CAPILLARY VISCOSIMETER FOR DETERMINING THE VISCOSITY OF VAPOR IN A CLOSED SYSTEM

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The construction and operating principles of a viscosimeter for studying the viscosity of corrosive and toxic vapors are described. This viscosimeter has been used to study the viscosity of water vapor over the temperature range 150-650°C.

The temperature dependence of the viscosity of vapors, especially of corrosive vapors, is usually studied by a capillary method in a closed circulation system. The apparatus is constructed in such a manner that only very small amounts of the substance are necessary. In addition, the closed circulation system permits a hermetic seal and continuous operation of the viscosimeter. The apparatus is simple in construction and convenient to use; Fig. 1 shows a diagram of it.

The test substance 1 is placed in an evaporator 2 in a copper thermostat 4. The moist vapor enters the superheater 5, where it is dried and heated to the experimental temperature t_0. The prepared vapor then passes through the working capillary 6 in the thermostat 7 and through a tube 8, heated from the outside, into the condenser 9, where it condenses. The condensate flows into the volume flow meter 10, from which it is periodically poured into the collector 11 and returned through tube 12 to the vapor generator. The pressure drop ΔP between the vapor generator and the condenser, which is practically equal to the pressure drop in the capillary, is determined from the height ΔH of the liquid column.

The level of the liquid in the evaporator is determined by means of the water-gauge tube 3, which is placed in an evacuated housing to prevent rapid condensation. The tube 3 can be used to measure the boiling temperature corresponding to the vapor pressure in the evaporator.

An inert gas (He) is fed into the apparatus, considerably simplifying the establishment of a given pressure at the output from the capillary and providing normal conditions for the operation of the flow meter. Shortly after the circulation starts in the system, the test vapor completely displaces the inert gas from the evaporator and capillary.

Calculations have shown that the diffusion rate of the inert gas is so much smaller than the oppositely directed vapor flux in the capillary that it is essentially impossible for a mixture of the test vapor with helium to form in any part of the capillary. The solubility of the helium in the liquid is so small that contamination of the test substance in the capillary by the helium and its effect on the viscosity measured can be neglected.

There is a hydrodynamic drag device 13 in the apparatus to provide hydrodynamic stability and to suppress possible oscillations in the system between the evaporator 2 and the manometric tube 12. The device is constructed in such a manner that its effect is sufficient to suppress oscillations yet small enough to be ignored in the measurement of ΔP.

The flow rate in all parts of the apparatus except the capillary is so small that no corresponding correction is necessary for the pressure drop.

The flow rate of the substance in the system is measured by an instrument 10 of novel design. The condensate, which flows continuously from the condenser to the flow meter, fills, during a measured time

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TABLE 1. Experimental Viscosity of Water Vapor

t,°C	151,0	258,5	351,5	475,4	632,2
$\eta\cdot 10^{-6}, \frac{\text{kg}\cdot\text{sec}}{\text{m}^2}$	1,410	1,886	2,274	2,764	4,390

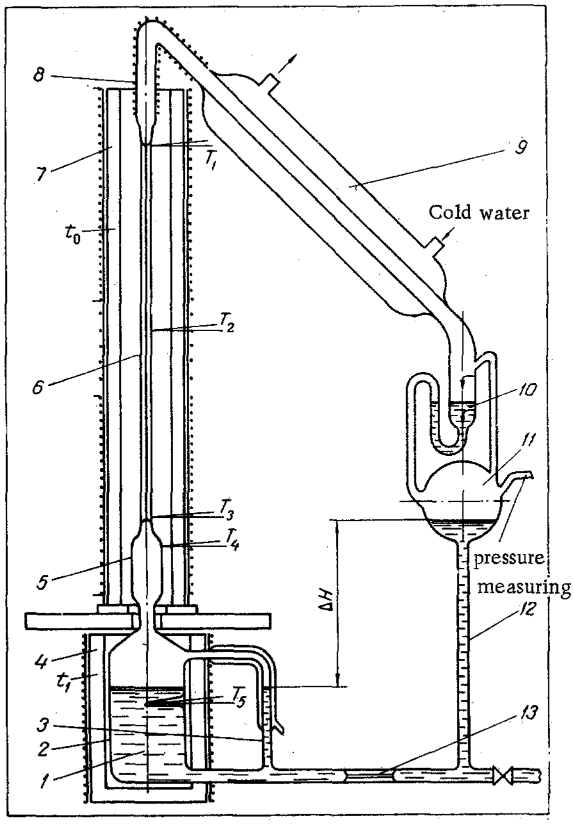

Fig. 1. Diagram of the viscosimeter.

τ, a control volume V_0 which occupies part of the vessel 10, bordered by the level indicators and part of the overflow siphon, and drops into the liquid collector.

Taking into account the method used to measure ΔP in the capillary (from the height of the liquid column), one can easily show that the kinematic viscosity ν found from the measurements can be determined from a modified Hagen–Poiseuille equation

$$\nu = k\Delta H\tau,$$

where τ is the time required to fill the control volume V_0 with the condensate, and k is the apparatus constant ($k = (\pi/8)(R^4/LV_0)$). A correction for the end effects in the capillary analogous to the Hagenbach–Couette correction should, of course, be introduced.

In an experiment to determine the kinematic viscosity, therefore, measurements must be made of the difference between liquid levels, the time required to fill the control volume, and the capillary temperature. To determine the dynamic viscosity, the vapor density under the experimental conditions must also be known.

This procedure has been used to determine the dynamic viscosity of water vapor over the temperature range 150-650°C at atmospheric pressure. The circulation system, except for the capillary and superheater, was made of molybdenum glass. The capillary and superheater, which were in the high-temperature zone, were of fused quartz.

Calibration of the capillary showed it to have a diameter of D = 0.455 mm and a length of L = 280 mm. In all the experiments, the Re values remained below 600. About 100 cm^3 of substance was required to fill the apparatus; this quantity could be reduced without difficulty. The difference between the levels in the liquid collector and in the water-gauge tube was 160-190 mm H_2O and was measured within 0.1 mm by a KM-6 cathetometer. A correction was introduced for the capillary depression in the water-gauge tube.

The pressure in the system, measured in a zone filled essentially with inert gas, was 1.3-1.4 atm. The time required to fill the 1.290 cm^3 control volume was 80-300 min (over the entire temperature range).

The flow rate and pressure drop were maintained constant by the constancy of the evaporator temperature, which was itself regulated within ±0.1°C by a photothyratron temperature regulator.

The thermostat for the high-temperature zone of the apparatus was equipped with a three-section electric heater, which was supplied from another photothyratron regulator, and which maintained a constant temperature, uniform over the length of the working region. The pickups for both regulators were resistance thermometers on the surfaces of the capillary and evaporator thermostats. The temperature was measured by Chromel–Alumel thermocouples (T_1-T_5). Each experimental point was obtained by averaging the results of three measurements. The Hagenbach–Couette correction did not exceed 0.3%.

Table 1 shows the results of our measurements; an error analysis showed that the experimental error did not exceed 2.5%.

TABLE 2. Comparison of Smoothed Data on the Viscosity of Water Vapor ($\eta \cdot 10^{-6}$, kg · sec/m^2)

Experimental data of:	t, °C										
	150	200	250	300	350	400	450	500	550	600	650
Bonilla	1,45	1,61	1,80	1,99	2,19	2,39	2,59	2,79	2,99	3,19	3,39
Timrot and Khlopkina	1,42	1,61	1,80	2,00	2,21	2,42	2,65	2,88	3,13	3,39	3,67
Shifrin	1,44	1,65	1,86	2,06	2,27	2,48	2,69	2,89	3,10	3,31	3,52
This study	1,41	1,63	1,85	2,07	2,27	2,47	2,67	2,87	3,07	3,27	3,46

Table 2 compares the smoothed values found in this study with the smoothed values found in other studies [2-4]. The discrepancy did not exceed the error in the experimental data of these authors, i.e., 3%. It should be noted that the discrepancy between our measured viscosities and the more reliable data of Shifrin averaged no more than 1%.

LITERATURE CITED

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