13. V. P. Glushko (ed.), Thermodynamic Properties of Individual Materials, Vol. 4, Book 2 [in Russian], Moscow (1982).
14. D. L. Timrot, V. V. Makhrov, and F. I. Pil'nen'skii, Teplofiz. Vys. Temp., 22, No. 1, 40-47 (1984).
15. N. B. Vargaftik, V. M. Kapitonov, and A. A. Voshchinin, Inzh.-Fiz. Zh., 49, No. 4, 634-640 (1985).
16. V. I. Dolgov and V. S. Yargin, Teplofiz. Vys. Temp., 24, No. 5, 1017-1019 (1986).
17. A. O. Erkimbaev and A. M. Semenov, Teplofiz. Vys. Temp., 24, No. 6, 1090-1095 (1986).
18. M. L. Olson and D. D. Konowalov, J. Chem. Phys., 21, No. 3, 393-399 (1977).
19. D. D. Konowalov and M. L. Olson, J. Chem. Phys., 71, 450-459 (1979).

# GENERALIZATION AND ANALYTIC DESCRIPTION OF THERMAL CONDUCTIVITY OF PARAFFIN AND AROMATIC HYDROCARBONS AND THEIR MIXTURES

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Experimental data on thermal conductivity of liquid binary mixtures of aromatic hydrocarbons with n-hexane are generalized.

At present unified theoretical expressions satisfactorily describing the thermal conductivity λ of liquids and gases as a function of temperature and pressure do not exist. Therefore the authors employed the cylindrical tricalorimeter method of [1, 2] to measure λ of aromatic hydrocarbons and their liquid binary mixtures with n-hexane. It was possible to generalize the measurement results by quite reliable equations.

The simplest sufficiently accurate expression was the Tait isotherm equation [3]. The authors of [4, 5] changed the form of the Tait equation and used it to describe thermal conductivity of liquids.

Since the analytical solution of the Tait isotherm equation presents definite difficulties, the authors of [6] derived two simple equations to calculate the coefficients of the former. The analytical description of the present data on thermal conductivity of individual hydrocarbons was performed with the first equation

$$\lambda_{p,T} = \lambda_T + \frac{Ap}{1+Bp}, \tag{1}$$

TABLE 1. Values of Quantities Appearing in Eqs. (2) and (3)

| Material | Values of $A_0$, $\alpha$, $T_0$ | | | Coeffs. $k_i$ for calc. of A | | | |
|---|---|---|---|---|---|---|---|
| | $A_0\cdot10^{-6}$ | $\alpha\cdot10^{-6}$ | $T_0$, K | $k_1\cdot10^{-6}$ | $k_2\cdot10^{-6}$ | $k_3\cdot10^{-6}$ | $k_4\cdot10^{-6}$ |
| Benzene | 468 | 1,6686 | 298,15 | | | | |
| Toluene | | | 198,15 | 1042 | —4,373 | 432,09 | —975,867 |
| Orthaxylene | | | 273,15 | 328 | —0,162 | 77,25 | —117,03 |
| Metaxylene | 265 | 2,2 | 248,15 | | | | |
| Paraxylene | 355 | 1,772 | 298,15 | | | | |

| Material | Values of $A_0$, $\alpha$, $T_0$ | | | Coeffs. $k_i$ for calc. of B | | | |
|---|---|---|---|---|---|---|---|
| | $A_0\cdot10^{-6}$ | $\alpha\cdot10^{-6}$ | $T_0$, K | $k_1\cdot10^{-6}$ | $k_2\cdot10^{-6}$ | $k_3\cdot10^{-6}$ | $k_4\cdot10^{-6}$ |
| Benzene | 468 | 1,6686 | 298,15 | 0 | —0,4921 | 20,932 | —28,205 |
| Toluene | | | 198,15 | 261,6 | —1,7786 | 139,443 | —308,6 |
| Orthaxylene | | | 273,15 | 5,3 | —0,9732 | 45,540 | —67,112 |
| Metaxylene | 265 | 2,2 | 248,15 | 256,49 | —1,852 | 142,11 | —311,56 |
| Paraxylene | 355 | 1,772 | 298,15 | 2 | —0,1479 | 11,933 | —14,767 |

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TABLE 2. Coefficients of Eq. (5)

| Coefficients | Benzene, toluene | Ortha-, meta-, and paraxylene |
|---|---|---|
| $\lambda_{\tau_0}$ | 1,33 | 1,278 |
| $m_1$ | 0,5533 | 0,619 |
| $m_2$ | 0,1927 | 0,4654 |
| $m_3$ | 0,0108 | —0,3148 |
| $\tau_0$ | 0,5552 | 0,668 |

TABLE 3. Values of A' and B' for Mixtures

| Conc., % | Mixture | $A'$ | $B'$ | Max. error $\Delta = \frac{\lambda_{cal} - \lambda_{exp}}{\lambda_{exp}} 100\ \%$ |
|---|---|---|---|---|
| | Benzene—n-hexane | | | |
| 25 | $C_6H_6 + 75\ \%\ C_6H_{14}$ | 0,081 | 1 | 1,1 |
| 50 | $C_6H_6 + 50\ \%\ C_6H_{14}$ | 0,0937 | 1,0167 | 1,2 |
| 75 | $C_6H_6 + 25\ \%\ C_6H_{14}$ | 0,0944 | 1,079 | 2,6 |
| | Toluene—n-hexane | | | |
| 25 | $C_6H_6 + 75\ \%\ C_6H_{14}$ | 0,0873 | 0,9526 | 1,3 |
| 50 | $C_6H_8 + 50\ \%\ C_6H_{14}$ | 0,0930 | 0,8938 | 2 |
| 75 | $C_6H_8 + 25\ \%\ C_6H_{14}$ | 0,0960 | 0,8721 | 3,1 |
| | Orthoxylene—n-hexane | | | |
| 25 | $C_8H_{10} + 75\ \%\ C_6H_{14}$ | 0,0857 | 0,9725 | 1,5 |
| 50 | $C_8H_{10} + 50\ \%\ C_6H_{14}$ | 0,0868 | 0,9954 | 2,4 |
| 75 | $C_8H_{10} + 25\ \%\ C_6H_{14}$ | 0,0887 | 0,974 | 3 |
| | Metaxylene—n-hexane | | | |
| 25 | $C_8H_{10} + 75\ \%\ C_6H_{14}$ | 0,0829 | 0,9824 | 1,8 |
| 50 | $C_8H_{10} + 50\ \%\ C_6H_{14}$ | 0,0880 | 0,9333 | 1,8 |
| 75 | $C_8H_{10} + 25\ \%\ C_6H_{14}$ | 0,0881 | 0,9443 | 3 |
| | Paraxylene—n-hexane | | | |
| 25 | $C_8H_{10} + 75\ \%\ C_6H_{14}$ | 0,0821 | 0,9541 | 1,9 |
| 50 | $C_8H_{10} + 50\ \%\ C_6H_{14}$ | 0,0852 | 0,9246 | 1,7 |
| 75 | $C_8H_{10} + 25\ \%\ C_6H_{14}$ | 0,0857 | 0,9148 | 4,1 |

where

$$A = \frac{\Delta\lambda_1 (1 + Bp_1)}{p_1}; \quad B = \frac{p_1 \Delta\lambda_2 - p_2 \Delta\lambda_1}{p_1 p_2 (\Delta\lambda_1 - \Delta\lambda_2)}.$$

A FORTRAN program for a Minsk-32 computer was written to calculate the coefficients A and B.

The functions A = f(T) and B = f(T) for the various hydrocarbons over the temperature range studied were not identical: for benzene, para- and metaxylene A(T) was practically rectilinear, while for toluene and orthaxylene it was curvolinear. For all hydrocarbons studied B(T) was curvolinear.

The rectilinear dependence was described by an equation of the type

$$A = A_0 + \alpha \Delta T, \tag{2}$$

where $A_0$ is the value of A at $\Delta T = 0$; $\alpha$ is a temperature coefficient, and $\Delta T = T - T_0$.

For the curvolinear dependence a convenient equation is one of the type

$$Z = \sum_{i,j} k_i \Delta T^{j-1}, \quad \left\{ \begin{array}{l} i = 1,\ 2,\ 3,\ 4 \\ j = 1,\ 2,\ \frac{3}{2},\ \frac{4}{3} \end{array} \right\}, \tag{3}$$

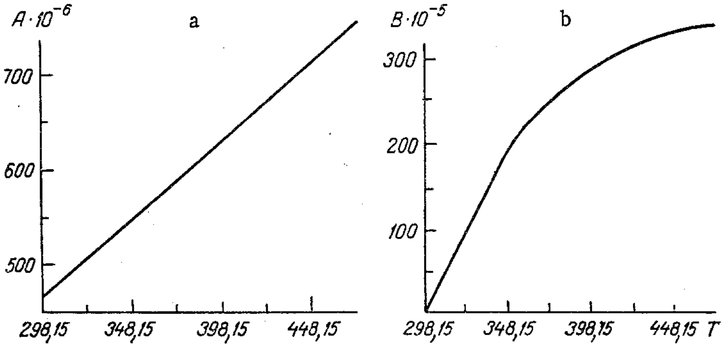


Fig. 1. Temperature dependence of coefficients A (a) and B (b) for benzene. A, W/m•K•MPa; B, 1/MPa; T, K.

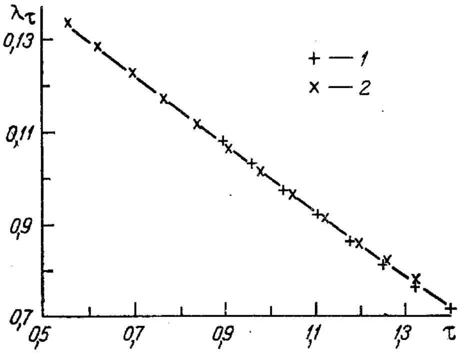


Fig. 2

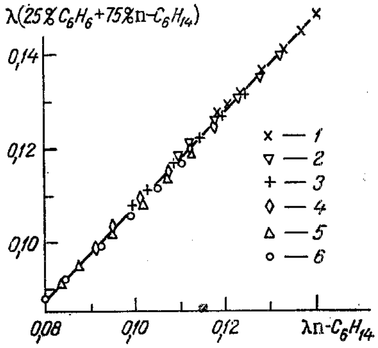


Fig. 3

Fig. 2. Dimensionless thermal conductivity vs dimensionless temperature for benzene (1) and toluene (2).

Fig. 3. Interrelationship of thermal conductivities of mixture (25% benzene + 75% n-hexane) and n-hexane at identical temperatures and pressures of 0.1-50 MPa: 1) 303.15 K; 2) 343.15; 3) 383.15; 4) 423.15; 5) 463.15; 6) 483.15 K.

where Z = A or B.

The coefficients of Eqs. (2) and (3) are presented in Table 1. As an example, Fig. 1 shows temperature dependence of the coefficients A and B for benzene.

To calculate $\lambda_{p,T}$ with Eq. (1) it is necessary to define the value of $\lambda_T$. The analytical description of aromatic hydrocarbon thermal conductivity along the saturation line was done with the equation

$$\lambda_T = \lambda_0 \exp\left(-\sum_{i=1}^{\infty} m_i \Delta T^i\right), \tag{4}$$

where $\lambda_0$ is the hydrocarbon thermal conductivity at $\Delta T = 0$; $m_i$ are coefficients.

Data on hydrocarbon thermal conductivity above the boiling temperature were obtained by extrapolation.

Equation (4) describes the experimental data with a maximum error of ±0.3%.

Relying upon the law of corresponding states we used the dependence for the thermal conductivity of aromatic hydrocarbons along the saturation line. For the generalization, equations of the form

$$\lambda_\tau = \lambda_{\tau_0} \exp\left(-\sum_{i=1}^{3} m_i \Delta\tau^i\right) \tag{5}$$

were chosen, where $\lambda_{\tau_0}$ is the thermal conductivity at temperature $\Delta\tau = 0$; $\Delta\tau = \tau - \tau_0$.

Since $\lambda_{cr}$ was not studied, for the dimensionless thermal conductivity in place of the ratio $\lambda/\lambda_{cr}$ the ratio $\lambda/\lambda_{0.6T_{cr}}$ was used. The coefficients of Eq. (5), as determined with the Minsk-32 computer, are presented in Table 2. Figure 2 shows the generalizing curve $\lambda_\tau = f(\tau)$ for benzene and toluene.

Knowing the values of the $\lambda_T$ coefficients, we can use Eqs. (2), (3), and (1) to calculate $\lambda_{p,T}$.

Equation (1) describes our experimental data with a maximum error of ~0.9%.

Methods of comparative calculation are of great practical interest, since from values of the thermal conductivity of one of the hydrocarbons they permit calculation of λ of mixtures of given mass concentrations.

To generalize the experimental data on mixture λ the comparative calculation method of Karapetyants [7] was used, according to which one and the same property of two materials is compared at different parameter values. This method corresponds to the approximate linear equation

$$G_M = A' + B'G_N, \tag{6}$$

which compares values of the property G of materials M and N at an identical but differing from point to point value of the parameter.

A generalization of the thermal conductivity of all the liquid binary mixtures and the components of which they were composed was carried out according to Eq. (6). Absolute values of the thermal conductivity coefficient of the individual hydrocarbons and mixtures were used. The λ values of n-hexane were taken from [8].

As an example, Fig. 3 shows the interrelationship of the thermal conductivity of a mixture of 25% benzene +75% n-hexane (by mass) and the thermal conductivity of n-hexane at identical temperature and pressures of 0.1-50 MPa. It is evident that the dependence of the mixture thermal conductivity on n-hexane thermal conductivity is rectilinear.

Table 3 presents values of the coefficients A' and B' and maximum errors in the data calculated by Eq. (6) for each of the mixtures.

In the generalization, data on thermal conductivity of aromatic hydrocarbons and their mixtures with n-hexane were taken from [9, 10].

## NOTATION

$k_i$, $m_i$, coefficients; $\lambda_\tau$, dimensionless thermal conductivity, $\lambda_\tau = \lambda_T/\lambda^*$; $\lambda^*$, thermal conductivity at temperature $0.6T_{cr}$.

## LITERATURE CITED


1. Ya. M. Naziev and A. A. Abasov, Izv. Vyssh. Uchebn. Zaved., Neft' Gaz, No. 3, 65-69 (1968).
2. Ya. M. Naziev, Proc. 5th Symposium on Thermophysical Properties, Vol. 5, New York (1970), pp. 8-15.
3. P. G. Tait, Report on the Voyage of "Challenger." Physics and Chemistry, Vol. 2, London (1988).
4. A. M. Mamedov, Inzh.-Fiz. Zh., 39, No. 1, 34-38 (1980).
5. B. A. Grigor'ev and P. M. Ishkhanov, Inzh.-Fiz. Zh., 41, No. 3, 491-499 (1981).
6. Ya. M. Naziev and A. M. Gumbatov, Thermophysical Properties of High Boiling Point Liquids [in Russian], Baku (1984), pp. 79-82.
7. M. Kh. Karapetyants, Methods of Comparative Calculation of Physicochemical Properties [in Russian], Moscow (1965).
8. Ya. M. Naziev, A. M. Gumbatov, and A. K. Akhmedov, Izv. Vyssh. Uchebn. Zaved., Neft' Gaz, No. 12, 43-47 (1981).
9. Ya. M. Naziev, A. S. Gasanov, and A. M. Gumbatov, Inzh.-Fiz. Zh., 50, No. 1, 135 (1986).
10. Ya. M. Naziev, A. M. Gumbatov, A. S. Gasanov, and A. A. Abasov, Inzh.-Fiz. Zh., 50, No. 4, 674-675 (1986).