



Thermophysical properties of industrially important fluids on the saturation line: Ammonia

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THERMOPHYSICAL PROPERTIES OF INDUSTRIALLY IMPORTANT FLUIDS ON THE SATURATION LINE: AMMONIA

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THERMOPHYSICAL PROPERTIES OF INDUSTRIALLY IMPORTANT FLUIDS ON THE SATURATION LINE: AMMONIA

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 ammonia on the saturation line, 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 363.15 K.

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 3 and Section 4 gives an explanation of the Tables and Figures in the Data Item.

2. NOTATION AND UNITS

b_1, b_2, b_3, b_4, b_5	constants in Equations (3.1) to (3.14)	*
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 $\mu\text{N s/m}^2$
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 (3.4) and (3.6), kJ/kg (all); Equations (3.7) to (3.9), kJ/kg K (b_1); Equation (3.10), mN s/m² ($\exp(b_1)$); Equation (3.11), $\mu\text{N s/m}^2$ ($\exp(b_1)$); Equations (3.12) and (3.13), mW/m K (b_1 and $\exp(b_1)$ respectively); Equation (3.14), mN/m (b_1).

State descriptors

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

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 B.1)
v	value at constant volume
vap	denotes evaporation.

3. EQUATIONS FOR PROPERTIES

3.1 Vapour Pressure

Data for the vapour pressure are represented by Equation (3.1).

$$\log_e \left(\frac{p}{p_c} \right) = \frac{1}{T_r} [b_1(1 - T_r) + b_2(1 - T_r)^{3/2} + b_3(1 - T_r)^3 + b_4(1 - T_r)^6]. \quad (3.1)$$

3.2 Density of the Saturated Liquid

Data for the density of the saturated liquid are represented by Equation (3.2).

$$\log_e \left(\frac{\rho(l)}{\rho_c} \right) = b_1(1 - T_r)^{1/3} + b_2(1 - T_r)^{2/3} + b_3(1 - T_r) + b_4(1 - T_r)^{4/3}. \quad (3.2)$$

3.3 Density of the Saturated Vapour

Data for the density of the saturated vapour are represented by Equation (3.3).

$$\log_e \left(\frac{\rho(g)}{\rho_c} \right) = b_1 \left(\frac{1}{T_r} - 1 \right)^{1/3} + b_2 \left(\frac{1}{T_r} - 1 \right)^{2/3} + b_3 \left(\frac{1}{T_r} - 1 \right) + b_4 \left(\frac{1}{T_r} - 1 \right)^{4/3} + b_5 \left(\frac{1}{T_r} - 1 \right)^{5/3}. \quad (3.3)$$

3.4 Specific Enthalpy of the Saturated Liquid

Data for the specific enthalpy of the saturated liquid are represented by Equation (3.4).

$$h(l) = b_1(1 - T_r)^{1/3} + b_2(1 - T_r)^{2/3} + b_3(1 - T_r) + b_4(1 - T_r)^{4/3}. \quad (3.4)$$

3.5 Latent Heat of Vaporisation (Specific Enthalpy of Vaporisation)

Data for the latent heat of vaporisation are represented by Equation (3.5).

$$\Delta_{\text{vap}} h = b_1(1 - T_r)^{1/3} + b_2(1 - T_r)^{2/3} + b_3(1 - T_r) + b_4(1 - T_r)^{4/3}. \quad (3.5)$$

3.6 Specific Enthalpy of the Saturated Vapour

Data for the specific enthalpy of the saturated vapour are represented by Equation (3.6).

$$h(g) = b_1(1 - T_r)^{1/3} + b_2(1 - T_r)^{2/3} + b_3(1 - T_r) + b_4(1 - T_r)^{4/3}. \quad (3.6)$$

(Equations (3.4), (3.5) and (3.6) are thermodynamically consistent).

3.7 Isobaric Specific Heat Capacity of the Saturated Liquid

Data for the isobaric specific heat capacity of the saturated liquid are represented by Equation (3.7).

$$c_p(l) = b_1[1 + b_2(1 - T_r)^{-2/3} + b_3(1 - T_r)^{-1/3} + b_4(1 - T_r)^{1/3}]. \quad (3.7)$$

Note: Two sets of constants are presented. The first set covers a temperature range from the melting temperature to $\leq -53^\circ\text{C}$ and the second set of constants covers a temperature range from $>-53^\circ\text{C}$ to 90°C .

The significance of $c_p(l)$ as a representation of specific heat capacity is fully explained in Appendix B, Section B.1.

3.8 Isobaric Specific Heat Capacity of the Saturated Vapour

Data for the isobaric specific heat capacity of the saturated vapour are represented by Equation (3.8).

$$c_p(g) = b_1[1 + b_2(1 - T_r)^{-2/3} + b_3(1 - T_r)^{-1/3} + b_4(1 - T_r)^{1/3} + b_5(1 - T_r)^{2/3}]. \quad (3.8)$$

The significance of $c_p(g)$ as a representation of specific heat capacity is fully explained in Appendix B, Section B.1.

3.9 Specific Heat Capacity at Saturation of the Saturated Liquid

Data for the specific heat capacity at saturation of the saturated liquid are represented by Equation (3.9).

$$c_{\text{sat}}(l) = b_1[1 + b_2(1 - T_r)^{-2/3} + b_3(1 - T_r)^{-1/3} + b_4(1 - T_r)^{1/3}]. \quad (3.9)$$

Note: Two sets of constants are presented. The first set covers a temperature range from the melting temperature to $\leq -53^\circ\text{C}$ and the second set of constants covers a temperature range from $>-53^\circ\text{C}$ to 90°C .

The significance of $c_{\text{sat}}(l)$ as a representation of specific heat capacity at saturation is fully explained in Appendix B, Section B.1.

3.10 Dynamic Viscosity of the Saturated Liquid

Data for the dynamic viscosity of the saturated liquid are represented by Equation (3.10).

$$\log_e \eta(l) = b_1 + b_2 \left(\frac{1}{T_r} - 1 \right)^{1/3} + b_3 \left(\frac{1}{T_r} - 1 \right)^{4/3} + b_4 \left(\frac{1}{T_r} - 1 \right)^{7/3}. \quad (3.10)$$

3.11 Dynamic Viscosity of the Saturated Vapour

Data for the dynamic viscosity of the saturated vapour are represented by Equation (3.11).

$$\log_e \eta(g) = b_1 + b_2 \left(\frac{1}{T_r} - 1 \right)^{1/3} + b_3 \left(\frac{1}{T_r} - 1 \right)^{4/3} + b_4 \left(\frac{1}{T_r} - 1 \right)^{7/3}. \quad (3.11)$$

3.12 Thermal Conductivity of the Saturated Liquid

Data for the thermal conductivity of the saturated liquid are represented by Equation (3.12).

$$\lambda(l) = b_1 [1 + b_2 (1 - T_r)^{1/3} + b_3 (1 - T_r)^{2/3} + b_4 (1 - T_r)]. \quad (3.12)$$

3.13 Thermal Conductivity of the Saturated Vapour

Data for the thermal conductivity of the saturated vapour are represented by Equation (3.13).

$$\log_e \lambda(g) = b_1 + b_2 (1 - T_r)^{-2/3} + b_3 (1 - T_r)^{-1/3} + b_4 (1 - T_r)^{1/3} + b_5 (1 - T_r)^{2/3}. \quad (3.13)$$

3.14 Surface Tension

Data for surface tension are represented by Equation (3.14).

$$\sigma = b_1 (1 - T_r)^{b_2} [1 + b_3 (1 - T_r)]. \quad (3.14)$$

4. EXPLANATION OF THE TABLES AND FIGURES

Table 6.1 provides values of the physical constants and constants for use in the equations given in Section 3, that represent the fluid properties in the SI units* of the Notation, Section 2. The values derived from the equations, Tables 6.2 and 6.3, are presented from the melting temperature to 363.15 K.

The data used in developing the constants of the equations are those considered to be the best available and the equations themselves introduce no significant fitting errors. For some properties, however, where experimental data are few or lacking, it has been necessary to estimate values for the Tables and these are indicated by the use of parentheses. For example, the tabulated values of vapour thermal conductivity have been calculated at specific values of temperature and pressure from a single representative equation as a function of density and temperature; the values of the thermodynamic properties necessary for this calculation have been obtained from Derivation 5. For vapour viscosity, values have been generated from semi-theoretical calculations.

* Appendix A gives conversion factors to other units.

Although the saturated liquid and vapour enthalpies tend to the same value as the critical point is approached, the saturated liquid enthalpy values calculated from Equation (3.4) pass through a physically unrealistic maximum at some value of reduced temperature below unity. Also modern theory requires the isobaric heat capacity, viscosity and thermal conductivity to tend to infinity as the critical point is approached; this theoretical limit has been included where appropriate in Table 6.3. However, Equations (3.10), (3.11) and (3.12) do not conform with theory in this respect as they approach a finite value at the critical temperature. Although the remaining equations, Equations (3.1), (3.2), (3.3), (3.5), (3.7), (3.8), (3.9), (3.13) and (3.14) extrapolate in a physically realistic manner, users should not extrapolate any of the equations in Section 3 outside the temperature limits specified in Table 6.1.

The variation with temperature of all the fluid properties is shown in Figures 1 to 7. The dashed lines show the extrapolated behaviour of some of these equations between 90 K and the critical temperature.

The specific enthalpies of vaporisation in column 7 were calculated directly from Equation (3.5) with subsequent rounding to the desired number of significant figures. Small differences, usually in the last figure may occur therefore, between these values and those obtained by subtraction of the specific enthalpies there in column 5 from those in column 6, since the values generated thereby are the differences between two rounded numbers.

5. DERIVATION

The Derivation lists selected sources that have assisted in the preparation of this Data Item.

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