ISOBARIC HEAT CAPACITY OF ETHYLENE OVER A WIDE RANGE OF TEMPERATURE AND PRESSURE

By

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CONTENTS

SUMMARY

The effect of pressure and temperature on the isobaric heat capacity at constant volume for ethylene relative to the ideal gas state is presented. The results cover pressures from 0 to 10,000 PSIA and temperatures from 32.0°F to 2372.0°F.

The deviation of the isobaric heat capacity of ethylene from the ideal gas state for the wide range of pressure and temperature covered was found from an equation derived from the Benedict-Webb-Rubin equation of state. Graphs and tables relating the deviation of the isobaric heat capacity, the deviation of heat capacity at constant volume, pressure, and temperature are included.

The results show that the deviation of the isobaric heat capacity from the ideal gas state caused by the effect of pressure must not be neglected. The correction is large enough to introduce considerable error in thermal calculations if it is not applied. The greatest error would occur near the critical point if the effect of pressure were neglected.

A comparison of the calculated data with those of previous investigators has been made and is included in the discussion.

INTRODUCTION

Engineering development has brought an extension of operating variables into the fields of high temperatures and pressures. The petroleum industry, which deals primarily with hydrocarbons, is making a continued effort to gather more and more accurate thermodynamic information over an increasing range of temperature and pressure. The use of increased temperatures and pressures in processing work has brought into the foreground the lack of basic knowledge of accurate design data.

A study of the available thermodynamic data, such as that published in the American Petroleum Institute Research Project 44 (1), indicates that data are lacking when higher pressures are encountered. There are very few data available on the effect of pressure on the heat capacity of gases and vapors. One reason for this lack of information is the difficulty encountered when trying to obtain accurate calorimetric data at high pressures. There are, however, several methods which give the information desired. These methods may be grouped as either generalized correlations, or equations of state.

Generalized methods of correlation are valuable when numerous accurate data are available and correlated. They are very helpful when no other data can be found. If any values are employed from generalized correlations they must be used with extreme caution and a full knowledge of the limitations involved. Some of the generalized correlations are those of Edmister (2), Hougen and Watson (3), and Watson and Smith (4).

Equations of state present an indirect method of obtaining thermodynamic information. An equation of state is an algebraic equation which relates the variables (pressure - volume - temperature) of fluids.

Several hundred equations of state have been suggested to cover the P-V-T relationship of fluids. Most of the equations presented are applicable to one fluid over a limited range of pressures and temperatures. The van der Waals equation is the oldest and best known but its use is rarely warranted except for its academic value.

Two of the more valuable equations of state are the Beattie-Bridgeman and Benedict-Webb-Rubin. In employing these equations it is necessary to have the empirical constants for the particular gas under consideration. Reasonable accuracy is obtained by the use of these equations and thermodynamic properties can be calculated from derived relationships.

The Beattie-Bridgeman equation of state is widely used and accurate. It was not designed, however, to reproduce properties of the gas in the critical range or above the critical density. The calculation of specific heats for several gases was performed by Ellenwood, Kulik, and Gay (5) by applying this equation. They covered a temperature range of 400° R to 4500° R and a pressure range of 0 to 10,000 PSIA in their work.

The Benedict-Webb-Rubin equation of state (6) was developed specifically for the lighter hydrocarbons. It may be regarded as an improved modification of the Beattie-Bridgeman equation to enable a more accurate determination of the properties of fluids at high densities. It contains more terms and has eight constants for a specific fluid whereas the Beattie-Bridgeman has five. The same equation is applicable to the liquid and gaseous phases, as van der Waals assumption of the continuity of liquid and gaseous states is retained.

The Benedict-Webb-Rubin equation reproduces P-V-T data accurately up to approximately 1.8 times the critical density. According to Benedict-Webb-Rubin (14) calculated and observed critical temperatures and pressures for ethylene agree within 0.30° C and 0.70 atmospheres.

This equation is believed to be the most accurate in this field to date, and since the constants have been evaluated for ethylene, (14), the Benedict-Webb-Rubin equation has been applied to ethylene in this work.

The use of this equation of state to predict isobaric heat capacities relative to the ideal gas state over a wide range of temperatures and pressures has been presented for methane by Sledjeski (7, 8), for propane by Seifarth (9, 10), and for n-butane by Glueck (11). Satisfactory agreement was established in all cases with published experimental data. Glueck also presented the variation of the specific heat of n-butane at constant volume with pressure and temperature relative to the ideal gas state. In this work the isobaric heat capacity of ethylene, and the heat capacity at constant volume of ethylene, relative to the ideal gas state over a wide range of temperatures and pressures is presented by the application of the Benedict-Webb-Rubin equation of state.

The isobaric heat capacity of ethylene was evaluated over a pressure range of 0 to 10,000 PSIA, and a temperature range of 400° R to 4500° R by the use of the Beattie-Bridgeman equation of state by Ellenwood, Kulik, and Gay cited previously. The only other published work which covered the effect of pressure on the thermodynamic properties of ethylene was presented by Michels, Geldermans, and De Groot (12, 13). They present the properties of ethylene under pressures up to 3,000 atmospheres and between 0°C and 150°C tabulated as a function of density. Included are tables of specific heat at constant volume and of enthalpy. Michels and associates expressed their experimental data as well as possible in a power series of the Kammerlingh Onnes equation of state, and from these results calculated the various thermodynamic properties.

Values for the specific heat in the ideal gas state for ethylene can be obtained from API Project 44 (1) for temperatures to 1500°K. No other published data have been found which cover the range given in this paper. The method of derivation of the heat capacity variation from the Benedict-Webb-Rubin equation follows.

DERIVATION OF THE EQUATION FOR $(c_p - c_p^*)$ FROM

THE BENEDICT-WEBB-RUBIN EQUATION OF STATE

The Benedict-Webb-Rubin Equation of State (6) is:

(1) $$P = RTd + (B_oRT - A_o - C_oT^{-2})d^2 + (bRT - a)d^3$$
$$+ a\alpha d^6 + cd^3\ (1 + \gamma d^2)\ T^{-2}e^{-\gamma d^2}$$

Expressing equation above in terms of volume rather than density.

(2) $$P = RTV^{-1} + (B_oRT - A_o - C_oT^{-2})V^{-2} + (bRT - a)V^{-3}$$
$$+ a\alpha V^{-6} + cV^{-3}\ (1 + \gamma V^{-2})T^{-2}e^{-(\gamma V^{-2})}$$

Expanding terms for mathematical convenience.

(3) $$P = RTV^{-1} + B_oRTV^{-2} - A_oV^{-2} - C_oT^{-2}V^{-2} + bRTV^{-3} - aV^{-3}$$
$$+ a\alpha V^{-6} + cT^{-2}V^{-3}e^{-(\gamma V^{-2})} + cT^{-2}\ V^{-5}e^{-(\gamma V^{-2})}$$

For an ideal gas:

(4) $$c_p^* - c_v^* = R$$

For an actual gas we can write:

(5) $$c_p - c_v^* - R = c_p - c_p^*$$

Adding and subtracting c_v on the left side of the equation and rearranging:

(6) $$(c_p - c_v) - (c_v - c_v^*) - R = c_p - c_p^*$$

From Hougen and Watson (3) (pg. 461, Equation 90):

(7) $$c_p - c_v = -T(\partial P/\partial T)_V^2(\partial V/\partial P)_T$$
$$= -T(\partial V/\partial T)_V^2(\partial P/\partial V)_T$$

By rearranging:

(8) $$c_p - c_v = -T(\partial P/\partial T)_V^2 \;/\; (\partial P/\partial V)_T$$

Differentiating equation (3) at constant volume with respect to temperature:

(9) $$(\partial P/\partial T)_V = RV^{-1} + (B_oR + 2C_oT^{-3})V^{-2} + bRV^{-3}$$
$$-2cV^{-3}T^{-3}(1 + \gamma V^{-2})e^{-\gamma V^{-2}}$$

Differentiating equation (3) at constant temperature with respect to volume:

(10) $$(\partial P/\partial V)_T = -RTV^{-2} - 2V^{-3}(B_oRT - A_o - C_oT^{-2}).$$
$$-3V^{-4}(bRT - a) - 6a\alpha V^{-7}$$
$$+ cT^{-2}e^{-\gamma V^{-2}}(-3V^{-4} - 3\gamma V^{-6} + 2\gamma^2V^{-8})$$

Substituting equations (9) and (10) in equation (8):

(11) $$c_p - c_v = -T\,\frac{\left[\begin{array}{l} RV^{-1} + (B_oR + 2C_oT^{-3})V^{-2} + bRV^{-3} \\ - 2cV^{-3}T^{-3}(1 + \gamma V^{-2})e^{-\gamma V^{-2}} \end{array}\right]^2}{\left[\begin{array}{l} -RTV^{-2} - 2V^{-3}(B_oRT - A_o - C_oT^{-2}) \\ - 3V^{-4}(bRT - a) - 6a\alpha V^{-7} \\ + cT^{-2}e^{-\gamma V^{-2}}(-3V^{-4} - 3\gamma V^{-6} + 2\gamma^2V^{-8}) \end{array}\right]}$$

From Hougen and Watson (3) (pg. 473, Equation 94) we have:

(12) $$(\partial c_v/\partial V)_T = T\,(\partial^2P/\partial T^2)_V$$

By rearranging:

(13) $$dc_v = T\,(\partial^2P/\partial T^2)_V dV$$

Or:

(14) $$c_v - c_v^* = \int_{\infty}^{V} T(\partial^2P/\partial T^2)_V dV$$

In order to evaluate the integral, which is the second derivative of the pressure at constant volume with respect to the temperature multiplied by the absolute temperature, Equation (9), the first derivative, must be differentiated again:

(15) $$(\partial^2P/\partial T^2)_V = 6T^{-4}(cV^{-3}e^{-\gamma V^{-2}} + c\gamma V^{-5}e^{-\gamma V^{-2}} - C_oV^{-2})$$

Multiplying through Equation (15) by T:

(16) $$(\partial c_v/\partial V)_T = 6T^{-3}(cV^{-3}e^{-\gamma V^{-2}} + c\gamma V^{-5}e^{-\gamma V^{-2}} - C_oV^{-2})$$

And:

(17) $$c_v - c_v^* = 6cT^{-3}\int_{\infty}^{V}(V^{-3}e^{-\gamma V^{-2}})dV + 6c\gamma T^{-3}\int_{\infty}^{V}(V^{-5}e^{-\gamma V^{-2}})dV - 6C_oT^{-3}\int_{\infty}^{V} V^{-2}dV$$

Evaluating this series of integrals by performing the indicated integrations by parts, the following equation is obtained after collecting terms.

(18) $$c_v - c_v^* = \frac{6c}{T^3}\left[\frac{e^{-\gamma V^{-2}}}{2V^2} + \frac{e^{-\gamma V^{-2}}}{\gamma} + \frac{C_o}{cV}\right]_{\infty}^{V}$$

Substituting Limits:

(19) $$c_v - c_v^* = \frac{6c}{T^3}\left[+\frac{e^{-\gamma V^{-2}}}{2V^2} + \frac{C_o}{cV}\right] - \frac{6c}{\gamma T^3} - \frac{6c\,e^{-\gamma V^{-2}}}{T^3\gamma}$$

Substituting Equations (11) and (19) into Equation (6), the desired expression for $(c_p - c_p^*)$ in the terms of the Benedict-Webb-Rubin equation of state is derived. The complete equation (20) is shown on the following page:

$$(20)\quad (c_p - c_p{*}) = -T\,\frac{\left[\dfrac{R}{V} + \dfrac{(B_oR + 2C_o/T^3)}{V^2} + \dfrac{bR}{V^3} - \dfrac{2c}{T^3V^3}\left(1 + \gamma/V^2\right)e^{-\gamma V^{-2}}\right]^2}{\left[-\dfrac{RT}{V^2} - \dfrac{2}{V^3}(B_oRT - A_o - C_o/T^2) - \dfrac{3}{V^4}(bRT - a) - \dfrac{6a\alpha}{V^7} + \dfrac{c}{T^2}\left(-3/V^4 - 3\gamma/V^6 + 2\gamma^2/V^8\right)e^{-\gamma V^{-2}}\right]}$$

$$+ \frac{6c}{T^3}\left[\frac{e^{-\gamma V^{-2}}}{\gamma} + \frac{e^{-\gamma V^{-2}}}{2V^2} + \frac{C_o}{cV}\right] - \frac{6c}{\gamma T^3} - R$$

METHOD OF CALCULATION

Table II presents the latest values of C_p* (1) for ethylene at various temperatures. The values of C_p* and C_v* are subject to constant revision as improved methods or techniques become available. Therefore, all of the calculations and graphs are presented in the form of deviations from the ideal gas state ($C_p - C_p$*) or ($C_v - C_v$*). This deviation can be applied to the latest values for the heat capacity in the ideal state to obtain the proper value for the pressure involved.

Since Equations (2) and (20) are explicit in pressure and implicit in volume, the simplest method of solution would be to assume a given temperature and volume, calculate the pressure using Equation (2), and then calculate the deviation which corresponds to the assumed values of temperature and volume by using Equation (20). A stepwise method of calculation follows:

1. Values of volume from 0.10 to 5.0 liters were assumed at a selected constant temperature, and the corresponding pressure was calculated from Equation (2).
2. For the same values of pressure, volume, and temperature, values of $(\partial P/\partial T)_v^{\ 2}$ were calculated from Equation (9).
3. Equation (10) was then solved to give values of $(\partial P/\partial V)_T$.
4. The values obtained in steps 2 and 3 were substituted into equation (11) to give $(c_p - c_v)$ values for the same conditions.

5. Values of $(c_v - c_v*)$ were calculated by the use of Equations (19) using the same initial assumptions.
6. The values obtained from Equations (11) and (19) were used as indicated in Equation (20) to give the desired values of $(c_p - c_p*)$.

This procedure of calculation was repeated for seventeen isotherms from 273.13°K to 1573.13°K for pressures up to about 10,000 PSIA. The results of these calculations are given in Table I. Figure I is a plot of these data and covers a range of 273.13°K to 1273.13°K and pressures up to about 10,000 PSIA. A complete stepwise calculation is given in the Sample Calculation.

From Figure 1, a cross-plot of the data was made showing the deviation in the heat capacity values as a function of temperature for isobars from 100 to 10,000 PSIA. This is shown in Figure 2.

In a like manner, values of $(C_v - C_v*)$ versus pressure were plotted in Figure 5 and cross-plotted in Figure 6 to show the variation of $(C_v - C_v*)$ with temperature for various isobars.

For the purpose of comparison the data of Ellenwood, Kulik, and Gay (5) which had been presented in graphical form were transformed into heat capacity deviations. To do this values of C_p* read from the 0 PSIA curve and were subtracted from C_p values read from the various isobar curves.

To secure a comparison of the data of Michels, Geldermans and De Groot (12, 13) enthalpy data had to be converted into mean values of heat capacity from the relation $\Delta H = C_p \Delta T$.

For selected pressures, values of enthalpy were obtained for three isotherms of 0° C, 100° C, and 150° C. For a given pressure the value of enthalpy at the lower isotherm was subtracted from the value at the higher isotherm giving a ΔH value over a definite temperature range. The ΔH value was then divided by the temperature difference ΔT to give a mean heat capacity value over the specified temperature range. To secure a deviation of the mean heat capacity, the mean heat capacity at 0 PSIA was subtracted from the mean heat capacity at higher pressures.

The data presented in the paper had to be expressed as mean heat capacity for purposes of comparison. This was done by selecting the same temperature interval and pressures and taking an arithmetic average of the heat capacity deviations to give a comparable mean heat capacity deviation over the selected temperature range. A comparison plot is shown in Figure 4.

Michels, Geldermans, and De Groot (13), also gave values of $(C_v - C_v^*)$ expressed in calories per gram mole per °C. Those were converted to BTU per pound per °F by dividing by the molecular weight. These data are compared in Figure 7.

DISCUSSION OF RESULTS

There is very little experiemental information published which covers the range in this work, therefore, it is difficult to evaluate and compare its accuracy.

The only information on the isobaric heat capacity of ethylene is that given by Ellenwood, Kulik, and Gay (5). These workers applied the Beattie-Bridgemen equation. A comparison of their data is shown in Figure 3. For pressures below approximately 3000 PSIA and below temperatures of 400°F the Beattie-Bridgeman equation gives lower values for the deviation of the isobaric heat capacity. At higher temperatures and the same relatively low pressures below 3000 PSIA the Beattie-Bridgeman gives larger deviations. At pressures above 3000 PSIA all of the Beattie-Bridgeman values for the deviation are greater than those obtained in this work. A previous comparison of the two equations of state was made by Sledjeski (7, 8) on methane. From a comparison with experimental data Sledjeski concluded that the Benedict-Webb-Rubin equation reproduced $(C_p - C_p^*)$ values more accurately above temperatures of 150° F. It can also be pointed out that the Beattie-Bridgeman equation was not designed to reproduce P-V-T properties of the fluid in the critical region or above the critical density whereas, the Benedict-Webb-Rubin equation is said to be accurate to 1.8 times the critical density. Therefore, the Benedict-Webb-Rubin equation is recommended in preference to the Beattie-Bridgeman as it gives more nearly accurate values.

The deviation of the mean heat capacity from the ideal state was compared with values obtained from data of Michels, Geldermans, and De Groot (12, 13). The method of calculating the data is mentioned on page (12). A graphical comparison is presented in Figure 4. The mean heat capacity deviation over the temperature range of 0°C to 100°C, and 100°C to 150°C was evaluated. In both cases the values of Michels and associates were lower than those obtained in this paper. For the lower temperature data between 0°C and 100°C the maximum pressure of comparison was approximately 500 PSIA. The curves of Michels et al (12, 13) were approximately 40% lower. For the higher temperature data between 100°C and 150°C the curves are close together up to 900 PSIA with Michels data being approximately 6% lower. At the higher pressures over 900 PSIA the difference between the curves is greater.

Data on the deviation of the heat capacity at constant volume were presented by Michels, Geldermans, and De Groot (13). Their data are compared graphically in Figure 7. Three isotherms were available for comparison 0° C, 100°C, and 150°C. In all cases Michels et al (13) data gave lower results. The deviation between the curves is large at 0°C, at 100°C the curves have a similar curvature and are coming closer together, and at 150°C the curves exhibit the same curvature but the deviation is increasing. Michels and his co-workers claim an accuracy of 5% based upon their experimental data. Therefore, for these low temperatures the values of Michels, Geldermans, and De Groot for the deviation of heat capacity at constant volume are recommended.

For higher temperatures the results reported herein should be used, since no other values are to be found in the literature.

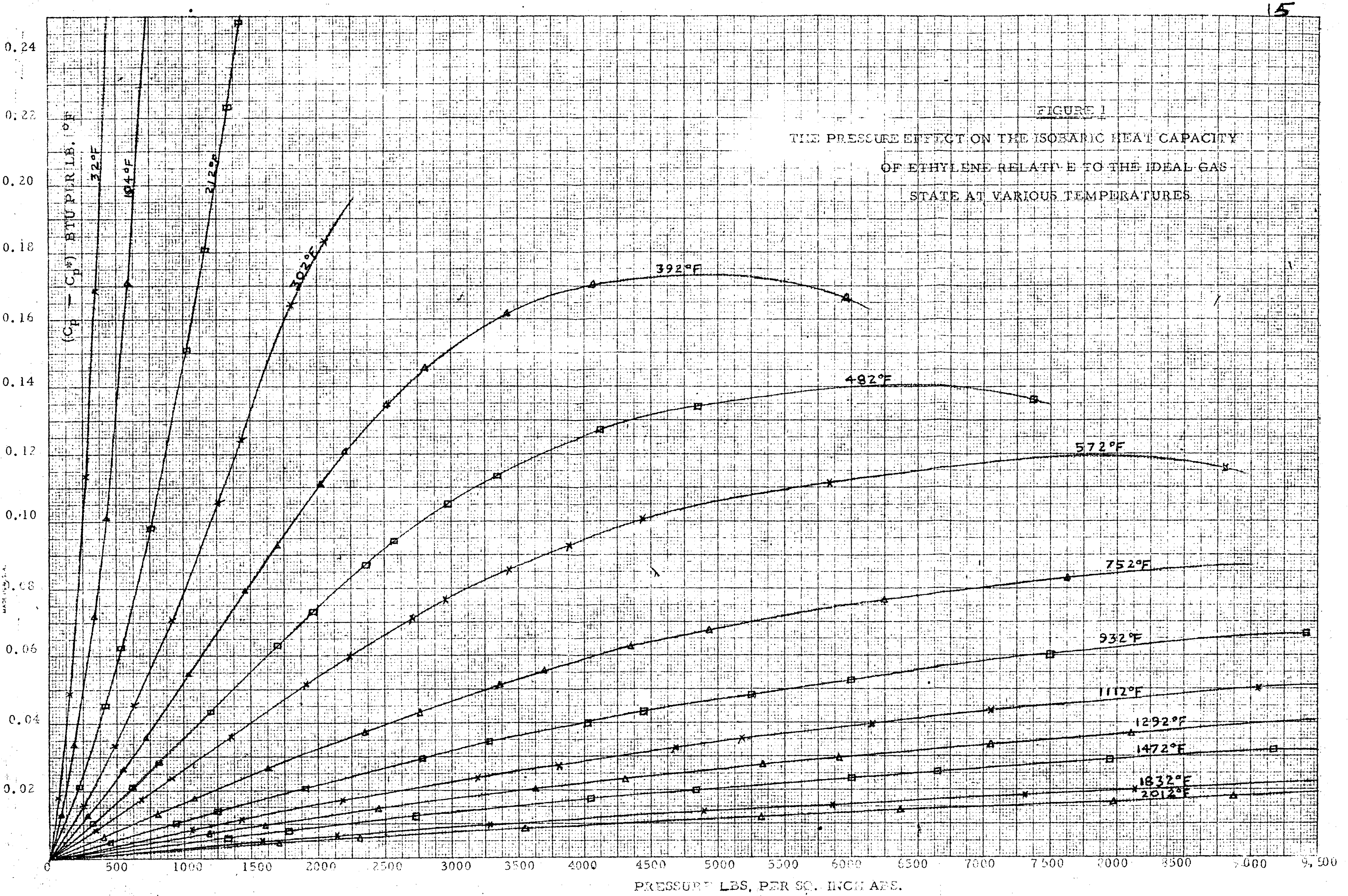

FIGURE 1

THE PRESSURE EFFECT ON THE ISOBARIC HEAT CAPACITY OF ETHYLENE RELATIVE TO THE IDEAL GAS STATE AT VARIOUS TEMPERATURES

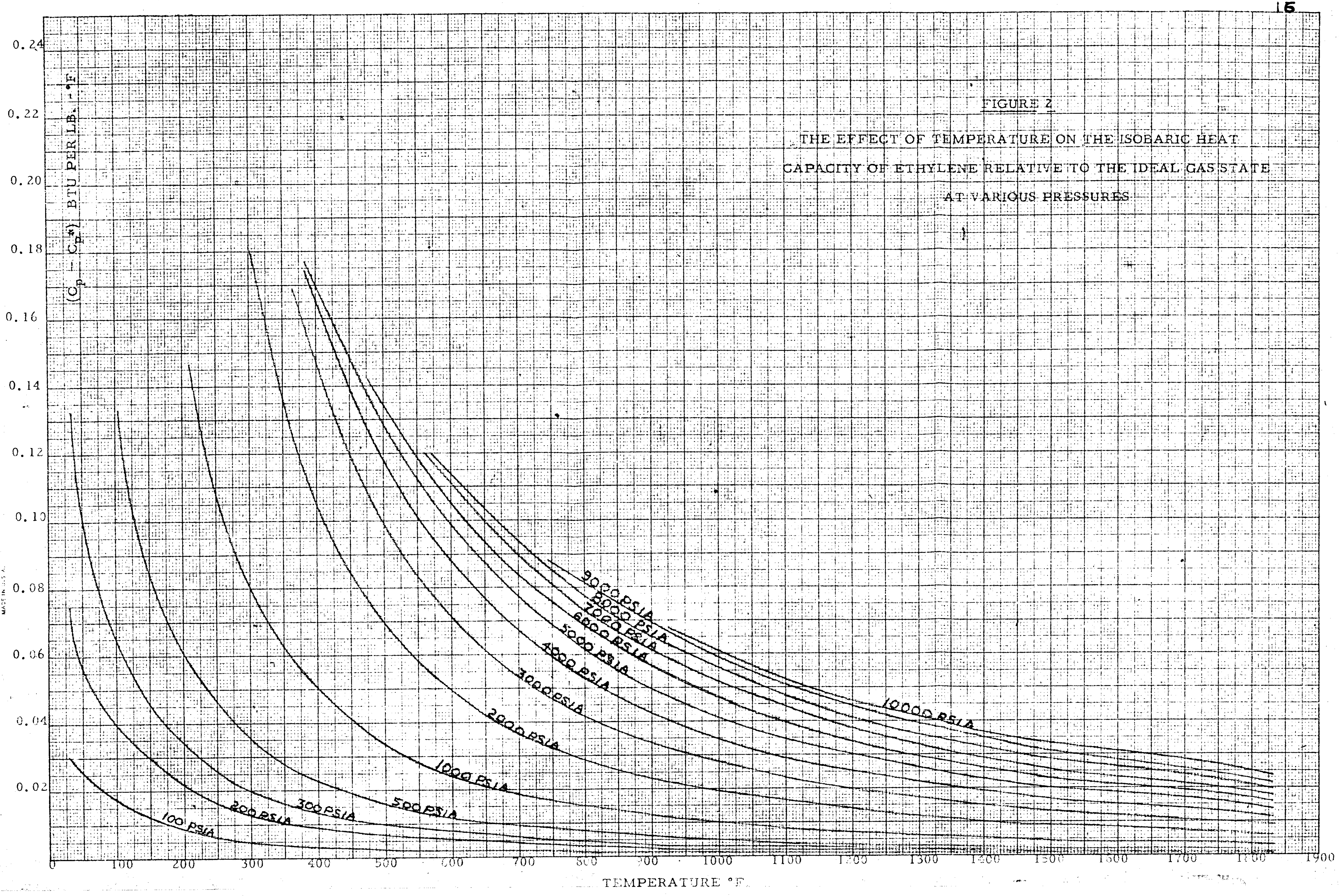

FIGURE 2

THE EFFECT OF TEMPERATURE ON THE ISOBARIC HEAT CAPACITY OF ETHYLENE RELATIVE TO THE IDEAL GAS STATE AT VARIOUS PRESSURES

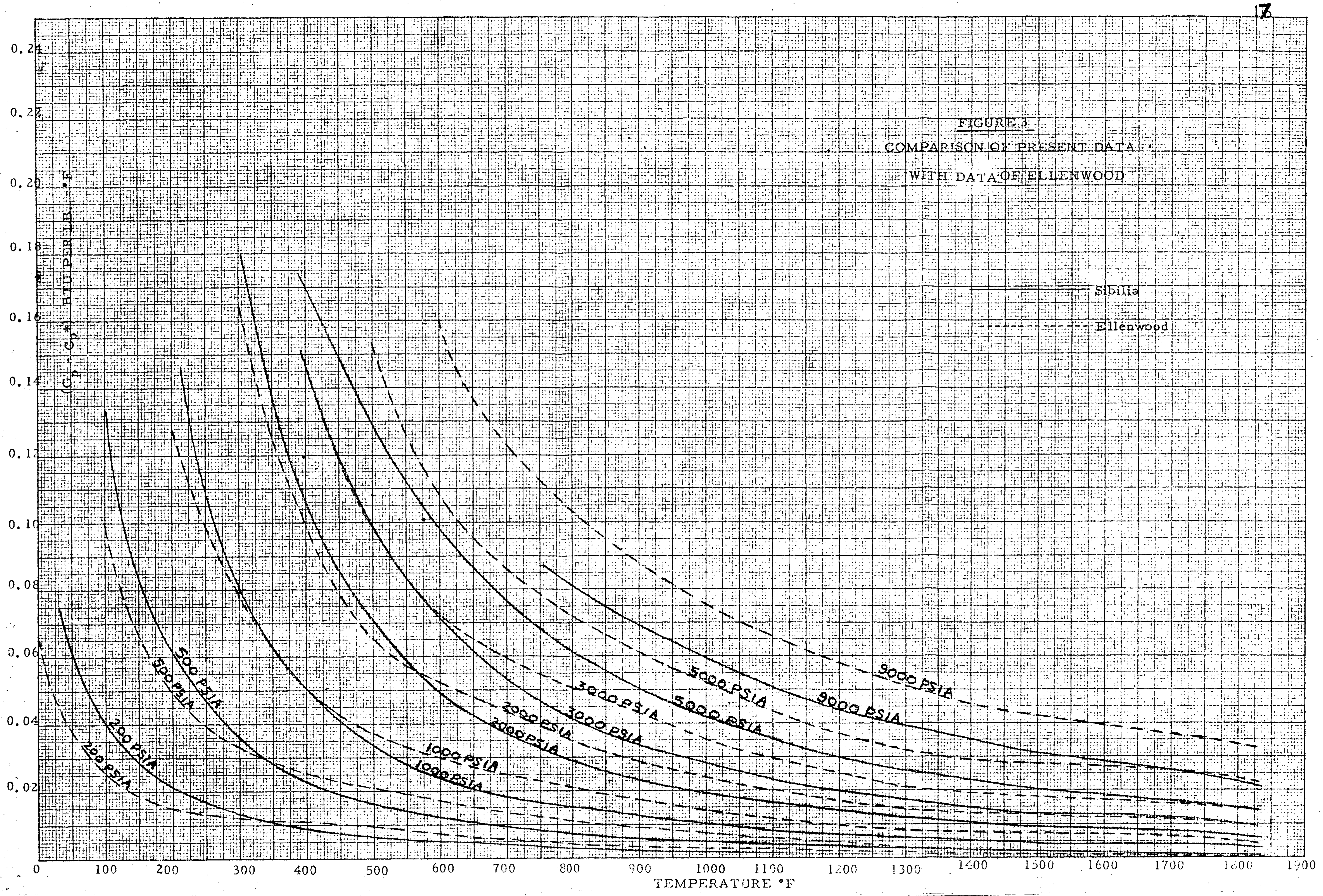

FIGURE 3

COMPARISON OF PRESENT DATA

WITH DATA OF ELLENWOOD

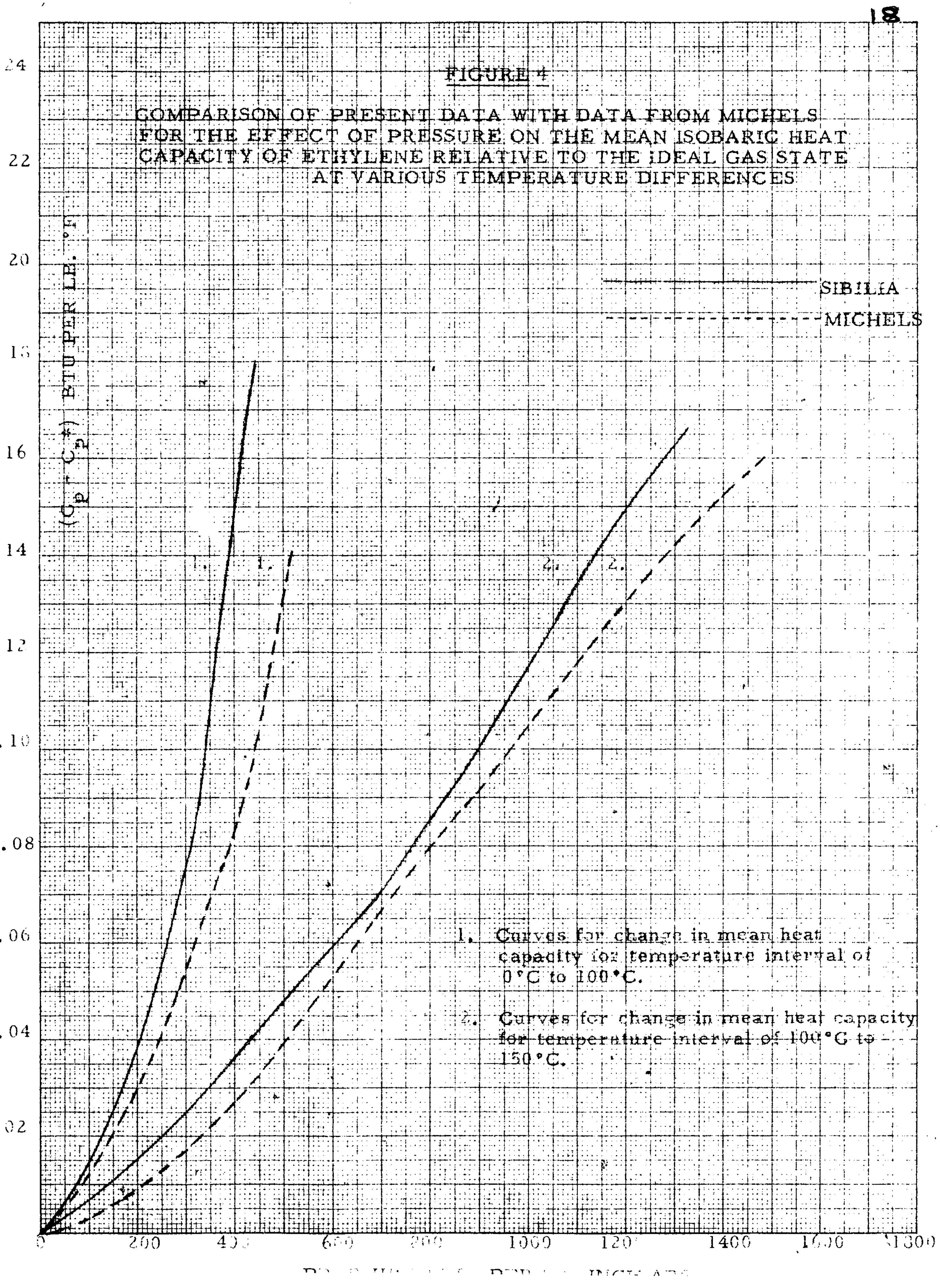

FIGURE 4

COMPARISON OF PRESENT DATA WITH DATA FROM MICHELS FOR THE EFFECT OF PRESSURE ON THE MEAN ISOBARIC HEAT CAPACITY OF ETHYLENE RELATIVE TO THE IDEAL GAS STATE AT VARIOUS TEMPERATURE DIFFERENCES

1. Curves for change in mean heat capacity for temperature interval of 0°C to 100°C.

2. Curves for change in mean heat capacity for temperature interval of 100°C to 150°C.

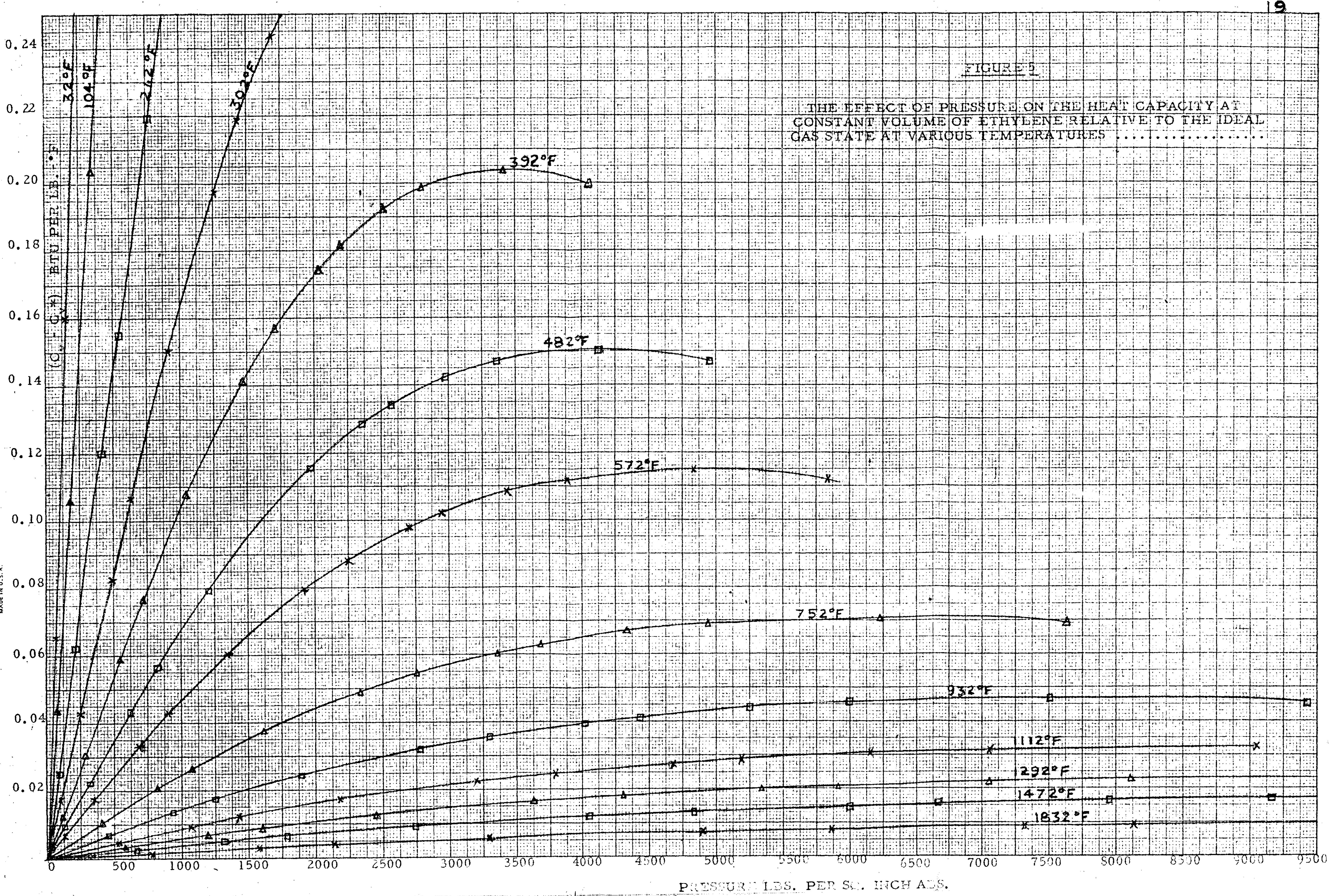

FIGURE 5

THE EFFECT OF PRESSURE ON THE HEAT CAPACITY AT CONSTANT VOLUME OF ETHYLENE RELATIVE TO THE IDEAL GAS STATE AT VARIOUS TEMPERATURES ....

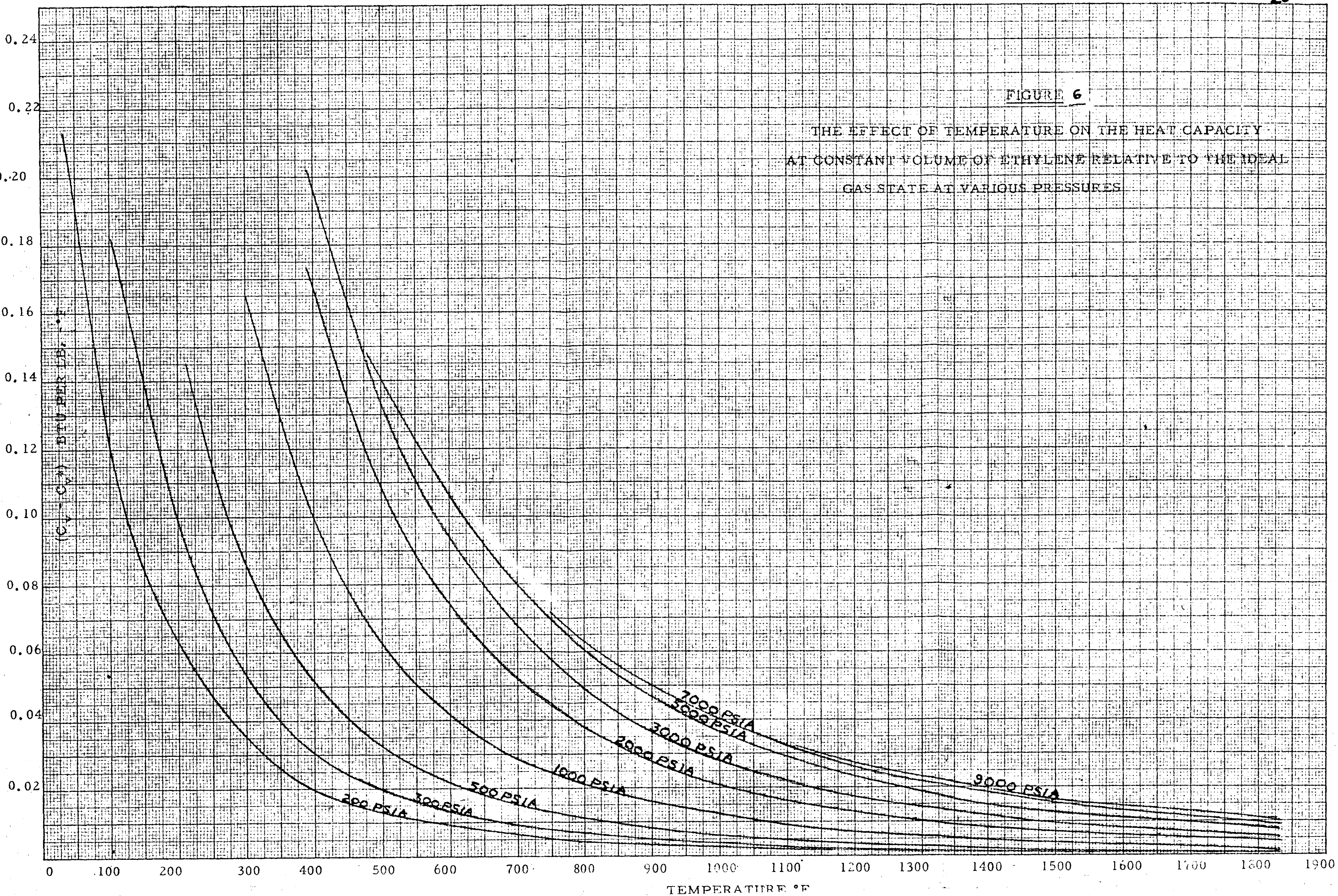

FIGURE 6

THE EFFECT OF TEMPERATURE ON THE HEAT CAPACITY AT CONSTANT VOLUME OF ETHYLENE RELATIVE TO THE IDEAL GAS STATE AT VARIOUS PRESSURES

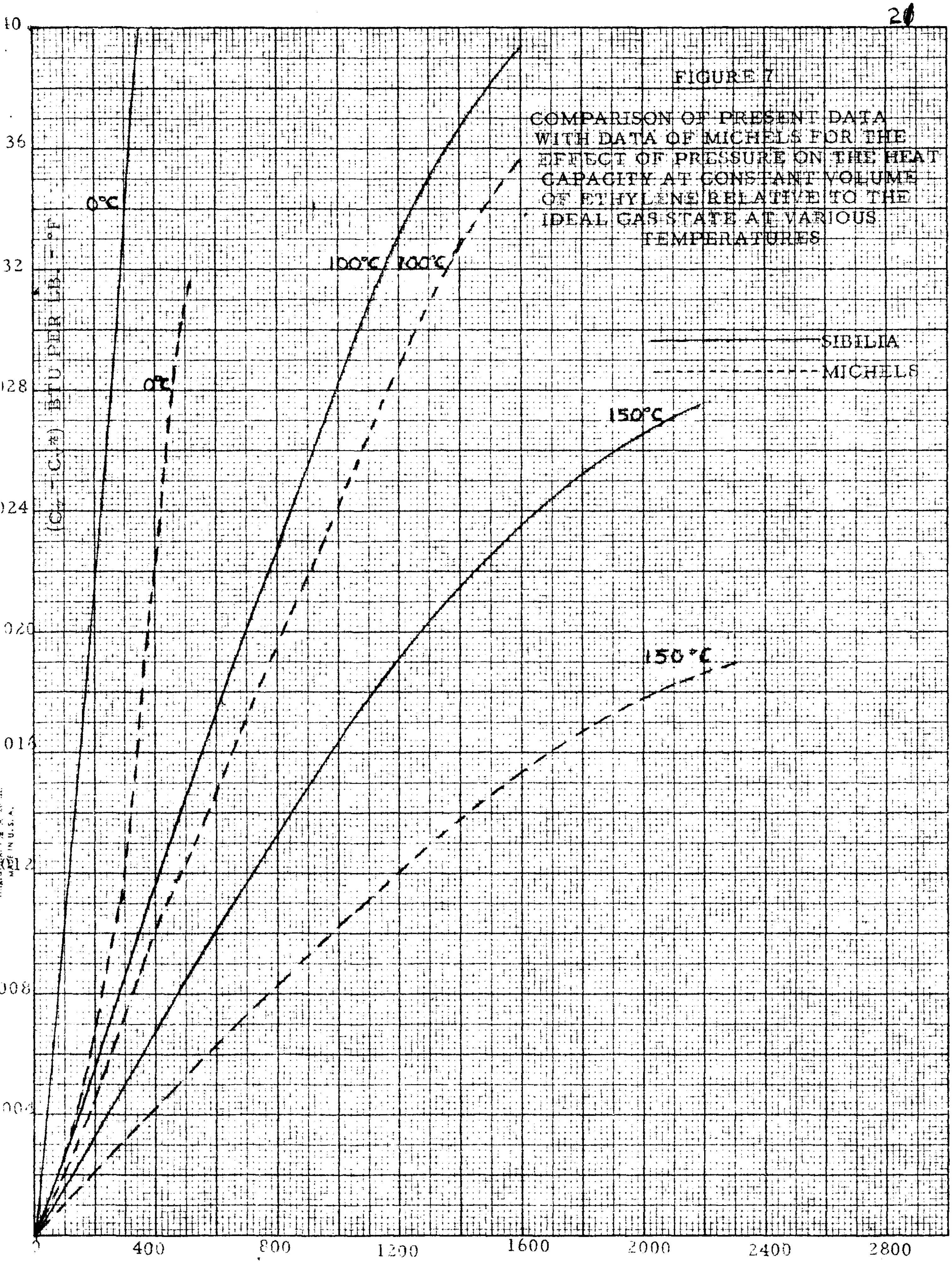

FIGURE 7

COMPARISON OF PRESENT DATA WITH DATA OF MICHELS FOR THE EFFECT OF PRESSURE ON THE HEAT CAPACITY AT CONSTANT VOLUME OF ETHYLENE RELATIVE TO THE IDEAL GAS STATE AT VARIOUS TEMPERATURES

SAMPLE CALCULATION — EQUATION (2)

$$P = RT/V + (B_oRT - A_o - C_o/T^2)1/V^2 + (bRT - a)1/V^3 - a\alpha/V^6 + (c/V^3T^2)(1 + \gamma/V^2)(1/e^{\gamma/V^2})$$

T = Absolute temperature, °K
 = °C + 273.13
 = 773.13°K = 500.0°C

$R = 0.08207 \frac{\text{Liter Atmospheres}}{\text{Gram-mol °K}}$

V = Volume, Liters
P = Absolute Pressure, Atmospheres

$B_o = 0.0556833$
$A_o = 3.33958$
$C_o = 131140.$
$b = 0.0086000$
$a = 0.259000$
$c = 21120.$
$\alpha = 0.000178000$
$\gamma = 0.00923000$

1 atm. = 14.696 lb./sq. in. abs.

$\frac{\text{1 Liter Atm.}}{\text{Gram-mol °K}} = \frac{\text{0.86358 BTU}}{\text{Lb. Ethylene °F}}$

$e = 2.7183$

V	RT/V	$\frac{(B_oRT-A_o-C_o/T^2)}{V^2}$	$\frac{(bRT - a)}{V^3}$	$a\alpha/V^6$	$\frac{c(1 + \gamma/V^2)}{V^3T^2e^{\gamma/V^2}}$	P - atm.	p - PSIA
0.13	488.08291	-1.528225	130.48566	9.551238	14.40191	640.99323	9420.033
0.15	423.00519	-1.147867	84.94133	4.047364	9.79592	510.84614	7507.393
0.18	352.50433	-0.797130	49.15586	1.355455	5.85481	408.07332	5997.045
0.20	317.25389	-0.645675	35.83463	.720343	4.31579	357.47898	5253.511
0.25	253.80312	-0.413232	18.34733	.188834	2.23898	274.16503	4029.129
0.30	211.50260	-0.286967	10.61767	.063240	1.30222	223.19876	3280.129
0.35	181.28794	-0.210833	6.686344	.0250791	0.813410	188.60194	2771.694
0.50	126.90156	-0.103308	2.293416	.0029505	0.282483	129.37710	1901.326
0.75	84.60104	-0.045915	0.679531	.00025931	0.083743	85.31866	1253.843
1.0	63.45078	-0.025827	0.286677	.0000461	0.035332	63.74701	936.826

SAMPLE CALCULATION - EQUATION (9)

$$(\partial P/\partial T)_V^2 = \left[R/V + B_oR/V^2 + 2C_o/V^2T^3 + bR/V^3 - (2c/V^3T^3)\,(1 + \gamma/V^2)\,(1/e^{\gamma/V^2}) \right]^2$$

V	R/V	B_oR/V^2	$2C_o/V^2T^3$	bR/V^3	$-(2c/V^3T^3)\,(1+\gamma/V^2)\,(1/e^{\gamma/V^2})$	$(\partial P/\partial T)_V$	$(\partial P/\partial T)_V^2$
0.13	0.631308	0.270410	0.0335834	0.321257	-0.0372561	1.219302	1.486697
0.15	0.547133	0.203108	0.0252249	0.209127	-0.0253409	0.959252	0.920164
0.18	0.455944	0.141047	0.0175173	0.121022	-0.0151457	0.720386	0.518956
0.20	0.410350	0.114248	0.0141891	0.0882250	-0.0111642	0.615848	0.379269
0.25	0.328280	0.073118	0.0090809	0.0451713	-0.0057919	0.449858	0.202372
0.30	0.273566	0.050777	0.0063062	0.0261408	-0.0033687	0.353422	0.125615
0.35	0.234486	0.037305	0.0046331	0.0164618	-0.0021042	0.290783	0.084554
0.50	0.164140	0.0182797	0.0022702	0.0056464	-0.0007308	0.189605	0.035950
0.75	0.109427	0.0081243	0.0010089	0.0016730	-0.0002166	0.120016	0.0144038
1.0	0.082070	0.0045699	0.0005676	0.0007058	-0.0000914	0.0878219	0.0077127

SAMPLE CALCULATION - EQUATION (10)

$$(\partial P/\partial V)_T = -RT/V^2 - (2/V^3)(B_oRT-A_o-C_o/T^2) - (3/V^4)(bRT-a) - 6a\alpha/V^7 + (c/T^2)(1/e^{\gamma/V^2})(-3/V^4 - 3\gamma/V^6 - 2\gamma^2/V^8)$$

V	$-RT/V^2$	$-\frac{2}{V^3}\left[B_oRT-A_o-\frac{C_o}{T^2}\right]$	$-(3/V^4)(bRT-a)$	$-6a\alpha/V^7$	$\frac{c}{T^2 e^{\gamma/V^2}}\left[\frac{-3}{V^4}-\frac{3\gamma}{V^6}+\frac{2\gamma^2}{V^8}\right]$	$(\partial P/\partial V)_T$
0.13	-3754.4840	23.511151	-3011.2076	-440.82633	-289.60706	-7472.6138
0.15	-2820.0346	15.304888	-1698.8266	-161.89452	-180.33255	-4845.7834
0.18	-1958.3574	8.856996	- 819.26440	- 45.181797	- 93.47134	-2907.4179
0.20	-1586.2695	6.456750	- 537.51938	- 21.610312	- 62.86974	-2201.8122
0.25	-1015.2125	3.305856	- 220.16794	- 4.532011	- 26.52741	-1263.1340
0.30	- 705.00865	1.913111	- 106.17667	- 1.264801	- 12.93944	- 823.47645
0.35	- 517.96554	1.204758	- 57.31152	- 0.429927	- 6.94755	- 581.44978
0.50	- 253.80312	0.413232	- 13.760496	- 0.035406	- 1.70989	- 268.88678
0.75	- 112.80138	0.122439	- 2.718123	- 0.0020745	- 0.334918	- 115.73406
1.0	- 63.45078	0.051654	- 0.860031	- 0.0002766	- 0.105991	- 64.36542

SAMPLE CALCULATION - EQUATION (19)

$$(c_v - c_v^*) = \frac{6c}{T^3}\left[\frac{1}{\gamma e^{\gamma/V^2}} + \frac{1}{2V^2 e^{\gamma/V^2}} + \frac{C_o}{cV}\right] - \frac{6c}{\gamma T^3}$$

V	$\frac{6c}{T^3}\left[\frac{1}{\gamma e^{\gamma/V^2}} + \frac{1}{2V^2 e^{\gamma/V^2}} + \frac{C_o}{cV}\right]$	$- 6c/\gamma T^3$	$(c_v - c_v^*)$
0.13	0.0350026	-0.0297088	0.0052938
0.15	0.0351060	-0.0297088	0.0053972
0.18	0.0349860	-0.0297088	0.0052772
0.20	0.0348216	-0.0297088	0.0051128
0.25	0.0343329	-0.0297088	0.0046241
0.30	0.0338634	-0.0297088	0.0041546
0.35	0.0334553	-0.0297088	0.0037465
0.50	0.0325659	-0.0297088	0.0028571
0.75	0.0317353	-0.0297088	0.0020265
1.0	0.0312743	-0.0297088	0.0015655

SAMPLE CALCULATION - EQUATION (20)

$$(c_p - c_p^*) = (c_p - c_v) + (c_v - c_v^*) - R$$

$$= -T \frac{(\partial P/\partial T)_V^2}{(\partial P/\partial V)_T} + (c_v - c_v^*) - R$$

V	$(\partial P/\partial T)_V^2$	$(\partial P/\partial V)_T$	$-T \frac{(\partial P/\partial T)_V^2}{(\partial P/\partial V)_T}$	$(c_v - c_v^*)$	$-R$	$(c_p - c_p^*)$ $\frac{\text{Liter-Atm.}}{\text{Gm-mol } ^\circ K}$	$(C_p - C_p^*)$ $\frac{\text{BTU}}{\text{Lb. } ^\circ F}$	p, PSIA
0.13	1.486697	-7472.6138	0.153816	0.0052938	-0.08207	0.077040	0.066530	9420.033
0.15	0.920164	-4845.7834	0.146809	0.0053972	-0.08207	0.070137	0.060569	7507.393
0.18	0.518956	-2907.4179	0.137999	0.0052772	-0.08207	0.061206	0.052856	5997.045
0.20	0.379269	-2201.8122	0.133174	0.0051128	-0.08207	0.056217	0.048548	5253.511
0.25	0.202372	-1263.1340	0.123866	0.0046241	-0.08207	0.046420	0.040087	4029.129
0.30	0.125615	- 823.47645	0.117935	0.0041546	-0.08207	0.040020	0.034560	3280.129
0.35	0.0845548 -	- 581.44978	0.112429	0.0037465	-0.08207	0.034106	0.029453	2771.694
0.50	0.035950	- 268.88678	0.103367	0.0028571	-0.08207	0.024154	0.020859	1901.326
0.75	0.0144038	- 115.73406	0.096221	0.0020265	-0.08207	0.016178	0.013971	1253.843
1.0	0.0077127	- 64.36542	0.0926416	0.0015655	-0.08207	0.012137	0.010481	936.826

TABLE I
CALCULATED DATA

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm./Gm-mol °K	$- R$	$(c_p - c_p^*)$ Liter-Atm./Gm-mol °K	$(C_p - C_p^*)$ BTU/Lb. °F	$(C_v - C_v^*)$ BTU/Lb. °F
T = 32.0 °F							
0.23	624.826	4.06368	0.109398	−0.08207	4.09101	3.532910	0.0944739
0.25	616.709	2.30651	0.104880	−0.08207	2.32933	2.011559	0.0905722
0.30	587.747	1.07158	0.094229	−0.08207	1.08374	0.935898	0.0813743
0.35	553.862	0.702843	0.084969	−0.08207	0.705742	0.609465	0.0733775
0.50	458.087	0.401513	0.064797	−0.08207	0.384240	0.331822	0.0559574
0.75	346.219	0.231525	0.045957	−0.08207	0.195412	0.168754	0.0396876
1.0	276.041	0.177765	0.035503	−0.08207	0.131198	0.113300	0.0306597
2.0	150.967	0.120342	0.018528	−0.08207	0.0567999	0.0490513	0.0160004
5.0	63.647	0.0955318	0.0075963	−0.08207	0.0210578	0.0181851	0.0065598
T = 104.0 °F							
0.20	1023.16	0.824613	0.076957	−0.08207	0.819502	0.707704	0.0664591
0.23	941.562	0.677884	0.072594	−0.08207	0.668413	0.577226	0.0626907
0.25	915.025	0.580478	0.068836	−0.08207	0.567239	0.489857	0.0594454
0.30	825.754	0.438827	0.062533	−0.08207	0.419290	0.362090	0.0540023

TABLE I

CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm./Gm-mol °K	-R	$(c_p - c_p^*)$ Liter-Atm./Gm-mol °K	$(C_p - C_p^*)$ BTU/Lb. °F	$(C_v - C_v^*)$ BTU/Lb. °F
T = 104.0 °F (Cont.)							
0.35	749.843	0.356413	0.056391	-0.08207	0.331734	0.286479	0.0486981
0.50	585.399	0.236872	0.043004	-0.08207	0.197806	0.170821	0.0371374
0.75	424.930	0.168410	0.030502	-0.08207	0.116841	0.100902	0.0263405
1.0	332.569	0.141691	0.023564	-0.08207	0.083185	0.071837	0.0203494
2.0	177.233	0.108487	0.012298	-0.08207	0.038715	0.033434	0.0106203
5.0	73.646	0.0919108	0.0050427	-0.08207	0.014884	0.012853	0.0043548
T = 212.0 °F							
0.20	1594.51	0.362561	0.045483	-0.08207	0.325974	0.281505	0.039278
0.23	1421.63	0.326981	0.042905	-0.08207	0.287816	0.248552	0.037052
0.25	1342.48	0.299617	0.041135	-0.08207	0.258682	0.223393	0.035523
0.30	1164.88	0.254633	0.036959	-0.08207	0.209522	0.180939	0.031917
0.35	1029.92	0.223893	0.033328	-0.08207	0.175151	0.151257	0.028781
0.50	766.849	0.170943	0.025416	-0.08207	0.114289	0.098698	0.021949
0.75	538.173	0.136117	0.018027	-0.08207	0.0720741	0.062242	0.015568
1.0	414.464	0.120651	0.013927	-0.08207	0.0525079	0.045345	0.012027

TABLE I
CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm./Gm-mol °K	-R	$(c_p - c_p^*)$ Liter-Atm./Gm-mol °K	$(C_p - C_p^*)$ BTU/Lb. °F	$(C_v - C_v^*)$ BTU/Lb. °F
T = 212.0 °F (Cont.)							
2.0	215.837	0.0999398	0.007269	-0.08207	0.0251390	0.021709	0.006277
5.0	88.5112	0.0888908	0.002980	-0.08207	0.0098008	0.0085501	0.002574
T = 302.0 °F							
0.20	2061.21	0.263713	0.031189	-0.08207	0.212832	0.183798	0.026934
0.23	1810.13	0.242917	0.029421	-0.08207	0.190268	0.164312	0.025407
0.25	1688.46	0.227238	0.028207	-0.08207	0.173375	0.149723	0.024359
0.30	1438.35	0.200378	0.025343	-0.08207	0.143651	0.124054	0.021886
0.35	1255.44	0.181260	0.022854	-0.08207	0.122044	0.105395	0.019736
0.50	913.537	0.146855	0.017428	-0.08207	0.082213	0.070998	0.015051
0.75	630.076	0.122649	0.012361	-0.08207	0.052940	0.045718	0.010675
1.0	481.229	0.111452	0.009550	-0.08207	0.038932	0.033621	0.0082472
2.0	247.603	0.0951650	0.004894	-0.08207	0.018079	0.015613	0.0043041
5.0	100.829	0.0854909	0.002043	-0.08207	0.0054639	0.0047185	0.0017643

TABLE I
CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm./Gm-mol °K	$-R$	$(c_p - c_p^*)$ Liter-Atm./Gm-mol °K	$(C_p - C_p^*)$ BTU/Lb. °F	$(C_v - C_v^*)$ BTU/Lb. °F
T = 392.0 °F							
0.10	5953.33	0.254665	0.019938	-0.08207	0.192533	0.166268	0.017218
0.13	4063.04	0.255860	0.023099	-0.08207	0.196889	0.170029	0.019948
0.15	3422.80	0.245990	0.023550	-0.08207	0.187470	0.161895	0.020337
0.18	2808.96	0.227624	0.023027	-0.08207	0.168581	0.145583	0.019886
0.20	2523.00	0.215623	0.022309	-0.08207	0.155862	0.134599	0.019266
0.23	2192.57	0.200879	0.021044	-0.08207	0.139853	0.120774	0.018173
0.25	2029.08	0.190189	0.020177	-0.08207	0.128296	0.110794	0.017425
0.30	1707.04	0.171369	0.018128	-0.08207	0.107427	0.092772	0.015655
0.35	1469.21	0.157729	0.016348	-0.08207	0.092007	0.079455	0.014118
0.50	1057.57	0.132667	0.012467	-0.08207	0.063064	0.054461	0.010766
0.75	720.690	0.114342	0.008842	-0.08207	0.041114	0.035505	0.007636
1.0	547.219	0.105641	0.006831	-0.08207	0.030402	0.026255	0.005899
2.0	279.153	0.0933702	0.003565	-0.08207	0.014865	0.012837	0.003079
5.0	113.112	0.0864619	0.001462	-0.08207	0.0058539	0.0050553	0.001263

TABLE I
CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm./Gm-mol °K	-R	$(c_p - c_p^*)$ Liter-Atm./Gm-mol °K	$(C_p - C_p^*)$ BTU/Lb. °F	$(C_v - C_v^*)$ BTU/Lb. °F
T = 482.0 °F							
0.10	7374.68	0.225136	0.014750	-0.08207	0.157816	0.136287	0.012738
0.13	4951.54	0.221034	0.017088	-0.08207	0.156052	0.134763	0.014757
0.15	4127.42	0.211863	0.017422	-0.08207	0.147215	0.127132	0.015045
0.18	3343.11	0.196812	0.017035	-0.08207	0.131777	0.113800	0.014711
0.20	2981.65	0.187421	0.016504	-0.08207	0.121855	0.105232	0.014253
0.23	2571.15	0.175917	0.015569	-0.08207	0.109416	0.094489	0.013445
0.25	2366.30	0.167895	0.014927	-0.08207	0.100752	0.087007	0.012891
0.30	1972.69	0.153498	0.013411	-0.08207	0.084839	0.073265	0.011581
0.35	1695.64	0.143019	0.012094	-0.08207	0.073043	0.063079	0.010444
0.50	1200.01	0.123419	0.009223	-0.08207	0.050572	0.043673	0.0079648
0.75	810.484	0.108763	0.006541	-0.08207	0.033234	0.028700	0.0056491
1.0	612.715	0.101692	0.005054	-0.08207	0.024676	0.021310	0.0043645
2.0	310.571	0.0915480	0.002638	-0.08207	0.012116	0.010463	0.0022781
5.0	125.372	0.0857672	0.001082	-0.08207	0.0047792	0.0041272	0.0093439

TABLE [illegible]

CALCULATED DATA (cont.)

V	P (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm./Gm-mol °K	$-R$	$(c_p - c_p^*)$ Liter-Atm./Gm-mol °K	$(C_p - C_p^*)$ BTU/Lb. °F	$(C_v - C_v^*)$ BTU/Lb. °F
T - 572.0 °F							
0.10	8805.06	0.205221	0.011217	-0.08207	0.134368	0.116038	0.0096867
0.13	5842.57	0.198255	0.012995	-0.08207	0.129180	0.111557	0.011222
0.15	4832.12	0.189678	0.013249	-0.08207	0.120857	0.104370	0.011442
0.18	3875.61	0.176752	0.012955	-0.08207	0.107636	0.092952	0.011187
0.20	3438.22	0.168974	0.012551	-0.08207	0.099455	0.085887	0.010839
0.23	2947.16	0.159486	0.011840	-0.08207	0.089251	0.077075	0.010225
0.25	2701.25	0.153089	0.011351	-0.08207	0.082370	0.071133	0.0098624
0.30	2236.31	0.141454	0.010199	-0.08207	0.069583	0.060091	0.0088076
0.35	1912.68	0.132907	0.009197	-0.08207	0.060034	0.051844	0.007942
0.50	1341.39	0.116950	0.007014	-0.08207	0.041894	0.036179	0.006057
0.75	899.730	0.104785	0.004975	-0.08207	0.027690	0.023913	0.004296
1.0	677.882	0.098847	0.003843	-0.08207	0.020620	0.017807	0.003319
2.0	341.898	0.090239	0.002006	-0.08207	0.010175	0.008787	0.001732
5.0	137.617	0.085871	0.0008232	-0.08207	0.004624	0.003993	0.0007107

TABLE I
CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v^*)$	$(c_v - c_v^*)$ Liter-Atm. / Gm-mol °K	$-R$	$(c_p - c_p^*)$ Liter-Atm. / Gm-mol °K	$(C_p - C_p^*)$ BTU / Lb. °F	$(C_v - C_v^*)$ BTU / Lb. °F
T = 752.0 °F							
0.13	7629.42	0.170295	0.008021	-0.08207	0.096245	0.083115	0.006926
0.15	6241.68	0.162634	0.008177	-0.08207	0.088741	0.076635	0.007062
0.18	4937.55	0.152296	0.007996	-0.08207	0.078221	0.067550	0.006905
0.20	4347.42	0.146405	0.007746	-0.08207	0.072081	0.062248	0.006689
0.23	3694.34	0.139278	0.007307	-0.08207	0.064515	0.055714	0.006310
0.25	3366.89	0.134741	0.007006	-0.08207	0.059677	0.051536	0.006050
0.30	2759.73	0.126333	0.006295	-0.08207	0.050558	0.043661	0.005436
0.35	2343.49	0.119659	0.005676	-0.08207	0.043265	0.037363	0.004902
0.50	1622.15	0.108554	0.004329	-0.08207	0.030813	0.026609	0.003738
0.75	1077.20	0.0995265	0.003070	-0.08207	0.020527	0.017727	0.002651
1.0	807.599	0.0950482	0.002372	-0.08207	0.015350	0.013254	0.002048
2.0	404.382	0.0884508	0.001238	-0.08207	0.0076190	0.0065790	0.001069
5.0	162.078	0.0845934	0.0005072	-0.08207	0.0030306	0.0026172	0.0004380

TABLE I
CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v^*)$	$(c_v - c_v^*)$ Liter-Atm./Gm-mol °K	-R	$(c_p - c_p^*)$ Liter-Atm./Gm-mol °K	$(C_p - C_p^*)$ BTU/Lb. °F	$(C_v - C_v^*)$ BTU/Lb. °F
T = 932 °F							
0.13	9420.03	0.153816	0.005294	-0.08207	0.077040	0.066530	0.004572
0.15	7507.39	0.146809	0.005397	-0.08207	0.070137	0.060569	0.004661
0.18	5997.05	0.137999	0.005277	-0.08207	0.061206	0.052856	0.004557
0.20	5253.51	0.133174	0.005113	-0.08207	0.056217	0.048548	0.004416
0.23	4437.69	0.127394	0.004823	-0.08207	0.050147	0.043306	0.004165
0.25	4029.13	0.123866	0.004624	-0.08207	0.046420	0.040087	0.003993
0.30	3280.13	0.117935	0.004155	-0.08207	0.040020	0.034560	0.003588
0.35	2771.69	0.112429	0.003747	-0.08207	0.034106	0.029453	0.003235
0.50	1901.33	0.103367	0.002857	-0.08207	0.024154	0.020859	0.002467
0.75	1253.84	0.0962211	0.002027	-0.08207	0.016178	0.013971	0.001751
1.0	936.826	0.0926416	0.001566	-0.08207	0.012137	0.010481	0.001352
2.0	466.733	0.0869806	0.0008171	-0.08207	0.0057281	0.0049466	0.0007056
5.0	186.517	0.0840828	0.0003350	-0.08207	0.0023478	.0020275	0.0002893

TABLE 1
CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm./Gm-mol °K	-R	$(c_p - c_p^*)$ Liter-Atm./Gm-mol °K	$(C_p - C_p^*)$ BTU/Lb. °F	$(C_v - C_v^*)$ BTU/Lb. °F
T = 1112.0 °F							
0.15	9061.10	0.1364439	0.0037470	-0.08207	0.0581209	0.0501921	0.0032358
0.18	7055.15	0.1286421	0.0036637	-0.08207	0.0502358	0.0433826	0.0031640
0.20	6157.83	0.1245009	0.0035496	-0.08207	0.0459805	0.0397078	0.0030654
0.23	5178.86	0.1195911	0.0033484	-0.08207	0.0408695	0.0352941	0.0028916
0.25	4689.45	0.1166898	0.0032103	-0.08207	0.0378301	0.0326693	0.0027724
0.30	3798.80	0.1112453	0.0028843	-0.08207	0.0320596	0.0276860	0.0024908
0.35	3198.41	0.1072699	0.0026010	-0.08207	0.0278009	0.0240083	0.0022462
0.50	2179.59	0.0998478	0.0019836	-0.08207	0.0197614	0.0170656	0.0017130
0.75	1430.03	0.0939580	0.0014069	-0.08207	0.0132949	0.0114812	0.0012150
1.0	1065.77	0.0909833	0.0010869	-0.08207	0.0100002	0.0086360	0.0009386
2.0	529.006	0.0837236	0.0005672	-0.08207	0.0022208	0.0019178	0.0004898
5.0	210.943	0.0838422	0.0002325	-0.08207	0.0020047	0.0017312	0.0002008

TABLE I
CALCULATED DATA (cont.)

T = 1292.0 °F

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm. / Gm-mol °K	-R	$(c_p - c_p^*)$ Liter-Atm. / Gm-mol °K	$(C_p - C_p^*)$ BTU / Lb. °F	$(C_v - C_v^*)$ BTU / Lb. °F
0.15	10,470.88	0.1291371	0.0027065	-0.08207	0.0497735	0.042983	0.0023373
0.18	8112.40	0.1220512	0.0026464	-0.08207	0.0426274	0.036812	0.0022854
0.20	7061.06	0.1183840	0.0025640	-0.08207	0.0388780	0.033574	0.0022142
0.23	5918.69	0.1140815	0.0024187	-0.08207	0.0344302	0.029733	0.0020887
0.25	5348.58	0.1116043	0.0023189	-0.08207	0.0318532	0.027508	0.0020026
0.30	4316.43	0.1069557	0.0020834	-0.08207	0.0269691	0.023290	0.0017992
0.35	3624.23	0.1036099	0.0018788	-0.08207	0.0234187	0.020224	0.0016225
0.50	2457.32	0.0973083	0.0014328	-0.08207	0.0166711	0.014397	0.0012373
0.75	1605.93	0.0923108	0.0010163	-0.08207	0.0112571	0.0097214	0.0008777
1.0	1194.55	0.0897737	0.0007851	-0.08207	0.0084888	0.0073308	0.0006780
2.0	591.234	0.0829785	0.0004098	-0.08207	0.0013183	0.0011385	0.0003539
5.0	235.361	0.0836376	0.0001681	-0.08207	0.0017357	0.0014989	0.0001452

TABLE I
CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm./Gm-mol °K	-R	$(c_p - c_p^*)$ Liter-Atm./Gm-mol °K	$(C_p - C_p^*)$ BTU/Lb. °F	$(C_v - C_v^*)$ BTU/Lb. °F
T = 1472.0 °F							
0.18	9169.10	0.1171598	0.0019734	-0.08207	0.0370632	0.032007	0.0017042
0.20	7963.59	0.1138413	0.0019119	-0.08207	0.0336832	0.029088	0.0016511
0.23	6657.66	0.1099859	0.0018036	-0.08207	0.0297195	0.025665	0.0015576
0.25	6006.95	0.1078141	0.0017292	-0.08207	0.0274732	0.023725	0.0014933
0.30	4833.37	0.1037449	0.0015536	-0.08207	0.0232285	0.020059	0.0013417
0.35	4049.45	0.1008118	0.0014010	-0.08207	0.0201428	0.017395	0.0012099
0.50	2734.68	0.0953882	0.0010684	-0.08207	0.0143866	0.012424	0.0009226
0.75	1781.64	0.0910578	0.0007578	-0.08207	0.0097456	0.0084161	0.0006544
1.0	1323.22	0.0888481	0.0005855	-0.08207	0.0073642	0.0063596	0.0005056
2.0	653.430	0.0823995	0.0003056	-0.08207	0.0006351	0.0005485	0.0002639
5.0	259.774	0.0834402	0.0001253	-0.08207	0.0014955	0.0012915	0.0001082

TABLE I
CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ $\frac{\text{Liter-Atm.}}{\text{Gm-mol } ^\circ\text{K}}$	$-R$	$(c_p - c_p^*)$ $\frac{\text{Liter-Atm.}}{\text{Gm-mol } ^\circ\text{K}}$	$(C_p - C_p^*)$ $\frac{\text{BTU}}{\text{Lb. } ^\circ\text{F}}$	$(C_v - C_v^*)$ $\frac{\text{BTU}}{\text{Lb. } ^\circ\text{F}}$
T = 1652.0 °F							
0.18	10225.44	0.1133878	0.0015104	-0.08207	0.0328282	0.0283498	0.0013044
0.20	8865.65	0.1103351	0.0014634	-0.08207	0.0297285	0.0259572	0.0012638
0.23	7396.05	0.1068227	0.0013797	-0.08207	0.0261324	0.0225674	0.0011915
0.25	6664.82	0.1048795	0.0013235	-0.08207	0.0241330	0.0208408	0.0011429
0.30	5349.86	0.1012523	0.0011891	-0.08207	0.0203714	0.0175923	0.0010269
0.35	4474.29	0.0986564	0.0010723	-0.08207	0.0176587	0.0152497	0.0009260
0.50	3011.80	0.0938845	0.0008177	-0.08207	0.0126322	0.0109089	0.0007061
0.75	1957.24	0.0900727	0.0005800	-0.08207	0.0085827	0.0074118	0.0005009
1.0	1451.81	0.0881201	0.0004481	-0.08207	0.0064982	0.0056117	0.0003870
2.0	715.607	0.0851276	0.0002388	-0.08207	0.0032914	0.0028424	0.0002019
5.0	284.184	0.0833016	0.0000959	-0.08207	0.0013275	0.0011464	0.0000828

TABLE I
CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm. / Gm-mol °K	-R	$(c_p - c_p^*)$ Liter-Atm. / Gm-mol °K	$(C_p - C_p^*)$ BTU / Lb. °F	$(C_v - C_v^*)$ BTU / Lb. °F
T = 1832 °F							
0.20	9767.38	0.1075474	0.0011450	-0.08207	0.0266224	0.0229906	0.0009888
0.23	8134.03	0.1043062	0.0010801	-0.08207	0.0232163	0.0200491	0.0009327
0.25	7322.32	0.1025411	0.0010356	-0.08207	0.0215067	0.0185728	0.0008943
0.30	5866.02	0.0992608	0.0009304	-0.08207	0.0181212	0.0156491	0.0008035
0.35	4898.85	0.0969305	0.0008390	-0.08207	0.0156995	0.0135578	0.0007245
0.50	3288.76	0.0926741	0.0006399	-0.08207	0.0112440	0.0097101	0.0005526
0.75	2132.74	0.0892756	0.0004538	-0.08207	0.0076594	0.0066145	0.0003919
1.0	1580.35	0.0875301	0.0003506	-0.08207	0.0058107	0.0050180	0.0003028
2.0	777.769	0.0848427	0.0001830	-0.08207	0.0029557	0.0025525	0.0001580
5.0	308.591	0.0832189	0.0000750	-0.08207	0.0012239	0.0010569	0.0000648

TABLE I
CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm. / Gm-mol °K	$-R$	$(c_p - c_p^*)$ Liter-Atm. / Gm-mol °K	$(C_p - C_p^*)$ BTU / Lb. °F	$(C_v - C_v^*)$ BTU / Lb. °F
T = 2012.0 °F							
0.20	10668.88	0.1052662	0.0009127	-0.08207	0.0241087	0.0208198	0.0007882
0.23	8871.79	0.1022451	0.0008609	-0.08207	0.0210359	0.0181662	0.0007435
0.25	7979.57	0.1006219	0.0008254	-0.08207	0.0193774	0.0167339	0.0007128
0.30	6381.96	0.0976225	0.0007416	-0.08207	0.0162941	0.0140713	0.0006404
0.35	5323.21	0.0955119	0.0006688	-0.08207	0.0141107	0.0121857	0.0005776
0.50	3565.59	0.0917005	0.0005100	-0.08207	0.0101405	0.0087571	0.0004404
0.75	2308.19	0.0886278	0.0003617	-0.08207	0.0069195	0.0059755	0.0003124
1.0	1708.85	0.0870400	0.0002795	-0.08207	0.0052495	0.0045333	0.0002414
2.0	839.921	0.0846034	0.0001459	-0.08207	0.0026793	0.0023138	0.0001260
5.0	332.996	0.0830957	0.0000642	-0.08207	0.0010899	0.00094121	0.0000534

TABLE I
CALCULATED DATA (cont.)

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm. / Gm-mol °K	-R	$(c_p - c_p^*)$ Liter-Atm. / Gm-mol °K	$(C_p - C_p^*)$ BTU / Lb. °F	$(C_v - C_v^*)$ BTU / Lb. °F
T = 2192.0 °F							
0.20	11570.20	0.1033957	0.0007389	-0.08207	0.0220646	0.0190546	0.0006381
0.23	9609.21	0.1005542	0.0006971	-0.08207	0.0191813	0.0165646	0.0006020
0.25	8636.62	0.0990464	0.0006684	-0.08207	0.0176448	0.0152377	0.0005772
0.30	6897.72	0.0962747	0.0006005	-0.08207	0.0148052	0.0127855	0.0005186
0.35	5747.42	0.0943369	0.0005415	-0.08207	0.0127701	0.0110280	0.0004676
0.50	3842.28	0.0908445	0.0004129	-0.08207	0.0091874	0.0079341	0.0003566
0.75	2483.59	0.0880676	0.0002929	-0.08207	0.0062905	0.0054324	0.0002529
1.0	1837.33	0.0866352	0.0002262	-0.08207	0.0047914	0.0041378	0.0001953
2.0	902.066	0.0844045	0.0001181	-0.08207	0.0024526	0.0021180	0.0001020
5.0	357.400	0.0830169	0.0000484	-0.08207	0.0009953	0.0008595	0.0000418

TABLE I
CALCULATED DATA (cont.)

T - 2372.0 °F

V	p (PSIA)	$(c_p - c_v)$	$(c_v - c_v^*)$ Liter-Atm./Gm-mol °K	-R	$(c_p - c_p^*)$ Liter-Atm./Gm-mol °K	$(C_p - C_p^*)$ BTU/Lb. °F	$(C_v - C_v^*)$ BTU/Lb. °F
0.20	12471.39	0.1018077	0.0006069	-0.08207	0.0203446	0.0175692	0.0005241
0.23	10346.52	0.0991185	0.0005726	-0.08207	0.0176211	0.0152172	0.0004945
0.25	9287.13	0.0977073	0.0005489	-0.08207	0.0161862	0.0139781	0.0004740
0.30	7413.36	0.0951281	0.0004932	-0.08207	0.0135513	0.0117026	0.0004259
0.35	6171.53	0.0933380	0.0004446	-0.08207	0.0117126	0.0101148	0.0003839
0.50	4119.02	0.0901368	0.0003392	-0.08207	0.0084060	0.0072593	0.0002929
0.75	2658.95	0.0875965	0.0002406	-0.08207	0.0057671	0.0049804	0.0002078
1.0	1965.78	0.0862829	0.0001859	-0.08207	0.0043988	0.0037987	0.0001605
2.0	964.205	0.0842328	0.0000970	-0.08207	0.0022598	0.0019515	0.0008377
5.0	381.804	0.0829497	0.0000398	-0.08207	0.0009195	0.0007941	0.0003437

TABLE II

VALUES OF THE ISOBARIC HEAT CAPACITY OF ETHYLENE IN THE IDEAL GAS STATE AT VARIOUS TEMPERATURES (1)

Temperature °F	C_p^* BTU/Lb. °F	Temperature °C	C_p^* Calories/Gram °C
0	0.3324	0	0.3485
32	0.3483	25	0.3711
60	0.3622	150	0.4369
68	0.3662	200	0.5197
77	0.3708	300	0.5920
100	0.3820	500	0.7070
200	0.4308	600	0.7535
300	0.4780	700	0.7944
400	0.5229	800	0.8303
500	0.5642	900	0.8617
600	0.6019	1000	0.8894
700	0.6365	1100	0.9134
800	0.6682	1200	0.9345
900	0.6976		
1000	0.7248		
1100	0.7501		
1200	0.7737		
1300	0.7956		
1400	0.8160		
1500	0.8349		
1600	0.8525		
1700	0.8688		
1800	0.8841		
1900	0.8983		
2000	0.9114		
2100	0.9235		
2200	0.9347		

NOMENCLATURE

c_p - Specific heat at constant pressure, Liter-Atm./Gm.-mol °K

C_p - Specific heat at constant pressure, BTU/Lb. °F

c^*_p - Specific heat at constant pressure for a gas in the ideal state, Liter-Atm./Gm.-mol °K

C^*_p - Specific heat at constant pressure for a gas in the ideal state, BTU/Lb. °F

c_v - Specific heat at constant volume, Liter-Atm./Gm.-mol °K

C_v - Specific heat at constant volume, BTU/Lb. °F

c^*_v - Specific heat at constant volume for a gas in the ideal state, Liter-Atm./Gm.-mol °K

C^*_v - Specific heat at constant volume for a gas in the ideal state, BTU/Lb. °F

T - Absolute temperature, $^\circ K = {}^\circ C + 273.13^\circ$

V - Volume, Liters

P - Absolute pressure, Atmospheres

p - Absolute pressure, Lbs. per Square Inch

R - Gas constant, 0.08207 Liter-Atm./Gm.-mol °K

A_o, B_o, C_o, a, b, c, α, γ, - Constants in the Benedict-Webb-Rubin Equation of State

e - Base of the natural logarithms

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