

CALCULATION OF THE CHANNELS IN THE TRANSONIC REGION  
OF NITROGEN-TETROXIDE FLOW ON THE BASIS OF A LINEAR  
APPROXIMATION OF ENTROPY

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In the hydrodynamic calculation of channels, the problem of avoiding the use of the hydrodynamic-drag coefficient, which is a sharply varying quantity, is posed. An accurate method based on the hypothesis of a linear approximation of entropy is adopted in the calculation.

In the hydrodynamic calculation of channels in the transonic flow region, errors arise in choosing the hydrodynamic drag coefficient, because it is a sharply varying quantity. Therefore, the problem posed here is to eliminate the use of the hydraulic drag coefficient by basing the calculation on a linear approximation of entropy.

In [1, 2], a modeling method was proposed for the solution of a series of hydrodynamic problems: the method involves using relations between the work of the frictional forces on an elementary section of the channel and the corresponding change in entropy. In fact, in the transonic flow region, in connection with the sharp changes in the drag coefficient  $\zeta$ , it is wrong to assume a constant value of this coefficient in the given conditions with a definite Reynolds number.

A fruitful approach is to take account of the linear dependence of the entropy variation along the channel in the expression

$$dL_{fr} = TdS \quad (1)$$

for adiabatic flow at high velocity, as shown in [2], since this variation is slow in comparison with the other parameters of state.

In considering the flow of dissociating gas in the transonic region, the method of investigation employed here is based on a linear approximation of the entropy along the channel.

Note that the problem formulated in the present case is solved in complex conditions, since the flow of dissociating nitrogen tetroxide which is undergoing molecular breakdown is investigated. Dissociation greatly complicates both the physics of the phenomenon and its mathematical description.

As is known, the elementary work of the frictional force on a section  $d\ell$  of a tube of diameter  $D$  is determined from the formula

$$dL_{fr} = \zeta \frac{w^2}{2} \frac{d\ell}{D} \quad (2)$$

Using the concept of reduced entropy [1, 2]

$$\sigma = \frac{S}{R/\mu_{N_2O_4}} \quad (3)$$

and taking account of Eq. (1), the following expression may be written

$$d\sigma = \frac{dS}{R/\mu_{N_2O_4}} = \frac{dL_{fr}}{TR/\mu_{N_2O_4}} \quad (4)$$

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TABLE 1. Coefficients  $\alpha_{1j}$  for Eq. (13)

$i$	$a_{1j}$	$a_{2j}$	$a_{3j}$
0	6,724331	-1,920155	4,22444
1	-13,12774	-0,2206247	-5,990096
2	-4,561842	1,044964	-8,061043
3	21,69903	10,70347	16,69250
4	-10,85284	-9,995447	-6,835001

The relation between  $\zeta$  and  $d\sigma$  is found by simultaneous solution of Eqs. (2) and (4) in the form

$$\zeta = \frac{2RT}{\mu\omega^2} \frac{D}{dl} d\sigma = \frac{2RT_0 k/(k+1)}{\mu_{N_2O_4} \omega^2 k/(k+1)} \frac{T}{T_0} D \frac{d\sigma}{dl}. \quad (5)$$

Earlier (3), the following expression was obtained

$$a_{cr} = \xi_{cr} \sqrt{2 \frac{k}{k+1} \frac{R}{\mu_{N_2O_4}} T_0}, \quad (6)$$

as well as the ratio of the stagnation temperature  $T_0$  to the thermodynamic temperature  $T$

$$\frac{T_0}{T} = \left\{ 1 + \frac{1}{\eta} \frac{k_T - 1}{k_T} [(Z_{ef})_{p,T} - (Z_{ef})_{p_0,T}] \right\} \left( 1 - \frac{1}{\eta} \frac{k_T - 1}{k_T} \frac{k}{k+1} \frac{\xi_{cr}^2 \lambda^2}{\tau^2} \right)^{-1}, \quad (7)$$

where in principle

$$Z_{ef} = (1 + \alpha_{10} + \alpha_{10}\alpha_{20}) \left( 1 + \sum_{i=1}^3 \sum_{j=0}^4 \frac{a_{ij}\pi^i}{\tau^j} \right), \quad (8)$$

$$\xi_{cr}^2 = \frac{k+1}{2} y_{cr}^2 \left[ 1 + \frac{1}{\eta} \frac{k_T - 1}{k_T} \left\{ \frac{k}{2} y_{cr}^2 - [(Z_{ef})_{p_0,T_{cr}} - (Z_{ef})_{p_{cr},T_{cr}}] \right\} \right]^{-1}, \quad (9)$$

$$y_{cr}^2 = \frac{(Z_{ef}^2)_{p_{cr},T_{cr}}}{k \left[ \eta_{cr} - \frac{R\omega_{cr}^2}{\mu_{N_2O_4}(C_{pef})_{cr}} \right]}, \quad (10)$$

$$\frac{k_T - 1}{k_T} = \frac{R}{\mu_{N_2O_4}} \frac{\omega}{C_{pef}}, \quad (11)$$

$$\bar{\eta} = \frac{1}{2} (\eta_0 + \eta). \quad (12)$$

From the Klepatskii equation [4]

$$Z = 1 + \sum_{i=1}^3 \sum_{j=0}^4 \frac{a_{ij}\pi^i}{\tau^j}. \quad (13)$$

The coefficients  $a_{1j}$ ,  $a_{2j}$ , and  $a_{3j}$  are given in Table 1 [4]. The isobaric specific heat  $C_{pef}$  for the corresponding parameters may be taken from [4].

Now substituting  $T_0/T$  from Eq. (7) into Eq. (5) and taking account of Eq. (6), it is found that

$$\zeta = \frac{k+1}{k} \frac{1}{\xi_{cr}^2 \lambda^2} \bar{D} \left( 1 - \frac{1}{\eta} \frac{k_T - 1}{k_T} \frac{k}{k+1} \lambda^2 \right) \left\{ 1 + \frac{1}{\eta} \frac{k_T - 1}{k_T} [(Z_{ef})_{p,T} - (Z_{ef})_{p_0,T}] \right\}^{-1} \frac{d\sigma}{dl}, \quad (14)$$

where  $\bar{D} = D/D_{cr}$ ;  $d\bar{l} = dl/D_{cr}$ ;  $D_{cr}$  is the diameter of the critical cross section. Expressions for  $\eta$  and  $\omega$  were obtained in [5].

The well-known relation between the partial derivatives of any function is used for further transformations, in the form

$$\left(\frac{\partial v}{\partial p}\right)_T \left(\frac{\partial p}{\partial T}\right)_v \left(\frac{\partial T}{\partial v}\right)_p = -1. \quad (15)$$

Hence

$$\left(\frac{\partial p}{\partial T}\right)_v = -\frac{1}{\left(\frac{\partial v}{\partial p}\right)_T \left(\frac{\partial v}{\partial T}\right)_p}. \quad (16)$$

The equation of state is written in the form

$$pv = Z_{ef} \frac{R}{\mu_{N_2O_4}} T, \quad (17)$$

where  $Z_{ef}$  is given by Eq. (8).

On the basis of Eq. (17)

$$\left(\frac{\partial v}{\partial p}\right)_T = \frac{RT}{\mu_{N_2O_4} p^2} \left[ Z_{ef} - p \left(\frac{\partial Z_{ef}}{\partial p}\right)_T \right], \quad (18)$$

$$\left(\frac{\partial v}{\partial T}\right)_p = \frac{R}{\mu_{N_2O_4} p} \left[ Z_{ef} + T \left(\frac{\partial Z_{ef}}{\partial T}\right)_p \right], \quad (19)$$

where

$$\eta = Z_{ef} - p \left(\frac{\partial Z_{ef}}{\partial p}\right)_T, \quad (20)$$

$$\omega = Z_{ef} + T \left(\frac{\partial Z_{ef}}{\partial T}\right)_p \quad (21)$$

or

$$\left(\frac{\partial v}{\partial p}\right)_T = -\frac{RT}{\mu_{N_2O_4} p^2} \eta, \quad (22)$$

$$\left(\frac{\partial v}{\partial T}\right)_p = \frac{R}{\mu_{N_2O_4} p} \omega. \quad (23)$$

Taking account of Eqs. (18) and (19), Eq. (16) takes the following form in the notation of Eqs. (20) and (21)

$$\left(\frac{\partial p}{\partial T}\right)_v = \frac{\omega}{\eta} \frac{p}{T}. \quad (24)$$

For a real, and hence dissociating, gas the first law of thermodynamics may be written in the form

$$dQ = C_v dT + T \left(\frac{\partial p}{\partial T}\right)_v dv, \quad (25)$$

and taking account of Eq. (24)

$$dQ = C_v dT + \frac{\omega}{\eta} p dv. \quad (26)$$

In view of Eqs. (17) and (26) and taking into account that  $dQ = TdS$  and  $dv/v = -d\rho/\rho$ , it is found that

$$dS = C_v \frac{dT}{T} - \frac{R}{\mu_{N_2O_4}} Z_{ef} \frac{\omega}{\eta} \frac{d\rho}{\rho}. \quad (27)$$

Substitution of Eq. (27) into Eq. (4) gives

$$d\sigma = \frac{C_v}{R/\mu_{N_2O_4}} \frac{dT}{T} - Z_{ef} \frac{\omega}{\eta} \frac{d\rho}{\rho}. \quad (28)$$

The well-known thermodynamic relation between  $C_p$  and  $C_v$  for a real gas is used here, in the form

$$C_p - C_v = T \left( \frac{dp}{dT} \right)_v \left( \frac{dv}{dT} \right)_p. \quad (29)$$

Taking account of Eqs. (24) and (23), Eq. (29) is written in the form

$$C_p - C_v = \frac{\omega^2}{\eta} \frac{R}{\mu_{N_2O_4}}. \quad (30)$$

Hence  $C_v(R/\mu_{N_2O_4})$  is determined and substituted into Eq. (28), to give

$$d\sigma = \left( \frac{C_p}{R/\mu_{N_2O_4}} - \frac{\omega^2}{\eta} \right) \frac{dT}{T} - Z_{ef} \frac{\omega}{\eta} \frac{d\rho}{\rho}. \quad (31)$$

Since with a constant gravimetric flow rate ( $G = \rho F w = \text{const}$ ),  $d\rho/\rho = -(dF/F + dw/w)$  and  $dw/w = d\lambda/\lambda$ , Eq. (31) takes the form

$$d\sigma = \left( \frac{C_{p\text{ef}}}{R/\mu_{N_2O_4}} - \frac{\omega^2}{\eta} \right) \frac{d\tau_{\text{cr}}}{\tau_{\text{cr}}} + Z_{ef} \frac{\omega}{\eta} \left( \frac{df}{f} + \frac{d\lambda}{\lambda} \right), \quad (32)$$

where\*  $\tau_{\text{cr}} = T/T_{\text{cr}}$ ;  $T_{\text{cr}}$  is the temperature of the dissociating gas in the critical cross section;  $f = F/F_{\text{cr}}$ ;  $F_{\text{cr}}$  is the area of the critical cross section.

In dimensionless parameters, Eq. (32) takes the form

$$d\sigma = d \ln \left[ (f\lambda)^{Z_{ef}\omega/\eta} \tau_{\text{cr}} \frac{C_p}{R/\mu_{N_2O_4}} - \frac{\omega^2}{\eta} \right] = d \ln \psi = \frac{d\psi}{\psi}, \quad (33)$$

where

$$\psi = (f\lambda)^{Z_{ef}\omega/\eta} \tau_{\text{cr}} \frac{C_p}{R/\mu_{N_2O_4}} - \frac{\omega^2}{\eta}. \quad (34)$$

For the critical velocity of dissociating nitrogen tetroxide, the following formulas were obtained earlier

$$a_{\text{cr}} = y_{\text{cr}} \sqrt{k \frac{R}{\mu_{N_2O_4}} T_{\text{cr}}} \quad (35)$$

and

$$a_{\text{cr}} = \xi_{\text{cr}} \sqrt{2 \frac{k}{k+1} \frac{R}{\mu_{N_2O_4}} T_0}. \quad (36)$$

\*It should be emphasized here, in particular, that  $\tau_{\text{cr}}$  must be distinguished from the parameter  $\tau$  appearing in the formulas, which denotes, as noted, the ratio of  $T$  to be the critical temperature of the material. Of course, this has nothing in common with the critical temperature in the critical cross section.

For  $y_{cr}^2$  and  $\xi_{cr}^2$ , see Eqs. (10) and (9).

It follows from Eqs. (35) and (36) that

$$T_{cr}/T_0 = \frac{2}{k+1} \left( \frac{\xi_{cr}}{y_{cr}} \right)^2. \quad (37)$$

Determining  $T_0$  from Eq. (37) and substituting the result into Eq. (7), an expression for  $\tau_{cr}$  is obtained in the form

$$\tau_{cr} = \frac{k+1}{2} \left( \frac{y_{cr}}{\xi_{cr}} \right)^2 \left( 1 - \frac{1}{\eta} \frac{k_T - 1}{k_T} \frac{k}{k+1} \xi_{cr}^2 \lambda^2 \right) \left\{ 1 + \frac{1}{\eta} \frac{k_T - 1}{k_T} [(Z_{ef})_{p,T} - (Z_{ef})_{p_0,T}] \right\}^{-1}. \quad (38)$$

If  $\tau_{cr}$  from Eq. (38) is introduced into Eq. (34), then for dissociating nitrogen tetroxide

$$\begin{aligned} \psi = & (f\lambda)^{Z_{ef}/\eta} \left[ \frac{k+1}{2} \left( \frac{y_{cr}}{\xi_{cr}} \right)^2 \left( 1 - \frac{1}{\eta} \frac{k_T - 1}{k_T} \frac{k}{k+1} \xi_{cr}^2 \lambda^2 \right) \right] \times \\ & \times \left\{ 1 + \frac{1}{\eta} \frac{k_T - 1}{k_T} [(Z_{ef})_{p,T} - (Z_{ef})_{p_0,T}] \right\}^{-1} \left[ \frac{c_p}{R/\mu_{N_2O_4}} - \frac{\omega^2}{\eta} \right]. \end{aligned} \quad (39)$$

In investigating gas flow at high velocity, it is convenient to use the so-called reduced pressure\*  $\pi_{re}$  (the dimensionless parameter for the pressure), on which is based the calculation system proposed in [1]

$$\pi_{re} = \frac{p}{\rho \omega a_{cr}}. \quad (40)$$

In [5], an expression was obtained for the sound velocity in dissociating gas, in the form

$$a = y \sqrt{k \frac{R}{\mu_{N_2O_4}} T}, \quad (41)$$

where

$$y = \frac{Z_{ef}}{\sqrt{k \left\{ Z_{ef} - p \left( \frac{\partial Z_{ef}}{\partial p} \right)_T - \frac{R}{\mu_{N_2O_4}} \frac{1}{C_{pef}} \left[ Z_{ef} + T \left( \frac{\partial Z_{ef}}{\partial T} \right)_p \right]^2 \right\}}}. \quad (42)$$

In motionless gas, the velocity of sound

$$a_0 = y_0 \sqrt{k \frac{R}{\mu_{N_2O_4}} T_0}. \quad (43)$$

Taking account of Eq. (36) and taking into account also that  $\lambda^2 = w^2/a_{cr}^2$ , Eq. (7) takes the form

$$\begin{aligned} T_0 = & T \left\{ 1 + \frac{1}{\eta} \frac{k_T - 1}{k_T} [(Z_{ef})_{p,T} - (Z_{ef})_{p_0,T}] \right\} + \\ & + \frac{1}{\eta} \frac{k_T - 1}{2k_T} \frac{1}{R/\mu_{N_2O_4}} \omega^2. \end{aligned} \quad (44)$$

\*Note that  $\pi_{re}$  must be distinguished from the parameter  $\pi$  (with no subscript), which is used in the present work to mean the ratio of the pressure to the critical pressure of the material of the material (in the present case, nitrogen tetroxide).

Substituting  $T_0$  from Eq. (43) into Eq. (44), taking account of Eq. (41), and dividing both sides of the equation by  $[(k+1)/2]a_{cr}^2$ , the following result is obtained after appropriate manipulations

$$\begin{aligned} \frac{2}{k+1} \frac{1}{y_0^2} \left( \frac{a_0}{a_{cr}} \right)^2 &= \frac{2}{k+1} \left\{ 1 + \frac{1}{\eta} \frac{k_T - 1}{k_T} [(Z_{ef})_{p,T} - (Z_{ef})_{p_0,T}] \right\} \times \\ &\times \frac{1}{y^2} \left( \frac{a}{a_{cr}} \right)^2 + \frac{1}{\eta} \frac{k}{k+1} \frac{k_T - 1}{k_T} \left( \frac{w}{a_{cr}} \right)^2. \end{aligned} \quad (45)$$

Taken together, Eqs. (17) and (41) give

$$a^2 = y^2 k \frac{p}{\rho Z_{ef}} \quad (46)$$

or

$$\left( \frac{a}{a_{cr}} \right)^2 = y^2 k \frac{1}{Z_{ef}} \frac{p}{\rho a_{cr}^2}. \quad (47)$$

Substituting  $p/\rho$  from Eq. (40) into Eq. (47), it follows that

$$\left( \frac{a}{a_{cr}} \right)^2 = ky^2 \frac{1}{Z_{ef}} \pi_{re} \frac{w}{a_{cr}}$$

or

$$\left( \frac{a}{a_{cr}} \right)^2 = ky^2 \frac{1}{Z_{ef}} \pi_{re} \lambda. \quad (48)$$

Simultaneous solution of Eqs. (6) and (43) gives

$$\left( \frac{a_0}{a_{cr}} \right)^2 = \frac{k+1}{2} \left( \frac{y_0}{\xi_{cr}} \right)^2. \quad (49)$$

Substituting  $(a/a_{cr})^2$  from Eq. (48) and  $(a_0/a_{cr})^2$  from Eq. (49) into Eq. (45), the reduced pressure is found in the form

$$\begin{aligned} \pi_{re} &= \frac{k+1}{2k} \frac{Z_{ef}}{\xi_{cr}^2} \left\{ 1 + \frac{1}{\eta} \frac{k_T - 1}{k_T} [(Z_{ef})_{p,T} - (Z_{ef})_{p_0,T}] \right\}^{-1} \times \\ &\times \frac{1}{\lambda} \left( 1 - \frac{1}{\eta} \frac{k}{k+1} \frac{k_T - 1}{k_T} \frac{\xi_{cr}^2 \lambda^2}{a_{cr}^2} \right). \end{aligned} \quad (50)$$

Simultaneous solution of Eqs. (38) and (50) gives

$$\frac{\pi \lambda}{\tau_{cr}} = \frac{1}{k} \frac{Z_{ef}}{y_{cr}^2}. \quad (51)$$

Fundamental to the entropic method of calculating the drag in transonic flow considered here is the hypothesis of inearity of the entropy. In other words, it is assumed that

$$d\sigma/d\bar{l} = \text{const}. \quad (52)$$

On the basis of Eq. (52), the form of the computational equations for real and dissociating gas - in particular, for dissociating nitrogen tetroxide - may be found.

After dividing both sides of Eq. (33) by  $d\bar{l} = d\ell/D_{cr}$ , it is found that

$$\frac{d\sigma}{d\bar{l}} = \frac{d \ln \psi}{d\bar{l}}. \quad (53)$$

Introducing the notation

$$\theta = \frac{d\sigma}{d\bar{l}} = \frac{d \ln \psi}{d\bar{l}} \quad (54)$$

and taking into account, according to the linearity hypothesis, that  $\theta = \text{const}$ , it follows from Eq. (54) that

$$\ln \psi = \theta \bar{l}. \quad (55)$$

In the case of isentropic gas flow,  $d\sigma = 0$  and, in accordance with Eq. (54),  $\psi = \text{const} = 1$ . Then it follows from Eq. (34) that:

$$f_s = \left[ \lambda \tau_{cr} \left( \frac{c_{p,ef}}{R/\mu_{N_2O_2}} - \frac{\omega^2}{\eta} \right) \frac{\eta}{\omega Z_{ef}} \right]. \quad (56)$$

Taking account of Eq. (56), Eq. (34) is written in the form

$$\psi = (f/f_s) Z_{ef}^{\omega/\eta}. \quad (57)$$

As a result of simultaneous solution of Eqs. (55) and (57), it is found that

$$f_s = f \exp \left( -\theta \bar{l} \frac{\eta}{\omega Z_{ef}} \right). \quad (58)$$

Experience shows that, for a nozzle with a polished internal surface, it may be assumed that  $\theta \approx 0.01-0.02$  [6].

Equation (58) permits hydrodynamic calculation of the channels.

For nondissociating ideal gas, when  $\eta = \omega = Z = 1$ , Eq. (58) takes the form [1, 2] (in the present notation

$$(f_s)_{id} = f \exp(-\theta \bar{l}). \quad (59)$$

In [1], two problems were solved: the direct and inverse problems. In the first case, the specified quantities are  $\theta$  and the variation in  $f$  over the length of the channel; the distribution of the parameters along the channel remains to be determined. The sequence of calculation is as follows: 1) from the value of  $\bar{l}$ , a series of values of  $\theta \bar{l}$  and the corresponding known values of  $f$  along the channel are written, and then  $(f_s)_{id}$  is found from Eq. (59); 2) using tables of gas-dynamic functions,  $\lambda_{id}$  is determined from the  $(f_s)_{id}$  found; 3) after finding  $\lambda_{id}$ , all the other given parameters may be determined from tables of gas-dynamic functions.

In solving the inverse problem, the geometric dimensions of the channel,  $\theta$ , and  $\lambda_{id}$  are specified; the cross section corresponding to the specified  $\lambda_{id}$  must be determined; the sequence of calculation was outlined in detail in [1, 2].

Comparison of Eq. (58), obtained here for dissociating gas, with Eq. (59) for an ideal gas shows that the exponent for the dissociating gas is  $(-\theta \bar{l} \eta / \omega Z_{ef})$  as a result of the condition  $d\sigma/d\bar{l} = \text{const}$ , i.e., in comparison with Eq. (59), the additional factor  $\eta / \omega Z_{ef}$ , which is a function of  $p$  and  $T$ , appears in the exponent. This complicates the calculation for a dissociating gas. The point is that, in this case, specifying  $\theta$  and the variation in  $f$  over the length of the channel is inadequate for the direct calculation. It is also necessary to know the law of pressure and temperature distribution along the channel, i.e., to know which is the desired distribution, since the aim of the direct problem is to determine the character of the variation specifically in the parameters of the gas.

The complexity of the problem is made worse by the lack of tables for gas-dynamic functions in the case of dissociating gas. Therefore, to solve the direct problem for dissociating nitrogen tetroxide, the distribution of parameters along the channel must be used, regarding the gas as ideal in the first approximation, and on this basis the problem is then solved by the successive-approximation method. Analogously, the same successive-approximation method must be used in solving the inverse problem.

\*The subscript  $s$  denotes that the flow is isentropic.

## NOTATION

$\zeta$ , hydrodynamic drag coefficient;  $p$ ,  $v$ ,  $T$ ,  $\rho$ , pressure, specific volume, temperature, and density;  $R$ , universal gas constant;  $\mu$ , molecular mass;  $C_{pef}$ , effective isobaric mass specific heat;  $k_T$ , adiabatic temperature index of dissociating gas;  $p_0$ ,  $T_0$ ,  $\rho_0$ , stagnation parameters;  $\alpha$ , degree of dissociation;  $k$ , adiabatic index of nondissociating ideal gas;  $w$ , velocity of dissociating nitrogen tetroxide;  $G$ , flow rate per second;  $F$ , cross section;  $a_{cr}$ , critical velocity of dissociating nitrogen tetroxide;  $\lambda$ , velocity coefficient.

## LITERATURE CITED

1. A. A. Gukhman, A. F. Gandel'sman, and N. V. Ilyukhin, *Teploénergetika*, No. 1, 17-23 (1955).
2. A. A. Gukhman, A. F. Gandel'sman, and P. N. Naurits, *Énergomashinostroenie*, No. 1, 10-14 (1955).
3. É. A. Orudzhaliev, *Inzh.-Fiz. Zh.*, 49, No. 1, 57-64 (1985).
4. V. B. Nestarenko, V. P. Bubnov, Yu. G. Kotelevskii, et al., *Physicochemical and Thermophysical Properties of Chemically Reacting System* [in Russian], Minsk (1976).
5. É. A. Orudzhaliev, *Inzh.-Fiz. Zh.*, 41, No. 2, 282-288 (1981).
6. M. E. Deich, *Engineering Gas Dynamics* [in Russian], Moscow (1974).

## DYNAMIC VISCOSITY OF GASES OVER A WIDE RANGE OF TEMPERATURES. I.

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The results are presented of a generalization of the experimental data on the viscosities of He, Ne, Ar, Kr, Xe, and N<sub>2</sub> at atmospheric pressure over the range of temperatures from the boiling point at atmospheric pressure to 2000 K using polynomial approximating relationships.

The recommended value of the viscosities of the inert gases and nitrogen which exist at present [1-4] differ fundamentally in the methods of generalizing the experimental data, in the type and quantity of the block of data used in the generalization, in the form of representing the results, and in the magnitude of the errors inherent in them.

The results of the direct generalization of the experimental data on the viscosities of the gases [1] are characterized by errors not exceeding 1.5%, but they are based on an incomplete collection of data obtained only up to 1972.

The standard handbook data [2] are based on a reliable theoretical model, but the generalization of the experimental results was carried out only for argon, and for the other gases the data were obtained by using the principle of corresponding states. As shown in [5], this method can lead to inaccuracies for neon at temperatures above room temperature and for helium in the low temperature region. In fact, the deviation of the data of [2] from the experimental viscosity values is largest for Ne at  $T > 300$  K compared to the other gases (Ar, Kr, Xe); as regards helium, the measured results for this gas were generalized graphically over the entire temperature range. The data of [2] on the viscosities and thermal conductivities had similar errors, though the errors of the initial experimental material were different.

The recalculation of thermal conductivity data into values of the viscosity carried out in [3] has the same deficiency: the error of the values which are obtained is caused by the

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