

Nitrous Oxide

23.1. PHYSICAL CONSTANTS

Nitrous oxide is a colorless, relatively nonreactive gas at ambient conditions. It supports combustion at sufficiently high temperatures. It is soluble in alcohol and ether and, to a lesser extent, in water. The most common method of preparation of the compound is by the decomposition of ammonium nitrate, although it can be formed by the controlled reduction of nitrates or nitrites. An asphyxiating gas, its main uses are as an anaesthetic, as an aerosol propellant, as a foaming agent, and in leak detection.

TABLE 23.1. PHYSICAL CONSTANTS OF NITROUS OXIDE

Chemical Formula	N ₂ O
Molecular Weight	44 kg [1]
Normal Melting Point (NMP)	182.3 K [2]
Heat of Fusion (at NMP)	148.6 kJ kg ⁻¹
Vapor Pressure (at NMP)	8.78 x 10 ⁴ Pa [2]
Normal Boiling Point (NBP)	184.7 K [2]
Heat of Vaporization (at NBP)	375.5 kJ kg ⁻¹
Critical Temperature	309.6 K [2]
Critical Pressure	7.24 x 10 ⁶ Pa [2]
Critical Compressibility Factor	0.274 [2]
Density (at 1 bar, 273.15 K)	1.978 kg m ⁻³

23.2. SPECIFIC HEAT AT CONSTANT PRESSURE

In an analysis of available information for the saturated liquid, Makita [3] was only able to locate one data source, that of Blue and Giauque [4] reported for temperatures from 182-187 K. These data could be represented by the linear equation

$$c_p \text{ [kJ kg}^{-1}\text{K}^{-1}] = 1.5402 + 1.2133 \times 10^{-3}T \quad (T \text{ in K})$$

to within a mean deviation of 0.10% and a maximum of 0.21%. The equation was used to generate the tabular values for which the uncertainty, lacking any independent sources, is difficult to estimate, but which may prove to be of the order of a few percent.

A similar analysis [3] for the dilute gas state located 24 data sources, of which the JANAF [5] and McBride and Gordon [6] sets were selected as basis for the recommended values. The correlation formula obtained for the ideal gas specific heat at temperatures between 100 and 1000 K is

$$c_p^0 [\text{kJ kg}^{-1} \text{K}^{-1}] = 3919.1/T^2 - 63.7157/T + 0.83098 + 8.56960 \times 10^{-4}T - 4.75302 \times 10^{-7}T^2 + 9.69822 \times 10^{-11}T^3 \quad (T \text{ in K})$$

This fitted the input values with a mean deviation of 0.10% and a maximum deviation of 0.32%. It was used to generate the recommended values, which are thought to have an uncertainty of about 1%.

Four sets [7-10] of experimental data at atmospheric pressure were located [3]. They did not cover a wide temperature range and were not analyzed by Makita [3]. However, an extensive calculation of thermodynamic functions to high pressures using an equation of state was located [11]. This only presented the enthalpy, h , as a function of pressure and temperature. Values of the specific heat at constant pressure could be obtained from the approximation $c_p = (\Delta h/\Delta T)_p$ and were obtained and plotted as functions of pressure and temperature. After appropriate unit conversion and interpolation into integral S.I. pressures and temperatures, a table was obtained for pressures from 20-100 bar. This, when extrapolated, was found to merge well with the zero pressure ideal gas values. Accordingly values at 10 bar were interpolated and the table resmoothed. Values at higher pressures than 100 bar were not derived as some inconsistencies had previously been found to occur, due to cumulative errors in the equation-of-state calculations. The uncertainty of the tabular values is difficult to estimate, as they are obtained as a derivative and, further, subject to the uncertainties of graphical smoothing. Probably 10% will be a reasonable average uncertainty estimate.

TABLE 23.2. SPECIFIC HEAT AT CONSTANT PRESSURE [$\text{kJ kg}^{-1} \text{K}^{-1}$] OF NITROUS OXIDE AS A FUNCTION OF PRESSURE AND TEMPERATURE

Temp. (K)	Pressure (bar)								
	1	10	20	30	40	50	60	80	100
270	0.85	1.02	1.22						
280	0.86	1.01	1.18	1.43					
290	0.87	1.01	1.15	1.35	1.59				
300	0.88	1.00	1.12	1.28	1.47	1.78	2.75		
310	0.89	0.99	1.09	1.23	1.38	1.62	2.08		
320	0.90	0.98	1.07	1.18	1.32	1.49	1.79		
330	0.91	0.98	1.05	1.14	1.26	1.41	1.65	2.67	
340	0.92	0.98	1.04	1.12	1.22	1.34	1.55	2.31	
350	0.93	0.98	1.03	1.10	1.18	1.28	1.46	2.09	2.61
360	0.94	0.98	1.02	1.08	1.14	1.24	1.39	1.94	2.31
370	0.94	0.98	1.02	1.06	1.12	1.21	1.33	1.82	2.07
380	0.95	0.98	1.02	1.04	1.10	1.18	1.28	1.71	1.90
390	0.96	0.99	1.02	1.04	1.09	1.16	1.24	1.60	1.74
400	0.97	1.00	1.03	1.05	1.09	1.14	1.20	1.51	1.59

©Critical point: 72 bar, 309.6 K.

TABLE 23.3. SPECIFIC HEAT AT CONSTANT PRESSURE OF NITROUS OXIDE

[Specific Heat, c_p , $\text{kJ kg}^{-1}\text{K}^{-1}$]

Saturated Liquid as a Function of Temperature		Saturated Liquid as a Function of Pressure		Dilute Gas as a Function of Temperature			
T(K)	c_p	P(bar)	c_p	T(K)	c_p	T(K)	c_p
176*	-	0.9	1.762	100	0.667	300	0.879
183	1.762	1.0	1.764	110	0.667	310	0.889
184	1.763	1.1	1.765	120	0.668	320	0.899
185	1.765	1.2	1.766	130	0.676	330	0.908
186	1.766	1.3	1.768	140	0.687	340	0.918
187	1.767	1.4	1.769	150	0.699	360	0.936
188	1.768	1.5	1.770	160	0.711	380	0.953
189	1.769	1.6	1.771	170	0.724	400	0.969
190	1.771	72.4**	-	180	0.737	420	0.985
310**	-			190	0.751	440	1.000
				200	0.764	460	1.014
				210	0.776	480	1.028
				220	0.789	500	1.041
				230	0.801	550	1.072
				240	0.813	600	1.100
				250	0.825	650	1.125
				260	0.836	700	1.148
				270	0.847	800	1.188
				280	0.858	900	1.222
				290	0.869	1000	1.250

*mp.

**Critical point.

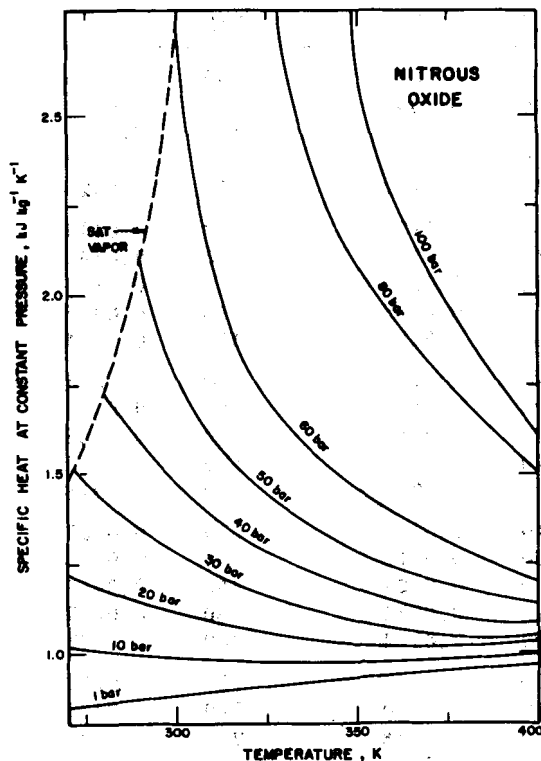


FIGURE 23.1. SPECIFIC HEAT AT CONSTANT PRESSURE OF NITROUS OXIDE.

23.3. THERMAL CONDUCTIVITY

In an extensive earlier analysis [12], 12 different experimental data sources [13-24] for the thermal conductivity of dilute, gaseous nitrous oxide were intercompared. One data set [22] was found to disagree with all other sets and so it was ignored. The data considered to be the most reliable and used as a basis were those of Johnston and Grilly [13] below about 360 K and those of Choy and Raw [24] for higher temperatures. Allowing for the possibility that the latter set might be a few percent high at the highest temperatures, a set of values was produced considered to be uncertain by about 2% at 400 K, 4% at 600 K, and possibly 10% from 800-1000 K.

Since this analysis, other studies have appeared. One is a Russian standards analysis [25] of nine data sets extending over a temperature range and also of two other sources. A table of values from 190-740 K was produced. Agreement to within 2% with the [12] values was found.

In another study [26], values were calculated from 180-900 K for pressures up to 230 bar. For the dilute gas, differences of up to 10% between the calculated and experimental values occurred. For the compressed fluid, differences between the calculations and the [22] data were within about 5% or less, but the fact that the atmospheric pressure data of [22] disagreed with all

TABLE 23.4. THERMAL CONDUCTIVITY OF NITROUS OXIDE

[Thermal Conductivity, λ , $\text{W m}^{-1}\text{K}^{-1}$]

Dilute Gas as a Function of Temperature			
T(K)	λ	T(K)	λ
190	0.0091	440	0.0293
200	0.0098	450	0.0301
210	0.0105	460	0.0309
220	0.0112	470	0.0317
230	0.0119	480	0.0325
240	0.0126	490	0.0333
250	0.0134	500	0.0341
260	0.0141	510	0.0349
270	0.0149	520	0.0357
280	0.0157	530	0.0365
290	0.0165	540	0.0373
300	0.0174	550	0.0380
310	0.0182	560	0.0388
320	0.0191	580	0.0403
330	0.0200	600	0.0418
340	0.0209	620	0.0433
350	0.0218	640	0.0448
360	0.0227	660	0.0463
370	0.0236	680	0.0477
380	0.0244	700	0.0492
390	0.0252	720	0.0507
400	0.0260	740	0.0522
410	0.0268	750	0.0529
420	0.0276		
430	0.0285		

others was noted above. So the use of their higher pressure values is questionable. Another set of measurements by the column method [27] from 50-900°C yielded differences with the [12] values of below 5%. The partial decomposition of nitrous oxide about 500°C was also noted in that paper.

With the above information as input, the choice was made to reuse the [12] values for the dilute gas in the present work. Their uncertainty is considered to be about 4% or less. However, the present tabulation is limited to temperatures below 760 K in view of the possibility of decomposition.

No tables for the saturated liquid or for the compressed fluid were prepared due to the difficulty encountered with the [22] data set.

23.4 VISCOSITY

No experimental data for the saturated liquid could be located [28]. The values tabulated here are obtained from a correlation by Yaws [29] published as a graph of the liquid viscosity as a function of temperature. An uncertainty of about 15% appears to be possible in these values.

Nine sets of experimental data for the dilute gas [30-38] were found in a survey [28] to be in reasonable agreement up to about 790 K. The possibility of chemical decomposition led to the analysis accompanying the survey [28] being limited to temperatures below 790 K. The equation η [10^{-6} Pa s] = $\sqrt{T}/(0.53469 + 293.56/T - 67545/T^2 + 1.44711 \times 10^7/T^3 - 1.12754 \times 10^9/T^4)$ (T in K) fitted the input data to a mean deviation of 0.5% and a maximum deviation of 1.9%. It was used to generate the tabular values, estimated by Tanaka [28] to have an uncertainty of about 2%.

Since Tanaka's analysis, three additional sources were noted [39-41], of which two have been examined [39,41]. Those of [39] agree to within 2% deviation, while those of [41] agree to a 1% deviation.

TABLE 23.5. VISCOSITY OF NITROUS OXIDE

[Viscosity, η , 10^{-4} Pa s]

Saturated Liquid as a Function of Temperature		Saturated Liquid as a Function of Pressure		Dilute Gas as a Function of Temperature	
T(K)	η	P(bar)	η	T(K)	η
182.3*	3.64	1	3.50	184.7**	-
185	3.49	2	2.71	190	0.095
190	3.28	3	2.32	200	0.100
195	2.95	4	2.12	210	0.105
200	2.71	5	1.95	220	0.110
205	2.48	6	1.83	230	0.115
210	2.27	7	1.73	240	0.120
215	2.08	8	1.65	250	0.125
220	1.92	9	1.58	260	0.130
225	1.78	10	1.51	270	0.135

TABLE 23.5. VISCOSITY OF NITROUS OXIDE (Continued)

[Viscosity, η , 10^{-4} Pa s]

Saturated Liquid as a Function of Temperature		Saturated Liquid as a Function of Pressure		Dilute Gas as a Function of Temperature	
T(K)	η	P(bar)	η	T(K)	η
230	1.64	15	1.24	280	0.140
235	1.52	20	1.09	290	0.145
240	1.41	25	0.92	300	0.150
245	1.31	30	0.84	310	0.154
250	1.21	35	0.74	320	0.159
255	1.12	40	0.6	330	0.163
260	1.03	45	0.58	340	0.168
265	0.95	50	0.52	350	0.173
270	0.87			360	0.177
275	0.79			370	0.181
280	0.71			380	0.186
285	0.63			390	0.190
290	0.56			400	0.194
295	0.49			420	0.203
300	0.42			440	0.211
310***	-			460	0.220
				480	0.228
				500	0.236
				550	0.255
				600	0.274
				650	0.292
				700	0.310
				750	0.327

*mp. **nbp. ***Critical point.

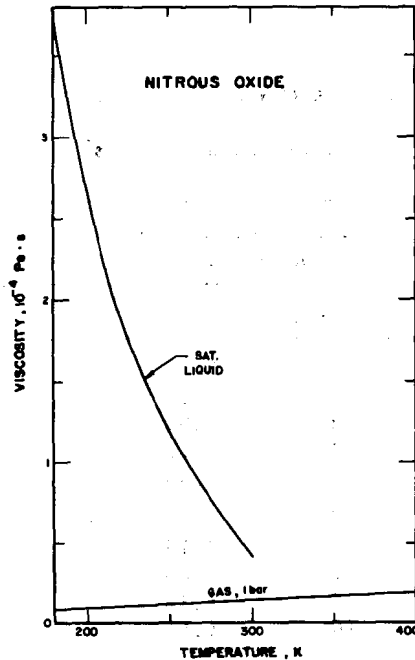


FIGURE 23.2. VISCOSITY OF NITROUS OXIDE.

23.5. PRANDTL NUMBER

The Prandtl number was calculated from the preceding constituent property tables. Only values for the dilute gas could be obtained in this way. Minor irregularities in the values so obtained, of the order of a few percent, were removed by differencing. The resulting values are those tabulated. While the sum of the uncertainties in the constituent properties is 16%, due to averaging, the true uncertainty is thought to be closer to 10%.

TABLE 23.6. PRANDTL NUMBER OF NITROUS OXIDE

[Prandtl Number, N_{Pr} , Dimensionless]

Dilute Gas as a Function of Temperature			
T(K)	N_{Pr}	T(K)	N_{Pr}
190	0.78	420	0.72
200	0.78	440	0.72
220	0.78	460	0.72
240	0.77	480	0.72
260	0.77	500	0.72
280	0.77	550	0.72
300	0.76	600	0.72
320	0.76	650	0.72
340	0.75	700	0.72
360	0.74	750	0.71
380	0.73		
400	0.72		

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