VELOCITY OF SOUND IN ARGON AND IN HELIUM–ARGON AND NITROGEN–CARBON DIOXIDE GAS MIXTURES AT HIGH PRESSURES

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The sound velocity is measured in argon and in mixtures of helium with argon and of nitrogen with carbon dioxide at pressures up to 800 MPa and at temperatures in the range 298.16-423.16°K.

We have previously [1, 2] measured the sound velocity in the system helium–argon at pressures up to 400 MPa for four mixture compositions and in the system nitrogen–carbon dioxide for two compositions; in the nitrogen–carbon dioxide mixtures we observed a nontrivial phenomenon: In the pressure interval 200-700 MPa at a temperature of 423.16°K the sound velocity in the mixture is lower than the sound velocity in the pure components. Calculations according to the procedure of Abovskii [3] for a helium–argon mixture with 0.2 mole fraction helium predict a similar effect in the temperature range 298.16-423.16°K at pressures of 800 MPa, which was not observed in [1], because a mixture of this particular composition was not investigated there.

In the present study we have attempted to verify the results of the theory of Abovskii and to determine the relationships between the sound velocities in a nitrogen–carbon dioxide mixture (N_{N_2} = 0.604) and in the original pure gases in the range of pressures 50-450 MPa and temperatures 298.16-423.16°K.

To measure the sound velocity in the nitrogen–carbon dioxide gas, we used a variant of the pulse technique described in [4]. The velocity measurements in pure argon and the helium–argon mixture were carried out on the apparatus shown in Fig. 1. Elevated pressures were created by a compressor designed and built at the Institute of High-Pressure Physics of the Academy of Sciences of the USSR (IFVD AN SSSR) for the compression of liquids to 1600 MPa. Certain design modifications made it possible to use the compressor for the compression of gases to 1000 MPa. The gaps between the ground-glass joint 1 and the bushing 2 od the cylinder 3 were eliminated, and the shape of the bushing itself was modified to minimize clearances.

The working pressure in the apparatus was measured with a Manganin manometer placed in the high-pressure cylinder 4, which was thermostatted at 298.16°K.

The ultrasonic chamber (Fig. 2) consisted of a single silvered X-cut piezoelectric quartz wafer 1, a sapphire reflector 2, and a hollow metal cylinder 3 for fixing the distance between the radiator and the reflector. The spring-loaded contact 4 was used to transmit rf pulses to and from the radiator through a single high-pressure input terminal. The procedure used to measure the sound velocity was similar to the one reported in [4].

The high-pressure cylinder 6 (Fig. 1) was a thick-walled container of steel 45KhNMFA (chrome–nickel alloy) enclosed in the metal jacket 7, through which a thermostatic liquid was circulated; the entire assembly was encased in thermal insulation 8.

We investigated a mixture of helium and argon with a mole fraction of helium N_{He} = 0.213 and also a mixture of nitrogen and carbon dioxide gas with N_{N_2} = 0.604. For comparison of the mixtures we used helium, argon, high-purity nitrogen, and alimentary carbon dioxide. The molecular mass of the mixtures was 32.29 for helium–argon and 34.3 for nitrogen–carbon dioxide. The error of determination was 0.1%.

We measured the velocity of ultrasound in pure argon at temperatures of 272.16 and 423.16°K in the pressure range 100-800 MPa, and also in the helium–argon mixture at temperatures of 298.16, 373.16, and 423.16°K in the same pressure range. The sound velocity in

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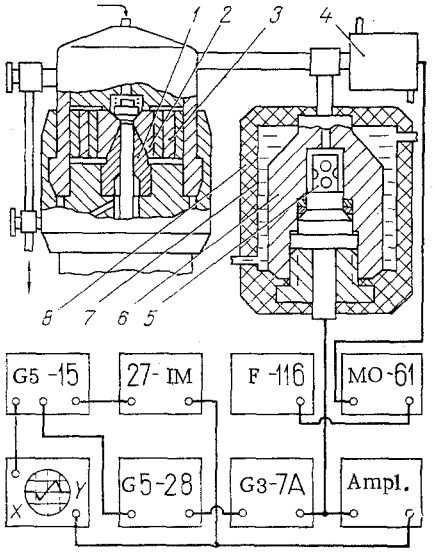

Fig. 1

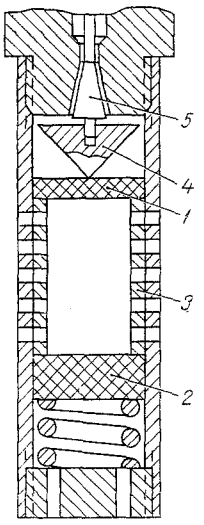

Fig. 2

Fig. 1. Schematic view of the apparatus: 1) ground-glass joint; 2) bushing; 3) cylinder; 4) high-pressure chamber with Manganin manometer; 5) ultrasonic chamber; 6) high-pressure cylinder; 7) metal jacket; 8) thermal insulation.

Fig. 2. Ultrasonic chamber: 1) quartz wafer; 2) sapphire reflector; 3) cylinder; 4) contact; 5) high-pressure input terminal.

TABLE 1. Sound Velocity c in Argon and in Helium–Argon and Nitrogen–Carbon Dioxide Gas Mixtures at Various Pressures and Temperatures

P	Argon		Helium–argon			Nitrogen–carbon dioxide			
	373°K	423°K	298°K	373°K	423°K	298°K	323°K	373°K	423°K
50	—	—	—	—	—	—	597	554	540
100	695	685	698	695	684	872	832	797	760
200	960	940	966	950	933	1194	1168	1110	1065
300	1150	1122	1150	1130	1114	1415	1391	1334	1289
400	1292	1272	1293	1274	1260	1587	1559	1508	1465
500	1414	1388	1413	1398	1380	—	—	—	—
600	1516	1490	1514	1508	1484	—	—	—	—
700	1606	1584	1600	1604	1580	—	—	—	—
800	1688	—	—	1688	—	—	—	—	—

the nitrogen–carbon dioxide mixture was determined at temperatures of 298.16, 323.16, 373.16, and 423.16°K in the pressure range 50-450 MPa. The values obtained for the sound velocity from the curves of the sound velocity pressure, which were smoothed by the least-squares principle, are given in Table 1.

It is evident from the results that in a helium–argon mixture with N_{He} = 0.213 the sound velocity is lower than in the original gases in the pressure interval 100-750 MPa at temperatures in the range 298.16-423.16°K. With an increase in the temperature the difference between the sound velocities in argon [5] and the helium–argon mixture diminishes. For example, at 298.16°K it lies in the interval 3.5-3.9%; at 373.16°K the maximum difference in the sound velocities occurs at 115 MPa and is equal to 2.2%, and at 100 and 800 MPa the sound velocities in the mixture and in the pure gas coincide; at 423.16°K the difference attains its maximum value of 1.1% at a pressure of ~375 MPa, and at 100 and 800 MPa the sound velocities in argon and in the mixture coincide. A comparison of the experimental values of the sound velocity in the mixture with the results of calculations according to Abovskii's procedure [3] shows that at 373.16 and 423.16°K in the pressure interval 100-600 MPa they agree within the experimental error limits (0.4%). On the other hand, at pressures of 700-800 MPa and a temperature of 373.16°K the mean discrepancy is 0.51%, and the maximum discrepancy is 0.95; at 423.16°K the corresponding values are 0.39 and 0.63%. At 298.16°K the mean discrepancy between the calculated values of the sound velocity and the experimental data over the entire investigated pressure range is 2.56%, and the maximum discrepancy is 3.66%.

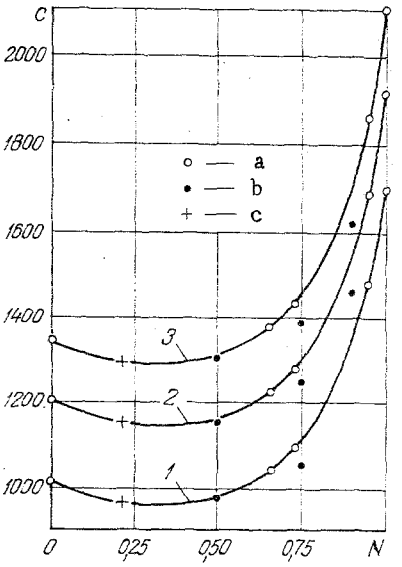

Fig. 3. Plot of sound velocity c (m/sec) vs helium mole fraction N in the mixture helium–argon at 298°K and different pressures: 1) P = 200 MPa; 2) 300 MPa; 3) 400 MPa; a) data of ref. [1]; b) data of [6]; c) data of the present authors.

In every case the theoretical values of the sound velocity are greater than the experimental. The variation of the sound velocity in a helium–agron mixture as a function of the mole fraction of helium is shown in Fig. 3. Also shown in this figure are the results of a previous investigation of these mixtures [6]. It is essential to note the discrepancy between our data and the results of [6], which attains 4-5%, far exceeding our experimental error limits.

We have interpolated the data of [7] on the sound velocity in argon to the investigated temperatures 373.16 and 423.16°K in our work and made a comparison with the experimental results. At a temperature of 373.16°K the mean discrepancy of the sound velocity values obtained by Sevast'yanov and Zykov [7] and according to our data is 0.74%, and the maximum discrepancy is 1.32%; at 423.16°K the corresponding discrepancies are 0.73 and 1.27%.

A comparison of our velocity values in a nitrogen–carbon dioxide mixture (N_{N_2} = 0.604) with the results of measurements for the pure gases [2] shows that at 298.16°K the sound velocity in the mixture in the range 50-450 MPa is lower than in pure carbon dioxide, but greater than in pure nitrogen. At 323.16°K the sound velocity in the mixture over the entire investigated pressure range coincides with the sound velocity in nitrogen within the experimental error limits. At 373.16°K the sound velocity in the mixture is lower than in either of the pure gases, where the difference of the sound velocities in nitrogen and the mixture decreases monotonically from 8.8% (at 50 MPa) to 1.32% (at 450 MPa). At 423.16°K the sound velocity in the mixture is lower than in the original gases (at this temperature, beginning with 200 MPa, the sound velocity in nitrogen coincides with the velocity in carbon dioxide) and the velocity difference increases monotonically from 0.93% (at 50 MPa in carbon dioxide) to 3.1% (at 450 MPa).

NOTATION

c, sound velocity, m/sec; P, pressure; N_{He}, mole fraction of helium in mixture; N_{N_2}, mole fraction of nitrogen in mixture.

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INVESTIGATION OF THE HYDRODYNAMIC REGIMES OF A LIQUID IN A SMOOTH-WALLED ROTATING HEAT PIPE. II

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The article deals with the analytical and experimental investigation of the influence of the slope of a rotating heat pipe and of the taper of its inner surface on the hydrodynamics of a liquid.

The heat transfer ability and other characteristics of a rotating heat pipe (RHP) depend largely on the orientation in the gravity field, which is particularly noticeable at relatively low rotational speeds, and on the geometry of the inner surface.

Let us examine the operation of a RHP in the range of slopes of the axis $0 \leqslant \beta < \beta_d$, where β_d is the maximum angle at which the axial component of the centrifugal force cannot ensure transport of the heat carrier from the zone of condensation to the zone of evaporation, i.e., the extreme section of the zone of heat supply begins to dry.

When $\beta > 0$ and the rotational speed ω is low, the liquid is redistributed along the x axis in the groove. If ω is sufficiently large for the liquid to spread over the inner surface without forming a groove, then the redistribution is determined by the ratio of the axial component of the force of gravity to the pressure gradient ΔP in the liquid layer formed on account of the longitudinal thickness gradient δ_x. In either case the mean thickness of the layer over the perimeter $\overline{\delta}_x = S_x/2\pi R$ is a function of the coordinate x. When $\beta = 0$ or $\omega \to \infty$, $\overline{\delta}_x = \delta = \text{const}$. When $\beta > 0$, the number $\mathrm{Re}_x = \omega(\overline{\delta}_x)^2/\nu$, determining, together with the number $\mathrm{Fr}_c = \omega^2 R/g$, the flow regime (see Fig. 1 [1]), is also a function of x as distinct from the horizontal position of the pipe at which the Reynolds number is constant for a specified value of ω.

Thus, when a RHP is inclined, the Reynolds number along the pipe changes, and in consequence a complex hydrodynamic pattern arises in it; this pattern is characterized by the simultaneous existence of different flow regimes described in [1].

We obtain the dependence of $\overline{\delta}_x$ on the coordinate x for two characteristic cases: a) for small values of ω at which there is a groove in the lower part of the pipe; b) for high speeds when the liquid spreads over the entire inner surface.

Taking small values of the angle β, and consequently a very slight longitudinal component of the force of gravity, we assume that with small ω the dependence of $\overline{\delta}_x$ on x with specified amount of liquid and specified geometry of the pipe is determined solely by the slope. This assumption means that in the range of rotational speeds at which there exists a groove, the liquid moves in a plane perpendicular to the longitudinal axis of the pipe, and does not move axially.

The expression for the volume of liquid in a pipe with $\beta > 0$ has the form (Fig. 1):

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