

APPROXIMATE TRANSPORT PROPERTIES OF HIGH-TEMPERATURE AIR IN DISSOCIATION EQUILIBRIUM

1. NOTATION AND UNITS

		<i>SI</i>	<i>British</i>
c_p	specific heat capacity at constant pressure	J/kg K	ft lbf/slug K
i	specific enthalpy	J/kg	ft lbf/slug
k	thermal conductivity	W/m K	ft lbf/ft s K
p	static pressure	N/m ²	lbf/ft ²
R	gas constant	J/kg K	ft lbf/slug K
T	temperature	K	K
μ	viscosity	kg/m s	slug/ft s
ρ	density	kg/m ³	slug/ft ³
σ	Prandtl number, $\mu c_p / k$		

Suffixes

1, 2	evaluated at conditions p_1 , i_1 and p_2 , i_2 , respectively
E	evaluated at reference enthalpy i_E and arbitrary pressure

REFERENCE VALUES

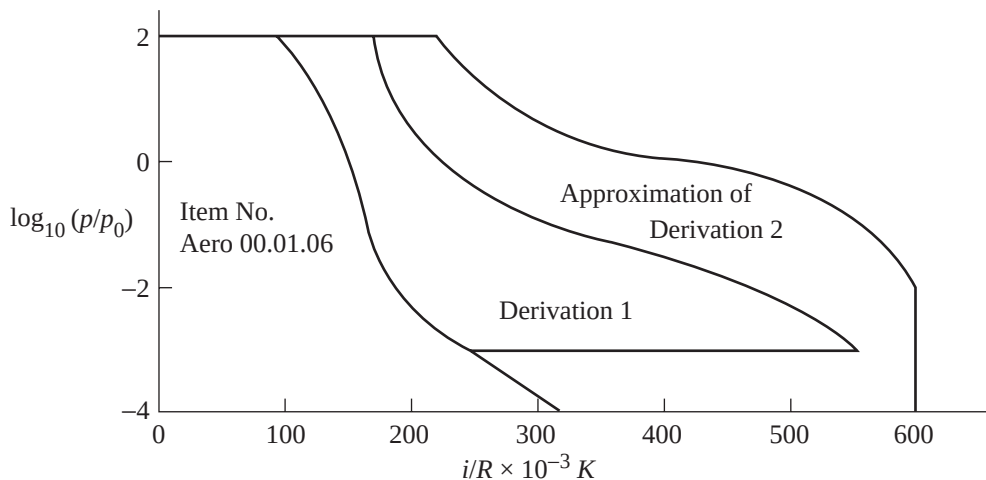
		<i>SI</i>	<i>British</i>
i_E	(= 250 RT_0)	19.60×10^6 J/kg	211.0×10^6 ft lbf/slug
p_0	(one atmosphere)	101.3×10^3 N/m ²	2116 lbf/ft ²
R		287.1 J/kg K	3090 ft lbf/slug K
T_0		273.15 K	273.15 K
μ_0		17.160×10^{-6} kg/m s	358.4×10^{-9} slug/ft s
ρ_0		1.287 kg/m ³	2.498×10^{-3} slug/ft ³

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2. NOTES

The curves, based on Derivation 2, give values of the viscosity, μ , the thermal conductivity, k , the Prandtl number, σ , and the product of viscosity and density, $\rho\mu$, as functions of pressure and i/R for air, the air being regarded as a mixture of nitrogen and oxygen in the ratio 4 : 1.

The transport properties are presented in Derivation 2 as a function of temperature and, in converting these to functions of i/R to plot the curves, three sources of data have been used. For consistency Item No. Aero 00.01.06 has been used where possible and, for values of i/R in excess of those given by 00.01.06, Derivation 1 and the approximation of Derivation 2 have been used. The following diagram gives details of the range of i/R for which each Derivation has been used.



A comparison has been made between the values given by the approximation of Derivation 2 and the more accurate values of Item No. Aero 00.01.06 and Derivation 1, in the lower temperature range where all three overlap. This shows that there is agreement to within 5 per cent.

It is suggested in Derivation 2 that the coefficients of viscosity and thermal conductivity may prove to be lower boundaries to more precise calculations or measurements. There is little experimental evidence to verify the calculated values but Derivation 2 suggests that thermal conductivity may be accurate to within some 30 per cent at the lower temperatures where oxygen dissociation is taking place. Approximate boundaries for oxygen and nitrogen dissociation and ionisation are shown in the Figures.

Values of transport properties given in Derivations 3, 4, and 6 differ somewhat from those presented in this Item; these Derivations give calculated results that cover a less comprehensive range of variables than those of Derivation 2. In these circumstances, and having regard for the imprecise nature of the results, it is concluded that the values given in this Item are useful engineering approximations to the transport properties of high temperature air.

In certain classes of boundary layer problems it may be more convenient to consider the product of density and viscosity, $\rho\mu$, and to express this product in an analytical form. Derivation 5 gives formulae that express ρ and $\rho\mu$ as functions of enthalpy and pressure. The functions are obtained from the calculated values of Derivation 2, for enthalpy ratios i/i_E^* , less than 1.6, by the method of least squares.

* It should be noted that the conditions denoted by suffix "E" are arbitrary and do not correspond to those denoted by suffix "0".

Density ratio is related to enthalpy ratio by the expression

$$\frac{\rho_E}{\rho} = 1 - 1.0477 \left\{ 1 - \left(\frac{i}{i_E} \right)^{0.6123} \right\}. \quad (2.1)$$

For pressures from 10^{-4} to 10 atmospheres the calculated values of Derivation 2 deviate from this function by a maximum of ± 25 per cent at low enthalpy ratios, the average deviation for all data being ± 6 per cent. Agreement is best in the range $0.2 < i/i_E < 1.6$.

The dependence of density on pressure is represented by

$$\frac{\rho_E}{\rho_0} = 0.0294 \left(\frac{p}{p_0} \right)^{0.965}. \quad (2.2)$$

The calculated values of Derivation 2 deviate from this function by less than half of one per cent.

To obtain the arbitrary density ratio ρ_1/ρ_2 , Equations (2.1) and (2.2) may be combined, *i.e.*

$$\begin{aligned} \frac{\rho_1}{\rho_2} &\equiv \frac{(\rho_E/\rho_2)_{p=p_2}}{(\rho_E/\rho_1)_{p=p_1}} \times \frac{(\rho_E)_{p=p_1}}{(\rho_E)_{p=p_2}} \\ &= \frac{1 - 1.0477 \{ 1 - (i_2/i_E)^{0.6123} \}}{1 - 1.0477 \{ 1 - (i_1/i_E)^{0.6123} \}} \times \left(\frac{p_1}{p_2} \right)^{0.965}. \end{aligned} \quad (2.3)$$

The product of density and viscosity, $\rho\mu$, may be expressed as a function of enthalpy ratio by the equation

$$\frac{\rho_E \mu_E}{\rho \mu} = 1 - 1.0213 \left\{ 1 - \left(\frac{i}{i_E} \right)^{0.3329} \right\}. \quad (2.4)$$

For pressures from 10^{-4} to 10 atmospheres the calculated values of Derivation 2 deviate from this function by a maximum of ± 8 per cent and the average deviation for all data is ± 3 per cent over the range $0.0152 < i/i_E < 2.0$.

The dependence of $\rho\mu$ on pressure is represented by

$$\frac{\rho_E \mu_E}{\rho_0 \mu_0} = 0.225 \left(\frac{p}{p_0} \right)^{0.992}. \quad (2.5)$$

The calculated values of Derivation 2 deviate from this function by less than half of one per cent.