GENERALIZED EQUATION FOR CALCULATING THE VISCOSITY OF INERT GASES AT HIGH PRESSURES

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A generalized equation for calculating the viscosity of compressed Ar, Kr, Xe, and Ne is constructed using a previously proposed method [3]. It is shown that there is good agreement between the calculated and experimental data.

The viscosity of inert gases at high pressures has not yet been studied experimentally with sufficient thoroughness. At present, relatively detailed experimental data covering a broad interval of temperatures and pressures are available only for argon.

Accordingly, considerable interest attaches to the development of theoretical methods of determining the viscosity of such substances without complicated and laborious experimentation.

Ar, Kr, Xe, and Ne are thermodynamically similar substances [14] and satisfy the common reduced equation of state

$$Z = \varphi(\omega, \tau).$$

On the basis of the principles of thermodynamic similarity, it may be assumed that the reduced coefficients of viscosity of these substances can also be described by some generalized equation

$$\eta/\eta_0 = f(\omega, \tau). \tag{1}$$

If experimental data are avaiable for a well-studied substance that can be taken as a standard, we can construct Eq. (1) and use it to calculate the viscosity of other similar substances.

The following specific form of Eq. (1) was proposed in [3]:

$$\eta/\eta_0 = P_0(\omega) + P_1(\omega)\frac{1}{\tau} + P_2(\omega)\frac{1}{\tau^2} + \cdots + P_m(\omega)\frac{1}{\tau^m}, \tag{2}$$

where

$$P_0(\omega) = 1 + \sum_{i=1}^{n} a_i \omega^i; \quad P_1(\omega) = \sum_{i=1}^{n} b_i \omega^i; \quad P_2(\omega) = \sum_{i=1}^{n} c_i \omega^i, \ldots;$$

a_i, b_i, c_i, ... are individual constants. In [3] it was shown that an equation of type (2) reliably describes the viscosity over a broad range of parameters of state in the gas and liquid phases as well as on the saturation line.

We have constructed Eq. (2) on the basis of experimental data on the viscosity of argon as a standard. The experimental data employed were those of Michels and coworkers [4], Golubev and Petrov [5], Makita [6], Kestin and Whitelaw [7], Kestin and Pilarczyk [8], and Filippova and Ishkin [9]. Corresponding values of the argon densities were taken from [1] and [2], and values of the viscosity coefficients at atmospheric pressure from [5]. The following values were taken for the critical parameters of argon: $\rho_c = 0.5357$ g/cm^3, $T_c = 150.86°$ K [1].

The values of the constants for the equation obtained [Eq. (2)] are presented in Table 1.

Equation (2) can be used to calculate values of the viscosity of argon in the interval of reduced densities ω = 0–2.2, starting from a reduced temperature τ = 0.7.

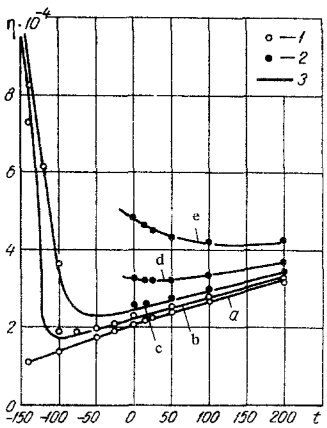
It should be kept in mind that as the temperature increases, so does the value of η_0, while the values of η/η_0

decrease. Accordingly, Eq. (2) permits reliable extrapolation into the high-temperature region considerably beyond the experimental limit.

Table 1. Values of Constants for Equation (2)

i	a_i	b_i	c_i	d_i
1	0.05395	0.42717	0.00597	0.00853
2	0.10766	0.85460	0.01070	0.01748
3	−0.045204	−0.35562	−0.00620	−0.00667
4	0.026614	0.209980	0.00340	0.00400

In Table 2 calculated values of the dynamic viscosity of argon are compared with the experimental data of [4], which embrace the broadest interval of pressures at temperatures in the range 0–75° C.



Dynamic viscosity of argon (g/cm · sec) as a function of pressure (atm) and temperature (°C): 1—experimental data of Filippova and Ishkin [9], 2—experimental data of Golubev [5], 3—calculations based on Eq. (2): a) 1; b) 50; c) 100; d) 200; e) 400 atm.

The figure shows that calculations based on Eq. (2) give good agreement with the experimental data of [5] at temperatures in the range 0–200° C and with the data of [9] in the range −150–0° C. Equation (2) also gives a good description of the experimental data on the viscosity of krypton, xenon, and neon. Tables 3–5 present the results of a comparison of the calculated values of the viscosity of the above-mentioned inert gases and the latest experimental data [10–12].

We also note that the value of the reduced viscosity at the critical point $(\eta/\eta_0)_c = 2.316$ calculated from Eq. (2) almost coincides with the value $(\eta/\eta_0)_c = 2.315$ found by Shimotake and Thodos [13] for inert gases.

This is an additional criterion of the relability of Eq. (2) in the critical region, which is most difficult to describe.

Thus, Eq. (2) is a generalized equation for Ar, Kr, Xe, and Ne and can be used to calculate detailed dynamic viscosity tables for these substances in the above-mentioned region of parameters of state.

NOTATION

$\omega = \rho/\rho_c$ is the reduced density;
$\tau = T/T_c$ is the reduced temperature;
ρ_a is the density in Amagat units
ρ_c is the critical density;
T_c is the critical temperature;
η is the viscosity of the compressed gas;

Table 2. Comparison of Values of the Dynamic Viscosity $\eta \cdot 10^{-6}$ g/cm · sec of Argon Calculated from (2) (column 1) and the Experimental Data of [4] (column 2)

0° C			25° C			50° C			75° C		
ρ_a	1	2	ρ_a	1	2	ρ_a	1	2	ρ_a	1	2
9.22	210.5	211.0	12.16	227.5	227.7	12.38	242.7	242.8	12.53	257.8	257.8
313.1	382.7	382.4	101.3	257.5	257.7	99.22	272.4	273.5	101.1	288.0	288.0
646.7	1056.7	1056	234.7	334.3	333.4	233.4	348.7	348.0	230.2	361.6	360.3
			343.2	429.1	428.4	334.8	436.5	436.2	334.5	451.4	450.5
			411.9	514.2	514.5	404.1	518.8	518.7	403.6	533.5	531.9
			498.8	659.9	656.9	504.5	686.8	682.6	503.6	700.6	695.9
			633.2	1016	1016	640.3	1056	1052	639.5	1069	1060
δ_m=0.13% δ_{max}=−0.24%			δ_m=0.14% δ_{max}=+0.45%			δ_m=0.22% δ_{max}=+0.61%			δ_m=0.34% δ_{max}=+0.85%		

Table 3. Comparison of Values of the Dynamic Viscosity $\eta \cdot 10^{-6}$ g/cm · sec of Krypton Calculated from (2) (column 1) and the Experimental Data of [10] (column 2)

25° C			50° C			75° C			125° C		
ρ_a	1	2	ρ_a	1	2	ρ_a	1	2	ρ_a	1	2
6.49	253.7	257.0	6.42	271.3	274.7	6.51	289.1	294.7	480.0	1307	1296
40.15	269.1	272.2	40.18	289.1	291.9	49.89	313.8	316.4	539.5	1669	1664
81.99	296.4	299.6	81.02	320.5	319.2	81.11	338.1	337.6			
150.4	358.4	364.3	150.3	391.6	383.9	150.3	407.4	402.8			
226.3	454.9	464.7	226.4	492.3	484.7	225.9	506.4	502.4			
327.8	651.0	667.7	328.2	684.7	683.5	328.4	701.7	704.7			
479.5	1215.6	1225	479.9	1250	1241	480.0	1270	1256			
δ_m=1.5% δ_{max}=−2.5%			δ_m=1.0% δ_{max}=+2.0%			δ_m=0.9% δ_{max}=−1.90%			δ_m=0.57% δ_{max}=+0.85%		

Table 4. Comparison of Values of the Dynamic Viscosity $\eta \cdot 10^{-6}$ g/cm · sec of Xenon Calculated from (2) (column 1) and the Experimental Data of [11] (column 2)

0° C			25° C			50° C			75° C		
ρ_a	1	2	ρ_a	1	2	ρ_a	1	2	ρ_a	1	2
11.91	222.0	221.0	11.98	236.2	241.0	11.99	256.0	259.1	11.95	272.4	277.6
66.22	275.3	275.1	66.10	287.5	291.4	66.35	318.6	311.1	56.20	315.5	323.0
			147.0	452.9	467.8	147.3	472.5	459.9	126.8	423.4	433.9
			179.5	530.5	565.2	183.5	558.1	547.2	183.6	548.8	562.4
			250.5	744.8	743.9	245.2	742.8	733.4	245.3	742.3	750.5
			329.9	1152	1170	329.8	1164	1158	330.2	1170.7	1181
			422.8	2115	2126	422.9	2115	2099	422.9	2007	2106
δ_m=0.26% δ_{max}=+0.45%			δ_m=2.24% δ_{max}=−6.2%			δ_m=1 39% δ_{max}=+2.61%			δ_m=2.24% δ_{max}=−4.7%		

Table 5. Comparison of Values of the Dynamic Viscosity $\eta \cdot 10^{-6}$ g/cm · sec of Neon Calculated from (2) (column 1) and the Experimental Data of [12] (column 2)

25° C			50° C			75° C		
ρ_a	1	2	ρ_a	1	2	ρ_a	1	2
6.39	314.6	317.6	9.17	335.0	335.3	9.19	351.5	353.0
58.56	319.1	320.2	77.63	341.7	339.9	77.93	355.6	356.9
167.3	332.2	330.7	173.7	348.7	348.6	201.0	369.0	368.4
282.5	351.1	347.4	314.7	366.6	370.7	351.6	396.2	394.7
440.0	385.5	380.8	479.6	408.6	408.0	517.7	438.8	436.1
636.1	446.5	440.3	633.8	463.9	456.9	684.0	494.8	493.7
770.0	505.5	495.9	770.4	514.6	514.1	771.0	529.3	532.7
δ_m=1.07% δ_{max}=+2.1%			δ_m=0.51% δ_{max}=+1.53%			δ_m=0,4% δ_{max}=−0,64%		

η_0 is the viscosity of the rarefied gas (at $P \leq 1$ atm).

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