# THE SENFTLEBEN METHOD OF MEASURING THE THERMAL CONDUCTIVITY OF GASES

N. B. Vargaftik and L. S. Zaitseva

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The results of measuring the thermal conductivity of gases by the modified hot-filament method [1, 2] are critically evaluated.

H. Senftleben has measured the thermal conductivity of 28 gases over the 0-200°C temperature range [1, 2].

On the basis of his data, the thermal conductivity up to 400°C of all these gases has been put into equations and tabulated for the calculation of heat transfer processes.

An analysis of the method by which these data have been obtained indicates, however, that the tabulated values ought to be used very cautiously.

H. Senftleben applied the method of a hot filament with the measuring tube in a horizontal position, the tube having a radius $R = 20$ mm and the platinum heater filament having a radius $r = 0.05$ mm.

The measurements were made on a relative basis. Carbon dioxide ($CO_2$) was used as the reference substance.

It is well known that the thermal flux transmitted conductively through a radial gas layer is

$$q = 2\pi l \Delta t \frac{\lambda}{\ln \frac{R}{r}} . \tag{1}$$

If two gases are considered under identical conditions, then the ratio of their thermal conductivities is

$$\frac{\lambda}{\lambda_0} = \frac{q}{q_0} . \tag{2}$$

Knowing the thermal conductivity of the reference gas $\lambda_0$, then having determined $q_0$ and $q$ from the tests, one can calculate the thermal conductivity of the other gas.

The electric current in the hot filament was measured at various gas pressures and a constant temperature difference $\Delta t$ across the gas layer.

The temperature difference $\Delta t$ was maintained constant by regulating the filament current.

The temperature of the outer gas layer was 0°C in all tests.

The pressure P was varied from 1 to 700 mm Hg, provided that the gas could withstand such a pressure range.

The thermal flux per second Q was calculated from the current and the electrical resistance of the filament, whereupon $Q = f(P)$ curves were plotted for each gas – all having the same shape.

The $Q = f(P)$ curve for $CO_2$ is shown in Fig. 1.

This curve bends more or less sharply for every gas, which is explained as follows.

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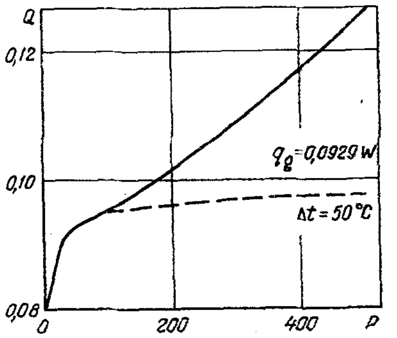

Fig. 1

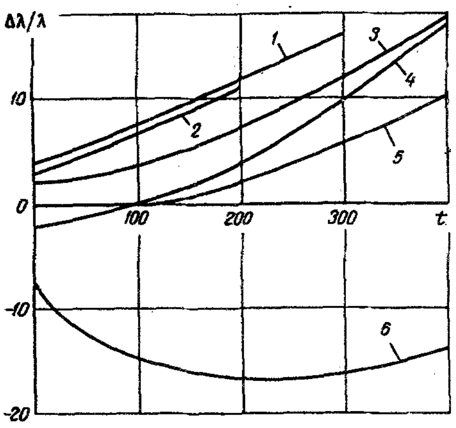

Fig. 2

Fig. 1. Graph of $Q = f(P)$ for $CO_2$ (P in mm Hg).

Fig. 2. Comparison of published data pertaining to the thermal conductivity of gases with those obtained by H. Senftleben: 1) propylene; 2) ethylene; 3) ammonia; 4) butane; 5) carbon dioxide; 6) krypton. Temperature t (°C), $\Delta\lambda/\lambda$ %.

At low pressures there occurs a temperature jump. As the pressure is raised, however, this jump becomes smaller and the thermal flux increases at the same time.

The convective flux is insignificant at low pressures. If there were no convection at all (if it were negligible), then, beginning at some pressure level at which there is almost no temperature jump, the thermal flux Q would not change under rising pressure (dashed line in Fig. 1). The presence of some convection, however, causes Q to increase as the pressure squared and, therefore, the curve bends.

In order to measure the thermal conductivity of a gas, therefore, the Q (P) curve was plotted and the value $Q = q$ was determined at the bending point.

If q is measured with the same apparatus and under the same conditions for two different gases, one of which is the reference substance, then λ of the test gas can be determined according to formula (2).

If the bending point is not very sharp, then accurate measurements are made as follows. In the bending region the curve can be approximated by the equation

$$Q = ap^2 + b - \frac{c}{p}, \tag{3}$$

where $ap^2$ is the thermal flux transmitted convectively, $(b - c/p)$ is the thermal flux transmitted conductively when a temperature jump occurs, and $a$, b, c are test constants.

Coefficients $a$, b, and c can be determined by reading three pairs of p and q values on the measured curve in the vicinity of the bending point.

At the bending point $d^2Q/dp^2 = 0$, and from this $p = (c/a)^{1/3}$.

Insertion into (3) yields $q = b$.

Since the coefficients in Eq. (3) are determined in the bending region, where convection may occur, hence the test value q is corrected to account for the convective flux depending on the molecular weight of the gas and on the temperature:

$$q_k = q_g - A\mu B(t), \tag{4}$$

with $q_k$ denoting the corrected value of q; $q_g$ denoting the measured value of q; u denoting the molecular weight of the gas; A denoting a test constant; and $B(t) = 1 + 0.0015t$.

If the measurement is based on $CO_2$ as the reference, then $A = 0.001q_g (CO_2)$ and the final expression for $q_k$ becomes

$$q_k = q_g - 0.001q_g (CO_2)(1 + 0.0015t)\mu. \tag{5}$$

A comparison of the results obtained by H. Senftleben [1] with those published in [3, 4] has shown that:

1. The results in [1] pertaining to the thermal conductivity of gases do not always agree with reliable published data. This is made clear in Fig. 2.

The discrepancy between test data increases with rising temperature and reaches ±14% at $t = 200°C$.

2. The extrapolated values at $t > 200°C$ do not agree with published data. The discrepancies are as wide as ±17%. Even for the reference substance $CO_2$ the thermal conductivity at $t = 400°C$ differs from the published values by 10%.
3. The discrepancies are widest for gases whose molecular weight differs from that of $CO_2$. The values of $\lambda$ tend to be too high for lighter gases and too low for heavier gases (for krypton, for example, the discrepancy is –16% at $t = 200°C$).

For gases whose molecular weight is close to that of $CO_2$ (argon, propane, etc.) the test values of $\lambda$ in [1] agree closely with published data.

The method proposed by H. Senftleben in [1] yields only rough orientative data on the thermal conductivity of gases.

A determination of $\lambda$ from test data in the bending region of the Q(P) curve when a temperature jump and convection occur cannot be considered reliable.

The corrections to the measured value of thermal flux are artificial without sufficient theoretical justification and, therefore, the values of $\lambda$ cannot be sufficiently accurate.

## LITERATURE CITED

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