HYDRAULIC PARAMETERS AND STRUCTURE FOR A GAS–LIQUID FLOW IN A SPIRAL CHANNEL

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Measurements have been made on the true volume gas content, pressure difference, and structural features of an air-water mixture moving in a spiral. The characteristics are similar to those of a two-phase medium flowing in a straight tube.

Coiled heat-transfer surfaces are promising elements for compact exchangers [1]. Tight reliability specifications make it necessary to make detailed studies not only of the average parameters in two-phase flows here but also on the internal structure, which has marked effects on the hydraulic, heat-transfer, and vibration aspects [2, 3].

We have measured the average parameters and structure of an adiabatic air-water flow in a spiral with a model built with a steel tube of internal diameter d = 11 mm, where the stretched length of the spiral $\ell$ was 9680 mm, height 780 mm, winding pitch h = 20 mm, and winding diameter $D_W$ = 80 mm. The model was set up in a water-air loop with forced circulation. Parameter ranges: 0.9-24 m/sec for a mixture velocity $w_m$, 0.2-0.98 for the gas content $\beta$, pressure 1.0-2.6 MPa, and temperature 15-25°C. The water flow was measured volumetrically with a measurement vessel, while the air flow was measured with calibrated construction devices. The gas was injected into the liquid at a distance of more than 500 times the diameter from the measurement point.

The structure was examined from recordings of fluctuations in the true volume gas content $\phi$; the instantaneous $\phi$ were measured by gamma transmission as well as with resistance probes (Fig. 1).

The Am-241 isotope sources had an activity of 0.55 Ci each and were placed along with the detectors in such a way that the transmission direction coincided with the tangent to the tube axis. The collimated beam passed through a toroidal segment with central angle 76°. The length of the axis in the irradiated volume was four times the diameter, which was much less than the length of the structures. The attenuated radiation was recorded with NaI(Tl) scintillation counters, and the instantaneous count rates were recorded with an N-115 loop oscillograph. The system recorded the instantaneous density averaged over the cross section with a time-constant of 0.02 sec, which on average was less by an order of magnitude than the characteristic fluctuation periods. The recording length was such as to cover not less than 8-10 characteristic periods. The true volume gas content is given by

$$\varphi = (y - y_{wat})/(y_{air} - y_{wat}),$$

where y is the corresponding beam deflection [4]. The values of $y_{wat}$ and $y_{gas}$ were recorded by irradiating the working part when it was completely filled with water or air before the tests and periodically during them.

A correction was applied for the unsymmetrical gas-content profile by means of weighting functions derived from geometry and from a preliminary study of the gas profile with resistance probes.

The resistance probes were made by passing a copper wire in PVC insulation through a copper capillary and then sealing the end with epoxide resin. The 5 V supply was provided by a VS-26 stabilized unit to the inner electrode; the outer electrode was connected to the coil. The electrical conductivity of the liquid was raised by adding NaCl at $2 \times 10^{-4}$ kg/kg.

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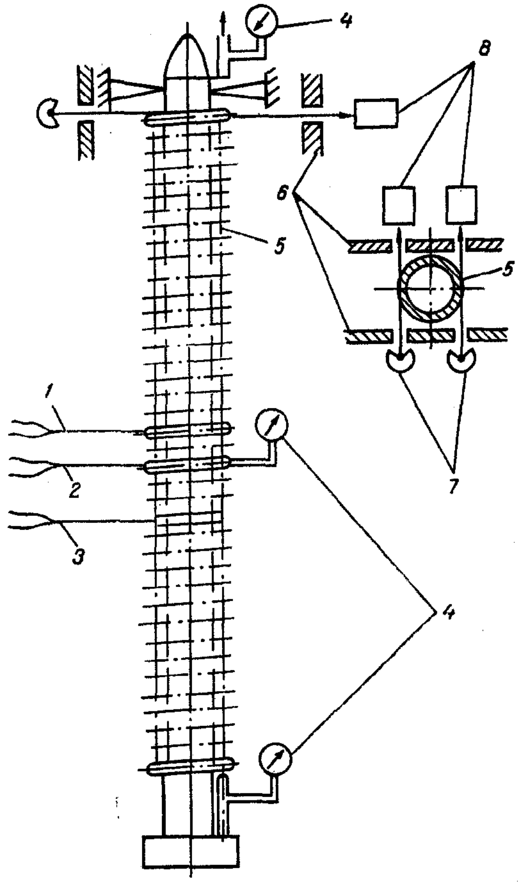


Fig. 1. Experimental scheme: 1-3) resistance probes; 4) manometers; 5) coils; 6) lead collimators; 7) Am-241 $\gamma$ sources; 8) $\gamma$ detectors.

The probe signals were recorded directly by the N-115.

Figure 2 shows the observed time-averaged true gas content by volume $\phi$ as a function of the flow content $\beta$, together with curves from the formulas of [5, 6] for vertical channels. There is quite good agreement, so the average structure in a spiral differs only slightly from that in a straight channel in these ranges.

A similar result was obtained in [7] in measurements on an air-water mixture in coils with $D_w/d = 11$ and $D_w/d = 22.7$; $\beta/\phi = 1.2$ for the range $0.18 \le \beta \le 0.95$.

We used $2\Delta pd/\rho' w_0^2 \ell = f(\beta)$ coordinates with a formula recommended in [8] to plot the data on the averaged pressure difference along the coil:

$$\frac{2\Delta pd}{\rho' w_0^2 l} = \zeta \left[ 1 + \frac{\beta\gamma_0\psi}{1+(1-\beta)\gamma_0} \right],$$

where $\gamma_0 = (\rho' - \rho'')/\rho''$ is the relative phase density (Fig. 3). The curve from this formula is also shown. The inhomogeneity factor $\psi$ was determined by the method of [6], while the hydraulic resistance factor $\zeta$ was determined by that of [9].

The good agreement means that the effects of the two-phase structure on the hydraulic resistance in a coil are almost as for a straight channel.

The structure was analyzed by comparing the true-volume fluctuations in different sections as found in this way and from the model described in detail in [10].

The fluctuation recordings indicated that the flow is of slug type for $0.2 < \beta < 0.8$. Figure 4 shows the slug speed (or the speed of some other structure feature) $w_c$ as a function of the mixture speed $w_m$ (a) and the same for $\beta$ (b). One can use $w_c/w_m = 1.35$ for $\beta \le 0.8$ and $w_c/w_m = 1.35 - 4.5(\beta - 0.8)$ for $\beta > 0.8$ to describe the results fairly accurately.

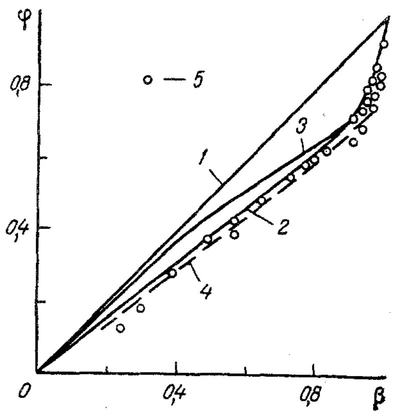


Fig. 2

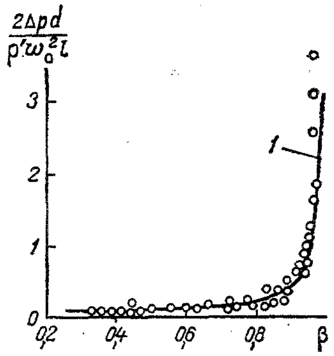


Fig. 3

Fig. 2. True volume gas content as a function of flow content: 1) calculated from homogeneous model; 2, 3) calculated by the methods of [5] and [6] correspondingly; 4) averaged relationship from data of [7]; 5) measurements; $w_0$ = 1.2 m/sec, p = 0.2 MPa.

Fig. 3. Effects of flow gas content on dimensionless pressure difference: 1) theoretical curve.

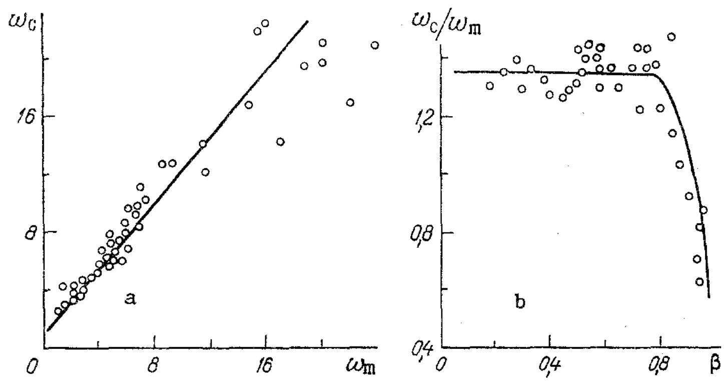


Fig. 4. Fits to measurements for speed of structure features, $w_c$ and $w_m$ in m/sec.

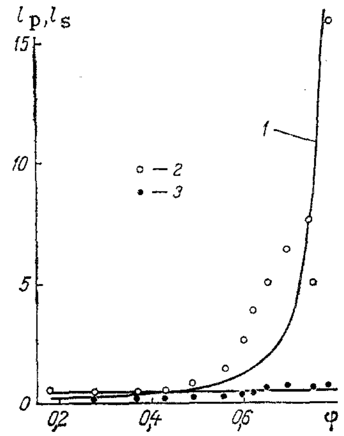


Fig. 5. Observed dependence of liquid plug length $\ell_p$ and gas slug length $\ell_s$ on $\varphi$: 1) theoretical curve; 2) $\ell_s$; 3) $\ell_p$; $\ell$ in m.

Figure 4 and the analogous curves for straight tubes [10] show virtually the same behavior, but somewhat lower $w_c/w_m$ apply for the straight tubes.

The liquid plugs change in size only slightly as the gas content increases, as with straight tubes (Fig. 5). On the other hand, $\ell_p/d = 10$ for straight tubes over a wide range in the flow parameters [10], whereas $\ell_p/d \cong 45$ for this spiral.

The slug length increases substantially with the gas content; Fig. 5 shows the formula proposed in [10] for straight tubes:

$$l_s = l_p \frac{\varphi - \varphi_p}{\varphi_s - \varphi},$$

where $\phi_p$ is the gas content in a section occupied by a liquid plug and $\phi_s$ is that in a section occupied by a gas slug. The $\phi_p$ and $\phi_s$ are correspondingly 0.11 and 0.79, as for straight tubes [10]. This theoretical curve gives a satisfactory qualitative description.

We therefore conclude that the two-phase mixture in a coil differs only slightly in structure from that in a straight tube (apart from the lengths of the liquid plugs) in the parameter range used.

## NOTATION

d, internal channel diameter; $D_w$, coil winding diameter; $w_0$, circulation velocity; $w_m$, mixture velocity; $w_c$, slug velocity; $\phi$, true volumetric gas content; $\beta$, flow rate volumetric gas content; p, pressure; $\Delta p$, pressure drop, $\rho$, density; $\ell$, coil length; $\gamma_0$, relative phase density; $\psi$, inhomogeneity coefficient; $\zeta$, hydraulic resistance coefficient; $\ell_p$, liquid plug length; $\ell_s$, gas slug length; ', liquid phase; ", gas phase.

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