New Jersey Institute of Technology
Digital Commons @ NJIT

Theses | Electronic Theses and Dissertations

6-30-1958

A generalized correlation for the effect of pressure on the difference in heat capacities of gases

Leon Bleich
New Jersey Institute of Technology

Follow this and additional works at: https://digitalcommons.njit.edu/theses

 Part of the Chemical Engineering Commons

Recommended Citation

Bleich, Leon, "A generalized correlation for the effect of pressure on the difference in heat capacities of gases" (1958). *Theses*. 2655.
https://digitalcommons.njit.edu/theses/2655

This Thesis is brought to you for free and open access by the Electronic Theses and Dissertations at Digital Commons @ NJIT. It has been accepted for inclusion in Theses by an authorized administrator of Digital Commons @ NJIT. For more information, please contact digitalcommons@njit.edu.

Copyright Warning & Restrictions

The copyright law of the United States (Title 17, United States Code) governs the making of photocopies or other reproductions of copyrighted material.

Under certain conditions specified in the law, libraries and archives are authorized to furnish a photocopy or other reproduction. One of these specified conditions is that the photocopy or reproduction is not to be "used for any purpose other than private study, scholarship, or research." If a, user makes a request for, or later uses, a photocopy or reproduction for purposes in excess of "fair use" that user may be liable for copyright infringement,

This institution reserves the right to refuse to accept a copying order if, in its judgment, fulfillment of the order would involve violation of copyright law.

Please Note: The author retains the copyright while the New Jersey Institute of Technology reserves the right to distribute this thesis or dissertation

Printing note: If you do not wish to print this page, then select "Pages from: first page # to: last page #" on the print dialog screen

NJIT New Jersey's Science & Technology University

The Van Houten library has removed some of the personal information and all signatures from the approval page and biographical sketches of theses and dissertations in order to protect the identity of NJIT graduates and faculty.

A GENERALIZED CORRELATION FOR THE EFFECT OF PRESSURE ON THE DIFFERENCE IN HEAT CAPACITIES OF GASES

BY

LEON BLEICH

A THESIS
SUBMITTED TO THE FACULTY OF
THE DEPARTMENT OF CHEMICAL ENGINEERING
OF
NEWARK COLLEGE OF ENGINEERING

IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE

OF

MASTER OF SCIENCE
IN CHEMICAL ENGINEERING

NEWARK, NEW JERSEY

1958

APPROVAL OF THESIS

FOR

DEPARTMENT OF CHEMICAL ENGINEERING

NEWARK COLLEGE OF ENGINEERING

BY

FACULTY COMMITTEE

APPROVED: _____

_____

_____

NEWARK, NEW JERSEY

JUNE, 1958

SUMMARY

A generalized correlation is presented for the difference in heat capacities at constant pressure and constant volume, C_p-C_v, as a function of reduced pressure with parameters of reduced temperature. The correlation covers a pressure range of $p_r = 0.2$ to $p_r = 15.0$ and a temperature range of $T_r = 1.0$ to $T_r = 5.5$. The correlation was based on values of C_p-C_v calculated from the Benedict - Webb - Rubin Equation of State for five hydrocarbons, namely, methane, ethylene, ethane, propane, and n-butane.

The results show that C_p-C_v approaches the universal gas constant, R, for all temperatures as the pressure approaches zero. In general, at any particular pressure, the value for C_p-C_v decreases with increasing temperature. The average deviation of the generalized correlation from the data on which it was based is ±0.93%. Deviations as high as 8% were found in the region of very high reduced pressure. A comparison has been made with an earlier correlation presented by Edmister. The relative accuracies of the two correlations have been discussed. A comparison has also been made with data for nitrogen and carbon monoxide. The results indicate that this correlation can be used not only for hydrocarbons, but for other non-polar or slightly polar gases as well.

ACKNOWLEDGEMENT

I wish to express my appreciation to Dr. Joseph Joffe for his advice and guidance in the preparation of this thesis.

I also wish to express my indebtedness to my wife, Gloria, for her valuable assistance in the preparation of this manuscript.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Thermodynamic data, at elevated temperatures and pressures, are becoming more essential for design purposes in both the chemical and petroleum fields.

Work sponsored by the American Petroleum Institute as Research Project 44 has reported heat capacities in the ideal gaseous state for many of the hydrocarbons (1). Very little actual experimental heat capacity data are available at high pressures. Although methods have been developed to accurately calculate heat capacities; these methods are often quite tedious and time consuming. To alleviate this problem the design engineer uses generalized correlations when actual data are not available. These correlations are developed in such a manner so as to be applicable to any gas.

It is the purpose of this work to submit a generalized correlation for $C_p - C_v$, in graphical form, to complement earlier work on heat capacities carried out at the Newark College of Engineering.

Early Generalized Correlation for $C_p - C_v$:

The first presentation of this type was prepared in graphical form by Wayne C. Edmister (2). The basis for his correlation is the difference between the ideal and

actual gas volume, α. This difference is defined as the Lewis and Randall volume residual quantity and is expressed by the equation $\alpha = RT/P - V$ (3). The residual quantity, α, adapts itself well to graphical methods and has been discussed by Deming and Shupe (4)(5). By setting $\alpha = \alpha_r \alpha_c$, $P = P_r P_c$, and $T = T_r T_c$, the following modified reduced equation of state is obtained:

$$\frac{V}{\alpha_c} = \frac{RT_r T_c}{P_r P_c \alpha_c} - \alpha_r$$

The equation for the difference in heat capacities is:

$$C_p - C_v = - T \frac{(\partial V/\partial T)_P^2}{(\partial V/\partial P)_T} \qquad (6)\ (p.461)$$

When reduced units and α_r are introduced this equation becomes:

$$C_p - C_v = - T_r \frac{\left[R/P_r - K_2\ (\partial \alpha_r/\partial T_r)_{P_r}\right]^2}{\left[RT_r/P_r^2 - K_2\ (\partial \alpha_r/\partial P_r)_{T_r}\right]}$$

where $K_2 = \alpha_c P_c/T_c$. The value of K_2 was found to be substantially constant varying from 1.41 to 1.47 and averaging 1.44 for all components except carbon dioxide and hydrogen (7). The derivatives $(\partial \alpha_r/\partial T_r)_{P_r}$ and $(\partial \alpha_r/\partial P_r)_{T_r}$ were determined graphically from large scale plots of α_r against T_r isobars and α_r against P_r

isotherms. Edmister has tabulated values for these derivatives and has presented a generalized correlation in graphical form for C_p-C_v as a function of reduced pressure, with parameters of reduced temperature (2)(8). Sixteen parameters of reduced temperature were presented varying from $T_r = 0.8$ to $T_r = 2.5$. Reduced pressure ranged between the limits of $P_r = 0.04$ to $P_r = 4.0$.

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

Since it is extremely difficult to make direct experimental heat capacity measurements accurately, an alternative approach must be used. An indirect, but fairly accurate, method is to use an equation of state which will reproduce with reasonable accuracy p-V-T relationships.

The Benedict - Webb - Rubin Equation is considered to be the best equation of state developed to date. It was developed primarily for hydrocarbons to reproduce most accurately p-V-T relations of gases.

Although the equation is extremely complex, employing eight constants, it provides a direct method of calculating the desired thermodynamic function. The equation is continuous for both the liquid and gaseous states and describes most accurately p-V-T data up to about 1.8

times the critical density.

The Newark College of Engineering has undertaken a program to calculate $C_p - C_p^*$ over a large range of temperature and pressure for various gases using the Benedict - Webb - Rubin Equation of State. The first five gases studied are reported in the following theses:

1. "Isobaric Heat Capacity of Methane over a Wide Range of Temperature and Pressure" (9)
2. "Isobaric Heat Capacity of Ethylene over a Wide Range of Temperature and Pressure" (10)
3. "Heat Capacities of Ethane over a Wide Range of Temperature and Pressure" (11)
4. "Isobaric Heat Capacity of Propane over a Wide Range of Temperature and Pressure" (12)
5. "Isobaric Heat Capacity of n-Butane over a Wide Range of Temperature and Pressure" (13)

In using the Benedict - Webb - Rubin Equation to calculate $C_p - C_p^*$, values of $C_p - C_v$ and $C_v - C_v^*$ are obtained as intermediate quantities.

Weiss has used the data reported in these five theses to prepare a graphical generalized correlation for $C_p - C_p^*$ (14).

De Laney has also used these data to calculate the ratio of C_p/C_v for the five gases previously investigated (15). Since the heat capacity ratio, C_p/C_v, cannot be generalized, the work submitted by De Laney is applicable only to the

specific gases investigated.

In this work, the data available in the original five theses has been used to prepare a generalized correlation for $C_p - C_v$. The work presented here, when used in conjunction with the generalized correlation presented by Weiss, will permit an investigator to estimate values for C_p, C_v, and the ratio of C_p/C_v. To find one or more of these terms it is necessary to know only the critical temperature and pressure and C_p^* for the given component. Values for these terms have been compiled for most hydrocarbons by the American Petroleum Institute as Research Project 44 (1).

DERIVATION OF THE EQUATION FOR $C_p - C_v$ FROM THE BENEDICT - WEBB - RUBIN EQUATION OF STATE

The Benedict - Webb - Rubin Equation is presented by the authors in the following form (9):

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

Equation (i) may be expressed in terms of volume rather than density as follows:

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

$$(iii) \quad C_p^* - C_v^* = R \; ; \quad \text{for an ideal gas.}$$

From Hougen and Watson (6) (p.461) for an actual gas:

$$(iv) \quad C_p - C_v = -T(\partial P/\partial T)_V^2 \; / \; (\partial P/\partial V)_T$$

Performing the indicated operation of Equation (iv) on Equation (ii):

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

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

Substituting Equations (v) and (vi) in Equation (iv):

$$(vii) \qquad C_p - C_v = - T \frac{\left[RV^{-1} + (B_oR + 2C_oT^{-3})V^{-2} + bRV^{-3} - 2cV^{-3}T^{-3}(1 + \gamma V^{-2})e^{-\gamma V^{-2}}\right]^2}{\left[- RTV^{-2} - 2V^{-3}(B_oRT - A_o - C_oT^{-2}) - 3V^{-4}(bRT - a) - 6a\alpha V^{-7} + cT^{-2}e^{-\gamma V^{-2}}(-3V^{-4} - 3\gamma V^{-6} + 2\gamma^2 V^{-8})\right]}$$

METHOD OF CALCULATION

Previous investigators, at the Newark College of Engineering, have already calculated values for C_p-C_v over a large range of temperature and pressure using the Benedict - Webb - Rubin Equation (9)(10)(11)(12)(13). The values obtained were specific for each gas studied. The constants used in the Benedict - Webb - Rubin Equation are also specific for each gas and are shown in Table 1.

A typical example which shows how the data were treated to obtain a generalized correlation is described below. T.A. Reiter presented values for C_p-C_v for ethane over a wide range of temperature and pressure (11). At 150°F., Reiter presented the following data:

t(°F)	p(psia)	c_p-c_v(Btu/#-°F)
150	744.0	0.3028
	556.5	0.1888
	374.0	0.1262
	238.7	0.09814
	125.0	0.08079

The generalized correlation presented as a result of this work is prepared in graphical form as a plot of C_p-C_v (expressed in molal units) vs. reduced pressure for a number of parameters of reduced temperature. Therefore it is necessary to convert the data shown above to these consistent units. The values used for the

critical temperature, critical pressure, and molecular weight are shown in Table 2 and were obtained from the American Petroleum Institute Research Project 44 (1). The following values were used for ethane:

$$T_c = 549.77\ ^{\circ}R.$$
$$p_c = 708.3\ psia$$
$$M.W. = 30.068\ \#/\#\text{-Mol.}$$

Using the constants shown above for ethane, the desired units of reduced temperature and pressure and molal heat capacity difference were calculated using the following equations:

$$T_r = \frac{T}{T_c} = \frac{t(^{\circ}F) + 459.69}{549.77}$$

$$p_r = \frac{p}{p_c} = \frac{p(psia)}{708.3}$$

$$C_p\text{-}C_v(Btu/\#\text{-Mol-}^{\circ}F) = c_p\text{-}c_v(Btu/\#\text{-}^{\circ}F) \times M.W.(\#/\#\text{-Mol})$$
$$= c_p\text{-}c_v(Btu/\#\text{-}^{\circ}F) \times 30.068$$

The data for the difference in heat capacities of ethane for the 150°F. isotherm becomes:

T_r	p_r	$C_p\text{-}C_v$ (Btu/#-Mol-°F)
1.109	1.050	9.10
	0.786	5.68
	0.528	3.79
	0.337	2.951
	0.1765	2.429

Calculations similar to those shown above were made for the other isotherms of ethane and also for ethylene, propane, and n-butane. For the latter three gases values of C_p-C_v were expressed in units of Liter-Atm/Gm-Mol-^oK. These units were converted to Btu/#-Mol-^oF by multiplying by 24.2021. Values of C_p-C_v for methane were not directly available. These data were calculated from the values of $C_p-C_p^*$ and C_p/C_v given by Weiss and De Laney, respectively, and the values of C_p^* (14)(15)(1). The calculated data for each gas is given in Tables 3-7. These data were plotted as a function of reduced pressure, with parameters of reduced temperature. An example of the type of curves obtained is illustrated for ethane in Figure 1.

In order to best utilize the data to prepare a generalized correlation, the data were converted into uniform parameters of reduced pressure and temperature. A total of fifteen isobars were chosen. These are numerically identical with the isobars chosen by Weiss since the two correlations may often be used together. The isobars selected are:

$$p_r = 0.2,\ 0.3,\ 0.4,\ 0.6,\ 0.8,\ 1.0,\ 1.5,\ 2,\ 3,\ 4,\ 6,\ 8,\ 10,\ 12,\ \text{and}\ 15.$$

As an example, the following data are obtained for ethane from Figure 1, for the isobar $p_r = 6.0$:

Ethane: $p_r = 6.0$

T_r	1.564	1.746	1.928	2.291	2.655	3.38
C_p-C_v	7.01	5.77	4.80	3.77	3.18	2.64

Values of C_p-C_v versus reduced temperature for parameters of reduced pressure were tabulated in a similar manner for all five gases and are presented in Tables 8-12.

The generalized correlation was prepared using Tables 8-12 as a basis. Values of C_p-C_v were plotted against reduced temperature, using the data for all five gases, for each parameter of reduced pressure. The type of plot obtained is illustrated in Figure 2 for a reduced pressure of 6.0. This figure also shows the excellent agreement between the data and the average line drawn. The family of curves obtained is shown in Figure 3. This plot is actually a generalized correlation of C_p-C_v versus reduced temperature with parameters of reduced pressure. This plot is not very convenient to use because of the crossing of lines. A more useful plot is one of C_p-C_v versus reduced pressure with parameters of reduced temperature, since crossing of lines is eliminated. In order to prepare this plot an arbitrary set of isotherms must be chosen. Eighteen isotherms were selected ranging from $T_r = 1.0$ to $T_r = 5.5$. These are also numerically equal to the isotherms chosen by Weiss. Values of C_p-C_v are obtained where the isotherms intersect with each of

the previously selected isobars.

As an example, for $p_r = 6.0$, from either Figure 2 or Figure 3, the following data are obtained:

T_r	1.6	1.75	2.0	2.25	2.5	2.75
C_p-C_v	6.85	5.79	4.62	3.86	3.39	3.06
T_r	3.0	3.5	4.0	4.5	5.0	5.5
C_p-C_v	2.85	2.58	2.42	2.32	2.25	2.21

Similar tabulations were made for each parameter of reduced pressure. These data are presented in Table 13. This table contains the coordinates for the generalized correlation of C_p-C_v versus reduced pressure, with parameters of reduced temperature. The data from Table 13 are plotted in Figure 4. This figure contains the desired generalized correlation.

Comparison of Generalized Correlation with Original Data:

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 representatively sampled. For each gas at least two extremes and a mean reduced temperature were chosen, and then, for each reduced temperature, at least two extremes and a mean reduced pressure were tabulated along with their corresponding values of C_p-C_v. Corresponding

to each value of reduced temperature and pressure selected, values of C_p-C_v were read from the generalized correlation presented in Figure 4.

The following example, for ethane, illustrates the method of sampling and manner in which the generalized correlation was compared with the original data:

I	II	III	IV	V	VI
		$C_p - C_v$			
T_r	p_r	Calc.	General.	Difference	% Deviation
1.291	0.2028	2.306	2.30	-0.006	-0.3
	1.006	4.28	4.35	0.07	1.6
	1.397	5.91	6.10	0.19	3.2
1.746	0.2866	2.169	2.17	0.001	0.05
	1.512	3.12	3.12	0.00	0.0
	2.938	4.36	4.32	-0.04	-0.9
	12.81	5.54	5.55	0.01	0.2
2.291	0.380	2.107	2.10	-0.007	-0.3
	1.260	2.395	2.40	0.005	0.2
	3.19	3.04	3.03	-0.01	-0.3
3.38	1.139	2.128	2.11	-0.018	-0.8
	5.09	2.551	2.55	-0.001	-0.04
	12.01	3.05	3.10	0.05	1.6

The values tabulated in columns I - III were taken directly from the original data given in Table 5. The values of C_p-C_v listed in column IV were read from the generalized correlation shown in Figure 4, corresponding to the reduced temperature and pressure conditions listed in columns I and II. These values are subject to the errors associated with averaging and interpolation.

To determine the accuracy of the generalized correlation, the difference was taken between the generalized and calculated values of C_p-C_v. This difference, shown in column V, was then divided by the calculated value of C_p-C_v, and expressed as a percentage deviation in column VI.

The same procedure was followed for the other four gases, providing a sampling of points which covers the entire range of temperature and pressure included in the correlation. This information is presented in detail in Table 14. The large number of points sampled, makes it possible to accurately estimate the deviation of the generalized correlation from the data on which it was based.

Comparison of Generalized Correlation with Correlation by Edmister:

Edmister has presented a generalized correlation for C_p-C_v, in graphical form, which partially covers the range submitted for this correlation (2). Specifically, the range common to both correlations include the reduced temperature range of $T_r = 1.0$ to $T_r = 2.5$ and the reduced pressure range of $p_r = 0.2$ to $p_r = 4.0$. Edmister's correlation was compared with this correlation using the original C_p-C_v data as a reference. Values of C_p-C_v were read from Edmister's correlation corresponding to

temperature and pressure conditions based on the original data presented in Tables 3-7. The sampling method described earlier was used to cover the range common to both correlations. Percentage deviations were calculated for each point sampled. These values are presented in detail in Table 14.

Comparison of Generalized Correlation with Data for Nitrogen and Carbon Monoxide:

Deming and Shupe have calculated values for C_p-C_v from very accurate p-V-T data obtained by Bartlett and co-workers for nitrogen and carbon monoxide (4)(5)(12). The range covered for nitrogen extends from -70°C. to 600°C. and up to 1200 atmospheres pressure. For carbon monoxide, the range covered extends from -70°C. to 400°C. and also up to 1200 atmospheres.

The generalized correlation prepared as a result of this work was used to estimate values of C_p-C_v for nitrogen and carbon monoxide over a large range of temperature and pressure. The sampling method used was similar to the one described earlier. For each gas, two extremes and a mean temperature were selected, and then, for each temperature, two extremes and a mean pressure were chosen. At each of these points, values of C_p-C_v were read from Figure 4 and compared with the values reported by Deming and Shupe.

The purpose in making this comparison was to find out whether the generalized correlation can predict with reasonable accuracy values for C_p-C_v for non-polar and slightly polar gases in addition to hydrocarbons.

A comparison was also made using Edmister's correlation where temperature and pressure conditions permitted the use of this correlation. The results of these comparisons are shown in Tables 15 and 16 for nitrogen and carbon monoxide, respectively.

DISCUSSION OF RESULTS

General:

Since there is very little actual data at high pressure for C_p and almost none for C_v, it is extremely difficult to compare and evaluate the generalized correlation prepared as a result of this work. However, the correlation can be compared with the original data on which it was based and with Edmister's generalized correlation for C_p-C_v. Final evaluation of this work must wait until additional experimental data are obtained.

The Generalized Correlation:

The generalized correlation prepared as a result of this work is presented in Table 13 and is shown graphically in Figure 4. C_p-C_v, in molal units, is plotted as a function of reduced pressure, with parameters of reduced temperature. Reduced pressure varies between $p_r = 0.2$ to $p_r = 15.0$. Eighteen parameters of reduced temperatures are presented ranging from $T_r = 1.0$ to $T_r = 5.5$.

For an ideal gas $C_p^*-C_v^* = R$. For an actual gas C_p-C_v is generally larger; its value depending on the particular gas in question and its temperature and pressure. As one might expect, C_p-C_v approaches R for all temperatures as the pressure approaches zero. In general, at any particular pressure, the value for C_p-C_v increases with

decreasing temperature.

Edmister has also presented a generalized correlation for C_p-C_v (2). The table below compares the range of variables presented in this correlation with that prepared by Edmister.

	Edmister	Bleich
p_r	0.04 - 4.0	0.2 - 15.0
T_r	0.8 - 2.5	1.0 - 5.5

Comparison of Generalized Correlations with Original Data:

Table 14 contains a representative sampling of data points for each of the five gases studied. The original calculated values of C_p-C_v, for each of these points, are compared with values read from Figure 4 and Edmister's generalized correlation. The percentage deviation for each point is also listed in Table 14. As mentioned earlier, the values of C_p-C_v read from the generalized correlations are subject to the errors associated with averaging and interpolation.

The data in Table 14 shows that the deviation of the generalized correlation from the original data ranges from -8.1% to +4.6% for the 68 points checked. The higher deviations occur in the region of very high reduced pressure. The average deviation for the 68 points investigated amounts to only ±0.93%.

Edmister's correlation has been compared in a similar manner using 44 data points common to both correlations. The table below compares the deviation of the two correlations from the original data for the five gases studied.

	Edmister	Bleich
Number of Data Points Compared	44	44
Range of Deviations, %	-8.8 to +3.5	-0.9 to +3.2
Average Percentage Deviation	±2.36	±0.56

Edmister's correlation shows over four times the average deviation as that obtained for this correlation. This comparison serves to emphasize that whenever data for a specific gas are unavailable, this correlation should be used in preference to Edmister's generalized correlation.

Comparison of Generalized Correlation with Data for Nitrogen and Carbon Monoxide:

C_p-C_v data, for nitrogen and carbon monoxide, reported by Deming and Shupe have been compared with corresponding values read from the generalized correlation shown in Figure 4 (4)(5). The individual data points used in this comparison are listed in Tables 15 and 16 for nitrogen and carbon monoxide, respectively. The deviations found in comparing the generalized correlation with the

original data are shown below:

	Nitrogen	Carbon Monoxide
Number of Data Points Compared	9	9
Range of Deviations, %	-2.9 to +14.6	-3.5 to +19.6
Average Percentage Deviation	±4.93	±6.40

The agreement shown in this table is close enough to indicate that Figure 4 is suitable for use as a generalized correlation for non-polar and slightly polar gases in addition to hydrocarbons.

CONCLUSIONS AND RECOMMENDATIONS

A generalized correlation for C_p-C_v has been prepared as a result of this work which is believed to be more accurate than the correlation previously published by Edmister (2). The present correlation has been prepared by averaging values of C_p-C_v, covering a wide range of temperature and pressure, for five hydrocarbons. The gases studied were methane, ethylene, ethane, propane, and n-butane. The values of C_p-C_v were calculated from the Benedict - Webb - Rubin Equation of State. This equation is considered to be the most accurate equation of state developed to date.

The generalized correlation prepared in this study has been compared with the original data on which it was based and with the generalized correlation presented by Edmister (2). The correlation was also used to predict values of C_p-C_v for nitrogen and carbon monoxide. The values obtained were compared with the data of Deming and Shupe (4)(5). The results of these comparisons indicate that this correlation is suitable for non-polar and slightly polar gases as well as hydrocarbons.

It is recommended that this correlation be used to obtain values for C_p-C_v in preference to other means whenever experimental data are unavailable or whenever time

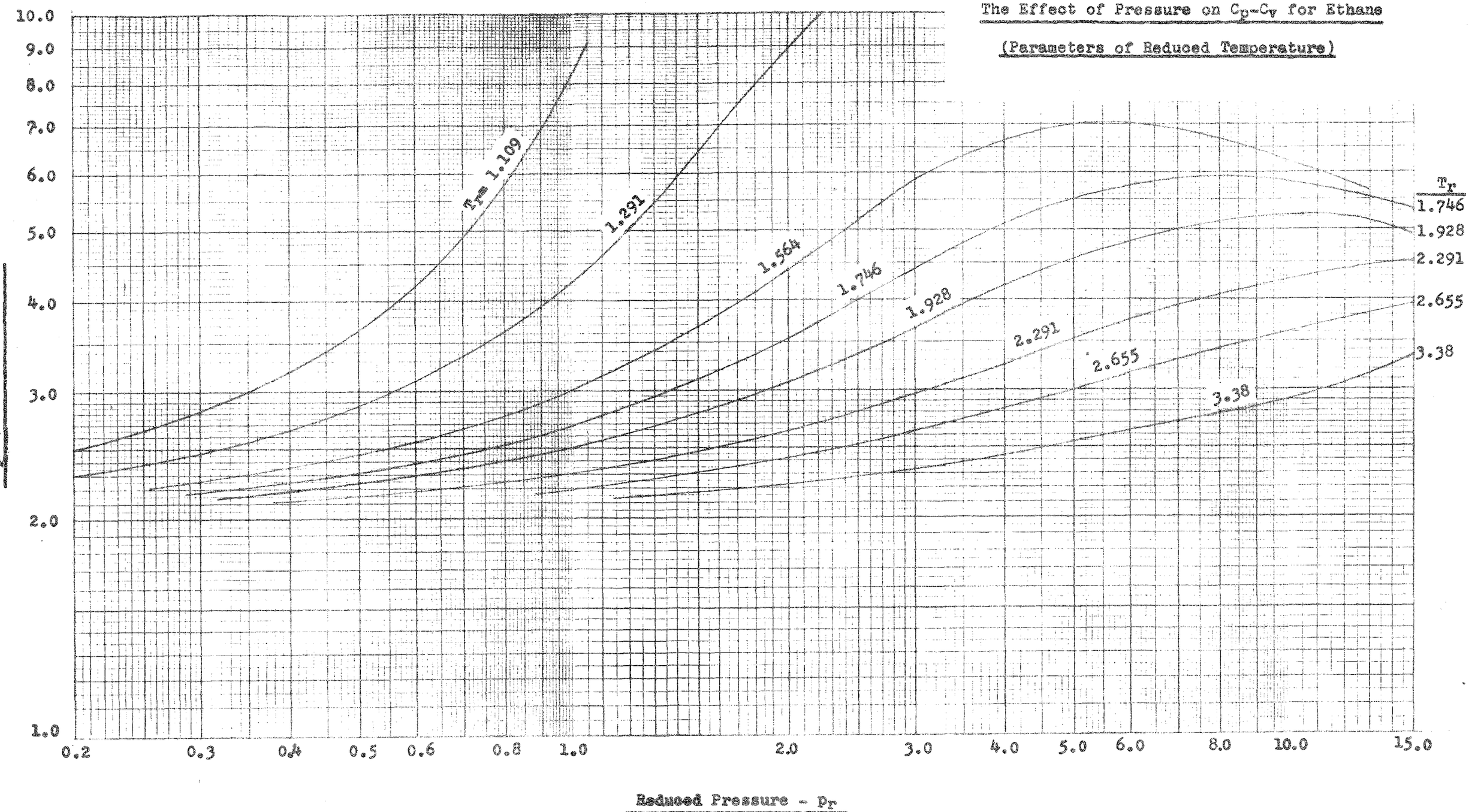
does not permit calculation of the desired value from the Benedict - Webb - Rubin Equation of State.

APPENDIX

Figure 1

The Effect of Pressure on $C_p - C_v$ for Ethane

(Parameters of Reduced Temperature)



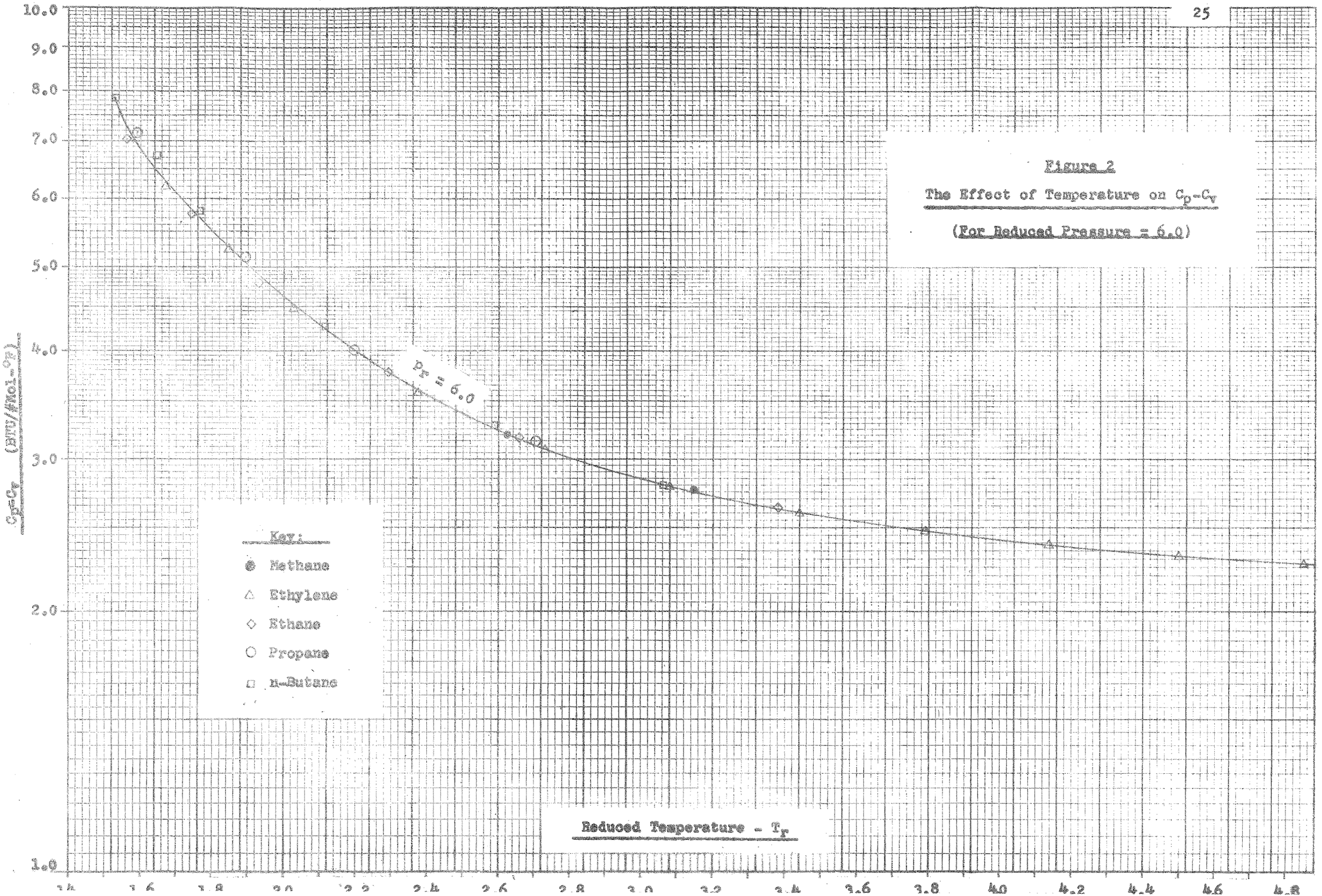


Figure 2

The Effect of Temperature on $C_p - C_v$

(For Reduced Pressure = 6.0)

Figure 3

The Effect of Temperature on $C_p - C_v$

(Parameters of Reduced Pressure)

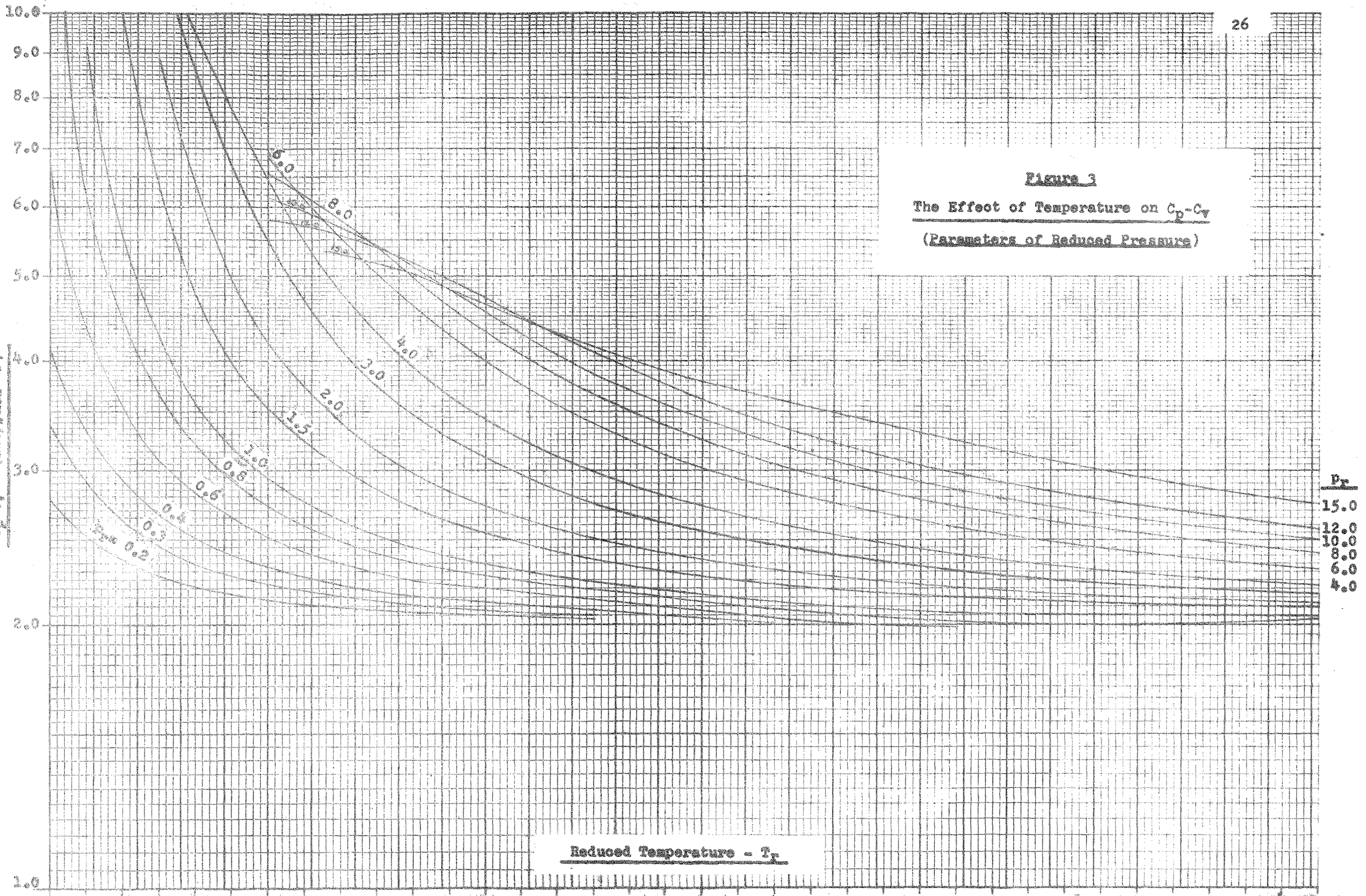


Figure 4

The Effect of Pressure on $C_p - C_v$

(Parameters of Reduced Temperature)

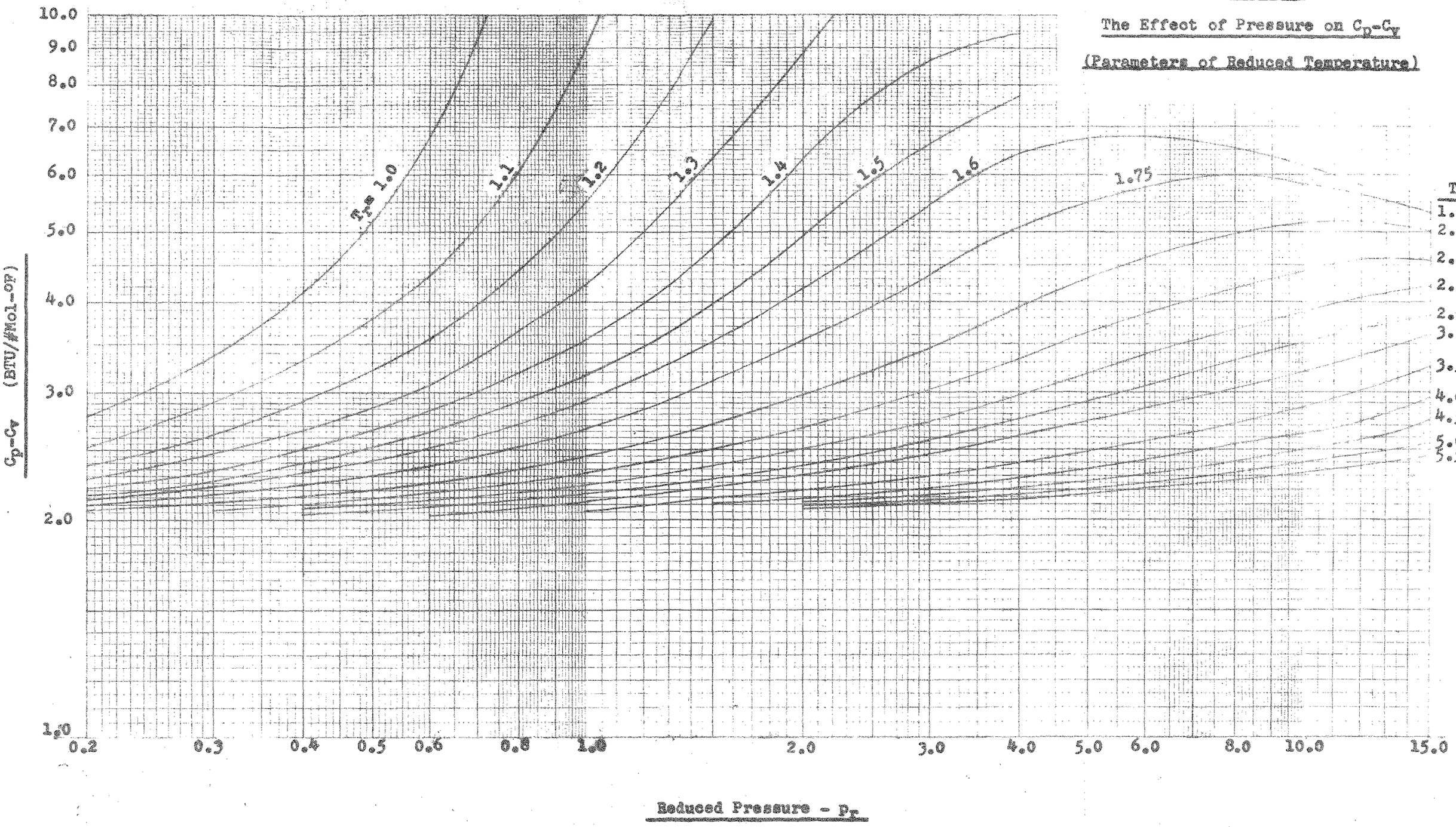


TABLE 1

Benedict - Webb - Rubin Equation of State:

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

where: P = Absolute Pressure (psia)
R = Gas Law Constant; 10.7335 (psia)(ft^3)/(#-mol)(^oR)
T = Absolute Temperature; ^oR ($459.69 - {}^oF$)
V = Molal Volume (ft^3/#-mol)
e = 2.71828

Benedict - Webb - Rubin Constants (psia, ft^3, #-mol, ^oR):

	Methane	Ethylene	Ethane	Propane	n-Butane
B_o	0.682401	0.891980	1.00554	1.55884	2.20329
$A_o \times 10^{-4}$	0.699525	1.25936	1.56707	2.59154	3.85874
$C_o \times 10^{-9}$	0.275763	1.60228	2.19427	6.20993	10.3847
b	0.867325	2.20678	2.85393	5.77355	10.8890
$a \times 10^{-4}$	0.298412	1.56455	2.08502	5.72480	11.7047
α	0.511172	0.731661	1.00044	2.49577	4.41496
$c \times 10^{-9}$	0.498106	4.13360	6.41314	25.2478	55.9777
γ	1.53961	2.36844	3.02790	5.64524	8.72447

TABLE 2

Molecular Weights and Critical Properties of Hydrocarbons

	Molecular Formula	Molecular Weight	Critical Temperature T_c (°R)	Critical Pressure p_c (psia)
Methane	CH_4	16.042	343.3	673.1
Ethylene	C_2H_4	28.052	509.51	742.1
Ethane	C_2H_6	30.068	549.77	708.3
Propane	C_3H_8	44.094	665.95	617.4
n-Butane	C_4H_{10}	58.120	765.31	550.7

TABLE 3

Difference in Heat Capacities for Methane

t (°F)	p (psia)	$C_p - C_v$ (Btu/#Mol-°F)	T_r	p_r	$C_p - C_v$ (Btu/#Mol-°F)
80.3	500	2.675	1.573	0.743	2.675
	750	3.11		1.114	3.11
170.3	500	2.400	1.835	0.743	2.400
	750	2.667		1.114	2.667
	1000	2.947		1.486	2.947
	1500	3.48		2.229	3.48
260.3	500	2.283	2.097	0.743	2.283
	750	2.448		1.114	2.448
	1000	2.612		1.486	2.612
	1500	2.948		2.229	2.948
	2000	3.26		2.971	3.26
	3000	3.79		4.46	3.79
440.3	500	2.156	2.622	0.743	2.156
	750	2.248		1.114	2.248
	1000	2.334		1.486	2.334
	1500	2.519		2.229	2.519
	2000	2.671		2.971	2.671
	3000	2.956		4.46	2.956
	4000	3.19		5.94	3.19
	5000	3.37		7.43	3.37
	6000	3.51		8.91	3.51
	7000	3.61		10.40	3.61
	8000	3.68		11.89	3.68

TABLE 3 (Con't)

Difference in Heat Capacities for Methane

t (°F)	p (psia)	C_p-C_v (Btu/#Mol-°F)	T_r	p_r	C_p-C_v (Btu/#Mol-°F)
620.3	500	2.103	3.15	0.743	2.103
	750	2.157		1.114	2.157
	1000	2.211		1.486	2.211
	1500	2.320		2.229	2.320
	2000	2.425		2.971	2.425
	3000	2.608		4.46	2.608
	4000	2.760		5.94	2.760
	5000	2.890		7.43	2.890
	6000	2.998		8.91	2.998
	7000	3.09		10.40	3.09
	8000	3.17		11.89	3.17
	9000	3.24		13.37	3.24
	10000	3.30		14.86	3.30
980.3	6000	2.536	4.19	8.91	2.536
	7000	2.601		10.40	2.601
	8000	2.655		11.89	2.655
	9000	2.707		13.37	2.707
	10000	2.748		14.86	2.748
1340.3	500	2.025	5.24	0.743	2.025
	1000	2.063		1.486	2.063
	2000	2.132		2.971	2.132
	3000	2.193		4.46	2.193
	4000	2.239		5.94	2.239
	5000	2.286		7.43	2.286
	6000	2.331		8.91	2.331
	7000	2.377		10.40	2.377
	8000	2.408		11.89	2.408
	9000	2.453		13.37	2.453
	10000	2.484		14.86	2.484

TABLE 4

Difference in Heat Capacities for Ethylene

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#Mol-°F)
32	624.8	4.064	0.965	0.842	98.4
	616.7	2.307		0.831	55.8
	587.7	1.072		0.792	25.94
	553.9	0.7028		0.746	17.01
	458.1	0.4015		0.617	9.72
	346.2	0.2315		0.467	5.60
	276.0	0.1778		0.372	4.30
	151.0	0.1203		0.2035	2.912
	63.65	0.09553		0.0858	2.312
104	1023.	0.8246	1.106	1.379	19.96
	941.6	0.6779		1.269	16.41
	915.0	0.5805		1.233	14.05
	825.8	0.4388		1.113	10.62
	749.8	0.3564		1.010	8.63
	585.4	0.2369		0.789	5.73
	424.9	0.1684		0.573	4.08
	332.6	0.1417		0.448	3.43
	177.2	0.1085		0.2388	2.626
	73.65	0.09191		0.0992	2.224
212	1595.	0.3626	1.318	2.149	8.78
	1422.	0.3270		1.916	7.91
	1342.	0.2996		1.808	7.25
	1165.	0.2546		1.570	6.16
	1030.	0.2239		1.388	5.42
	766.8	0.1709		1.033	4.14
	538.2	0.1361		0.725	3.29
	414.5	0.1207		0.559	2.921
	215.8	0.09994		0.2908	2.419
	88.51	0.08889		0.1193	2.151

TABLE 4 (Con't.)

Difference in Heat Capacities for Ethylene

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#Mol-°F)
302	2061.	0.2637	1.495	2.777	6.38
	1810.	0.2429		2.439	5.88
	1688.	0.2272		2.275	5.50
	1438.	0.2004		1.938	4.85
	1255.	0.1813		1.691	4.39
	913.5	0.1469		1.231	3.56
	630.1	0.1226		0.849	2.967
	481.2	0.1115		0.648	2.699
	247.6	0.09517		0.334	2.303
	100.8	0.08549		0.1358	2.069
392	5953.	0.2547	1.672	8.02	6.16
	4063.	0.2559		5.48	6.19
	3423.	0.2460		4.61	5.95
	2809.	0.2276		3.79	5.51
	2523.	0.2156		3.40	5.22
	2193.	0.2009		2.955	4.86
	2029.	0.1902		2.734	4.60
	1707.	0.1714		2.300	4.15
	1469.	0.1577		1.980	3.82
	1058.	0.1327		1.426	3.21
	720.7	0.1143		0.971	2.766
	547.2	0.1056		0.737	2.556
	279.2	0.09337		0.376	2.260
	113.1	0.08646		0.1524	2.093

TABLE 4 (Con't.)

Difference in Heat Capacities for Ethylene

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#Mol-°F)
482	7375.	0.2251	1.848	9.94	5.45
	4952.	0.2210		6.67	5.35
	4127.	0.2119		5.56	5.13
	3343.	0.1968		4.50	4.76
	2982.	0.1874		4.02	4.54
	2571.	0.1759		3.46	4.26
	2366.	0.1679		3.19	4.06
	1973.	0.1535		2.659	3.72
	1696.	0.1430		2.285	3.46
	1200.	0.1234		1.617	2.987
	810.5	0.1088		1.092	2.633
	612.7	0.1017		0.826	2.461
	310.6	0.09155		0.419	2.216
	125.4	0.08577		0.1690	2.076
572	8805.	0.2052	2.025	11.86	4.97
	5843.	0.1983		7.87	4.80
	4832.	0.1897		6.51	4.59
	3876.	0.1768		5.22	4.28
	3438.	0.1690		4.63	4.09
	2947.	0.1595		3.97	3.86
	2701.	0.1531		3.64	3.71
	2236.	0.1415		3.01	3.42
	1913.	0.1329		2.578	3.22
	1341.	0.1170		1.807	2.832
	899.7	0.1048		1.212	2.536
	677.9	0.09885		0.913	2.392
	341.9	0.09024		0.461	2.184
	137.6	0.08587		0.1854	2.078

TABLE 4 (Con't.)

Difference in Heat Capacities for Ethylene

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#Mol-°F)
752	7629	0.1703	2.378	10.28	4.12
	6242	0.1626		8.41	3.94
	4938	0.1523		6.65	3.69
	4347	0.1464		5.86	3.54
	3694	0.1393		4.98	3.37
	3367	0.1347		4.54	3.26
	2760	0.1263		3.72	3.06
	2343	0.1197		3.16	2.897
	1622	0.1086		2.186	2.628
	1077	0.09953		1.451	2.409
	807.6	0.09505		1.088	2.300
	404.4	0.08845		0.545	2.141
	162.1	0.08459		0.2184	2.047
932	9420	0.1538	2.731	12.69	3.72
	7507	0.1468		10.12	3.55
	5997	0.1380		8.08	3.34
	5254	0.1332		7.08	3.22
	4438	0.1274		5.98	3.08
	4029	0.1239		5.43	2.999
	3280	0.1179		4.42	2.853
	2772	0.1124		3.74	2.720
	1901	0.1034		2.562	2.502
	1254	0.09622		1.690	2.329
	936.8	0.09264		1.262	2.242
	466.7	0.08698		0.629	2.105
	186.5	0.08408		0.2513	2.035

TABLE 4 (Con't.)

Difference in Heat Capacities for Ethylene

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#Mol-°F)
1112	9061	0.1364	3.08	12.21	3.30
	7055	0.1286		9.51	3.11
	6158	0.1245		8.30	3.01
	5179	0.1196		6.98	2.895
	4689	0.1167		6.32	2.824
	3799	0.1112		5.12	2.691
	3198	0.1073		4.31	2.597
	2180	0.09985		2.938	2.417
	1430	0.09396		1.927	2.274
	1066	0.09098		1.436	2.202
	529.0	0.08372		0.713	2.026
	210.9	0.08384		0.2842	2.029
1292	10470	0.1291	3.44	14.11	3.12
	8112	0.1221		10.93	2.955
	7061	0.1184		9.51	2.866
	5919	0.1141		7.98	2.761
	5347	0.1116		7.21	2.701
	4316	0.1070		5.82	2.590
	3624	0.1036		4.88	2.507
	2457	0.09731		3.31	2.355
	1606	0.09231		2.164	2.234
	1195	0.08977		1.610	2.173
	591.2	0.08298		0.797	2.008
	235.4	0.08364		0.317	2.024
1472	9169	0.1172	3.79	12.36	2.836
	7964	0.1138		10.73	2.754
	6658	0.1100		8.97	2.662
	6007	0.1078		8.09	2.609
	4833	0.1037		6.51	2.510
	4049	0.1008		5.46	2.440
	2735	0.09539		3.69	2.309
	1782	0.09106		2.401	2.204
	1323	0.08885		1.783	2.150
	653.4	0.08240		0.880	1.994
	259.8	0.08344		0.350	2.019

TABLE 4 (Con't.)

Difference in Heat Capacities for Ethylene

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#Mol-°F)
1652	10230	0.1134	4.14	13.79	2.745
	8866	0.1103		11.95	2.669
	7396	0.1068		9.97	2.585
	6665	0.1049		8.98	2.539
	5350	0.1013		7.21	2.452
	4474	0.09866		6.03	2.388
	3012	0.09388		4.06	2.272
	1957	0.09007		2.637	2.180
	1452	0.08812		1.957	2.133
	715.6	0.08513		0.964	2.060
	284.2	0.08330		0.383	2.016
1832	9767	0.1075	4.50	13.16	2.602
	8134	0.1043		10.96	2.524
	7322	0.1025		9.87	2.481
	5866	0.09926		7.90	2.402
	4899	0.09693		6.60	2.346
	3289	0.09267		4.43	2.243
	2133	0.08928		2.874	2.161
	1580	0.08753		2.129	2.118
	777.8	0.08484		1.048	2.053
	308.6	0.08322		0.416	2.014
2012	10670	0.1053	4.85	14.38	2.548
	8872	0.1022		11.96	2.473
	7980	0.1006		10.75	2.435
	6382	0.09762		9.60	2.363
	5323	0.09551		7.17	2.312
	3566	0.09170		4.81	2.219
	2308	0.08863		3.11	2.145
	1709	0.08704		2.303	2.107
	839.9	0.08460		1.132	2.047
	333.0	0.08310		0.449	2.011

TABLE 4 (Con't.)

Difference in Heat Capacities for Ethylene

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#Mol-°F)
2192	11570	0.1034	5.20	15.59	2.502
	9609	0.1006		12.95	2.435
	8637	0.09905		11.64	2.397
	6898	0.09627		9.30	2.330
	5747	0.09434		7.74	2.283
	3842	0.09084		5.18	2.199
	2484	0.08807		3.35	2.131
	1837	0.08664		2.475	2.097
	902.1	0.08440		1.216	2.043
	357.4	0.08302		0.482	2.009
2372	12470	0.1018	5.56	16.80	2.464
	10350	0.09912		13.95	2.399
	9287	0.09771		12.51	2.365
	7413	0.09513		9.99	2.302
	6172	0.09334		8.32	2.259
	4119	0.09014		5.55	2.182
	2659	0.08760		3.58	2.120
	1966	0.08628		2.649	2.088
	964.2	0.08432		1.299	2.039
	381.8	0.08295		0.514	2.008

TABLE 5

Difference in Heat Capacities for Ethane

t (°F)	p (psia)	C_p-C_v (Btu/#-°F)	T_r	p_r	C_p-C_v (Btu/#-Mol-°F)
150	744.0	0.3028	1.109	1.050	9.10
	556.5	0.1888		0.786	5.68
	374.0	0.1262		0.528	3.79
	238.7	0.09814		0.337	2.951
	125.0	0.08079		0.1765	2.429
250	1676	0.3544	1.291	2.366	10.66
	1232	0.2562		1.739	7.70
	989.2	0.1964		1.397	5.91
	712.3	0.1422		1.006	4.28
	456.8	0.1066		0.645	3.21
	285.8	0.08860		0.404	2.664
	147.5	0.07670		0.2082	2.306
400	9154	0.1885	1.564	12.92	5.76
	7016	0.2078		9.91	6.25
	5437	0.2241		7.68	6.74
	4178	0.2334		5.90	7.02
	3137	0.2282		4.43	6.86
	2574	0.2137		3.63	6.43
	1745	0.1697		2.464	5.10
	1344	0.1417		1.898	4.26
	929.1	0.1136		1.312	3.42
	577.6	0.09272		0.815	2.788
	355.0	0.08134		0.501	2.446
	180.9	0.07344		0.2554	2.208

TABLE 5 (Con't.)

Difference in Heat Capacities for Ethane

t (°F)	p (psia)	C_p-C_v (Btu/#-°F)	T_r	p_r	C_p-C_v (Btu/#Mol-°F)
500	11757	0.1715	1.746	16.60	5.16
	9070	0.1842		12.81	5.54
	7018	0.1934		9.91	5.82
	5337	0.1971		7.53	5.93
	3929	0.1892		5.55	5.69
	3170	0.1773		4.48	5.33
	2081	0.1449		2.938	4.36
	1575	0.1247		2.224	3.75
	1071	0.1037		1.512	3.12
	657.0	0.08763		0.928	2.635
	400.7	0.07856		0.566	2.362
	203.0	0.07215		0.2866	2.169
600	10447	0.1637	1.928	14.75	4.92
	8611	0.1740		12.16	5.23
	7395	0.1748		10.44	5.26
	6505	0.1739		9.18	5.23
	4722	0.1657		6.67	4.98
	3764	0.1553		5.31	4.67
	2414	0.1296		3.41	3.90
	1211	0.09717		1.710	2.922
	735.7	0.08411		1.039	2.529
	446.1	0.07662		0.630	2.304
	225.1	0.07124		0.318	2.142

TABLE 5 (Con't.)

Difference in Heat Capacities for Ethane

t (°F)	p (psia)	C_p-C_v (Btu/#-°F)	T_r	p_r	C_p-C_v (Btu/#Mol-°F)
800	11821	0.1506	2.291	16.69	4.53
	8855	0.1474		12.50	4.43
	4951	0.1302		6.99	3.91
	3075	0.1116		4.34	3.36
	2259	0.1010		3.19	3.04
	1489	0.08925		2.102	2.684
	892.3	0.07965		1.260	2.395
	536.7	0.07410		0.758	2.228
	269.2	0.07007		0.380	2.107
1000	11211	0.1323	2.655	15.83	3.98
	6136	0.1163		8.66	3.50
	3732	0.1015		5.27	3.05
	2710	0.09312		3.83	2.800
	1766	0.08410		2.493	2.529
	1319	0.07968		1.862	2.396
	1048	0.07694		1.480	2.313
	626.9	0.07180		0.885	2.159
1400	14262	0.1340	3.38	20.14	4.03
	8504	0.1014		12.01	3.05
	5041	0.09057		7.12	2.723
	3608	0.08483		5.09	2.551
	2323	0.07882		3.28	2.370
	1359	0.07344		1.919	2.208
	806.9	0.07076		1.139	2.128

TABLE 6

Difference in Heat Capacities for Propane

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#-Mol-°F)
200	43.07	0.09252	0.991	0.0698	2.239
	298.3	0.2136		0.483	5.17
	338.5	0.2529		0.548	6.12
	442.0	0.5277		0.716	12.77
400	112.1	0.09402	1.291	0.1816	2.275
	505.7	0.1550		0.819	3.75
	613.0	0.1785		0.993	4.32
	778.1	0.2222		1.260	5.38
	900.2	0.2605		1.458	6.30
	1070	0.3210		1.733	7.77
	1539	0.4663		2.493	11.29
	2701	0.4921		4.37	11.91
500	207.4	0.09842	1.441	0.336	2.382
	585.5	0.1375		0.948	3.33
	1085	0.2086		1.757	5.05
	1697	0.3291		2.749	7.96
	2543	0.3592		4.12	8.69
	3000	0.3599		4.86	8.71
600	231.0	0.09559	1.591	0.374	2.313
	664.1	0.1264		1.076	3.06
	1267	0.1793		2.052	4.34
	2058	0.2456		3.33	5.94
	3213	0.2914		5.20	7.05
	4939	0.2977		8.00	7.20

TABLE 6 (Con't.)

Difference in Heat Capacities for Propane

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#-Mol-°F)
800	276.4	0.09194	1.892	0.448	2.225
	550.2	0.1024		0.891	2.478
	818.9	0.1135		1.326	2.747
	1162	0.1282		1.882	3.10
	2769	0.1900		4.48	4.60
	4565	0.2242		7.39	5.43
	5554	0.2310		9.00	5.59
	7233	0.2359		11.72	5.71
1000	97.64	0.08436	2.192	0.1581	2.042
	486.1	0.09391		0.787	2.273
	973.4	0.1063		1.577	2.573
	1394	0.1172		2.258	2.836
	1976	0.1317		3.20	3.19
	3484	0.1627		5.64	3.94
	4364	0.1756		7.07	4.25
	5925	0.1909		9.60	4.62
	6958	0.1964		11.27	4.75
	8465	0.2019		13.71	4.89
	9554	0.2029		15.47	4.91
1340	120.7	0.08377	2.702	0.1955	2.027
	491.5	0.09670		0.796	2.340
	1230	0.09940		1.992	2.406
	1785	0.1069		2.891	2.587
	2569	0.1169		4.16	2.829
	4689	0.1386		7.59	3.35
	8248	0.1543		13.36	3.73

TABLE 7

Difference in Heat Capacities for n-Butane

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#-Mol-°F)
350.4	896.1	1.570	1.059	1.627	38.0
	610.9	0.8406		1.109	20.34
	492.5	0.4085		0.894	9.89
	407.0	0.2796		0.739	6.77
	237.0	0.1550		0.429	3.75
	102.6	0.1067		0.1863	2.582
440.4	801.0	0.4598	1.176	1.455	11.13
	637.0	0.3078		1.157	7.45
	605.9	0.2854		1.100	6.91
	486.6	0.2159		0.884	5.23
	270.5	0.1364		0.491	3.30
	115.5	0.1012		0.2097	2.449
485.4	1296	0.5802	1.235	2.353	14.04
	1153	0.5320		2.094	12.88
	893.9	0.3725		1.623	9.02
	813.1	0.3317		1.476	8.03
	661.4	0.2377		1.201	5.75
	525.4	0.1965		0.954	4.76
	287.8	0.1300		0.523	3.15
	121.9	0.09923		0.2214	2.402
530.4	1764	0.4979	1.294	3.20	12.05
	1482	0.4795		2.691	11.60
	1305	0.4420		2.370	10.70
	985.8	0.3285		1.790	7.95
	715.8	0.2271		1.300	5.50
	563.7	0.1817		1.024	4.40
	305.0	0.1248		0.554	3.02

TABLE 7 (Con't.)

Difference in Heat Capacities for n-Butane

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#-Mol-°F)
575.4	2013	0.4308	1.353	3.66	10.43
	1669	0.4125		3.03	9.98
	1470	0.3815		2.669	9.23
	1077	0.2910		1.956	7.04
	769.7	0.2084		1.398	5.04
	601.6	0.1701		1.092	4.12
	322.0	0.1206		0.585	2.919
620.4	3063	0.3753	1.411	5.56	9.08
	2514	0.3843		4.57	9.30
	2263	0.3830		4.11	9.27
	1856	0.3648		3.37	8.83
	1600	0.3381		2.905	8.18
	1167	0.2631		2.119	6.37
	639.1	0.1607		1.161	3.89
	442.8	0.1307		0.804	3.16
	338.9	0.1171		0.615	2.834
647.4	2681	0.3623	1.447	4.87	8.77
	2413	0.3600		4.38	8.71
	1968	0.3423		3.57	8.28
	1688	0.3176		3.07	7.69
	1221	0.2495		2.217	6.04
	855.2	0.1868		1.553	4.52
	661.5	0.1559		1.210	3.77

TABLE 7 (Con't.)

Difference in Heat Capacities for n-Butane

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#-Mol-°F)
665.4	2797	0.3495	1.470	5.08	8.46
	2513	0.3468		4.56	8.39
	2043	0.3292		3.71	7.97
	1748	0.3056		3.17	7.40
	1257	0.2415		2.283	5.84
	876.1	0.1819		1.591	4.40
	676.4	0.1530		1.228	3.70
	355.8	0.1141		0.646	2.761
	148.1	0.09399		0.2689	2.275
710.4	3814	0.3203	1.529	6.93	7.75
	3088	0.3223		5.61	7.80
	2764	0.3187		5.02	7.71
	2230	0.3016		4.05	7.30
	1895	0.2803		3.44	6.78
	1346	0.2244		2.444	5.43
	928.7	0.1723		1.686	4.17
	713.4	0.1467		1.295	3.55
	372.5	0.1115		0.676	2.699
800.4	4574	0.2943	1.647	8.31	7.12
	3269	0.2779		5.94	6.73
	2603	0.2616		4.73	6.33
	2190	0.2436		3.98	5.90
	1523	0.1944		2.766	4.70
	786.9	0.1367		1.429	3.31
	405.8	0.1074		0.737	2.599
	166.1	0.09168		0.302	2.219

TABLE 7 (Con't.)

Difference in Heat Capacities for n-Butane

t (°F)	p (psia)	C_p-C_v (Liter-Atm)/(Gm-Mol-°K)	T_r	p_r	C_p-C_v (Btu)/(#-Mol-°F)
890.4	5340	0.2589	1.764	9.70	6.27
	3776	0.2496		6.86	6.04
	2977	0.2313		5.41	5.60
	1698	0.1769		3.08	4.28
	859.7	0.1293		1.561	3.13
	439.0	0.1043		0.797	2.524
	178.6	0.09056		0.324	2.192
1160.4	7660	0.2132	2.117	13.91	5.16
	5305	0.2005		9.63	4.85
	4097	0.1870		7.44	4.53
	2220	0.1496		4.03	3.62
	1076	0.1154		1.954	2.793
	537.6	0.09818		0.976	2.376
	216.0	0.08731		0.392	2.113
1520.4	7574	0.1690	2.587	13.75	4.09
	5592	0.1572		10.15	3.80
	2908	0.1294		5.28	3.13
	1361	0.1059		2.471	2.563
	672.6	0.09381		1.221	2.270
1880.4	9408	0.1520	3.06	17.08	3.68
	7087	0.1413		12.87	3.42
	3593	0.1185		6.52	2.868
	1644	0.1005		2.985	2.432
	798.2	0.09129		1.449	2.209

TABLE 8

C_p-C_v Data for Methane (Parametors of p_r)

	T_r						
p_r	1.523	1.835	2.097	2.622	3.15	4.19	5.24
15							2.48
12					3.18	2.66	2.41
10				3.59	3.06	2.58	2.36
8				3.43	2.92		2.30
6				3.20	2.77		2.24
4			3.62	2.87	2.55		2.17
3			3.27	2.68	2.43		2.13
2		3.29	2.84	2.46	2.29		2.08
1.5		2.95	2.63	2.35	2.23		2.06
1.0	3.00	2.60	2.40	2.23	2.15		2.03
0.8	2.75	2.45	2.30	2.18	2.11		2.025
0.6							
0.4							
0.3							
0.2							

TABLE 9

C_p-C_v Data for Ethylene (Parameters of p_r)

	T_r					
p_r	0.965	1.106	1.318	1.495	1.672	1.848
15						
12						
10						5.45
8					6.16	5.40
6					6.20	5.24
4					5.70	4.53
3					4.88	3.95
2			8.25	4.97	3.85	2.27
1.5			5.87	4.01	3.30	2.90
1.0		8.45	4.05	3.19	2.79	2.57
0.8	29	5.85	3.47	2.90	2.60	2.45
0.6	9.0	4.24	3.01	2.64	2.44	2.33
0.4	4.65	3.25	2.63	2.38	2.28	2.21
0.3	3.57	2.86	2.44	2.26	2.20	2.15
0.2	2.90	2.50	2.27	2.13	2.12	2.09

TABLE 9 (Con't.)

C_p-C_v Data for Ethylene (Parameters of p_r

	T_r					
p_r	2.025	2.378	2.731	3.08	3.44	3.79
15						
12	4.97		3.69	3.29	3.02	2.83
10	4.92	4.10	3.53	3.15	2.90	2.71
8	4.81	3.88	3.33	2.99	2.76	2.60
6	4.48	3.58	3.08	2.80	2.60	2.48
4	3.87	3.14	2.78	2.57	2.41	2.33
3	3.42	2.86	2.59	2.44	2.32	2.26
2	2.94	2.57	2.40	2.28	2.20	2.17
1.5	2.69	2.43	2.29	2.21	2.15	2.10
1.0	2.43	2.28	2.18	2.10	2.06	2.01
0.8	2.33	2.22	2.13	2.06	2.01	1.98
0.6	2.23	2.16	2.10	2.01	1.99	1.98
0.4	2.15	2.10	2.06	2.00	2.00	2.00
0.3	2.10	2.06	2.04	2.02		
0.2	2.07	2.04				

TABLE 9 (Con't.)

C_p-C_v Data for Ethylene (Parameters of p_r)

	T_r				
p_r	4.14	4.50	4.85	5.20	5.56
15				2.48	2.44
12	2.67	2.57	2.48	2.41	2.36
10	2.59	2.49	2.40	2.36	2.30
8	2.50	2.41	2.34	2.30	2.25
6	2.39	2.32	2.27	2.23	2.20
4	2.26	2.22	2.20	2.15	2.13
3	2.20	2.17	2.15	2.12	2.10
2	2.14	2.12	2.10	2.08	2.06
1.5	2.10	2.09	2.08	2.05	2.05
1.0	2.07	2.05	2.04	2.02	2.03
0.8	2.04	2.03	2.02	2.01	2.02
0.6	2.02	2.01	2.01	2.00	2.01
0.4	2.01				
0.3					
0.2					

TABLE 10

C_p-C_v Data for Ethane (Parameters of p_r)

	T_r							
p_r	1.109	1.291	1.564	1.746	1.928	2.291	2.655	3.38
15				5.31		4.50	3.92	3.35
12			5.83	5.65	5.23	4.40	3.76	3.04
10			6.22	5.81	5.24	4.29	3.60	2.90
8			6.69	5.90	5.13	4.08	3.42	2.78
6			7.01	5.77	4.80	3.77	3.18	2.64
4			6.67	5.10	4.17	3.27	2.82	2.44
3			5.88	4.41	3.65	2.97	2.64	2.34
2		8.95	4.40	3.52	3.09	2.64	2.44	2.225
1.5		6.50	3.69	3.10	2.80	2.48	2.32	2.17
1.0	8.60	4.25	3.01	2.68	2.50	2.31	2.20	
0.8	5.81	3.61	2.77	2.53	2.39	2.25		
0.6	4.19	3.10	2.56	2.38	2.28	2.19		
0.4	3.20	2.66	2.36	2.24	2.175	2.12		
0.3	2.83	2.46	2.26	2.18				
0.2	2.51	2.30						

TABLE 11

C_p-C_v Data for Propane (Parameters of p_r)

	T_r						
p_r	0.991	1.291	1.441	1.591	1.892	2.192	2.702
15						4.90	
12						4.78	3.68
10					5.64	4.65	3.54
8				7.20	5.50	4.40	3.38
6				7.19	5.13	4.01	3.15
4		11.90	8.69	6.50	4.32	3.43	2.80
3		11.85	8.20	5.54	3.74	3.10	2.61
2		9.45	5.80	4.27	3.15	2.73	2.41
1.5		6.50	4.41	3.57	2.85	2.55	2.37
1.0		4.35	3.42	2.97	2.55	2.35	2.35
0.8		3.70	3.09	2.75	2.43	2.28	2.34
0.6	7.21	3.15	2.77	2.55	2.31	2.20	2.29
0.4	4.27	2.70	2.475	2.35		2.125	2.225
0.3	3.48	2.50				2.09	2.15
0.2	2.86	2.30				2.05	2.03

TABLE 12

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

	T_r						
p_r	1.059	1.176	1.235	1.294	1.353	1.411	1.447
15							
12							
10							
8							
6							
4						9.20	8.55
3				12.0	9.95	8.33	7.55
2			12.3	9.05	7.21	5.98	5.51
1.5	34.8		8.20	6.40	5.40	4.60	4.42
1.0	14.4	6.10	4.92	4.37	3.90	3.53	
0.8	7.85	4.72	4.18	3.72	3.39	3.15	
0.6	5.07	3.71	3.44	3.15	2.95	2.80	
0.4	3.59	3.00					
0.3	3.07	2.80					
0.2	2.63	2.43					

TABLE 12 (Con't.)

C_p-C_v Data for n-Butane (Parameters of p_r)

	T_r						
p_r	1.470	1.529	1.647	1.764	2.117	2.587	3.06
15							3.55
12					5.05	3.96	3.35
10					4.89	3.79	3.20
8			7.10	6.19	4.63	3.58	3.02
6		7.85	6.75	5.82	4.27	3.28	2.80
4	8.19	7.28	5.91	4.89	3.61	2.90	2.56
3	7.17	6.23	5.00	4.23	3.26	2.69	2.45
2	5.27	4.66	3.90	3.50	2.82	2.46	2.30
1.5	4.21	3.87	3.39	3.09	2.60	2.34	2.22
1.0	3.29	3.15	2.88	2.69	2.39		
0.8	2.97	2.87	2.67	2.53	2.30		
0.6	2.69		2.47	2.38	2.21		
0.4	2.43		2.39	2.23	2.12		
0.3	2.30		2.21				
0.2							

TABLE 13

Generalized Correlation for $C_p - C_v$

(Parameters of Reduced Pressure and Temperature)

	T_r					
P_r	1.0	1.1	1.2	1.3	1.4	1.5
15						
12						
10						
8						
6						
4				11.7	9.47	7.74
3				11.6	8.66	6.66
2				8.85	6.32	4.94
1.5		21.6	9.85	6.31	4.77	3.98
1.0		9.15	5.53	4.27	3.56	3.18
0.8	13.7	6.10	4.44	3.66	3.20	2.915
0.6	6.78	4.35	3.54	3.08	2.835	2.65
0.4	4.11	3.32	2.92	2.67	2.51	2.40
0.3	3.376	2.90	2.625	2.46	2.345	2.27
0.2	2.78	2.52	2.375	2.275	2.21	2.17

TABLE 13 (Con't.)

Generalized Correlation for $C_p - C_v$

(Parameters of Reduced Pressure and Temperature)

	T_r					
p_r	1.60	1.75	2.00	2.25	2.50	2.75
15		5.31	5.02	4.57	4.20	3.83
12	5.80	5.65	5.18	4.60	4.09	3.68
10	6.18	5.81	5.13	4.41	3.85	3.50
8	6.55	6.00	4.97	4.18	3.65	3.31
6	6.85	5.79	4.62	3.86	3.39	3.06
4	6.43	5.08	3.93	3.335	2.985	2.77
3	5.46	4.37	3.47	3.04	2.74	2.58
2	4.19	3.55	2.965	2.68	2.505	2.39
1.5	3.53	3.11	2.71	2.505	2.375	2.285
1.0	2.94	2.69	2.45	2.325	2.24	2.175
0.8	2.715	2.53	2.35	2.255	2.185	2.14
0.6	2.515	2.38	2.245	2.19	2.145	2.09
0.4	2.33	2.24	2.155	2.11	2.08	2.04
0.3	2.225	2.18	2.115	2.07	2.05	2.03
0.2	2.13	2.10	2.07	2.05	2.03	

TABLE 13 (Con't.)

Generalized Correlation for $C_p - C_v$

(Parameters of Reduced Pressure and Temperature)

p_r	3.0	3.5	4.0	4.5	5.0	5.5
15	3.61	3.27	2.95	2.75	2.55	2.45
12	3.375	2.98	2.725	2.57	2.46	2.375
10	3.22	2.87	2.63	2.50	2.40	2.32
8	3.05	2.725	2.54	2.41	2.325	2.26
6	2.85	2.58	2.42	2.32	2.25	2.21
4	2.61	2.40	2.29	2.22	2.17	2.13
3	2.47	2.30	2.22	2.17	2.125	2.10
2	2.31	2.20	2.15	2.12	2.09	2.065
1.5	2.225	2.15	2.11	2.09	2.09	2.05
1.0	2.125	2.06	2.055	2.05	2.045	2.035
0.8	2.08	2.01	2.00	2.03	2.025	2.02
0.6	2.03	1.99	2.00	2.01	2.01	2.01
0.4	2.005	2.00	2.00			
0.3	2.02					
0.2						

TABLE 14

Comparison of the Generalized Correlations of Bleich and Edmister with Original Data

METHANE

		$C_p - C_v$			Difference		% Deviation	
T_r	p_r	Calculated	Bleich	Edmister	Bleich	Edmister	Bleich	Edmister
1.573	0.743	2.675	2.70	2.69	0.025	0.015	0.9	0.6
	1.114	3.11	3.12	3.11	0.01	0.00	0.3	0.0
1.835	0.743	2.400	2.42	2.48	0.02	0.08	0.8	3.3
	1.486	2.947	2.95	2.95	0.003	0.003	0.1	0.1
	2.229	3.48	3.50	3.40	0.02	-0.08	0.6	-2.3
2.097	0.743	2.283	2.28	2.33	-0.003	0.047	-0.1	2.1
	1.486	2.612	2.62	2.69	0.008	0.078	0.3	3.0
	2.971	3.26	3.28	3.30	0.02	0.04	0.6	1.2
2.622	0.743	2.156	2.15	*	-0.006		-0.3	
	4.46	2.956	2.95	*	-0.006		-0.2	
	11.89	3.68	3.85	*	0.17		4.6	
4.19	8.91	2.536	2.53	*	-0.006		-0.2	
	11.89	2.655	2.66	*	0.005		0.2	
	14.86	2.748	2.85	*	0.102		3.7	

* Outside of the limits of Edmister's correlation.

TABLE 14 (Con't.)

Comparison of the Generalized Correlations
of Bleich and Edmister with Original Data

ETHYLENE

		$C_p - C_v$			Difference		% Deviation	
T_r	p_r	Calculated	Bleich	Edmister	Bleich	Edmister	Bleich	Edmister
1.106	0.2388	2.626	2.65	2.62	0.024	-0.006	0.9	-0.2
	0.789	5.73	5.80	5.60	0.07	-0.13	1.2	-2.3
	1.010	8.63	8.70	8.50	0.07	-0.13	0.8	-1.5
1.672	0.376	2.260	2.26	2.28	0.00	0.02	0.0	0.9
	1.980	3.82	3.82	3.75	0.00	-0.07	0.0	-1.8
	3.79	5.51	5.55	5.30	0.04	-0.21	0.7	-3.8
2.378	0.545	2.141	2.14	2.20	-0.001	0.059	-0.05	2.8
	2.186	2.628	2.63	2.72	0.002	0.092	0.1	3.5
	3.72	3.06	3.06	3.15	0.00	0.09	0.0	3.0
	4.54	3.26	3.27	*	0.01		0.3	
	10.28	4.12	4.14	*	0.02		0.5	
4.85	2.303	2.107	2.11	*	0.003		0.1	
	7.17	2.312	2.32	*	0.008		0.3	
	14.38	2.548	2.59	*	0.042		1.6	

* Outside of the limits of Edmister's correlation.

TABLE 14 (Con't.)

Comparison of the Generalized Correlations
of Bleich and Edmister with Original Data

ETHANE

		$C_p - C_v$			Difference		% Deviation	
T_r	Pr	Calculated	Bleich	Edmister	Bleich	Edmister	Bleich	Edmister
1.291	0.2028	2.306	2.30	2.31	-0.006	0.004	-0.3	0.2
	1.006	4.28	4.35	4.13	0.07	-0.15	1.6	-3.5
	1.397	5.91	6.10	5.70	0.19	-0.21	3.2	-3.6
1.746	0.2866	2.169	2.17	2.20	0.001	0.031	0.05	1.4
	1.512	3.12	3.12	3.11	0.00	-0.01	0.0	-0.3
	2.938	4.36	4.32	4.20	-0.04	-0.16	-0.9	-3.7
	12.81	5.54	5.55	*	0.01		0.2	
2.291	0.380	2.107	2.10	2.15	-0.007	0.043	-0.3	2.0
	1.260	2.395	2.40	2.44	0.005	0.045	0.2	1.9
	3.19	3.04	3.03	3.10	-0.01	0.06	-0.3	2.0
3.38	1.139	2.128	2.11	*	-0.018		-0.8	
	5.09	2.551	2.55	*	-0.001		-0.04	
	12.01	3.05	3.10	*	0.05		1.6	

* Outside of the limits of Edmister's correlation.

TABLE 14 (Con't.)

Comparison of the Generalized Correlations of Bleich and Edmister with Original Data

PROPANE

		$C_p - C_v$			Difference		% Deviation	
T_r	Pr	Calculated	Bleich	Edmister	Bleich	Edmister	Bleich	Edmister
1.291	0.819	3.75	3.76	3.60	0.01	-0.15	0.3	-0.2
	1.260	5.38	5.40	5.10	0.02	-0.28	0.4	-5.2
	1.458	6.30	6.35	5.90	0.05	-0.40	0.8	-6.3
1.892	0.448	2.225	2.22	2.25	-0.005	0.025	-0.2	1.1
	0.891	2.478	2.48	2.50	0.002	0.022	0.1	0.9
	1.882	3.10	3.13	3.10	0.03	0.0	1.0	0.0
	4.48	4.60	4.62	*	0.02		0.4	
	11.72	5.71	5.40	*	-0.31		-5.4	
2.192	0.787	2.273	2.27	2.33	-0.003	0.057	-0.1	2.5
	2.258	2.836	2.85	2.90	0.014	0.064	0.5	2.3
	3.20	3.19	3.18	3.25	-0.01	0.06	-0.3	1.9
2.702	0.796	2.340	2.15	*	-0.19		-8.1	
	2.891	2.587	2.58	*	-0.007		-0.3	
	13.36	3.73	3.80	*	0.07		1.9	

* Outside of the limits of Edmister's correlation.

TABLE 14 (Con't.)

Comparison of the Generalized Correlations of Bleich and Edmister with Original Data

n-BUTANE

		$C_p - C_v$			Difference		& Deviation	
T_r	p_r	Calculated	Bleich	Edmister	Bleich	Edmister	Bleich	Edmister
1.176	0.2097	2.449	2.44	2.45	-0.009	0.001	-0.4	0.04
	0.884	5.23	5.35	4.95	0.12	-0.28	2.3	-5.4
	1.100	6.91	7.10	6.30	0.19	-0.61	2.7	-8.8
1.647	0.302	2.219	2.21	2.24	-0.009	0.021	-0.4	0.9
	1.429	3.31	3.30	3.27	-0.01	-0.04	-0.3	-1.2
	3.98	5.90	5.90	5.60	0.00	-0.30	0.0	-5.1
2.117	0.392	2.113	2.12	2.18	0.007	0.067	0.3	3.2
	0.976	2.376	2.37	2.42	-0.006	0.044	-0.3	1.9
	1.954	2.793	2.79	2.85	-0.003	0.057	-0.1	2.0
	13.91	5.16	4.82	*	-0.34		-6.6	
3.06	1.449	2.209	2.20	*	-0.009		-0.4	
	6.52	2.868	2.87	*	0.002		0.1	
	12.87	3.42	3.40	*	-0.02		-0.6	

* Outside of the limits of Edmister's correlation.

TABLE 15

Comparison of the Generalized Correlations of Bleich and Edmister with Data of Deming and Shupe for Nitrogen

Nitrogen $t_c = -147.1^{\circ}C.$ $p_c = 33.5$ atm.

				$C_p - C_v$			% Deviation	
t(°C)	p(psia)	T_r	p_r	Deming & Shupe	Bleich	Edmister	Bleich	Edmister
-70	20	1.61	0.600	2.44	2.5	2.5	2.5	2.5
	100		2.985	5.51	5.35	5.1	- 2.9	-7.4
	500		14.925	5.08	5.4	*	6.3	
50	20	2.56	0.600	2.14	2.12	*	- 0.9	
	100		2.985	2.72	2.69	*	- 1.1	
	500		14.925	3.62	4.15	*	14.6	
400	100	5.34	2.985	2.09	2.11	*	1.0	
	300		8.955	2.18	2.32	*	6.4	
	500		14.925	2.29	2.49	*	8.7	

* Outside of the limits of Edmister's correlation.

TABLE 16

Comparison of the Generalized Correlations of Bleich and Edmister with Data of Deming and Shupe for Carbon Monoxide

Carbon Monoxide $t_c = -139°C.$ $p_c = 35.0$ atm.

				$C_p - C_v$			% Deviation	
t(°C)	p(psia)	T_r	p_r	Deming & Shupe	Bleich	Edmister	Bleich	Edmister
-50	25	1.66	0.714	2.51	2.57	2.57	2.4	2.4
	100		2.86	4.46	4.82	4.65	8.1	4.3
	400		11.43	5.10	5.82	*	14.1	
50	25	2.41	0.714	2.22	2.18	2.25	- 1.8	1.4
	100		2.86	2.86	2.90	2.90	- 2.4	1.4
	500		14.29	3.62	4.33	*	19.6	
300	100	4.27	2.86	2.24	2.17	*	- 3.1	
	300		8.57	2.59	2.50	*	- 3.5	
	500		14.29	2.73	2.80	*	2.6	

* Outside of the limits of Edmister's correlation.

NOTATION

C_p	Heat capacity at constant pressure, molal basis - Btu/#-Mol-^oF
c_p	Specific heat at constant pressure, weight basis - Btu/#-^oF
C_p^*	Heat capacity at constant pressure of a gas exhibiting ideal behavior, molal basis Btu/#-Mol-^oF
C_v	Heat capacity at constant volume, molal basis - Btu/#-Mol-^oF
c_v	Specific heat at constant volume, weight basis - Btu/#-^oF
C_v^*	Heat capacity at constant volume of a gas exhibiting ideal behavior, molal basis Btu/#-Mol-^oF
p, P	Absolute pressure
T	Absolute temperature
t	Temperature - $^oC.$ or $^oF.$
R	Universal gas constant
V	Molal volume
sub c	At critical conditions
sub r	At reduced conditions
α	Lewis and Randall volume residual quantity
$A_o, B_o, C_o,$ a, b, c, α, γ	Constants for Benedict - Webb - Rubin Equation of State

REFERENCES

1. Rossini, F. D., Pitzer, K. S., Arnett, R. L., Braun, R. M., and Pimental, G. C., American Petroleum Institute Research Project 44, Carnegie Press, 1953

2. Edmister, W. C., Petroleum Refiner, 27, 613 (1948)

3. Lewis and Randall, Thermodynamics, New York, N. Y., McGraw - Hill Book C., 1923

4. Deming, W. E. and Shupe, L. E., Physical Review, 37, 638 (1931)

5. Deming, W. E. and Shupe, L. E., Physical Review, 38, 2245 (1931)

6. Hougen, O. A. and Watson, K. M., Chemical Process Principles, Part II, New York, N. Y., John Wiley and Sons, 1947

7. Edmister, W. C., Petroleum Refiner, 27, 314 (1948)

8. Edmister, W. C., Industrial and Engineering Chemistry, 30, 355 (1938)

9. Sledjeski, E. W., Thesis in Chemical Engineering, Newark College of Engineering, 1950

10. Sibilia, R. J., Thesis in Chemical Engineering, Newark College of Engineering, 1952

11. Reiter, T. A., Thesis in Chemical Engineering, Newark College of Engineering, 1954

12. Seifarth, J. H., Thesis in Chemical Engineering, Newark College of Engineering, 1951

13. Glueck, R. M., Thesis in Chemical Engineering, Newark College of Engineering, 1952

14. Weiss, A. H., Thesis in Chemical Engineering, Newark College of Engineering, 1955

15. De Laney, E. G., Thesis in Chemical Engineering, Newark College of Engineering, 1955

16. Benedict, M., Webb, G. W., and Rubin, L. C., Journal of Chemical Physics, 8, 334 (1940)

17. Bartlett, Journal of the American Chemical Society, 49, 687 (1927)