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Thermophysical properties of nitrous oxide

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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:

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THERMOPHYSICAL PROPERTIES OF NITROUS OXIDE

CONTENTS

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THERMOPHYSICAL PROPERTIES OF NITROUS OXIDE

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 nitrous oxide 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 27 kelvin of the critical temperature. The properties of the ideal and dilute gas are given for temperatures from 182.33 to 1000 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 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, $(T - 273.15)$	ºC
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 µN 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/m^2 (b_4); Equation (4.10), µN s/m^2 (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), µN s/m^2 (all); Equation (4.17), mW/m K (all).

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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, *e.g.* $T_r = T/T_c$
sat	value at saturation (defined in Appendix B, Section B1)
v	value at constant volume
vap	denotes evaporation.

3. THERMOPHYSICAL PROPERTIES

A computer software package, codename 'LOADER', developed by the National Engineering Laboratory (Derivation 22) 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 evaluated by the relationship defined in Appendix B, Section B1.

The tables, Tables 7.1 to 7.5 are derived from Equations (4.1) to (4.17), which were fitted to values derived from the following data sources:

Physical constants	Derivation 19
Vapour pressure	Derivations 10, 11, 13, 14
Density of the saturated liquid	Derivations 11, 13, 16
Density of the saturated vapour	Derivations 11, 13
Latent heat of vaporisation	Derivations 10, 13
Specific heat capacity of the saturated liquid	Derivations 9, 23
Viscosity of the saturated liquid	Derivation 23
Thermal conductivity of the saturated liquid	Derivations 15, 18
Surface tension of the liquid	Derivation 17
Specific heat capacity of the ideal gas	Derivation 25
Viscosity of the dilute gas	Derivations 12, 20, 21
Thermal conductivity of the dilute gas	Derivation 24.

4. EQUATIONS FOR PROPERTIES

4.1 Vapour Pressure

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

$$\log_e\left(\frac{p}{p_c}\right) = \frac{1}{T_r}[b_1(1-T_r)+b_2(1-T_r)^{3/2}+b_3(1-T_r)^{5/2}+b_4(1-T_r)^5]. \quad (4.1)$$

4.2 Density of the Saturated Liquid

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

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

4.3 Density of the Saturated Vapour

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

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

4.4 Specific Enthalpy of the Saturated Liquid

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

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

4.5 Latent Heat of Vaporisation (Specific Enthalpy of Vaporisation)

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

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

4.6 Specific Enthalpy of the Saturated Vapour

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

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

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).

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

The significance of $c_p(\mathrm{l})$ 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).

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

The significance of $c_p(\mathrm{g})$ 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).

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

where $\theta = (T_\mathrm{c} - b_3)/(T - b_3)$.

4.10 Dynamic Viscosity of the Saturated Vapour

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

$$\log_\mathrm{e} \eta(\mathrm{g}) = b_1 + b_2\left(\frac{1}{T_\mathrm{r}} - 1\right)^{1/3} + b_3\left(\frac{1}{T_\mathrm{r}} - 1\right)^{4/3}. \quad (4.10)$$

4.11 Thermal Conductivity of the Saturated Liquid

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

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

4.12 Thermal Conductivity of the Saturated Vapour

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

$$\log_\mathrm{e} \lambda(\mathrm{g}) = b_1 + b_2(1 - T_\mathrm{r})^{-2/3} + b_3(1 - T_\mathrm{r})^{-1/3} + b_4(1 - T_\mathrm{r})^{1/3} + b_5(1 - T_\mathrm{r})^{2/3}. \quad (4.12)$$

4.13 Surface Tension

Data for surface tension are represented by Equation (4.13).

$$\sigma = b_1(1 - T_\mathrm{r})^{b_2}[1 + b_3(1 - T_\mathrm{r})]. \quad (4.13)$$

4.14 Isobaric Specific Heat Capacity of the Ideal Gas

Data for the isobaric specific heat capacity of the ideal gas are represented by Equation (4.14).

$$c_p^{\mathrm{id}}(\mathrm{g}) = b_1 + b_2 T_\mathrm{r}^{-1/2} + b_3 T_\mathrm{r}^{1/2} + b_4 T_\mathrm{r}. \quad (4.14)$$

4.15 Specific Enthalpy of the Ideal Gas

Data for the specific enthalpy of the ideal gas are represented by Equation (4.15).

$$h^{\mathrm{id}}(\mathrm{g}) = b_1 + b_2 T_{\mathrm{r}}^{1/2} + b_3 T_{\mathrm{r}} + b_4 T_{\mathrm{r}}^{3/2} + b_5 T_{\mathrm{r}}^2 . \qquad (4.15)$$

(Equations (4.14) and (4.15) are thermodynamically consistent.)

4.16 Dynamic Viscosity of the Dilute Gas

Data for the dynamic viscosity of the dilute gas are represented by Equation (4.16).

$$\eta^{(\mathrm{o})}(\mathrm{g}) = b_1 + b_2 T_{\mathrm{r}} + b_3 T_{\mathrm{r}}^2 + b_4 T_{\mathrm{r}}^3 . \qquad (4.16)$$

4.17 Thermal Conductivity of the Dilute Gas

Data for the thermal conductivity of the dilute gas are represented by Equation (4.17).

$$\lambda^{(\mathrm{o})}(\mathrm{g}) = b_1 + b_2(1 - T_{\mathrm{r}}) + b_3(1 - T_{\mathrm{r}})^2 + b_4(1 - T_{\mathrm{r}})^3 . \qquad (4.17)$$

5. EXPLANATION OF THE TABLES

Table 7.1 provides values of the physical constants and constants for use in the equations given in Section 4, that represent the fluid properties in the SI units* of the Notation, Section 2. Although the saturated liquid and vapour enthalpies tend to the same value as the critical point is approached, the slope of the saturated liquid enthalpy curve, Equation (4.4) tends to $-\infty$, not ∞ as required. 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 Tables 7.2 and 7.3. However, Equations (4.9), (4.10), (4.11) and (4.12) do not conform with theory in this respect; Equations (4.9), (4.10) and (4.11) approach a finite value and Equation (4.12) goes to zero at the critical temperature. Although the remaining equations, Equations (4.1), (4.2), (4.3), (4.5), (4.6), (4.7), (4.8) and (4.13), applying on the saturation line extrapolate in a physically realistic manner, users should not extrapolate any of the equations in Section 4 outside the temperature limits specified in Table 7.1.

The values derived from the equations applying on the saturation line, Tables 7.2 and 7.3, are presented from the melting temperature to approximately $T_{\mathrm{r}} = 0.98$, except for Equations (4.11) and (4.12) which terminate at $T_{\mathrm{r}} = 0.90$, and Equations (4.1), (4.2), (4.3), (4.6) and (4.13) which are valid to the critical temperature. The specific enthalpy values are calculated on the basis that the enthalpy of the ideal gas is zero at 298.15 K.

The specific enthalpies of vaporisation in column 7 of Tables 7.2 and 7.3 were calculated directly from Equation (4.5) 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 in column 5 from those in column 6, since the values generated thereby are the differences between two rounded numbers.

Tables 7.4 and 7.5 present values for the ideal and dilute gas from 182.33 to 1000 K.

Parentheses are used in all the tables to indicate the values not directly supported by experimental data.

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* Appendix A gives conversion factors to other units.

6. REFERENCES AND DERIVATION

References

The references given are recommended sources of information supplementary to that in this Data Item.

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Derivation

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

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7. TABLES

N_2O NITROUS OXIDE
CAS Reg. No: 10024-97-2

TABLE 7.1 Physical constants of nitrous oxide and constants for Equation (4.1) to (4.17)

Physical Constants	*Symbol*	*Value*	
Molecular Weight	M	44.013	
Critical Temperature	T_c	309.57 K	(36.42 °C)
Critical Pressure	p_c	7251. kPa	
Critical Density	ρ_c	452. kg/m^3	
Critical Molar Volume	V_c	97. cm^3/mol	
Normal Boiling Temperature	T_b	184.69 K	(-88.46 °C)
Normal Melting Temperature	T_m	182.33 K	(-90.82 °C)
Acentric Factor	ω	0.160	

Constants used in Equations (4.1) to (4.13)

Property	Equation in Section 4	b_1	b_2	b_3	b_4	b_5	Range of Applicability °C		
p	(4.1)	-6.71893	1.35966	-1.3779	-4.051	-	-90	to	36
ρ(l)	(4.2)	1.72328	-0.83950	0.51060	-0.10412	-	-90	to	36
ρ(g)	(4.3)	-1.00900	-6.28792	7.50332	-7.90463	0.629427	-90	to	36
h(l)	(4.4)	-200.	116.043	-917.225	794.779	-589.587	-90	to	35
h(g)	(4.6)	-200.	440.055	-459.701	434.081	-485.338	-90	to	36
c_p(l)	(4.7)	2.49973	0.023454	-3.80136	13.0945	-14.5180	-90	to	30
c_p(g)	(4.8)	132.632	0.052187	-0.364923	-1.20233	0.536141	-90	to	30
η(l)	(4.9)	1.6089	2.0439	5.24	0.0293423	-	-90	to	30
η(g)	(4.10)	3.3281	-1.18237	-0.055155	-	-	-90	to	30
λ(l)	(4.11)	72.35	1.5	-3.5	4.5	-	-90	to	10
λ(g)	(4.12)	-7.08870	-0.276962	2.88672	16.6116	-11.8221	-90	to	10
σ	(4.13)	69.31	1.19346	0	-	-	-90	to	36

Constants used in Equations (4.14) to (4.17)

Property	Equation in Section 4	b_1	b_2	b_3	b_4	b_5	Range of Applicability °C		
c_p^{id}(g)	(4.14)	-0.169903	0.099053	1.20822	-0.248324	-	-90	to	727
h^{id}(g)	(4.15)	-209.559	61.3277	-52.5969	249.352	-38.4368	-90	to	727
$\eta^{(o)}$(g)	(4.16)	-0.955565	18.8315	-2.34589	0.164927	-	-90	to	727
$\lambda^{(o)}$(g)	(4.17)	18.32	-24.84	-0.09	0.06	-	-90	to	727

TABLE 7.2
Thermophysical properties of nitrous oxide on the saturation line for temperature in degree Celsius

t °C	*p* kPa	ρ(l) kg/m^3	ρ(g) kg/m^3	*h*(l) kJ/kg	*h*(g) kJ/kg	$\Delta_{vap}h$ kJ/kg
-90.82	(87.73)	1222.8	(2.613)	(-474.)	(-96.8)	(377.)
-90	(92.29)	1220.6	(2.738)	(-473.)	(-96.3)	(377.)
-88.46	101.325	1216.3	(2.987)	(-470.)	(-95.4)	375.
-85	124.2	(1206.7)	(3.609)	(-464.)	(-93.3)	371.
-80	164.2	(1192.7)	(4.680)	(-455.)	(-90.4)	365.
-75	213.6	(1178.3)	(5.982)	(-446.)	(-87.6)	359.
-70	273.6	(1163.7)	(7.546)	(-438.)	(-85.0)	353.
-65	345.7	(1148.8)	(9.406)	(-429.)	(-82.5)	346.
-60	431.5	(1133.6)	(11.60)	(-420.)	(-80.2)	340.
-55	532.3	(1118.0)	(14.16)	(-411.)	(-78.1)	333.
-50	649.9	(1102.0)	(17.14)	(-402.)	(-76.1)	326.
-45	785.8	(1085.6)	(20.58)	(-392.)	(-74.4)	318.
-40	941.7	(1068.8)	(24.53)	(-383.)	(-72.9)	310.
-35	1119.	(1051.4)	(29.05)	(-374.)	(-71.6)	302.
-30	1321.	1033.4	34.22	(-364.)	(-70.5)	294.
-25	1547.	1014.8	40.11	(-355.)	(-69.8)	285.
-20	1801.	995.4	46.82	(-345.)	(-69.3)	276.
-15	2083.	975.2	54.47	(-335.)	(-69.2)	266.
-10	2397.	953.9	63.21	(-325.)	(-69.5)	255.
-5	2744.	931.4	73.26	(-315.)	(-70.3)	244.
0	3127.	907.4	84.86	(-304.)	(-71.7)	232.
5	3547.	881.6	98.41	(-293.)	(-73.7)	219.
10	4007.	853.5	114.5	(-281.)	(-76.6)	204.
15	4510.	822.2	133.9	(-269.)	(-80.6)	188.
20	5060.	786.6	158.1	(-255.)	(-86.2)	169.
25	5660.	743.9	190.0	(-241.)	(-94.4)	147.
30	6315.	688.0	236.7	(-224.)	(-108.)	117.
35	7033.	589.4	330.4	(-203.)	(-138.)	64.9
36.42	7251.	452.	452.	(-200.)	(-200.)	0

TABLE 7.2 (concluded)
Thermophysical properties of nitrous oxide on the saturation line for temperature in degree Celsius

t °C	c_p(l) kJ/kg K	c_p(g) kJ/kg K	η(l) mN s/m²	η(g) μN s/m²	λ(l) mW/m K	λ(g) mW/m K	σ mN/m
-90.82	1.747	(0.7999)	(0.4619)	(9.4)	(146.9)	(8.2)	24.0
-90	1.750	(0.7997)	(0.4507)	(9.5)	(146.4)	(8.3)	23.8
-88.46	1.756	(0.7996)	(0.4306)	(9.6)	(145.6)	(8.4)	(23.5)
-85	1.768	(0.8009)	(0.3900)	(9.7)	(143.8)	(8.7)	(22.7)
-80	(1.781)	(0.8063)	(0.3404)	(10.0)	(141.2)	(9.1)	(21.6)
-75	(1.791)	(0.8160)	(0.2995)	(10.2)	(138.6)	(9.6)	(20.5)
-70	(1.798)	(0.8300)	(0.2654)	(10.5)	(136.0)	(10.0)	(19.4)
-65	(1.803)	(0.8485)	(0.2367)	(10.8)	(133.5)	(10.5)	(18.3)
-60	(1.807)	(0.8716)	(0.2123)	(11.0)	(131.0)	(11.0)	(17.2)
-55	(1.812)	(0.8995)	(0.1915)	(11.3)	(128.5)	(11.5)	(16.2)
-50	(1.818)	(0.9322)	(0.1736)	(11.6)	(126.0)	(12.0)	15.1
-45	(1.827)	(0.9700)	(0.1580)	(11.9)	(123.6)	(12.6)	14.1
-40	(1.840)	(1.013)	(0.1444)	(12.2)	(121.2)	(13.2)	13.1
-35	(1.858)	(1.061)	(0.1325)	(12.5)	(118.8)	(13.8)	12.0
-30	(1.883)	(1.115)	(0.1219)	(12.8)	(116.4)	(14.4)	11.0
-25	(1.915)	(1.176)	(0.1125)	(13.2)	(114.1)	(15.1)	10.1
-20	(1.957)	(1.243)	(0.1041)	(13.5)	(111.8)	(15.8)	9.1
-15	(2.011)	(1.318)	(0.0965)	(13.9)	(109.6)	(16.5)	8.1
-10	(2.079)	(1.402)	(0.0896)	(14.3)	(107.4)	(17.3)	7.2
-5	(2.166)	(1.500)	(0.0833)	(14.7)	(105.2)	(18.2)	6.3
0	(2.274)	(1.618)	(0.0774)	(15.2)	103.0	(19.1)	5.4
5	(2.412)	(1.769)	(0.0720)	(15.7)	100.9	(20.2)	4.5
10	(2.592)	(1.982)	(0.0668)	(16.3)	98.8	(21.4)	3.7
15	(2.834)	(2.322)	(0.0619)	(16.9)			2.9
20	(3.188)	(2.967)	(0.0570)	(17.7)			2.1
25	(3.781)	(4.493)	(0.0520)	(18.7)			1.4
30	(5.143)	(9.718)	(0.0465)	(20.1)			0.7
35							0.1
36.42	∞	∞	∞	∞	∞	∞	0

TABLE 7.3
Thermophysical properties of nitrous oxide on the saturation line for temperature in kelvin

T K	p kPa	ρ(l) kg/m^3	ρ(g) kg/m^3	h(l) kJ/kg	h(g) kJ/kg	$\Delta_{vap}h$ kJ/kg
182.33	(87.73)	1222.8	(2.613)	(-474.)	(-96.8)	(377.)
184.69	101.325	1216.3	(2.987)	(-470.)	(-95.4)	375.
185	103.2	(1215.5)	(3.039)	(-470.)	(-95.2)	374.
190	138.0	(1201.6)	(3.980)	(-461.)	(-92.2)	369.
195	181.3	(1187.4)	(5.133)	(-452.)	(-89.3)	363.
200	234.5	(1172.9)	(6.528)	(-443.)	(-86.6)	357.
205	298.8	(1158.2)	(8.198)	(-434.)	(-84.0)	350.
210	375.8	(1143.2)	(10.18)	(-425.)	(-81.6)	344.
215	466.9	(1127.8)	(12.50)	(-416.)	(-79.4)	337.
220	573.8	(1112.1)	(15.21)	(-407.)	(-77.3)	330.
225	698.0	(1096.0)	(18.36)	(-398.)	(-75.5)	323.
230	841.1	(1079.5)	(21.98)	(-389.)	(-73.8)	315.
235	1005.	(1062.4)	(26.13)	(-380.)	(-72.3)	307.
240	1191.	(1044.8)	(30.89)	(-370.)	(-71.1)	299.
245	1401.	1026.6	36.31	(-361.)	(-70.2)	291.
250	1638.	1007.7	42.49	(-351.)	(-69.6)	282.
255	1902.	988.0	49.53	(-341.)	(-69.2)	272.
260	2196.	967.4	57.57	(-331.)	(-69.3)	262.
265	2522.	945.7	66.77	(-321.)	(-69.8)	251.
270	2881.	922.7	77.35	(-311.)	(-70.7)	240.
275	3278.	898.1	89.62	(-300.)	(-72.3)	227.
280	3712.	871.5	104.0	(-288.)	(-74.6)	214.
285	4188.	842.3	121.2	(-277.)	(-77.9)	199.
290	4708.	809.7	142.1	(-264.)	(-82.4)	182.
295	5276.	771.8	168.8	(-250.)	(-88.9)	161.
300	5896.	725.3	204.9	(-235.)	(-98.5)	137.
305	6573.	660.5	261.5	(-217.)	(-115.)	102.
309.57	7251.	452.	452.	(-200.)	(-200.)	0

TABLE 7.3 (concluded)
Thermophysical properties of nitrous oxide on the saturation line for temperature in kelvin

T K	c_p(l) kJ/kg K	c_p(g) kJ/kg K	η(l) mN s/m^2	η(g) µN s/m^2	λ(l) mW/m K	λ(g) mW/m K	σ mN/m
182.33	1.747	(0.7999)	(0.4619)	(9.4)	(146.9)	(8.2)	24.0
184.69	1.756	(0.7996)	(0.4306)	(9.6)	(145.6)	(8.4)	(23.5)
185	1.757	(0.7997)	(0.4267)	(9.6)	(145.5)	(8.4)	(23.4)
190	(1.773)	(0.8024)	(0.3705)	(9.8)	(142.8)	(8.9)	(22.3)
195	(1.785)	(0.8094)	(0.3244)	(10.1)	(140.2)	(9.3)	(21.2)
200	(1.794)	(0.8206)	(0.2861)	(10.3)	(137.6)	(9.7)	(20.1)
205	(1.800)	(0.8363)	(0.2542)	(10.6)	(135.1)	(10.2)	(19.0)
210	(1.804)	(0.8565)	(0.2272)	(10.9)	(132.6)	(10.7)	(17.9)
215	(1.809)	(0.8813)	(0.2042)	(11.1)	(130.0)	(11.2)	(16.8)
220	(1.814)	(0.9110)	(0.1846)	(11.4)	(127.6)	(11.7)	(15.8)
225	(1.821)	(0.9456)	(0.1676)	(11.7)	(125.1)	(12.2)	14.7
230	(1.832)	(0.9853)	(0.1528)	(12.0)	(122.7)	(12.8)	13.7
235	(1.846)	(1.030)	(0.1399)	(12.3)	(120.3)	(13.4)	12.7
240	(1.866)	(1.081)	(0.1284)	(12.6)	(117.9)	(14.0)	11.7
245	(1.894)	(1.137)	(0.1183)	(12.9)	(115.6)	(14.7)	10.7
250	(1.929)	(1.200)	(0.1093)	(13.3)	(113.3)	(15.3)	9.7
255	(1.976)	(1.269)	(0.1012)	(13.7)	(111.0)	(16.1)	8.7
260	(2.035)	(1.348)	(0.0939)	(14.0)	(108.7)	(16.8)	7.8
265	(2.109)	(1.437)	(0.0872)	(14.4)	(106.5)	(17.6)	6.9
270	(2.203)	(1.541)	(0.0810)	(14.9)	(104.4)	(18.5)	6.0
275	(2.321)	(1.669)	(0.0754)	(15.4)	102.2	(19.5)	5.1
280	(2.473)	(1.838)	(0.0700)	(15.9)	100.1	(20.6)	4.2
285	(2.672)	(2.087)	(0.0650)	(16.5)			3.4
290	(2.948)	(2.509)	(0.0601)	(17.2)			2.6
295	(3.367)	(3.369)	(0.0552)	(18.1)			1.8
300	(4.133)	(5.642)	(0.0501)	(19.2)			1.1
305							0.5
309.57	∞	∞	∞	∞	∞	∞	0

TABLE 7.4
Thermophysical properties of nitrous oxide in the ideal and dilute gas for temperature in degree Celsius

	Ideal gas		Dilute gas	
t °C	c_p^{id}(g) kJ/kg K	h^{id}(g) kJ/kg	$\eta^{(o)}$(g) μN s/m²	$\lambda^{(o)}$(g) mW/m K
-90.82	(0.7402)	(-94.1)	(9.356)	8.099
-80	0.7549	(-86.0)	9.921	8.969
-60	0.7810	(-70.6)	10.95	10.58
-40	0.8057	(-54.8)	11.97	12.18
-20	0.8292	(-38.4)	12.97	13.79
0	0.8514	(-21.6)	13.95	15.40
20	0.8725	(-4.38)	14.91	17.00
25	0.8776	0	15.15	17.40
40	0.8926	(13.3)	15.86	18.61
60	0.9117	(31.3)	16.80	20.21
80	0.9300	(49.7)	17.72	21.81
100	0.9475	(68.5)	18.62	23.42
120	0.9642	(87.6)	19.51	25.02
140	0.9802	(107.)	20.39	26.62
160	0.9956	(127.)	21.25	28.22
180	1.010	(147.)	22.10	29.82
200	1.024	(167.)	22.94	31.41
220	1.038	(188.)	23.76	33.01
240	1.051	(209.)	24.57	34.60
260	1.063	(230.)	25.36	36.19
280	1.076	(251.)	26.14	37.78
300	1.087	(273.)	26.92	39.37
320	1.098	(295.)	27.67	40.95
340	1.109	(317.)	28.42	42.54
360	1.119	(339.)	29.16	44.12
380	1.129	(362.)	29.88	45.70
400	1.139	(384.)	30.60	47.27
420	1.148	(407.)	31.30	48.85
440	1.157	(430.)	31.99	50.42
460	1.166	(453.)	32.68	51.99
480	1.174	(477.)	33.35	53.55
500	1.182	(500.)	34.01	55.11
520	1.190	(524.)	34.67	56.67
540	1.197	(548.)	35.31	58.23
560	1.204	(572.)	35.95	59.78
580	1.211	(596.)	36.58	61.33
600	1.218	(620.)	37.20	62.88
620	1.224	(645.)	37.81	64.42
640	1.230	(669.)	38.41	65.96
660	1.236	(694.)	39.01	67.50
680	1.242	(719.)	39.60	69.03
700	1.248	(744.)	40.18	70.56
720	1.253	(769.)	40.76	72.09

TABLE 7.5
Thermophysical properties of nitrous oxide in the ideal and dilute gas for temperature in kelvin

	Ideal gas		Dilute gas	
T K	$c_p^{id}(g)$ kJ/kg K	$h^{id}(g)$ kJ/kg	$\eta^{(o)}(g)$ μN s/m^2	$\lambda^{(o)}(g)$ mW/m K
182.33	(0.7402)	(-94.1)	(9.356)	8.099
200	0.7640	(-80.8)	10.28	9.519
220	0.7897	(-65.3)	11.30	11.13
240	0.8139	(-49.2)	12.31	12.73
260	0.8369	(-32.7)	13.30	14.34
280	0.8587	(-15.8)	14.28	15.95
298.15	0.8776	0	15.15	17.40
300	0.8795	(1.62)	15.24	17.55
320	0.8992	(19.4)	16.19	19.16
340	0.9181	(37.6)	17.12	20.76
360	0.9361	(56.1)	18.03	22.36
380	0.9533	(75.0)	18.93	23.97
400	0.9698	(94.3)	19.82	25.57
420	0.9855	(114.)	20.69	27.17
440	1.001	(134.)	21.54	28.77
460	1.015	(154.)	22.39	30.36
480	1.029	(174.)	23.22	31.96
500	1.042	(195.)	24.04	33.55
520	1.055	(216.)	24.84	35.14
540	1.068	(237.)	25.63	36.74
560	1.080	(259.)	26.41	38.32
580	1.091	(280.)	27.18	39.91
600	1.102	(302.)	27.93	41.50
620	1.113	(324.)	28.68	43.08
640	1.123	(347.)	29.41	44.66
660	1.133	(369.)	30.13	46.24
680	1.142	(392.)	30.84	47.81
700	1.151	(415.)	31.54	49.38
720	1.160	(438.)	32.23	50.96
740	1.169	(461.)	32.91	52.52
760	1.177	(485.)	33.58	54.09
780	1.185	(509.)	34.24	55.65
800	1.192	(532.)	34.89	57.21
820	1.200	(556.)	35.53	58.76
840	1.207	(580.)	36.17	60.32
860	1.213	(604.)	36.79	61.86
880	1.220	(629.)	37.41	63.41
900	1.226	(653.)	38.02	64.95
920	1.232	(678.)	38.62	66.49
940	1.238	(703.)	39.21	68.03
960	1.244	(727.)	39.80	69.56
980	1.249	(752.)	40.38	71.08
1000	1.255	(777.)	40.96	72.61

APPENDIX A CONVERSION FACTORS

To convert from	to	multiply by
Pressure in kPa (kN/m^2)	Pressure in Pa	10^3
	Pressure in bar	10^{-2}
	Pressure in atm	$9.869\,233 \times 10^{-3}$
	Pressure in kgf/cm^2	$10.197\,16 \times 10^{-3}$
	Pressure in lbf/in^2	$145.037\,7 \times 10^{-3}$
	Pressure in mmHg	7.500 617
Density in kg/m^3	Density in g/cm^3	10^{-3}
	Density in lb/ft^3	62.428×10^{-3}
Specific enthalpy in kJ/kg	Specific enthalpy in cal/g*	238.846×10^{-3}
	Specific enthalpy in Btu/lb*	429.923×10^{-3}
Specific heat capacity in kJ/kg K	Specific heat capacity in cal/g K*	238.846×10^{-3}
	Specific heat capacity in Btu/lb °F*	238.846×10^{-3}
Dynamic viscosity in μN s/m^2	Dynamic viscosity in N s/m^2	10^{-6}
	Dynamic viscosity in poise or g/cm s	10^{-5}
	Dynamic viscosity in kg/m s	10^{-6}
	Dynamic viscosity in lb/ft h	$2.419\,09 \times 10^{-3}$
	Dynamic viscosity in kgf s/m^2	101.972×10^{-9}
	Dynamic viscosity in lbf s/in^2	145.038×10^{-12}
Dynamic viscosity in mN s/m^2	Dynamic viscosity in N s/m^2	10^{-3}
	Dynamic viscosity in poise or g/cm s	10^{-2}
	Dynamic viscosity in kg/m s	10^{-3}
	Dynamic viscosity in lb/ft h	2.419 09
	Dynamic viscosity in kgf s/m^2	101.972×10^{-6}
	Dynamic viscosity in lbf s/in^2	145.038×10^{-9}
Thermal conductivity in mW/m K	Thermal conductivity in W/m K	10^{-3}
	Thermal conductivity in J/cm s K	10^{-5}
	Thermal conductivity in kcal/m h K*	859.845×10^{-6}
	Thermal conductivity in cal/cm s K*	$2.388\,46 \times 10^{-6}$
	Thermal conductivity in Btu/ft h °F*	577.789×10^{-6}
	Thermal conductivity in Btu in/ft^2 h °F*	$6.933\,47 \times 10^{-3}$
Surface tension in mN/m	Surface tension in N/m	10^{-3}
	Surface tension in J/m^2	10^{-3}
	Surface tension in dyn/cm	1
	Surface tension in erg/cm^2	1
	Surface tension in lbf/ft	68.52×10^{-6}

* Note: the values used for the calorie and British Thermal Unit are International Table values.

APPENDIX B

B1. SPECIFIC HEAT CAPACITIES OF SATURATED LIQUIDS AND VAPOURS

In addition to the constant pressure and constant volume specific heat capacities, there is another specific heat capacity which relates to the saturation line conditions of either phase.

The thermodynamic definitions of the three specific heat capacities are:

$$c_p = \left(\frac{\partial h}{\partial T}\right)_p , \tag{B1.1}$$

$$c_v = \left(\frac{\partial u}{\partial T}\right)_v , \tag{B1.2}$$

and

$$c_{sat} = c_p - T\left(\frac{\partial v}{\partial T}\right)_p\left(\frac{dp}{dT}\right)_{sat} , \tag{B1.3}$$

where c_p and c_v represent respectively the change in specific enthalpy with temperature at constant pressure and the change in specific internal energy with temperature at constant volume (the values commonly used in engineering design calculations), and

c_{sat} is not $(\partial h/\partial T)_{sat}$ but is the specific energy required to effect a temperature change while maintaining the fluid in a saturated state, and is the specific heat capacity commonly measured.

The three specific heat capacities are inter-related as follows:

$$c_p = c_v + T\left(\frac{\partial v}{\partial T}\right)_p\left(\frac{\partial p}{\partial T}\right)_v , \tag{B1.4}$$

$$\left(\frac{dh}{dT}\right)_{sat} = c_p + \left[v - T\left(\frac{\partial v}{\partial T}\right)_p\right]\left(\frac{dp}{dT}\right)_{sat} , \tag{B1.5}$$

$$\left(\frac{dh}{dT}\right)_{sat} = c_{sat} + v\left(\frac{dp}{dT}\right)_{sat} , \tag{B1.6}$$

where $(dp/dT)_{sat}$ represents the change in vapour pressure with temperature.

In practice, the specific heat capacity at saturation conditions cannot be measured by a constant pressure process since a phase change would accompany an energy input and the specific enthalpy of vaporisation and not the specific heat capacity would be determined. For the liquid phase, the specific heat capacities c_p and c_{sat} are in close numerical agreement at low reduced temperatures and differences can usually be neglected. For the saturated vapour, the difference between c_p and c_{sat} should not be ignored.

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ESDU 91022 provides evaluated thermophysical properties data for nitrous oxide. Equations, based on a critical evaluation of experimental data in the literature are given for the variation with temperature along the saturation line for the following liquid and vapour properties: density, specific enthalpy, specific heat capacity at constant pressure, dynamic viscosity and thermal conductivity. Also given are equations for the variation with temperature along the saturation line of the vapour pressure, latent heat of vaporisation and surface tension. Also presented are equations for the variation with temperature of the specific heat capacity at constant pressure and specific enthalpy in the ideal gas, the dilute gas dynamic viscosity and the dilute gas thermal conductivity.

Saturation line properties in SI units, calculated from the equations are tabulated at 5 K intervals and at 5 degree Celsius intervals from the melting temperature to the critical temperature for the vapour pressure, saturation densities, enthalpies and surface tension and to within at least 27 kelvin of the critical temperature for the remainder. Ideal and dilute gas properties, also in SI units calculated from the equations are tabulated at 20 K and at 20 degree Celsius intervals from the melting temperature to 1000 K. In the absence of experimental data, the tabulated data are extrapolated values and these are indicated in the tables. Conversion factors to facilitate use of the equations and tables in British units are included.

A full bibliography is given of the sources consulted.

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