THERMODYNAMIC PROPERTIES OF TRIMETHYLAMINE

BY

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The thermodynamic properties of trimethylamine have been evaluated at temperatures from 32°F to 600°F and from the saturation pressure to 2000 lb/in^2 based on available experimental data. An equation relating the pressure, volume and temperature of the system has been derived for the range in which experimental data were available and it was used to evaluate the thermodynamic properties in this range. Values for pressure, volume, temperature, enthalpy and entropy have been presented in the form of tables and graphs.

INTRODUCTION

The increasing use of substituted amines in the chemical and petroleum industries makes desirable a compilation of their thermodynamic properties under various conditions of temperature and pressure. These data are necessary for many engineering calculations such as plate to plate calculations in distillation or compressor design. While such charts have been prepared at low temperatures and pressures for other substituted amines no evaluation of these properties for trimethylamine has been prepared up to this time. It is the purpose of this paper to present values of the thermodynamic properties of trimethylamine in the easily used form of tables and graphs.

The requirements for evaluating the network of thermodynamic properties for any compound are not absolutely fixed, but they should include some thermal and some volumetric data. While it is possible using generalizations to determine values for thermodynamic properties from direct data for the normal boiling point, specific gravity of the liquid and chemical structure, such values will be inherently less accurate than those based on more complete direct experimental data. Complete evaluation of the thermodynamic properties from experimental data requires values for enthalpies, entropies, latent heats, heat capacities and Joule-Thomson coefficients as well as PVT data in the saturated and superheated vapor regions. Usually such complete data are unavailable and the properties are evaluated by a combination of experimental data and data taken from averaged values for other similar materials. (1)

In the present study available experimental data were gathered and used as a basis for evaluating the properties of trimethylamine. Extrapolation and interpolation were used in extending the available data and in those regions where experimental data were completely lacking, generalized methods of Hougen et al (2) and Hansen (3) were used. The need for additional experimental data is evident.

SOURCES OF DATA

The literature survey undertaken in order to secure data for use in calculating the thermodynamic properties of trimethylamine disclosed a surprising lack of material on this compound. The exceedingly small amount of PVT data was the greatest cause of difficulty and with the notable exception of the determinations of Day and Felsing (4,5) over a rather limited temperature and pressure range near the critical point, PVT data were nonexistent. In the course of investigation (5) the critical constants were also determined quite accurately. The saturated liquid volume was available from the work of Swift (6) over the temperature range 0 to 35°C and of Felsing and Phillips (7) in the range -20 to +45°C. At temperatures from 45°C to the critical point no data were available. The deviation from ideality of trimethylamine at 0°C has been calculated by Arthur and Felsing (19) with the aid of an equation which relates the pressure-volume product to the pressure.

Considerable work has been done evaluating the vapor pressure of trimethylamine over a wide temperature range from -90°C to the critical point (5,8,9,10,11). The equations derived by Swift and Hochandel (9) and by Day and Felsing (5) covered the temperature range of the present investigation. The molal heat of vaporization has been reported by several investigators (7,8,9). Aston et al (8) have reported values at the normal boiling point and at one other temperature which were checked calorimetrically and appear to be accurate. These investigators also determined values of entropy at several temperatures in the ideal gaseous state and there is good agreement with other reported values (12). Kobe and Harrison (12) using data obtained by Aston and others (8,13) evaluated a four-term heat capacity equation from which they calculated enthalpy and entropy values for trimethylamine in the ideal gaseous state. This heat capacity equation was used in the present investigation.

DERIVATION OF EQUATIONS USED IN CALCULATIONS

Several hundred equations of state have been proposed to express the PVT relationship of gases but none has been found to be universally satisfactory, and most are applicable only over a limited range of temperatures and pressures. The most generally satisfactory equation of state is that of Beattie and Bridgeman(14) wherein the various constants must be determined uniquely for each gas. Maron and Turnbull (15) using the approximate form of the Beattie-Bridgeman equation, explicit in volume, have derived a series of equations which are complete analytical expressions for the calculation of changes in enthalpy and entropy. Initial work was done on this project using their method but comparison of the results obtained with this method, and the available experimental data indicated that it was unsatisfactory, even at low pressures, near the critical point. Since this project covers the region below $T_r = 1.2$ a different approach was necessary.

The equation of state may be written

$$PV = ZRT \qquad (1)$$

where Z is termed the compressibility factor and is a function of pressure, temperature and the nature of the gas. Values of Z at any temperature and pressure can be calculated from compressibility data since

$$Z = \frac{PV}{RT} \qquad (2)$$

When values of the compressibility factor of a gas are known, all calculations involving its PVT relationships may be carried out by simple proportionalities derived from Equation (1).

Experimental compressibility data for trimethylamine were available at the following temperatures and pressures (4,5).

t (°c)	P (atm)
175	47-49
200	58-64
225	69-79
250	80-94
275	90-106

Using these experimental data, the constants for an empirical equation for Z were evaluated. The equation takes the form of a power series in the pressure; thus,

$$Z = 1 + BP + CP^2 + DP^3 \qquad (3)$$

B, C and D are virial coefficients which depend on the temperature only. The simplest functions relating the virials to T were sought and it was found that the following equations gave the most satisfactory agreement:

$$B = b_1T^{-1} + b_2T^{-2} + b_4T^{-4} \quad (4)$$

$$C = c_1T^{-2} + c_2T^{-3} + c_3T^{-5} \quad (5)$$

$$D = d_1T^{-3} + d_2T^{-4} + d_3T^{-6} \quad (6)$$

The equation thus involves nine empirical constants derived from the experimental data and has the form:

$$Z = 1 + \left(\frac{b_1}{T} + \frac{b_2}{T^2} + \frac{b_4}{T^4}\right)P + \left(\frac{c_1}{T^2} + \frac{c_2}{T^3} + \frac{c_3}{T^5}\right)P^2 + \left(\frac{d_1}{T^3} + \frac{d_2}{T^4} + \frac{d_3}{T^6}\right)P^3 \quad (7)$$

While this equation is valid over a temperature range from $T_r = 1.1$ to $T_r = 1.28$, in the range $T_r = 1.05$ to $T_r = 1.1$ it was necessary to include a tenth term to reproduce the experimental values. The B virial in Equation (3) then takes the form:

$$B = b_1{}^1 \; T^{-1} + b_2 \; T^{-2} + b_3 \; T^{-3} + b_4 \; T^{-4}$$

The constants for Equation (7) were evaluated using the following method:

1. Values of the compressibility factors were calculated using Equation (2) and experimental volume data and were plotted as a function of temperature and pressure. Since data at five temperatures were available five curves were obtained.

2. Solution of three simultaneous equations of the form:

   $$Z = 1 + BP + CP^2 + DP^3$$

   using three selected compressibility factors and corresponding pressures from each curve gave values of B, C and D which enabled values on these curves to be reproduced with reasonable accuracy.

3. The five values of each of the constants B, C and D were then plotted against the reciprocal of the temperature at which they were evaluated. Figure (1) is such a curve for values of C. Evaluation of Equations (4,5 and 6) to reproduce the resulting curves gave the values which appear in Table I.

In as much as the thermodynamic properties of a material can be calculated from derived relationships, the empirically determined equation for the compressibility factor was used to evaluate the effect of pressure on the enthalpy and entropy of trimethylamine. It has been shown (16,17) that the enthalpy of an ideal gas is independent of pressure and a function only of temperature. However, at elevated pressures all actual gases deviate from ideal behavior, and enthalpy changes with change in pressure particularly in the critical region. The enthalpy of a real gas relative to the enthalpy of an ideal gas when both are at the same temperature may be obtained by integration of

$$\left(\frac{\partial H}{\partial P}\right)_T = V - T\left(\frac{\partial V}{\partial T}\right)_P \qquad (8)$$

between the limits of existing pressure and zero pressure where all gases behave ideally and the enthalpy becomes independent of pressure. Thus

$$(H^* - H)_T = \int_0^P \left[T\left(\frac{\partial V}{\partial T}\right)_P - V\right]_T \partial P \qquad (9)$$

The value of $(H^*-H)_T$ may be expressed in terms of the compressibility factor as a variable and thus obtained from these factors for a specific material. Differentiation of Equation (1) gives

$$\left(\frac{\partial V}{\partial T}\right)_p = \frac{R}{P}\left[Z + T\left(\frac{\partial Z}{\partial T}\right)_p\right] \qquad (10)$$

combining Equations (8) and (10) ,

$$\left(\frac{\partial H}{\partial p}\right)_T = -\frac{RT^2}{P}\left(\frac{\partial Z}{\partial T}\right)_p \quad . \qquad (11)$$

On substituting Equation (7)

$$\left(\frac{\partial H}{\partial p}\right)_T = -\frac{RT^2}{P}\left(\frac{\partial}{\partial T}\left[1+\left(\frac{b_1}{T}+\frac{b_2}{T^2}+\frac{b_4}{T^4}\right)P+\left(\frac{c_1}{T^2}+\frac{c_2}{T^3}+\frac{c_3}{T^5}\right)P^2+\left(\frac{d_1}{T^3}+\frac{d_2}{T^4}+\frac{d_3}{T^6}\right)P^3\right]\right)_p . \qquad (12)$$

Differentiating and combining terms

$$\left(\frac{\partial H}{\partial p}\right)_T = R\left[\left(b_1+\frac{2b_2}{T}+\frac{4b_4}{T^3}\right)+\left(\frac{2c_1}{T}+\frac{3c_2}{T^2}+\frac{5c_3}{T^4}\right)P+\left(\frac{3d_1}{T}+\frac{4d_2}{T^3}+\frac{6d_3}{T^5}\right)P^2\right] \quad . \qquad (13)$$

Integration between p=o and p gives the desired expression

$$H^*-H_p = R\left[\left(b_1+\frac{2b_2}{T}+\frac{4b_4}{T^3}\right)P+\left(\frac{2c_1}{T}+\frac{3c_2}{T^2}+\frac{5c_3}{T^4}\right)\frac{P^2}{2}+\left(\frac{3d_1}{T^2}+\frac{4d_2}{T^3}+\frac{6d_3}{T^5}\right)\frac{P^3}{3}\right] . \qquad (14)$$

The entropy deviation of a gas from ideal behavior may be derived in a similar fashion from the Maxwell relation

$$\left[dS = -\left(\frac{\partial V}{\partial T}\right)_p dp\right]_T \qquad (15)$$

From Hougen and Watson (17) pg. 497, Equation 24,

$$\left(S_p^*-S_p\right)_T = -R\int_0^p\left[\frac{1-Z}{P}-\frac{T}{P}\left(\frac{\partial Z}{\partial T}\right)_p\right]dp$$

Substitution of Equation (7), differentiation and combination of terms gives:

$$\left(S_p^* - S_p\right)_T = -R\int_0^p\left[\left(\frac{b_2}{T^2}+\frac{3b_4}{T^4}\right)+\left(\frac{c_1}{T^2}+\frac{2c_2}{T^3}+\frac{4c_3}{T^5}\right)p+\left(\frac{2d_1}{T^3}+\frac{3d_2}{T^4}+\frac{5d_3}{T^6}\right)p^2\right]dp. \qquad (17)$$

Integration between p=o and p gives the desired expression:

$$\left(S_p^* - S_p\right)_T = -R\left[\left(\frac{b_2}{T^2}+\frac{3b_4}{T^4}\right)p+\left(\frac{c_1}{T^2}+\frac{2c_2}{T^3}+\frac{4c_3}{T^5}\right)\frac{p^2}{2}+\left(\frac{2d_1}{T^3}+\frac{3d_2}{T^4}+\frac{5d_3}{T^6}\right)\frac{p^3}{3}\right]. \qquad (18)$$

METHOD OF CALCULATION

In the superheated vapor region between temperatures of 400°F and 540°F and pressures of 700 lb/in^2 to 1200 lb/in^2 calculations for specific volume, enthalpy and entropy are based on the equations derived from available experimental data. In the saturated vapor and liquid region and in the superheated vapor region outside the limits of pressure and temperature given above, calculations are made using the method of Hougen, Lydersen and Greenkorn (2). This method is based on the theorem of corresponding states and the values for PVT relationships as well as for each thermodynamic property have been obtained by these authors by evaluating 82 different compounds for which PVT data and the three critical constants Pc, Tc and Vc were available. All constants and equations used in this present study in making these calculations are listed in Table II.

The following steps were traversed in appraising the thermodynamic properties:

1. An arbitrary datum of unit mass of the saturated liquid at 32°F was chosen for zero value of enthalpy and a datum of 0°R for a zero value of entropy. The value for entropy at 32°F in the

ideal gaseous state at one atmosphere is 1.13534 Btu/lb ^{o}R (12).

2. The latent heat reported by Aston et al (8) as 166.95 Btu/lb was used in preference to other reported values. Values of the latent heat of vaporization from 32°F to the critical temperature were computed from Aston's value using Watson's method (18).

3. The following vapor pressure equations were used:

   a) from 32°F to 120°F (9)
   $\log_{10} P(mm) = -(2018.37/T) - 6.0303 \log T + 24.91300$

   b) from 120°F to 270°F (5)
   $\log_{10} P(mm) = -1202.2908/T + 7.250828$

   c) from 270°F to critical temperature (5)
   $\log_{10} P(mm) = -738.6065/T + .0028426T \quad 4.914884$

4. Volume of the saturated liquid was calculated from 32°F to 120°F using (7)

   density (g/cc) $= 0.87406 - 4.433 \times 10^{-4} T - 1.29236 \times 10^{-6} T^2$. From 120°F to critical temperature Hanson's method (3) was used. This method is based on the theorem of corresponding states and it allows calculation of the volume of a liquid at temperatures from the normal boiling point to the critical temperature. The only required data are the critical temperature and the critical volume, which are available for trimethylamine.

5. Volume of the saturated vapor was calculated using the compressibility factors taken from ref (2) using a value of $Zc = .286$ and Equation (1).
6. Enthalpy of the vapor at zero pressure and 32°F was obtained by adding the isothermal variation of enthalpy with pressure for saturated vapor to the latent heat of vaporization at this temperature. Values of the enthalpy over the entire temperature range at zero pressure were obtained by integrating the heat capacity Equation (12) at constant pressure with respect to the temperature in °F between 32°F and the temperature in question.
7. Values of enthalpy of the vapor at different pressures were obtained by subtracting the isothermal variation in enthalpy from the enthalpy at zero pressure. In the range 400°F to 540°F and 700 lb/in^2 to 1200 lb/in^2 the isothermal change in enthalpy with change of pressure was calculated from Equation (14). At other temperatures and pressures in the superheated vapor region and in the saturated vapor region the isothermal change in enthalpy with change of pressure was obtained from ref. (2).

8. Values of the enthalpy of the saturated liquid were found by subtracting the enthalpy of vaporization from the enthalpy of the saturated vapor at the same temperature.

9. Values of the Entropy over the entire temperature range in the ideal state at one atmosphere were found by evaluating the expression

$$\Delta S = \int_{T_1}^{T_2} C_p \frac{dT}{T}$$

between 32°F and the temperature in question and adding this value to the entropy in the ideal gaseous state at one atmosphere at 32°F.

10. Values of entropy of the vapor at different pressures were obtained by subtracting the isothermal variation in entropy from the entropy at one atmosphere. This variation is a combination of two correction factors, one for change in pressure under ideal behavior and a second for deviation from ideal behavior at the given temperature and pressure. The isothermal change in entropy with change in pressure for ideal behavior is evaluated from the expression

$$-R \ln \frac{P_2}{P_1}$$

In the range 400°F to 540°F and 600 lb/in^2 to 1200 lb/in^2 the isothermal correction for deviation from ideal behavior was obtained from Equation (18). At other temperatures and pressures in the superheated vapor region and in the saturated vapor region the isothermal correction for deviation from ideal behavior was obtained from ref. (2).

11. Values of the entropy of vaporization were derived by dividing the latent heat of vaporization by the absolute temperature.
12. Values of the entropy of the saturated liquid were found by subtracting the entropy of vaporization from the entropy of the saturated vapor at the same temperature.
13. Values of the volume in the superheated vapor region were computed from Equation (1) and compressibility factors derived from Equation (7) where applicable, and from ref. (2) at other temperatures and pressures.

DISCUSSION OF RESULTS

The lack of available experimental data in the literature makes it difficult to estimate the accuracy of this work. Since certain portions of the work are based on averaged data rather than direct experimental data, a high order of accuracy could not be attained. However, generalized methods for estimating thermodynamic properties of pure fluids based upon the theorem of corresponding states are commonly used where reliable experimental data or accurate equations of state for specific fluids are not available. These methods are satisfactory for most engineering purposes, such as process design, where extreme accuracy is not required. The data of Hougen et al (2) which were used in this investigation are a decided advance over previous generalized methods in that a third parameter, the critical compressibility factor Z_c, has been used to increase the accuracy. Methods have been developed which allow certain portions of the calculated data to be checked and this has been done.

Saturated liquid volumes in the range 32°F to 100°F were checked using the equation derived by Swift (6) from experimental data, and give good agreement with those reported in this work. The accuracy of the liquid volume above this temperature range is that of Hansen's method (3) which has been reported as $\pm 8\%$. The equation developed by Haggenmacher (20) was used to evaluate the volume of the saturated vapor at selected points and these values were compared with the values calculated using the compressibility factor and Equation (1). This equation is $v_g + v_l = (CT/P) - 2B$ where $C = R/\text{mol. wt.}$ and $B = (CT_c/2P_c) - v_c$. There is no significant deviation between the values obtained by these two methods. Values of the volume in the superheated vapor region where Equation (4) is applicable are consistent with the experimental data. At other temperatures and pressures the accuracy is dependent on the accuracy of the compressibility factor taken from reference (2). The deviation of these values from the experimental data from which they were derived is reported as increasing from zero at low pressures up to 2.5% in the critical region and then diminishing to 2.0% at higher pressures. The same order of accuracy should hold in this work.

Aston et al (8) have given values for the latent heat of vaporization at two temperatures and therefore Watson's method of obtaining the latent heat of vaporization at other temperatures could be checked. Agreement was obtained within 1% and values of the latent heat at other temperatures should be of the same order of accuracy.

Enthalpy values in the saturated and superheated vapor regions were obtained by correcting the enthalpy of the ideal gas as previously described. The enthalpy of the ideal gas at the datum temperature of 32°F was established by adding a correction for non-ideality of 4 Btu/lb to the enthalpy of the saturated vapor at that temperature. If this correction is in error by 30% the value for the enthalpy at the datum plane has an error of 0.5%. Such an error is well within the accuracy of this work. The use of the derived equation for $(H^*-H)_T$ in one region and values of $(H^*-H)_T$ from reference (2) in other regions resulted in some inconsistencies in values of enthalpy in the superheated vapor region. In this region values of enthalpy were plotted on a large scale graph and smoothed values, to remove the inconsistencies, taken from this graph are given in the tables. Figure 2, is such a graph for values at 700 lb/in^2 abs. Although Hougen et al (2) have not indicated the order of accuracy obtained using their data, Hougen and Watson (17) estimate the magnitude of the maximum error in the correction for non-ideality which may be encountered using generalized methods as 30%. Since the generalized method used in this work is more accurate than those for which this estimation was made and the correction terms are relatively small in themselves, the values given in this work should be more accurate than this.

Values of the entropy in the ideal gaseous state at one atmosphere were obtained using the data given by Kobe and Harrison (12) who report an average error of 0.18%.

The accuracy of entropy values at other pressures in the real gas state are dependent upon the accuracy of the corrections used. Hougen and Watson (17) estimate the maximum errors in generalized non-ideality corrections for the entropy of gas as 30%. The accuracy of the corrections used here should be better than this for the same reasons as given above. Again the use of two methods for obtaining these corrections, derived equation and reference (2), resulted in some inconsistencies and smoothed values are given in the tables.

The present work is the only systematic compilation of thermodynamic properties of trimethylamine. It is recommended that these values be used in engineering calculations where extreme accuracy is not required. Further experimental data must be collected before a more accurate evaluation of these properties may be presented.

APPENDIX

SAMPLE CALCULATIONS

$H^*_{32°F} = 169.65$ Btu/lb; $S^*_{1\ atm}$ at $32°F = 1.13534$ Btu/lb °R

Molal heat capacity in Btu/lb mole °F at zero pressure
$C_p = 19.055 + 3.9043\times10^{-2}T - 1.4186\times10^{-5}T^2 + 2.1317\times10^{-9}T^3$

Molal heat capacity in Btu/lb mole °R at zero pressure
$C_p = -2.098 + 5.3427\times10^{-2}T - 1.7126\times10^{-5}T^2 + 2.1317\times10^{-9}T^3$

$T_r nbp = .6374 \quad \lambda_b = 9867.6$ Btu/lb mole

a) At $T = 100°F$ $\quad P = 20$ lb/in^2

$$H^* = 169.65 + \frac{1}{59.11}\int_{32}^{100}\left[19.055 + 3.9043\times10^{-2}T - 1.4186\times10^{-5}T^2 + 2.1317\times10^{-9}T^3\right]dT$$

$H^* = 194.46$ Btu/lb

$\frac{H^* - H}{TC} = .142$ (ref. 2) $\quad H^* - H = 1.873$ Btu/lb

$H = 192.59$ Btu/lb

$$S^* = 1.13534 \ \frac{1}{59.11}\int_{492}^{560}\left[\frac{-2.098}{T} + 5.3437\times10^{-2} - 1.7126\times10^{-5}T + 2.1317\times10^{-9}T^2\right]dT$$

$S^* = 1.18254$ Btu/lb °R

$S^*_{20psia} = S^*_{14.7psia} - R\ln\frac{P_2}{P_1}$

$-R\ln\frac{P_2}{P_1} = 0.01035$ Btu/lb

$S^*_{20psia} - S = 0.00213$ Btu/lb (ref. 2)

$S = 1.18254 - .01035 - .00213 = 1.17006$ Btu/lb °R

$V = \frac{ZRT}{59.11P}$ $\quad Z = .962 \quad$ (ref.2)

$V = 4.8805$ ft^3/lb

b) At $T = 500^{o}F$ $P = 700$ Psi

$$H^{*} = 169.65 + \frac{1}{59.11}\int_{32}^{500}\left[19.055 + 3.9043x10^{-2}T - 1.4186x10^{-5}T^{2} + 2.1317x10^{-9}T^{3}\right]dT$$

$H^{*} = 393.30$ Btu/lb

$$H^{*}-H = 1.987\left[\left(68.51 - \frac{2(4.1206x10^{4})}{T} + \frac{4(3.829x10^{9})}{T^{3}}\right)P + \left(\frac{2(-9.407x10^{2})}{T} + \frac{3(7.819x10^{5})}{T^{2}} - \frac{5(8.095x10^{10})}{T^{4}}\right)\frac{P^{2}}{2} + \left(\frac{3(5.19x10^{3})}{T^{2}} - \frac{4(4.193x10^{6})}{T^{3}} + \frac{6(4.111x10^{11})}{T^{5}}\right)\frac{P^{3}}{3}\right]$$

where $T = {}^{o}K$ and $P = $ atm.

$H^{*}-H = 26.44$ Btu/lb

Using Hougen et al method (ref.2)

$H^{*}-H = 24.36$ Btu/lb

Values of $H^{*}-H$ from these two methods were determined over the temperature range and values of $H^{*}-H$ were smoothed so that consistent results were obtained. (Figure 2)

In this case

$H^{*}-H = 25.73$ Btu/lb

$H = 393.30 - 25.73 = 367.57$ Btu/lb

$$S^{*} = 1.13534 + \frac{1}{59.11}\int_{492}^{960}\left[\frac{-2.098}{T} + 5.3437x10^{-2} - 1.7126x10^{-5}T + 2.1317x10^{-9}T^{2}\right]dT$$

$S^{*} = 1.44549$

At saturation pressure $T = 100^oF$

vapor pressure

$\log_{10} P(mm) = -(2018.37/T) - 6.0303 \log T + 24.91300$

where $T = 273.16 \quad t^oc$

$P = 2401 mm = 46.43 lb/in^2$

$\frac{H^* - H}{T_C} = .317$ (ref.2) $H^* - H = 4.183$ Btu/lb

$H_{sat\,vap} = 190.28$ Btu/lb

$-R \ln \frac{P_2}{P_1} = .03867$ Btu/lb ^oR

$S^* - S = .00573$ Btu/lb ^oR (ref.2)

$S = 1.13814$ Btu/lb ^oR

Heat of vaporization $T_r = .7179$

$$\lambda_T = \left(\frac{1-T_r}{1-T_{rb}}\right)^{0.38} \lambda_{Tb}$$

$$\left(\frac{1-.7179}{1-.6374}\right)^{0.38} \frac{9867.6}{59.11} = 151.77 \text{ Btu/lb}$$

H sat. liquid $= 190.28 - 151.77 = 38.51$ Btu/lb

$S\ vap = \frac{H\ vap}{T} = \frac{151.77}{559.7} = 0.27102$ Btu/lb ^oR

S sat.liquid $= 1.13814 - .27102 = 0.86712$ Btu/lb ^oR

volume of saturated vapor
$Z = .900$ $V = 1.9608\ ft^3/lb$

volume of saturated liquid
density (g/cc) $= 0.87406 - 4.433 \times 10^{-4} T - 1.29236 \times 10^{-6} T^2$
where $T = {}^oK$
density at $100^oF = .62101$ g/cc
volume $= .02620\ ft^3/lb$

$$S^{*}-S=-1.987\left[\left(\frac{-4.1206\times10^{4}}{T^{2}}+\frac{3(3.829\times10^{9})}{T^{4}}\right)P\right.$$

$$+\left(\frac{-9.407\times10^{2}}{T^{2}}+\frac{2(7.819\times10^{5})}{T^{3}}+\frac{4(-8.095\times10^{10})}{T^{5}}\right)\frac{P^{2}}{2}$$

$$\left.+\left(\frac{2(5.19\times10^{3})}{T^{3}}+\frac{3(-4.193\times10^{6})}{T^{4}}+\frac{5(4.111\times10^{11})}{T^{6}}\right)\frac{P^{3}}{3}\right]$$

$S^{*}-S=1.237$ Btu/lb mole ^{o}R

$S^{*}-S=1.08$ Btu/lb mole ^{o}R (Hougen et al)

Using smoothed values

$S^{*}-S=1.11$ Btu/lb mole $^{o}R=.01979$ Btu/lb ^{o}R

$-R\ln\frac{P_2}{P_1}=.12989$ Btu/lb

$S=1.44549-.12989-.01979=1.29581$ Btu/lb ^{o}R

Volume of superheated vapor

$Z=.786$ $V=.1953\ ft^3/lb$

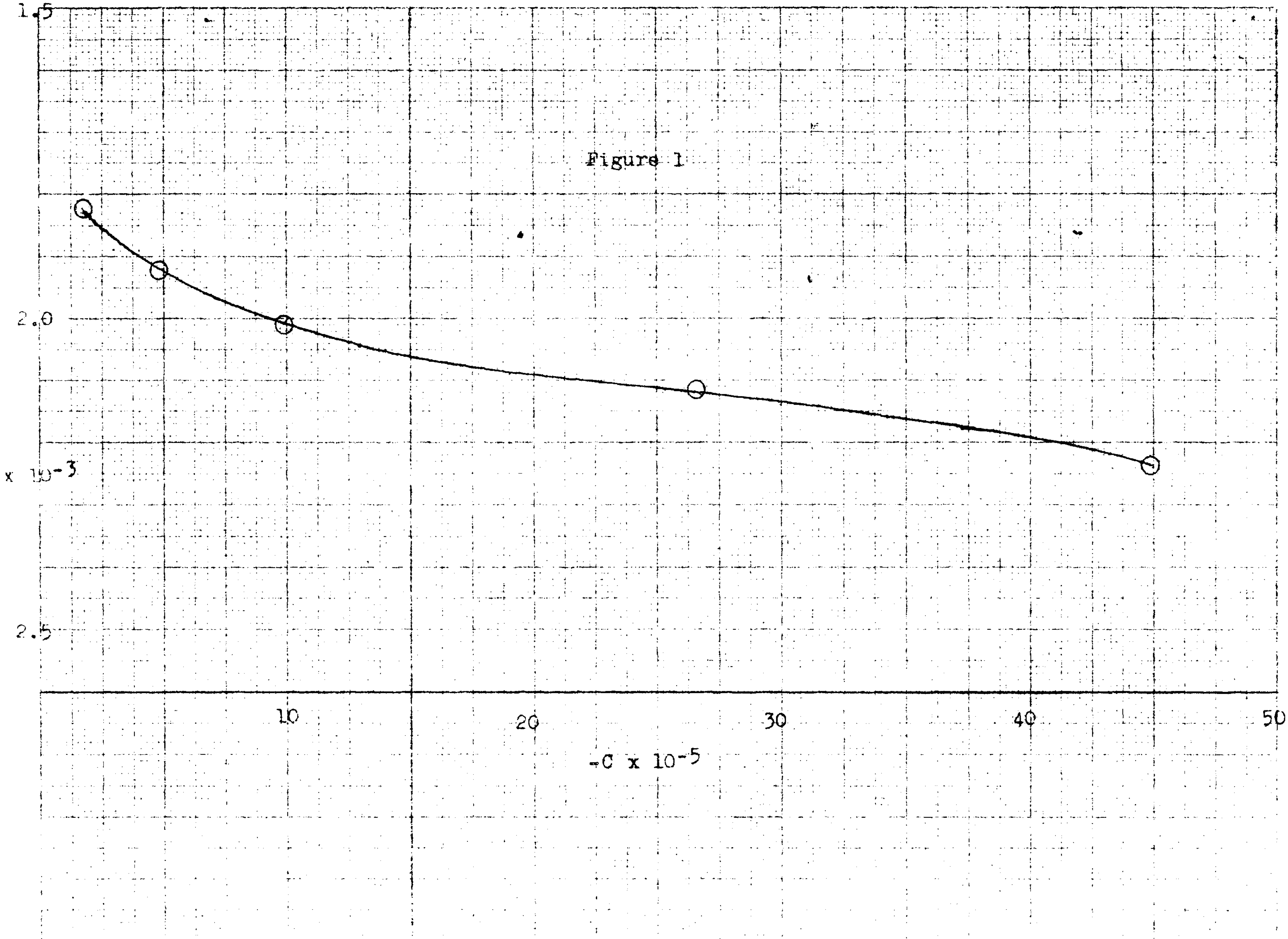

Figure 1

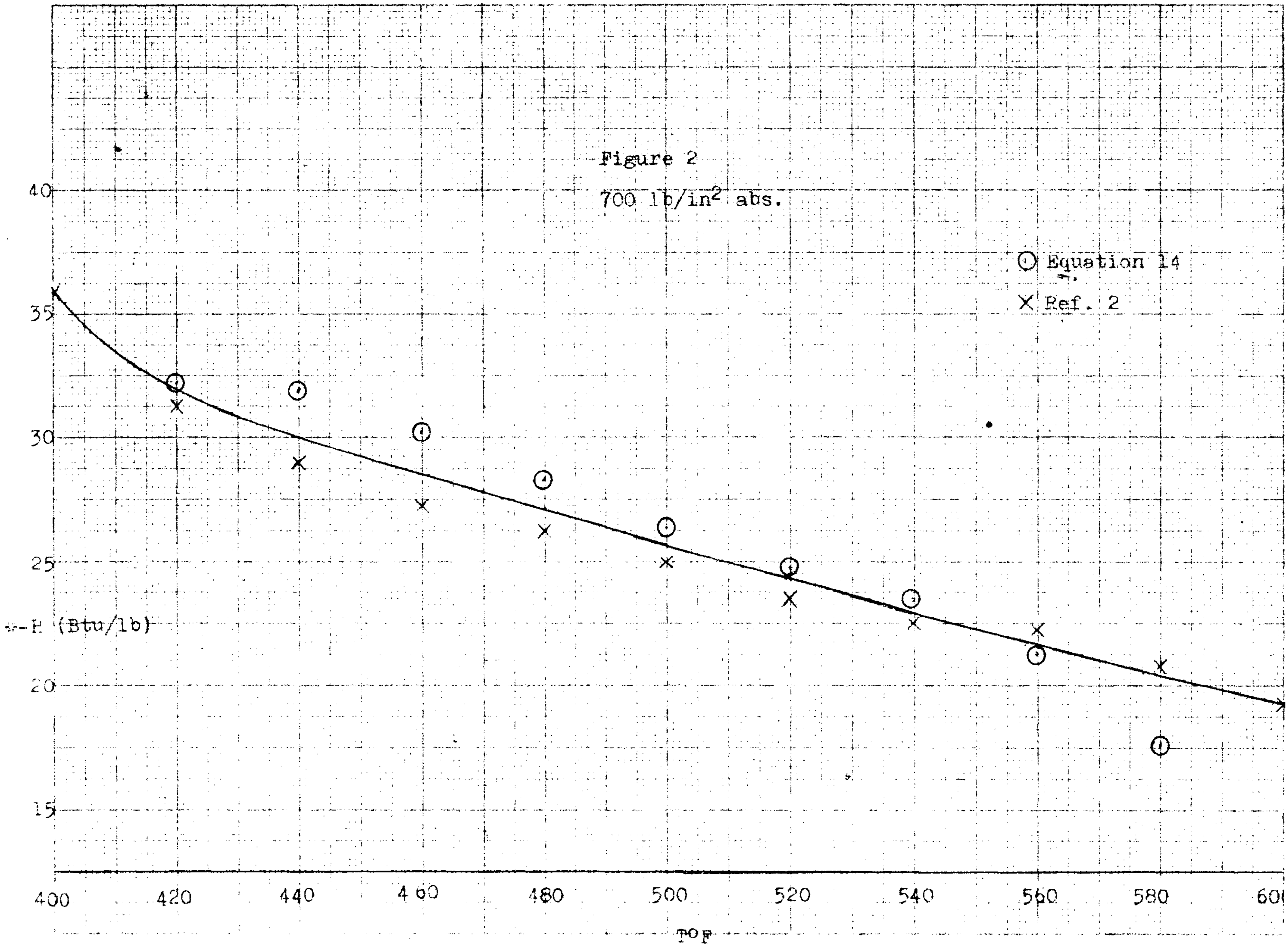
Figure 2
700 lb/in2 abs.
Equation 14
Ref. 2
40
35
30
25
20
15
-H (Btu/lb)
400
420
440
460
480
500
520
540
560
580
600
T°F

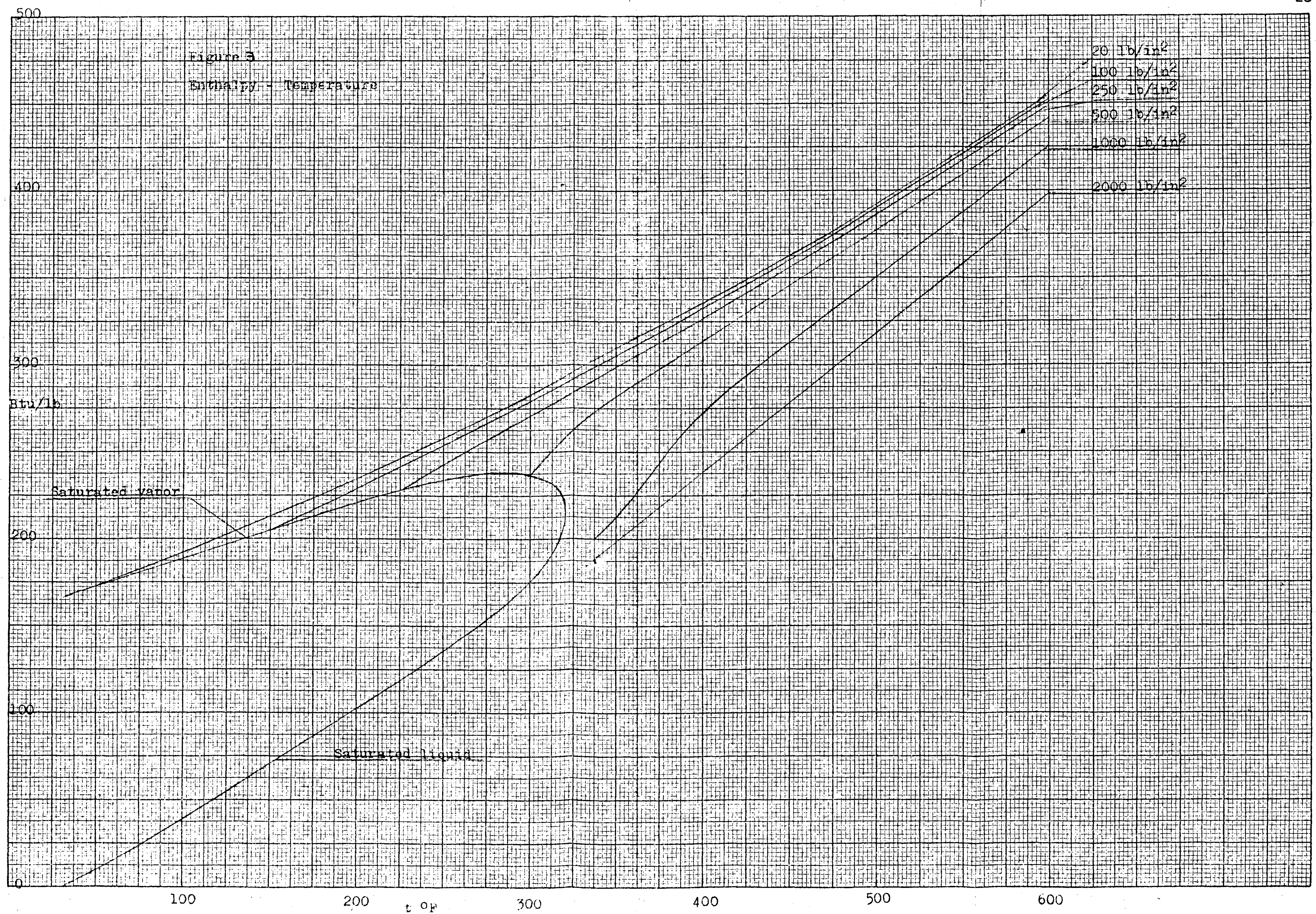
Figure 3
Enthalpy - Temperature
20 lb/in²
100 lb/in²
250 lb/in²
500 lb/in²
1000 lb/in²
2000 lb/in²
Saturated vapor
Saturated liquid
Btu/lb
500
400
300
200
100
0
100
200
300
400
500
600
t °F

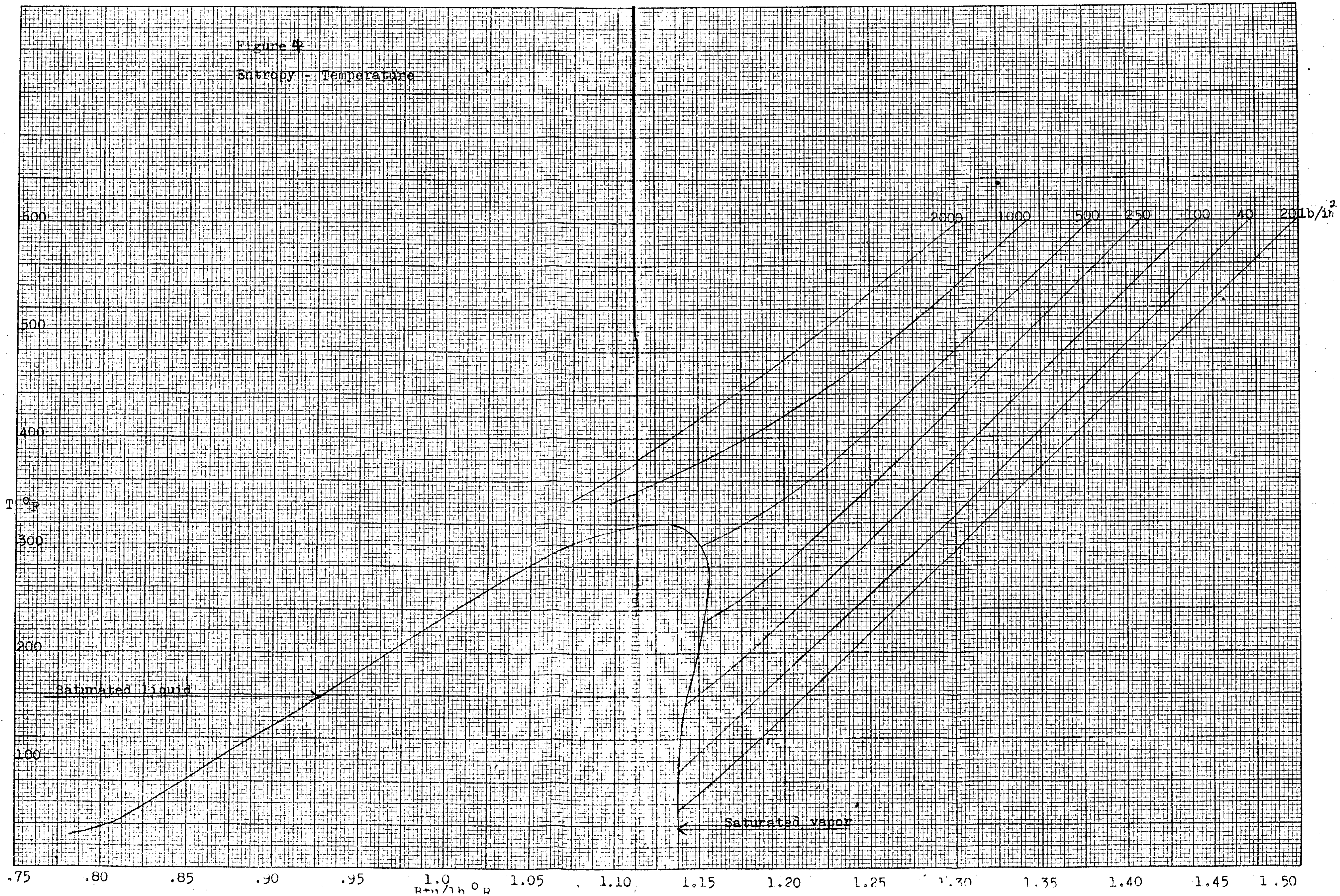
Figure 4
Entropy - Temperature
600
500
400
300
200
100
T °F
2000
1000
500
250
100
40
20 lb/in²
Saturated liquid
Saturated vapor
.75
.80
.85
.90
.95
1.0
1.05
1.10
1.15
1.20
1.25
1.30
1.35
1.40
1.45
1.50
Btu/lb °R

TABLE I

Derived Constants for Compressibility Factor Equation

b_1	+68.51
b_2	-8.2412×10^{4}
b_4	$+1.5316 \times 10^{10}$
b_1'	$+1.5247 \times 10^{3}$
b_2'	-4.514×10^{6}
b_3'	$+3.3201 \times 10^{9}$
b_4'	-7.1968×10^{11}
c_1	-9.407×10^{2}
c_2	$+7.819 \times 10^{5}$
c_3	-8.095×10^{10}
d_1	$+5.19 \times 10^{3}$
d_2	$+4.193 \times 10^{6}$
d_3	$+4.111 \times 10^{11}$

TABLE II

Constants and Equations Used In Calculations

t_c = 160.15 °C

P_c = 40.24 atm.

V_c = 4.28 ml/g

C_p = $19.055 + 3.904 \times 10^{-2} t - 1.4186 \times 10^{-5} t^2 + 2.1317 \times 10^{-9} t^3$ - Btu/lb mole °F

C_p = $-2.098 + 5.3437 \times 10^{-2} t - 1.7126 \times 10^{-5} t^2 + 2.1317 \times 10^{-9} t^3$ - Btu/lb mole °R

h_{nbp} = 166.95 Btu/lb

S*(1 atm., 32°F) = 1.13534 Btu/lb °R

R = 1.987 (Cal)/(g-mole) (°K); 82.06 (cu. cm.) (atm.)/(g-mole) °K; 10.71 (lb/in^2) (ft^3)/(lb-mole) °R

T °R = 459.7 + t°F

T °K = 273.16 + t°C

$$\Delta H = \int C_p \, dT$$

$$\Delta S = \int C_p \frac{dT}{T} - R \ln \frac{P_2}{P_1}$$

TABLE III

Thermodynamic Properties of Saturated Trimethylamine

T °F	Abs. Press. lb/in²	Volume ft³/lb Liquid	Volume ft³/lb Vapor	Enthalpy Btu/lb Liquid	Enthalpy Btu/lb Evap.	Enthalpy Btu/lb Vapor	Entropy Btu/lb °R Liquid	Entropy Btu/lb °R Evap.	Entropy Btu/lb °R Vapor
32	13.21	0.02440	6.5795	0	168.13	168.13	0.78529	0.35173	1.13702
37.16	14.7	0.02453	5.9321	2.76	166.95	169.71	0.80087	0.33581	1.13668
40	15.38	0.02460	5.6547	4.37	166.21	170.68	0.80454	0.33242	1.13696
60	23.10	0.02510	3.8217	15.16	161.69	176.85	0.82556	0.31094	1.13650
80	32.20	0.02564	2.7954	26.84	156.86	183.70	0.84712	0.29048	1.13760
100	46.43	0.02620	1.9668	38.51	151.77	190.28	0.86712	0.27102	1.13814
120	62.92	0.02702	1.4581	50.69	146.33	197.02	0.88727	0.25229	1.13956
140	84.95	0.02796	1.0826	62.91	140.61	203.52	0.90741	0.23435	1.14176
160	110.7	0.02890	0.83313	75.75	134.39	210.14	0.92722	0.21676	1.14398
180	142.4	0.02982	0.64738	88.90	127.80	216.70	0.94678	0.19969	1.14647
200	184.1	0.03099	0.50016	100.55	120.53	221.08	0.96640	0.18262	1.14902
220	225.2	0.03222	0.40534	113.89	112.44	226.33	0.98611	0.16535	1.15146
240	277.8	0.03378	0.31228	128.37	102.72	231.09	1.00709	0.14674	1.15383

T °F	Abs. Press. lb/in²	Volume ft³/lb Liquid	Volume ft³/lb Vapor	Enthalpy Btu/lb Liquid	Enthalpy Btu/lb Evap.	Enthalpy Btu/lb Vapor	Entropy Btu/lb °R Liquid	Entropy Btu/lb °R Evap.	Entropy Btu/lb °R Vapor
260	338.6	0.03575	0.24658	143.15	92.65	235.80	1.02698	0.12868	1.15566
280	409.2	0.03820	0.18803	160.06	78.68	238.74	1.05228	0.10362	1.15590
300	498.2	0.04353	0.13820	175.05	61.06	236.11	1.07191	0.08034	1.15225
320	589.9	0.06250	0.06948	214.89	12.60	227.49	1.12167	0.01615	1.13782
320.28	591.4	0.06858	0.06858	222.30	0	222.30	1.13566	0	1.13566

TABLE IV

Thermodynamic Properties

of

Superheated Trimethylamine

from 20 lb/in^2 to 2000 lb/in^2

Abs. press. 20 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
51.9	4.4056	175.42	1.13682
60	4.4894	177.31	1.14289
80	4.6863	184.85	1.15623
100	4.8805	192.59	1.17006
120	5.0705	200.51	1.18294
140	5.2617	208.70	1.19780
160	5.4537	217.15	1.21162
180	5.6472	225.82	1.22521
200	5.8416	235.08	1.23874
220	6.0372	243.86	1.25228
240	6.2274	253.19	1.26582
260	6.4184	262.35	1.27944
280	6.6101	272.50	1.29288
300	6.7956	282.47	1.30624
320	6.9815	292.66	1.31945
340	7.1678	303.02	1.33344
360	7.3470	313.25	1.34665
380	7.5337	324.36	1.35855
400	7.7209	335.31	1.37110
420	7.9085	345.95	1.38426
440	8.0964	357.82	1.39702
460	8.2846	369.42	1.40970

T °F	V ft³/lb	H Btu/lb	S Btu/lb °R
480	8.4729	381.05	1.42232
500	8.6528	392.91	1.43482
520	8.8339	404.96	1.44723
540	9.0232	417.17	1.45959
560	9.2034	429.56	1.47185
580	9.3837	442.12	1.48405
600	9.5735	454.84	1.49617

Abs. press. 40 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
91.1	2.2666	187.76	1.13771
100	2.3387	190.50	1.14251
120	2.4591	198.74	1.15764
140	2.5656	207.15	1.17230
160	2.6708	215.76	1.18663
180	2.7743	224.52	1.20073
200	2.8760	233.85	1.21459
220	2.9755	242.70	1.22822
240	3.0757	252.11	1.24179
260	3.1733	261.78	1.25529
280	3.2719	271.60	1.26875
300	3.3703	281.63	1.28209
320	3.4660	291.88	1.29539
340	3.5621	302.30	1.30950
360	3.6549	312.60	1.32278
380	3.7479	323.77	1.33473
400	3.8410	334.78	1.34735
420	3.9343	345.46	1.36059
440	4.0278	357.35	1.37339
460	4.1215	368.99	1.38608
480	4.2151	380.67	1.39868

T °F	V ft³/lb	H Btu/lb	S Btu/lb °R
500	4.3095	392.55	1.41118
520	4.4036	404.63	1.42361
540	4.4974	416.86	1.43597
560	4.5878	429.26	1.44825
580	4.6801	441.83	1.46045
600	4.7723	454.56	1.47258

Abs. press. 60 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
116.8	1.5328	195.60	1.13932
120	1.5851	197.02	1.14267
140	1.6615	205.50	1.15695
160	1.7318	214.24	1.17097
180	1.8012	223.17	1.18489
200	1.8715	232.56	1.19876
220	1.9405	241.51	1.21256
240	2.0082	251.01	1.22730
260	2.0764	260.73	1.23997
280	2.1453	270.68	1.25358
300	2.2147	280.77	1.26711
320	2.2824	291.08	1.28057
340	2.3488	301.64	1.29485
360	2.4118	311.94	1.30827
380	2.4757	323.13	1.32037
400	2.5398	334.17	1.33304
420	2.6043	344.91	1.34623
440	2.6689	356.85	1.35902
460	2.7310	368.54	1.37183
480	2.7931	380.15	1.38455
500	2.8556	392.05	1.39708
520	2.9182	404.14	1.40952
540	2.9820	416.42	1.42193

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
560	3.0462	428.83	1.43419
580	3.1090	441.41	1.44641
600	3.1719	454.14	1.45855

Abs. press. 80 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
135.9	1.1499	202.00	1.14115
140	1.2026	203.92	1.14501
160	1.2230	212.91	1.15961
180	1.3005	221.85	1.17387
200	1.3752	231.44	1.18791
220	1.4292	240.52	1.20188
240	1.4823	250.09	1.21578
260	1.5361	259.94	1.22962
280	1.5888	269.95	1.24340
300	1.6404	280.17	1.25693
320	1.6924	290.56	1.27040
340	1.7412	301.11	1.28467
360	1.7884	311.42	1.29817
380	1.8416	322.61	1.31036
400	1.8919	333.65	1.32303
420	1.9392	344.42	1.33631
440	1.9873	356.41	1.34918
460	2.0357	368.15	1.36199
480	2.0820	379.86	1.37471
500	2.1286	391.78	1.38726
520	2.1751	403.89	1.39972
540	2.2240	416.13	1.41209

T °F	V ft³/lb	H Btu/lb	S Btu/lb °R
560	2.2731	428.55	1.42438
580	2.3223	441.14	1.43660
600	2.3694	453.88	1.44875

Abs. press. 100 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
152.2	0.9217	208.52	1.14307
160	0.9661	210.81	1.14991
180	1.0112	220.27	1.16490
200	1.0643	229.93	1.17888
220	1.1150	239.00	1.19301
240	1.1605	248.64	1.20709
260	1.2067	258.62	1.22101
280	1.2496	268.83	1.23487
300	1.2916	278.99	1.24857
320	1.3341	289.37	1.26221
340	1.3755	299.99	1.27666
360	1.4173	310.62	1.29016
380	1.4580	321.95	1.30234
400	1.4990	333.12	1.31518
420	1.5386	343.92	1.32846
440	1.5785	355.93	1.34133
460	1.6169	367.62	1.35414
480	1.6554	379.35	1.36686
500	1.6942	391.32	1.37947
520	1.7330	403.49	1.39200
540	1.7702	415.83	1.40443
560	1.8074	428.27	1.41674

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
580	1.8446	440.90	1.42896
600	1.8821	453.67	1.44112

Abs. press. 125 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
169.6	0.7447	213.93	1.14518
180	0.7792	218.02	1.15411
200	0.8227	228.34	1.16942
220	0.8743	237.69	1.18383
240	0.9071	247.39	1.19824
260	0.9497	257.31	1.21241
280	0.9815	267.64	1.22636
300	1.0168	278.06	1.24023
320	1.0515	288.45	1.25403
340	1.0854	299.21	1.26848
360	1.1196	309.78	1.28215
380	1.1518	321.20	1.29434
400	1.1843	332.43	1.30717
420	1.2169	343.31	1.32062
440	1.2498	355.33	1.33366
460	1.2828	367.09	1.34647
480	1.3148	378.83	1.35919
500	1.3456	390.79	1.37179
520	1.3793	402.94	1.38430
540	1.4103	415.23	1.39671
560	1.4400	427.69	1.40902
580	1.4697	440.42	1.42126
600	1.4995	453.29	1.43341

Abs. press. 150 lb/in^2

T ^oF	V ft^3/lb	H Btu/lb	S Btu/lb ^oR
184.3	0.6173	218.70	1.14703
200	0.6617	226.23	1.16108
220	0.7006	235.97	1.17665
240	0.7356	246.13	1.19120
260	0.7679	256.25	1.20527
280	0.8000	266.46	1.21938
300	0.8308	276.88	1.23342
320	0.8611	287.65	1.24723
340	0.8909	298.47	1.26184
360	0.9202	309.04	1.27551
380	0.9497	320.49	1.28770
400	0.9775	331.80	1.30054
420	1.0045	342.66	1.31399
440	1.0317	354.74	1.32702
460	1.0591	366.56	1.33983
480	1.0866	378.29	1.35255
500	1.1132	390.27	1.36520
520	1.1400	402.44	1.37778
540	1.1669	414.77	1.39026
560	1.1938	427.28	1.40263
580	1.2210	439.91	1.41491
600	1.2470	452.68	1.42712

Abs. press. 175 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
197.4	0.5289	222.41	1.14865
200	0.5433	224.52	1.15284
220	0.5773	234.38	1.16962
240	0.6081	244.42	1.18452
260	0.6374	254.53	1.19889
280	0.6658	265.14	1.21318
300	0.6948	275.69	1.22722
320	0.7228	286.47	1.24119
340	0.7496	297.42	1.25581
360	0.7760	308.11	1.26964
380	0.8019	319.70	1.28200
400	0.8281	331.01	1.29484
420	0.8519	342.00	1.30829
440	0.8759	354.08	1.32133
460	0.8992	365.90	1.33430
480	0.9246	377.63	1.34702
500	0.9482	389.61	1.35966
520	0.9721	401.78	1.37218
540	0.9950	414.11	1.38466
560	1.0180	426.62	1.39702
580	1.0412	439.31	1.40930
600	1.0634	452.09	1.42150

Abs. press. 200 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
209.2	0.4628	225.30	1.15013
220	0.4805	230.56	1.15998
240	0.5137	241.65	1.17608
260	0.5420	252.55	1.19214
280	0.5678	263.29	1.20649
300	0.5935	274.10	1.22069
320	0.6190	285.15	1.23484
340	0.6450	296.10	1.24980
360	0.6686	306.93	1.26397
380	0.6917	318.52	1.27650
400	0.7137	329.95	1.28950
420	0.7358	341.08	1.30312
440	0.7583	353.29	1.31616
460	0.7801	365.11	1.32914
480	0.8021	376.84	1.34194
500	0.8236	388.88	1.35468
520	0.8443	401.12	1.36725
540	0.8642	413.45	1.37968
560	0.8852	425.96	1.39202
580	0.9064	438.79	1.40430
600	0.9276	451.76	1.41650

Abs. press. 250 lb/in^2

T ^oF	V ft^3/lb	H Btu/lb	S Btu/lb ^oR
228.8	0.3544	230.22	1.15252
240	0.3780	237.16	1.16589
260	0.4070	248.07	1.18192
280	0.4317	259.45	1.19603
300	0.4539	270.67	1.21110
320	0.4765	281.98	1.22575
340	0.4975	293.33	1.24087
360	0.5182	304.42	1.25505
380	0.5376	316.14	1.26775
400	0.5566	327.71	1.28110
420	0.5753	338.84	1.29488
440	0.5942	351.18	1.30800
460	0.6134	363.13	1.32098
480	0.6316	375.13	1.33382
500	0.6485	387.23	1.34660
520	0.6648	399.53	1.35927
540	0.6813	412.00	1.37186
560	0.6978	424.64	1.38437
580	0.7138	437.40	1.39673
600	0.7298	450.31	1.40897

Abs. press. 300 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
247.6	0.2863	235.10	1.15448
260	0.3139	242.66	1.16720
280	0.3352	255.38	1.18558
300	0.3562	267.11	1.20080
320	0.3783	278.55	1.21580
340	0.3972	290.16	1.23109
360	0.4155	301.39	1.24560
380	0.4323	313.37	1.25855
400	0.4493	325.07	1.27198
420	0.4656	336.33	1.28594
440	0.4821	348.80	1.29932
460	0.4995	360.89	1.31246
480	0.5171	373.02	1.32544
500	0.5316	385.38	1.33830
520	0.5469	397.82	1.35109
540	0.5605	410.28	1.36377
560	0.5735	423.06	1.37640
580	0.5879	435.88	1.38889
600	0.6024	448.86	1.40118

Abs. press. 350 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
263.5	0.2341	236.60	1.15576
280	0.2643	248.91	1.17312
300	0.2845	262.10	1.19037
320	0.3049	274.86	1.20664
340	0.3243	286.60	1.22270
360	0.3413	298.62	1.23755
380	0.3510	310.73	1.25075
400	0.3726	322.70	1.26427
420	0.3881	334.09	1.27822
440	0.4035	346.56	1.29160
460	0.4182	358.78	1.30508
480	0.4316	370.90	1.31831
500	0.4448	383.27	1.33130
520	0.4576	395.84	1.34422
540	0.4706	408.57	1.35706
560	0.4842	421.48	1.36983
580	0.4975	434.56	1.38236
600	0.5103	447.80	1.39473

Abs. press. 400 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
277.4	0.1961	238.30	1.15595
280	0.2095	240.47	1.16002
300	0.2358	255.63	1.18021
320	0.2562	271.03	1.19844
340	0.2736	283.56	1.21448
360	0.2897	295.84	1.23035
380	0.3044	308.22	1.24389
400	0.3190	320.32	1.25775
420	0.3332	331.84	1.27204
440	0.3477	344.58	1.28559
460	0.3609	356.93	1.29890
480	0.3739	369.19	1.31213
500	0.3862	381.56	1.32528
520	0.3986	394.26	1.33837
540	0.4099	406.99	1.35130
560	0.4209	419.76	1.36407
580	0.4315	432.85	1.37660
600	0.4422	446.09	1.38897

Abs. press. 450 lb/in^2

T ^oF	V ft^3/lb	H Btu/lb	S Btu/lb ^oR
289.2	0.1683	238.20	1.15482
300	0.1836	251.01	1.16760
320	0.2120	265.09	1.18913
340	0.2271	278.15	1.20714
360	0.2427	292.02	1.22317
380	0.2581	305.19	1.23739
400	0.2722	317.68	1.25142
420	0.2856	329.20	1.26588
440	0.2986	341.94	1.27976
460	0.3112	354.69	1.29342
480	0.3224	366.95	1.30682
500	0.3336	379.18	1.31997
520	0.3445	392.15	1.33306
540	0.3555	405.01	1.34607
560	0.3667	418.04	1.35885
580	0.3781	431.26	1.37154
600	0.3892	444.63	1.38417

Abs. press. 500 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
300.4	0.1361	236.40	1.15280
320	0.1682	257.83	1.17760
340	0.1890	273.14	1.19630
360	0.2089	287.79	1.21541
380	0.2259	301.23	1.23081
400	0.2384	314.52	1.24551
420	0.2503	326.70	1.26031
440	0.2619	339.83	1.27436
460	0.2734	352.31	1.28802
480	0.2844	364.83	1.30141
500	0.2957	377.60	1.31474
520	0.3061	390.43	1.32800
540	0.3163	403.42	1.34118
560	0.3260	416.46	1.35429
580	0.3380	429.81	1.36715
600	0.3457	443.18	1.37978

Abs. press. 550 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
311.4	0.0991	234.12	1.14753
320	0.1182	247.28	1.15757
340	0.1555	266.14	1.18482
360	0.1783	283.44	1.20745
380	0.1937	298.99	1.22438
400	0.2068	311.48	1.23942
420	0.2197	324.03	1.25473
440	0.2313	337.45	1.26929
460	0.2425	350.20	1.28312
480	0.2524	362.72	1.29668
500	0.2625	365.62	1.31018
520	0.2728	388.58	1.32343
540	0.2827	401.71	1.33662
560	0.2927	414.75	1.34972
580	0.3029	427.83	1.36276
600	0.3122	440.94	1.37556

Abs. press. 600 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
340	0.1232	256.80	1.17108
360	0.1511	277.30	1.19963
380	0.1674	293.97	1.21775
400	0.1810	308.44	1.23363
420	0.1948	321.29	1.24910
440	0.2066	334.94	1.26383
460	0.2164	347.96	1.27800
480	0.2265	360.48	1.29190
500	0.2363	373.37	1.30556
520	0.2462	386.34	1.31899
540	0.2549	399.46	1.33234
560	0.2634	412.90	1.34545
580	0.2720	426.51	1.35849
600	0.2807	440.15	1.37128

Abs. press. 700 lb/in^2

T $^\circ$F	V ft^3/lb	H Btu/lb	S Btu/lb $^\circ$R
340	0.06964	227.49	1.13510
360	0.1040	258.77	1.17583
380	0.1234	281.70	1.20240
400	0.1391	300.27	1.22150
420	0.1519	314.56	1.23814
440	0.1655	328.21	1.25340
460	0.1774	341.23	1.26790
480	0.1861	354.28	1.28197
500	0.1953	367.57	1.29581
520	0.2044	381.06	1.30974
540	0.2128	394.58	1.32326
560	0.2210	398.28	1.33637
580	0.2291	422.03	1.34941
600	0.2368	435.79	1.36220

Abs. press. 800 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
340	0.05073	212.76	1.11455
360	0.07150	245.30	1.15511
380	0.09322	269.16	1.18253
400	0.1077	287.46	1.20349
420	0.1206	303.87	1.22320
440	0.1323	319.38	1.23996
460	0.1439	333.97	1.25581
480	0.1533	347.42	1.27056
500	0.1609	362.03	1.28524
520	0.1687	375.65	1.29985
540	0.1766	389.57	1.31422
560	0.1848	403.53	1.32817
580	0.1932	417.67	1.34171
600	0.2012	431.97	1.35501

Abs. press. 900 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
340	0.04509	204.79	1.10467
360	0.05448	231.45	1.13897
380	0.07086	255.57	1.16858
400	0.08449	278.49	1.19293
420	0.09744	295.82	1.21365
440	0.1087	312.78	1.23109
460	0.1202	328.56	1.24796
480	0.1272	342.67	1.26338
500	0.1368	357.14	1.27840
520	0.1460	371.56	1.29335
540	0.1552	386.00	1.30755
560	0.1637	399.97	1.32167
580	0.1696	414.37	1.33504
600	0.1750	428.80	1.34818

Abs. press. 1000 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
340	0.04261	200.43	1.09722
360	0.04873	223.40	1.12612
380	0.05783	248.97	1.15488
400	0.06731	270.97	1.17923
420	0.07940	289.09	1.20113
440	0.08969	304.99	1.22060
460	0.10001	322.36	1.23882
480	0.10865	336.73	1.25476
500	0.1171	357.87	1.27046
520	0.1252	367.87	1.28591
540	0.1326	381.91	1.30078
560	0.1395	396.14	1.31508
580	0.1460	411.60	1.32913
600	0.1517	425.50	1.34209

Abs. press. 1200 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
340	0.03889	196.34	1.08923
360	0.04222	215.22	1.11339
380	0.04718	238.55	1.14030
400	0.05194	260.68	1.16565
420	0.05926	280.12	1.18908
440	0.06686	298.26	1.20720
460	0.07529	313.91	1.22576
480	0.08132	328.70	1.24152
500	0.08944	344.61	1.25739
520	0.09663	359.55	1.27318
540	0.10418	374.92	1.28873
560	0.11027	389.67	1.30387
580	0.11541	404.48	1.31843
600	0.12243	419.83	1.33258

Abs. press 1400 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
340	0.03624	195.81	1.08455
360	0.03926	212.31	1.10888
380	0.04261	233.27	1.13308
400	0.04563	252.89	1.15573
420	0.04863	271.59	1.17882
440	0.05839	289.29	1.19642
460	0.06215	305.53	1.21515
480	0.06740	320.23	1.23109
500	0.07231	336.30	1.24678
520	0.07914	351.63	1.26207
540	0.08477	367.27	1.27813
560	0.09056	382.15	1.29377
580	0.09556	397.22	1.30850
600	0.10220	414.02	1.32316

Abs. press. 1600 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
340	0.03614	193.30	1.08107
360	0.03807	210.20	1.10387
380	0.04033	229.31	1.12587
400	0.04295	247.35	1.14734
420	0.04634	262.70	1.16806
440	0.04892	282.43	1.18634
460	0.05459	298.87	1.20440
480	0.05822	313.90	1.22050
500	0.06349	329.96	1.23704
520	0.06814	345.57	1.25283
540	0.07304	360.80	1.26856
560	0.07716	376.48	1.28454
580	0.08102	391.94	1.29876
600	0.08642	409.01	1.31257

Abs. press.1800 lb/in^2

T ^oF	V ft^3/lb	H Btu/lb	S Btu/lb ^oR
340	0.03462	190.53	1.07797
360	0.03665	207.83	1.09942
380	0.03889	224.30	1.12007
400	0.04104	241.81	1.14001
420	0.04394	260.19	1.16023
440	0.04666	276.49	1.17766
460	0.05149	292.40	1.19572
480	0.05611	307.56	1.21284
500	0.05943	323.76	1.22938
520	0.06234	339.36	1.25785
540	0.06513	355.26	1.26106
560	0.06776	371.73	1.27620
580	0.07129	386.79	1.29126
600	0.07660	402.80	1.30575

Abs. press. 2000 lb/in^2

T °F	V ft^3/lb	H Btu/lb	S Btu/lb °R
340	0.03334	189.48	1.07475
360	0.03604	205.98	1.09569
380	0.03783	222.71	1.11600
400	0.03967	239.96	1.13459
420	0.04209	256.50	1.15379
440	0.04403	273.45	1.17246
460	0.04709	288.84	1.18979
480	0.04973	304.66	1.20623
500	0.05279	319.01	1.22277
520	0.05593	335.67	1.23890
540	0.05898	351.83	1.25481
560	0.06182	368.03	1.27027
580	0.06520	384.16	1.28549
600	0.06818	398.98	1.30050

NOMENCLATURE

P	pressure
V	volume
Z	compressibility factor
R	gas constant
T	absolute temperature
t	temperature °F or °C as noted
B, C, D	viral coefficients
b_1', b_2', b_3', b_4', c_1, c_2, c_3, d_1, d_2, d_3, b_1, b_2, b_4	constants in the equation for Z
C_p	specific heat at constant pressure
H	enthalpy
S	entropy
λ	heat of vaporization
$*$	ideal gaseous state when used as superscript
p	constant pressure when used as subscript
T	constant temperature when used as subscript
r	reduced condition when used as subscript
c	critical state when used as subscript

REFERENCES

1. West, James R., _Chemical Engineering Progress_, April 1948, Vol 44, pp. 287-292.

2. Hougen, O. A., Lydersen, A. L., Greenkorn, R. A., _Generalized Thermodynamic Properties of Pure Fluids_, Eng. Exp. Station Report No. 4, University of Wisconsin, 1955.

3. Hansen, E. S., Ind. Eng. Chem., Jan. 1949., pp. 96-99

4. Day, H. O., and Felsing, W. A., _J. Am. Chem. Soc._, Vol. 73., 1951, pp. 5868-5869.

5. Day, H. O., and Felsing, W. A., _J. Am. Chem. Soc._, Vol. 72, 1950, pp. 1698-1700.

6. Swift, E., _J. Am. Chem. Soc._, Vol. 64, 1942, pp. 155-166.

7. Felsing, W. A. and Phillips, B. S., _J. Am. Chem. Soc._, Vol. 58, 1936, pp. 1973-1975.

8. Aston, J. G., Sagenkahn, M. L., Szasz, G. J., Morssen, G. W., Zuhr, H. F., _J. Am. Chem. Soc._, Vol. 66, 1944, pp. 1171-1177.

9. Swift, E. and Hochandel, H. P., _J. Am. Chem. Soc._, Vol. 67, 1945, pp. 880-881.

10. Thomson, J. and Linnett, H., _Trans. Faraday Soc._, Vol. 32, 1936, pp. 681-683.

11. Simon, K. and Huter, M., Zeit. fur Elektrochemie, Vol. 41, 1935, pp. 28-29.

12. Kobe, K. A. and Harrison, R. H., _Petroleum Refiner_, Vol. 33, 1954, pp. 161-165.

13. Aston, J. G., Eidinoff, M. L., Forster, W. S., _J. Am._ Chem. Soc., Vol. 61, 1939, pp. 1539-1543.

14. Beattie, J. A. and Bridgeman, _J. Am. Chem. Soc._, Vol. 49, 1927, pp. 1665-1669.

15. Maron, S. H. and Turnbull, D., Ind. Eng. Chem., Vol. 34, 1942, pp. 544-551.

16. Dodge, B. F., Chemical Engineering Thermodynamics, first edition, McGraw-Hill Book Co., Inc., 1944, pp. 257-260.

17. Hougen, O. A. and Watson, K. M., Chemical Process Principles, Part II, John Wiley and Sons, 1947.

18. Watson, K. M., Ind. Eng. Chem., Vol. 35, 1943, p. 398.

19. Arthur, J. C. and Felsing, W. A., J. Am. Chem. Soc., Vol. 68, 1946, pp. 1883-1885.

20. Haggenmachen, J. R., J. Am. Chem. Soc., Vol. 68, 1946, p. 1123.