experiments carried out here, the freon inlet temperature to the test section was maintained within a few degrees centigrade below the saturation temperature by control of the preheater, the inlet temperature being monitored to within 1°C approximately. This represents, in terms of heat content, approximately 3 per cent of the heat required to evaporate the liquid to a void fraction of 0·8. At low void fractions, this percentage increases and it may be seen that these small variations of inlet temperature could affect the void fraction (or quality) at exit from the heater significantly. For this reason, control of the system and estimation of the flow void fraction is subject to a greater uncertainty at low void fractions. The flow entered the test section through a control valve located in a 5·08 cm dia supply line and a 24·3 cm long conical contraction to the test section (as shown in Fig. 1). The test section was divided into two parts, the lower part being heated by passing an electric current through the wall of the tube which was constructed of stainless steel with a wall thickness of 1·68 mm and a heated length between the current connections of 156 cm. During the present experiments the flow rate of freon was varied between 95 g/s and 1500 g/s, and heating rates of between 0·4 kW and 10 kW were applied. With the freon at inlet at close to the saturation temperature, these values were selected so that the resulting flow at exit from the heater section would remain of an approximately bubbly form. From the applied heat flux, inlet temperature and freon flow rate values of the average mixture quality, void fraction and velocity were calculated, these being the nominal average values obtained by neglecting any relative motion between the phases. A number of authors such as Zuber and Findlay [5] have discussed relative slip motions between the phases and it is known that the vapour phase tends to move increasingly faster than the liquid phase as the void fraction is increased. However, the detailed dependence of the ratio of vapour to liquid velocity upon flow conditions and the resultant reduction in void fraction in the test section are subject to some uncertainty and, for this reason, only the average mixture values have been calculated for the experiments discussed in this paper.

From the heated portion of the test section the flow passed vertically upwards into an adiabatic section with provision for mounting pressure transducers at a series of positions along the tube, the tapping positions being located vertically above one another· Blanking plugs were inserted in all the tappings not being used to give a flush internal finish. This instrumented section, with an overall tube length of 152·3 cm, was connected to the heater section by a flanged joint and provision for mounting the pressure transducers in each tapping position was made by welding a machined 1·9 cm square block along the side of the test section tube. The pressure transducers used were Kulite type XS-080-100 with a sensing head diameter of 2·03 mm and an operating pressure range of 0·7 MPa. These incorporated a diaphragm with an integral semiconductor strain gauge bridge and provision for varying the pressure on the reverse side of the diaphragm. The transducers were calibrated under steady loading conditions and no frequency calibration was carried out as the specified dynamic response was beyond 100 kHz. The transducers when mounted in the test section occupied a flush mounted position in the wall of the pipe. Some small imperfection in this mounting arrangement would arise since the transducers had flat sensing faces and were mounted in a circular tube, although the non-uniform protrusion, due to this effect, of 0·05 mm was probably less than other irregularities in the diaphragm and in the correct alignment of the diaphragm with the tube wall. The latter effect was checked by micrometer, mounting shims under the transducer shoulder to locate it correctly. The transducer signals were passed through a pre-amplifier and analysed using a narrow band (6 per cent bandwidth) analogue spectrum analyser and an on-line digital correlator.

After passing through the test section, the flow entered a conical diffuser of length 24·3 cm and thence into the 5·08 cm dia return pipe line to the condenser unit. A sight glass was included in this line immediately above the test section and permitted visual observation of the mixture although at a much reduced velocity so that it could only be used as a monitor to ensure that boiling was taking place steadily rather than as an indicator of the test section flow mode. At low void fractions, this sight glass was useful in detecting any unsteadiness in the operating conditions since it was found difficult to maintain steady conditions for exit void fractions of less than 0·1. In these cases, the power applied was lower and it seems likely that the system became more sensitive to slight variations of inlet temperature, as mentioned above. The return line passed the freon to a pair of vertical tube condensers before being re-circulated. The loop pressure was maintained constant by a pressuriser tank connected to the pump feed line, this tank incorporating a heater and being part filled with freon liquid with saturated vapour in the upper part of the tank. The loop pressure could be controlled by means of this heater and was maintained in 1·045 MPa.

3. MEASUREMENTS OF FLUCTUATING PRESSURES

Although the test section was not located immediately adjacent to the circulation pump being separated from it by the pre-heater, feed lines, control valve and metering orifice in one

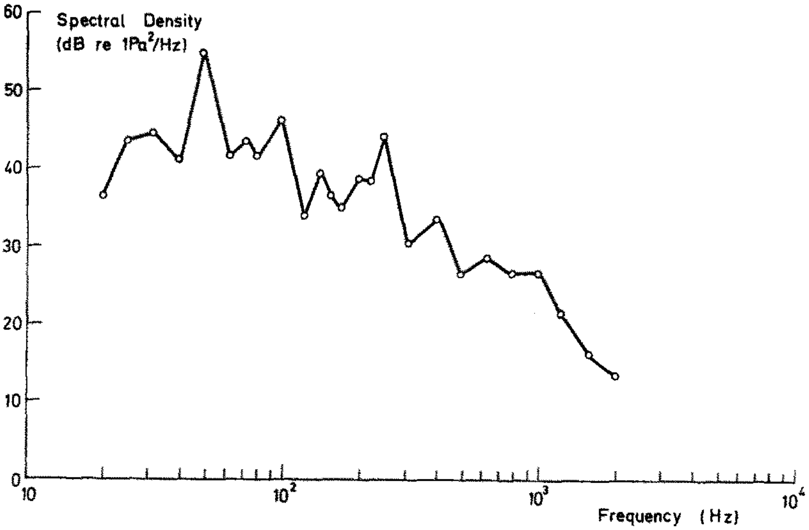

FIG. 2. Pressure fluctuations in test section with no boiling (transducer 20·3 cm above heated section, liquid flow 764 g/s).

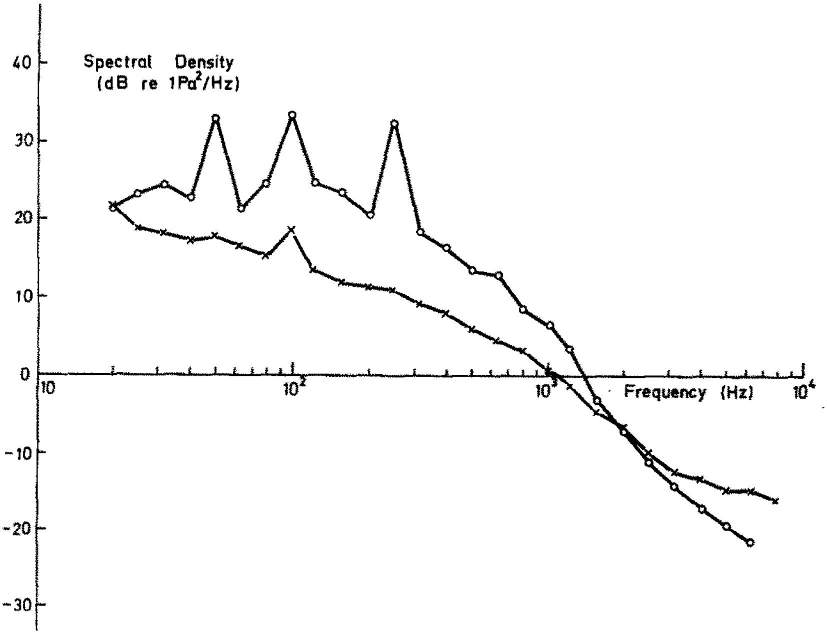

FIG. 3. Attenuation of incident pressure fluctuations by vapour–liquid mixture (average mixture velocity u_m = 2·27 m/s, flow void fraction α = 0·061).

○ Transducer 20·3 cm above heated section;
× Transducer 157·6 cm above heated section.

direction and by the condenser in the return direction, it was found that relatively strong pressure disturbances due to the circulation pump were detected in the test section if the latter contained freon liquid and the feed line control valve was open. Figure 2 shows a pressure fluctuation spectrum obtained with liquid only flowing through the test section and it may be seen that the spectrum contains peaks corresponding to the pump rotational frequency (50 Hz) and at various multiples of this frequency. Transmission of these disturbances through the system structure to the transducer was discounted, as they were found to be absent if there was no liquid in the test section showing that the transmission path lay through the liquid in the section.

With the onset of boiling in the heater section, the transmitted pressure fluctuations from the circulation pump were found to reduce rapidly as the void fraction increased. This is shown in Fig. 3 where the fluctuation spectra for two transducers are shown, one located near the upper end of the heater section and the other near the upper end of the instrumented unheated section. It may be seen that the incident fluctuations are attenuated between the measuring points by approximately 15 dB for frequencies in the range of 50–100 Hz, whilst the fluctuations at 250 Hz have been reduced by at least 21 dB. Also, comparison of Figs. 2 and 3 shows that the incident fluctuations have been reduced by between 10 and 20 dB in this same range of frequencies. Since the flow in the heater is not homogeneous, it is difficult to place any detailed conclusions on these last results but it does appear that in the adiabatic section, where the flow will be more uniform along the tube length, an attenuation of 11 dB/m is taking place at frequencies below 100 Hz, whilst at frequencies in the range of 250 Hz this has increased to approximately 15 dB/m. The attenuation in the heater length appears to be of comparable magnitude. These results were obtained with a mixture nominal void fraction of 0·061; when this was increased to 0·106 the attenuation rate in the adiabatic section approximately doubled to around 25

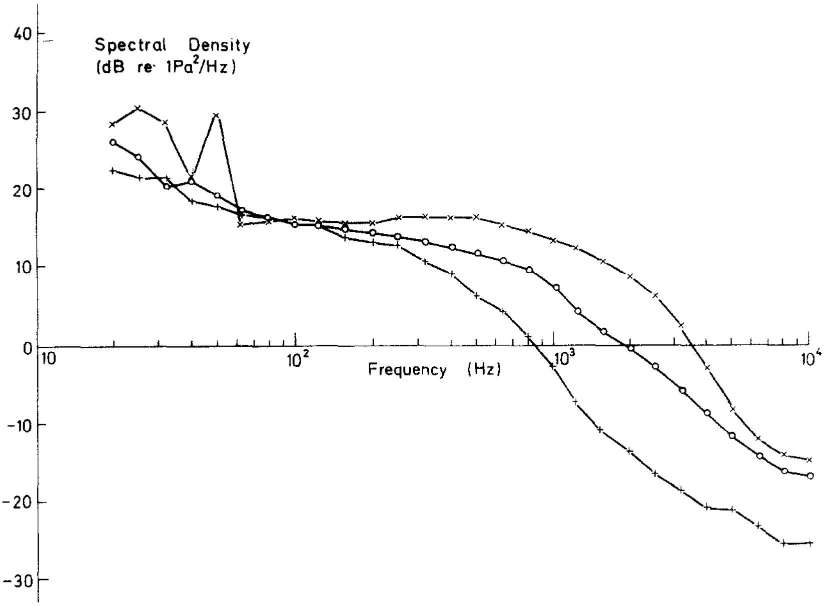

FIG. 4. Increase of turbulent pressure fluctuations with mixture density (transducer 20·3 cm above heated section).

× $u_m = 4{\cdot}82$ m/s, $\alpha = 0{\cdot}105$;
○ $u_m = 4{\cdot}37$ m/s, $\alpha = 0{\cdot}535$;
+ $u_m = 3{\cdot}39$ m/s, $\alpha = 0{\cdot}802$.

dB/m, depending upon frequency. For higher void fractions, especially at the higher velocities, the pump-generated disturbances reduced below the level of the turbulent two-phase flow pressure fluctuations and no further estimates of the attenuation rates were possible. Also, since the condenser and return lines would contain a substantial length of vapour–liquid mixture, it may be assumed from these results that the transmission of disturbances via the return lines would be eliminated under conditions of vapour formation in the test section.

The generation of turbulent pressure fluctuations by the two-phase mixture is shown in Fig. 4, where fluctuation spectra for different mixture flow void fractions are shown. Whilst there is some variation in flow speed between these flow conditions, it may be seen that the effect of increasing the void fraction, that is decreasing the mixture density, is to decrease the intensity of the turbulent pressure fluctuations. Between the two extreme conditions shown, the mixture density varies by a factor of 4·5. Taking account of the increase of mixture velocity by a factor of 1·25, the value of $\rho_m u_m^2/2$ would change by a factor of 7·0. This would suggest that the pressure fluctuations would, if they scaled with $\rho_m u_m^2/2$, increase by 17 dB. From Fig. 4 it may be seen that the change in spectral density in the range of frequency between 1000 Hz and 5000 Hz is of comparable magnitude, varying between 16 and 21 dB depending upon frequency. Hence it seems that the intensity of the turbulent pressure fluctuations, on the basis of these experiments at different mixture void fractions, does increase by an amount comparable to the change of mixture dynamic pressure. The Strouhal number range, based on the mixture velocity, corresponding to this frequency range is between approximately six and thirty, confirming that it is physically realistic to associate these fluctuations with the bubble structure of the flow within the pipe, as the fluctuations would be characterized by lengths in the range of $d/6$ to $d/30$. It should be noted that at the higher mixture void fraction the reduction of the spectral density could, in part,

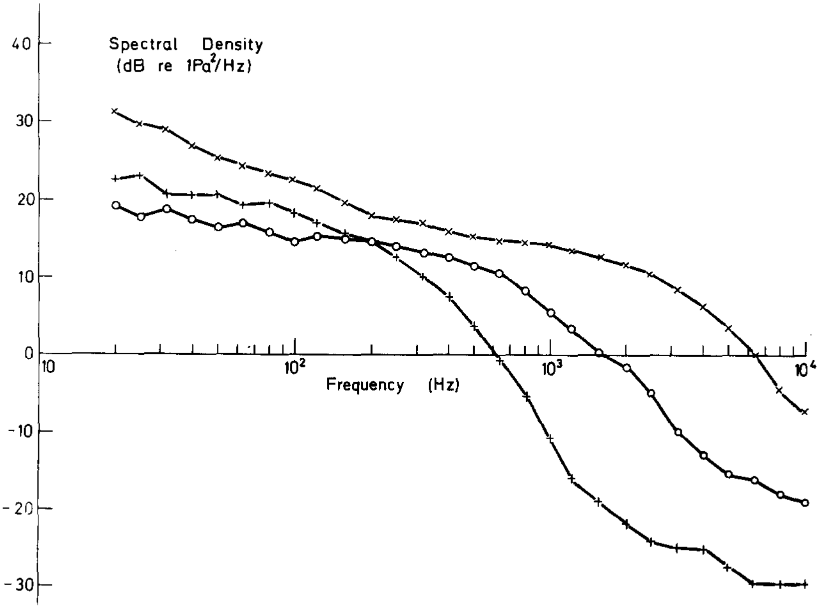

FIG. 5. Increase of turbulent pressure fluctuations with velocity (transducer 20·3 cm above heated section).

× u_m = 6·61 m/s, α = 0·362;
○ u_m = 3·32 m/s, α = 0·375;
+ u_m = 1·25 m/s, α = 0·380.

be due to the increase in attenuation of disturbances being propagated from the body of the flow to the wall. This could account for the rather larger proportionate change in the intensity of the pressure fluctuations by comparison with the change of mixture dynamic head.

The effect of changing the flow velocity at approximately constant average flow void fraction is shown in Fig. 5. The interpretation of these results is complicated by the movement of the frequency range of the turbulent pressure fluctuations to higher frequencies by virtue of the increase in flow speed. However, the upper and lower curves on Fig. 5 show a difference in spectral density of up to 31 dB and it may be seen that this is again of comparable magnitude with the increase of 28 dB which would arise if the pressure fluctuations scaled with the mixture dynamic head, the mixture velocity increasing by a factor of 5·2 between the two flow conditions.

Integration of the pressure fluctuation spectra to obtain the root mean square pressure fluctuation shows that, for the condition with flow void fraction of 0·105 and a mixture velocity of 4·82 m/s the mixture dynamic pressure $\rho_m u_m^2/2$ is $1{\cdot}6 \times 10^4$ Pa compared with a root mean square pressure fluctuation of approximately $2{\cdot}3 \times 10^2$ Pa. That is, the pressure fluctuations are approximately 1·5 per cent of the nominal mixture dynamic pressure. This would be approximately the result for other flow conditions, since the preceding discussion has indicated an approximate variation of the pressure fluctuations in proportion to the mixture dynamic pressure.

As the flow passed from the bottom to the top of the instrumented portion of the test section, relatively small changes were noticed in the fluctuating pressure intensity. This is shown in Fig. 6, where a decrease of approximately 6 dB in the region of the fluctuations generated by the

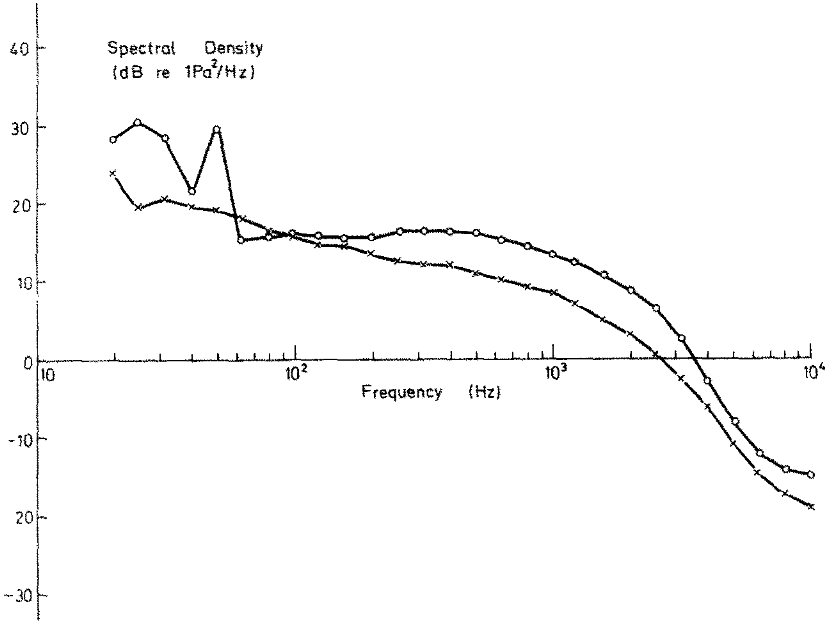

FIG. 6. Reduction of turbulent pressure fluctuations along test section ($u_m = 4{\cdot}82$ m/s, $\alpha = 0{\cdot}105$).

○ Transducer 20·3 cm above heated section;
× Transducer 157·6 cm above heated section.

flow may be noted. This result suggests that the transducer at the lower position is experiencing a significantly stronger turbulent fluctuation due to the relatively close proximity of the heater section which terminated only eleven tube diameters below the transducer position. The attenuation of the disturbances at 50 Hz along the instrumented section may again be observed in Fig. 6.

The propagation of pressure disturbances along the test section is shown by the cross correlation diagrams (Fig. 7) between the upper lower pressure transducers, the correlation coefficient being defined as

$$R_{ul}(\tau) = \frac{\langle p_u(t+\tau)\,.\,p_l(t)\rangle}{\langle p_u^2(t)\rangle^{\frac{1}{2}}\,.\,\langle p_l^2(t)\rangle^{\frac{1}{2}}}.$$

p_u and p_l being the fluctuations in pressure at upper and lower transducer positions. τ denotes a time delay between the two signals. The lower transducer was located 20·3 cm above the end of the heated section throughout these experiments and the upper transducer was moved to different positions. A peak may be observed in the cross correlation coefficient, showing that there is a progression of the wall pressure pattern from the lower to upper transducer. A convection speed ($u_c = \Delta y/\tau_m$) may be defined in terms of this time

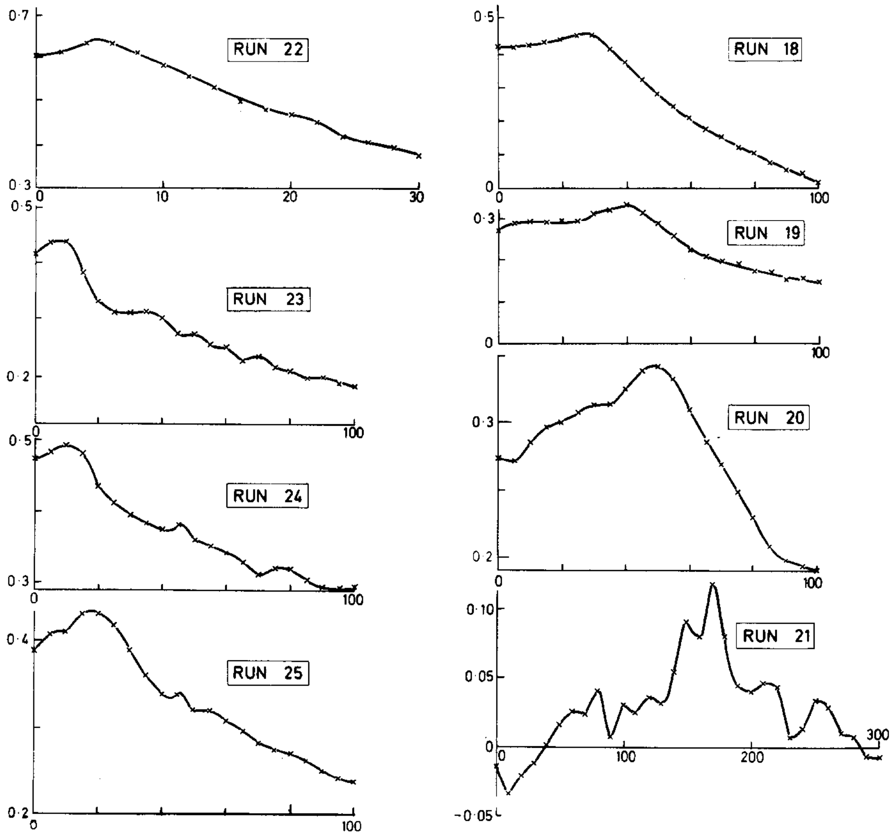

FIG. 7. Cross correlation for two transducers (lower transducer 20·3 cm above heated section —see table 1 for remaining data). Horizontal scales: τ (millisec); vertical scales: $R_{ul}(\tau)$.

delay for a maximum correlation (τ_m) and the separation distance (Δy). At the largest separation, the maximum correlation has become rather low (less than 0·1) and the form of $R_{ul}(\tau)$ has become apparently irregular although a peak is still evident. A comparison between the convection velocities obtained from the correlation function and the average mixture is shown in Table 1. It may be seen that the convection velocity varies between 1·2 and 1·6 times the mixture velocity. No clear trend is evident in these results, which are subject to some uncertainty in the evaluation of the convection velocity u_c due to the occurrence of indistinct peaks or of small oscillations on the correlation diagrams. The low void fraction data do appear to give, on the average, rather lower values of the ratio u_c/u_m. The average value of u_c/u_m was 1·40 over all the results, the spread being approximately ±20 per cent. These results indicate that there is a significant slip or relative motion between the two phases in the test section, as it appears that the pressure disturbances would be associated with the passage of the bubble structure along the pipe in the flow direction.

Table 1. Convection velocities measured from cross correlation data

Run No.	u_m (m/s)	α	u_c (m/s)	Δy (cm)	u_c/u_m
1	1·95	0·619	2·55	5·1	1·31
2	1·95	0·619	2·72	38·1	1·39
3	1·88	0·601	2·57	60·9	1·37
4	4·68	0·582	6·93	7·6	1·48
5	4·63	0·568	6·72	10·2	1·45
6	4·69	0·574	6·93	15·2	1·48
7	4·71	0·562	7·63	22·8	1·62
8	4·77	0·582	7·27	30·5	1·53
9	4·73	0·576	7·03	45·6	1·49
10	2·36	0·097	3·38	5·1	1·43
11	2·32	0·080	2·90	7·6	1·25
12	4·53	0·049	5·40	2·5	1·20
13	4·53	0·049	6·75	5·1	1·49
14	4·58	0·047	5·69	22·8	1·24
15	4·50	0·041	6·93	38·1	1·54
16	7·23	0·419	9·55	30·5	1·32
17	7·44	0·439	9·50	2·5	1·28
18	6·42	0·341	7·90	22·8	1·23
19	6·66	0·366	9·50	38·1	1·43
20	6·42	0·363	9·15	45·6	1·43
21	6·42	0·362	8·07	142·3	1·26
22	5·81	0·266	9·25	5·1	1·59
23	6·68	0·371	8·48	7·6	1·27
24	6·60	0·360	10·1	10·2	1·53
25	6·49	0·349	8·48	15·2	1·31

In order to confirm that the apparent convection velocity is due to the passage of the flow and not of incident disturbances of pressure through the mixture at a reduced velocity due to the mixture compressibility, the velocity of propagation of pressure disturbances has been evaluated as

$$a = (\partial p/\partial \rho_m)^{\frac{1}{2}}$$

at constant entropy. This velocity was evaluated from tables of the properties of Freon 12 for a range of void fractions and at several average pressures. The resulting variation of the velocity a is shown in Fig. 8 where it may be observed that the lowest propagation velocity corresponding to the average pressure of 1·045 MPa at which the experiments were carried out was 63 m/s

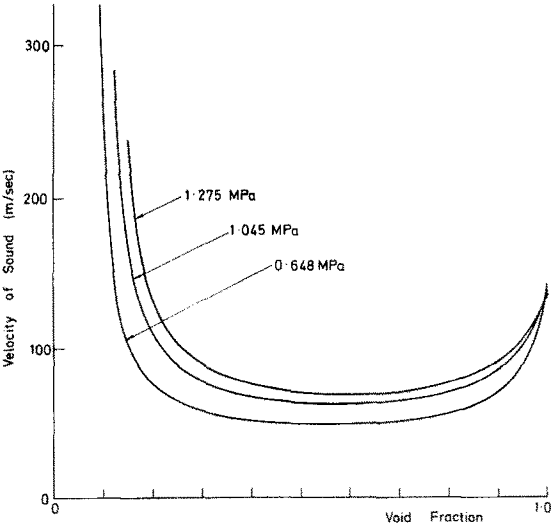

FIG. 8. Variation of velocity of sound for Freon 12.

at a mixture void fraction of 0·6. Since this is nearly an order of magnitude faster than the highest mixture velocity obtained, it seems unlikely that the propagation velocity indicated in the correlation diagrams can be associated with the characteristic propagation velocity of the mixture itself. Thus it appears that the observed velocity does represent the motion of the bubble structure between the two transducers at approximately 1·4 times the nominal mixture average velocity.

The magnitude of the maximum correlation coefficient decreased to approximately 0·35 within approximately 30 cm separation distance at a mixture velocity of 5·67 m/s and then decreased more slowly to a value of approximately 0·1 at a distance of 142 cm. From these results it appears that the flow structural lifetime, defined as the time taken for the correlation to decrease to a value of $1/e$, would be approximately 30 ms.

4. CONCLUSIONS

These experiments have shown the strong attenuation of incident pressure fluctuations along a two-phase pipe flow to be of the order of 11 dB/m at a vapour flow void fraction of 0·061, increasing to above 20 dB/m at a flow void fraction of 0·108. In the absence of detailed information concerning the void structure of the mixture, comparison of these results with the predicted values of available analyses for homogeneous mixtures is not possible. Further, any close comparison would be dependent upon the inter-phase mass transfer during the propagation of disturbances, which is subject to some uncertainty. However, the increases of attenuation with void fraction and frequency do demonstrate that the expected trends are shown in the experimental results.

It has been found that the pressure fluctuations generated by the turbulent two-phase flow itself increase approximately with the dynamic pressure of the flow, the root mean square turbulent pressure fluctuation being of the order of 1·5 per cent of the dynamic pressure. Measurements further away from the heater section showed a lower turbulent pressure fluctuation.

Cross correlation measurements between pairs of pressure transducers indicate that the pressure fluctuations associated with the flow propagate at approximately 1·4 times the mixture average velocity and that the structural lifetime indicated by the decay of the correlation with increasing separation is of the order of 0·03 s. The velocity measurements suggest that there is a relatively strong slip between the phases with the gas phase moving faster than the liquid and the pressure fluctuations being caused primarily by the disturbances associated with the vapour bubbles. It may be noted that the magnitude of this slip effect indicated by these experiments is in general agreement with other measurements of slip, such as those reported by Zuber and Findlay [5] for similar conditions of flow.

From these experiments it appears that wall pressure fluctuations do provide a useful method for the investigation of the unsteady characteristics of turbulent vapour–liquid mixture flows. The attenuation of incident fluctuations, the generation of pressure fluctuations due to the turbulent nature of the flow and the propagation of disturbances with the flow at a velocity higher than the nominal average velocity may all be observed.

ACKNOWLEDGEMENTS

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FLUCTUATIONS DE PRESSION DANS L'ECOULEMENT D'UN MELANGE VAPEUR-LIQUIDE

Résumé—Cet article présente les résultats d'une série de mesures de fluctuations de pression à la paroi pour l'écoulement ascendant d'un mélange vapeur–liquide de fréon dans un tube circulaire. Les résultats montrent la forte atténuation des perturbations incidentes de pression par le mélange, la génération de fluctuations de pression par l'écoulement turbulent biphasique et la propagation de perturbations de pression associées à l'écoulement dans la direction du mouvement. Ces perturbations de pression semblent se déplacer à une vitesse 1,4 fois plus grande que la vitesse moyenne nominale du mélange.

DRUCKSCHWANKUNGEN IN EINER DAMPF-FLÜSSIGKEITS-MISCHSTRÖMUNG

Zusammenfassung—Diese Arbeit liefert die Ergebnisse einer Reihe von Messungen der instationären Wanddruckschwankungen für die Aufwärtsströmung einer Frigen-Dampf-Flüssigkeits-Mischung in einem Rohr kreisförmigen Querschnitts. Die Ergebnisse zeigen eine starke Dämpfung der auftretenden Druckstörungen durch die Mischung, die Erzeugung von Druckschwankungen durch die turbulente Zweiphasen- Mischströmung und die Fortpflanzung der Druckstörungen, mit der Strömung in Strömungsrichtung. Die zuletzt genannten Druckstörungen scheinen sich mit einer Geschwindigkeit von ungefähr dem 1,4-fachen der nominellen durchschnittlichen Mischungsgeschwindigkeit zu bewegen.

ПУЛЬСАЦИИ ДАВЛЕНИЯ В ПОТОКЕ ПАРОЖИДКОСТНОЙ СМЕСИ

Аннотация—В статье приведены результаты ряда измерений нестационарных пульсаций давления на стенке при движении вверх парожидкостной смеси фреона в круглой трубе. Результаты измерений показали, что случайные возмущения давления в смеси быстро затухают, при турбулентном течении возникают пульсации давления, а возмущения давления, связанные с течением, распространяются в направлении потока. Скорость распространения возмущений в последнем случае примерно в 1,4 раза больше средней номинальной скорости смеси.