A GENERALIZED CORRELATION FOR THE EFFECT OF PRESSURE ON THE ISOBARIC HEAT CAPACITY OF GASES

BY

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SUMMARY

A generalized correlation is submitted for the deviation of the isobaric heat capacity of hydrocarbons from the ideal state. The range of conditions included is from reduced pressure = 0.2 - 15 and reduced temperature = 1.0 - 5.5. The curves presented have been based on data calculated from the Benedict - Webb - Rubin Equation of State, which is believed to be the most accurate method presently available for calculating the heat capacity deviation.

The results indicate that the order of magnitude of the correction is quite large, especially in the critical region. The average absolute error of this correlation is approximately 4.2% from the data on which it was based, but errors as high as 16% may occur in the regions of high heat capacity deviation. This indicates that, whenever possible, specific data should be used in preference to a generalized correlation. Comparisons have been made with the correlations submitted by previous investigators, and the relative accuracies of all have been discussed. A comparison with experimental heat capacity data for nitrogen and oxygen has shown that the correlation is also suitable for non-polar gases; and there are indications, based on the experimental data, that this correlation is more accurate than the earlier correlations which have been published.

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TABLE OF CONTENTS

Page

INTRODUCTION

METHOD OF CALCULATION

DISCUSSION OF RESULTS

APPENDIX

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Present advances in petroleum and petrochemical technology have extended operating variables into regions of high temperature and pressure. Design problems have resulted from these extreme conditions, in that it is not possible to extrapolate known physical properties at low pressure into the high pressure regions. Molecular forces come into play, and the perfect gas laws lose their significance. In the case of heat capacity, when pressure corrections are neglected, actual values may deviate as much as one hundred percent from those calculated.

The design engineer is confronted with the problem that the literature has very little to offer in the way of actual experimental data. He is forced to turn to generalized correlations in order to determine the properties of his system. These correlations may take the form of universal curves, applicable to any gas; or of universal equations of state for which the constants for a given gas may be inserted. It is the purpose of this work to submit a graphical correlation for $C_p-C_p^*$ which has a generalized application.

Early Generalized Correlations for $C_p-C_p^*$:

The original presentation of this nature was by Watson and Smith (1) . They presented generalized curves for compressibility factor, activity coefficient, Joule-Thomson coefficient, and enthalpy and specific heat deviation from the ideal state.

The work of Watson and Smith was based on experimental determinations of compressibility factors. These data were graphically integrated to give activity coefficient curves, and then, two successive graphical differentiations resulted in the data required for a generalized plot of $C_p-C_p^*$ versus p_r. Naturally, this sort of mathematical manipulation is subject to considerable error, and use of the resulting correlation is only justifiable when there is no other data at hand. Watson and Smith indicate these considerations in their discussion of the curves obtained.

Edmister (2) has presented a generalized correlation for $(C_p-C_p^*)$ in tabular form. His data are in the form $(C_p-C_p^*)/k_2$, where k_2 is a specific constant for each gas. The basis of the correlation is the difference between ideal and actual gas volumes, rather than their ratio, as Watson and Smith employed. This difference, defined as the Lewis and Randall Volume Residual Quantity (3), is represented by the equation $\alpha = RT/P - V$ and has been discussed by Deming and Shupe (4). It is considered by them to be much better adapted to graphical treatment than is the compressibility factor. Nevertheless, the fact that Edmister had to resort to the same graphical integration and differentiations as Watson and Smith must of necessity result in a certain amount of arithmetical error, aside from the accuracy of the original data.

Edmister (5) has also presented his tabulation in graphical form. To do this, he used an average calculated value of $k_2 = 1.44$ for all gases and plotted $C_p - C_p^*$ vs p_r , with parameters of t_r . Edmister states that his correlation is recommended in preference to the correlation submitted by Hougen and Watson (6) , which is a modification of the correlation of Watson and Smith (1). Both $C_p - C_p^*$ correlations were tested by Edmister for hydrocarbons and other fluids, with the conclusion that the correlation of Edmister was the more accurate.

In a later work (7), Edmister discusses the constant k_2 and states that, although k_2 is defined by the equation $k_2 = P_c \alpha_c / T_c$, it (k_2) need not be considered as rigidly established by the critical constants of the system, but that empirical revisions may be made in order that the generalized thermodynamic properties fit experimental data better. He also states that it most probably should not be necessary to modify the constants which he had already presented for pure components.

Dodge (8) has presented an early work in which C_p / C_p^* is plotted as a function of p_r with parameters of T_r . Dodge's data can be converted into $C_p - C_p^*$ values by the following equation:

$$C_p - C_p^* = C_p^*\left[(C_p/C_p^*) - 1\right]$$

This does require a knowledge of C_p^* at the given temperature and for the gas in question, but C_p^* data are generally available.

Dodge based his correlation on the compressibility data obtained by Bartlett, etal (8) . These data were converted into C_p/C_p^* by graphical differentiation methods similar to those used by Watson and Smith (1).

C_p-C_p^* Data Based on the Benedict - Webb - Rubin Equation of State:

Considering the doubts expressed by Edmister and the inherent inaccuracies of graphical differentiation processes, there still remains a need for a more accurate generalized correlation. Because of the difficulties and inaccuracies involved in experimental C_p measurements, it would be practical to limit experimental work to p-V-T data, and then mathematically calculate C_p-C_p^* from an equation of state based on these accurately measured values.

Of the presently available equations of state, the Benedict - Webb - Rubin Equation (9) presents itself as the most applicable for the purposes of a generalized C_p-C_p^* correlation. This equation was developed primarily for hydrocarbons, and has the property of being continuous for both the liquid and gaseous states. Benedict, Webb, and Rubin (10) have found that the average absolute deviation of pressure predicted by their equation is only 0.46% , which is well within the limits of accuracy needed for engineering calculations. Accurate results can be obtained up to 1.8 times critical density. Above this, the Benedict - Webb - Rubin Equation does not correlate well.

The Benedict - Webb - Rubin Equation is presented by the authors in the following form:

$$P = RTd + (B_oRT - A_o - C_o/T^2)d^2 + (bRT - a)d^3$$

$$a\alpha d^6 + (cd^3/T^2)\left[(1+\gamma d^2)e^{-\gamma d^2}\right]$$

By application of well known thermodynamic and Mathematical principles, Sledjeski (11)(12) has derived the following relationship for $C_p - C_p^*$:

(See over)

$$C_p - C_p^* = \frac{T\left[R + \frac{B_0 R}{V} + \frac{2C_0}{T^3 V} + \frac{bR}{V^2} - \frac{2c}{V^2 T^3}\left(1 + \frac{\gamma}{V^2}\right) e^{-\gamma/V^2}\right]^2}{RT + \frac{2}{V}\left(B_0 RT - A_0 - \frac{C_0}{T^2}\right) + \frac{3}{V^2}\left(bRT - a\right) + \frac{6a\alpha}{V^5} + \frac{c e^{-\gamma/V^2}}{V^2 T^2}\left(3 + \frac{3\gamma}{V^2} - \frac{2\gamma^2}{V^4}\right)}$$

$$+ \frac{6C_0}{T^3 V} + \frac{6c}{T^3 \gamma}\left(e^{-\gamma/V^2} - 1\right) + \frac{3c}{T^3 V^2} e^{-\gamma/V^2} - R$$

The preceding equation presents a means of calculating $C_p - C_p^*$ without resorting to graphical differentiation processes. However, because of its cumbersome nature, it is of limited utility to design engineers. Furthermore, it can only be applied to gases for which the Benedict - Webb - Rubin Constants are known.

A program has been undertaken at Newark College of Engineering to solve the expression $C_p - C_p^*$ for specific gases. Five gases have been studied to date, and their specific heat properties have been reported in the following theses:

1. "Isobaric Heat Capacity of Methane over a Wide Range of Temperature and Pressure" (11)
2. "Isobaric Heat Capacity of Propane over a Wide Range of Temperature and Pressure" (13)
3. "Isobaric Heat Capacity of n-Butane over a Wide Range of Temperature and Pressure" (10)
4. "Isobaric Heat Capacity of Ethylene over a Wide Range of Temperature and Pressure" (15)
5. "Heat Capacities of Ethene over a Wide Range of Temperature and Pressure" (16)

As of this writing, Sledjeski (12) and Seifarth and Joffe (17) have published articles presenting, respectively, the $C_p-C_p^*$ data obtained for methane and propane.

Actual experimental data for the five gases are very limited. The authors of the theses have discussed the existing experimental data for their gases, and they found the literature to be very deficient. What data were available applied only to the lower regions of reduced pressure.

A Generalized Correlation for $C_p-C_p^*$ Based upon the Benedict - Webb - Rubin Equation of State:

In this work, data described in the five theses have been assembled into the useful form of a generalized correlation. Data for specific gases are only of utility when the systems concerned consist of these gases only. Mixtures, or systems containing higher homologs than those included in the known data, cannot be treated with such limited information.

The data in each of the five theses are plotted as $c_p-c^*_p$ (Btu/#/°F) vs p (psia) with parameters of temperature (°F.) , and each thesis is applicable only to its own specific gas. In order to convert to a generalized correlation, it is necessary to express $c_p-c_p^*$ in molal units and temperature and pressure as the reduced values. According to the Law of Corresponding States, such data for one gas would yield an expression applicable to all other gases. However, the accuracy of such information would be very doubtful, and it is the object of the present work to average data pertaining to five gases in order to cancel out, in so far as possible, the deviations of the individual gases from the Law of Corresponding States and obtain a correlation based on the average behavior of the five hydrocarbons.

It should be borne in mind that a generalized correlation cannot be as exact as the data from which it is drawn, and, when possible, specific data should always be used. Newton (18) has discussed the Theory of Corresponding States, and the accuracy and deviations which result from its use. However, one must conclude that, in the absence of specific data, generalization is the most satisfactory means available for the estimation of physical properties of either pure hydrocarbons or mixtures.

This work presents a generalized correlation which is based on the most accurate specific heat data available. While the accuracy of the data upon which the correlation is based cannot be retained, it should be of a higher order than that of previous correlations.

The major distinctions between this correlation and the previous correlations are as follows:

1. C_p-C_p^* data are calculated by mathematical differentiation of the Benedict - Webb - Rubin Equation rather than by graphical differentiation of compressibility

factor data. These calculations have been carried out in the five theses previously mentioned, and the $C_p-C_p^*$ data used in the present work are therefore considered more accurate than earlier data obtained by graphical differentiation, in that the inherent inaccuracies of graphical differentiation processes are avoided.

2. $C_p-C_p^*$ data are averaged in the present work to obtain the generalized correlation. In earlier correlations, compressibility factor data were averaged; and from this, the $C_p-C_p^*$ generalization was calculated.

In essence, this has been the major purpose of this work: To average $C_p-C_p^*$ data which have previously been calculated from Benedict - Webb - Rubin relationships and to construct a generalized graphical correlation.

It is expected that the two distinctive methods of approach listed above and used in the present work will tend to strengthen the accuracy of the present correlation relative to the earlier generalized correlations for $C_p-C_p^*$.

METHOD OF CALCULATION

Generalized Correlation:

As previously stated, the data used in the preparation of this correlation has been taken directly from five theses submitted to Newark College of Engineering (11)(13)(14)(15)(16)(19). Each thesis dealt with the deviation of the isobaric specific heat of a specific gas, and the five gases studied were methane, ethylene, ethane, propane, and n-butane. The relationship $C_p - C_p^*$ was calculated directly from the Benedict-Webb-Rubin Equation of State (after appropriate mathematical manipulation) and the results were presented as a function of pressure with parameters of temperature. Table 1 lists the values of the Benedict - Webb - Rubin Constants used by each author for the calculation of his data. All of the constants are in agreement with the values presented by Benedict, et al(10).

A typical example of the manner in which data were presented can be taken from the thesis by Glueck (14) entitled "Isobaric Heat Capacity of n-Butane over a Wide Range of Temperature and Pressure". For the isotherm of 350.4°F , Glueck presents the following data (Table 5):

t (°F)	p (psia)	$c_p - c_p^*$ (Btu/#/°F)
350.4	896	0.657
	611	0.3533
	492.5	0.1647
	407	0.1053
	236	0.04294
	102.6	0.01584

From "American Petroleum Institute Research Project 44" (20), for n-butane

$$T_c = 765.31^\circ R$$

$$p_c = 550.7 \text{ psia} \qquad \text{(Table 2)} \quad ,$$

$$M = 58.120$$

Using the above constants, it is a straightforward calculation to convert to reduced conditions and molal quantities by the following equations:

$$T_r = \frac{459.69 + t\ (^\circ F)}{T_c (^\circ R)} = \frac{459.69 + t(^\circ F)}{765.31}$$

$$p_r = \frac{p\ (\text{psia})}{p_c (\text{psia})} = \frac{p\ (\text{psia})}{550.7}$$

$$C_p - C_p^* = c_p - c_p^* \ (\text{Btu}/\#/^\circ F) \times M = c_p - c_p^* \ (\text{Btu}/\#/^\circ F) \times 58.120$$

The specific heat data for the 350.4°F isotherm of n-Butane then becomes:

T_r	p_r	$C_p-C_p^*$ (Btu/#mol/°F)
1.059	1.627	38.18
	1.110	20.53
	.894	9.57
	.739	6.12
	.4286	2.496
	.1863	.921

Similar calculations were performed for the other isotherms of n-butane (presented by Glueck) and also for the other four gases. The tables of calculated data for the individual gases are presented in tables 3 - 7 . These $C_p-C_p^*$ data were then plotted for each gas as a function of reduced pressure, with a parameter of reduced temperature. The family of curves for ethane is presented in Figure 1 , and this is typical of the other four gases.

In order to utilize the $C_p-C_p^*$ data for each gas, the data must first be converted into uniform parameters of reduced temperature and pressure. The most direct means of accomplishing this is to arbitrarily choose a set of isobars and to read the value of $C_p-C_p^*$ for each parameter of reduced temperature crossing a given isobar. As an example, for the case of $p_r = 10$, the following data are obtained from Figure 1 :

$p_r = 10$ for ethane

T_r	3.383	2.656	2.292	1.928	1.746	1.564
$C_p-C_p^*$ (Btu/#mol/°F)	1.005	1.775	2.495	3.59	4.21	4.72

A total of fifteen isobars were chosen. These are p_r = 15 , 12 , 10 , 8 , 6 , 4 , 3, 2 , 1.5 , 1.0 , 0.8 , 0.6 , 0.4 , 0.3 , and 0.2 . Tabulations of C_p-C_p^* versus T_r with parameters of reduced pressure were made in this manner for all five gases and are presented in Tables 8 - 12 .

The data of Tables 8 - 12 serve as the basis for preparing the generalized correlation. For each parameter of reduced pressure, it was possible to plot C_p-C_p^* as a function of reduced temperature, plotting, for the given isobar, the data of all the gases on the same figure. Figure 2 is representative of the type of plot obtained. This was performed for the isobar of p_r = 6 , and, as can be seen, the points for the different gases are in quite close agreement to the average line drawn. Correlation was essentially the same for all of the other chosen parameters. Figure 3 is presented to show the family of curves obtained by this procedure.

It should be noted that Figure 3 is a generalized correlation of C_p-C_p^* versus reduced temperature with parameters of reduced pressures. However, this is not a convenient form of presentation because of the crossing of lines. Of more value is a plot of C_p-C_p^* versus reduced pressure, with parameters of reduced temperature. To prepare such a plot, it is only necessary to choose a set of isotherms and to then tabulate $C_p-C_p^*$ for each isotherm that the average line for each parameter of reduced pressure crosses.

Referring to Figure 2 , for $p_r = 6$, the following data are obtained:

T_r	1.5	1.75	2.0	2.25	2.5	3.0	4.0	5.0
$C_p-C_p^*$ (Btu/#mol/°F)	6.47	4.23	2.90	2.07	1.547	.845	.462	.277

Tabulations of T_r and $C_p-C_p^*$ were made in this manner for each parameter of reduced pressure, and the data are presented in Table 13 . This table represents the coordinates for the generalized correlation of $C_p-C_p^*$ versus p_r , with parameters of reduced temperature. The data from Table 13 are plotted on Figure 4 , which is the desired correlation of this work.

Comparison of Generalized Correlation with Original Data:

In order to determine quantitatively the deviation of the generalized correlation from the data used in its preparation, the original data contained in Tables 3 - 7 were representavely sampled. For each gas two extremes and a mean of reduced temperature were chosen, and then, for each parameter of reduced temperature, two extremes and a mean of reduced pressure were tabulated together with their corresponding values of $C_p-C_p^*$.

Thus, from Table 10, the following information was tabulated for ethylene:

I T_r	II p_r	III Calculated $C_p-C_p^*$	IV Generalized $C_p-C_p^*$	V Δ	VI Δ/Calc. %
1.107	0.2389	0.937	.93	- .007	- .7
	0.789	4.79	4.98	.019	.4
	1.379	19.86	17.0	-2.9	-14.6
2.379	0.545	0.1846	.198	.013	7.0
	4.539	1.445	1.49	.04	2.8
	10.29	2.331	2.53	.20	8.6
4.853	1.132	0.0649	.065	0	0
	7.17	0.3419	.342	0	0
	14.38	0.584	.561	-2.3	-3.9

The same procedure was followed for the other four gases, and this method provided a sampling of points over the entire range of reduced temperatures and pressures included in the correlation.

Column IV represents values of $C_p-C_p^*$ (corresponding to the conditions of Columns I and II) which were read from the generalized correlation of Figure 4. These values are subject to the errors of interpolation.

In order to determine the accuracy of the work, the difference (Δ) between the generalized and calculated $C_p-C^*_p$ values was taken. This difference was then divided by the value of the calculated $C_p-C_p^*$ for the given conditions, and the result (Column VI), expressed as percentage, represents the deviation of the generalized correlation from the data on which it was based.

Conversion of Data of Edmister:

Edmister (2) has presented his data for the generalized correlation of $C_p-C_p^*$ as a tabulation of $\Delta C_p/k_2$, where $\Delta C_p = C_p-C_p^*$ (Btu/#mol/°F) and k_2 is a constant specific for each gas. For the purposes of the comparison, it was decided to arithmetically average the k_2 values, which are very close in value to each other.

	k_2
Methane	1.413
Ethylene	1.410
Ethane	1.457
Propane	1.455
n-Butane	1.477
	= 7.212

$$\bar{k}_2 = 7.212/5 = 1.442$$

Edmister's $\Delta C_p/k_2$ values were then multiplied by $\bar{k}_2$ to give $C_p-C_p^*$. The resulting data are listed in Table 15.

Comparison of Generalized Correlation with Experimental Data for Nitrogen and Oxygen:

Experimental values of C_p were obtained by Krase and Mackey (21)(22) for nitrogen. These values are listed in Table 17. Critical data and an equation for C_p^* are presented by Hougen and Watson (23).

for N_2 : $t_c = -147.1$ °C

$$p_c = 33.5 \text{ atm}$$

$$C_p^* = 6.30 + 1.819 \times 10^{-3}T - 0.345 \times 10^{-6}T^2 \quad (T = {}^\circ K)$$

Values of C_p^* were calculated from the above equation and were deducted from the C_p values presented by Krase and Mackey. The result, $C_p - C_p^*$, was then compared to the values read from Figure 4 for the same reduced temperature and pressure.

The experimental data of Workman (24) for N_2 and O_2 are presented in the form C_p/C_p^* (See Table 18). These were converted to $C_p - C_p^*$ data by the following equation:

$$C_p - C_p^* = C_p^* \left[(C_p/C_p^*) - 1 \right]$$

where C_p^* was calculated in the same manner as above.

The critical data and heat capacity data which were used for O_2 are as follows:

$$t_c = -118.8^\circ C.$$

$$p_c = 49.7 \text{ atm.}$$

$$C_p^* = 6.10 + .0018T - .314 \times 10^{-6}T^2 \quad (T = {}^\circ R)$$

The values of $C_p - C_p^*$ calculated from Workman's experimental data are tabulated in Table 18. In addition, values of $C_p - C_p^*$ read from Figure 4, Edmister's (5) and Hougen and Watson's (6) curves are also listed, and the deviations of the latter from the experimental values have been calculated.

DISCUSSION OF RESULTS

The Accuracy of Benedict - Webb - Rubin Data:

Before proceeding with an evaluation of the results obtained in this work, it would be well to consider the accuracy of the data used as the basis of the generalized correlation. In the theses from which this work has been drawn, each author has evaluated his results in reference to the known data pertaining to his chosen gas. The following is an abbreviated summary of their remarks:

1. Methane: Sledjeski (11) used Budenholzer, Sage, and Lacey (25) as the basis for reference, since he felt that data obtained from Joule-Thomson Coefficients were more accurate than data based on p-V-T information. Ellenwood, Kulik, and Gay (26) , who used the Beattie - Bridgeman Equation, and Edmister (2) deviated substantially from Budenholzer. Sledjeski concludes that the data of Budenholzer, et al, should be used below 220°F and 1500 psia ($T_r = 2$ and $p_r = 2.25$) and those of Sledjeski above those limits.

2. Propane: Seifarth (13) compared his work with that of Sage, Kennedy, and Lacey (27), who based their work on Joule - Thomson Coefficients. He concluded that their experimental work was subject to considerable error and resulted in lower values than those calculated from Benedict - Webb - Rubin relationships. Seifarth found that the correlation of Edmister (2) agreed within a reasonable

degree of accuracy with Seifarth's results. Seifarth states that below 200°F. and 550 psia (T_r = .99 and p_r = .9) the data of Sage, et al, should be used; and above those limits the data of Seifarth are the most accurate.

3. n-Butane: The only comparison that Glueck (14) makes above 350°F. (the lower limit of his correlation) is with Edmister (2). He found that Edmister gave a lesser deviation of $C_p-C_p^*$, especially at higher pressures, and recommended that the data of Glueck be used.

4. Ethylene: Sibilia (15) compared his $C_p-C_p^*$ data to the work of Ellenwood, Kulik, and Gay (26) (who used the Beattie - Bridgeman Equation) and found considerable deviations. He also compared $C_p-C_p^*$ data to those of Michels, Geldermans, and DeGroot (28)(29) and found the data of Michels, et al, to be approximately 6% to 40% lower than that calculated by Benedict - Webb - Rubin relationships. Sibilia implies that the data he presents are the most acceptable.

5. Ethane: Reiter (16) has compared his work to Sage, et al, (30)(31) who obtained their data from Joule-Thomson Coefficients, and also to Edmister (2). Reiter found that the results of Edmister differed significantly from his own at higher pressures and that the values of Sage are in question above 600 psia. Reiter recommends that below 250°F. and 600 psia (T_r = 1.29 and p_r = .85)

the data of Sage should be used, and above those limits the values of Reiter be used.

From the comments just stated, the conclusion can be drawn that the most accurate $C_p-C_p^*$ information presently available is that based on the Benedict - Webb - Rubin Equation of State, except in the regions of lower reduced temperature and pressure. There, data based on Joule - Thomson measurements are most satisfactory.

Unfortunately, Joule - Thomson data has been obtained for relatively few gases, and then only for a limited range of temperature and pressure. When the system in question meets these restrictions, then the data of Sage, et al, should be used. Outside of these limits, Benedict - Webb - Rubin relationships are the most accurate.

The Generalized Correlation:

Figure 4 and Table 13 represent the generalized correlation for $C_p-C_p^*$, which was the purpose of this work. $C_p-C_p^*$ (in molal units) is plotted as a function of reduced pressure, with parameters of reduced temperature. Eighteen parameters of reduced temperature are presented, varying from $T_r = 1.0$ to $T_r = 5.5$. Reduced pressure ranges between the limits of $p_r = 0.2$ to $p_r = 15$. Referring to the correlation of Hougen and Watson (6) and Edmister (2) , it can be noted that the range of variables which these authors have included is as follows:

	Hougen & Watson	Edmister	Weiss
p_r	.01 - 7.0	.01 - 6.0	.2 - 15
T_r	.625- 3.0	.6 - 4.0	1.0 - 5.5

Outside of the limits of this correlation, it is recommended that the data of Edmister be used (i.e., from $p_r \geqq .01$ to $p_r < 0.2$ and $T_r \geqq 0.6$ to $T_r < 1.0$). Where neither the data of Edmister nor Weiss apply, the data of Hougen and Watson may be used, although, as will be shown, they may be subject to severe errors.

Comparison of Generalized Correlation with Original Data:

Table 14 presents a representative sampling of $C_p - C_p^*$ for each of the five gases studied. The calculated values of $C_p - C_p^*$ versus the values read from Figure 4 have been compared, and their deviations are listed. It should again be noted that the values of $C_p - C_p^*$ read from the generalized curves are subject to the errors of interpolation.

A study of Table 14 shows that the deviations of the generalized correlation from the original data range from 0% to 16% . The higher deviations occur in the regions of either extreme curvature or extremely high values of $C_p - C_p^*$, where the differences between individual gases may be expected to increase. The average deviation, calculated from the results of Table 14, amounts to ± 4.2% .

Table 14 serves to emphasize that, whenever possible, the data for specific gases should be used in preference to information from a generalized correlation. However, excluding the aforementioned regions of high $C_p - C_p^*$ or curvature, the correlation will provide an accuracy (± 4.2%) which is suitable for most engineering calculations.

Comparison of Generalized Correlation to Those of Edmister and Watson and Smith:

Comparisons of this generalized correlation with those submitted by Edmister (2) and Watson and Smith (1) have been made for the parameters of T_r = 1.0 , 1.2 , 1.5 , and 2.5 . Table 15 lists the pertinent data from Edmister's correlation and Table 16 lists the data of Watson and Smith, which were read from the chart presented by Hougen and Watson (6).

Figure 5 graphically depicts the differences between the three correlations. It is significant that the three are close to each other and so similar in general shapes of curves. Using the curves calculated in this work as the reference, the range of deviations of the other two may be tabulated as follows:

T_r	1.0	1.2	1.5	2.5
Edmister	11 to 37%	-1 to -11%	-4 to -8%	-22 to -23%
Watson & Smith	59 to 62%	26 to 55%	33 to 64%	43 to 63%

Thus, it is seen that the correlation of Edmister agrees quite well with this correlation for T_r = 1.2 and T_r = 1.5 . But for T_r = 1.0 and T_r = 2.5 the deviations are quite serious, and are, respectively, positive and negative. The data of Watson and Smith are about 50% to 60% too high over the entire range of reduced temperature.

Comparison of Generalized Correlation with Experimental Data for Nitrogen and Oxygen:

In order to test the applicability of this correlation to gases other than hydrocarbons, experimental data of Krase and Mackey (21)(22) for nitrogen were utilized. Table 17 lists their results, and the corresponding values of $C_p-C_p^*$ read from Figure 4 are tabulated. It is seen that the results of Figure 4 vary from 9 to 21% higher than the experimental values. This is close enough agreement to indicate that Figure 4 is suitable for use as a generalized correlation both for non - polar gases and hydrocarbons.

In addition, Krase and Mackey's data for nitrogen have been compared to the values read from the curves presented by Hougen and Watson and by Edmister. Unfortunately, both of these correlations are only applicable to one of Krase and Mackey's points.

t_r	p_r	Krase & Mackey $C_p-C_p^*$	Weiss $C_p-C_p^*$	Edmister $C_p-C_p^*$	Hougen & Watson $C_p-C_p^*$
2.37	5.97	1.47	1.78	1.45	2.6
Percentage Deviations from Experimental			21	-1	77

It is interesting that this point corresponds to the point of maximum disagreement of Krase and Mackey's experimental data from Weiss and of exceedingly high disagreement for Hougen and Watson; while the value presented by Edmister is only 1% lower than the experimental value. However, one point is not sufficient as a basis for any significant conclusions.

Table 18 lists some of the experimental data (arbitrarily chosen) obtained by Workman (24) for nitrogen and oxygen. Workman's values of C_p/C_p^* have been converted to $C_p-C_p^*$ data, and these have been compared to Figure 4, Edmister's correlation, and Hougen and Watson's correlation.

A study of Table 18 will show that there is essentially no disagreement between the experimental values of nitrogen and the values read from Figure 4 and Edmister's curves (5). (The deviations of the latter two are on the order of 3% from the experimental). This is in confirmation of Figure 5 , which shows that the correlations of Edmister and Weiss agree in the region of this particular reduced temperature (t_r = 1.938) . Hougen and Watson's curves give values which are on the order of 45% higher than the experimental values.

The data for oxygen corresponds to t_r = 2.64, where there is significant disagreement between Figure 4 and Edmister. In this instance, Table 18 indicates that Figure 4 is significantly closer to the experimental values (1% to 13% different). Values read from Hougen and Watson's curves for this isotherm are about 50% higher than the experimental.

This test would indicate that Figure 4 is not only applicable to gases other than hydrocarbons, but that it may be preferable to the other correlations which have been published. However, this must be a strictly qualified conclusion, in that only one set of experimental data (O_2) indicates that Figure 4 is more accurate than that of Edmister. Comparison of experimental data for other gases might well indicate that Edmister is more accurate.

Further, the data of Krase and Mackey and of Workman have only provided checks of $C_p - C_p^*$ in the range of $t_r \overset{\sim}{=} 1.9 - 3.4$. It is very possible that more extensive data might show that, e.g., the correlation of Edmister is more suitable than Figure 4 in the range of $t_r = 1.0 - 1.9$. This is strictly hypothetical, however, since no such checks in the lower reduced temperature range have been made because of lack of experimental data.

Conclusions and Recommendations:

This work has provided a generalized correlation for $C_p - C_p^*$ which is believed to be more accurate than correlations which have been previously published. This has been effected by averaging $C_p - C_p^*$ data for five hydrocarbon gases. The data for the individual hydrocarbons were obtained by previous authors (16)(18)(19)(20)(21)(24) by mathematical differentiation of the Benedict - Webb - Rubin Equation of State and are considered to be the most accurate source of C_p-C_p^* data presently available for these hydrocarbons.

This correlation (Figure 4) differs from previously published correlations (1)(2)(8) both in the source of data and in the method of calculation. Earlier correlations were based on compressibility factor type of data, which have been found to be less accurate than the Benedict - Webb - Rubin relationships used for this work. In addition, to obtain the C_p-C_p^* correlation, it was necessary for earlier authors to graphically differentiate a generalized compressibility factor (or α) correlation. Figure 4 was based upon the drastically different method of averaging specific C_p-C_p^* data for five gases, the data having been obtained by mathematical differentiation processes. These considerations should all tend to strengthen confidence in the accuracy of Figure 4 in comparison to the earlier C_p-C_p^* correlations.

Comparison of Figure 4 with experimental data for oxygen and nitrogen has indicated that Figure 4 is suitable for gases other than hydrocarbons, and there are indications that Figure 4 approaches the experimental C_p-C_p^* values more closely than the most accurate earlier work (Edmister (2)).

Considering these factors, it is recommended that the generalized correlation for $C_p - C_p^*$ presented in this work be used in preference to the earlier generalized correlations which have been published. However, this must be qualified by the understanding that a generalized correlation is inherently subject to error (Figure 4 differs as much as 16% from the data for specific gases on which it is based.). In consideration of this, the following rules are suggested to help determine the method to be followed when it is necessary to obtain $C_p - C_p^*$ data for a given gas or gaseous system:

1. When possible, experimental $C_p - C_p^*$ data should be used for the particular system in question.

2. Lacking experimental data, $C_p - C_p^*$ information for hydrocarbons should be calculated from the Benedict - Webb - Rubin Equation of State. This is the most accurate means of calculating $C_p - C_p^*$ which is presently available.

3. When there is no other practical alternative, $C_p - C_p^*$ values should be taken from a generalized correlation. The present correlation, which is based on Benedict - Webb - Rubin relationships, may be the most accurate work available to data, and is recommended in preference to the correlations which have been previously published.

APPENDIX

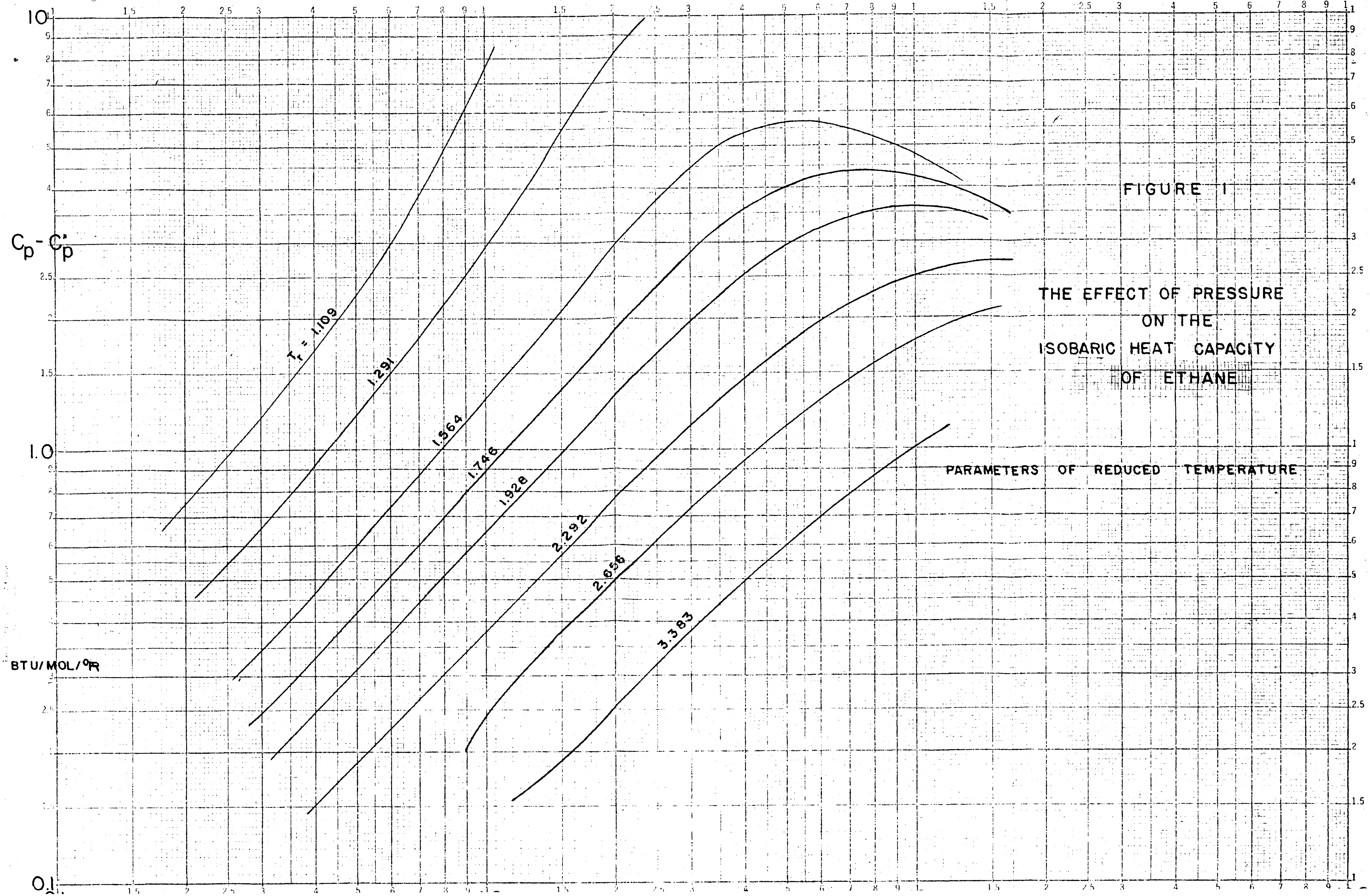

FIGURE 1

THE EFFECT OF PRESSURE
ON THE
ISOBARIC HEAT CAPACITY
OF ETHANE

PARAMETERS OF REDUCED TEMPERATURE

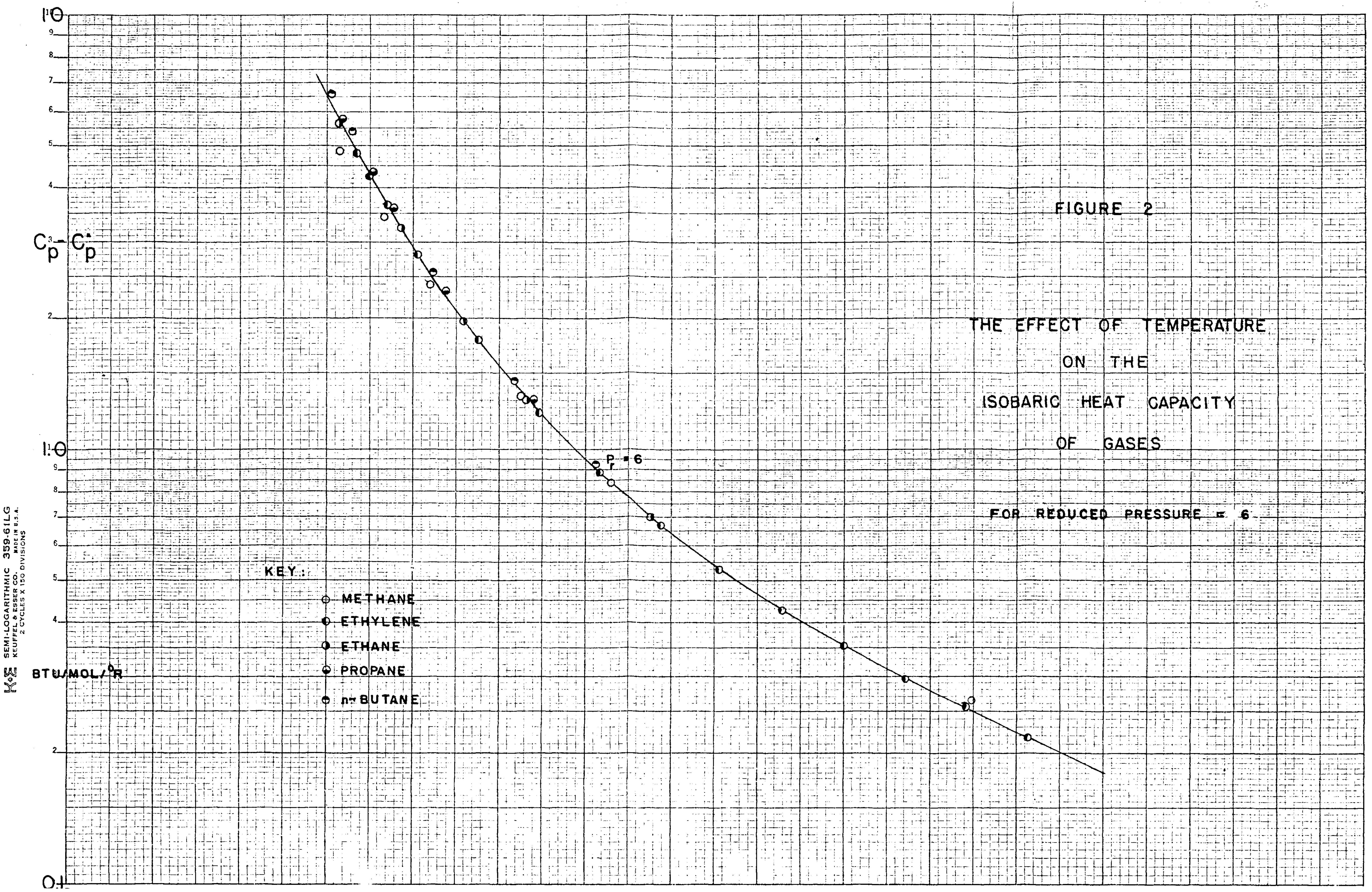

FIGURE 2

THE EFFECT OF TEMPERATURE ON THE ISOBARIC HEAT CAPACITY OF GASES

FOR REDUCED PRESSURE = 6

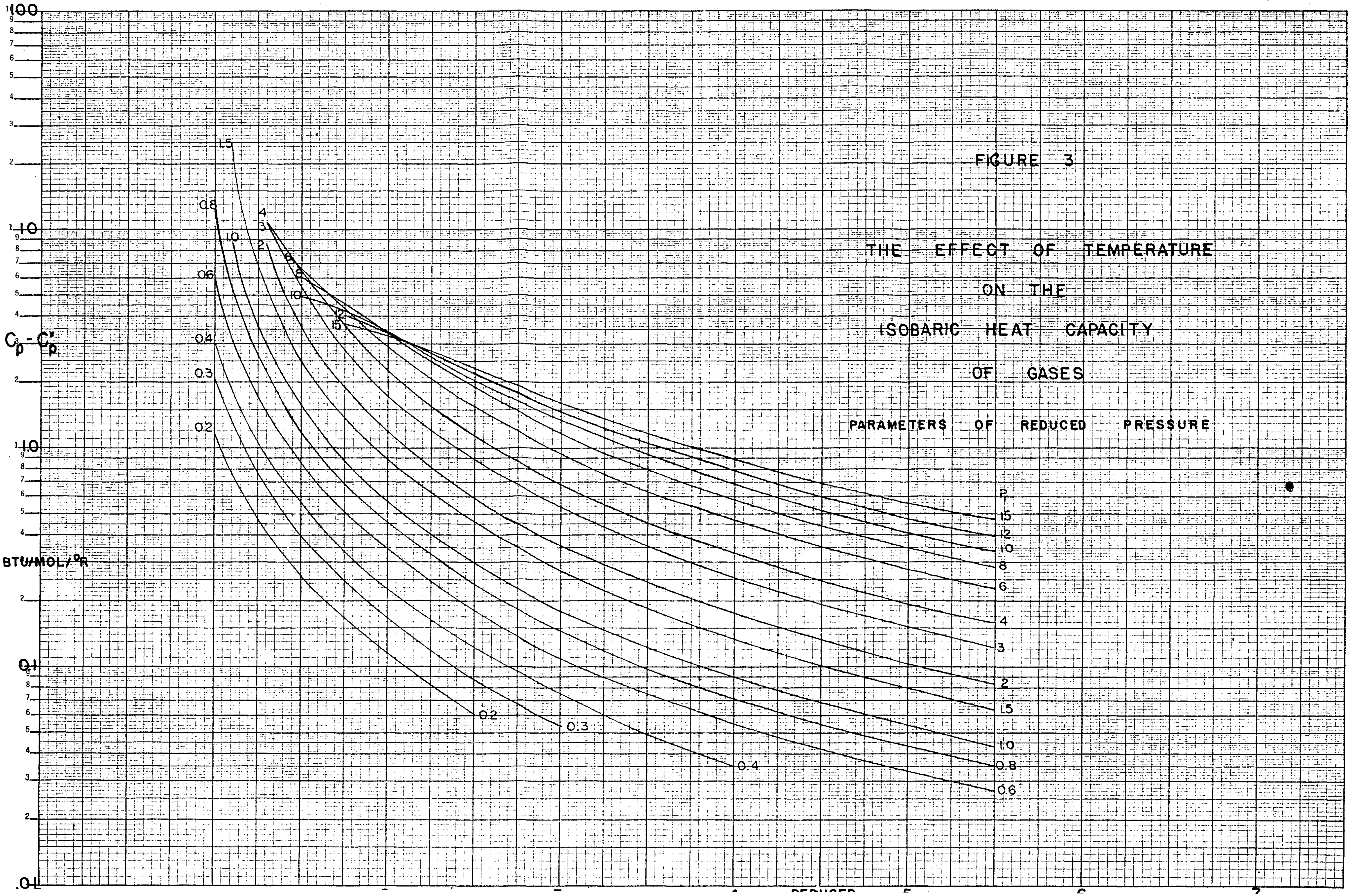

FIGURE 3

THE EFFECT OF TEMPERATURE ON THE ISOBARIC HEAT CAPACITY OF GASES

PARAMETERS OF REDUCED PRESSURE

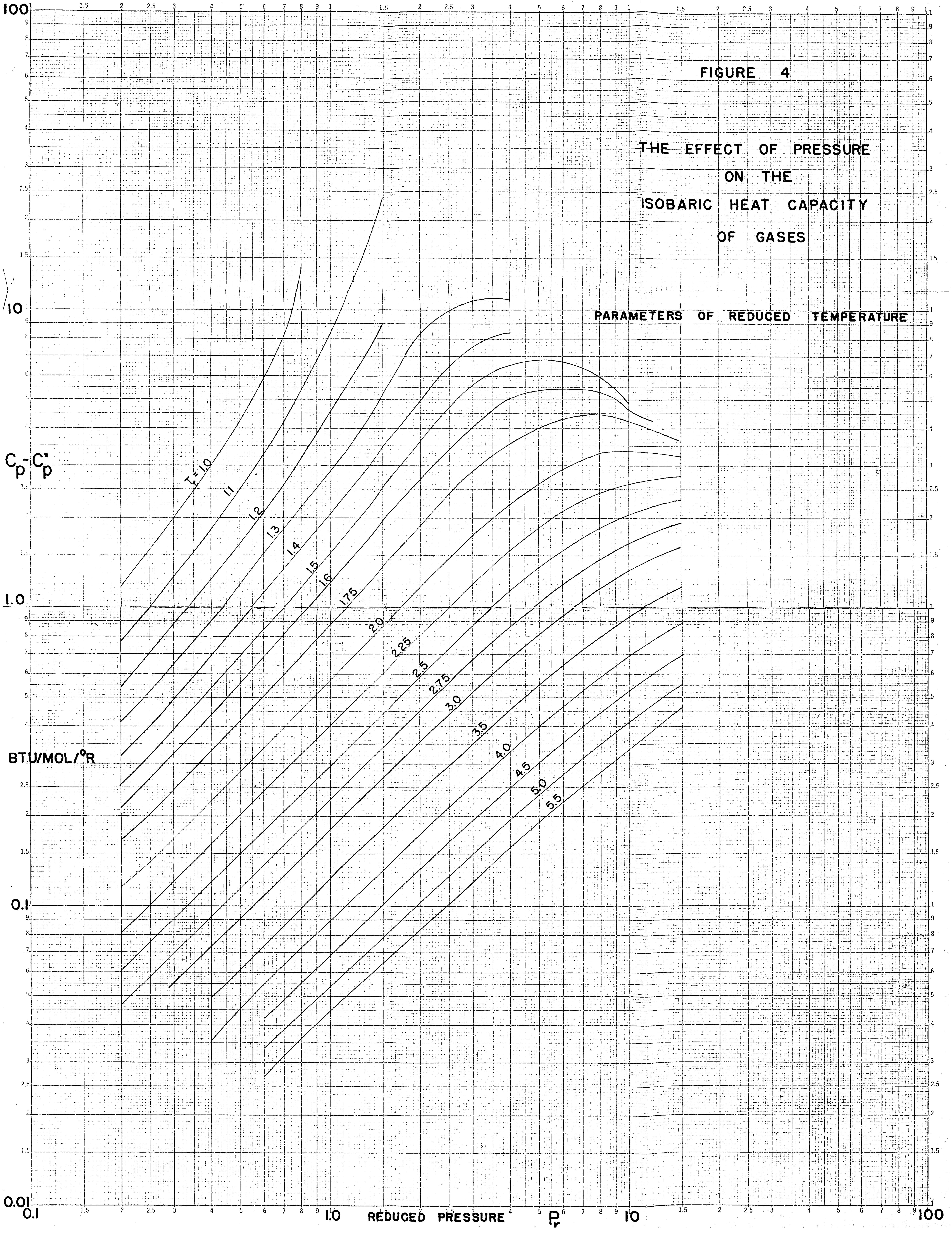

FIGURE 4

THE EFFECT OF PRESSURE ON THE ISOBARIC HEAT CAPACITY OF GASES

PARAMETERS OF REDUCED TEMPERATURE

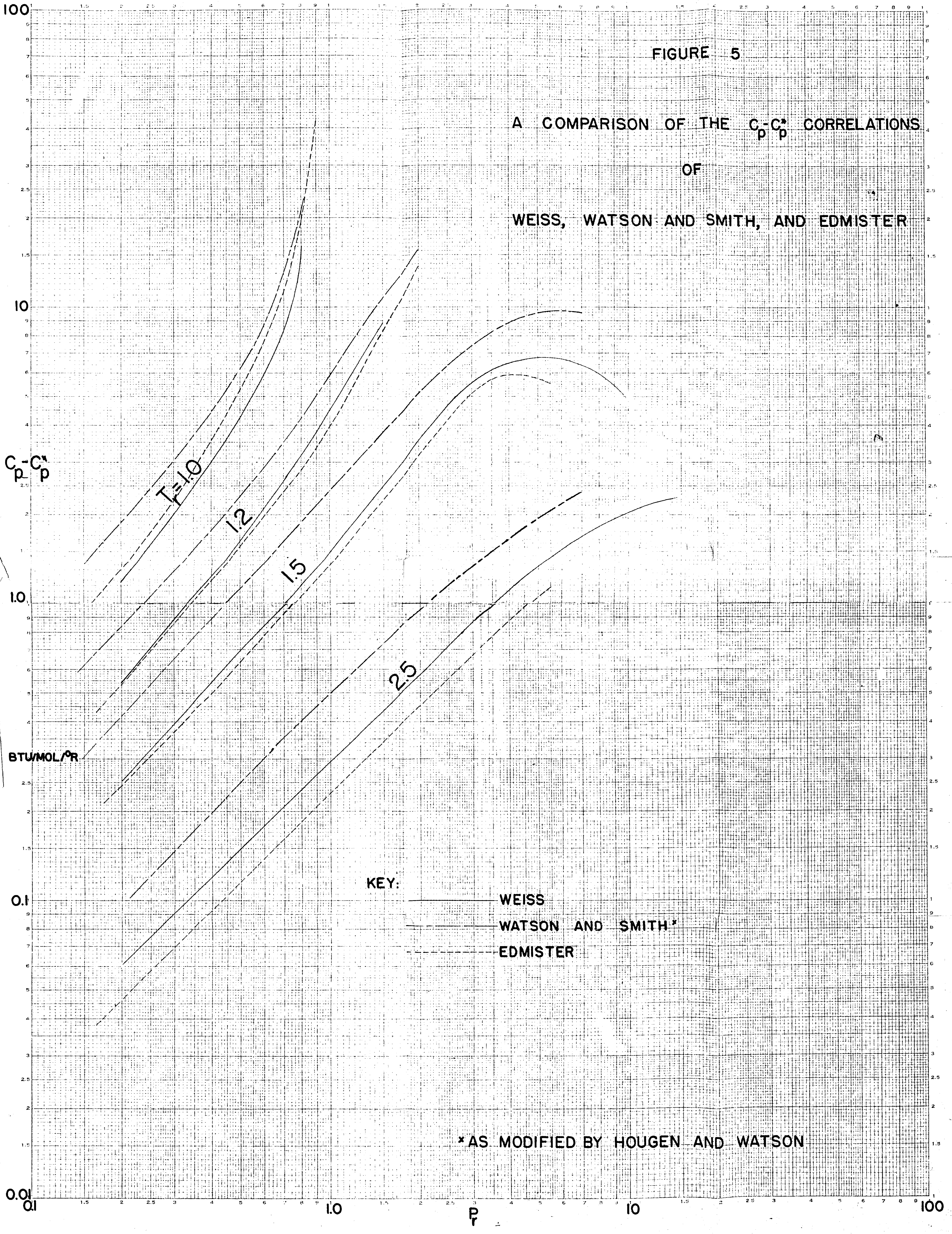

FIGURE 5

A COMPARISON OF THE $C_p-C_p^*$ CORRELATIONS OF WEISS, WATSON AND SMITH, AND EDMISTER

*AS MODIFIED BY HOUGEN AND WATSON

Table 1

Benedict - Webb - Rubin Constants

Ethylene : (10)(15)

(liters,atm,gm mol,°K)

B_0 = 0.0556833
A_0 = 3.33958
C_0 = 131,140
b = 0.0086000
a = 0.259000
c = 21120
γ = 0.00923000
α = 0.000178000

Butane : (14)(9)

(liters,atm,gm mol,°K)

B_0 = 0.124361
A_0 = 10.0847
C_0 = 992,830
b = 0.0399983
a = 1.88231
c = 316,400
γ = 0.0340000
α = 0.00110132

Propane : (9)(13)

(liters,atm,gm mol,°K)

B_0 = 0.0973130
A_0 = 6.87225
C_0 = 508,256
b = 0.0225000
a = 0.947700
c = 129,000
γ = 0.0220000
α = 0.000607175

Methane : (9)11)

(liters,atm,gm mol,°K)

B_0 = 0.042600
A_0 = 1.85500
C_0 = 22,570
b = 0.00338004
a = 0.049400
c = 2,545
γ = 0.006000
α = 0.00124359

Ethane : (9)(16)

(ft³,psia,# mol,°R)

B_0 = 1.00554
A_0 = 15,670.7
C_0 = 2.19427×10^9
b_0 = 2.85393
a = 20,850.2
c = 6.41314×10^9
γ = 3.02790
α = 1.00044

Table 2

Molecular Weights and Critical Properties of Hydrocarbons

Refernce = (20)

	M	T_c (°R)	p_c (psia)
CH_4	16.042	343.3	673.1
C_2H_4	28.052	509.51	742.1
C_2H_6	30.068	549.77	708.3
C_3H_8	44.094	665.95	617.4
C_4H_{10}	58.120	765.31	550.7
n-C_5H_{12}	72.146	845.60	489.5

Table 3

Specific Heat Data for Methane (11)(19)

T (°F.)	p (psia)	$c_p - c_p^*$ (Btu/#/°F.)	t_r	p_r	$C_p - C_p^*$ (Btu/# mol/°F.)
80.3	196.4	.01950	1.573	.2919	.3128
	252.0	.02524		.3745	.4049
	291.3	.02948		.4329	.4729
	347.2	.03545		.516	.569
	563.4	.0624		.837	1.001
	822	.0940		1.221	1.508
	1067	.1283		11586	2.058
	1536	.1961		2.232	3.146
	1689	.2172		2.510	3.484
	2131	.2680		3.167	4.299
	2290	.2814		3.403	4.514
	2479	.2946		3.684	4.726
	3017	.3135		4.483	5.03
	3206	.3150		4.764	5.05
	4026	.3043		5.98	4.882
	429.8	.04480		.639	.719
	669	.0759		.994	1.186
	928	.1087		1.379	1.744
	1174	.1437		1.745	2.305
	1355	.1702		2.014	2.730
	1779	.2288		2.644	3.670
	1997	.2556		2.968	4.100
	2479	.2946		3.684	4.726
	3428	.3131		5.094	5.02
170.3	411.1	.02537	1.835	.611	.4070
	511	.03224		.759	.517
	675	.04486		1.003	.720
	996	.0709		1.480	1.137
	1311	.0914		1.948	1.466
	1938	.1359		2.880	2.180
	2419	.1666		3.595	2.673
	2778	.1815		4.128	2.912
	3008	.1905		4.470	3.056
	3287	.1991		4.884	3.194
	4082	.2140		6.07	3.433
	4689	.2175		6.97	3.486
	5570	.2146		8.28	3.443
	3634	.2080		5.40	3.337

Table 3 Con't.

Specific Heat Data for Methane

t (°F)	p (psia)	$c_p - c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p - C_p^*$ (Btu/#mol/°R)
260.3	265.5	.01157	2.098	.3945	.1856
	474.8	.02016		.706	.3234
	592	.02555		.880	.4099
	785	.03503		1.167	.562
	1169	.0527		1.737	.845
	1553	.0704		2.308	1.129
	2336	.1028		3.471	1.649
	2954	.1239		4.390	1.988
	3421	.1366		5.08	2.191
	4091	.1503		6.08	2.411
	4551	.1569		6.76	2.517
	5150	.1628		7.65	2.612
	5950	.1667		8.84	2.674
	7120	.1674		10.58	2.685
	8950	.1610		13.30	2.583
	1862	.0838		2.767	1.344
	3169	.1301		4.709	2.087
	3723	.1437		5.53	2.305
	4307	.1537		6.40	2.466
	4828	.1560		7.17	2.503
	5520	.1651		8.20	2.649
	6360	.1676		9.45	2.689
	6720	.1678		9.99	2.692
440.3	602	.01455	2.622	.895	.2334
	752	.01816		1.117	.2913
	1004	.02444		1.492	.3921
	1513	.03599		2.248	.577
	2033	.04740		3.021	.760
	3128	.0683		4.648	1.096
	7280	.1103		10.82	1.769
	2268	.0523		3.370	.839
	2688	.0604		3.994	.969
	3514	.0746		5.22	1.197
	4017	.0820		5.97	1.315
	4331	.0861		6.44	1.381
	4702	.0904		6.99	1.450
	5148	.0954		7.65	1.530
	5695	.1002		8.46	1.607
	6380	.1052		9.48	1.688
	7830	.1127		11.64	1.808
	8480	.1105		12.60	1.773
	501	.01218		.744	.1954

Table 3 Con't.

Specific Heat Data for Methane

t (°F)	p (psia)	$c_p - c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p - C_p^*$ (Btu/#mol/°R)
620.3	403.2	.00626	3.146	.599	.1004
	519	.00799		.771	.1282
	606	.00931		.901	.1494
	728	.01117		1.082	.1792
	912	.01393		1.355	.2235
	1222	.01866		1.816	.2977
	1854	.02717		2.755	.4359
	2509	.03556		3.728	.570
	3914	.0509		5.82	.817
	4417	.0555		6.56	.890
	5080	.0610		7.55	.979
	5980	.0675		8.89	1.083
	6570	.0712		9.76	1.142
	7300	.0752		10.85	1.206
	9400	.0842		13.97	1.351
	10140	.0865		15.07	1.388
	8210	.0796		12.20	1.277
	8770	.0819		13.03	1.314
980.3	5480	.03332	4.195	8.14	.535
	6220	.03677		9.24	.590
	6670	.03854		9.91	.618
	7190	.04052		10.68	.650
	7800	.04295		11.59	.689
	8530	.04517		12.68	.725
	8950	.04651		13.30	.746
	9560	.04793		14.21	.769
	9920	.04945		14.74	.793
	10500	.05105		15.60	.819

Table 3 Con't.

Specific Heat Data for Methane

t (°F)	p (psia)	$c_p - c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p - C_p^*$ (Btu/#mol/°R)
1340.3	678	.003296	5.244	1.008	.0529
	875	.004181		1.300	.0671
	1024	.004830		1.522	.0778
	1233	.00578		1.832	.0927
	1551	.00717		2.305	.1150
	2092	.00938		3.109	.1503
	2534	.01111		3.766	.1782
	3217	.01372		4.780	.2201
	4410	.01763		6.55	.2828
	5420	.02069		8.05	.3319
	7050	.02515		10.48	.4035
	467.5	.002268		.695	.03638
	1781	.00812		2.647	.1303
	2835	.01225		4.213	.1965
	3606	.01498		5.36	.2403
	3968	.01619		5.90	.2597
	4765	.01873		7.08	.3005
	5180	.02000		7.70	.3208
	5970	.02227		8.87	.3573
	6290	.02315		9.35	.3714
	6650	.02406		9.88	.3863
	7500	.02627		11.15	.4214
	8020	.02757		11.92	.4423
	8610	.02895		12.79	.4644
	9300	.03053		13.82	.4898
	10110	.03229		15.02	.518

Table 4

Specific Heat Data for Propane (13)

t (°F)	p (psia)	$c_p - c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p - C_p^*$ (Btu/#mol/°F)
200	43.1	.00920	.990	.0698	.406
	298.3	.0980		.484	4.32
	338.5	.1235		.549	5.45
	442	.2893		.716	12.77
400	112.1	.00958	1.290	.1818	.4225
	506	.0534		.320	2.355
	615	.0691		.994	3.05
	778	.0971		1.260	4.29
	900	.1209		1.459	5.33
	1070	.1574		1.735	6.95
	1539	.2417		2.492	10.67
	2701	.2495		4.375	11.00
500	207.4	.01251	1.440	.336	.5525
	586	.0401		.950	1.770
	1085	.0859		1.760	3.79
	1697	.1570		2.747	6.93
	2543	.1737		4.12	7.66
	3000	.1726		4.86	7.61
600	231.0	.01005	1.590	.3745	.4435
	664	.03151		1.075	1.390
	1267	.0656		2.052	2.895
	2058	.1057		3.335	4.66
	3213	.1309		5.20	5.77
	4940	.1314		8.00	5.80
800	276.4	.00696	1.890	.448	.3075
	550	.01414		.891	.624
	819	.02149		1.328	.949
	1162	.0310		1.884	1.369
	2769	.0687		4.49	3.133
	4570	.0875		7.41	3.86
	5550	.0908		9.00	4.00
	7230	.0922		11.71	4.065

Table 4 Con't.

Specific Heat Data for Propane

t (°F)	p (psia)	$c_p - c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p - C_p^*$ (Btu/#mol/°R)
1000	97.6	.001580	2.19	.1581	.0698
	426	.00798		.787	.352
	975	.01604		1.577	.708
	1394	.02294		2.26	1.012
	1976	.03193		3.20	1.410
	3484	.0503		5.65	2.22
	4360	.0577		7.06	2.547
	5920	.0659		9.60	2.91
	6960	.0686		11.29	3.03
1340	120.7	.001097	2.70	.1955	.0484
	492	.00866		.798	.362
	1230	.01097		1.992	.484
	1785	.01560		2.893	.689
	2569	.02160		4.16	.954
	4690	.03428		7.60	1.312
	8250	.0429		13.37	1.891

Table 5

Specific Heat Data for n-Butane (14)

t (°F)	p (psia)	$c_p - c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p - C_p^*$ (Btu/#mol/°R)
350.4	896	.657	1.059	1.627	38.18
	611	.3533		1.110	20.53
	492.5	.1647		.894	9.57
	407	.1053		.739	6.12
	236	.04294		.4286	2.496
	102.6	.01584		.1863	.921
440.4	801	.1845	1.176	1.455	10.72
	637	.1160		1.157	6.74
	606	.1056		1.100	6.14
	487	.0725		.884	4.214
	270.5	.0318		.4912	1.848
	115.5	.01205		.2097	.700
485.4	1296	.235	1.235	2.354	13.66
	1153	.2145		2.094	12.47
	894	.1445		1.624	8.40
	813	.1258		1.476	7.31
	661	.0829		1.200	4.818
	525	.0621		.953	3.609
	287.8	.02786		.523	1.620
	121.9	.01067		.2214	.620
530.4	1764	.1964	1.294	3.203	11.41
	1482	.1895		2.691	11.01
	1305	.1734		2.370	10.08
	986	.1231		1.791	7.15
	716	.0761		1.300	4.423
	564	.0541		1.024	3.144
	305	.02467		.554	1.434
575.4	2013	.1656	1.353	3.656	9.62
	1669	.1586		3.031	9.22
	1470	.1453		2.670	8.44
	1077	.1045		1.956	6.07
	770	.0664		1.398	3.859
	602	.04784		1.093	2.780
	322	.02207		.585	1.285

Table 5 Con't.

Specific Heat Data for n-Butane

t (°F)	p (psia)	$c_p - c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p - C_p^*$ (Btu/#mol/°R)
620.4	3063	.1378	1.412	5.56	8.00
	2514	.1431		4.565	8.32
	2263	.1432		4.110	8.32
	1856	.1362		3.370	7.92
	1560	.1248		2.833	7.25
	1167	.0911		2.119	5.29
	639	.04243		1.160	2.466
	443	.02711		.804	1.576
	339	.01988		.616	1.155
647.4	2682	.1327		4.871	7.71
	2413	.1324	1.447	4.382	7.70
	1968	.1255		3.574	7.29
	1688	.1149		3.065	6.68
	1221	.0844		2.217	4.905
	855	.0549		1.553	3.191
	662	.03976		1.202	2.311
665.4	2797	.1266	1.470	5.08	7.36
	2513	.1261		4.564	7.33
	2043	.1193		3.710	6.93
	1748	.1091		3.174	6.34
	1257	.0803		2.283	4.667
	876	.0523		1.591	3.04
	676	.03813		1.228	2.216
	355.8	.01802		.646	1.047
	148.1	.00705		.2689	.4097
710.4	3814	.1114	1.529	6.93	6.47
	3088	.1136		5.61	6.60
	2764	.1126		5.02	6.54
	2230	.1059		4.05	6.15
	1895	.0968		3.441	5.63
	1346	.0716		2.444	4.161
	929	.0471		1.687	2.737
	713	.03452		1.295	2.006
	372.5	.01644		.676	.955
800.4	4574	.0981	1.647	8.31	5.70
	3269	.0928		5.94	5.39
	2603	.0864		4.727	5.02
	2190	.0787		3.977	4.574
	1523	.0567		2.766	3.295
	787	.02884		1.429	1.676
	405.8	.01391		.737	.808
	166.1	.00549		.3016	.3191

Table 5 Con't.

Specific Heat Data for n-Butane

t (°F)	p (psia)	$c_p-c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p-C_p^*$ (Btu/#mol/°R)
890.4	5340	.0815	1.764	9.70	4.737
	3776	.0789		6.86	4.586
	2977	.0716		5.41	4.161
	1698	.04754		3.084	2.763
	860	.02461		1.562	1.430
	439	.01196		.797	.695
	178.6	.004745		.3245	.2758
1160.4	7660	.0592	2.117	13.91	3.441
	5300	.0546		9.62	3.173
	4097	.04917		7.44	2.858
	2220	.0328		4.032	1.906
	1076	.01673		1.954	.974
	538	.00828		.977	.4812
	216	.002884		.3923	.1676
1520.4	7570	.03911	2.588	13.75	2.273
	5590	.0343		10.15	1.994
	2908	.02228		5.28	1.295
	1361	.01149		2.472	.668
	675	.00575		1.222	.3342
1880.4	9410	.03088	3.058	17.09	1.795
	7090	.0265		12.88	1.540
	3593	.01674		6.52	.973
	1644	.00864		2.986	.502
	798	.004363		1.449	.2536

Table 6

Specific Heat Data for Ethylene (15)

t (°F)	p (psia)	$c_p - c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p - C_p^*$ (Btu/#mol/°R)
32.0	625	3.533	.965	.843	99.1
	617	2.012		.832	56.4
	588	.936		.793	26.25
	554	.609		.747	17.08
	458	.332		.617	9.51
	346	.1688		.4664	4.735
	276	.1133		.372	3.178
	151.0	.04905		.2035	1.376
	63.6	.01819		.0857	.510
104.0	1023	.708	1.107	1.379	19.86
	942	.577		1.270	16.18
	915	.490		1.233	15.74
	826	.362		1.113	10.15
	750	.286		1.011	8.02
	585	.1708		.789	4.79
	425	.1009		.573	2.83
	333	.0718		.4489	2.014
	177.2	.0334		.2389	.937
	73.6	.01285		.0992	.3604
212.0	1595	.2815	1.319	2.15	7.90
	1422	.2486		1.917	6.97
	1342	.2234		1.809	6.77
	1165	.1809		1.570	5.07
	1030	.1513		1.388	4.244
	767	.0987		1.034	2.769
	538	.0622		.725	1.745
	414	.0453		.558	1.271
	216	.0217		.2912	.609
	88.5	.00855		.1193	.2398
302.0	2060	.1838	1.496	2.777	5.16
	1810	.1643		2.440	4.61
	1688	.1497		2.275	4.20
	1438	.1241		1.938	3.481
	1255	.1054		1.692	2.956
	914	.0710		1.232	1.992
	630	.0457		.849	1.282
	481	.0336		.648	.942
	24716	.01561		.3358	.438
	100.8	.00472		.1359	.1324

Table 6 Con't.

Specific Heat Data for Ethylene

t (°F)	p (psia)	$c_p - c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p - C_p^*$ (Btu/#mol/°R)
392	5950	.1663	1.672	8.02	4.665
	4060	.1700		5.47	4.77
	3423	.1619		4.614	4.54
	2810	.1456		3.788	4.084
	2523	.1346		3.401	3.776
	2193	.1208		2.956	3.388
	2029	.1108		2.735	3.108
	1707	.0928		2.301	2.603
	1469	.0795		1980	2.230
	1058	.0545		1.426	1.529
	721	.0355		.972	.996
	547	.02626		.737	.737
	279	.01284		.3761	.3602
	113.1	.00506		.1525	.1419
482	7370	.1363	1.849	9.93	3.823
	4950	.1348		6.67	3.781
	4130	.1271		5.57	3.565
	3343	.1138		4.506	3.193
	2982	.1052		4.020	2.951
	2570	.0945		3.464	2.651
	2366	.0870		3.189	2.44
	1973	.0733		2.660	2.056
	1696	.0631		2.286	1.770
	1200	.0437		1.618	1.226
	810	.0287		1.092	.805
	613	.0213		.826	.597
	310.6	.01046		.4187	.2934
	125.4	.00413		.1690	.1158
572	8810	.1160	2.026	11.88	3.254
	5840	.1116		7.87	3.130
	4830	.1044		6.51	2.928
	3880	.0930		5.23	2.609
	3440	.0859		4.637	2.409
	2947	.0771		3.973	2.163
	2700	.0711		3.640	1.994
	2236	.0601		3.014	1.686
	1913	.0518		2.579	1.453
	1341	.0362		1.808	1.015
	900	.0239		1.213	.670
	678	.01781		.914	.500

Table 6 Con't.

Specific Heat Data for Ethylene

t (°F)	p (psig)	$c_p - c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p - C_p^*$ (Btu/#mol/°F)
752	7630	.0831	2.379	10.29	2.331
	6240	.0766		8.41	2.149
	4940	.0676		6.66	1.896
	4350	.0622		5.86	1.745
	3694	.0557		4.98	11562
	3367	.0515		4.539	1.445
	2760	.0437		3.720	1.226
	2343	.03736		3.158	1.048
	1622	.02661		2.186	.746
	1077	.01773		1.452	.4973
	808	.01326		1.089	.3719
	404	.00658		.545	.1846
	162.1	.002617		.2185	.0734
932	9420	.0665	2.732	12.70	1.865
	7510	.0606		10.12	1.670
	6000	.0529		8.09	1.484
	5250	.0485		7.08	1.360
	4440	.0433		5.99	1.215
	4030	.0401		5.43	1.125
	3280	.03456		4.421	.969
	2772	.02945		3.737	.826
	1901	.02086		2.563	.585
	1254	.01397		1.690	.3919
	937	.01048		1.263	.2940
	467	.00495		.630	.1388
	186.5	.002028		.2514	.0569
1112	9060	.0502	3.086	12.21	1.408
	7060	.0434		9.52	1.217
	6160	.0397		8.30	1.114
	5180	.0353		6.98	.990
	4690	.03267		6.32	.916
	3800	.0277		5.12	.777
	3200	.0240		4.314	.673
	2180	.01707		2.939	.4788
	1430	.01148		1.928	.3220
	1066	.00864		1.437	.2424
	529	.001918		.713	.0538
	211	.001731		.2844	.04855

Table 6 Con't.

Specific Heat Data for Ethylene

t (°F)	p (psia)	$c_p - c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p - C_p^*$ (Btu/#mol/°R)
1292	10470	.0430	3.439	14.11	1.206
	8110	.0368		10.93	1.032
	7060	.03357		9.52	.942
	5920	.02973		7.98	.834
	5350	.0275		7.21	.771
	4320	.0233		5.82	.654
	3624	.02022		4.885	.567
	2457	.01440		3.312	.4039
	1606	.00972		2.165	.2726
	1195	.00733		1.611	.2056
	591	.001139		.797	.03195
	235.4	.001499		.3173	.04205
1472	9170	.0320	3.793	12.36	.898
	7960	.0291		10.73	.816
	6660	.02567		8.98	.720
	6010	.02373		8.10	.666
	4830	.02006		6.51	.563
	4050	.01740		5.46	.4881
	2735	.01242		3.687	.3484
	1782	.00842		2.402	.2362
	1323	.00636		1.783	.1784
	653	.000549		.880	.01540
	259.8	.001292		.3502	.03624
1652	10230	.02835	4.146	13.79	.795
	8870	.02596		11.96	.728
	7400	.02257		9.98	.633
	6660	.02084		8.98	.585
	5350	.01759		7.21	.4934
	4470	.01525		6.03	.4278
	3012	.01091		4.06	.3060
	1957	.00741		2.638	.2079
	1452	.00561		1.957	.1574
	716	.002842		.965	.0797
	284.2	.001146		.3831	.03215
1832	9770	.0230	4.499	13.17	.645
	8130	.02005		10.96	.562
	7320	.01857		9.87	.521
	5870	.01565		7.91	.439
	4900	.01356		6.61	.3804
	3290	.00971		4.435	.2724
	2133	.00661		2.875	.1854
	1580	.00502		2.130	.1408
	778	.002553		1.049	.0716
	308.6	.001057		.416	.02965

Table 6 Con't.

Specific Heat Data for Ethylene

t (°F)	p (psia)	$c_p-c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p-C_p^*$ (Btu/#mol/°R)
2012	10670	.02082	4.855	14.38	.584
	8870	.01817		11.96	.510
	7980	.01673		10.76	.4693
	6380	.01407		8.60	.3947
	5320	.01219		7.17	.3419
	3566	.00876		4.807	.2457
	2308	.00598		3.111	.1677
	1709	.00453		2.304	.1271
	840	.002314		1.132	.0649
	333	.000941		.4489	.0264
2192	11570	.01905	5.206	15.60	.534
	9610	.01656		12.95	.4645
	8640	.01524		11.65	.4275
	6900	.01279		9.30	.3588
	5750	.01103		7.75	.3094
	3842	.00793		5.18	.2224
	2484	.00543		3.348	.1523
	1837	.00414		2.476	.1161
	902	.002118		1.216	.0594
	357.4	.000860		.4818	.02412
[illegible]	12470	.01757	5.559	16.81	.4928
2372	10350	.01522		13.95	.4269
	9290	.01398		12.52	.3921
	7410	.01170		9.99	.3282
	6170	.01011		8.32	.2836
	4120	.00726		5.55	.2036
	2660	.00498		3.584	.1397
	1966	.00380		2.650	.1066
	964	.001952		1.299	.0548
	381.8	.000794		.515	.02227

Table 7

Specific Heat Data for Ethane (16)

t (°F)	p (psia)	$c_p-c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p-C_p^*$ (Btu/#mol/°R)
150	744	.2818	1.109	1.050	8.47
	557	.1560		.786	4.69
	374.0	.0816		.528	2.454
	238.7	.04551		.3370	1.368
	125.0	.02164		.1765	.651
250	1676	.3277	1.291	2.366	9.85
	1232	.2242		1.739	6.74
	989	.1589		1.396	4.778
	712	.0972		1.005	2.923
	456.8	.0542		.645	1.630
	285.8	.03102		.4035	.933
	147.5	.01500		.2082	.4510
400	9150	.1365	1.564	12.92	4.104
	7020	.1572		9.91	4.727
	5440	.1757		7.68	5.28
	4178	.1876		5.90	5.64
	3137	.1843		4.429	5.54
	2574	.1698		3.634	5.11
	1745	.1229		2.464	3.695
	1344	.0917		1.897	2.757
	929	.0594		1.312	1.786
	578	.03430		.816	1.031
	355	.02004		.501	.603
	180.9	.00981		.2554	.2950
500	11760	.1156	1.746	16.60	3.476
	9070	.1293		12.81	3.888
	7020	.1401		9.91	4.213
	5340	.1455		7.54	4.375
	3929	.1391		5.55	4.182
	3170	.1271		4.475	3.822
	2081	.0926		2.938	2.784
	1575	.0702		2.224	2.111
	1071	.04616		1.512	1.388
	657	.02704		.928	.813
	400.7	.01591		.566	.4784
	203.0	.00783		.2866	.2354

Table 7 Con't

Specific Heat Data for Ethane

t (°F)	p (psia)	$c_p-c_p^*$ (Btu/#/°F)	t_r	p_r	$C_p-C_p^*$ (Btu/#mol/°R)
600	10450	.1109	1.928	14.75	3.335
	8610	.1173		12.16	3.527
	7400	.1189		10.45	3.575
	6510	.1189		9.19	3.575
	4722	.1114		6.67	3.350
	3764	.1010		5.31	3.037
	2414	.0737		3.408	2.216
	1211	.03741		1.710	1.125
	736	.02211		1.039	.665
	446.1	.01308		.630	.3933
	225.1	.00646		.3178	.1942
800	11820	.0901	2.292	16.69	2.709
	8850	.0877		12.49	2.637
	4951	.0711		6.99	2.138
	3075	.0516		4.341	1.552
	2259	.04005		3.189	1.204
	1489	.02671		2.102	.803
	892	.01598		1.259	.4805
	537	.00953		.758	.2865
	269.2	.004756		.3801	.1430
1000	11210	.0703	2.656	15.83	2.114
	6140	.0547		8.67	1.645
	3732	.03933		5.27	1.183
	2710	.03030		3.826	.911
	1766	.02042		2.493	.614
	1319	.01548		1.862	.4655
	1048	.01240		1.480	.3728
	627	.00668		.885	.2009
1400	14260	.0699	3.383	20.13	2.102
	8500	.03750		12.00	1.128
	5040	.02636		7.12	.793
	3608	.02031		5.09	.611
	2323	.01389		3.280	.4176
	1359	.00810		1.919	.2436
	807	.00513		1.139	.1542

Table 8

$C_p-C_p^*$ Data for Methane (Parameters of p_r)

	T_r						
p_r	5.244	4.195.	3.146	2.622	2.098	1.835	1.573
15	.511	.800	1.385				
12	.442	.700	1.27	1.80	2.65		
10	.390	.620	1.16	1.735	2.69		
8	.330		1.015	1.575	2.645		
6	.263		.835	1.325	2.40	3.42	4.86
4	.1875		.593	.97	1.855	2.88	4.92
3	.1455		.468	.757	1.45	2.25	4.11
2	.100		.328	.519	.980	1.53	2.70
1.5	.076		.250	.395	.725	1.145	1.93
1.0	.0525		.165	.255	.471	.718	1.185
.8	.0419		.132	.210	.369	.547	.92
.6			.100		.275		.670
.4					.1875		.437
.3							.321
.2							

Table 9

$C_p - C_p^*$ Data for Propane (Parameters of p_r)

	T_r						
p_r	2.70	2.19	1.890	1.590	1.440	1.290	.990
15	1.92	3.14					
12	1.84	3.08					
10	1.73	2.95	4.01				
8	1.56	2.70	3.92	5.80			
6	1.30	2.31	3.60	5.78			
4	.923	1.71	2.90	5.28	7.60	10.9	
3	.71	1.33	2.23	4.25	7.33	10.8	
2	.489	.895	1.46	2.80	4.52	8.4	
1.5	.369	.667	1.07	2.01	3.08	5.55	
1.0	.248	.445	.705	1.28	1.89	3.05	
.8	.199	.358	.560	1.01	1.46	2.3	
.6	.150	.268	.415	.74	1.06	1.65	6.7
.4	.100	.178	.272	.479	.675	1.04	3.4
.3	.075	.134				.75	2.40
.2	.0498	.0885				.475	1.46

Table 10

$C_p - C_p^*$ Data for n-Butane (Parameters of p_r)

	T_r						
Pr	3.058	2.588	2.117	1.764	1.647	1.529	1.470
15	1.675						
12	1.475	2.16	3.37				
10	1.32	1.98	3.20				
8	1.135	1.74	2.96	4.70	5.70		
6	.92	1.43	2.55	4.35	5.40	6.60	
4	.658	1.035	1.90	3.46	4.60	6.10	7.08
3	.508	.803	1.475	2.72	3.62	5.07	6.02
2	.345	.547	1.00	1.845	2.37	3.33	4.00
1.5	.262	.41	.74	1.37	1.75	2.39	2.82
1.0			.497	.885	1.15	1.50	1.73
.8			.395	.695	.895	1.155	1.33
.6			.293	.506	.680		.960
.4			.173	.336	.430		.625
.3							.460
.2							

	T_r						
Pr	1.447	1.412	1.353	1.294	1.235	1.176	1.059
4	7.60	8.27					
3	6.60	7.50	9.15	11.3			
2	4.35	4.93	6.33	8.4	11.9		
1.5	3.04	3.41	4.22	5.5	7.47		34.6
1.0		2.045	2.505	3.05	3.92	5.21	11.55
.8		1.555	1.90	2.275	2.83	3.60	7.27
.6			1.325	1.595	1.94	2.40	4.20
.4					1.185	1.445	2.30
.3					.86	1.045	1.60
.2							.995

Table 11

$C_p - C_p^*$ Data for Ethylene (Parameters of p_r)

p_r	T_r 5.559	5.206	4.853	4.499	4.146	3.793
15	.451	.519				
12	.380	.438	.511	.602	.730	.880
10	.329	.379	.445	.528	.632	.777
8	.274	.319	.374	.441	.535	.657
6	.217	.253	.295	.351	.426	.526
4	.153	.1775	.2095	.249	.301	.375
3	.119	.1375	.1625	.193	.232	.2905
2	.0820	.0950	.1105	.132	.160	.199
1.5	.0625	.0725	.0845	.1005	.122	.150
1.0	.0427	.0493	.0580	.0683	.0820	.101
.8	.0346	.0400	.0471	.0553	.0660	.0810
.6	.02625	.0300	.0358	.0420	.0499	.0610
.4					.0337	.0410
.3						
.2						

p_r	T_r 3.439	3.086	2.732	2.379	2.026	1.849
15						
12	1.095	1.395	3.25		3.25	
10	.975	1.255	1.66	2.300	3.25	3.80
8	.835	1.065	1.465	2.095	3.125	3.85
6	.668	.880	1.210	1.78	2.80	3.65
4	.478	.627	.875	1.305	2.155	2.93
3	.370	.487	.678	1.01	1.67	2.30
2	.253	.332	.460	.68	1.125	1.53
1.5	.1925	.251	.350	.51	.833	1.125
1.0	.1295	.1675	.228	~~x342~~ .342	.549	.730
.8	.1035	.1345	.179	.274	.438	.579
.6	.0785	.101	.1315	.204	.324	.428
.4	.0528	.0675	.0860	.135	.214	.2805
.3		.051	.0658	.101	.163	.209
.2					.117	.1375

Table 11 Con't.

$C_p-C_p^*$ Data for Ethylene (Parameters of p_r)

	T_r				
p_r	1.672	1.496	1.319	1.107	0.985
8	4.68				
6	4.81				
4	4.22				
3	3.40				
2	2.25	3.61	7.33		
1.5	1.615	2.54	4.70		
1.0	1.025	1.55	2.66	7.80	
.8	.805	1.195	1.98	4.93	29.0
.6	.585	.853	1.38	3.01	7.70
.4	.383	.538	.860	1.76	3.59
.3	.287	.387	.627	1.235	2.28
.2	.1905	.240	.401	.760	1.345

Table 12

$C_p - C_p^*$ Data for Ethane (Parameters of p_r)

	T_r							
p_r	3.383	2.656	2.292	1.928	1.746	1.564	1.291	1.109
15		2.08	2.70	3.32	3.64			
12	1.125	1.93	2.61	3.53	4.00	4.29		
10	1.005	1.775	2.495	3.59	4.21	4.72		
8	.863	1.57	2.29	3.51	4.34	5.20		
6	.695	1.30	1.96	3.22	4.23	5.65		
4	.499	.945	1.46	2.51	3.58	5.34		
3	.381	.730	1.14	1.965	2.84	4.48		
2	.253	.496	.763	1.33	1.89	2.94	8.10	
1.5	.191	.380	.572	.987	1.38	2.09	5.33	
1.0		.242	.380	.643	.885	1.31	2.89	7.7
.8			.303	.509	.693	1.015	2.155	4.94
.6			.227	.377	.509	.732	1.50	3.00
.4			.1505	.2475	.330	.469	.920	1.70
.3					.247	.344	.662	1.19
.2								.748

Table 13

The Generalized Correlation for $C_p - C_p^*$

(Parameters of Reduced Pressure and Temperature)

	T_r					
P_r	1.0	1.1	1.2	1.3	1.4	1.5
.2	1.165	.758	.550	.419	.322	.260
.3	2.09	1.315	.882	.640	.490	.392
.4	3.00	1.83	1.25	.905	.705	.555
.6	5.90	3.21	2.06	1.46	1.10	.855
.8	14.0	5.35	3.23	2.21	1.55	1.15
1.0		8.4	4.58	2.90	2.09	1.59
1.5		23.7	8.90	5.27	3.44	2.50
2.0				8.50	5.00	3.59
3.0				10.8	7.60	5.53
4.0				10.8	8.40	6.52
6.0						6.47
8.0						6.03
10.0						4.85
12.0						
15.0						

	T_r					
P_r	1.6	1.75	2.0	2.25	2.5	2.75
.2	.216	.169	.1165	.0818	.0609	.0476
.3	.321	.247	.1675	.119	.0873	.0667
.4	.442	.331	.227	.1615	.1205	.0940
.6	.686	.513	.340	.243	.1805	.138
.8	.907	.687	.461	.323	.237	.1805
1.0	1.225	.875	.571	.401	.294	.227
1.5	1.91	1.355	.864	.608	.449	.344
2.0	2.71	1.89	1.185	.810	.590	.455
3.0	4.17	2.87	1.75	1.20	.877	.670
4.0	5.04	3.58	2.24	1.555	1.135	.862
6.0	5.45	4.23	2.90	2.07	1.547	1.195
8.0	5.35	4.48	3.31	2.48	1.89	1.465
10.0	4.61	4.19	3.35	2.60	2.05	1.635
12.0	4.25	3.99	3.32	2.69	2.19	1.79
15.0		3.64	3.22	2.78	2.31	1.93

Table 13 Con't.

The Generalized Correlation for $C_p - C_p^*$

(Parameters of Reduced Pressure and Temperature)

	t_r					
p_r	3.0	3.5	4.0	4.5	5.0	5.5
.2						
.3	.0540					
.4	.0747	.0490	.0354			
.6	.108	.0737	.0542	.0419	.0333	.0270
.8	.1445	.0987	.0713	.0547	.0439	.0361
1.0	.180	.1235	.0895	.0685	.0544	.0442
1.5	.273	.183	.132	.101	.0793	.0640
2.0	.359	.242	.174	.132	.1025	.0834
3.0	.529	.352	.254	.193	.1515	.122
4.0	.673	.456	.329	.249	.195	.157
6.0	.845	.635	.462	.352	.277	.224
8.0	1.164	.797	.582	.444	.349	.283
10.0	1.325	.935	.690	.525	.412	.338
12.0	1.48	1.05	.788	.603	.478	.389
15.0	1.60	1.17	.890	.698	.555	.462

Table 14

Comparison of Generalized Correlation with Original Data

t_r	p_r	Calculated $C_p-C_p^*$	Generalized $C_p-C_p^*$	Difference $\triangle$	$\triangle$/Calc. (%)
		METHANE			
1.573	.3745	.4049	.431	.026	6.4
	1.221	1.508	1.64	.013	7.9
	5.98	4.882	5.75	.87	15.1
2.098	.3945	.1856	.195	.009	4.8
	1.167	.562	.589	.027	4.6
	5.08	2.191	2.3	.11	4.8
	13.30	2.585	3.06	.48	15.7
5.244	1.008	.0529	.0500	-.0029	-5.8
	6.55	.2828	.267	-.016	-5.7
	11.92	.4425	.429	-.013	-2.9
		ETHYLENE			
1.107	.2389	.937	.93	-.007	-0.7
	.789	4.79	4.98	.019	0.4
	1.379	19.86	17.0	-2.9	-14.6
2.379	.545	.1846	.198	.013	7.0
	4.539	1.445	1.49	.04	2.8
	10.29	2.331	2.53	.20	8.6
4.853	1.132	.0649	.065	0	0
	7.17	.3419	.342	0	0
	14.38	.584	.561	-.23	-3.9
		ETHANE			
1.291	.2082	.4510	.440	-.011	-2.4
	1.005	2.923	3.02	.10	3.4
	1.396	4.778	4.90	.12	2.5
1.746	.2866	.2354	.235	0	0
	2.938	2.784	2.82	.04	1.4
	12.81	3.388	3.39	0	0
3.383	1.139	.1542	.155	.001	0.6
	5.09	.611	.61	0	0
	12.00	1.128	1.13	0	0

Table 14 Con't.

Comparison of Generalized Correlation with Original Data

t_r	p_r	Calculated $C_p-C_p^*$	Generalized $C_p-C_p^*$	Difference Δ	Δ/Calc. (%)
		PROPANE			
1.290	.320	2.355	2.34	-.02	-0.8
	1.260	4.299	4.17	-.13	-3.0
	1.459	5.33	5.28	-.05	-0.9
1.890	.448	.3075	.299	-.009	-2.9
	4.49	3.133	2.92	-.21	-6.7
	11.71	4.065	3.60	-.47	-11.5
2.70	.1955	.0484	.0494	.0010	2.1
	2.693	.689	.680	-.009	-1.3
	13.37	1.891	1.93	.04	2.1
		n-BUTANE			
1.059	.4236	2.496	2.42	-.08	-3.2
	.739	6.12	6.22	.10	1.6
1.647	.3016	.3191	.299	-.020	-6.3
	3.977	4.574	4.51	-.06	-1.3
	8.31	5.70	5.00	-.70	-14.0
3.058	1.449	.2536	.250	-.004	-1.6
	6.52	.973	.95	-.02	-2.1
	12.88	1.540	1.45	-.09	-5.8

Table 15

The Generalized Correlation of Edmister (2)

t_r	p_r	$\triangle C_p/k_2$	$\triangle C_p$	t_r	p_r	$\triangle C_p/k_2$	$\triangle C_p$
1.0	.05	.200	.288	1.2	.05	.088	.1269
	.1	.416	.600		.1	.182	.263
	.2	.91	1.313		.2	.376	.542
	.3	1.55	2.236		.3	.593	.855
	.4	2.48	3.58		.4	.830	1.197
	.5	3.60	5.19		.5	1.08	1.558
	.6	5.45	7.86		.6	1.36	1.962
	.7	8.45	12.19		.8	2.00	2.88
	.8	14.0	20.2		1.0	2.80	4.04
	.9	28.0	40.4		1.2	3.79	5.47
	.95	44.5	64.2		1.4	5.03	7.26
	1.0	108.0	155.8		1.6	6.60	9.52
	1.02	180.0	260		1.8	8.30	11.97
	1.05	200.0	288		2.0	9.65	13.92
	1.1	122.0	176		2.25	10.1	14.57
	1.15	88.0	126.9		2.5	9.4	13.56
	1.2	69.5	100.2		2.75	8.8	12.69
	1.3	51.0	73.6		3.0	8.25	11.90
	1.4	41.4	59.7		3.5	7.46	10.76
	1.5	35.7	51.5		4.0	6.95	10.02
	1.6	31.8	45.9		4.5	6.60	9.52
	1.8	27.1	39.1		5.0	6.34	9.14
	2.0	24.7	35.6		5.5	6.16	8.89
	2.25	22.9	33.0				
	2.5	21.7	31.3				
	2.75	20.9	30.1				
	3.0	20.2	29.1				
	3.5	19.2	27.7				

Table 15 Con't.

The Generalized Correlation of Edmister (2)

t_r	p_r	$\triangle C_p/k_2$	$\triangle C_p$	t_r	p_r	$\triangle C_p/k_2$	$\triangle C_p$
1.5	.05	.043	.0620	2.5	.1	.016	.0231
	.1	.085	.1226		.2	.032	.0462
	.2	.170	.245		.4	.064	.0923
	.4	.344	.496		.6	.096	.1385
	.6	.530	.764		.8	.128	.1846
	.8	.733	1.057		1.0	.160	.231
	1.0	.950	1.370		1.2	.192	.277
	1.2	1.175	1.695		1.4	.224	.323
	1.4	1.420	2.05		1.6	.255	.368
	1.6	1.67	2.41		1.8	.288	.415
	1.8	1.94	2.80		2.0	.319	.460
	2.0	2.21	3.19		2.5	.395	.570
	2.5	2.90	4.18		3.0	.467	.674
	3.0	3.55	5.12		3.5	.535	.772
	3.5	3.97	5.73		4.0	.605	.873
	4.0	4.11	5.93		4.5	.665	.959
	4.5	4.09	5.90		5.0	.725	1.046
	5.0	3.99	5.76		5.5	.785	1.132
	5.5	3.85	5.55				

Table 16

The Generalized Correlation of Watson and Smith (1) (Values Read from the Curves Presented by Hougen and Watson(6))

t_r	p_r	$C_p - C_p^*$
1.0	.8	21.0
	.7	12.6
	.6	8.6
	.5	6.2
	.4	4.9
	.3	3.05
	.2	1.87
	.15	1.37
1.2	2.0	15.8
	1.3	8.8
	1.0	5.75
	.8	4.18
	.7	3.50
	.6	2.85
	.5	2.29
	.4	1.78
	.3	1.15
	.2	.84
	.15	.615
1.5	7.0	9.6
	6.0	9.7
	5.0	9.6
	4.0	8.9
	3.0	7.5
	2.2	5.7
	1.5	3.77
	1.0	2.4
	.8	1.89
	.6	1.38
	.4	.88
	.3	.64
	.2	.412
	.15	.3
2.5	7.0	2.38
	5.0	1.93
	4.0	1.67
	3.0	1.34
	2.2	1.03
	1.5	.74
	1.0	.505
	.8	.405
	.6	.305
	.4	.200
	.3	.149
	.207	.100

Table 17

Comparison of the Generalized Correlations of Weiss, Edmister, and Hougen and Watson with Experimental Data of Krase and Mackey (21)(22) for Nitrogen

				Experimental Data for Nitrogen			Weiss	Edmister
t (°C)	p (atm)	t_r	p_r	C_p^*	C_p	$C_p-C_p^*$	$C_p-C^*{}_p$	$C_p-C_p^*$
25.7	200	2.37	5.97	6.81	8.28	1.47	1.78	1.45
30	500	2.40	14.91	6.82	9.12	2.30	2.50	
50	500	2.56	14.91	6.85	8.85	2.00	2.25	
100	500	2.96	14.91	6.93	8.39	1.46	1.60	
150	500	3.36	14.91	7.01	8.13	1.12	1.27	

		Percentage Deviations from Experimental Values		
t (°C)	H & W $C_p-C_p^*$	Weiss	Edmister	H & W
25.7	2.6	21	-1	77
30		9		
50		13		
100		10		
150		13		

Table 18

Comparison of the Generalized Correlations of Weiss, Edmister, and Hougen and Watson with Experimental Data of Workman (24) for Nitrogen and Oxygen

Oxygen at 26°C. (t_r = 1.938 , C_p^* = 6.98) :

p (atm)	p_r	$(C_p/C_p^*)-1$	Experimental $C_p-C_p^*$	Weiss $C_p-C_p^*$	Edmister $C_p-C_p^*$	H & W $C_p-C_p^*$
9.9	.199	.016	.1116		.111	.178
29.7	.597	.052	.363	.36	.35	.53
49.5	.996	.088	.614	.62	.600	.89
69 .3	1.392	.1255	.875	.87	.84	1.22
89.1	1.792	.1637	1.141	1.12	1.10	1.58
108.9	2.39	.202	1.41	1.54	1.45	2.10
128.7	2.58	.241	1.68	1.65	1.58	2.25

p (atm)	Percentage Deviations from Experimental Values Weiss	Edmister	H & W
9.9		-1	59
29.7	-1	-4	46
49.5	1	-2	45
69.3	-1	-4	39
89.1	-2	-4	38
108.9	9	3	49
128.7	2	-6	34

Nitrogen at 60°C. (t_r = 2.64 , C_p^* = 6.92) :

p (atm)	p_r	$(C_p/C_p^*)-1$	Experimental $C_p-C_p^*$	Weiss $C_p-C_p^*$	Edmister $C_p-C_p^*$	H & W $C_p-C_p^*$
9.9	.295	.0097	.0671	.076	.057	.131
29.7	.895	.0322	.223	.228	.172	.39
49.5	1.478	.0551	.382	.377	.28	.64
69.3	2.06	.0780	.540	.52	.38	.83
89.1	2.66	.0991	.686	.67	.48	1.05
108.9	3.24	.1194	.826	.81	.58	1.21
128.7	3.84	.1390	.962	.95	.69	1.35

p (atm)	Percentage Deviations from Experimental Values Weiss	Edmister	H & W
9.9	13	-15	49
29.7	2	-23	75
49.5	-1	-26	68
69.3	-4	-30	54
89.1	-2	-30	53
108.9	-2	-30	46
128.7	-1	-28	40

NOTATION

C_p = specific heat at constant pressure, molal basis

c_p = specific heat at constant pressure, weight basis

C_p^* = specific heat at constant pressure of a gas exhibiting ideal behavior, molal basis

c_p^* = specific heat at constant pressure of a gas exhibiting ideal behavior, weight basis

ΔC_p = $C_p - C_p^*$ = difference in heat capacities at constant pressure of a real gas and a gas exhibiting ideal behavior, molal basis

Δc_p = $c_p - c_p^*$ = difference in heat capacities at constant pressure of a real gas and a gas exhibiting ideal behavior, weight basis

p , P = absolute pressure

T = absolute temperature

t = temperature ($^{\circ}$C or $^{\circ}$F)

sub c = at critical conditions

sub r = reduced conditions

R = universal gas constant

α = Lewis and Randall Volume Residual Quantity

V = molal volume

a , b , c , A_0 , B_0 , C_0 , α , γ = constants used in the Benedict - Webb - Rubin Equation of State

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