MEASURING THE VISCOSITY OF GASES BY THE TRANSIENT-FLOW METHOD

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Results are shown of relative viscosity measurements made on nine different gases at 300°K by the transient-flow method. The data are compared with those obtained by other authors.

Test data obtained at small pressure, temperature, and concentration gradients are most reliable in terms of establishing the intermolecular potentials on the basis of viscosity, heat conduction, diffusion, and thermodiffusion. With small gradients, the choice of reference parameters for a measured transfer coefficient is not necessarily arbitrary, the number of corrections is substantially reduced, secondary effects such as pressure rises during the mixing of pure gases for diffusion measurements are eliminated, etc. For this reason, the method used earlier [12] for studying the flow of rarefied gases (transient-flow method) appears, with some modifications, sufficiently satisfactory for measuring the viscosity coefficients. The gist of this method is to measure the relaxation time τ_p of a small pressure drop across a capillary tube connecting two almost equal volumes V_1 and V_2, as a function of the mean pressure p in the system. The use of a diaphragm-type micromanometer with a digital readout and with a $3.1 \cdot 10^{-4}$ $(N/m^2)/Hz$ sensitivity for recording Δp has made it possible to perform the measurements with a relative pressure drop $\Delta p/p$ not exceeding $5 \cdot 10^{-4}$. The digital information about the magnitude of the pressure drop is transmitted to a frequency meter within time intervals defined by a quartz oscillator.

From the equation of balance between the number of gas molecules in each volume, and from the well-known expression for a viscous gas stream (Poiseuille's formula with sliding), one can derive the necessary relations for calculating the viscosity of a gas η. The pressure drop as a function of time is

$$\Delta p = \Delta p_0 \exp(-t/\tau_p),$$

with Δp_0 denoting the pressure drop at the instant at which the measurement begins. Here

$$\frac{1}{\tau_p} = \frac{Ap + B}{V + ap}; \quad A = \frac{\pi R^4}{8\eta l}; \quad B = \frac{\pi^{3/2}}{4l} R^3 \left(\frac{2kT}{m}\right)^{1/2} \sigma; \quad V = \frac{V_1 \cdot V_2}{V_1 + V_2};$$

and a is a characteristic of the pressure drop recording instrument. In our case a is the magnitude of the volume change due to the diaphragm deflection, referred to the magnitude of the pressure drop causing this deflection.

For the derivation of these formulas one uses the equation of state of an ideal gas. In this notation, the expression for the sliding flow B is valid for a model medium consisting of solid spheres.

The test curve $\tau_p = \tau_p(p)$ was evaluated by the method of least squares with A and B as unknown parameters. In this way, the viscosity and the sliding coefficient could be determined independently.

When the radius of the capillary is calculated from the known viscosity of any (reference) gas, then the calculated viscosity of another gas is a relative quantity. If the radius of the capillary is measured by another method, on a microscope or by filling with mercury, then the results yield absolute values of viscosity.

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TABLE 1

Gas	H_2	He	D_2	Ne	N_2	Ar	CO_2	Kr	Xe
$\eta \cdot 10^5$, $N \cdot sec/m^2$	0,889	1,972	1,260	3,203	1,790	(2,272)	1,503	2,530	2,308

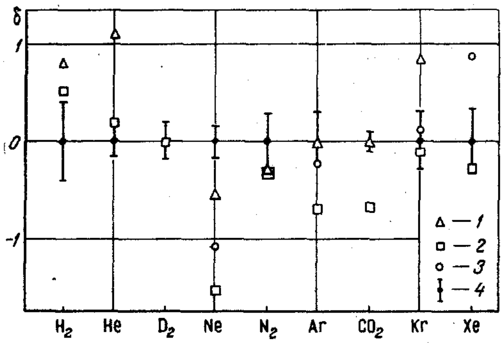

Fig. 1. Comparison between our viscosity measurements and those of other authors: 1) [3-5]; 2) [6]; 3) [7]; 4) our data.

For a study of the interaction between gases and a surface over a wide range of the Knudsen number (10^{-3} to 10^3), the authors used a bundle of 100 glass capillaries ~3 cm long, each having a radius of 0.0049-0.0051 cm. The use of such a bundle was dictated by the necessity of studying the flow in a highly rarefied gas, where the relaxation time for a single capillary of that particular radius was beyond the stable operating period of the micromanometer. For an independent study of the gas viscosity alone, of course, it would be worthwhile to use a single capillary with dimensions designed to optimize (in terms of accuracy) the measurement of the pressure-drop relaxation time and to minimize any final corrections.

The viscosity η measured within the range of viscous flow with sliding 7000-27,000 N/m^2 at a 300°K temperature is given in Table 1 for nine gases (argon was used as the reference).

A comparison is shown in Fig. 1 between our values and those of other authors [3-5] as well as with generalized test values according to [6, 7]. Along the ordinate axis has been plotted the relative (percent discrepancy between other authors' values and ours. The error in our values of viscosity, according to the diagram, has been calculated on a digital computer from test data evaluated by the method of least squares. All values of viscosity were reduced to the same temperature according to formulas for a "point-center of repulsion" model.

The satisfactory agreement (for most gases) between viscosity test data obtained by us and those found in the technical literature lets us hope that the described method may become useful for a quick and very accurate determination of, at least, the relative viscosity of gases. The use of a digital instrument for recording small perturbations in the system, and the feasibility of repeating individual measurements many times without significant changes in the test conditions will make it possible to automate the measurement process and to simultaneously evaluate the test data on a digital computer.

NOTATION

Δp	is the pressure drop along capillary;
τ_p	is the pressure-drop relaxation time;
p	is the mean pressure in the system;
V_1, V_2	are the volumes connected through the capillary;
a	is the characteristic of elastic properties of membrane in micromanometer;
R, l	are the radius and length of capillary;
σ	is the sliding coefficient (gas along the wall);
T	is the absolute temperature;
k	is the Boltzmann constant;
m	is the mass of gas molecule;
η	is the dynamic viscosity of gas.

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