EXPERIMENTAL STUDY OF THE SPEED OF SOUND IN DOWTHERM VAPOR

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An apparatus using the ultrasonic interferometer principle is used to measure the speed of sound in Dowtherm vapor over the temperature range 230-360°C and pressure range 0.2-6.2 bar.

It is convenient to investigate the thermodynamic properties of important heat-transfer agents such as Dowtherm by studying the speed of sound in the material. However at the present time the literature offers no data on the speed of sound in Dowtherm vapor. Moreover, such data are important for performing gasdynamic calculations and calculating thermodynamic parameters such as the adiabatic index, heat-capacity ratio c_p/c_V, second virial coefficient in the equation of state, etc.

The present study measures the speed of sound in Dowtherm vapor, a diphenyl mixture consisting of 28.20% diphenyl and 71.67% diphenyl ether, over the temperature range 230-360°C and the pressure range 0.2-6.2 bar. The upper limits of these ranges were determined by the decomposition temperature and saturation pressure of Dowtherm vapor.

An apparatus was constructed for the study using the ultrasonic-interferometer principle. This approach was chosen because the most reliable data available on speed of sound in gases has, as a rule, been obtained with the ultrasonic interferometer. The oscillation source is a movable quartz plate 1 (Fig. 1) 50 mm in diameter and 9.4 mm thick with a natural frequency of 300 kHz. An identical plate 2 is used as the receiver. Measurements were performed during the process of plane-parallel displacement of one plate relative to the other. The number of half-waves included between the plates was varied. The device indications were recorded at the moment of resonance when the receiver was located at an antinode, corresponding to a maximum in the interference picture on the oscilloscope screen.

The quartz pieces with channels along their center lines are mounted in holders 3. As was shown in [1], plate mounting at points lying in the symmetry plane is optimal, permitting oscillation at the natural frequency with a minimum of noise. Due to the free suspension type mounting the interferometer sensitivity was increased significantly. The faces of the quartz plates were polished and coated with an 0.5-μ layer of silver by vacuum deposition. The current leads 4 are light platinum springs in contact with the lower surface of the generator and the upper surface of the receiver.

The operating parts of the interferometer are enclosed in chamber 5, made of 1Kh18N9T stainless steel. The chamber bottom 6 was sealed by the knife edge-channel method with a 0.5-mm-thick aluminum seal. Leads were sealed in the lower part of hollow rod 7 by seals of silicone nonoxidizing vacuum rubber.

The quartz generator was mounted in a clamp attached to movable rod 7. The rod was sealed by bellows 8, permitting rotational and translational motion of the quartz. Discharge chamber 9 to which inert gas is supplied protects the bellows from the pressure difference between the inside and outside of the operating chamber. The pressure difference between operating and discharge chambers is about 1 bar, while the pressure under the bellows is always higher, eliminating backlash in the displacement system.

Displacement of the quartz plate is measured by the vertical-length meter, type IZV-2, whose indicator bar is rigidly connected to the interferometer rod 7.

The interferometer body is placed within copper vessel 10, on which a two section nichrome heater is attached. The current to each heater section is controlled by type VRT-2 high-current temperature regulators,

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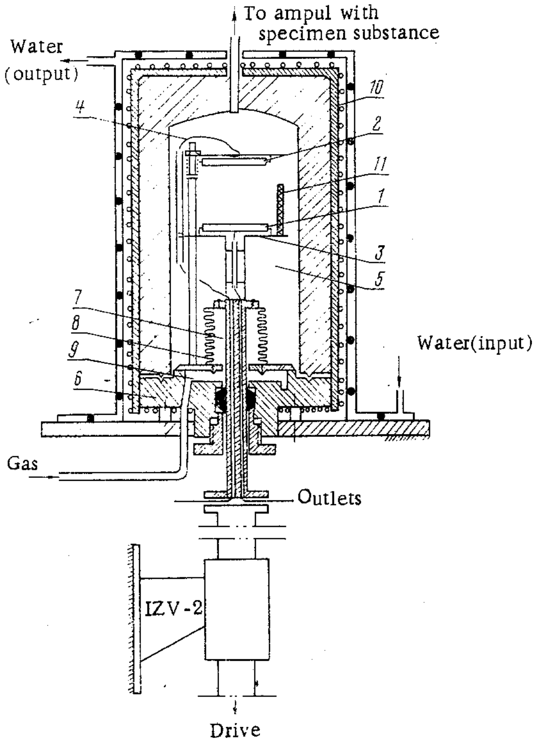

Fig. 1. Ultrasonic interferometer: 1, 2) quartz; 3) clamps; 4) current leads; 5) operating chamber; 6) chamber bottom; 7) hollow rod; 8) bellows; 9) discharge chamber; 10) copper vessel; 11) resistance thermometer.

which ensures a maximum temperature change over the operating section of the interferometer of not more than 0.1°C. The temperature is measured by a platinum resistance thermometer 11 and a class 0.002 type R-348 potentiometer. The thermometer is attached to the mounting point of the lower quartz plate, allowing monitoring of temperature field uniformity during experiment.

Up to 2 bar, the pressure in the chamber is measured by a U-shaped mercury manometer, while above 2 bar a reference manometer with limit of 6 kgf/cm^2 and individual calibration. The relatively weak dependence of the speed of sound on pressure allowed relaxation of the accuracy required in measuring this parameter. As is well known, Dowtherm is a eutectic azeotropic mixture, for which the temperature dependence of saturation pressure is expressed, as for a pure substance, by a single-valued function $P_S = f(T_S)$.

The material to be studied is poured into a 1Kh18N9T stainless-steel ampul provided with an electric heater which permits continuous change of temperature, and, thus, pressure in the interferometer chamber. All connecting leads are provided with heaters to eliminate condensation of the material.

Before performing the main experiments the apparatus was checked with gases for which the speed of sound is well known, namely, argon, nitrogen, and xenon. The maximum deviation of measured values from data in the literature over the temperature and pressure ranges studied was 0.1%, which is produced mainly by diffraction phenomena. An estimate of the effect of diffraction, using the recommendations of [1, 2] for the given wavelengths, sensor diameters, and intersensor distances, gives a diffraction correction not exceeding 0.1%.

The speed of sound is determined from the formula

$$a = \lambda f,$$

where a is the speed of sound, m/sec; f, frequency of quartz plate oscillations, kHz; λ, length of sound wave, mm. The wavelength λ is found by measuring the distance between the quartz plates corresponding to decades of half-wavelengths. This allowed measurement of λ to a high degree of accuracy. The distance between the quartz plates was measured by the IZV-2 vertical-length meter to an accuracy of 1 μ. The frequency of the quartz generator plate was set by a GZ-49 precision generator to an accuracy of ± 1 Hz.

TABLE 1. Speed of Sound in Dowtherm Vapor

P, bar	a, m/sec	P, bar	a, m/sec
232 °C		310 °C	
0,25	160,49	0,31	172,36
0,29	160,35	0,62	170,57
0,44	158,74	0,94	169,05
0,47	158,58	1,79	164,34
0,54	157,97	1,95	163,49
0,60	157,21	2,63	159,09
		2,71	158,72
260 °C		335 °C	
0,30	164,43		
0,39	163,56	0,57	174,38
0,52	162,88	1,06	172,57
0,59	162,21	1,67	169,59
0,96	159,23	2,33	166,77
1,03	158,70	3,17	162,27
		4,01	157,47
283 °C		4,04	156,70
0,24	168,00		
0,55	166,53	360 °C	
0,84	164,48	0,40	178,02
0,87	164,23	1,63	173,94
0,96	163,83	2,11	172,45
1,18	162,10	3,53	166,49
1,27	161,87	4,41	162,39
1,62	159,18	5,26	158,14
		5,50	156,97
		6,19	152,50

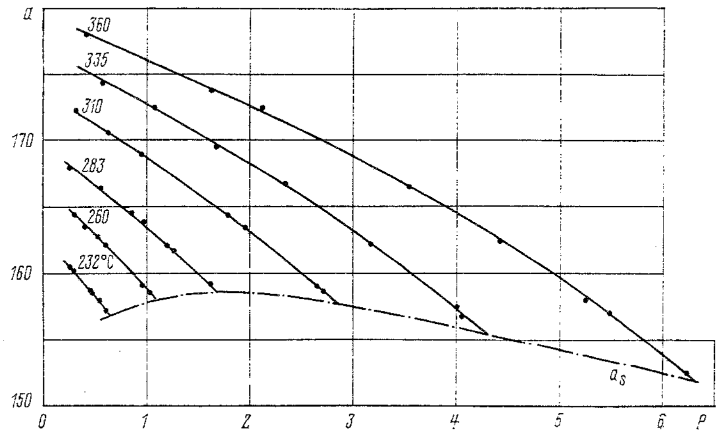

Fig. 2. Experimental data on speed of sound in Dowtherm vapor.

The IZV-2 length meter was read when a maximum appeared in the interference pattern on the oscilloscope screen. Experiments showed that the uncertainty in determination of the position of the standing wave antinode did not exceed ± 3 μ. In measuring distances of 9-12 mm, corresponding to approximately 20 wavelengths or 40 half-wavelengths, this uncertainty produced a contribution to total uncertainty of approximately 0.03%. Minimum distance between plates was 60 mm. The quartz plates were aligned with a type AK-0.25 autocollimator with a resolving power of 2". This allowed very accurate positioning, as was confirmed by the absence of satellites in the interference pattern. As was noted above, measurements were performed at a frequency of 300 kHz. Calculations and control experiments performed at 500 kHz showed that at 300 kHz dispersion was absent.

The maximum relative error of the experimental data on speed of sound in Dowtherm vapor with consideration of diffraction corrections and errors in state parameter data comprises 0.2%.

Series of measurements were performed along isotherms. The isotherms 232, 260, 283, 310, 335, and 360°C were studied. Results are presented in Table 1 and Fig. 2 where the dashed-dot line represents the saturation line.

The results obtained were compared with speed of sound data calculated from p−V−T data for Dowtherm [3]. The divergence between the experimental and calculated data averaged 0.35%, reaching 0.6% at a temperature of 360° and pressure of 6 bar.

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ACTION OF QUANTUM EFFECTS ON THERMAL CONDUCTIVITY OF LIGHT GASES (HELIUM-3, HELIUM-4, AND HYDROGEN)

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Expressions are found for quantum corrections considering symmetry effects expressed in terms of collision integrals, and their contribution to the thermal-conductivity coefficient of gases is calculated. It is shown that quantum effects for light gases are insignificant at temperatures above 20°K.

The study of gas transfer properties at low temperatures and high pressures is of practical interest because of the use of the phenomenon of superconductivity in many scientific and industrial fields. Experimental study of such properties is complicated by large material expenditures, the limited number of objects for study (isotopes of helium and hydrogen), and severe methodological difficulties.

The literature offers isolated experimental data on the transfer properties of helium-3, helium-4, hydrogen, and their mixtures at low temperatures, usually at atmospheric pressure.

Together with the experimental methods of studying transfer properties, there exist two theoretical approaches to describing such properties. The first of these is the thermodynamic approach, based on the quantum theory of irreversible transfer phenomena [1], in which one initially establishes linear phenomenological relationships between the Fourier components of the corresponding flux densities $I^{(p)}(q;\ \omega)$ and the forces acting on the equilibrium system $X^{(p)}(q;\ \omega)$ in the form

$$I^{(p)}(q;\ \omega) = L^{pp'}(q;\ \omega) X^{(p)}(q;\ \omega),$$

where $L^{pp'}(q;\ \omega)$ are kinetic coefficients; $I^{(p)}(q;\ \omega) = \int dx e^{iqx} \int dt e^{i\omega t} \times I^{(p)}(x, t)$. Then general formulas are found for $L^{pp'}(q;\ \omega)$ commencing from a microscopic (quantum mechanical) description of the macroscopic system. Finally the values of these quantities are calculated as functions of temperature.

In particular, for the thermal-conductivity coefficient the relationship [2]

$$\lambda = \beta^{-1} \int_0^\infty dt \int_0^\beta d\lambda^* \langle I^{(p)}(x,\ 0)\, I^{(p')}(x,\ t + i\lambda^*) \rangle, \tag{1}$$

may be obtained, where $\beta = (kT)^{-1}$; t, time; $I(x, t) = e^{-iHt} I(x, 0)$. Equation (1) is valid for both classical and quantum systems.

The viscosity coefficient is determined from the expression

$$\eta = \lim_{N,V\to\infty} \frac{1}{VkT} \int_0^\infty dt \langle I(0)\, I(t) \rangle = \frac{n}{kT} \int_0^\infty dt \int dp^* \frac{p_x^* p_y^*}{m} \Phi(p^*,\ q,\ t) -$$
$$- \frac{n^2}{kT} \int_0^\infty dt \int dp_1^* dp_2^* dr_{12} \frac{r_{12,x}}{2} \frac{\partial \varphi(r_{12})}{\partial r_{12,y}} \Phi(p_1^*,\ q_1,\ p_2^*,\ q_2,\ t), \tag{2}$$

p_i^*, q_i characterize the momentum and position of the i-th particle; $r_{ij} = q_i - q_j$; $\varphi(r_{ij})$ is the intermolecular interaction potential; V, volume;

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