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EXPERIMENTAL STUDY OF THERMALLY INDUCED OSCILLATIONS OF GASEOUS HELIUM

S. P. Gorbachev, A. L. Korolev, V. K. Matyushchenkov,
and V. A. Sysoev

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Results of a study of thermally induced oscillations of helium gas in semi-open and closed tubes are presented.

At the present time a number of high-power cryogenic power generation devices have been designed and are undergoing testing [1]. As a rule, the thermal rise in such devices is above the calculated value. One of the more probable causes of excess thermal loading is thermoinduced oscillations of a gas, which can develop in the tubes connecting regions at low and high temperatures [2-8]. A quite broad range of works has been dedicated to study of such oscillations. Nevertheless, up to the present there is no unified approach to describing this phenomenon [4, 9, 10]. In the authors' opinion the model which best explains the conditions for development of thermally induced oscillations is the linear model proposed by Rott [5]. According to the Rott model, oscillations develop in tubes with a sufficiently high temperature gradient. An analysis performed with use of the Rott model shows that oscillations can occur not only in tubes with an open cold end and closed hot end, but also in acoustically closed tubes. However, up to the present oscillations in closed tubes have not been observed experimentally. In contrast to Rott, a number of researchers have related the appearance of oscillations to mass exchange at the open (cold) tube and [4] and to the position of this end relative to the liquid level [2-4].

Experiments were performed to determine the effect of the temperature profile and distance from the open tube end to the liquid level on gas oscillations in the tube, and also to search for oscillations in a closed tube. The experimental units used were tubes of stainless steel with Ø 4 × 0.3 mm, l = 1320 mm and Ø 10 × 0.5 mm, l = 1320 mm. Tube 1 (Fig. 1) is inserted into a collar formed by the larger diameter tube 2. This tube has an orifice 3 for gas escape. Tube 1 and sleeve 2 are fitted into a standard STG-40 helium cryostat. By regulating the flow of gas through the annular gap between tube 1 and sleeve 2, changing the relative position of the tubes, and varying the distance to which the pair was inserted into the cryostat, various temperature profiles were produced in the tube. The required amount of gas flow for cooling of tube 1 was produced by evaporator 7, located at the bottom of the cryostat. Tube temperature was measured by thermocouples, and in addition a resistance thermometer was installed at the cold end, producing temperature measurements with an uncertainty of ~0.01°K. Pressure pulsations were recorded by piezosensor 4. For study of oscillations in a closed

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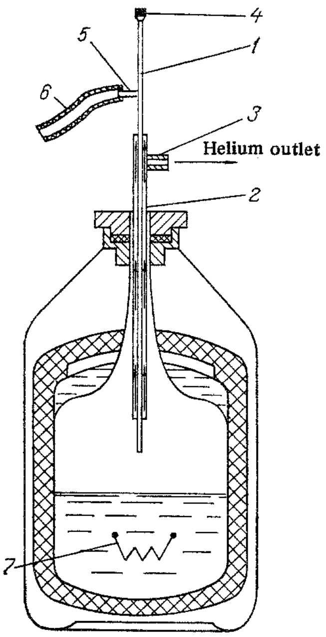

Fig. 1. Diagram of experimental arrangement.

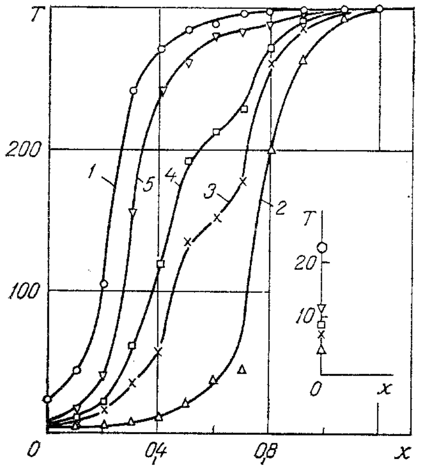

Fig. 2

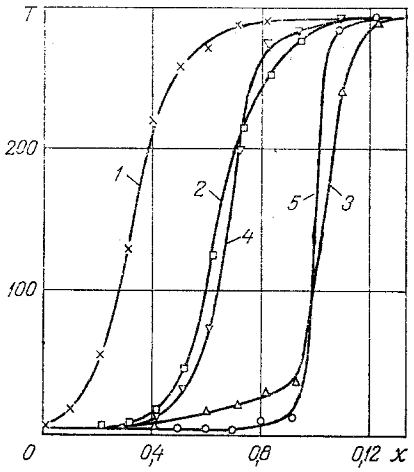

Fig. 3

Fig. 2. Temperature profile dynamics in ø4 × 0.3 mm tube: 1) P = 0, f = 0, t = 0; 2) 7.7, 32.5 Hz, 420 sec; 3) 8, 52.6, 1500; 4) 2.7, 66, 1800; 5) 0, 0, 2100. T, °K; x, m.

Fig. 3. Temperature profiles for open (1-3) and closed (4, 5) tubes ø4 × 0.3 mm; 1) T_{cold} = 5.2°K, P - 7.6, f = 53.6 Hz; 2) 4.45, 16.2, 31.9; 3) 4.45, 8.5, 20; 4) 4.25, 0, 0; 5) 4.4, 4.2, 46.9.

tube a nozzle 5 was connected to the tube, through which tube 1 was connected by vacuum hose 6 to a helium volume or a forevacuum pump. The additional volumes created by installation of the piezosensor and nozzle were about 0.1 cm^3.

The primary phenomenon studied was gas column oscillations in the tube open at the cold end and closed at the hot end. Published experimental studies [2-4] have related development of oscillations to the distance between the open tube end and the liquid level. The experiments of [2-4] were repeated and good agreement was obtained. Nevertheless, in our opinion, the distance between liquid level and open tube end plays a secondary role, the primary condition necessary for formation of oscillations being creation of a certain temperature profile within the tube. To confirm this conclusion, the open tube end was situated at a quite large distance (~30-40 cm) from the liquid level. A typical temperature profile for such a case is shown in Fig. 2, curve 1. In this case oscillations were absent. After feeding gas to cool the tube, the temperature profile took on the form shown by curve 2, and gas oscillations were excited within the tube. After switching the evaporator off, oscillations continued about 0.5 h. During this period the temperature profile in the mid part of the tube changed intensely, while the temperature of the open end increased slowly (curves 3-5). Oscillations disappeared at the time that the temperature profile took on the form shown in curve 5. The oscillation frequency varied and was close to the natural frequency of gas oscillations in the tube with consideration of the temperature dependence of speed of sound in the gas. For a period of almost 20 min after switchoff of the evaporator the amplitude of the oscillations remained practically constant, and then decreased smoothly to zero. After termination of oscillations the temperature profile took on its original form. Figure 2, curve 1, is the temperature profile which existed before and after oscillations.

The form of the profile and the temperature of the open tube end had a significant effect on oscillation amplitude. Oscillations were not observed if the temperature of the open end was above 11°K. Reduction in open end temperature led to an increase in oscillation amplitude. For example, a reduction in temperature from 7.25 to 5.27°K caused an increase in amplitude by a factor of five. The oscillation frequency also decreased from 64 to 54 Hz; the overall character of the temperature profile changed only slightly and temperature values at one and the same points of the high-temperature portion differed by not more than 15°K.

The results of the measurements established that the oscillation amplitude depends significantly on the length of the low- and high-temperature segments. The highest oscillation amplitudes were observed when these two lengths were equal (curve 2, Fig. 3). Increase in the length of one section as the other decreased led to a reduction in oscillation amplitude. The slope of the temperature profile also affected oscillation amplitude. Lower amplitude oscillations appeared in tubes with a lower temperature gradient.

A comparison of oscillation amplitudes in ∅10 × 0.5 mm and ∅4 × 0.3 mm tubes showed that for identical temperature profiles the tube with larger diameter had a lower amplitude than the smaller diameter tube.

It was observed during the study that during oscillations the tube temperature at the closed end increased and became higher than the temperature of the surrounding medium. In individual experiments this increase reached 7°K. Such an effect has not been observed previously [2-8] in studies of thermally induced oscillations.

The experiment to detect thermal oscillations in an acoustically closed tube was performed in the following manner. Tube 1 (∅4 × 0.3 mm, l = 1320 mm) was evacuated through hose 6 and then filled with gaseous helium. This cycle was repeated 4-5 times. Then various temperature profiles were created in tube 1. This was done just as for the open tube. Oscillations were excited at certain temperature profiles. A sufficiently high temperature gradient was required (curve 5, Fig. 3), higher than for the tube open at its cold end. Figure 3 shows a profile (curve 4) for which there are no oscillations in the closed tube, while the same figure shows a profile for an open tube (curve 2) for which gas oscillations exist. Oscillations in the closed tube do not damp out if the temperature profile is not changed. However, the following must be considered: aside from the special temperature distribution, to produce oscillations it was necessary to pinch off hose 6 as close as possible to tube 1. If the hose is not closed off, no oscillations are observed.

The oscillation frequency in the closed tube was double that in the tube open at the cold end. This is because half-wave oscillations occur in the closed tube, while quarter-wave ones take place in the open one.

NOTATION

P, pressure pulsation amplitude, relative units; f, frequency, Hz; t, time, sec; T, temperature, °K; T_{cold}, temperature of cold tube end, °K; x, coordinate, m; l, length, m.

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EFFECT OF MOTION OF A GAS MEDIUM ON THE ACCURACY OF MEASUREMENT BY ACOUSTIC METHODS

V. Ya. Zenin, V. I. Krylovich,
and V. V. Mikhal'kov

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The effect of velocity and direction of motion of a gas medium on the propagation time of an acoustic signal is treated in the regions of unidirectional radiation and echo ranging.

Acoustic methods of measuring sizes and relative velocities of motion of objects are noted by their simplicity and high accuracy. They have found particularly wide application in oceanic studies [1]. Studies have recently appeared, devoted to applying these acoustic methods to solve similar problems in a gas medium. To this group belong problems such as the measurement of distance [2], noninertial temperature measurement of a gas medium [3], measurement of velocity and direction of displaced air flows [4], etc.

It must be noted that these problems are more complicated for a gas medium than for a liquid medium. This is primarily related to the fact that under real conditions a gas medium is quite mobile, the interference level is significantly higher in it, and the damping of acoustic waves is substantially higher [2]. For example, in a marine medium and for a sound velocity of approximately 1500 m/sec the flow velocity can reach values on the order of 1.5-2 m/sec, which can be neglected in many cases, with approximate equations used in the calculations. For a gas medium these equations are not valid under real conditions, since for a sound velocity of 340 m/sec the wind velocity can reach dozens of m/sec.

Approximate equations are derived in [2], devoted to these problems, which in the authors' opinion are valid for gas flow velocities up to 10 m/sec. However, the calculations presented below show that even in this velocity range of gas medium motion the measurement error for certain angles between the wind direction and the direction of sound emission is quite large.

We carried out a rigorous calculation of the propagation time of a sound wave for arbitrary values of the velocity and the directions of motion of the gas medium in the case of unidirectional sound emission and for the echo ranging regime, i.e., for the case in which sound

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