

Thermophysical properties of toluene:

Part 1. The ideal gas and the saturated liquid and vapour

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Physical Data and Reaction Kinetics Committee, which first met in 1966 and now has the following membership:

Chairman	
Mr C.F. Beaton	— Independent
Members	
Dr D. Ambrose [*]	— Independent
Dr E. Brunner [†]	— BASF AG, Ludwigshafen, Germany
Dr M.W. Chase [†]	— National Institute of Standards & Technology, Gaithersburgh, USA
Dr J.R. Downey [†]	— Dow Chemical, Midland, USA
Dr G. Hobson	— Imperial Chemical Industries plc, Petrochemicals & Plastics Division, Wilton, UK
Dr A.E. Humphreys	— British Gas plc, Loughborough, UK
Dr D.T. Jamieson	— National Engineering Laboratory, East Kilbride, UK
Mr S.R. Knight	— Stone & Webster Engineering Ltd, Milton Keynes, UK
Dr M. Schoenberg [†]	— Hoechst AG, Frankfurt, Germany.
[*] Emeritus Member.	
[†] Corresponding Member.	

The technical work involved in the assessment of the available information and the construction and subsequent development of the Data Item was undertaken (under contract to ESDU) by

Mr C.F. Beaton	— Independent
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with the assistance of Mr J. Walton.

The person with overall responsibility for the work in this subject area is Mr G.H. Walter, Head of Heat Transfer, Internal Flow and Physical Data Group.

THERMOPHYSICAL PROPERTIES OF TOLUENE: PART 1. THE IDEAL GAS AND THE SATURATED LIQUID AND VAPOUR

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THERMOPHYSICAL PROPERTIES OF TOLUENE: PART 1. THE IDEAL GAS AND THE SATURATED LIQUID AND VAPOUR

1. INTRODUCTION

This Item, which is one of a series concerned with the thermophysical properties of industrially important fluids, gives equations representing the thermophysical properties of toluene on the saturation line, and in the ideal gas state and dilute gas state, together with tabulated values calculated from the equations.

The data on which the recommended values of the fluid properties are based are considered to be the best available and the range covered for the saturation line properties is from the melting temperature to within at least 69 kelvin of the critical temperature. The properties of the ideal and dilute gas are given for temperatures from 178.18 to 960 K for the isobaric specific heat capacity and thermal conductivity. The dilute gas viscosity tables terminate at 860 K. Superheat properties are given in Data Item 88010.

All quantities are expressed in SI units or their multiples (see Section 2) but, for users who require them in other units, conversion factors are provided in Appendix A. Equations representing the fluid properties are given in Section 4, and Section 5 gives an explanation of the Tables in the Data Item.

2. NOTATION AND UNITS

b_1, b_2, b_3, b_4, b_5	constants in Equations (4.1) to (4.17)	*
c	specific heat capacity	kJ/kg K
h	specific enthalpy	kJ/kg
M	molecular weight (relative molecular mass)	—
p	vapour pressure	kPa
T	kelvin temperature	K
t	Celsius temperature, $(T - 273.15)$	°C
u	specific internal energy	kJ/kg
V	molar volume	cm ³ /mol
v	specific volume, $v = 1/\rho$	m ³ /kg
η	dynamic viscosity	mN s/m ² or μ N s/m ²
θ	temperature dependent variable in Equation (4.9)	—
λ	thermal conductivity	mW/m K
ρ	density	kg/m ³
σ	surface tension	mN/m
ω	acentric factor	—

* The constants b are dimensionless except for the following: Equations (4.4) and (4.6), kJ/kg (all); Equations (4.7) and (4.8), kJ/kg K (b_1); Equation (4.9), K (b_3), mN s/m² (b_4); Equation (4.10), μ N s/m² ($\exp(b_1)$); Equations (4.11) and (4.12), mW/m K (b_1 and $\exp(b_1)$ respectively); Equation (4.13), mN/m (b_1); Equation (4.14), kJ/kg K (all); Equation (4.15), kJ/kg (all); Equation (4.16), μ N s/m² (all); Equation (4.17), mW/m K (all).

State descriptors

(g)	value for gas or saturated vapour
(l)	value for saturated liquid
Δ	denotes property difference between two states

Superscripts

id	denotes ideal gas
(o)	denotes dilute gas

Subscripts

b	value at normal boiling point
c	value at critical point
m	value at normal melting point
p	value at constant pressure
r	denotes reduced quantity, <i>e.g.</i> $T_r = T/T_c$
sat	value at saturation (defined in Appendix B, Section B1)
v	value at constant volume
vap	denotes evaporation.

3. THERMOPHYSICAL PROPERTIES

Equations for the ideal gas specific heat capacity and specific enthalpy were fitted to values derived from those published by the Thermodynamics Research Center (Derivation 32).

A limited set of tables for the thermodynamic properties at saturation were issued in an earlier Data Item (Derivation 20)*. These were extended down to the melting temperature, using data from the available literature (see References and Derivation).

A computer software package, codename 'LOADER', developed by the National Engineering Laboratory (Derivation 29) was used to check that a thermodynamically consistent set of results was evaluated. The specific enthalpy of the saturated liquid was determined from the specific enthalpy of the saturated vapour and the specific enthalpy of vaporisation. The liquid specific heat capacity at constant pressure was then evaluated by the relationship defined in Appendix B, Section B1.

The equation for the viscosity of the vapour in the dilute gas was fitted to values derived from data in Derivation 17. Conflicting values of thermal conductivity at low pressure were ignored in favour of values predicted by the NEL software package. These were within 5% of the most recent data reported in Derivation 23. The saturation values for these vapour properties were determined from these data by the software package.

The surface tension data (Derivation 18) were extended and fitted by the package (Derivation 29).

The liquid viscosity, liquid thermal conductivity and vapour pressure were available from previous work (Derivations 25, 26 and 27). Equation (4.2) for the liquid density was based on a new correlation for aromatic hydrocarbons (Derivation 30).

* Reissued as Table 6.2 of Data Item 88010 at selected intervals of pressure.

Equations (4.1) to (4.17), fitted to data derived from the above sources were used to generate the property values in Table 7.2 to 7.5.

4. EQUATIONS FOR PROPERTIES

4.1 Vapour Pressure

Data for the vapour pressure are represented by Equation (4.1).

$$\log_e \left(\frac{p}{p_c} \right) = \frac{1}{T_r} [b_1(1 - T_r) + b_2(1 - T_r)^{3/2} + b_3(1 - T_r)^3 + b_4(1 - T_r)^6]. \quad (4.1)$$

4.2 Density of the Saturated Liquid

Data for the density of the saturated liquid are represented by Equation (4.2).

$$\log_e \left(\frac{\rho(l)}{\rho_c} \right) = b_1(1 - T_r)^{1/3} + b_2(1 - T_r)^{2/3} + b_3(1 - T_r) + b_4(1 - T_r)^{4/3}. \quad (4.2)$$

4.3 Density of the Saturated Vapour

Data for the density of the saturated vapour are represented by Equation (4.3).

$$\log_e \left(\frac{\rho(g)}{\rho_c} \right) = b_1 \left(\frac{1}{T_r} - 1 \right)^{1/3} + b_2 \left(\frac{1}{T_r} - 1 \right)^{2/3} + b_3 \left(\frac{1}{T_r} - 1 \right) + b_4 \left(\frac{1}{T_r} - 1 \right)^{4/3} + b_5 \left(\frac{1}{T_r} - 1 \right)^{5/3}. \quad (4.3)$$

4.4 Specific Enthalpy of the Saturated Liquid

Data for the specific enthalpy of the saturated liquid are represented by Equation (4.4).

$$h(l) = b_1 + b_2(1 - T_r)^{1/3} + b_3(1 - T_r)^{2/3} + b_4(1 - T_r) + b_5(1 - T_r)^{4/3}. \quad (4.4)$$

4.5 Latent Heat of Vaporisation (Specific Enthalpy of Vaporisation)

Data for the latent heat of vaporisation are represented by Equation (4.5).

$$\Delta_{\text{vap}} h = h(g) - h(l). \quad (4.5)$$

4.6 Specific Enthalpy of the Saturated Vapour

Data for the specific enthalpy of the saturated vapour are represented by Equation (4.6).

$$h(g) = b_1 + b_2(1 - T_r)^{1/3} + b_3(1 - T_r)^{2/3} + b_4(1 - T_r) + b_5(1 - T_r)^{4/3}. \quad (4.6)$$

4.7 Isobaric Specific Heat Capacity of the Saturated Liquid

Data for the isobaric specific heat capacity of the saturated liquid are represented by Equation (4.7).

$$c_p(l) = b_1[1 + b_2(1 - T_r)^{-1} + b_3(1 - T_r) + b_4(1 - T_r)^2 + b_5(1 - T_r)^3]. \quad (4.7)$$

The significance of $c_p(l)$ as a representation of specific heat capacity is fully explained in Appendix B, Section B1.

4.8 Isobaric Specific Heat Capacity of the Saturated Vapour

Data for the isobaric specific heat capacity of the saturated vapour are represented by Equation (4.8).

$$c_p(g) = b_1[1 + b_2(1 - T_r)^{-2/3} + b_3(1 - T_r)^{-1/3} + b_4(1 - T_r)^{1/3} + b_5(1 - T_r)^{2/3}]. \quad (4.8)$$

The significance of $c_p(g)$ as a representation of specific heat capacity is fully explained in Appendix B, Section B1.

4.9 Dynamic Viscosity of the Saturated Liquid

Data for the dynamic viscosity of the saturated liquid are represented by Equation (4.9).

$$\eta(l) = b_4 \exp[b_1(\theta - 1)^{1/3} + b_2(\theta - 1)^{4/3}] \quad (4.9)$$

where $\theta = (T_c - b_3) / (T - b_3)$.

4.10 Dynamic Viscosity of the Saturated Vapour

Data for the dynamic viscosity of the saturated vapour are represented by Equation (4.10).

$$\log_e \eta(g) = b_1 + b_2 \left(\frac{1}{T_r} - 1 \right)^{1/3} + b_3 \left(\frac{1}{T_r} - 1 \right)^{4/3}. \quad (4.10)$$

4.11 Thermal Conductivity of the Saturated Liquid

Data for the thermal conductivity of the saturated liquid are represented by Equation (4.11).

$$\lambda(l) = b_1[1 + b_2(1 - T_r)^{1/3} + b_3(1 - T_r)^{2/3} + b_4(1 - T_r)]. \quad (4.11)$$

4.12 Thermal Conductivity of the Saturated Vapour

Data for the thermal conductivity of the saturated vapour are represented by Equation (4.12).

$$\log_e \lambda(g) = b_1 + b_2(1 - T_r)^{-2/3} + b_3(1 - T_r)^{-1/3} + b_4(1 - T_r)^{1/3} + b_5(1 - T_r)^{2/3}. \quad (4.12)$$