THE VISCOSITY OF MOIST AIR

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UDC 533.16

An empirical formula is proposed for calculations of the viscosity of a mixture of water vapor and air.

Experimental data on the viscosity of moist air were first obtained by Kestin and Whitelaw [1] in the temperature range 25-75°C and the pressure range 1-7 atm. The mole fraction of water vapor in the air did not exceed 0.4. The measurements were taken by the oscillating disk method to within ±1%.

The authors [1] compared the experimental data obtained with the results of theoretical calculations performed by Mason and Monchick [2] by the method proposed in [3]. The first approximation of the coefficient of viscosity of the air–water vapor mixture, according to [3], is determined by the following expression:

$$[\eta_m]_1=\left[\frac{x_1^2}{H_{11}}+\frac{x_2^2}{H_{22}}-\frac{2x_1x_2H_{12}}{H_{11}H_{22}}\right]\left[1-\frac{H_{12}^2}{H_{11}H_{22}}\right]^{-1}, \tag{1}$$

where

$$H_{11}=\frac{x_1^2}{[\eta_1]_1}+\frac{2x_1x_2}{M_1+M_2}\cdot\frac{RT}{p[D_{12}]_1}\left[1+\frac{3M_2}{5M_1}A_{12}^*\right]; \tag{1a}$$

$$H_{22}=\frac{x_2^2}{[\eta_2]_1}+\frac{2x_1x_2}{M_1+M_2}\cdot\frac{RT}{p[D_{12}]_1}\left[1+\frac{3M_1}{5M_2}A_{21}^*\right]; \tag{1b}$$

$$H_{12}=-\frac{2x_1x_2}{M_1+M_2}\cdot\frac{RT}{p[D_{12}]_1}\left[1-\frac{3}{5}A_{12}^*\right]. \tag{1c}$$

In Eqs. (1) x_1 and x_2 are the mole fractions of the mixture components; $[\eta_1]_1$, $[\eta_2]_1$, $[D_{12}]_1$ are the first approximations of the viscosity coefficients and coefficient of mutual diffusion of the components, determined according to [4]; M_1 and M_2 are the molecular weights of the components; P and T are the pressure and temperature of the mixture; R is the universal gas constant; A_{12}^* and A_{21}^* are some functions of temperature, determined by the form of the selected potential of intermolecular interaction and tabulated for certain potentials in [4].

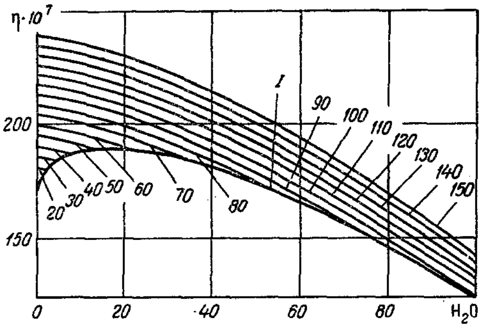

Fig. 1. Calculation of the viscosity of moist air in the temperature range 20–150°C. η, N·sec/m^2; H_2O, %. I) Saturation line.

To calculate the viscosity of moist air the authors of [2] selected the Stockmayer potential. They determined the parameters of this potential on the basis of experimental data on the viscosity of a mixture and a known rule of combination. The maximum divergence between the experimental and calculated values of viscosity is less than 1%. Thus we can consider that Eq. (1) describes nicely the experimental data on the viscosity of moist air, but for practical calculations it is quite complex and it seems reasonable to approximate the experimental data by a simpler relation enabling us to obtain sufficiently good results.

An analysis of the empirical and semiempirical formulas proposed by various authors [5, 6] shows that none of these

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Sergo Ordzhonikidze Aviation Institute, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 19, No. 2, pp. 338-340, August, 1970. Original article submitted August 12, 1969.

TABLE 1. Viscosity of Water Vapor–Air Mixture at $P \leq P_{s_{H_2O}}$, $\eta \cdot 10^7$, N • sec/m²

t, °C	H₂O, %										
	0	10	20	30	40	50	60	70	80	90	100
20	181,4										
30	186,5										
40	190,8										
50	195,5	191,4									
60	200,1	196,0	190,4								
70	204,6	200,5	195,0	188,0							
80	209,1	205,1	199,5	192,5	184,3	175,0					
90	213,5	209,5	203,9	196,9	188,7	179,2	168,9	157,7			
100	218,0	214,0	208,4	201,4	193,1	183,6	173,2	161,8	149,9	137,5	124,7
110	222,3	218,4	212,8	205,8	197,5	187,9	177,4	166,0	153,9	141,3	128,4
120	226,6	222,7	217,2	210,1	201,8	192,2	181,6	170,1	157,9	145,2	132,1
130	230,9	227,1	221,6	214,5	206,1	196,4	185,8	174,2	161,9	149,0	135,8
140	235,0	231,2	225,8	218,7	210,3	200,6	189,9	178,4	165,8	152,9	139,5
150	239,2	235,5	230,1	223,1	214,7	204,9	194,2	182,4	169,9	156,8	143,3

formulas conveys satisfactorily the character of the dependence of the viscosity of the water vapor–air mixture on the concentration of components.

Lehman [7] proposed an empirical formula for calculating the thermal conductivity of mixtures containing a polar component:

$$\lambda_m = (x_1\lambda_1 + x_2\lambda_2)\left(1 + \frac{x_p - x_p^2}{a}\right), \tag{2}$$

where λ_1 and λ_2 are the coefficients of thermal conductivity of the components; x_p is the mole fraction of the polar (or nonpolar) component; a is an empirical factor.

Lehman used $a = 3.5$ regardless of the types of gases composing the mixture.

It was of interest to determine the possibility of using an analogous formula for calculating the mixture of air with water vapor, one of the components of which is polar (H_2O).

In this case we obtain the following expression:

$$\eta_m = (x_1\eta_1 + x_2\eta_2)\left(1 + \frac{x_p - x_p^2}{a}\right). \tag{3}$$

The viscosity of moist air was calculated by Eq. (3) with the use of the value $a = 3.5$. A comparison of the calculation results with the experimental data [1] shows that the maximum deviation of the calculated and experimental values of viscosity does not exceed 1%.

Treatment of the experimental data [1] by the method of least squares allowed the value of a for the given mixture to be refined.

The value $a = 2.75$ obtained was used for calculating the viscosity of moist air in the temperature range 20-150°C and in the entire concentration range of the components. The results of the calculations are given in Table 1 and in Fig. 1. The maximum divergence between the experimental and calculated values of viscosity is 0.32% and the average ±0.1%.

Thus Eq. (1) can be used for calculating the viscosity of a mixture of water vapor and air.

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