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THERMODYNAMIC PROPERTIES OF PHOSGENE

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Abstract

Thermodynamic properties of phosgene have been evaluated up to a temperature of 600°K and a pressure of 150 atmospheres using Martin and Hou equation of state. The results are presented in tabular form and as an entropy-temperature diagram.

Introduction

Phosgene is used in chemical warfare. It is also used as an intermediate, capable of producing a wide variety of new products in very many fields ranging from solvents to plastics. However, thermodynamic data needed for the purposes of design are completely lacking. Hence it is desirable to know the thermodynamic properties of phosgene.

Survey of Existing Data

1. *Molecular weight and critical data* :

The available data on the critical constants of phosgene are presented in Table I.

TABLE 1

Molecular weight and critical constants of phosgene

Molecular weight of Phosgene = 98 924

Year	Investigator	T_c, °K	P_c, atm.	d_c gm./c.c.	Method*	Reference
1919	Hackspill and Mathieu ...	456.31	....	....	a	8
1926	Germann and Taylor ...	455.16	56 0	0.52	a, b	4
Values selected :		455.16	56.0	0.52		

a : Disappearance meniscus.

b : Law of rectilinear diameters.

Hackspill and Mathieu[8] fractionally distilled the industrial phosgene to remove contaminants consisting of sulfur compounds and removed chlorine by contact with mercury for 24 hours.

For obtaining a relatively pure sample, Germann and Taylor[4] repeatedly fractionated commercial phosgene. However, these investigators could not condense the sample completely at constant pressure. The temperatures of disappearance and reappearance of the meniscus were found to be 454 96 °K and 454 76 °K respectively. The critical pressure found by observation was 55.3 atmospheres where as by extrapolation of vapour pressure curve, it was found to be 55.6 atmospheres. The value reported by these investigators namely 455.16 °K for the critical temperature has been accepted for this investigation.

Vapour pressure equation as given by these investigators[4] predict a pressure of 56 0 atmospheres at the accepted critical temperature. Hence a pressure of 56.0 atmospheres for the critical pressure was accepted for this investigation.

Critical density was determined by using the law of rectilinear diameters by making use of the density data of Paterno and Mazzuchelli[11], by Germann and Taylor.

For this investigation, the critical data of Germann and Taylor[4] have been used. Thus the critical constants used for this work are :

$T_c = 455.16\ °K$

$P_c = 56.0$ atms.

$d_c = 0.52$ gm /c.c.

2. *Vapour pressure :*

The vapour pressure data of phosgene has been experimentally determined by Atkinson *et al.*[1], Paterno and Mazzucchelli[11], Germann and Taylor[4] and Giauque and Jones[5]. Vapour pressure data is also presented in the International Critical Tables[9]. Table 2 gives the available data along with the range of availability.

The method adopted by Germann and Taylor[4] for the purification of the sample used is mentioned earlier. The vapour pressure data are stated to be accurate to 0.1 atm. The sample used by Giauque and Jones[5] is stated to be 99.993 mole % pure. However, the accuracy of the vapour pressure data are not reported. Paterno and Mazzucchelli[11] have not reported the accuracy of the data. Germann and Taylor[4] determined vapour pressure of phosgene over two temperature regions, namely 273.16 – 301.06 °K and 420.26 – 455.16 °K. These authors fitted their data to the equation :

$$\log P = 4.4659 - (1207.9/T) + (13297/T^2) \qquad [1]$$

where T is in °K and P is in atmospheres.

TABLE 2

Vapour pressure of phosgene

Year	Investigator	Range of Temperature, °K	Range of Pressure, atms.	Reference
1920	Atkinson *et al.*	193.16-373.16	0.00-16.07	1
1920	Paterno and Mazzucchelli	249.74-294.29	0.25-1.75	11
1926	Germann and Taylor	273.16-455.16	0.73-56.00	4
1928	International Critical Tables	281.11-455.16	1.00-56.00	9
1948	Giauque and Jones	215.48-281.10	0.03-1.02	5

The vapour pressure data was calculated using Equation [1] and was found to be in very good agreement with that presented in International Critical Tables.

For this investigation, the vapour pressure data above 1 atm. has been taken from the International Critical Tables. Below 1 atm., the data of Giauque and Jones[5] has been used.

Giauque and Jones[5] fitted their data to the equation :

$$\log P = 7.7994 - (1690.3/T) - (7.8981 \times 10^{-3} T) + (5.5847 \times 10^{-6} T^2) \qquad [2]$$

where, P is in atmospheres and T is in °K.

Equation [2] predicts the vapour pressure data with a maximum diviation of 0.1%.

In the present work, the vapour pressure data above 1 atm. was fitted to the equation,

$$\log P = A + (B/T) + C \log T + DT \qquad [3]$$

where, $A = 3.7349229$

$B = -1290.8709$

$C = 0.41355479$

$D = -5.5134925 \times 10^{-4}$

This equation predicts vapour pressure data[9] with average absolute and maximum deviations of 0.1% and 0.23% respectively.

For this work Equations [2] and [3] have been used.

3. *Saturated Liquid and Vapour Densities* :

Saturated Liquid and Vapour Densities of phosgene have been determined over a temperature range of 163 to 323 °K by Atkinson *et al*[1] and over a temperature range of 258 to 455 °K by Paterno and Mazzucchelli[11].

Both the investigators did not mention the purity of the sample used and the accuracy of the data. Vapour density of phosgene has been determined by Paterno and Mazzucchelli[11] over a temperature range of 333-455 °K.

Liquid and vapour density data over a temperature range of 281 to 455 °K are presented in the International Critical Tables[9]. For this investigation all the available data on the densities of saturated liquid and vapour were combined and smoothened. Smoothened data have been used for this investigation. The smoothened data agree with the raw data within a maximum deviation of 1%.

4. *Heat Capacity from Calorimetric Data* :

Heat capacity of phosgene over a temperature range of 15 °K to 280 °K has been determined by Giauque and Jones[5]. As stated earlier, the sample used by these investigators was very pure. Later, in a careful study Giaque and Ott[6] found, that the data of Giauqe and Jones[5] below a temperature of 118.3°K was applicable to pure solid II and above this temperature, to solid I. These authors have presented heat capacity data for solid I, which is the most stable state and also for solid II. The accuracy of the data are not reported. The entropy evaluated using the heat capacity data of solid I at 280.71 °K (normal boiling point) is in very good agreement with their entropy calculated using spectroscopic data.

5. *Heat Capacity of Ideal Gas* :

Heat capacity of phosgene in the ideal gaseous state have been evaluated by Thompson[13], Gordon and Goland[7] and by Giauque and Ott[6]. Giauque and Ott used the constant recommended by Rossini *et al.*[12] and Dumond and Cohen[3]. The data of Gordon and Goland[7] deviates by about 5% with the data of Giauque and Ott[6].

For this investigation, the data of Giauque and Ott has been used. The heat capacity data of Giauque and Ott was fitted by the method of least squares to the equation :

$$C_p^* = a + bT + cT^2 + dT^3 \qquad [4]$$

where, $a = 3.3388$

$b = 5.6707 \times 10^{-2}$

$c = -8.8784 \times 10^{-5}$

$d = 5.4200 \times 10^{-8}$.

Equation [4] predicts heat capacity data with maximum and average absolute deviations of 0.03% and 0.02% respectively. For the calculation of thermodynamic properties, Equation [4] has been used.

6. *Heat of Vaporization* :

Heat of vaporization of phosgene has been experimentally determined by Giauque and Jones[5]. No other data is available on the heat of vaporization of phosgene.

As already mentioned, Giauque and Jones[5] used very pure sample of phosgene. They claim an accuracy of 99·9 %.

Heat of vaporization was calculated using Clausius-Clapeyron equation,

viz.,

$$\Delta H_v = (dP/dT)T \cdot (V_g - V_l) \qquad [5]$$

by making use of the experimental specific volumes. The heat of vaporization calculated at the normal boiling point agrees within 2% with the experimental data of Giauque and Jones[5].

CALCULATION OF THERMODYNAMIC PROPERTIES

For the calculation of thermodynamic properties Martin and Hou (MH equation of state:

$$P = \frac{RT}{(V-b_0)} + \frac{A_2 + B_2T + C_2 \exp.(-KT/T_c)}{(V-b_0)^2} + \frac{A_3 + B_3T + C_3 \exp(-KT/T_c)}{(V-b_0)^3} + \frac{A_4}{(V-b_0)^4} + \frac{B_5T + C_5 \exp.(-KT/T_c)}{(V-b_0)^5} \qquad [6]$$

with $K = 5.475$ has been used.

The constants in Equation (6), evaluated following the procedures outlined by the authors[10] are:

$b_0 = 0\cdot 04516972$

$A_2 = -16\cdot 059997$

$B_2 = 1\cdot 2038081 \times 10^{-2}$

$C_2 = 142\cdot 96485$

$A_3 = 2\cdot 0331332$

$B_3 = -1\cdot 3197412 \times 10^{-3}$

$C_3 = -22\cdot 568742$

$A_4 = -9\cdot 005015 \times 10^{-2}$

$B_5 = 5\cdot 0038055 \times 10^{-6}$

$C_5 = 3\cdot 849143 \times 10^{-2}.$

Using the available experimental specific volumes of saturated vapour in Equation [6], pressures were computed. For 21 points tested, the average absolute and maximum deviations were found to be 1·23% and 3·08% respectively. Such a comparison is shown in Table 3. Comparison could not be made in the superheated vapour region because of lack of data.

Specific volumes of saturated and superheated vapour were calculated using Equation [6] by making use of Newton-Raphson iterative method on IBM 1620 digital computer, for various temperatures and pressures.

Entropy and Enthalpy of the Superheated Vapour:

Considering the entropy and enthalpy to be function of volume temperature, we have,

$$dS = (\partial S/\partial T)_V\, dT + (\partial S/\partial V)_T\, dV \qquad [7]$$

TABLE 3

Comparison of Calculated Pressures

T, °K	P, atms	PCOM, atms.	% Deviation
340.0	6.295	6.0908	3.244
350.0	8.100	7.9941	1.308
360.0	10.21	10.1397	0.688
370.0	12.72	12.6762	0.344
380.0	15.70	15.4213	1.775
385.0	17.40	17.009	2.247
390.0	19.15	18.673	2.491
395.0	21.10	20.449	3.085
400.0	23.00	22.384	2.677
405.0	25.15	24.592	2.219
410.0	27.50	26.98	1.892
415.0	30.05	29.626	1.410
420.0	32.55	32.456	0.281
425.0	35.50	35.208	0.822
430.0	38.45	38.278	0.448
435.0	41.50	41.551	−0.124
440.0	44.80	44.881	−0.180
445.0	48.15	48.317	−0.347
450.0	51.95	52.013	−0.121
455.0	55.95	55.883	0.119
455.16	56.00	56.000	0.000

% Deviation = (P—PCOM)/P × 100

sing Maxwell's relations, we obtain,

$$dS = (C_v^* \,/\, T)\, dT + (\partial P/\partial T)_V\, dV \tag{8}$$

sing $dH = TdS + VdP$ in Equation [8] we obtain

$$\begin{aligned} dH &= C_v^*\, dT + T(\partial P/\partial T)_V\, dV + VdP \\ &= C_v^*\, dT + d(PV) - PdV + T(\partial P/\partial T)_V\, dV \end{aligned} \tag{9}$$

From Equation [6] we have

$$(dP/dT)_V = \frac{R}{(V-b_0)} + \frac{B_2 - (K/T_c)\, C_2 \exp.\,(-KT/T_c)}{(V-b_0)^2}$$

$$+ \frac{B_3 - (K/T_c)\, C_3 \exp\,(-KT/T_c)}{(V-b_0)^3} + \frac{B_5 + C_5\,(K/T_c) \exp.\,(-KT/T_c)}{(V-b_0)^5} \qquad [10]$$

Using Equations [8] and [9],

$$S = \int (C_v^* /T)\, dT + \int (\partial P/\partial T)_V\, dV \qquad [11]$$

and

$$H = \int (C_v^*)\, dT + \int T\,(\partial P/\partial T)_V\, dV - \int P dV + PV \qquad [12]$$

Using Equations [4] and [10] in the above equations and carrying out the integration, we obtain expressions for entropy and enthalpy as:

$$S = (a - R) \ln T + bT + (c/2)T^2 + (d/3)T^3 + R \ln (V - b_0)$$

$$- \frac{B_2}{(V-b_0)} - \frac{B_3}{2\,(V-b_0)^2} - \frac{B_5}{4\,(V-b_0)^4}$$

$$+ \left[\frac{C_2}{(V-b_0)} + \frac{C_3}{2\,(V-b_0)^2} + \frac{C_5}{4\,(V-b_0)^4}\right] (K/T_c) \exp.\,(-KT/T_c) + C_S \qquad (13)$$

and

$$H = (a - R)\, T + (b/2)\, T^2 + (c/3)\, T^3 + (d/4)\, T^4$$

$$+ \frac{A_2 + (1 + KT/T_c)\, C_2 \exp.\,(-KT/T_c)}{(V-b_0)} + \frac{A_3 + (1 + KT/T_c)\, C_3 \exp\,(-KT/T_c)}{(V-b_0)^2}$$

$$+ \frac{A_4}{3\,(V-b_0)^3} + \frac{(1 + KT/T_c)\, C_5 \exp.\,(-KT/T_c)}{4\,(V-b_0)^4} + PV - RT + C_H \qquad [14]$$

where C_S and C_H are the constants of integration.

Reference State :

The reference state chosen depends upon the available data. The reference state chosen should facilitate easy comparison and utilization of the tabulated data. The reference state $H = 0$ and $S = R \ln P = 0$ for elements[2] is applicable for pure substances and also for pure substances that undergo a chemical reaction.

In the present work the reference state as given above has been used.

Entropy value at the normal boiling point was evaluated using the ideal gas thermodynamic properties and the Berthelot correction. Enthalpy at the normal boiling point was evaluated by making use of the heat of formation at $O^{\circ}H$, the ideal gas thermodynamic properties and the Berthelot correction for enthalpy The integration constants C_S and C_H were evaluated using the values of entropy and enthalpy at the normal boiling point.

Entropy and enthalpy of saturated vapour were evaluated by using the experimental specific volumes in Equations [13] and [14]. Wherever the experimental data were not available these were calculated using Equation [6] and were used.

Entropy and Enthalpy of the Saturated Liquid :

The entropy of vaporization is related to the heat of vaporization by the relation

$$\Delta H_v = T \Delta S_v \qquad [15]$$

The entropy and enthalpy of the saturated liquid were calculated using the equations

$$S_l = S_g - \Delta S_v \qquad [16]$$

$$H_l = H_g - \Delta H_v \qquad [17]$$

The properties of saturated and superheated phosgene are presented in the graphical form as Fig. 1.

Internal Consistency of the Tabulated Results :

The relation $dH = TdS + VdP$ may be used to check the internal consistency of the entropy and enthalpy values.

At constant pressure,

$$dH = TdS \qquad [18]$$

Hence, $dH = d\,(TS) - SdT$ from which

$$H_1^2 = T_2S_2 - T_1S_1 - \int_1^2 SdT \qquad [19]$$

Internal consistency checks were made for superheated region by using Equation [19]. The definite integral in Equation [19] was evaluated by Simpson's rule. Table 4a gives the comparison of calculated and tabulated values of changes of enthalpy ΔH for 5 isobars.

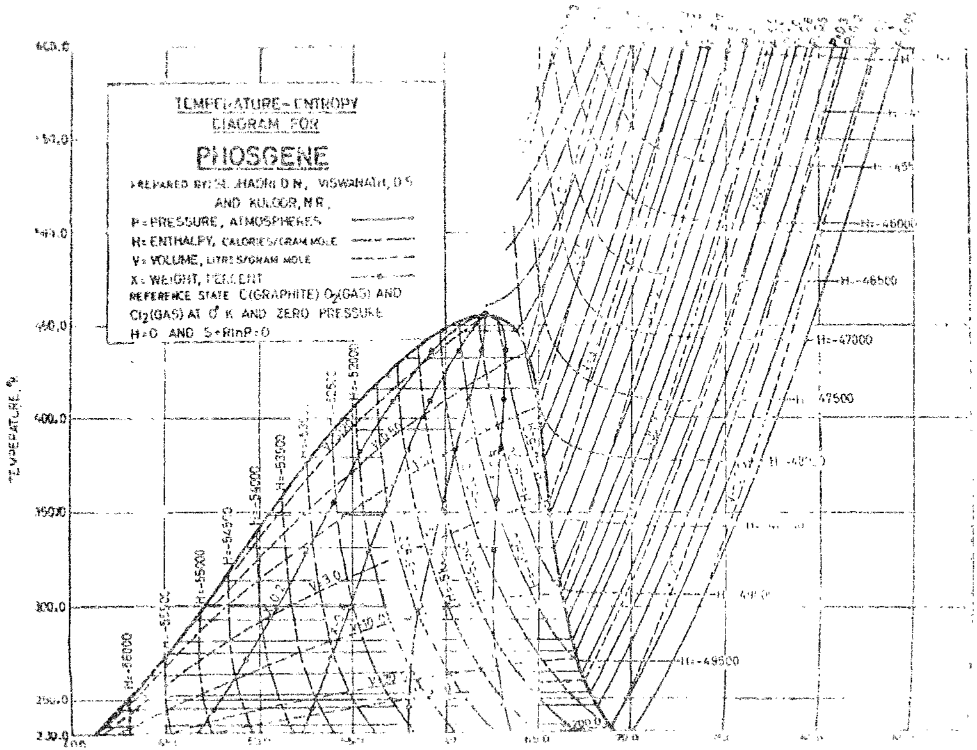
TEMPERATURE-ENTROPY
DIAGRAM FOR
PHOSGENE
PREPARED BY: SESHADRI D.N., VISWANATH, D.S
AND KULOOR, N.R.
P = PRESSURE, ATMOSPHERES
H = ENTHALPY, CALORIES/GRAM MOLE
V = VOLUME, LITRES/GRAM MOLE
X = WEIGHT, PERCENT
REFERENCE STATE C(GRAPHITE) O2(GAS) AND
Cl2(GAS) AT 0° K AND ZERO PRESSURE
H = 0 AND S + RlnP = 0
TEMPERATURE, °K
400.0
350.0
300.0
250.0
230.0
H=-56000
H=-55500
H=-55000
H=-54500
H=-54000
H=-53500
H=-53000
H=-52000
H=-46000
H=-46500
H=-47000
47500
H=-49500
V=3.0
70.0

TABLE 4*a*

Comparison of the values of ΔH

Isobar atm.	Range of temp. °K	$\Delta H_{calc.}$	ΔH_{tables}	% Deviation
0.10	240 – 600	5500.0	5501	0.02
0.00	300 – 600	4706.0	4704	0.04
10.00	380 – 600	3584.0	3583	0.03
50.00	460 – 600	2760.2	2760	0.01
100.00	540 – 600	1466.7	1465	0.08

NOMENCLATURE

A, B, C, D	Constants in Equation [3]
a, b, c, d	Constants in Equation (4)
$b_0, A_2, B_2, C_2,$ $A_3, B_3, C_3, A_4,$ B_5, C_5, K	Constants in Equation [6]
C_p	Heat capacity at constant pressure, cal./gram mole °K
C_v	Heat capacity at constant volume, cal./gram mole °K
C_S, C_H	Constants of integration in Equations [13] and [14]
H	Enthalpny, cal./gram mole
P	Pressure, atmospheres
R	Gas constant
S	Entropy, cal./gram mole °K
T	Temperature, °K
V	Specific volume, litres/gram mole
ΔH_V	Enthalpy of vaporization, cals./gram mole
ΔS_V	Entropy of vaporization, cals /gram mole °K

Superscript

*	Properties at zero pressure or ideal gaseous state

Subscripts

c	Critical point
g	Gas or vapour
l	Liquid
p	Pressure
T	Temperature
v	Volume

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TABLE 4

Properties of Saturated Liquid and Vapour

T°K	P, Atm.	V_l	V_g	S_l	ΔS_v	S_g	H_l	ΔH_v	H_g
230.0	0.0850	0.06477	221.8	41.27	27.90	69.17	− 56439	6417	− 50022
240.0	0.1534	0.06557	128.2	42.18	26.46	68.64	− 56247	6350	− 49897
250.0	0.2585	0.06661	79.07	43.04	25.02	68.06	− 56021	6255	− 49766
260.0	0.4180	0.06770	50.77	43.89	23.69	67.58	− 55800	6159	− 49641
270.0	0.6517	0.06887	33.71	44.80	22.39	67.19	− 55500	6045	− 49535
280.0	0.9640	0.07008	23.54	45.54	21.36	66.90	− 55360	5980	− 49380
290.0	1.390	0.07138	22.74	46.33	20.31	66.64	− 55138	5890	− 49248
300.0	1.965	0.07267	16.82	47.09	19.33	66.42	− 54917	5800	− 49117
310.0	2.693	0.07553	9. 39	47.84	18.40	66.24	− 54702	5705	− 48997
320.0	3.650	0.07704	6.896	48.55	17.51	66.06	− 54461	5603	− 48858
330.0	4.845	0.07874	5.302	49.27	16.71	65.96	− 54247	5514	− 48733
340.0	6.295	0.08045	4.148	49.98	15.88	65.86	− 53986	5399	− 48587
350.0	8.100	0.08231	3.257	50.70	15.00	65.70	− 53733	5250	− 48483
360.0	10.21	0.08439	2.601	51.38	14.20	65.58	− 53488	5112	− 48376
370.0	12.72	0.08658	2.099	52.16	13.32	65.48	− 53202	4928	− 48274
380.0	15.70	0.08780	1.705	52.91	12.51	65.42	− 52919	4753	− 48166

TABLE 4—(*concld.*)

T°K	P. atm.	V_l	V_g	S_l	ΔS_v	S_g	H_l	ΔH_v	H_g
390.0	19.15	0.08921	1.399	53.68	11.64	65.32	−52613	4540	−48073
400.0	23.00	0.09208	1.149	54.54	10.69	65.23	−52271	4276	−47995
410.0	27.50	0.09569	0.9263	55.46	9.63	65.09	−51895	3948	−47947
420.0	32.55	0.1005	0.7342	56.44	8.43	64.87	−51476	3541	−47935
425.0	35.50	0.1034	0.6595	57.06	7.71	64.77	−51204	3277	−47927
430.0	38.45	0.1068	0.5854	57.63	7.01	64.64	−50953	3014	−47939
435.0	41.50	0.1111	0.5152	58.19	6.29	64.48	−50704	2736	−47968
440.0	44.80	0.1161	0.4517	58.82	5.47	64.29	−50417	2407	−48010
445.0	48.15	0.1226	0.3910	59.55	4.52	64.07	−50088	2011	−48077
450.0	51.95	0.1226	0.3243	60.31	3.39	63.70	−49733	1525	−48208
455.0	55.95	0.1667	0.2096	61.70	0.82	62.52	−49092	373·1	−48719
455.16	56.00	0.1902	0.1902	62.19	0.00	62.19	−48880	0·0	−48880

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TABLE 5

Properties of Superheated Vapour

(Pressure range: 0 05 to 3.00 atms.)

T°K	P Atms.	0.05	0.10	0.20	0.30	0.50	0 80	1.00	1.50	2.00	3.00
240.0	V	393 6	196.7								
	H	−49899	−49898								
	S	70.75	69.38								
260.0	V	426.4	213.1	106.4	70.84						
	H	−49643	−49643	−49644	−49644						
	S	71.78	70.40	69 03	68.23						
280.0	V	459.2	229.5	114.6	76.29	45.65	28.42				
	H	−49378	−49378	−49379	−46379	−49379	−49379				
	S	72.76	71.38	70.01	66.20	68.19	67.27				
300.0	V	492.0	245.9	122.8	81.75	48.93	30.46	24.31	16.10		
	H	−49106	−49106	−49107	−49107	−49108	−49110	−49111	−49114		
	S	73.70	72.32	70 94	70.14	69.13	68.19	67.75	66.95		
320.0	V	524.8	262.3	131.0	87.22	52.21	32.52	25.95	17 20	12.82	8.439
	H	−48826	−48826	−48827	−48828	−48830	−48833	−48834	−48838	−48843	−48852
	S	74.60	73.22	71.85	71.04	70.02	69 09	68.65	67.84	67.27	66.45
340.0	V	557.7	278.7	139 2	92.69	55 50	34.57	27.60	18 30	13.65	8.993
	H	−48540	−48540	−48541	−48542	−48544	−48548	−48550	−48555	−48561	−48572
	S	75.47	74.09	72.71	71.91	70 89	69.95	69.51	68.70	68.12	67 30

TABLE 5—(*contd.*)

Pressure Range: 0.05 to 3.00 atm.

T°K	P Atms.	0.05	0.10	0.20	0.30	0.50	0.80	1.00	1.50	2.00	3.00
360.0	V	590.5	295.1	147.4	98.18	58.79	36.63	29.25	19.40	14.48	9.551
	H	−48247	−48248	−48249	−48250	−48252	−48256	−48258	−48264	−48271	−48283
	S	76.30	74.93	73.55	72.74	71.72	70.79	70.34	69.53	68.95	68.13
380.0	V	623.3	311.5	155.6	103.7	62.08	38.70	30.90	20.51	15.31	10.11
	H	−47949	−47950	−47951	−47952	−47955	−47958	−47961	−47968	−47974	−47987
	S	77.11	75.73	74.35	73.55	72.53	71.59	71.14	70.33	69.75	68.93
400.0	V	656.2	328.0	163.8	109.1	65.38	40.76	32.56	21.62	16.15	10.67
	H	−47646	−47646	−47648	−47649	−47652	−47656	−47658	−47665	−47672	−47685
	S	77.89	76.51	75.13	74.32	73.31	72.37	71.92	71.11	70.53	69.70
420.0	V	689.0	344.4	172.1	114.6	68.68	42.83	34.21	22.73	16.98	11.24
	H	−47338	−47338	−47340	−47341	−47344	−47348	−47350	−47357	−47364	−47378
	S	78.64	77.26	75.88	75.08	74.06	73.12	72.67	71.86	71.28	70.45
440.0	V	721.8	360.8	180.3	120.1	71.97	44.89	35.87	23.83	17.82	11.80
	H	−47025	−47026	−47027	−47029	−47031	−47035	−47038	−47045	−47052	−47065
	S	79.37	77.99	76.61	75.80	74.78	73.85	73.40	72.58	72.00	71.18
460.0	V	754.7	377.2	188.5	125.6	75.27	46.96	37.52	24.94	18.65	12.36
	H	−46709	−46710	−46711	−46712	−46715	−46719	−46722	−46728	−46735	−46749
	S	80.07	78.69	77.31	76.51	75.49	74.55	74.10	73.29	72.71	71.88

TABLE 5—(*contd*)

Pressure Range: 0.05 to 3.00 atms.

T°K	P Atms.	0.05	0.10	0.20	0.30	0.50	0.80	1.00	1.50	2.00	3.00
480.0	V	787.5	393.7	196.7	131.1	78.57	49.03	39.18	26.05	19.49	12.92
	H	−46389	−46390	−46391	−46392	−46395	−46399	−46401	−46408	−46414	−46428
	S	80.75	79.37	77.99	77.19	76.17	75.23	74.78	73.97	73.39	72.57
500.0	V	820.3	410.1	204.9	136.6	81.86	51.09	40.83	27.16	20.32	13.48
	H	−46065	−46066	−46067	−46068	−46071	−46075	−46077	−46084	−46090	−46103
	S	81.41	80.03	78.65	77.85	76.83	75.89	75.44	74.63	74.05	73.23
520.0	V	853.2	426.5	213.2	142.0	85.16	53.16	42.49	28.27	21.16	14.04
	H	−45738	−45739	−45740	−45741	−45744	−45747	−45750	−45756	−45762	−45775
	S	82.05	80.67	79.30	78.49	77.47	76.53	76.09	75.27	74.69	73.87
540.0	V	886.0	442.9	221.4	147.5	88.45	55.22	44.14	29.37	21.99	14.60
	H	−45408	−45408	−45409	−45411	−45413	−45417	−45419	−45425	−45431	−45443
	S	82.68	81.30	79.92	79.11	78.10	77.16	76.71	75.90	75.32	74.50
560.0	V	918.9	459.3	229.6	153.0	91.75	57.28	45.80	30.48	22.82	15.16
	H	−45074	−45074	−45076	−45077	−45079	−45083	−45084	−45091	−45096	−45108
	S	83.28	81.90	80.53	79.72	78.70	77.76	77.32	76.51	75.93	75.11
580.0	V	951.7	475.8	237.8	158.5	95.04	59.35	47.45	31.58	23.65	15.72
	H	−44737	−44737	−44738	−44740	−44742	−44745	−44747	−44753	−44759	−44770
	S	83.87	82.50	81.12	80.31	79.29	78.36	77.91	77.10	76.52	75.70
600.0	V	984.5	492.2	246.0	164.0	98.33	61.41	49.10	32.69	24.48	16.28
	H	−44396	−44397	−44398	−44399	−44401	−44404	−44407	−44412	−44417	−44428
	S	84.45	83.07	81.70	80.89	79.87	78.93	78.49	77.68	77.10	76.28

TABLE 5—(*contd.*)

Pressure Range: 5.0 to 150 atms.

T°K	P Atms.	5.0	8.0	10.0	15.0	20.0	30.0	50 0	80 0	100.0	150 0
	V	5.267									
340 0	H	– 48595									
	S	66 27									
	V	5 607	3.383								
360.0	H	– 48309	– 48350								
	S	67.08	66 10								
	V	5.950	3.604	2.819	1.764						
380 0	H	– 48015	– 48058	– 48088	– 48170						
	S	67 88	66.89	66.40	65.48						
	V	6.293	3.826	3.001	1.895	1.332					
400.0	H	– 47713	– 47757	– 47788	– 47870	– 47962					
	S	68.65	67.66	67.17	66.25	65.54					
	V	6 638	4.048	3.183	2.025	1.409	0 8326				
420.0	H	– 47406	– 47450	– 47480	– 47561	– 47650	– 47869				
	S	69.40	68.41	67.92	67.00	66.30	65.14				
	V	6.982	4.270	3.365	2.154	1.544	0 9,98				
440.0	H	– 47094	– 47137	– 47167	– 47245	– 47331	– 47530				
	S	70.13	69.14	68.65	67 74	67.04	65 93				
	V	7.326	4.492	3.546	2 282	1.646	1.002	0.4399			
460 0	H	– 46776	– 46819	– 46848	– 46924	– 47005	– 47189	– 47747			
	S	70.83	69.84	69.36	68.45	67.76	66.69	64 76			

TABLE 5—(*contd.*)

Pressure Range: 5.0 to 150.0 atms.

T°K	P Atms.	5.0	8.0	10.0	1.50	20.0	30.0	50.0	80.0	100.0	150.0
	V	7.669	4.712	3.726	2.409	1.748	1.080	0.5212			
480.0	H	−46455	−46 96	−46524	−46597	−46675	−46846	−47298			
	S	71.52	70.53	70.05	69.15	68.47	67.42	65.71			
	V	8.011	4.932	3.905	2.534	1.847	1.155	0.5871	0.2415		
500.0	H	−46129	−46169	−46196	−46267	−46340	−46500	−46892	−47844		
	S	72.18	71.20	70.72	69.82	69.15	68.13	66.54	64.07		
	V	8.353	5.152	4.084	2.659	1.945	1.228	0.6457	0.3045	0.2079	
520.0	H	−45800	−45839	−45865	−45932	−46002	−46152	−46502	−47225	−47738	
	S	72.83	71.84	71.37	70.48	69.81	68.81	67.31	65.29	64.07	
	V	8.694	5.370	4.262	2.783	2.042	1.300	0.6998	0.3559	0.2493	
540.0	H	−45467	−45505	−45530	−45594	−45661	−45801	−46119	−46717	−47156	
	S	73.45	72.48	72.00	71.11	70.46	69.47	68.03	66.25	65.17	
	V	9.035	5.588	4.438	2.905	2.138	1.369	0.7509	0.4002	0.2882	0.1755
560.0	H	−45132	−45167	−45191	−45253	−45316	−45448	−45740	−46257	−46633	−47307
	S	74.07	73.09	72.62	71.73	71.08	70.11	68.72	67.09	66.12	64.44
	V	9.375	5.805	4.614	3.027	2.233	1.438	0.7997	0.4401	0.3239	0.1951
580.0	H	−44792	−44827	−44850	−44908	−44969	−45093	−45364	−45822	−46149	−46809
	S	74.66	73.69	73.22	72.34	71.69	70.74	69.38	67.85	66.97	65.32
	V	9.714	6.021	4.790	3.148	2.327	1.505	0.8467	0.4770	0.3569	0.2156
600.0	H	−44450	−44483	−44505	−44561	−44618	−44736	−44987	−45402	−45691	−46318
	S	75.24	74.27	73.80	72.93	72.29	71.34	70.02	68.56	67.75	66.15

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