5-31-1964

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Recommended Citation

Patel, Ghanshyam R., "The virial equation of state based on critical constants" (1964). *Theses*. 2134.
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THE VIRIAL EQUATION OF STATE BASED ON CRITICAL CONSTANTS

BY

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A THESIS
PRESENTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE
OF
MASTER OF SCIENCE IN CHEMICAL ENGINEERING
AT
NEWARK COLLEGE OF ENGINEERING

Newark, New Jersey

1964

ABSTRACT

Results obtained from the Epstein equation of state[15] i.e. equation (8), which is theoretically valid up to the critical density, are compared with the experimental values of the compressibility factor. The calculated values of compressibility factor for ethylene, ethane, propane, and n-butane were obtained using two methods of evaluation for the second and third virial coefficients. In addition, using these two methods and excluding fourth, fifth, and sixth virials in the Epstein equation of state, compressibility factors were calculated for all the four compounds to test the effect of higher virial terms. In the proposed method-(A) and method-(C), the force constants were calculated from critical properties while, in methods-(B) and (D), force constants which are based on experimental p-v-t data, were directly taken from the literature. For methods-(A) and (B), Epstein equation of state i.e. equation (8), was used. While, for methods-(C) and (D), fourth, fifth, and sixth virials were neglected in the Epstein equation of state, which reduced to equation (11).

The proposed method-(A) which only requires the

information on critical properties, gave results within the acceptable range of accuracy for all the four compounds. The other methods gave poor results. Epstein has suggested that his equation is valid only for non-polar and spherical molecules. It is, however, shown in this work that his equation is also valid for linear molecules, if the force constants from critical properties are used in the evaluation of second and third virial coefficients. The proposed method-(A) requires only three parameters i.e. critical constants, and is comparable in accuracy to the Beattie-Bridgeman equation.

APPROVAL OF THESIS

FOR

DEPARTMENT OF CHEMICAL ENGINEERING

NEWARK COLLEGE OF ENGINEERING

BY

FACULTY COMMITTEE

APPROVED: ______________________

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NEWARK, NEW JERSEY

MAY, 1964

ACKNOWLEDGMENTS

I would like to acknowledge and express my appreciation to -

Dr. Joseph Joffe, who as my advisor, suggested the thesis topic and aided immeasurably by his assistance and advice during the development of the thesis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

LIST OF TABLES (CONTINUED)

INTRODUCTION

Engineering design work and petroleum industry operations require an accurate prediction of the pressure-volume-temperature behavior of gases. Assumptions made for calculating these properties under ideal gaseous conditions do not apply for real gases, thus the equation

$$PV = RT \tag{1}$$

cannot be used for real gases. However, the introduction of the compressibility factor will allow the use of the equation

$$PV = ZRT \quad , \tag{2}$$

where Z is the compressibility factor.

In recent years, several attempts have been made to establish a more acceptable form of the equation of state. Several charts[1,2,3] are available from the laws of corresponding states which have been discussed many times[3,4]. Generalized equations of state which have appeared in the literature in the form of analytical expressions, were modified van der Waal equation[5], generalized Beattie-Bridgeman equation[6], a modified equation of Dieterici[7], a modified Benedict equation[8], and forms suggested by Joffe[9], Woolsey[10], Su et al[11,12], and Hirschfelder et al[13].

A current equation of state suggested by Epstein[15] which is theoretically valid up to critical density involves six virial coefficients. In the present work, results obtained from the Epstein equation of state using methods of evaluation for the second and third virials, are compared with the experimental value of the compressibility factor.

The Virial Equation and its Development:

In recent years, an accurate approach has been suggested for the equation of state. In 1901 Onnes[16] suggested the expansion in terms of a power series;

$$\frac{PV}{RT} = Z = 1 + \frac{B(T)}{(V)} + \frac{C(T)}{(V)^2} + \frac{D(T)}{(V)^3} + \ldots\ldots \qquad (3)$$

which is known as the virial equation of state. In the above equation (3) experimental data can be fitted over a wide range of temperature and pressure. The terms B(T), C(T), and D(T) etc., are known as the second, third, fourth, and higher virial coefficients and are also taken as a functions of temperature. The virial coefficients are used to give the deviations from ideality in terms of attraction and repulsion forces between the molecules during the collisions. The above equation (3) was used only to fit the experimental data. Later, it was proved that the equation (3) is theoretically and empirically correct. From statistical mechanics, it has been shown that the virial coefficients may be derived in terms of the intermolecular potential functions. This is well treated by Hirschfelder[14].

The Lennard-Jones 6-12 potential[17] can be employed in the evaluation of second and third virial coefficients. This potential can be written as:

$$\psi(r) = 4 \epsilon (\frac{\sigma}{r})^{12} - (\frac{\sigma}{r})^{6} \qquad (4)$$

where σ and ψ are parameters in the intermolecular potential function. From the above mentioned Lennard-Jones 6-12 potential the second and third virials can easily be calculated in terms of reduced quantities $B^*(T^*)$, and $C^*(T^*)$ using the relationships:

$$B(T) = b_o B^*(T^*) \quad , \qquad (5\text{-a})$$

$$C(T) = b_o^2 \, C^*(T^*) \quad , \qquad (5\text{-b})$$

$$T^* = \frac{T}{\epsilon/k} \quad , \qquad (6)$$

$$\text{and } b_o = 2/3 \, \pi \, N \sigma^3 \qquad (6\text{-a})$$

The force constant ϵ/k and kinetic constant b_o have been established for some gases by various workers and are listed by Hirschfelder[14]. The values of $B^*(T^*)$ and $C^*(T^*)$ which are functions of the dimensionless quantity T^* are given by Hirschfelder[14].

It is evident from the above mentioned outline that knowing the constants ϵ/k and b_o, second and third virial coefficients can be calculated. Force constant ϵ/k and kinetic constant b_o are established for some gases. For most of the hydrocarbons the constants are not yet determined. Hence, it is necessary to use values of ϵ/k and b_o which can easily be predicted from the critical constants, since it has been shown that these constants can be obtained from the critical properties of gases by Hirschfelder et al[14] and Nelson et al[18]. The relations are purely empirical and derived by taking average values with the help of the law of corresponding states. The relationships of Nelson and Obert[18] are:

$$\epsilon/k = 0.756\ T_c \quad \text{and} \tag{7-a}$$

$$b_o = 17.0\ T_c/P_c \tag{7-b}$$

where T_c is the critical temperature in °K and P_c is the critical pressure in atm. Hirschfelder proposes similar equations but with different numerical constants. The relationships of Nelson et al are used throughout this work.

Using the force constants, the dimensionless quantity T^* can be calculated and, using the tables given in reference[14], $B^*(T^*)$ and $C^*(T^*)$ can be determined to give the values of second and third virial coefficients.

Epstein Equation of State:

Using the virial equation of state and also using the analytical information from the pressure-volume-temperature behavior, Epstein[15] has suggested an equation of state. His equation is valid up to the critical density and involves six virial coefficients. The equation is:

$$Z = 1 + \frac{B(T)}{(V)} + \frac{C(T)}{(V)^2} + \left\{\frac{D'}{(V)^3} + \frac{E'}{(V)^4} + \frac{F'}{(V)^5}\right\}\left(\frac{T_c}{T}\right)^3 \qquad (8)$$

In this equation the second and third virial coefficients can be calculated as mentioned in the foregoing discussion. The procedure of evaluating fourth, fifth, and sixth virial coefficients is more complicated because it involves intermolecular forces due to four, five, and six molecule collisions respectively. The expression developed by Epstein assumes that these coefficients are dependent on temperature in terms of the same factor, $(T_c/T)^3$. The factor $(T_c/T)^3$ in the above equation of state is purely empirical and suggested by the fact that the Beattie-Bridgeman equation[19] includes the fourth virial coefficient which has the form $B_o bc/(T)^3$.

Using the critical constants and the application of the critical condition,

$$\left(\frac{\partial P}{\partial V}\right) = \left(\frac{\partial^2 P}{\partial V^2}\right) = 0 \qquad , \tag{9-a}$$

Epstein has proposed the following equations for the constants D', E', and F' in equation (8):

$$D' = \left[15Z_c - 10. - \frac{6B(T_c)}{(V_c)} - \frac{3C(T_c)}{(V_c)^2}\right](V_c)^3 \quad , \tag{10-a}$$

$$E' = \left[-24Z_c + 15. + \frac{8B(T_c)}{(V_c)} + \frac{3C(T_c)}{(V_c)^2}\right](V_c)^4 \quad , \tag{10-b}$$

$$F' = \left[10Z_c - 6. - \frac{3B(T_c)}{(V_c)} - \frac{C(T_c)}{(V_c)^2}\right](V_c)^5 \quad , \tag{10-c}$$

where $$P_cV_c = Z_cRT_c \tag{9-b}$$

In applying above equations it is necessary to compute second and third virials at the critical temperature. The other necessary data are the critical constants. Knowing five parameters P_c, V_c, T_c, ϵ/k, and b_o, pressure-volume-temperature behavior can be established up to the critical density. Equations (9-a) and (9-b) for the critical conditions show that the equation (8) can be justified up to the critical density point.

Purpose of the Thesis:

From the foregoing discussions it is clear that the equation (8) requires a proper computation procedure for the virial coefficients, or it can be said that it requires the use of proper force constants. However, it is known that the force constants are related to the critical constants. The relations have been shown in the equations (7-a) and (7-b). These relationships are valid only for non-polar molecules. The purpose of the present work is to test the equation (8) by using methods:

(A) using force constants derived from critical constants and

(B) using force constants from second virial coefficients in the literature, based on experimental P-V-T data.

The virial equation of state can be written in the form:

$$Z = 1 + \frac{B(T)}{(V)} + \frac{C(T)}{(V)^2} \tag{11}$$

omitting all the higher virial coefficients. The relative accuracy of equation (11) as compared with equation (8), is evaluated in the present work by using two methods:

(C) using the force constants derived from critical constants and

(D) using force constants from second virial coefficients in the literature, based on experimental P-V-T data.

The four hydrocarbons i.e. (1) Ethylene, (2) Ethane, (3) Propane, and (4) n-Butane were selected. The reasons are:

(1) these are non-polar compounds, which justifies the proposed method (A),

(2) the force constants for these compounds are available in the literature, and

(3) these hydrocarbons have been used in the derivation of generalized charts and equations of state, such as the Benedict-Webb-Rubin equation.

These compounds were used in all the four methods and the results were compared with the experimental data.

PROCEDURE

Data involving a wide range of temperature and pressure were used in all four methods;

(A) using equation (8) and force constants from equations (7-a) and (7-b),

(B) using equation (8) and force constants taken from literature,

(C) using equation (11) and force constants from equations (7-a) and (7-b), and

(D) using equation (11) and force constants taken from literature.

The critical properties for the compounds; (1) Ethylene, (2) Ethane, (3) Propane, and (4) n-Butane are listed in table-(1).

Selection of P-V-T Data:

The experimental pressure-volume-temperature data for the above listed compounds were previously determined by various workers. Since this work is restricted to non-polar molecules, choice fell on hydrocarbons. These hydrocarbons are non-polar in molecular structure and are non-spherical. The first method which is proposed in this work is valid for non-polar molecules and requires only critical data.

TABLE I

CRITICAL CONSTANTS

Comp.	T_c deg. K	P_c atm.	V_c c.c./mole	Ref.
Ethylene	283.1	50.5	124.0	35, 36
Ethane	305.4	48.2	148.0	37
Propane	369.9	42.0	200.0	37
n-Butane	425.2	37.5	255.0	37

The P-V-T data were taken from references listed in table (II). For ethylene, nine isotherms were selected at different intervals of temperature, while seven isotherms were selected for n-butane at a regular interval of sixty degrees F.

Evaluation of B(T) and C(T):

In order to use equation (8) the second and third virials must be evaluated. The reduced quantities $B^*(T^*)$ and $C^*(T^*)$ which are related to B(T) and C(T) may be interpolated using the reduced quantity, T^*, calculated from equation (6). $B^*(T^*)$ and $C^*(T^*)$ as a function of T^*, were determined from the Lennard-Jones 6-12 potential and are given by Hirschfelder et al[14]. The second virial coefficient for non-polar compounds can also be determined by using the Buckingham-Corner potential which may be called the exp. 6-8 potential. For ethylene, Barua[24] suggested that both the Lennard-Jones 6-12 and exp. 6-8 potentials give an equally good fit with the experimental value of B(T). However, only Lennard-Jones 6-12 potential is used in this investigation.

For methods (A) and (C), T^* is obtained from equation (6) using force constants from equation (7-a). While for method (B) and (D), force constants from

TABLE II

REFERENCES FOR P-V-T DATA

Compound	Selected References	Other References
Ethylene	20	26,27
Ethane	21	28,29
Propane	22	30
n-Butane	23	31,32

literature are used in order to calculate T^*. Using this T^*, $B^*(T^*)$ and $C^*(T^*)$ are interpolated from tables given in reference (14). The second and third virials are calculated from equations (5-a) and (5-b). The value of b_o in these equations depends on the method used, i.e. (A) vs. (B) or (C) vs. (D). The same procedure is repeated for each temperature and then repeated for each compound.

In the similar manner, the second and third virial coefficients are determined at the critical temperature by each method and are listed in table (III) and (IV) along with the force constants. For methods (A) and (B), the constants, D', E', and F' are calculated from the equations, (10-a), (10-b), and (10-c) respectively.

Thus, required virial coefficients and constants are determined in order to use equations (8) and (11). For every temperature and method, volumes from experimental p-v-t data are used to calculate the compressibility factors for each compound. Knowing these calculated values, deviations are computed from the experimental data.

To calculate compressibility factors, a computer program has been set up on the IBM 1620 computer, after

TABLE III

FORCE CONSTANTS FROM CRITICAL DATA AND SECOND AND THIRD VIRIALS AT T_c

Compound	ϵ/k °K	b_o c.c./mole	$B(T_c)$	$C(T_c)$
Ethylene	214.02	95.301	-146.25	5305.3
Ethane	230.88	107.714	-165.29	6777.3
Propane	279.64	149.721	-229.76	13094.3
n-Butane	321.45	192.760	-295.80	21703.8

TABLE IV

FORCE CONSTANTS FROM LITERATURE*

AND

SECOND AND THIRD VIRIALS AT T_c

Compound	ϵ/k °K	b_o c.c./mole	$B(T_c)$	$C(T_c)$	Ref.
Ethylene	199.2	116.7	-156.05	7621.5	33
Ethane	243.0	78.0	-131.63	3605.2	34
Propane	242.0	226.0	-261.43	27381.4	34
n-Butane	297.0	155.0	-204.32	13468.2	34

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* Force constants from experimental second virial coefficients are taken from the reference (14), Hirschfelder et al, 'Molecular Theory of Gases and Liquid', New York, John Wiley & Sons, 1954; p. 1110-17.

evaluating the required virial coefficients and constants. The consistency of results is to seven figures in the calculated compressibility factors, but results are rounded off to four figures.

DISCUSSION OF RESULTS

The deviations of computed values from the experimental values are tabulated in tables (V) through (XX). The deviations are calculated by dividing the difference between the computed and the experimental value by the experimental value. The second and third virial coefficients, as a function of temperature, are also tabulated in tables (XX) through (XXIV).

The Lennard-Jones 6-12 potential gives results for the second virial coefficient in agreement with experimental values. The third virial coefficient is doubtful, as it is mentioned in the introduction that the third virial coefficient is also evaluated from the Lennard-Jones 6-12 potential, since this potential gives a poor agreement between the experimental and calculated third virial coefficient for non-spherical elongated molecules. Hence it is necessary to employ a correction factor in this potential for elongated molecules or other potentials should be used in the evaluation of the third virial coefficient.

A semiempirical relationship between the critical constants and the chain length of hydrocarbons has been established by Rastogi and Girdhar[25]. This relationship can be used in the evaluation of virial coefficients to give better results. It is used indirectly in the proposed method-(A). In fact, the proposed method-(A) gives better results than method-(B).

The results would have been better if $B^*(T^*)$ and $C^*(T^*)$ were calculated from equations rather than using the interpolation in tables. In interpolation, it is assumed that the $B^*(T^*)$ and $C^*(T^*)$ are linearly related to T^* between two terminal values of T^*. This linear relationship is not valid. At terminal values of T^*, $B^*(T^*)$ and $C^*(T^*)$ may agree with the experimental values but as the value of T^* moves from the terminal values the interaction of molecules will vary between the terminal values of T^* and will give deviation from the true one. The equation is very sensitive to the value of the second virial coefficient. Even a small change in the value of the second virial coefficient will give a large deviation in the compressibility factor.

Figures (1) through (4) give the comparison of second virial coefficients calculated for each method versus temperature in degree Kelvin. Figures show that the second virial coefficient calculated from critical constants differs from the second virial which is calculated using the force constants based on experimental data. The difference increases as the chain length of the hydrocarbon increases. The second virials for ethylene are nearly identical, since it is a short molecule, whereas, curves of second virials for n-butane are separated.

Figures (5) through (8) show the third virial coefficients for each method versus temperatures in degrees Kelvin. These figures show that the third virial coefficients also differ more as the chain length of the hydrocarbon increases.

RESULTS (SPECIFIC):

Ethylene: The percent deviations for respective methods versus pressure at each isotherm are shown in figures (9) through (12). The figure (9) which is for method-(A) shows the least deviations among all the methods. In figure (9), at each isotherm, the deviation at high density is less than one percent and almostly linear with pressure. While, at low density deviation increases as the temperature increases. The maximum deviation for the top three highest isotherms is 4.5 percent. Except for these three points, the deviation is less than 3.0 percent. It is clear from the figure (10) that proposed method-(A) gives better results than the method-(B). The maximum deviation at low density is more than 7.0 percent. Deviation at low density decreases as the temperature increases. Figures (11) and (12) show that the deviations for ethylene using methods-(C) and (D) are high at all the temperatures. This shows that the higher virials are effective beyond one tenth of the critical density. The equation (11) does not justify itself beyond some pressures where collisions between four and higher numbers of molecules occur. The equation (8) is best suited and gives better results for ethylene if the force constants are evaluated from the critical data, which considers the effect of the chain length of hydrocarbons.

Ethane: Deviations of this compound are plotted against pressure at each temperature. The proposed method-(A) gives the best agreement for this compound. Figures (13) through (16) show the deviations for the respective methods. In figure (13), the deviation varies smoothly with pressure giving less than 2.5 percent deviation. The deviation at low density increases as the temperature increases. The maximum deviation is 3.01 percent for a few points. The curve for each isotherm is almost a straight line and all curves except the one at 100.0°F are on the negative side. This shows that the deviation is systematic for all temperatures. Method-(B) gives smooth curves with pressure but the deviations at high density are higher than for the proposed method-(A). In figures (15) and (16), deviations for methods-(C) and (D) are plotted for each isotherm. The results are worse beyond approximately one sixth of the critical density, where collisions between four or higher numbers of molecules occur. This shows that the equation (11) works up to a certain limit of density. Remarkably, deviations at the high densities decrease with the increases in temperature.

Propane: Deviations for propane are shown in figures (17) through (20). Figure (17) is the better choice at high temperatures, while figure (18) is good at low temperatures. The proposed method-(A) gives a slightly higher deviation at low temperatures than the method (B). Conversely, method-(B) gives worse results at high temperatures than the proposed method-(A). The method-(A) is the best of all the four methods. The maximum deviation is 3.5 percent occuring only at one temperature. At the temperature of 280.0 F, there is a little peak which gives maximum deviation for method-(A). Otherwise, method-(A) gives less than 3.0 percent deviations. This peak occurs in all four methods. It is possible that this peak might be due to experimental error. Method-(B) i.e. figure (18), gives more than 10.0 percent deviations at high temperatures. Methods-(C) and (D) i.e. figures (19) and (20), give greater deviations than methods-(A) and (B) respectively because fourth, fifth, and sixth virial coefficients are neglected. However, method-(C) which derives the force constants from critical constants, is better than the method-(D). The proposed method-(A) gives the smallest deviations up to the critical density.

n-Butane: Figures (21) through (24) show the deviations for n-butane. Method-(A) i.e. figure (21), gives the best results for n-butane up to the critical density. It gives less than 2.5 percent deviations, while the other methods give more than 10.0 percent deviations. It is clear from figures (22) and (23) that method-(C) is better than the method-(B). This indicates that the chain length of elongated molecules becomes more important as it increases. Figure (21) for method-(A) shows that the proposed method is better than the other three methods. In figure (22), curves at some isotherms are returning to the zero deviation line after giving maximum deviations. This is due to the fulfillment of the critical conditions in equation (8). Methods-(C) and (D) i. e. figures (23) and (24), give increasingly poor results, because fourth, fifth, and sixth coefficients are neglected in these methods.

Generally, method-(A) gives better results than the other methods. Equation (8) works better than equation (11) in which fourth, fifth, and sixth virial coefficients are neglected. Force constants from critical constants give better results than the force constants from literature which are based on second virial coefficients from experimental data. From figures (9) through (24) it is clear that the method-(B) becomes worse as the chain length of hydrocarbons increases, i. e. from ethylene to n-butane. While method-(A) gives better results than method-(B) from ethylene to n-butane. Another reason why method-(B) is inferior is that the Lennard-Jones 6-12 potential gives poor agreement between experimental and calculated third virial coefficient for elongated molecules. The chain length of elongated molecules plays a vital role in the interaction due to collisions of molecules.

It can be generalized from the results that the equation (8) is more realistic for elongated molecules if the force constants are evaluated from critical constants. As the pressure increases, higher virial coefficients become more effective. The other advantage of the proposed method-(A) is that it does not require information about force constants. If critical constants are provided, the pressure-volume-temperature behavior of gases can easily be established. Method-(A) is as good as the Beattie-Bridgeman equation.

CONCLUSIONS

The Epstein equation of state i.e. equation (8), gives better results than the equation (11) which excludes fourth, fifth, and sixth virial coefficients of equation (8). The equation (8) is valid up to the critical density because fourth, fifth, and sixth virial coefficients are derived using the critical conditions. Epstein suggested that the equation (8) gives better results for gases which have spherical shape in molecular structure. But it is shown in this work that the proposed method-(A) which uses force constants from critical data in the evaluation of second and third virial coefficients, is as good as the generalized Beattie-Bridgeman equation for hydrocarbons which are non-polar in molecular structure, i.e. non-polar linear molecules.

Since the Epstein equation of state is valid up to the critical density, the proposed method-(A) is also valid up to the critical density. The proposed method-(A) is restricted to non-polar molecules. Hence it cannot be generalized for all compounds.

If the critical constants are provided, pressure-volume-temperature behavior of non-polar hydrocarbons can easily be established with reasonable accuracy up to the critical density by using the proposed method-(A).

RECOMMENDATIONS

The results of the method-(A) suggest that this method-(A) should be tested for more compounds using different potentials in the evaluation of second and third virial coefficients. The encouraging results of the proposed method-(A) suggest that the equation (8) can be used in derivations of equations for thermodynamic properties i.e. internal energy, enthalpy, and entropy etc. The proposed method-(A) and the method-(B) can be compared simultaneously with experimental values for these properties. Using the Epstein equation of state, equations for these properties can be derived as follows:

Internal Energy: The deviations of internal energy from the ideal gas values may be written in the form of equation:

$$U - U^{o} = - \int_{V}^{\infty} T\left[\left(\frac{dP}{dT}\right)_{V} - P \right] dV \qquad (12)$$

To integrate the above equation (12), it is necessary to derive the term $(\frac{dP}{dT})_{V}$ from the Epstein equation of state which can be written as:

$$Z = \frac{PV}{RT} = 1 + \frac{B(T)}{V} + \frac{C(T)}{V^2} + \frac{D}{V^3} + \frac{E}{V^4} + \frac{F}{V^5} \qquad (13)$$

where D, E, and F are given by the following equations:

$$D = \left[15\ Z_c - 10.0 - \frac{6\ B(T_c)}{V} - \frac{3\ C(T_c)}{V_c^2}\right] V_c^3 \left[\frac{T_c}{T}\right]^3 \qquad (14)$$

$$E = \left[-24\ Z_c + 15.0 + \frac{8\ B(T_c)}{V_c} + \frac{3\ C(T_c)}{V_c^2}\right] V_c^4 \left[\frac{T_c}{T}\right]^3 \qquad (15)$$

$$F = \left[10\ Z_c - 6.0 - \frac{3\ B(T_c)}{V_c} - \frac{C(T_c)}{V_c^2}\right] V_c^5 \left[\frac{T_c}{T}\right]^3 \qquad (16)$$

Differentiating equation (13) with respect to T and keeping V constant, will give:

$$\left[\frac{dP}{dT}\right]_V = \frac{R}{V}\left[1 + \frac{B(T)}{V} + \frac{C(T)}{V^2} + \frac{D}{V^3} + \frac{E}{V^4} + \frac{F}{V^5}\right] + \frac{RT}{V}\left[\frac{dB}{VdT} + \frac{dC}{V^2dT} + \frac{dD}{V^3dT} + \frac{dE}{V^4dT} + \frac{dF}{V^5dT}\right] \qquad (17)$$

In order to get the first derivatives of fourth, fifth, and sixth virial coefficients, it is required to differentiate equations (14), (15), and (16) respectively with respect to T. This leads to the following three equations:

$$\frac{dD}{dT} = \left[15\ Z_c - 10.0 - \frac{6\ B(Tc)}{Vc} - \frac{3C(Tc)}{Vc^2}\right] Vc^3 \left[\frac{-3Tc^3}{T^4}\right] \qquad (18)$$

$$\frac{dE}{dT} = \left[-24\ Zc + 15.0 + \frac{8B(Tc)}{V_c} + \frac{3C(Tc)}{V_c^2}\right] Vc^4 \left[\frac{-3Tc^3}{T^4}\right] \qquad (19)$$

$$\frac{dF}{dT} = \left[10\ Zc - 6.0 - \frac{3B(Tc)}{V_c} - \frac{C(Tc)}{V_c^2}\right] V_c^5 \left[\frac{-3Tc^3}{T^4}\right] \qquad (20)$$

Substituting equation (17) in equation (12) and integrating it as a definite integral, leads to the following form:

$$U - U^o = -RT\left[\frac{T\ dB}{V\ dT} + \frac{T\ dC}{2V^2dT} + \frac{T\ dD}{3V^3dT} + \frac{T\ dE}{4V^4dT} + \frac{T\ dF}{5V^5dT}\right] \qquad (21)$$

In the above equation (21), some of the terms in the right hand side can be written as reduced quantities. The first derivatives of second and third virial coefficients can be obtained from the tables given by Hirschfelder et al[14] in the following way using the reduced quantity T^*:

$$B_1^* = T^* \frac{dB^*}{dT^*} = f\ (T^*) \qquad (22)$$

$$C_1^* = T^* \frac{dC^*}{dT^*} = f'\ (T^*) \qquad (23)$$

In order to use equation (21), it is necessary to use equations (18), (19), and (20) for the first derivatives of fourth, fifth, and sixth virial coefficients.

Enthalpy: In the similar manner, equation for enthalpy can be derived. The enthalpy departure of a real gas from the ideal gaseous state can be given as:

$$H - H^{o} = PV - RT - \int_{V}^{\infty} \left[T \left(\frac{dP}{dT}\right)_{V} - P \right] dV \qquad (24)$$

Substituting the term $(^{dP}/dT)_V$ from the equation (17) and integrating between two limits, equation (24) gives the following form:

$$H - H^{o} = RT \left[\frac{1}{V} \quad B - \frac{TdB}{dT} \quad + \frac{1}{V^{2}} \left(C - \frac{T\,dC}{2\,dT} \right) + \frac{1}{V^{3}} \left(D - \frac{TdD}{3dT} \right) + \frac{1}{V^{4}} \left(E - \frac{T\,dE}{4\,dT} \right) + \frac{1}{V^{5}} \left(F - \frac{T\,dF}{5\,dT} \right) \right] \qquad (25)$$

In the above equation (25), second and third virial coefficients can be written in reduced terms and can be valuated from tables. The first derivatives of second and third virial coefficients can be obtained using equations given by Hirschfelder et al[14] or from the tables using T^{*}. The first derivatives of fourth, fifth, and sixth virial coefficients can be calculated using equations (18), (19), and (20) which require only the critical constants.

Entropy: The entropy departure of a real gas from the ideal gaseous state can be represented by the equation:

$$S - S^o = - R \ln(P) + R \ln(\frac{PV}{RT}) - \int_V^\infty \left[\left(\frac{dP}{dT}\right)_V - \frac{R}{V} \right] dV \qquad (26)$$

In order to integrate the equation (26), the terms PV/RT and $(dP/dT)_V$ should be substituted in terms of equations (13) and (17) respectively. Integration of equation (26) leads to the form:

$$S - S^o = - R \left[\ln(P) + \frac{T\, dB}{V\, dT} + \frac{B^2}{2V^2} - \frac{C}{2V^2} + \frac{T\, dC}{2V^2 dT} - \frac{2\, D}{3V^3} + \frac{T\, dD}{3V^3 dT} - \frac{3\, E}{4V^4} + \frac{T\, dE}{4V^4 dT} - \frac{4\, F}{5V^5} + \frac{T\, dF}{5V^5 dT} \right] \qquad (27)$$

The above equation (27) can be reduced in some of its terms. The virial coefficients can be calculated from the equations or from the tables given by Hirschfelder[14]. The first derivatives of second and third virials can be obtained from tables, while equations (18), (19), and (20) can be used for higher virials derivatives.

The deviations of internal energy, enthalpy, and entropy from the ideal gas values may be derived using the equations (21), (25), and (27) respectively. The first derivatives of fourth, fifth, and sixth virial coefficients can be calculated from the equations (18), (19), and (20) respectively. The first derivatives of second and third virial coefficients can be evaluated from the reduced quantity T^* using tables given in reference[14].

An attempt should be made to evaluate the consistency of equations (21), (25), and (27) with experimental results when using force constants from critical properties.

APPENDIX

FIGURE NO. 1

SECOND VIRIALS FOR ETHYLENE

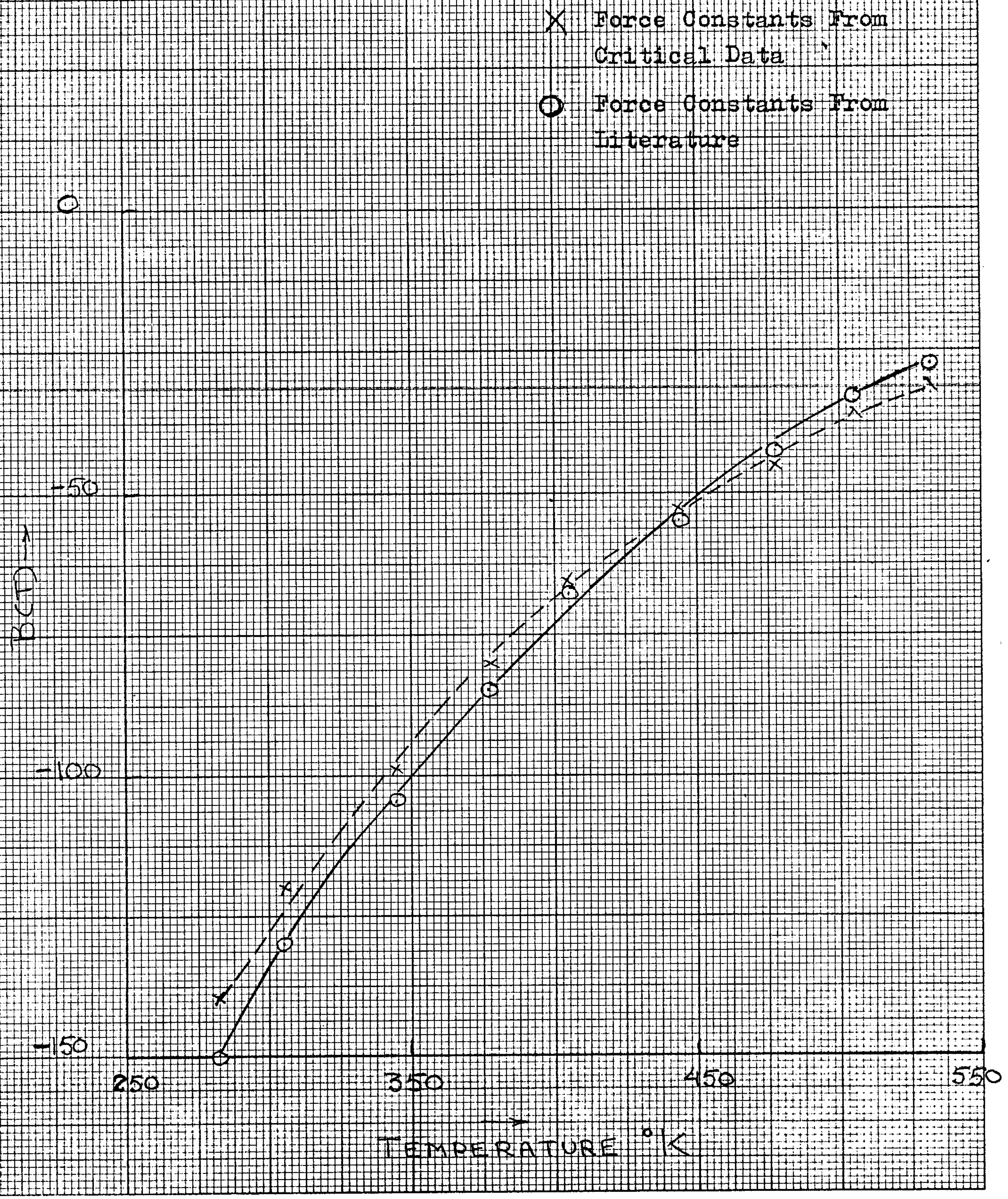


FIGURE NO. 2

SECOND VIRIALS FOR ETHANE

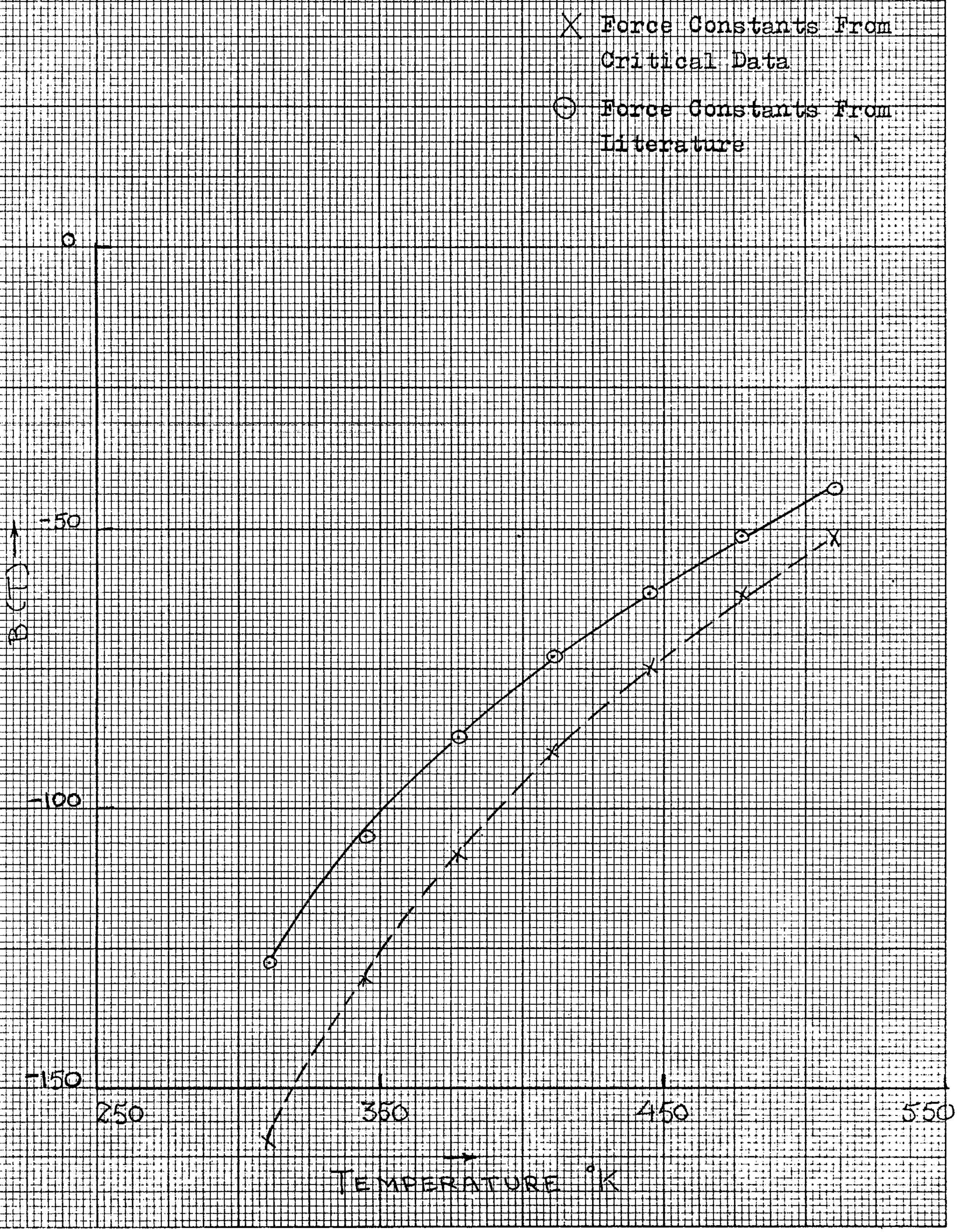


FIGURE NO. 3

SECOND VIRIALS FOR PROPANE

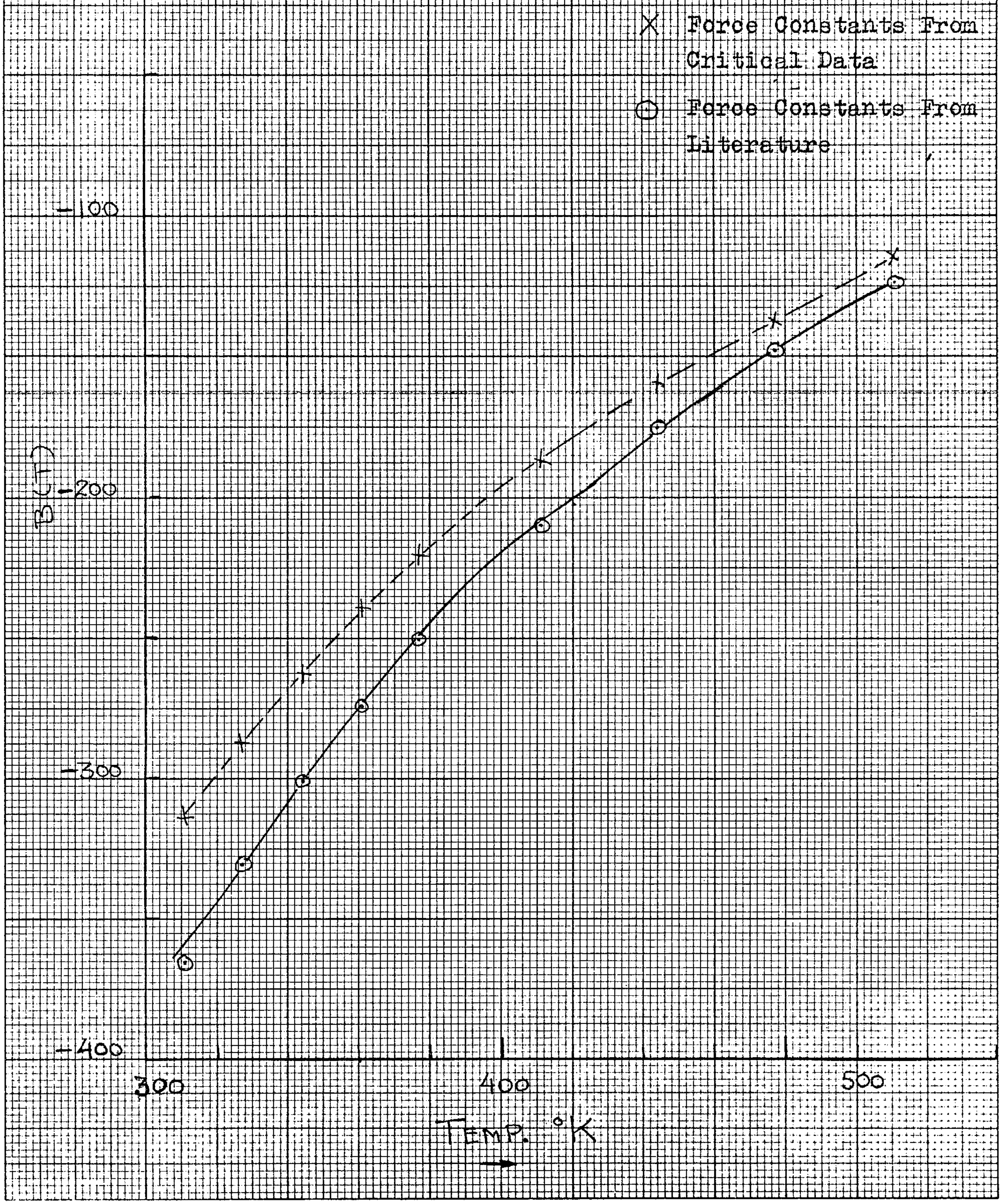


FIGURE NO. 4

SECOND VIRIALS FOR n-BUTANE

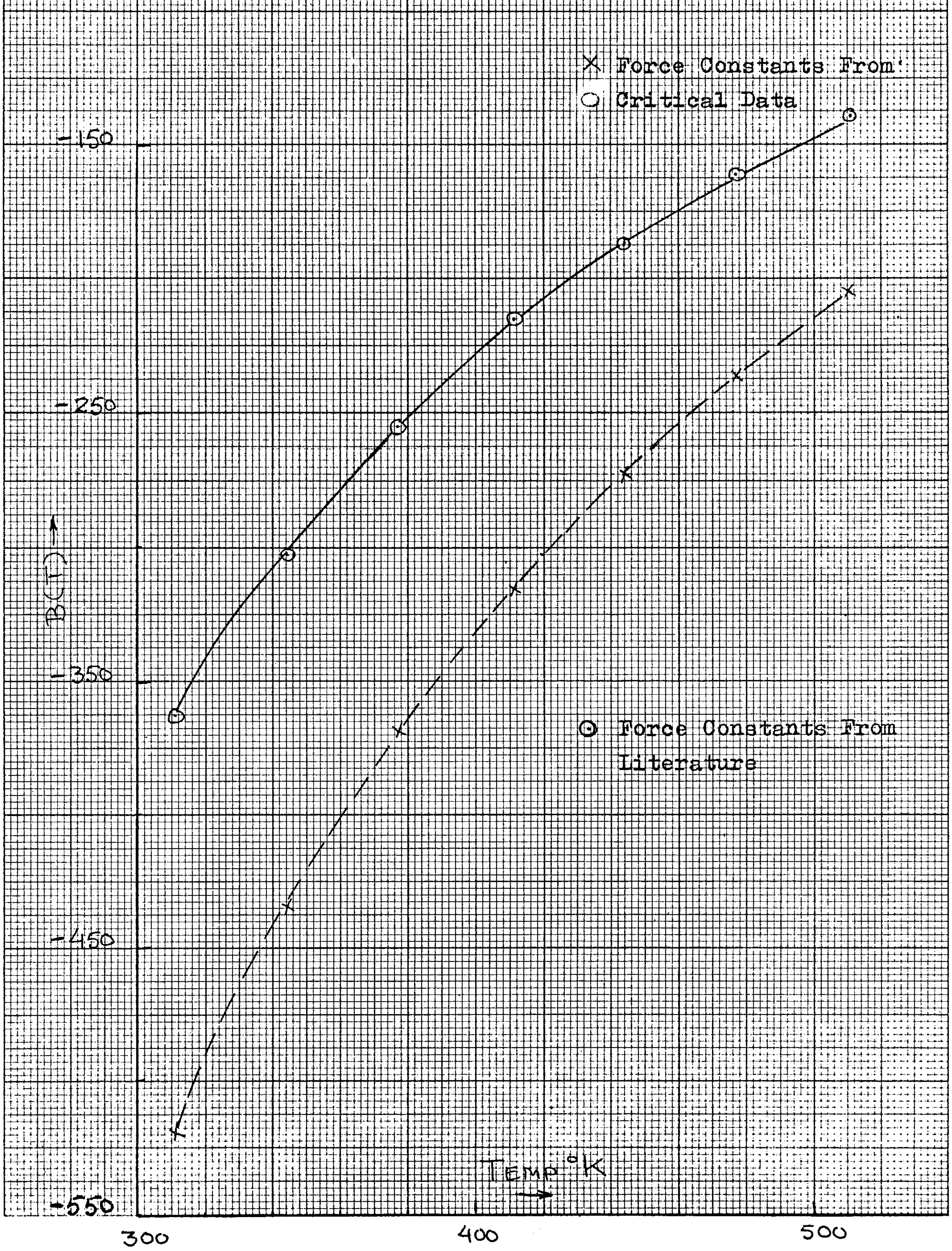


FIGURE NO. 5

THIRD VIRIALS FOR ETHYLENE

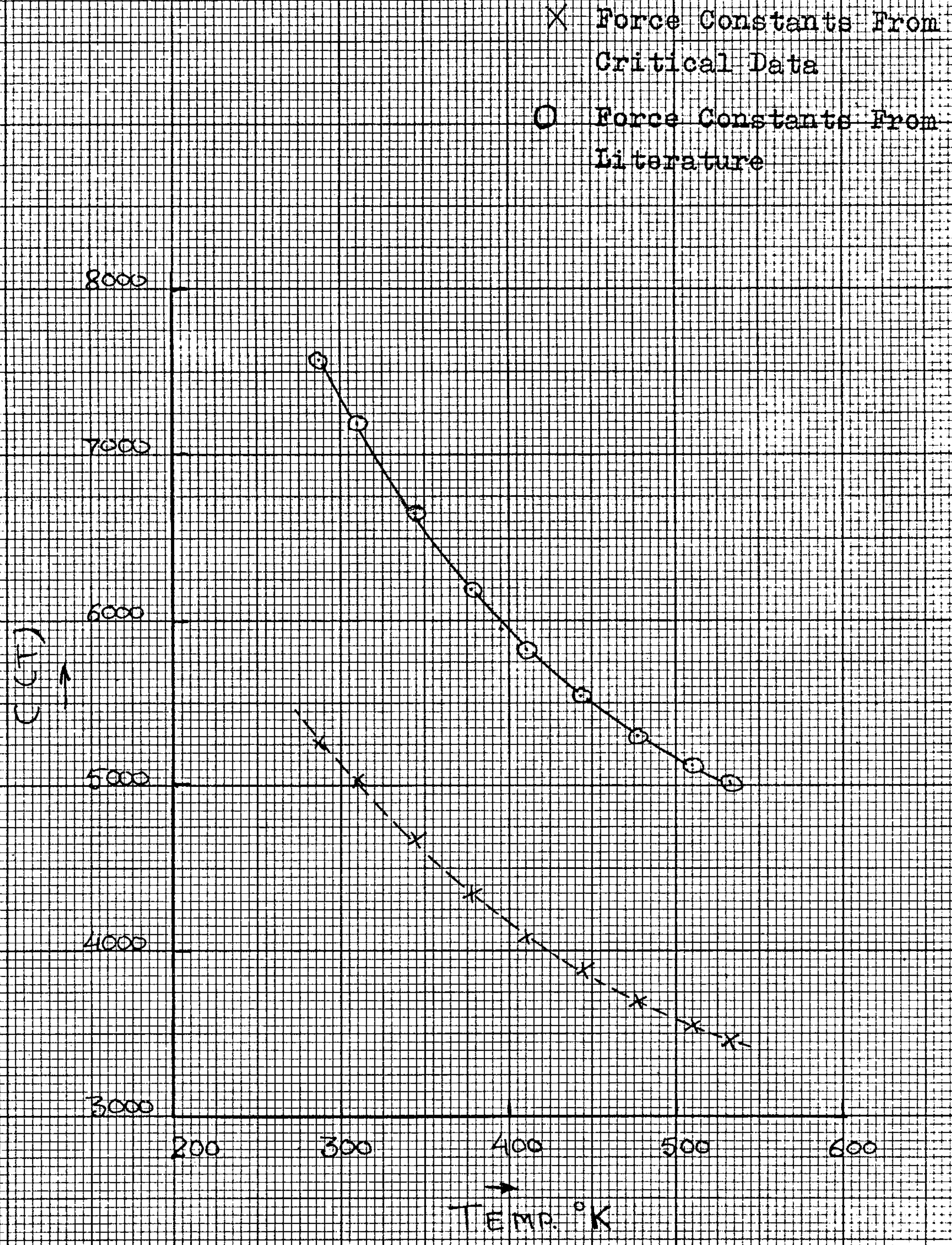


FIGURE NO. 6

THIRD VIRIALS FOR ETHANE

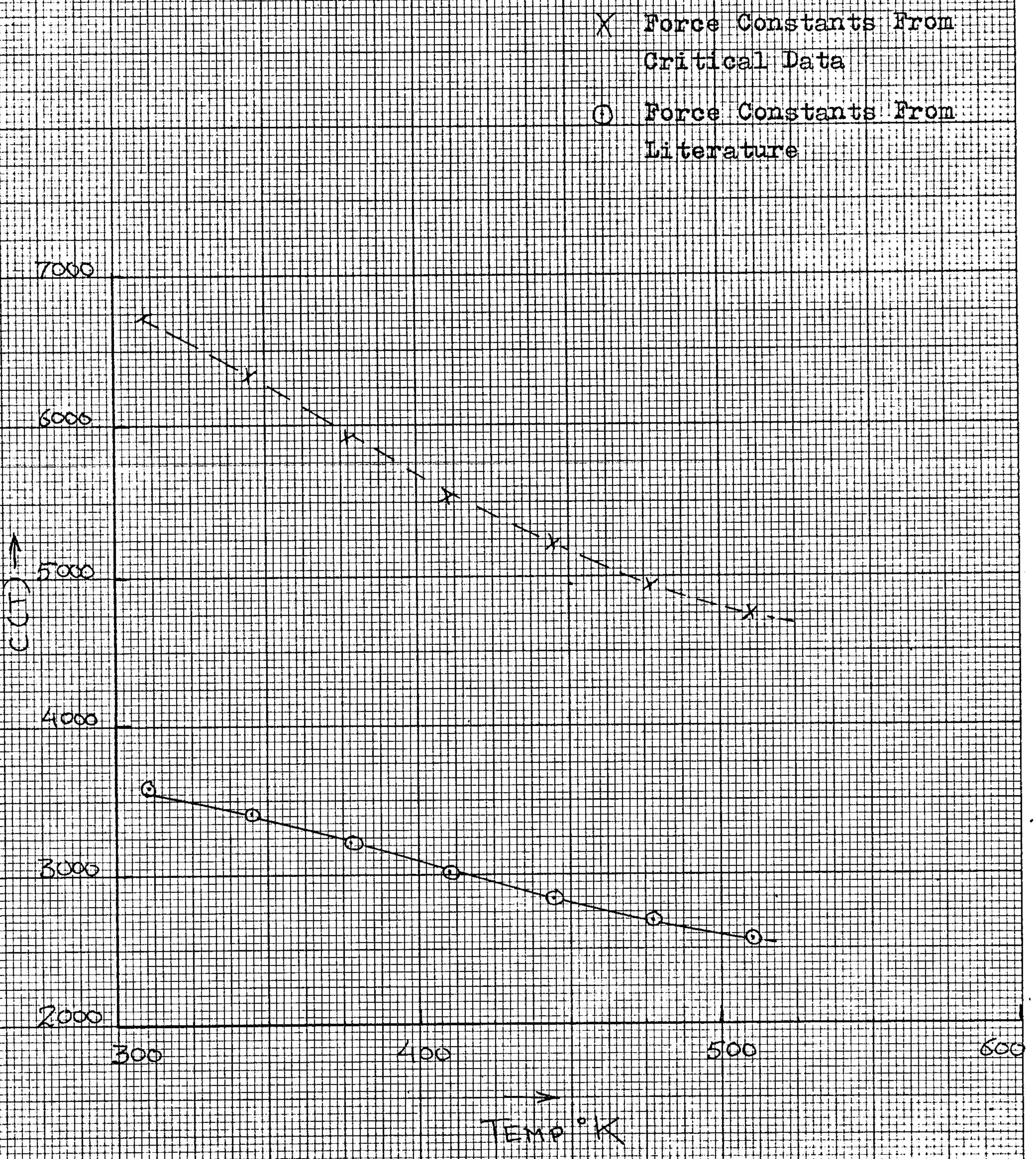


FIGURE NO. 7

THIRD VIRIALS FOR PROPANE

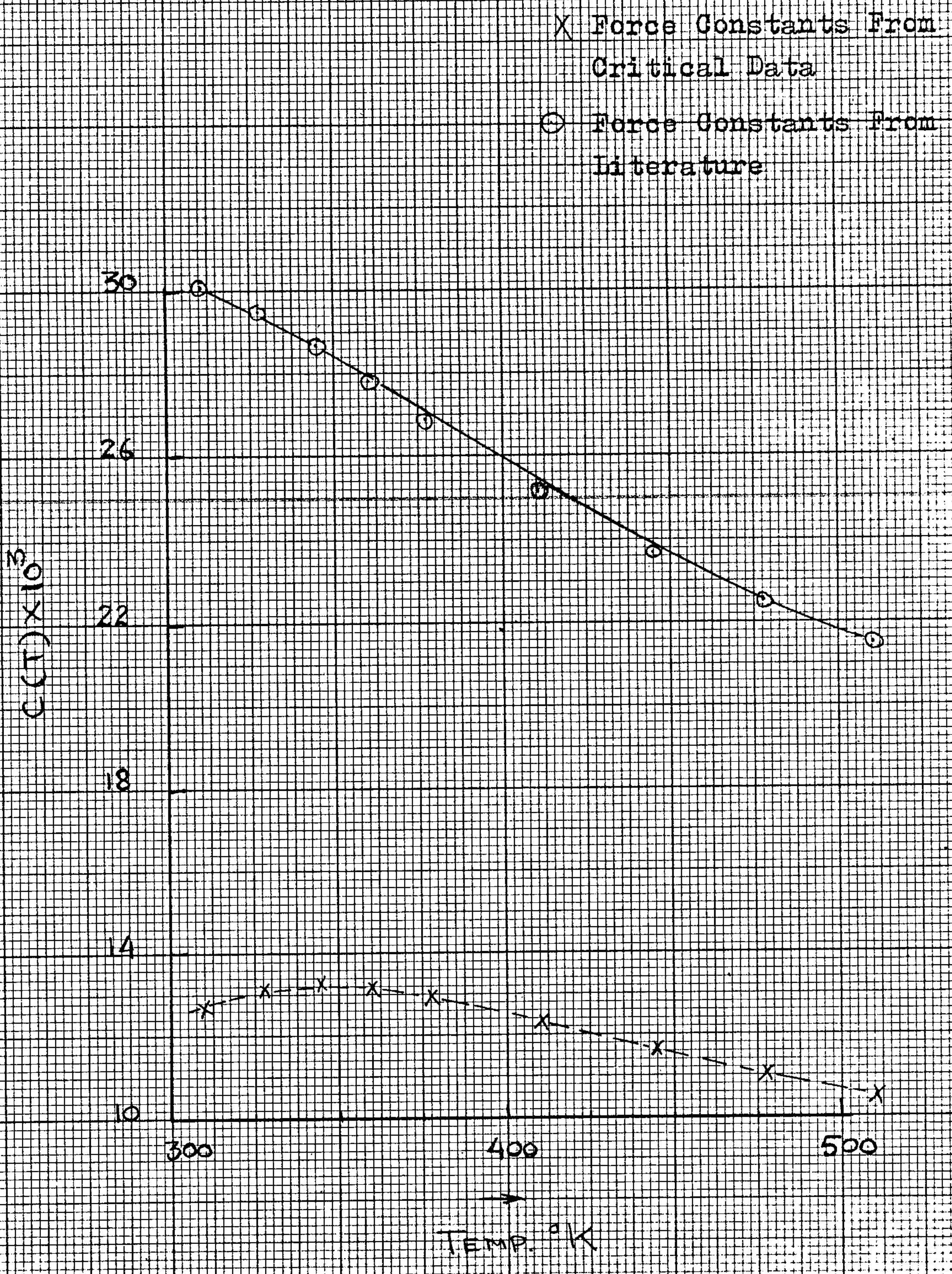


FIGURE NO. 8

THIRD VIRIALS FOR n-BUTANE

FIGURE No. 9

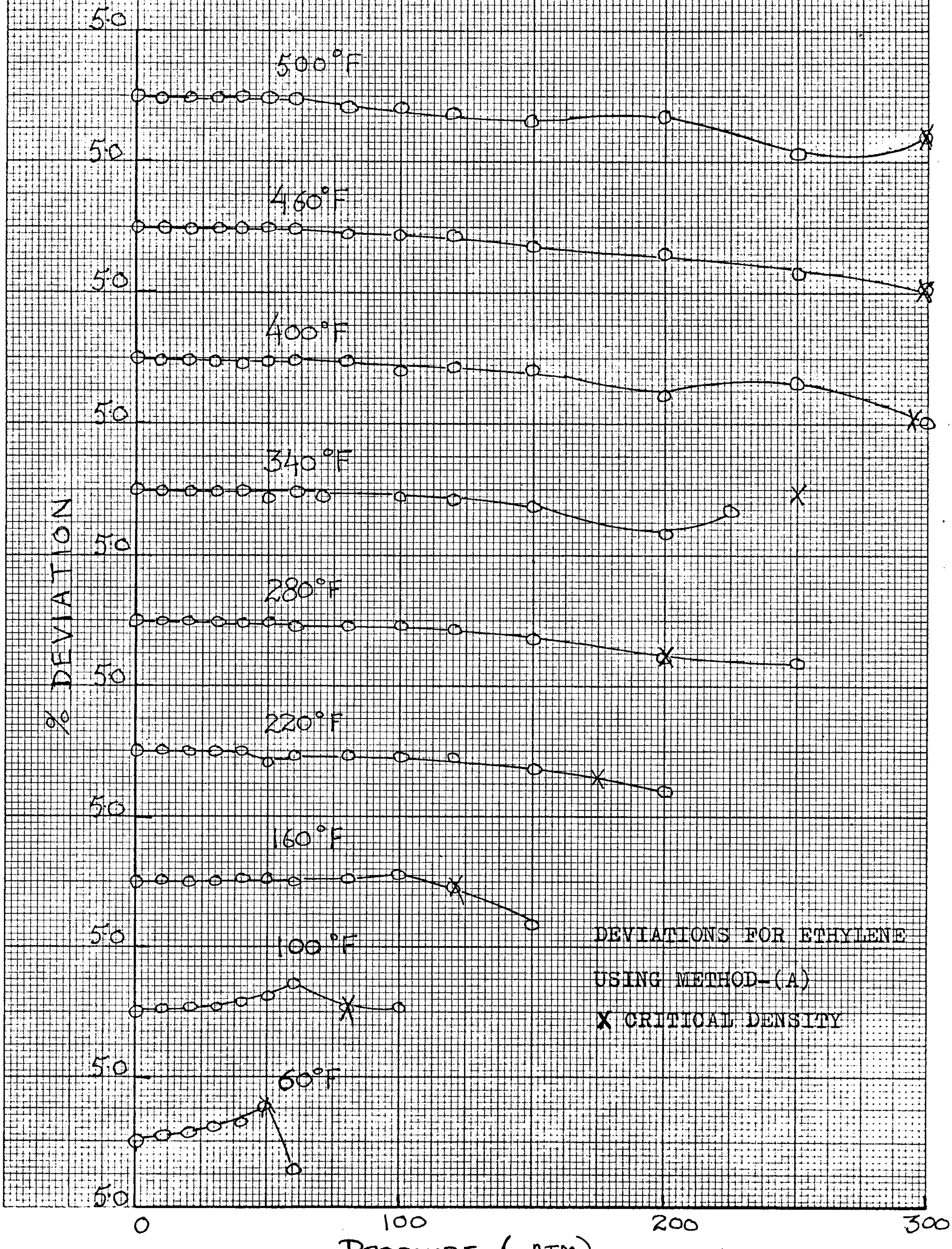

5.0
500°F
5.0
460°F
5.0
400°F
5.0
340°F
5.0
280°F
5.0
220°F
5.0
160°F
5.0
100°F
5.0
60°F
5.0
% DEVIATION
0
100
200
300
PRESSURE (ATM)
DEVIATIONS FOR ETHYLENE
USING METHOD-(A)
X CRITICAL DENSITY

FIGURE No. 10

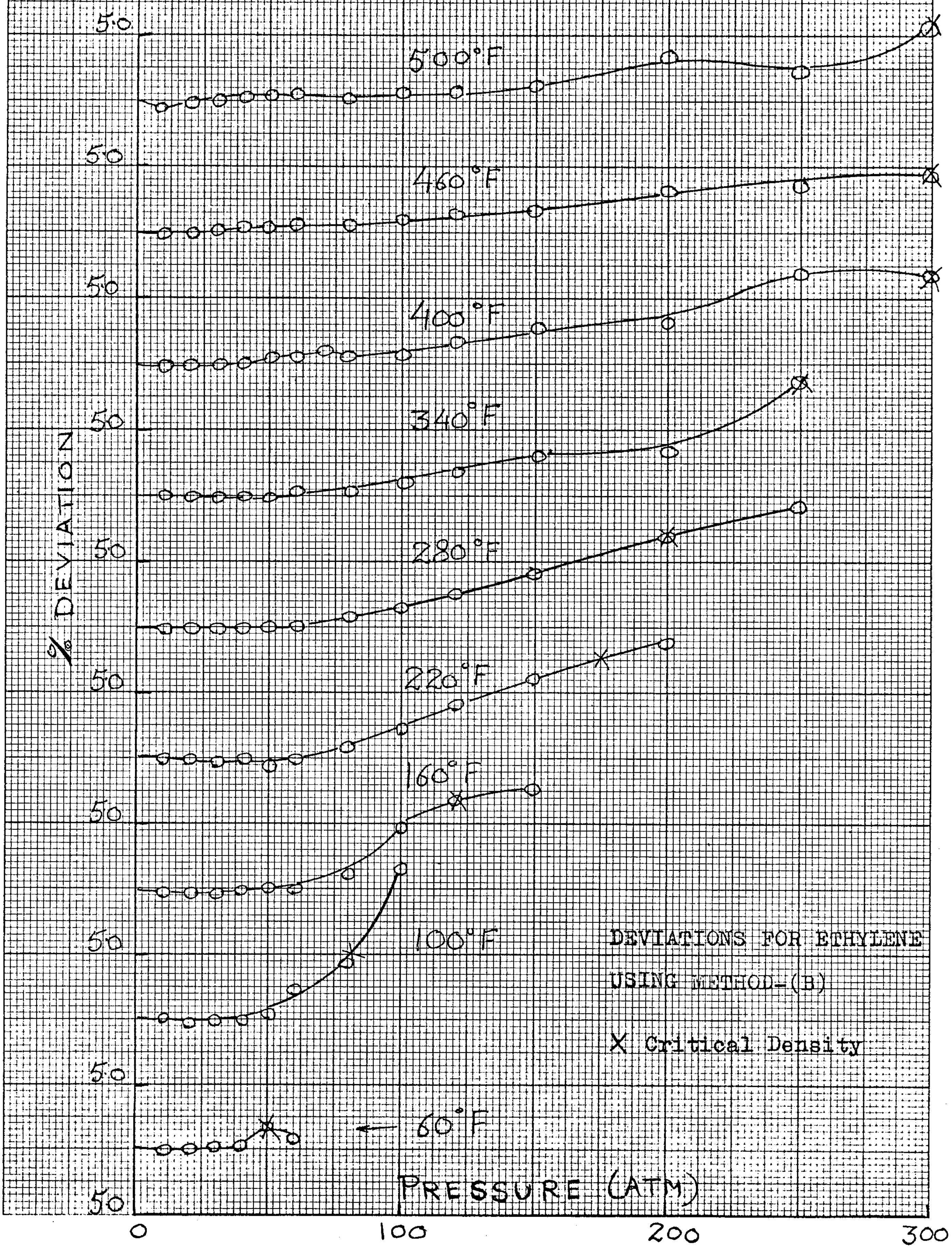
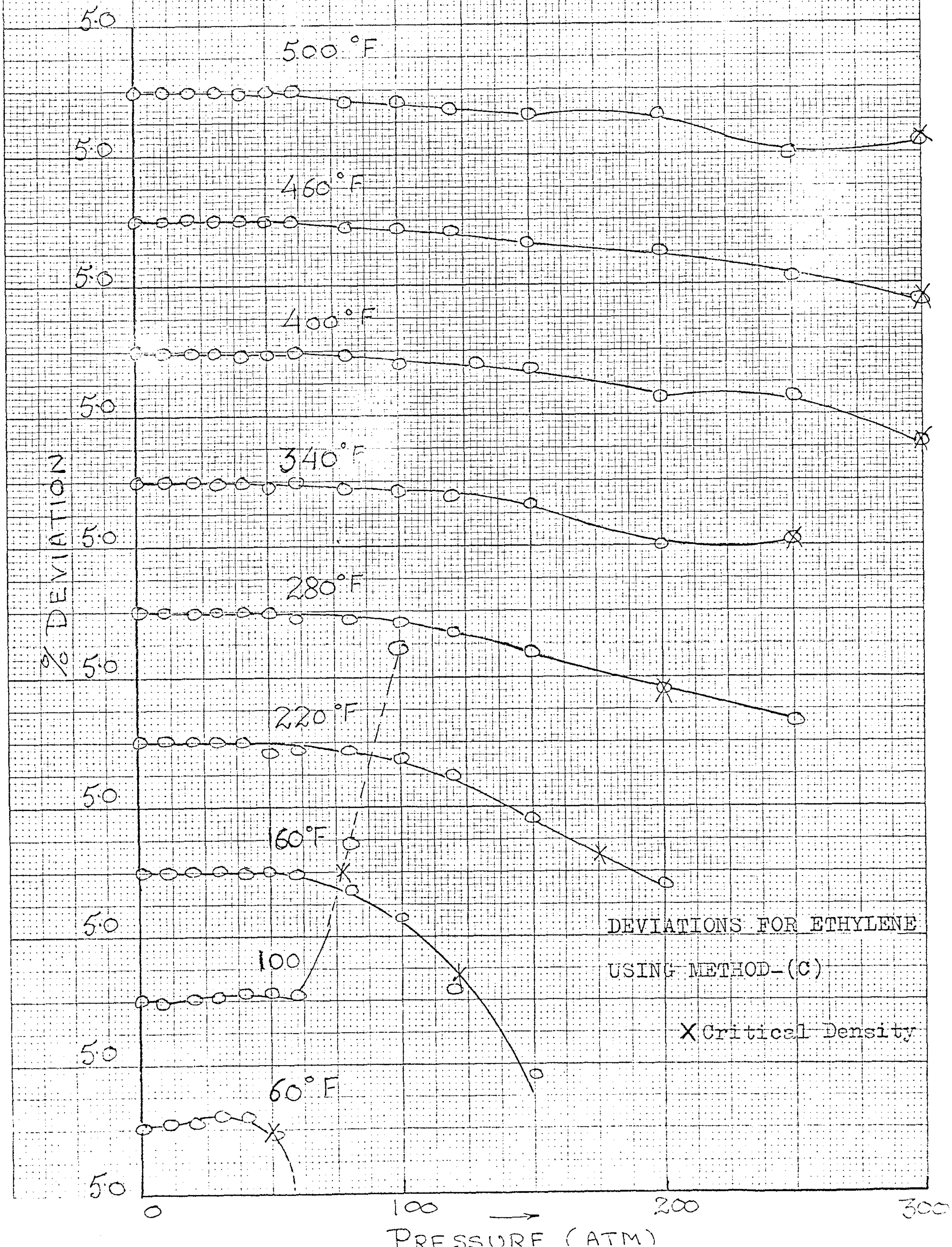

% DEVIATION
5.0
500°F
5.0
460°F
5.0
400°F
5.0
340°F
5.0
280°F
5.0
220°F
160°F
5.0
5.0
100°F
5.0
← 60°F
5.0
PRESSURE (ATM)
0
100
200
300
DEVIATIONS FOR ETHYLENE
USING METHOD-(B)
X Critical Density

FIGURE No. 11


5·0
500 °F
5·0
460° F
5·0
400 °F
5·0
340 °F
5·0
280 °F
5·0
220 °F
5·0
160 °F
5·0
100
5·0
60° F
5·0
% DEVIATION
0
100
200
300
PRESSURE (ATM)
DEVIATIONS FOR ETHYLENE
USING METHOD-(C)
X Critical Density

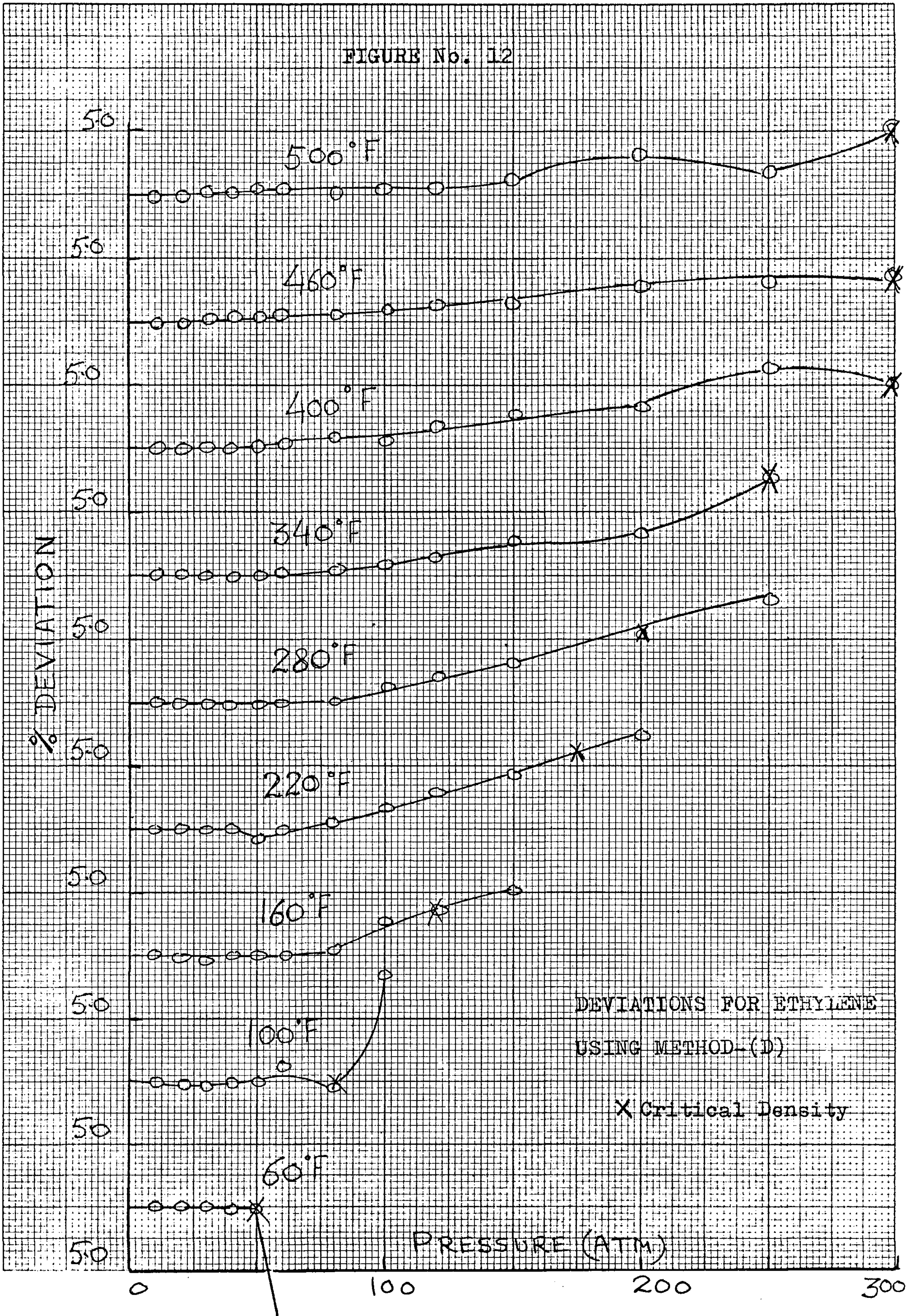
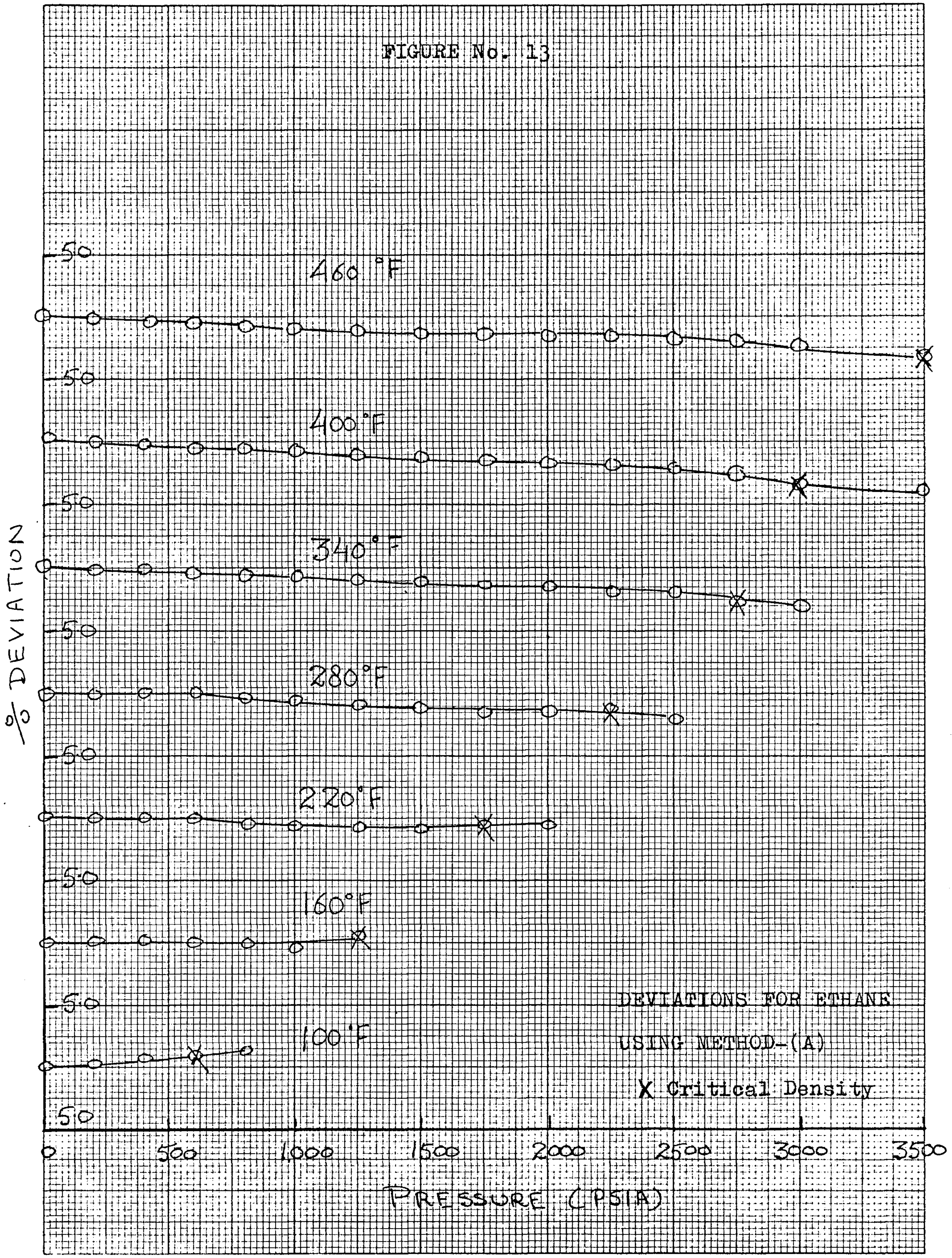


FIGURE No. 12

DEVIATIONS FOR ETHYLENE USING METHOD-(D)

FIGURE No. 13

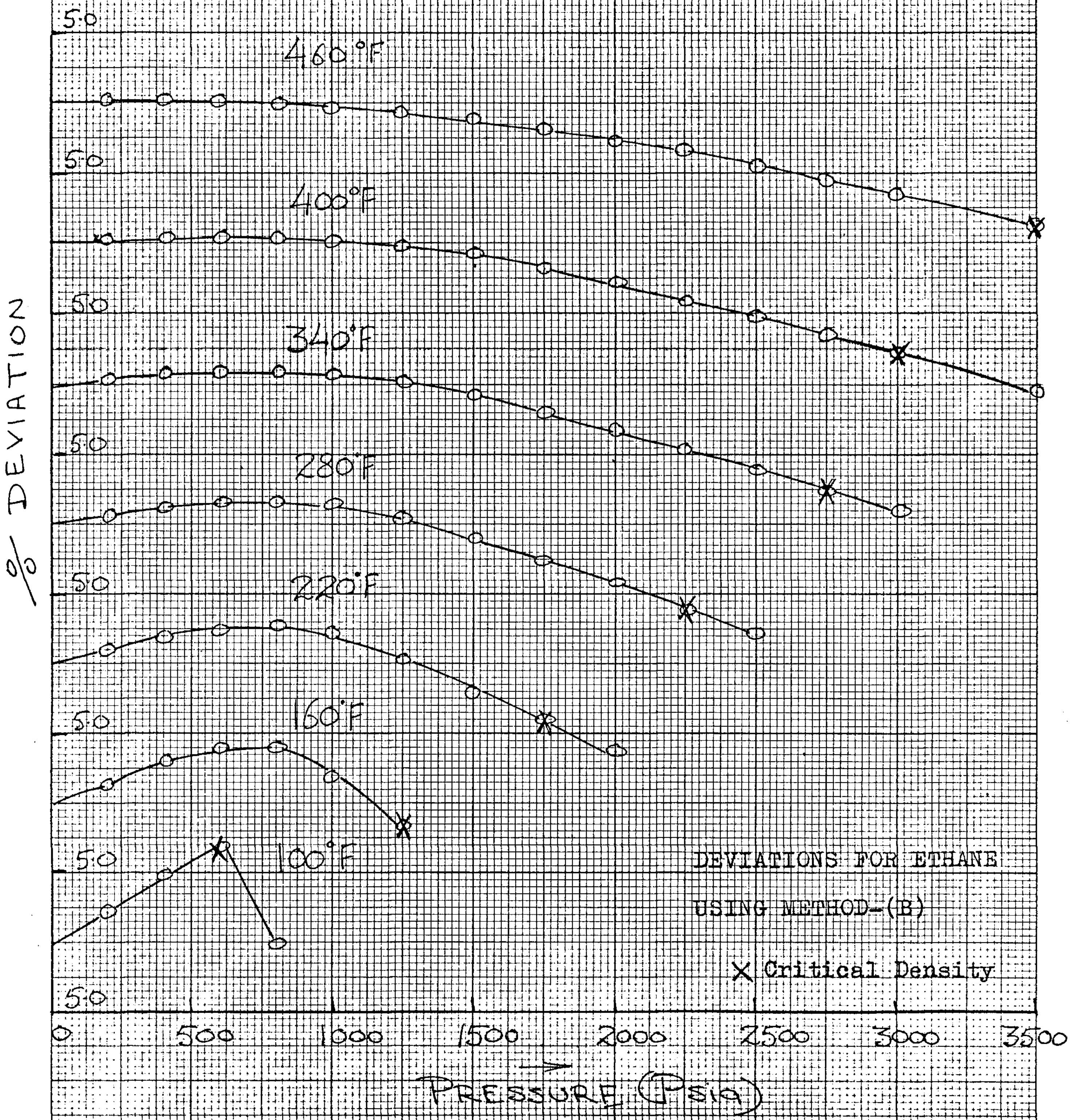


DEVIATIONS FOR ETHANE

USING METHOD-(A)

X Critical Density

FIGURE No. 14



DEVIATIONS FOR ETHANE USING METHOD-(B)

FIGURE No. 15

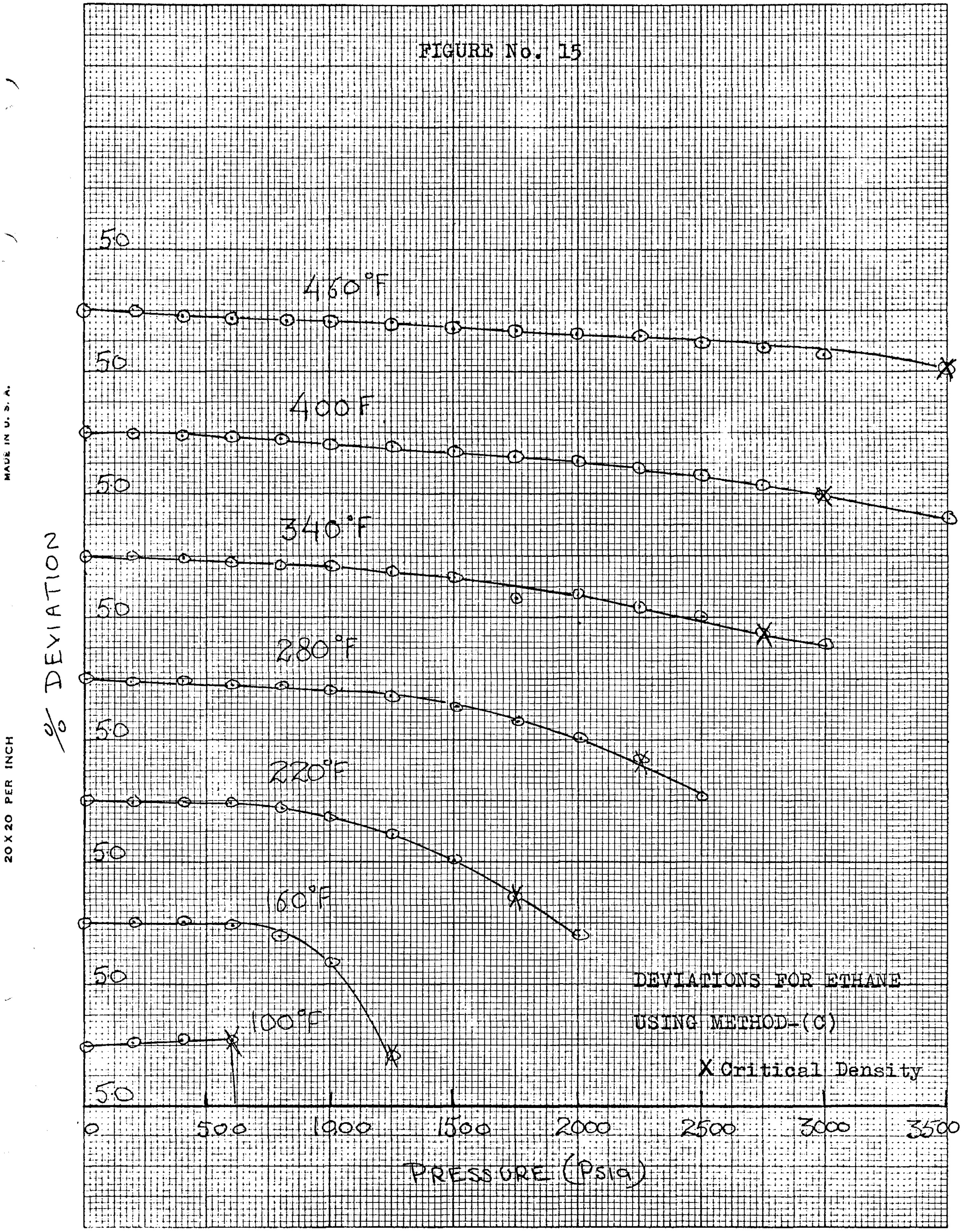
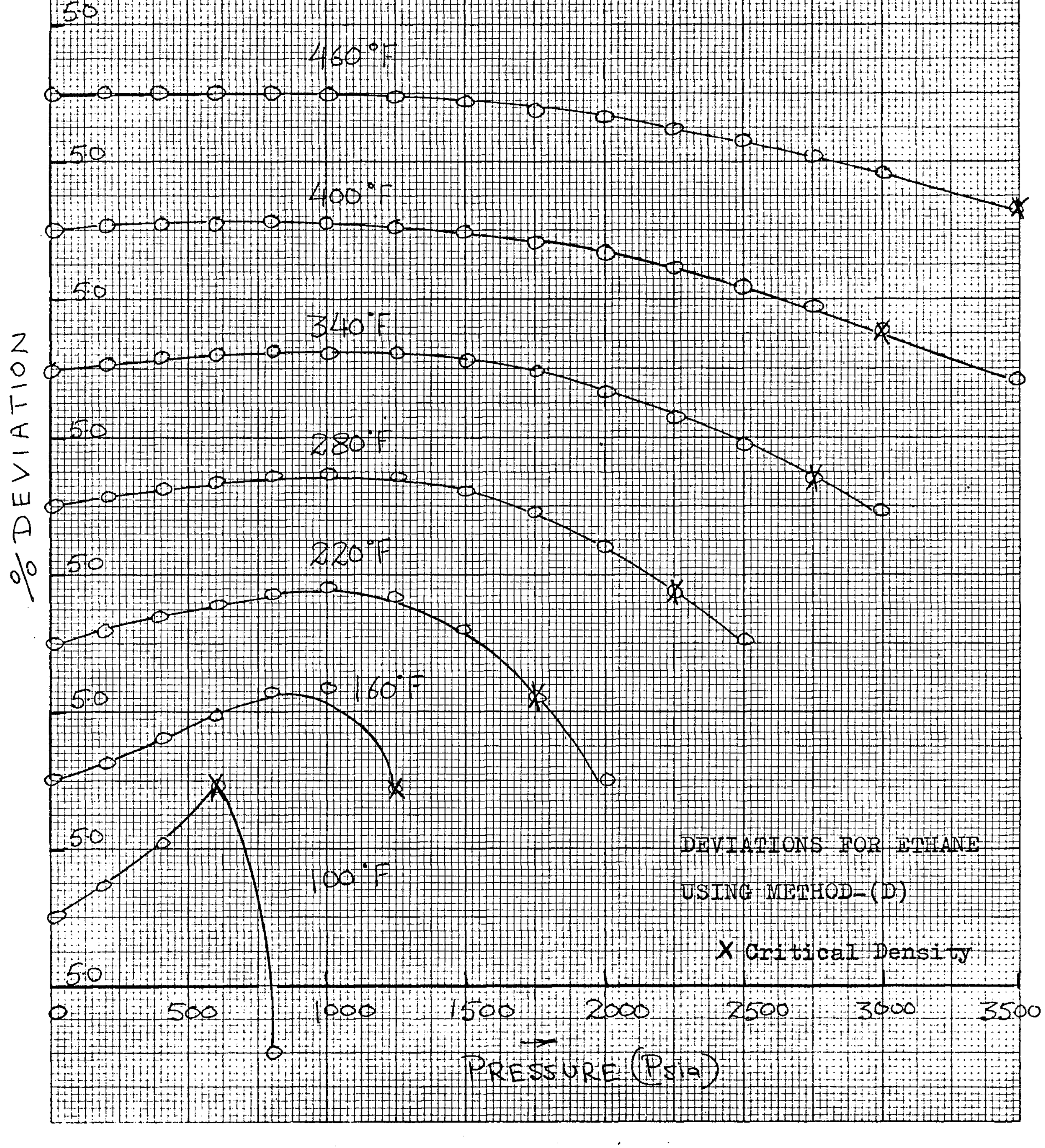

460°F
400 F
340°F
280°F
220°F
60°F
100°F
50
50
50
50
50
50
50
50
% DEVIATION
0
500
1000
1500
2000
2500
3000
3500
PRESSURE (Psig)
DEVIATIONS FOR ETHANE
USING METHOD-(C)
X Critical Density
20 X 20 PER INCH
MADE IN U. S. A.

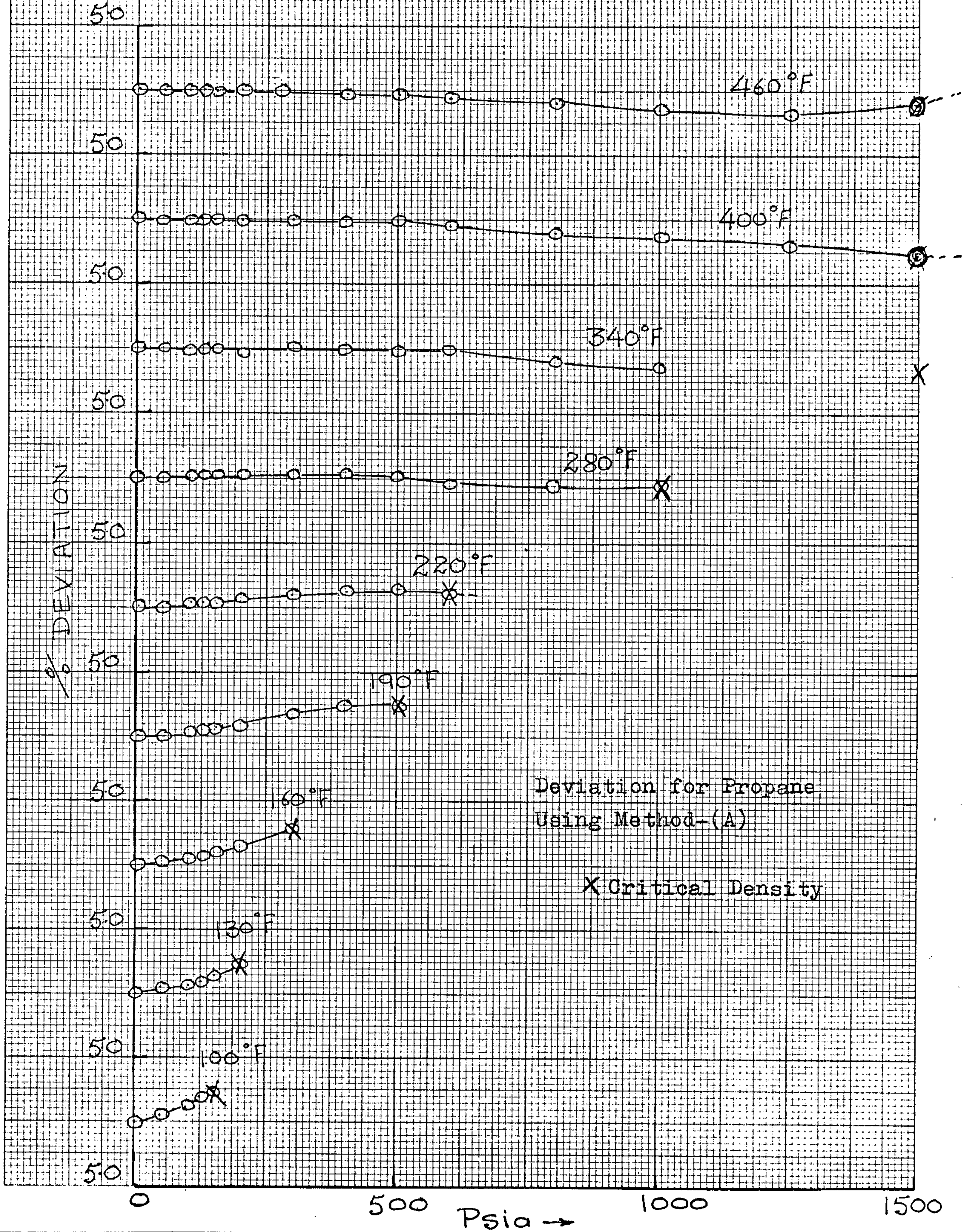
FIGURE NO. 16



DEVIATIONS FOR ETHANE
USING METHOD-(D)

X Critical Density

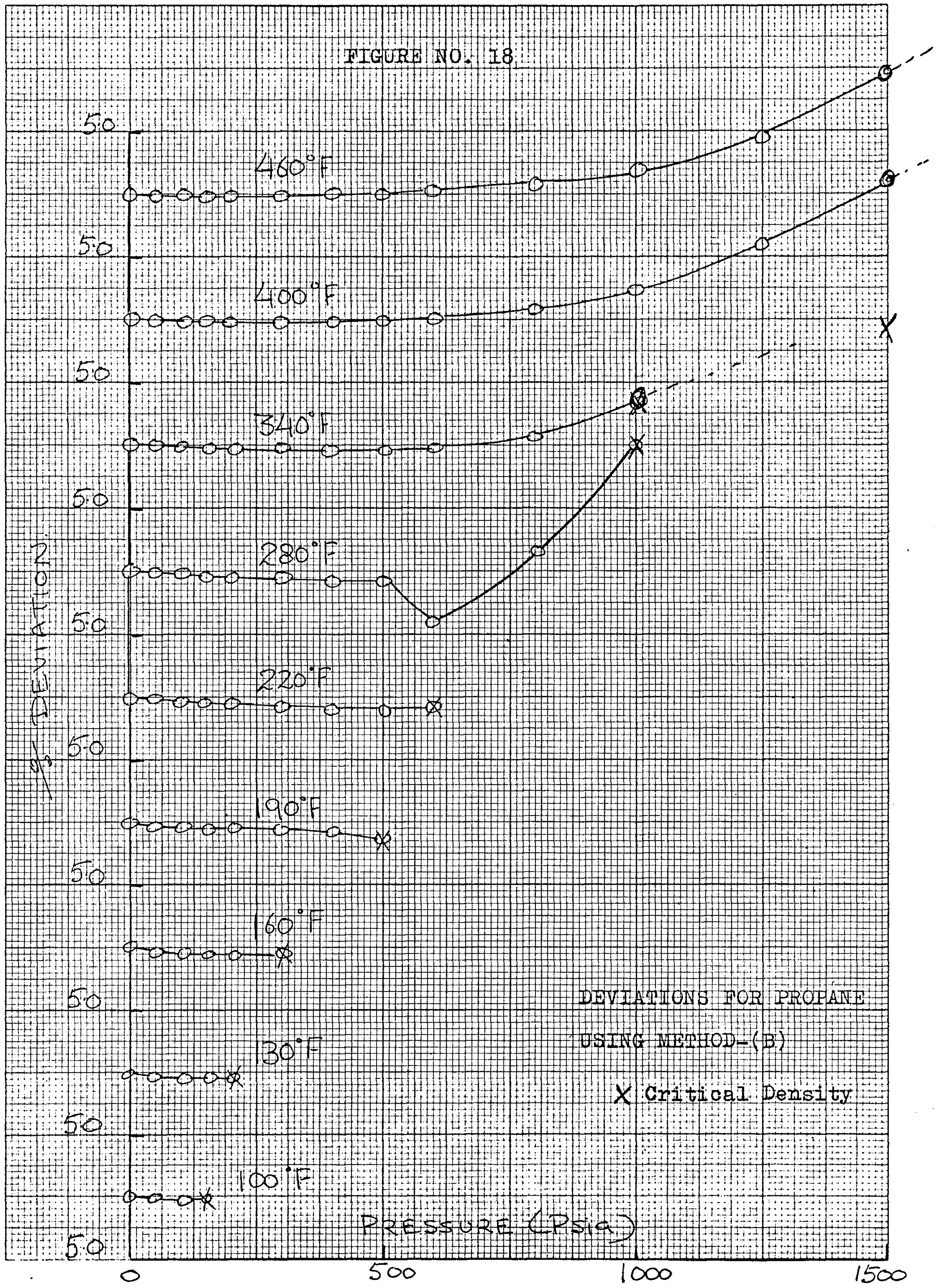
FIGURE No. 17



Deviation for Propane
Using Method-(A)

X Critical Density

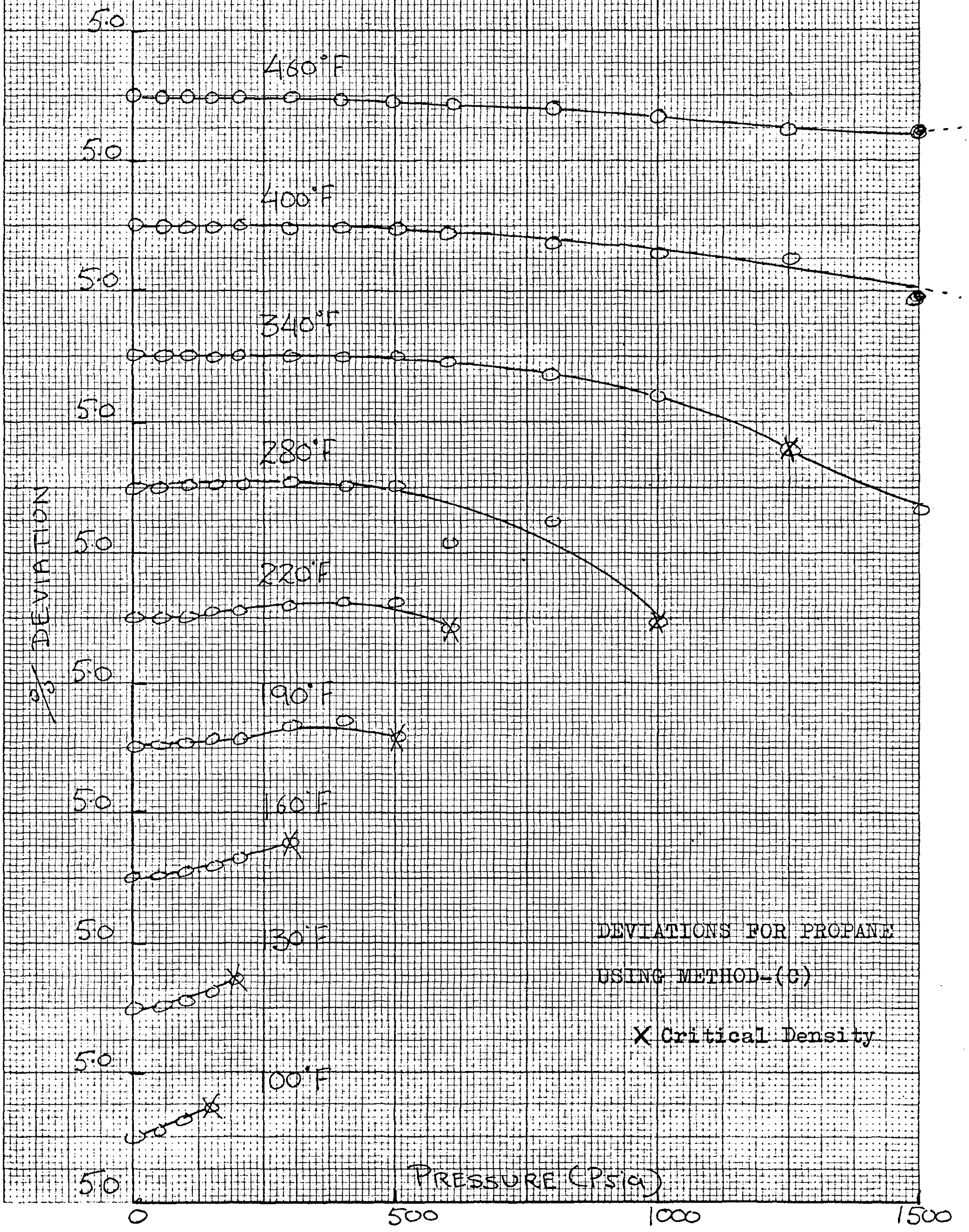
FIGURE NO. 18



DEVIATIONS FOR PROPANE

USING METHOD-(B)

FIGURE NO. 19


DEVIATIONS FOR PROPANE USING METHOD-(C)

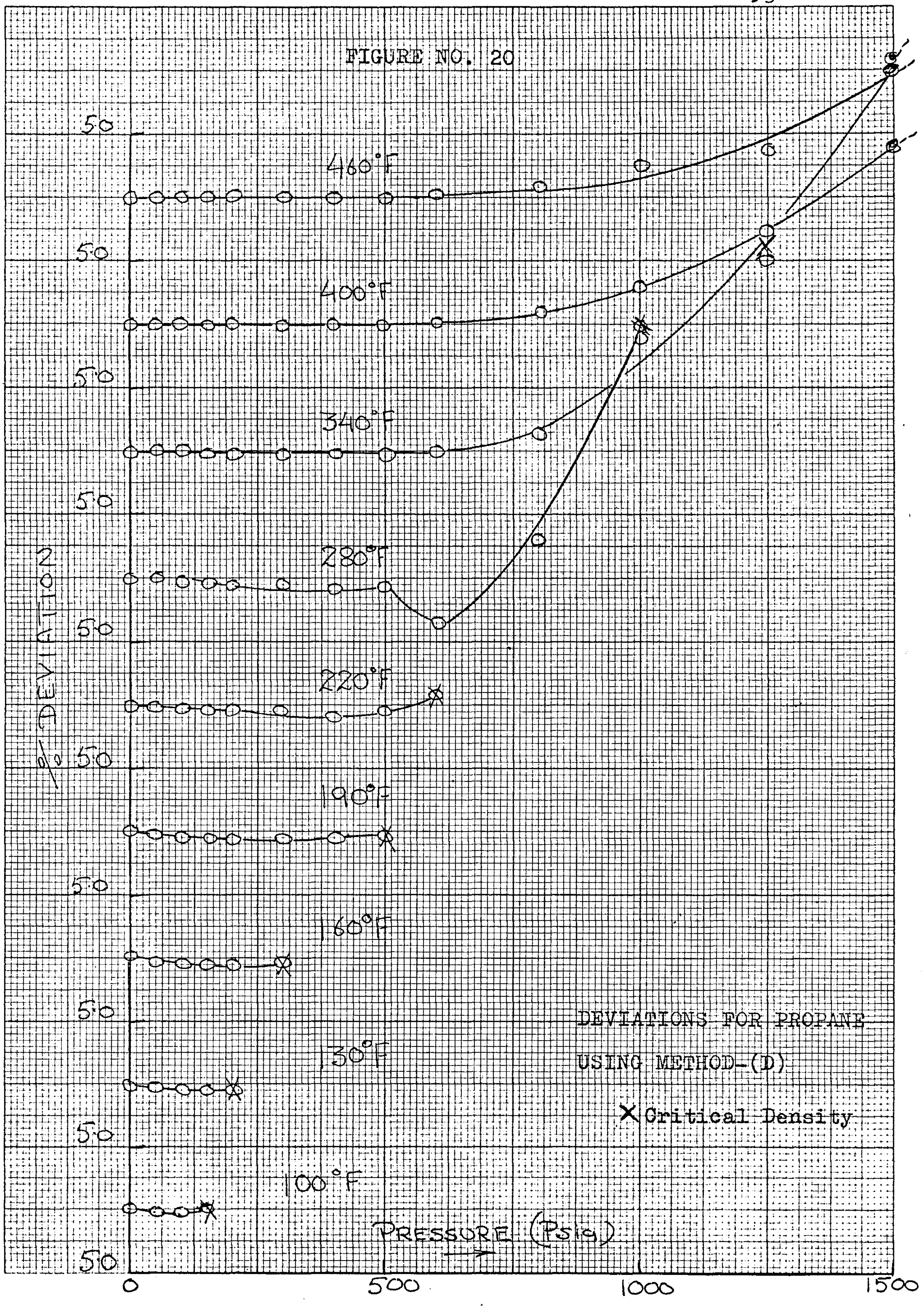
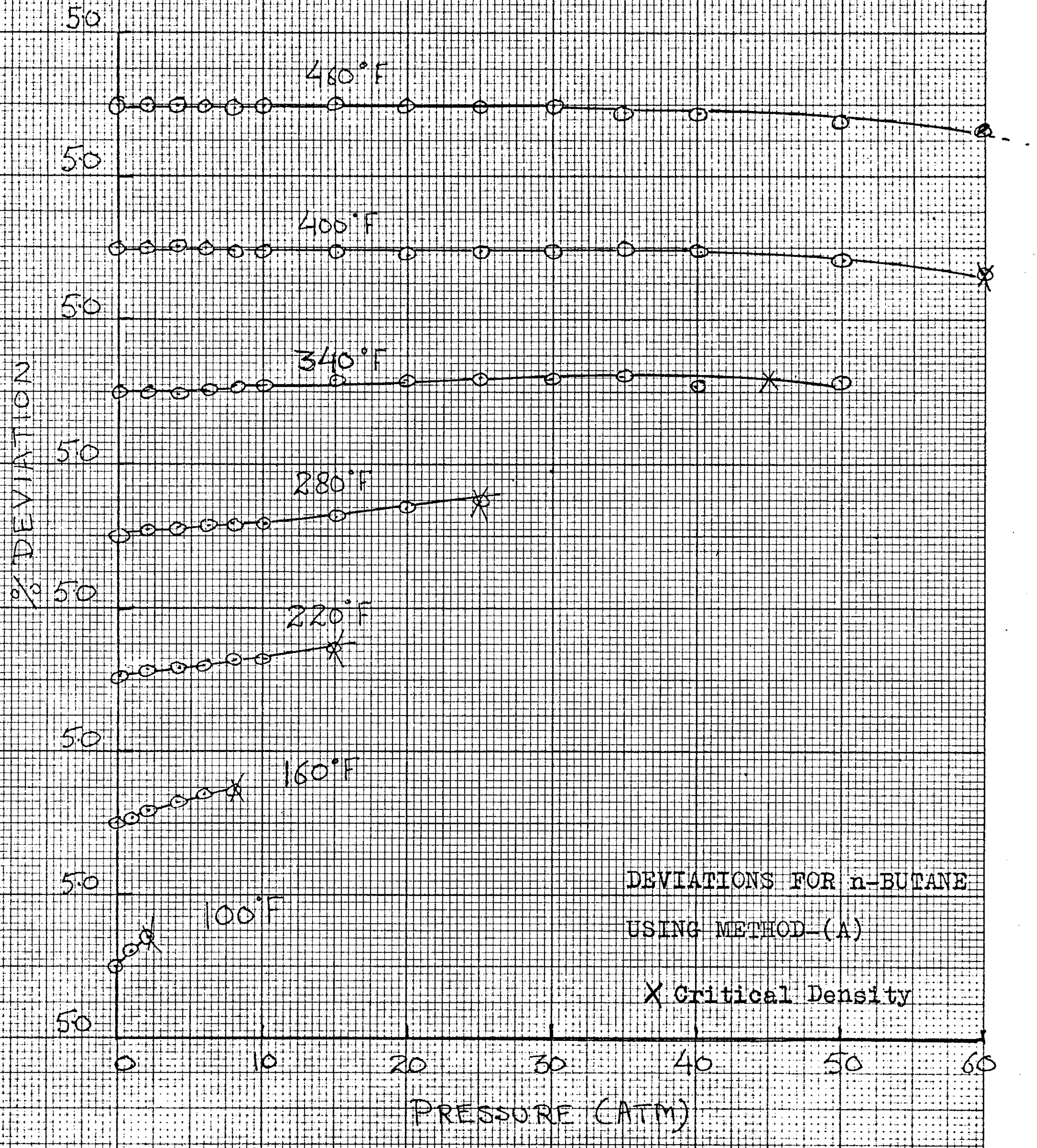


FIGURE NO. 20

DEVIATIONS FOR PROPANE USING METHOD-(D)

FIGURE NO. 21



DEVIATIONS FOR n-BUTANE USING METHOD-(A)

FIGURE NO. 22

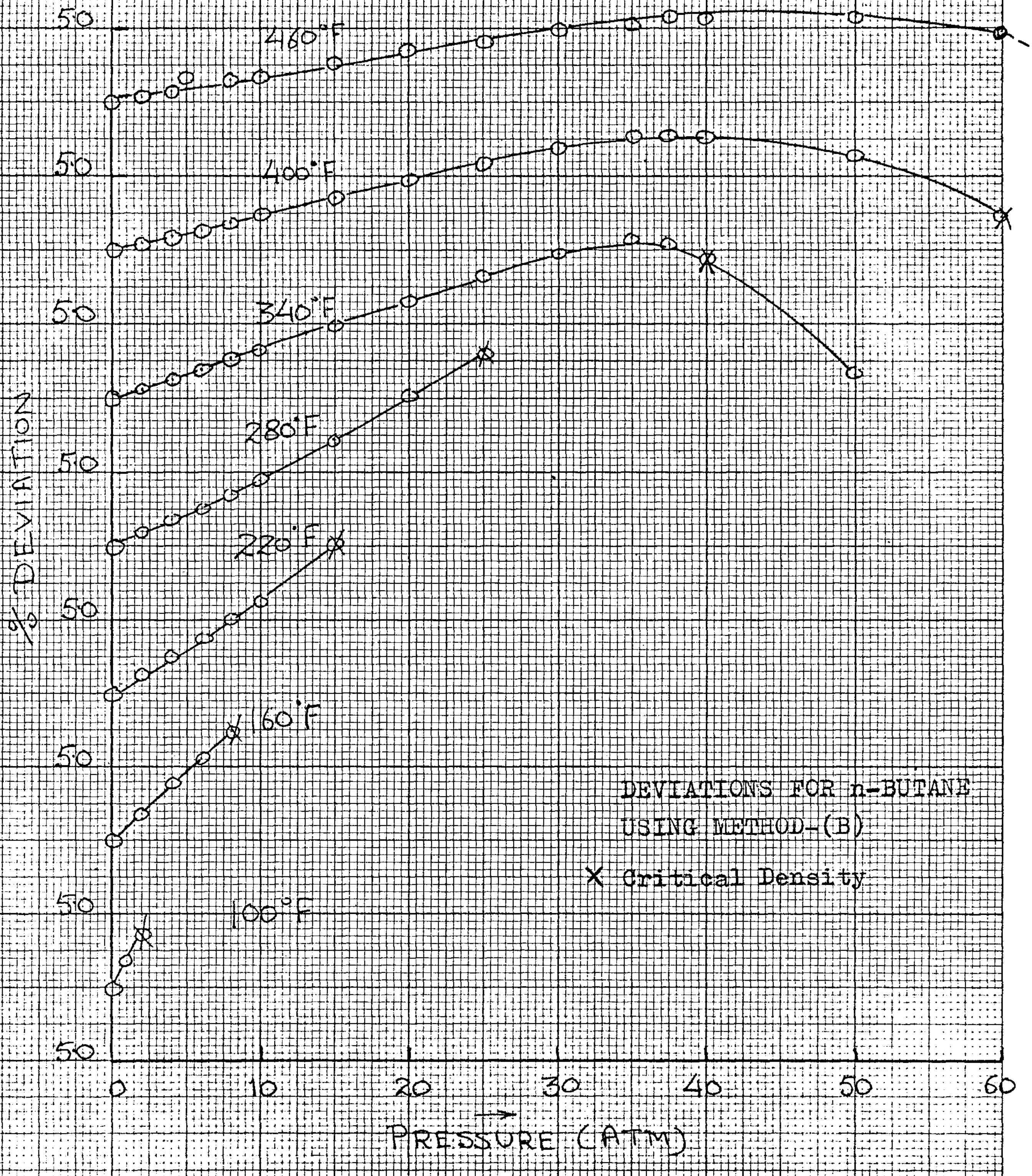
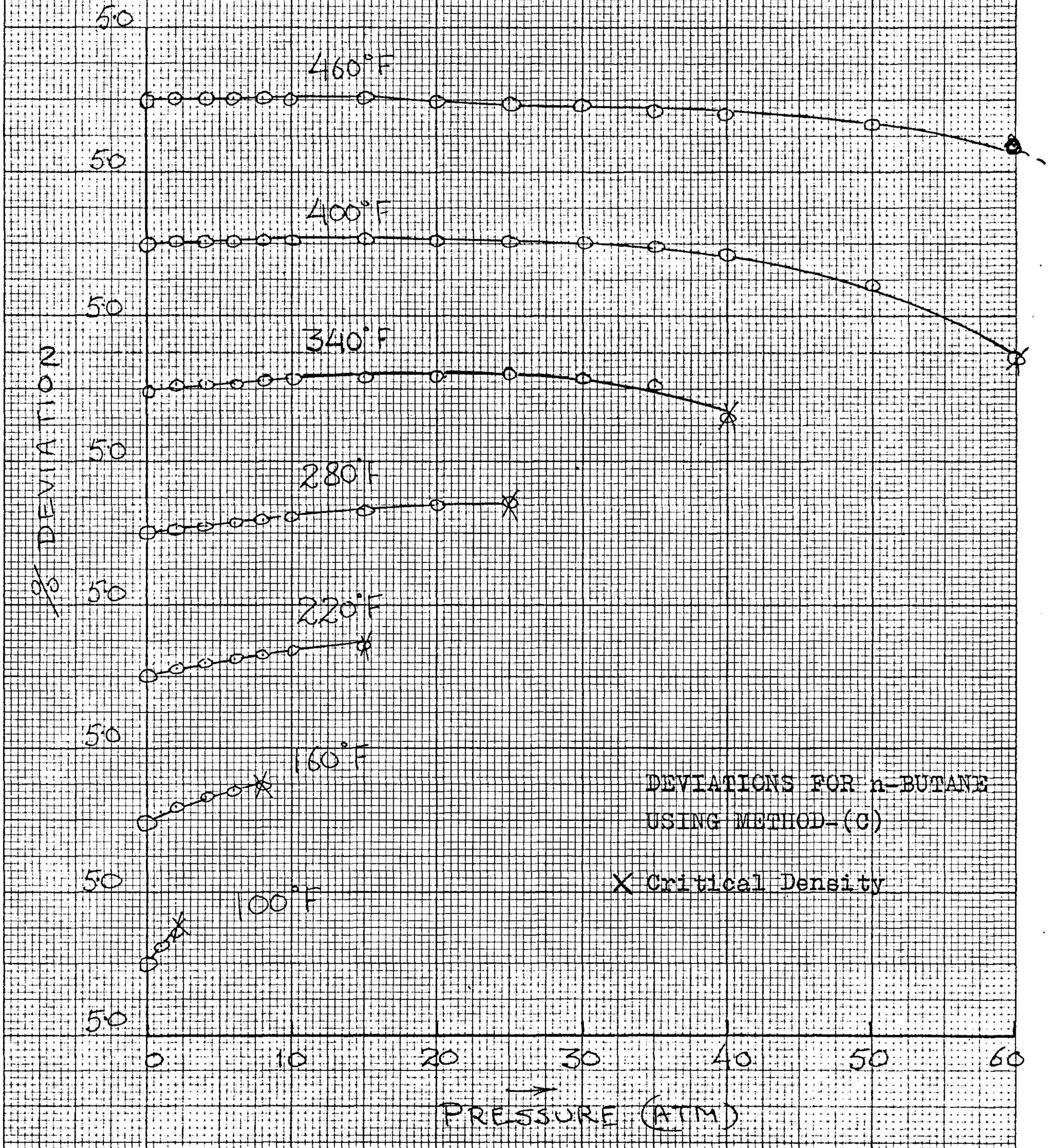

460°F
400°F
340°F
280°F
220°F
160°F
100°F
50
50
50
50
50
50
50
50
% DEVIATION
0
10
20
30
40
50
60
PRESSURE (ATM)
DEVIATIONS FOR n-BUTANE
USING METHOD-(B)
X Critical Density

FIGURE NO. 23



DEVIATIONS FOR n-BUTANE USING METHOD-(C)

FIGURE NO. 24

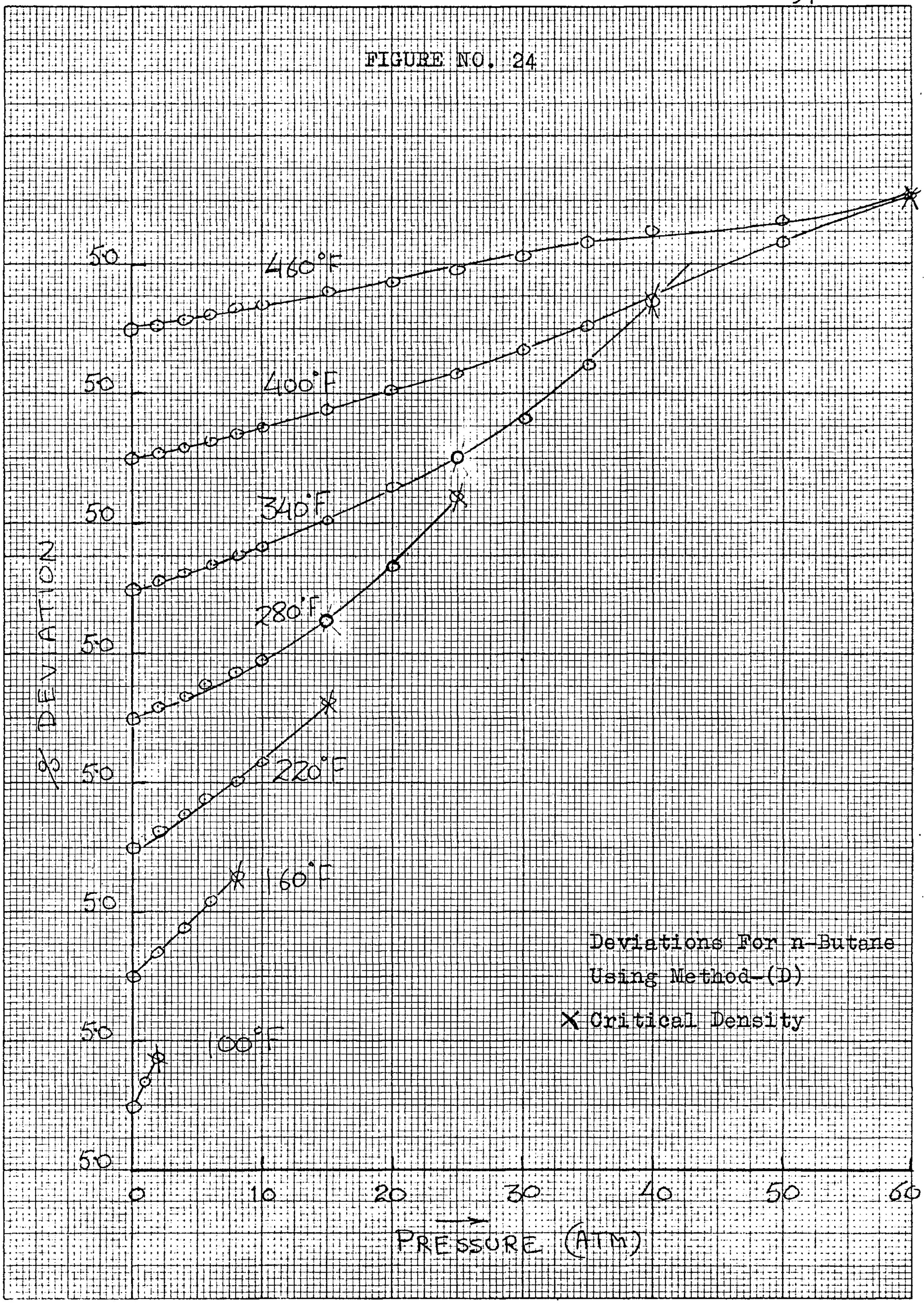

460°F
400°F
340°F
280°F
220°F
160°F
100°F
50
50
50
50
50
50
50
50
% DEVIATION
0
10
20
30
40
50
60
PRESSURE (ATM)
Deviations For n-Butane
Using Method-(D)
X Critical Density

TABLE V

SUMMARY OF CALCULATIONS FOR ETHYLENE USING METHOD-A*

Temperature: 60.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$**	$Z_{cal.}$	% Dev.
1.0	13.453	0.9946	0.9940	-0.06
2.0	6.683	0.9882	0.9880	-0.02
4.0	3.297	0.9750	0.9758	+0.08
6.0	2.168	0.9617	0.9633	+0.17
8.0	1.604	0.9487	0.9506	+0.20
10.0	1.264	0.9345	0.9375	+0.32
15.0	0.811	0.8994	0.9036	+0.47
20.0	0.583	0.8620	0.8673	+0.61
25.0	0.443	0.8188	0.8277	+1.09
30.0	0.350	0.7763	0.7852	+1.15
35.0	0.281	0.7271	0.7374	+1.42
40.0	0.228	0.6743	0.6838	+1.41
50.0	0.138	0.5101	0.5235	+2.63
60.0	0.069	0.3061	0.2990	-2.32

Temperature: 100.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$**	$Z_{cal.}$	% Dev.
1.0	14.510	0.9961	0.9952	-0.09
2.0	7.217	0.9909	0.9904	-0.05
4.0	3.571	0.9806	0.9806	0.00
6.0	2.356	0.9704	0.9707	+0.03
8.0	1.753	0.9627	0.9608	-0.20
10.0	1.382	0.9487	0.9505	+0.19
15.0	0.897	0.9237	0.9244	+0.08
20.0	0.652	0.8952	0.8972	+0.22

* Method-A: $Z_{cal.}$ is obtained using the equation (8) and also using generalized form for the force constants.

** $Z_{exp.}$ observed in reference (20), York, R., White, E. F., Trans. Am. Inst. Chem. Engrs., Vol. 40, 1944; p. 227-245.

TABLE V (CONTINUED)

Temperature: 100.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
25.0	0.504	0.8650	0.8685	+0.22
30.0	0.405	0.8341	0.8385	+0.40
35.0	0.333	0.8001	0.8065	+0.53
40.0	0.279	0.7661	0.7729	+0.80
50.0	0.201	0.6899	0.6982	+1.20
60.0	0.144	0.5931	0.6068	+2.31
80.0	0.082	0.4503	0.4512	+0.20
100.0	0.057	0.3913	0.3933	+0.51

Temperature: 160.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	16.090	0.9976	0.9965	-0.11
2.0	8.015	0.9939	0.9930	-0.09
4.0	3.978	0.9866	0.9859	-0.07
6.0	2.633	0.9795	0.9787	-0.08
8.0	1.960	0.9722	0.9715	-0.07
10.0	1.556	0.9647	0.9643	-0.04
15.0	1.108	0.9468	0.9459	-0.10
20.0	0.748	0.9275	0.9271	-0.04
25.0	0.585	0.9068	0.9078	+0.11
30.0	0.478	0.8891	0.8884	-0.08
35.0	0.399	0.8659	0.8680	+0.24
40.0	0.341	0.8457	0.8477	+0.24
50.0	0.259	0.8029	0.8055	+0.32
60.0	0.205	0.7626	0.7629	+0.04
80.0	0.137	0.6795	0.6777	-0.26
100.0	0.097	0.6014	0.6050	+0.60
120.0	0.077	0.5729	0.5704	-0.44
150.0	0.062	0.5766	0.5578	-3.26

TABLE V (CONTINUED)

Temperature: 220.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	17.660	0.9983	0.9974	-0.09
2.0	8.808	0.9958	0.9948	-0.10
4.0	4.380	0.9904	0.9895	-0.09
6.0	2.905	0.9853	0.9842	-0.11
8.0	2.167	0.9800	0.9790	-0.10
10.0	1.724	0.9746	0.9736	-0.10
15.0	1.134	0.9615	0.9603	-0.12
20.0	0.838	0.9474	0.9468	-0.06
25.0	0.661	0.9341	0.9333	-0.08
30.0	0.543	0.9208	0.9197	-0.12
35.0	0.458	0.9062	0.9059	-0.03
40.0	0.395	0.8931	0.8922	-0.10
50.0	0.309	0.8734	0.8657	-0.88
60.0	0.248	0.8411	0.8377	-0.40
80.0	0.174	0.7869	0.7845	-0.30
100.0	0.131	0.7405	0.7379	-0.35
120.0	0.104	0.7055	0.7029	-0.37
150.0	0.081	0.6868	0.6776	-1.34
200.0	0.062	0.7010	0.6792	-3.11

Temperature: 280.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	19.230	0.9989	0.9980	-0.09
2.0	9.600	0.9973	0.9961	-0.12
4.0	4.781	0.9934	0.9921	-0.13
6.0	3.174	0.9892	0.9882	-0.10
8.0	2.371	0.9853	0.9843	-0.10
10.0	1.889	0.9812	0.9803	-0.09
15.0	1.247	0.9716	0.9705	-0.11
20.0	0.925	0.9620	0.9607	-0.14

TABLE V (CONTINUED)

Temperature: 280.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
25.0	0.733	0.9519	0.9508	-0.12
30.0	0.605	0.9428	0.9411	-0.18
35.0	0.514	0.9345	0.9314	-0.33
40.0	0.445	0.9246	0.9217	-0.31
50.0	0.348	0.9038	0.9025	-0.14
60.0	0.285	0.8882	0.8841	-0.46
80.0	0.205	0.8519	0.8485	-0.40
100.0	0.158	0.8207	0.8173	-0.41
120.0	0.128	0.7978	0.7923	-0.69
150.0	0.100	0.7791	0.7687	-1.33
200.0	0.075	0.7791	0.7619	-2.21
250.0	0.062	0.8051	0.7790	-3.24

Temperature: 340.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	20.800	0.9994	0.9985	-0.09
2.0	10.390	0.9984	0.9970	-0.14
4.0	5.178	0.9951	0.9941	-0.10
6.0	3.442	0.9922	0.9911	-0.11
8.0	2.573	0.9890	0.9882	-0.08
10.0	2.053	0.9864	0.9852	-0.12
15.0	1.359	0.9794	0.9779	-0.15
20.0	1.012	0.9724	0.9706	-0.18
25.0	0.803	0.9645	0.9634	-0.11
30.0	0.664	0.9571	0.9562	-0.09
35.0	0.566	0.9518	0.9493	-0.26
40.0	0.491	0.9436	0.9422	-0.15
50.0	0.389	0.9345	0.9289	-0.60
60.0	0.318	0.9167	0.9154	-0.14

TABLE V (CONTINUED)

Temperature: 340.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
80.0	0.233	0.8956	0.8912	-0.49
100.0	0.182	0.8744	0.8698	-0.53
120.0	0.149	0.8591	0.8524	-0.78
150.0	0.117	0.8432	0.8346	-1.02
200.0	0.089	0.8552	0.8268	-3.32
250.0	0.071	0.8528	0.8408	-1.41

Temperature: 400.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	22.370	0.9998	0.9989	-0.09
2.0	11.170	0.9984	0.9978	-0.06
4.0	5.575	0.9966	0.9955	-0.11
6.0	3.702	0.9927	0.9932	+0.05
8.0	2.775	0.9922	0.9911	-0.11
10.0	2.215	0.9899	0.9889	-0.10
15.0	1.469	0.9848	0.9834	-0.14
20.0	1.096	0.9797	0.9781	-0.16
25.0	0.872	0.9743	0.9728	-0.15
30.0	0.722	0.9680	0.9675	-0.05
35.0	0.617	0.9651	0.9624	-0.28
40.0	0.537	0.9600	0.9574	-0.27
50.0	0.425	0.9497	0.9476	-0.22
60.0	0.350	0.9385	0.9382	-0.03
80.0	0.258	0.9225	0.9211	-0.15
100.0	0.205	0.9162	0.9070	-1.00
120.0	0.168	0.9010	0.8949	-0.68
150.0	0.133	0.8916	0.8829	-0.98

TABLE V (CONTINUED)

Temperature: 400.0 F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
200.0	0.101	0.9028	0.8778	-2.77
250.0	0.081	0.9050	0.8889	-1.78
300.0	0.071	0.9520	0.9062	-4.81

Temperature: 460.0°F

1.0	23.940	1.0001	0.9992	-0.09
2.0	11.960	0.9993	0.9983	-0.10
4.0	5.970	0.9976	0.9967	-0.09
6.0	3.973	0.9959	0.9950	-0.09
8.0	2.975	0.9943	0.9934	-0.09
10.0	2.376	0.9926	0.9917	-0.09
15.0	1.577	0.9882	0.9877	-0.05
20.0	1.178	0.9843	0.9837	-0.06
25.0	0.938	0.9797	0.9798	+0.01
30.0	0.779	0.9763	0.9760	-0.03
35.0	0.665	0.9724	0.9723	-0.01
40.0	0.579	0.9676	0.9686	+0.10
50.0	0.461	0.9630	0.9618	-0.12
60.0	0.381	0.9550	0.9551	+0.01
80.0	0.284	0.9492	0.9436	-0.59
100.0	0.225	0.9400	0.9338	-0.66
120.0	0.186	0.9325	0.9261	-0.69
150.0	0.149	0.9337	0.9190	-1.57
200.0	0.112	0.9358	0.9174	-1.97
250.0	0.092	0.9609	0.9267	-3.56
300.0	0.079	0.9901	0.9438	-4.67

TABLE V (CONTINUED)

Temperature: 500.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	24.990	1.0004	0.9993	-0.11
2.0	12.480	0.9993	0.9986	-0.07
4.0	6.234	0.9983	0.9973	-0.10
6.0	4.150	0.9969	0.9959	-0.10
8.0	3.125	1.0009	0.9946	-0.63
10.0	2.483	0.9941	0.9932	-0.09
15.0	1.650	0.9909	0.9900	-0.09
20.0	1.233	0.9873	0.9868	-0.05
25.0	0.983	0.9839	0.9836	-0.03
30.0	0.817	0.9813	0.9806	-0.07
35.0	0.698	0.9781	0.9776	-0.05
40.0	0.609	0.9753	0.9747	-0.06
50.0	0.484	0.9689	0.9692	+0.03
60.0	0.402	0.9657	0.8642	-0.16
80.0	0.301	0.9641	0.9554	-0.90
100.0	0.239	0.9569	0.9480	-0.93
120.0	0.199	0.9560	0.9426	-1.40
150.0	0.159	0.9549	0.9378	-1.79
200.0	0.119	0.9528	0.9389	-1.46
250.0	0.099	0.9909	0.9477	-4.36
300.0	0.083	0.9969	0.9669	-3.01

TABLE VI

SUMMARY OF CALCULATIONS FOR ETHYLENE USING METHOD-B*

Temperature: 60.0°F

Pressure atm.	Volume cu.ft./lb.	$Z^{**}_{exp.}$	$Z_{cal.}$	% Dev.
1.0	13.453	0.9946	0.9937	-0.09
2.0	6.683	0.9882	0.9872	-0.10
4.0	3.297	0.9750	0.9743	-0.07
6.0	2.168	0.9617	0.9610	-0.07
8.0	1.604	0.9487	0.9476	-0.12
10.0	1.264	0.9345	0.9338	-0.08
15.0	0.811	0.8994	0.8983	-0.12
20.0	0.583	0.8620	0.8606	-0.16
25.0	0.443	0.8188	0.8198	+0.12
30.0	0.350	0.7763	0.7764	+0.01
35.0	0.281	0.7271	0.7281	+0.14
40.0	0.228	0.6743	0.6747	+0.06
50.0	0.138	0.5101	0.5192	+1.78
60.0	0.069	0.3061	0.3086	+0.82

Temperature: 100.0°F

1.0	14.510	0.9961	0.9949	-0.12
2.0	7.217	0.9909	0.9898	-0.11
4.0	3.571	0.9806	0.9795	-0.11
6.0	2.356	0.9704	0.9691	-0.13
8.0	1.753	0.9627	0.9587	-0.42
10.0	1.382	0.9487	0.9478	-0.09
15.0	0.897	0.9237	0.9207	-0.32
20.0	0.652	0.8952	0.8924	-0.31

* Method-B: $Z_{cal.}$ is obtained using equation (8) and also using established force constants.

** $Z_{exp.}$ observed in reference (20), York, R. and White, E. F., Trans. Am. Inst. Chem. Engrs., Vol. 40, 1944; p. 227-245.

TABLE VI (CONTINUED)

Temperature: 100.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
25.0	0.504	0.8650	0.8630	-0.23
30.0	0.405	0.8341	0.8325	-0.19
35.0	0.333	0.8001	0.8002	+0.01
40.0	0.279	0.7661	0.7668	+0.09
50.0	0.201	0.6899	0.6938	+0.57
60.0	0.144	0.5931	0.6076	+2.45
80.0	0.082	0.4503	0.4709	+4.57
100.0	0.057	0.3913	0.4366	+11.58

Temperature: 160.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	16.090	0.9976	0.9963	-0.13
2.0	8.015	0.9939	0.9926	-0.13
4.0	3.978	0.9866	0.9852	-0.14
6.0	2.633	0.9795	0.9778	-0.17
8.0	1.960	0.9722	0.9703	-0.20
10.0	1.556	0.9647	0.9627	-0.21
15.0	1.108	0.9468	0.9438	-0.32
20.0	0.748	0.9275	0.9245	-0.32
25.0	0.585	0.9068	0.9049	-0.21
30.0	0.478	0.8891	0.8854	-0.42
35.0	0.399	0.8659	0.8651	-0.09
40.0	0.341	0.8457	0.8450	-0.08
50.0	0.259	0.8029	0.8041	+0.15
60.0	0.205	0.7626	0.7639	+0.17
80.0	0.137	0.6795	0.6878	+1.22
100.0	0.097	0.6014	0.6306	+4.86
120.0	0.077	0.5729	0.6117	+6.78
150.0	0.062	0.5766	0.6205	+7.62

TABLE VI (CONTINUED)

Temperature: 220.0°F

Pressure atm.	Volume cu.ft./lb	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	17.660	0.9983	0.9973	-0.10
2.0	8.808	0.9958	0.9946	-0.12
4.0	4.380	0.9904	0.9892	-0.12
6.0	2.905	0.9853	0.9838	-0.15
8.0	2.167	0.9800	0.9783	-0.17
10.0	1.724	0.9746	0.9729	-0.17
15.0	1.134	0.9615	0.9594	-0.22
20.0	0.838	0.9474	0.9458	-0.17
25.0	0.661	0.9341	0.9323	-0.19
30.0	0.543	0.9208	0.9188	-0.22
35.0	0.458	0.9062	0.9053	-0.10
40.0	0.395	0.8931	0.8920	-0.12
50.0	0.309	0.8734	0.8667	-0.77
60.0	0.248	0.8411	0.8408	-0.04
80.0	0.174	0.7869	0.7940	+0.90
100.0	0.131	0.7405	0.7572	+2.26
120.0	0.104	0.7055	0.7348	+4.16
150.0	0.081	0.6868	0.7294	+6.20
200.0	0.062	0.7010	0.7643	+9.03

Temperature: 280.0°F

1.0	19.230	0.9989	0.9980	-0.09
2.0	9.600	0.9973	0.9960	-0.13
4.0	4.781	0.9934	0.9920	-0.14
6.0	3.174	0.9892	0.9880	-0.12
8.0	2.371	0.9853	0.9841	-0.12
10.0	1.889	0.9812	0.9801	-0.11
15.0	1.247	0.9716	0.9703	-0.13
20.0	0.926	0.9620	0.9606	-0.15

TABLE VI (CONTINUED)

Temperature: 280.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
25.0	0.733	0.9519	0.9509	-0.11
30.0	0.605	0.9428	0.9415	-0.14
35.0	0.514	0.9345	0.9322	-0.25
40.0	0.445	0.9246	0.9230	-0.17
50.0	0.348	0.9038	0.9051	+0.14
60.0	0.285	0.8882	0.8885	+0.03
80.0	0.205	0.8519	0.8582	+0.74
100.0	0.158	0.8207	0.8343	+1.68
120.0	0.128	0.7978	0.8186	+2.61
150.0	0.100	0.7791	0.8111	+4.11
200.0	0.075	0.7791	0.8338	+7.01
250.0	0.062	0.8051	0.8806	+9.38

Temperature: 340.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	20.800	0.9994	0.9985	-0.09
2.0	10.390	0.9984	0.9970	-0.14
4.0	5.178	0.9951	0.9941	-0.10
6.0	3.442	0.9922	0.9911	-0.11
8.0	2.573	0.9890	0.9882	-0.08
10.0	2.053	0.9864	0.9853	-0.11
15.0	1.359	0.9794	0.9781	-0.13
20.0	1.012	0.9724	0.9710	-0.14
25.0	0.803	0.9645	0.9640	-0.05
30.0	0.664	0.9571	0.9572	+0.01
35.0	0.565	0.9518	0.9507	-0.12
40.0	0.491	0.9436	0.9442	+0.06
50.0	0.389	0.9345	0.9321	-0.26
60.0	0.318	0.9167	0.9202	+0.38

TABLE VI (CONTINUED)

Temperature: 340.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
80.0	0.233	0.8956	0.9003	+0.52
100.0	0.182	0.8744	0.8848	+1.19
120.0	0.149	0.8591	0.8747	+1.82
150.0	0.117	0.8432	0.8699	+3.07
200.0	0.089	0.8552	0.8853	+3.52
250.0	0.071	0.8528	0.9287	+8.91

Temperature: 400.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	22.370	0.9998	0.9989	-0.09
2.0	11.170	0.9984	0.9978	-0.06
4.0	5.575	0.9966	0.9957	-0.09
6.0	3.702	0.9927	0.9936	+0.09
8.0	2.775	0.9922	0.9915	-0.07
10.0	2.215	0.9899	0.9894	-0.05
15.0	1.469	0.9848	0.9843	-0.05
20.0	1.096	0.9797	0.9793	-0.04
25.0	0.872	0.9743	0.9744	+0.01
30.0	0.722	0.9680	0.0607	+0.18
35.0	0.617	0.9651	0.9652	+0.01
40.0	0.537	0.9600	0.9608	+0.08
50.0	0.425	0.9497	0.9525	+0.30
60.0	0.350	0.9385	0.9448	+0.67
80.0	0.258	0.9225	0.9321	+1.04
100.0	0.205	0.9162	0.9233	+0.77
120.0	0.168	0.9010	0.9178	+1.86
150.0	01.33	0.8916	0.9173	+2.88

TABLE VI (CONTINUED)

Temperature: 400.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
200.0	0.101	0.9028	0.9331	+3.36
250.0	0.081	0.9050	0.9696	+7.15
300.0	0.071	0.9520	1.0073	+6.86

Temperature: 460.0°F

1.0	23.940	1.0001	0.9992	-0.09
2.0	11.960	0.9993	0.9984	-0.09
4.0	5.970	0.9976	0.9969	-0.07
6.0	3.973	0.9959	0.9954	-0.05
8.0	2.975	0.9943	0.9939	-0.04
10.0	2.376	0.9926	0.9924	-0.02
15.0	1.577	0.9882	0.9887	+0.05
20.0	1.178	0.9843	0.9852	+0.09
25.0	0.938	0.9797	0.9818	+0.21
30.0	0.779	0.9763	0.9786	+0.24
35.0	0.665	0.9724	0.9755	+0.32
40.0	0.579	0.9676	0.9725	+0.51
50.0	0.461	0.9630	0.9671	+0.43
60.0	0.381	0.9550	0.9622	+0.75
80.0	0.284	0.9492	0.9547	+0.58
100.0	0.225	0.9400	0.9499	+1.05
120.0	0.186	0.9325	0.9480	+1.66
150.0	0.149	0.9337	0.9504	+1.79
200.0	0.112	0.9358	0.9681	+3.45
250.0	0.092	0.9609	0.9971	+3.77
300.0	0.079	0.9901	1.0348	+4.52

TABLE VI (CONTINUED)

Temperature: 500.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	24.990	1.0004	0.9994	-0.10
2.0	12.480	0.9993	0.9988	-0.05
4.0	6.234	0.9983	0.9975	-0.08
6.0	4.150	0.9969	0.9963	-0.06
8.0	3.125	1.0009	0.9952	-0.57
10.0	2.483	0.9941	0.9940	-0.01
15.0	1.650	0.9909	0.9912	+0.03
20.0	1.233	0.9873	0.9885	+0.12
25.0	0.983	0.9839	0.9859	+0.20
30.0	0.817	0.9813	0.9834	+0.21
35.0	0.698	0.9781	0.9811	+0.31
40.0	0.609	0.9753	0.9789	+0.37
50.0	0.484	0.9689	0.9749	+0.62
60.0	0.402	0.9657	0.9715	+0.60
80.0	0.301	0.9641	0.9666	+0.26
100.0	0.239	0.9569	0.9639	+0.73
120.0	0.199	0.9560	0.9637	+0.81
150.0	0.159	0.9549	0.9680	+1.37
200.0	0.119	0.9528	0.9871	+3.61
250.0	0.099	0.9909	1.0132	+2.25
300.0	0.083	0.9969	1.0546	+5.78

TABLE VII

SUMMARY OF CALCULATIONS FOR ETHYLENE USING METHOD-C*

Temperature: 60.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$**	$Z_{cal.}$	% Dev.
1.0	13.453	0.9946	0.9940	-0.06
2.0	6.683	0.9882	0.9880	-0.02
4.0	3.297	0.9750	0.9758	+0.08
6.0	2.168	0.9617	0.9633	+0.17
8.0	1.604	0.9487	0.9506	+0.20
10.0	1.264	0.9345	0.9375	+0.32
15.0	0.811	0.8994	0.9035	+0.46
20.0	0.583	0.8620	0.8672	+0.60
25.0	0.443	0.8188	0.8273	+1.04
30.0	0.350	0.7763	0.7843	+1.03
35.0	0.281	0.7271	0.7357	+1.18
40.0	0.228	0.6743	0.6804	+0.90
50.0	0.138	0.5101	0.5076	-0.49
60.0	0.069	0.3061	0.1953	-36.20

Temperature: 100.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$**	$Z_{cal.}$	% Dev.
1.0	14.510	0.9961	0.9952	-0.09
2.0	7.217	0.9909	0.9904	-0.05
4.0	3.571	0.9806	0.9806	0.00
6.0	2.356	0.9704	0.9707	+0.03
8.0	1.753	0.9627	0.9606	-0.22
10.0	1.382	0.9487	0.9505	+0.19
15.0	0.897	0.9237	0.9244	+0.08
20.0	0.652	0.8952	0.8971	+0.21

* Method-C: $Z_{cal.}$ is obtained using the equation (11) and also using generalized form for the force constants.

** Zexp. observed in reference (20), York, R., White E.F., Trans. Am. Inst. Chem. Engrs., Vol 40, 1944; p. 227-245.

TABLE VII (CONTINUED)

Temperature: 100.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb	$Z_{exp.}$	$Z_{cal.}$	% Dev.
25.0	0.504	0.8650	0.8683	+0.38
30.0	0.405	0.8341	0.8381	+0.48
35.0	0.333	0.8001	0.8057	+0.70
40.0	0.279	0.7661	0.7715	+0.70
50.0	0.201	0.6899	0.6942	+0.62
60.0	0.144	0.5931	0.5957	+0.44
80.0	0.082	0.4503	0.3952	-12.24
100.0	0.057	0.3913	0.2842	-27.37

Temperature: 160.0°F

Pressure atm.	Volume cu.ft./lb	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	16.090	0.9976	0.9965	-0.11
2.0	8.015	0.9939	0.9930	-0.09
4.0	3.978	0.9866	0.9859	-0.07
6.0	2.633	0.9795	0.9787	-0.08
8.0	1.960	0.9722	0.9715	-0.07
10.0	1.556	0.9647	0.9642	-0.05
15.0	1.018	0.9468	0.9459	-0.10
20.0	0.748	0.9275	0.9270	-0.05
25.0	0.585	0.9068	0.9077	+0.10
30.0	0.478	0.8891	0.8882	-0.10
35.0	0.399	0.8659	0.8677	+0.21
40.0	0.341	0.8457	0.8471	+0.17
50.0	0.259	0.8029	0.8042	+0.16
60.0	0.205	0.7626	0.7602	-0.31
80.0	0.137	0.6795	0.6681	-1.68
100.0	0.097	0.6014	0.5787	-3.77
120.0	0.077	0.5729	0.5224	-8.81
150.0	0.062	0.5766	0.4842	-16.02

TABLE VII (CONTINUED)

Temperature: 220.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	17.660	0.9983	0.9974	-0.09
2.0	8.808	0.9958	0.9948	-0.10
4.0	4.380	0.9904	0.9895	-0.09
6.0	2.905	0.9853	0.9842	-0.11
8.0	2.167	0.9800	0.9789	-0.11
10.0	1.724	0.9746	0.9736	-0.10
15.0	1.134	0.9615	0.9603	-0.12
20.0	0.838	0.9474	0.9468	-0.06
25.0	0.661	0.9341	0.9332	-0.10
30.0	0.543	0.9208	0.9196	-0.13
35.0	0.458	0.9062	0.9057	-0.06
40.0	0.395	0.8931	0.8920	-0.12
50.0	0.309	0.8734	0.8651	-0.95
60.0	0.248	0.8411	0.8365	-0.55
80.0	0.174	0.7869	0.7810	-0.75
100.0	0.131	0.7405	0.7296	-1.47
120.0	0.104	0.7055	0.6865	-2.69
150.0	0.081	0.6868	0.6457	-5.98
200.0	0.062	0.7010	0.6234	-11.07

Temperature: 280.0°F

1.0	19.230	0.9989	0.9980	-0.09
2.0	9.600	0.9973	0.9961	-0.12
4.0	4.781	0.9934	0.9921	-0.13
6.0	3.174	0.9892	0.9882	-0.10
8.0	2.371	0.9853	0.9843	-0.10
10.0	1.889	0.9812	0.9803	-0.09
15.0	1.247	0.9716	0.9705	-0.11
20.0	0.926	0.9620	0.9606	-0.15

TABLE VII (CONTINUED)

Temperature: 280.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
25.0	0.733	0.9519	0.9508	-0.12
30.0	0.605	0.9428	0.9410	-0.19
35.0	0.514	0.9345	0.9313	-0.34
40.0	0.445	0.9246	0.9216	-0.32
50.0	0.348	0.9038	0.9021	-0.19
60.0	0.285	0.8882	0.8835	-0.53
80.0	0.205	0.8519	0.8469	-0.59
100.0	0.158	0.8207	0.8136	-0.87
120.0	0.128	0.7978	0.7854	-1.55
150.0	0.100	0.7791	0.7545	-3.16
200.0	0.075	0.7791	0.7319	-6.06
250.0	0.062	0.8051	0.7358	-8.61

Temperature: 340.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	20.800	0.9994	0.9985	-0.09
2.0	10.390	0.9984	0.9970	-0.14
4.0	5.178	0.9951	0.9941	-0.10
6.0	3.442	0.9922	0.9911	-0.11
8.0	2.573	0.9890	0.9882	-0.08
10.0	2.053	0.9864	0.9852	-0.12
15.0	1.359	0.9794	0.9779	-0.15
20.0	1.012	0.9724	0.9706	-0.19
25.0	0.803	0.9645	0.9634	-0.11
30.0	0.664	0.9571	0.9562	-0.09
35.0	0.566	0.9518	0.9492	-0.27
40.0	0.491	0.9436	0.9422	-0.15
50.0	0.389	0.9345	0.9287	-0.62
60.0	0.318	0.9167	0.9151	-0.17

TABLE VII (CONTINUED)

Temperature: 340.0 F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
80.0	0.233	0.8956	0.8903	-0.59
100.0	0.182	0.8744	0.8679	-0.74
120.0	0.149	0.8591	0.8490	-1.18
150.0	0.117	0.8432	0.8274	-1.87
200.0	0.089	0.8552	0.8112	-5.14
250.0	0.071	0.8528	0.8140	-4.55

Temperature: 400.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	22.370	0.9998	0.9989	-0.09
2.0	11.170	0.9984	0.9978	-0.06
4.0	5.575	0.9966	0.9955	-0.11
6.0	3.702	0.9927	0.9933	+0.06
8.0	2.775	0.9922	0.9911	-0.11
10.0	2.215	0.9899	0.9889	-0.10
15.0	1.469	0.9848	0.9834	-0.14
20.0	1.096	0.9797	0.9781	-0.16
25.0	0.872	0.9743	0.9727	-0.16
30.0	0.722	0.9680	0.9675	-0.05
35.0	0.617	0.9651	0.9624	-0.28
40.0	0.537	0.9600	0.9574	-0.27
50.0	0.425	0.9497	0.9475	-0.23
60.0	0.350	0.9385	0.9380	-0.05
80.0	0.258	0.9225	0.9206	-0.21
100.0	0.205	0.9162	0.9060	-1.11
120.0	0.168	0.9010	0.8930	-0.89
150.0	0.133	0.8916	0.8790	-1.41

TABLE VII (CONTINUED)

Temperature: 400.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
200.0	0.101	0.9028	0.8690	-3.74
250.0	0.081	0.9050	0.8730	-3.54
300.0	0.071	0.9520	0.8846	-7.08

Temperature: 460.0°F

1.0	23.940	1.0001	0.9992	-0.09
2.0	11.960	0.9993	0.9983	-0.10
4.0	5.970	0.9976	0.9967	-0.09
6.0	3.973	0.9959	0.9950	-0.09
8.0	2.975	0.9943	0.9934	-0.09
10.0	2.376	0.9926	0.9917	-0.09
15.0	1.577	0.9882	0.9877	-0.05
20.0	1.178	0.9843	0.9837	-0.06
25.0	0.938	0.9797	0.9798	+0.01
30.0	0.779	0.9763	0.9760	-0.03
35.0	0.665	0.9724	0.9723	-0.01
40.0	0.579	0.9676	0.9686	+0.10
50.0	0.461	0.9630	0.9617	-0.13
60.0	0.381	0.9550	0.9550	0.00
80.0	0.284	0.9492	0.9433	-0.62
100.0	0.225	0.9400	0.9332	-0.72
120.0	0.186	0.9325	0.9250	-0.80
150.0	0.149	0.9337	0.9167	-1.82
200.0	0.112	0.9358	0.9121	-2.53
250.0	0.092	0.9609	0.9174	-4.53
300.0	0.079	0.9901	0.9300	-6.07

TABLE VII (CONTINUED)

Temperature: 500.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	24.990	1.0004	0.9993	-0.11
2.0	12.480	0.9993	0.9986	-0.07
4.0	6.234	0.9983	0.9973	-0.10
6.0	4.150	0.9969	0.9959	-0.10
8.0	3.125	1.0009	0.9946	-0.63
10.0	2.483	0.9941	0.9932	-0.09
15.0	1.650	0.9909	0.9900	-0.09
20.0	1.2332	0.9873	0.9867	-0.06
25.0	0.983	0.9839	0.9836	-0.03
30.0	0.817	0.9813	0.9806	-0.07
35.0	0.698	0.9781	0.9776	-0.05
40.0	0.609	0.9753	0.9747	-0.06
50.0	0.484	0.9689	0.9692	+0.03
60.0	0.402	0.9657	0.9641	-0.17
80.0	0.301	0.9641	0.9552	-0.92
100.0	0.239	0.9569	0.9476	-0.97
120.0	0.199	0.9560	0.9418	-1.49
150.0	0.159	0.9549	0.9362	-1.96
200.0	0.119	0.9528	0.9348	-1.89
250.0	0.099	0.9909	0.9410	-5.04
300.0	0.083	0.9969	0.9562	-4.08

TABLE VIII

SUMMARY OF CALCULATIONS FOR ETHYLENE USING METHOD-D*

Temperature: 60.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$**	$Z_{cal.}$	% Dev.
1.0	13.453	0.9946	0.9937	-0.09
2.0	6.683	0.9882	0.9872	-0.10
4.0	3.297	0.9750	0.9743	-0.07
6.0	2.168	0.9617	0.9610	-0.07
8.0	1.604	0.9487	0.9476	-0.12
10.0	1.264	0.9345	0.9338	-0.08
15.0	0.811	0.8994	0.8982	-0.13
20.0	0.583	0.8620	0.8604	-0.19
25.0	0.443	0.8188	0.8194	+0.07
30.0	0.350	0.7763	0.7756	-0.09
35.0	0.281	0.7271	0.7266	-0.07
40.0	0.228	0.6743	0.6721	-0.33
50.0	0.138	0.5101	0.5093	-0.16
60.0	0.069	0.3061	0.2779	-9.22

Temperature: 100.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$**	$Z_{cal.}$	% Dev.
1.0	14.510	0.9961	0.9949	-0.12
2.0	7.217	0.9909	0.9898	-0.11
4.0	3.571	0.9806	0.9795	-0.11
6.0	2.356	0.9704	0.9691	-0.13
8.0	1.753	0.9627	0.9587	-0.42
10.0	1.382	0.9487	0.9478	-0.09
15.0	0.897	0.9237	0.9206	-0.34
20.0	0.652	0.8952	0.8923	-0.32

* Method-D: $Z_{cal.}$ is obtained using equation (11) and also using established force constants.

** $Z_{exp.}$ observed in reference (20), York, R., White, E. F., Trans. Am. Inst. Chem. Engrs., Vol. 40, 1944; p. 227-245.

TABLE VIII (CONTINUED)

Temperature: 100.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
25.0	0.504	0.8650	0.8628	-0.25
30.0	0.405	0.8341	0.8321	-0.24
35.0	0.333	0.8001	0.7995	-0.08
40.0	0.279	0.7661	0.7656	-0.07
50.0	0.201	0.6899	0.6908	+0.13
60.0	0.144	0.5931	0.6005	+1.25
80.0	0.082	0.4503	0.4484	-0.42
100.0	0.057	0.3913	0.4253	+8.69

Temperature: 160.0°F

1.0	16.090	0.9976	0.9963	-0.13
2.0	8.015	0.9939	0.9926	-0.13
4.0	3.978	0.9866	0.9852	-0.14
6.0	2.633	0.9795	0.9778	-0.17
8.0	1.960	0.9722	0.9703	-0.20
10.0	1.556	0.9647	0.9627	-0.21
15.0	1.108	0.9468	0.9438	-0.32
20.0	0.748	0.9275	0.9245	-0.32
25.0	0.585	0.9068	0.9048	-0.22
30.0	0.478	0.8891	0.8852	-0.44
35.0	0.399	0.8659	0.8648	-0.13
40.0	0.341	0.8457	0.8445	-0.14
50.0	0.259	0.8029	0.8030	+0.01
60.0	0.205	0.7626	0.7618	-0.10
80.0	0.137	0.6795	0.6819	+0.35
100.0	0.097	0.6014	0.6180	+2.76
120.0	0.077	0.5729	0.5941	+3.70
150.0	0.062	0.5766	0.6056	+5.03

TABLE VIII (CONTINUED)

Temperature: 220.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	17.660	0.9983	0.9973	-0.10
2.0	8.808	0.9958	0.9946	-0.12
4.0	4.380	0.9904	0.9892	-0.12
6.0	2.905	0.9853	0.9838	-0.15
8.0	2.167	0.9800	0.9783	-0.17
10.0	1.724	0.9746	0.9729	-0.17
15.0	1.134	0.9615	0.9594	-0.22
20.0	0.838	0.9474	0.9458	-0.17
25.0	0.661	0.9341	0.9322	-0.20
30.0	0.543	0.9208	0.9187	-0.23
35.0	0.458	0.9062	0.9051	-0.12
40.0	0.395	0.8931	0.8918	-0.15
50.0	0.309	0.8734	0.8662	-0.82
60.0	0.248	0.8411	0.8398	-0.15
80.0	0.174	0.7869	0.7916	+0.60
100.0	0.131	0.7405	0.7522	+1.58
120.0	0.104	0.7055	0.7264	+2.96
150.0	0.081	0.6868	0.7167	+4.36
200.0	0.062	0.7010	0.7530	+7.42

Temperature: 280.0°F

1.0	19.230	0.9989	0.9980	-0.09
2.0	9.600	0.9973	0.9960	-0.13
4.0	4.781	0.9934	0.9920	-0.14
6.0	3.174	0.9892	0.9880	-0.12
8.0	2.371	0.9853	0.9841	-0.12
10.0	1.889	0.9812	0.9801	-0.11
15.0	1.247	0.9716	0.9703	-0.13
20.0	0.926	0.9620	0.9605	-0.16

TABLE VIII (CONTINUED)

Temperature: 280.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
25.0	0.733	0.9519	0.9509	-0.11
30.0	0.605	0.9428	0.9414	-0.15
35.0	0.514	0.9345	0.9321	-0.26
40.0	0.445	0.9246	0.9229	-0.18
50.0	0.348	0.9038	0.9048	+0.11
60.0	0.285	0.8882	0.8880	-0.02
80.0	0.205	0.8519	0.8570	+0.60
100.0	0.158	0.8207	0.8319	+1.37
120.0	0.128	0.7978	0.8145	+2.09
150.0	0.100	0.7791	0.8041	+3.21
200.0	0.075	0.7791	0.8232	+5.66
250.0	0.062	0.8051	0.8718	+8.27

Temperature: 340.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	20.800	0.9994	0.9985	-0.09
2.0	10.390	0.9984	0.9970	-0.14
4.0	5.178	0.9951	0.9941	-0.10
6.0	3.442	0.9922	0.9911	-0.11
8.0	2.573	0.9890	0.9882	-0.08
10.0	2.053	0.9864	0.9853	-0.11
15.0	1.359	0.9794	0.9781	-0.13
20.0	1.012	0.9724	0.9710	-0.14
25.0	0.803	0.9645	0.9640	-0.05
30.0	0.664	0.9571	0.9572	+0.01
35.0	0.566	0.9518	0.9506	-0.13
40.0	0.491	0.9436	0.9441	+0.05
50.0	0.389	0.9345	0.9319	-0.28
60.0	0.318	0.9167	0.9200	+0.36

TABLE VIII (CONTINUED)

Temperature: 340.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
80.0	0.233	0.8956	0.8997	+0.46
100.0	0.182	0.8744	0.8835	+1.04
120.0	0.149	0.8591	0.8725	+1.56
150.0	0.117	0.8432	0.8660	+2.71
200.0	0.089	0.8552	0.8784	+2.72
250.0	0.071	0.8528	0.9202	+7.91

Temperature: 400.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	22.370	0.9998	0.9989	-0.09
2.0	11.170	0.9984	0.9978	-0.06
4.0	5.575	0.9966	0.9957	-0.09
6.0	3.702	0.9927	0.9936	+0.09
8.0	2.775	0.9922	0.9915	-0.07
10.0	2.215	0.9899	0.9894	-0.05
15.0	1.469	0.9848	0.9843	-0.05
20.0	1.096	0.9797	0.9793	-0.04
25.0	0.872	0.9743	0.9744	+0.01
30.0	0.722	0.9680	0.9696	+0.17
35.0	0.617	0.9651	0.9651	0.00
40.0	0.537	0.9600	0.9607	+0.07
50.0	0.425	0.9497	0.9524	+0.28
60.0	0.350	0.9385	0.9446	+0.65
80.0	0.258	0.9225	0.9317	+1.00
100.0	0.205	0.9162	0.9225	+0.69
120.0	0.168	0.9010	0.9165	+1.72
150.0	0.133	0.8916	0.9149	+2.61

TABLE VIII (CONTINUED)

Temperature: 400.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
200.0	0.101	0.9028	0.9287	+2.87
250.0	0.081	0.9050	0.9633	+6.44
300.0	0.071	0.9520	1.0005	+5.09

Temperature: 460.0 F

1.0	23.940	1.0001	0.9992	-0.09
2.0	11.960	0.9993	0.9984	-0.09
4.0	5.970	0.9976	0.9969	-0.07
6.0	3.973	0.9959	0.9954	-0.05
8.0	2.975	0.9943	0.9939	-0.04
10.0	2.376	0.9926	0.9924	-0.02
15.0	1.577	0.9882	0.9887	+0.05
20.0	1.178	0.9843	0.9852	+0.09
25.0	0.938	0.9797	0.9818	+0.21
30.0	0.779	0.9763	0.9786	+0.24
35.0	0.665	0.9724	0.9755	+0.32
40.0	0.579	0.9676	0.9725	+0.51
50.0	0.461	0.9630	0.9670	+0.42
60.0	0.381	0.9550	0.9621	+0.74
80.0	0.284	0.9492	0.9545	+0.56
100.0	0.225	0.9400	0.9494	+1.00
120.0	0.186	0.9325	0.9471	+1.57
150.0	0.149	0.9337	0.9490	+1.64
200.0	0.112	0.9358	0.9652	+3.14
250.0	0.092	0.9609	0.9929	+3.33
300.0	0.079	0.9901	1.0295	+3.98

TABLE VIII (CONTINUED)

Temperature: 500.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1.0	24.990	1.0004	0.9994	-0.10
2.0	12.480	0.9993	0.9988	-0.05
4.0	6.234	0.9983	0.9975	-0.08
6.0	4.150	0.9969	0.9963	-0.06
8.0	3.125	1.0009	0.9952	-0.57
10.0	2.483	0.9941	0.9940	-0.01
15.0	1.650	0.9909	0.9912	+0.03
20.0	1.233	0.9873	0.9885	+0.12
25.0	0.983	0.9839	0.9859	+0.20
30.0	0.817	0.9813	0.9834	+0.21
35.0	0.698	0.9781	0.9811	+0.31
40.0	0.609	0.9753	0.9789	+0.37
50.0	0.484	0.9689	0.9748	+0.61
60.0	0.402	0.9657	0.9714	+0.59
80.0	0.301	0.9641	0.9664	+0.24
100.0	0.239	0.9569	0.9635	+0.69
120.0	0.199	0.9560	0.9631	+0.74
150.0	0.159	0.9549	0.9669	+1.26
200.0	0.119	0.9528	0.9848	+3.36
250.0	0.099	0.9909	1.0099	+1.92
300.0	0.083	0.9969	1.0502	+5.35

TABLE IX

SUMMARY OF CALCULATIONS FOR ETHANE
USING METHOD-A*

Temperature: 100.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$**	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	27.198	0.9057	0.9083	+0.29
400.0	11.893	0.7921	0.7977	+0.71
600.0	6.417	0.6411	0.6477	+1.03
800.0	2.203	0.2935	0.2974	+1.33

Temperature: 160.0°F

0.0	-	1.0000	1.0000	0.00
200.0	31.015	0.9328	0.9341	+0.14
400.0	14.287	0.8594	0.8614	+0.23
600.0	8.627	0.7784	0.7799	+0.19
800.0	5.717	0.6878	0.6874	-0.06
1000.0	3.911	0.5881	0.5855	-0.44
1250.0	2.537	0.4769	0.4804	+0.73

Temperature: 220.0°F

0.0		1.0000	1.0000	0.00
200.0	34.674	0.9508	0.9513	+0.05
400.0	16.409	0.8999	0.9001	+0.13
600.0	10.304	0.8476	0.8466	-0.12
800.0	7.238	0.7939	0.7911	-0.35
1000.0	5.393	0.7394	0.7350	-0.60

* Method-A: $Z_{cal.}$ is obtained using the equation (8) and also using generalized form for the force constants.

** $Z_{exp.}$ observed in reference(21), Reamer et al, <u>Industrial and Engineering Chemistry</u>, Vo. <u>36</u>, 1944; p. 957-958.

TABLE IX (CONTINUED)

Temperature: 220.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	3.940	0.6753	0.6694	-0.87
1500.0	3.035	0.6242	0.6190	-0.83
1750.0	2.575	0.5939	0.5913	-0.44
2000.0	2.132	0.5845	0.5815	-0.51
Temperature: 280.0°F				
0.0	-	1.0000	1.0000	0.00
200.0	38.238	0.9635	0.9634	-0.01
400.0	18.389	0.9267	0.9260	-0.08
600.0	11.774	0.8900	0.8883	-0.19
800.0	8.474	0.8541	0.8508	-0.39
1000.0	6.504	0.8194	0.8142	-0.63
1250.0	4.948	0.7792	0.7716	-0.98
1500.0	3.937	0.7440	0.7353	-1.17
1750.0	3.254	0.7175	0.7082	-1.30
2000.0	2.782	0.7010	0.6917	-1.33
2250.0	2.453	0.6954	0.6846	-1.32
2500.0	2.216	0.6979	0.6839	-2.01
Temperature: 340.0°F				
0.0	-	1.0000	1.0000	0.00
200.0	41.740	0.9728	0.9721	-0.07
400.0	20.297	0.9461	0.9444	-0.18
600.0	13.160	0.9201	0.9171	-0.33
800.0	9.601	0.8950	0.8905	-0.50
1000.0	7.476	0.8712	0.8650	-0.71

TABLE IX (CONTINUED)

Temperature: 340.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	5.794	0.8440	0.8357	-0.98
1500.0	4.691	0.8200	0.8102	-1.19
1750.0	3.928	0.8010	0.7898	-1.40
2000.0	3.380	0.7877	0.7751	-1.60
2250.0	2.978	0.7807	0.7662	-1.86
2500.0	2.673	0.7788	0.7626	-2.08
2750.0	2.442	0.7827	0.7631	-2.50
3000.0	2.262	0.7908	0.7666	-3.06

Temperature: 400.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	45.195	0.9798	0.9787	-0.12
400.0	22.145	0.9602	0.9578	-0.25
600.0	14.475	0.9414	0.9376	-0.40
800.0	10.651	0.9236	0.9183	-0.57
1000.0	8.368	0.9071	0.9001	-0.77
1250.0	6.557	0.8884	0.8794	-1.01
1500.0	5.364	0.8722	0.8615	-1.23
1750.0	4.529	0.8591	0.8467	-1.44
2000.0	3.918	0.8494	0.8356	-1.62
2250.0	3.460	0.8438	0.8281	-1.86
2500.0	3.107	0.8419	0.8243	-2.09
2750.0	2.832	0.8441	0.8237	-2.42
3000.0	2.612	0.8494	0.8257	-2.79
3500.0	2.289	0.8683	0.8356	-3.77

TABLE IX (CONTINUED)

Temperature: 460.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	48.621	0.9853	0.9837	-0.16
400.0	23.965	0.9713	0.9680	-0.34
600.0	15.758	0.9580	0.9531	-0.51
800.0	11.664	0.9455	0.9390	-0.69
1000.0	9.218	0.9340	0.9260	-0.86
1250.0	7.272	0.9210	0.9113	-1.05
1500.0	5.987	0.9100	0.8987	-1.24
1750.0	5.079	0.9006	0.8883	-1.37
2000.0	4.410	0.8937	0.8805	-1.48
2250.0	3.903	0.8898	0.8753	-1.63
2500.0	3.508	0.8887	0.8726	-1.81
2750.0	3.195	0.8903	0.8722	-2.03
3000.0	2.942	0.8943	0.8740	-2.27
3500.0	2.566	0.9099	0.8825	-3.01
4000.0	2.303	0.9334	0.8955	-4.06

TABLE X

SUMMARY OF CALCULATIONS FOR ETHANE USING METHOD-B*

Temperature: 100.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$**	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	27.198	0.9057	0.9258	+2.22
400.0	11.893	0.7921	0.8305	+4.85
600.0	6.417	0.6411	0.6852	+6.88
800.0	2.203	0.2935	0.2930	-0.17
Temperature: 160.0°F				
0.0	-	1.0000	1.0000	0.00
200.0	31.015	0.9328	0.9465	+1.47
400.0	14.287	0.8594	0.8846	+2.93
600.0	8.627	0.7784	0.8097	+4.02
800.0	5.717	0.6878	0.7153	+4.00
1000.0	3.911	0.5881	0.5987	+1.80
1250.0	2.537	0.4769	0.4691	-1.66
Temperature: 220.0°F				
0.0		1.0000	1.0000	0.00
200.0	34.674	0.9508	0.9603	+1.00
400.0	16.409	0.8999	0.9169	+1.89
600.0	10.304	0.8476	0.8686	+2.48
800.0	7.238	0.7939	0.8145	+2.60
1000.0	5.393	0.7394	0.7546	+2.06

* Method-B: $Z_{cal.}$ is obtained using the equation (8) and also using established force constants.

** $Z_{exp.}$ observed in reference (21), Reamer et al, Industrial and Engineering Chemistry, Vol. 36, 1944; p. 957-958.

TABLE X (CONTINUED)

Temperature: 220.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	3.940	0.6753	0.6768	+0.22
1500.0	3.035	0.6242	0.6107	-2.16
1750.0	2.475	0.5939	0.5699	-4.04
2000.0	2.132	0.5845	0.5480	-6.25

Temperature: 280.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	38.239	0.9635	0.9699	+0.66
400.0	18.389	0.9267	0.9382	+1.24
600.0	11.774	0.8900	0.9044	+1.62
800.0	8.474	0.8541	0.8685	+1.69
1000.0	6.504	0.8194	0.8307	+1.38
1250.0	4.948	0.7792	0.7824	+0.41
1500.0	3.937	0.7440	0.7363	-1.03
1750.0	3.254	0.7175	0.6978	-2.75
2000.0	2.782	0.7010	0.6700	-4.42
2250.0	2.453	0.6954	0.6530	-6.10
2500.0	2.216	0.6979	0.6428	-7.90

Temperature: 340.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	41.740	0.9728	0.9769	+0.42
400.0	20.297	0.9461	0.9532	+0.75
600.0	13.160	0.9201	0.9286	+0.92
800.0	9.601	0.8950	0.9033	+0.93
1000.0	7.476	0.8712	0.8774	+0.71

TABLE X (CONTINUED)

Temperature: 340.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	5.794	0.8440	0.8448	+0.09
1500.0	4.691	0.8200	0.8132	-0.83
1750.0	3.928	0.8010	0.7846	-2.05
2000.0	3.380	0.7877	0.7606	-3.44
2250.0	2.978	0.7807	0.7425	-4.90
2500.0	2.673	0.7788	0.7299	-6.28
2750.0	2.442	0.7827	0.7221	-7.74
3000.0	2.262	0.7908	0.7173	-9.29

Temperature: 400.0°F

0.0	-	1.0000	1.0000	0.00
200.0	45.195	0.9798	0.9822	+0.25
400.0	22.145	0.9602	0.9641	+0.41
600.0	14.475	0.9414	0.9459	+0.48
800.0	10.651	0.9236	0.9274	+0.41
1000.0	8.368	0.9071	0.9089	+0.20
1250.0	6.557	0.8884	0.8859	-0.28
1500.0	5.364	0.8722	0.8637	-0.97
1750.0	4.529	0.8591	0.8430	-1.87
2000.0	3.918	0.8494	0.8247	-2.91
2250.0	3.460	0.8438	0.8095	-4.07
2500.0	3.107	0.8419	0.7979	-5.23
2750.0	2.832	0.8441	0.7892	-6.50
3000.0	2.612	0.8494	0.7836	-7.71
3500.0	2.289	0.8683	0.7786	-11.52

TABLE X (CONTINUED)

Temperature: 460.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	48.621	0.9853	0.9862	+0.09
400.0	23.965	0.9713	0.9724	+0.11
600.0	15.758	0.9580	0.9587	+0.07
800.0	11.664	0.9455	0.9450	-0.05
1000.0	9.218	0.9340	0.9315	-0.27
1250.0	7.272	0.9210	0.9149	-0.66
1500.0	5.987	0.9100	0.8989	-1.22
1750.0	5.079	0.9006	0.8839	-1.85
2000.0	4.410	0.8937	0.8704	-2.61
2250.0	3.903	0.8898	0.8587	-3.49
2500.0	3.508	0.8887	0.8490	-4.47
2750.0	3.194	0.8903	0.8415	-5.48
3000.0	2.942	0.8943	0.8361	-6.51
3500.0	2.566	0.9099	0.8307	-8.70
4000.0	2.303	0.9334	0.8304	-11.04

TABLE XI

SUMMARY OF CALCULATIONS FOR ETHANE USING METHOD-C*

Temperature: 100.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$**	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	27.198	0.9057	0.9083	+0.29
400.0	11.893	0.7921	0.7972	+0.64
600.0	6.417	0.6411	0.6434	+0.36
800.0	2.203	0.2935	0.1948	-33.60
Temperature: 160.0°F				
0.0	-	1.0000	1.0000	0.00
200.0	31.015	0.9328	0.9341	+0.14
400.0	14.287	0.8594	0.8612	+0.21
600.0	8.627	0.7784	0.7787	+0.04
800.0	5.717	0.6878	0.6828	-0.73
1000.0	3.911	0.5881	0.5699	-3.09
1250.0	2.537	0.4769	0.4256	-10.76
Temperature: 220.0°F				
0.0	-	1.0000	1.0000	0.00
200.0	34.674	0.9508	0.9513	+0.05
400.0	16.409	0.8999	0.9000	+0.01
600.0	10.304	0.8476	0.8461	-0.18
800.0	7.238	0.7939	0.7895	-0.55
1000.0	5.393	0.7394	0.7307	-1.18

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* Method-C: $Z_{cal.}$ is obtained using the equation (11) and also using generalized form for the force constants.

** $Z_{exp.}$ observed in reference (21), Reamer et al, Industrial and Engineering Chemistry, Vol. 36, 1944; p. 957-958.

TABLE XI (CONTINUED)

Temperature: 220.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	3.940	0.6753	0.6578	-2.59
1500.0	3.035	0.6242	0.5935	-4.92
1750.0	2.475	0.5939	0.5472	-7.88
2000.0	2.132	0.5845	0.5205	-10.97

Temperature: 280.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	38.239	0.9635	0.9634	-0.01
400.0	18.389	0.9267	0.9260	-0.08
600.0	11.774	0.8900	0.8881	-0.21
800.0	8.474	0.8541	0.8500	-0.48
1000.0	6.504	0.8194	0.8124	-0.88
1250.0	4.948	0.7792	0.7673	-1.55
1500.0	3.937	0.7440	0.7262	-2.26
1750.0	3.254	0.7175	0.6921	-3.54
2000.0	2.782	0.7010	0.6664	-4.80
2250.0	2.453	0.6954	0.6496	-6.59
2500.0	2.216	0.6979	0.6400	-9.63

Temperature: 340.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	41.740	0.9728	0.9721	-0.07
400.0	20.297	0.9461	0.9444	-0.18
600.0	13.160	0.9201	0.9169	-0.35
800.0	9.601	0.8950	0.8901	-0.55
1000.0	7.476	0.8712	0.8641	-0.82

TABLE XI (CONTINUED)

Temperature: 340.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	5.794	0.8440	0.8337	-1.22
1500.0	4.691	0.8200	0.8061	-1.70
1750.0	3.928	0.8010	0.7826	-3.39
2000.0	3.380	0.7877	0.7636	-3.06
2250.0	2.978	0.7807	0.7497	-4.01
2500.0	2.673	0.7788	0.7403	-4.95
2750.0	2.442	0.7827	0.7351	-6.08
3000.0	2.262	0.7908	0.7333	-7.27

Temperature: 400.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	45.194	0.9798	0.9787	-0.11
400.0	22.145	0.9602	0.9578	-0.25
600.0	14.475	0.9414	0.9376	-0.40
800.0	10.651	0.9236	0.9181	-0.60
1000.0	8.368	0.9071	0.8997	-0.82
1250.0	6.557	0.8884	0.8783	-1.14
1500.0	5.364	0.8722	0.8593	-1.48
1750.0	4.529	0.8591	0.8430	-1.87
2000.0	3.918	0.8494	0.8297	-2.32
2250.0	3.460	0.8438	0.8196	-2.87
2500.0	3.107	0.8419	0.8125	-3.49
2750.0	2.832	0.8441	0.8084	-4.23
3000.0	2.612	0.8494	0.8067	-5.03
3500.0	2.289	0.8683	0.8094	-6.78

TABLE XI (CONTINUED)

Temperature: 460.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	48.621	0.9853	0.9837	-0.16
400.0	23.965	0.9713	0.9680	-0.34
600.0	15.758	0.9580	0.9530	-0.52
800.0	11.664	0.9455	0.9389	-0.70
1000.0	9.218	0.9340	0.9257	-0.89
1250.0	7.272	0.9210	0.9106	-1.13
1500.0	5.987	0.9100	0.8974	-1.38
1750.0	5.079	0.9006	0.8863	-1.59
2000.0	4.410	0.8937	0.8772	-1.85
2250.0	3.903	0.8898	0.8705	-2.17
2500.0	3.508	0.8887	0.8659	-2.57
2750.0	3.195	0.8903	0.8634	-3.02
3000.0	2.943	0.8943	0.8627	-3.53
3500.0	2.566	0.9099	0.8662	-4.81
4000.0	2.303	0.9334	0.8744	-6.32

TABLE XII

SUMMARY OF CALCULATIONS FOR ETHANE

USING METHOD-D*

Temperature: 100.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}^{**}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	27.198	0.9057	0.9262	+2.26
400.0	11.893	0.7921	0.8350	+5.42
600.0	6.417	0.6411	0.7045	+9.89
800.0	2.203	0.2935	0.2638	-10.10
Temperature: 160.0°F				
0.0	-	1.0000	1.0000	0.00
200.0	31.015	0.9328	0.9467	+1.49
400.0	14.287	0.8594	0.8867	+3.18
600.0	8.627	0.7784	0.8170	+4.96
800.0	5.717	0.6878	0.7330	+6.57
1000.0	3.911	0.5881	0.6278	+6.75
1250.0	2.537	0.4769	0.4744	-0.52
Temperature: 220.0°F				
0.0	-	1.0000	1.0000	0.00
200.0	34.674	0.9508	0.9604	+1.01
400.0	16.409	0.8999	0.9180	+2.01
600.0	10.304	0.8476	0.8722	+2.90
800.0	7.238	0.7939	0.8228	+3.64
1000.0	5.393	0.7394	0.7695	+4.07

* Method-D: $Z_{cal.}$ is obtained using the equation (11) and also using established force constants.

** $Z_{exp.}$ observed in reference (21), Reamer et al, Industrial and Engineering Chemistry, Vol. 36, 1944; p. 957-958.

TABLE XII (CONTINUED)

Temperature: 220.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	3.940	0.6753	0.6988	+3.48
1500.0	3.035	0.6242	0.6296	+0.87
1750.0	2.475	0.5939	0.5707	-3.91
2000.0	2.132	0.5845	0.5267	-9.89

Temperature: 280.0°F

0.0	-	1.0000	1.0000	0.00
200.0	38.239	0.9635	0.9700	+0.67
400.0	18.389	0.9267	0.9388	+1.31
600.0	11.774	0.8900	0.9064	+1.84
800.0	8.474	0.8541	0.8730	+2.21
1000.0	6.504	0.8194	0.8388	+2.37
1250.0	4.948	0.7792	0.7957	+2.12
1500.0	3.937	0.7440	0.7534	+1.26
1750.0	3.254	0.7175	0.7144	-0.43
2000.0	2.782	0.7010	0.6804	-2.94
2250.0	2.453	0.6954	0.6528	-6.13
2500.0	2.216	0.6979	0.6308	-9.62

Temperature: 340.0°F

0.0	-	1.0000	1.0000	0.00
200.0	41.740	0.9728	0.9770	+0.43
400.0	20.297	0.9444	0.9535	+0.78
600.0	13.160	0.9208	0.9298	+1.05
800.0	9.601	0.8950	0.9060	+1.23
1000.0	7.476	0.8712	0.8821	+1.25

TABLE XII (CONTINUED)

Temperature: 340.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	5.794	0.8440	0.8528	+1.04
1500.0	4.691	0.8200	0.8245	+0.55
1750.0	3.928	0.8010	0.7981	-0.36
2000.0	3.380	0.7877	0.7742	-1.71
2250.0	2.978	0.7807	0.7535	-3.49
2500.0	2.673	0.7788	0.7359	-5.51
2750.0	2.442	0.7827	0.7215	-7.93
3000.0	2.262	0.7908	0.7098	-10.23
Temperature: 400.0°F				
0.0	-	1.0000	1.0000	0.00
200.0	45.195	0.9798	0.9822	+0.24
400.0	22.145	0.9602	0.9644	+0.44
600.0	14.475	0.9414	0.9466	+0.55
800.0	10.651	0.9236	0.9291	+0.60
1000.0	8.368	0.9071	0.9118	+0.52
1250.0	6.557	0.8884	0.8910	+0.29
1500.0	5.364	0.8722	0.8711	-0.13
1750.0	4.529	0.8591	0.8526	-0.76
2000.0	3.918	0.8494	0.8356	-1.62
2250.0	3.460	0.8438	0.8206	-2.75
2500.0	3.107	0.8419	0.8075	-4.08
2750.0	2.832	0.8441	0.7965	-5.65
3000.0	2.832	0.8494	0.7872	-7.32
3500.0	2.289	0.8683	0.7735	-10.91

TABLE XII (CONTINUED)

Temperature: 460.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
200.0	48.621	0.9853	0.9862	+0.09
400.0	23.965	0.9713	0.9725	+0.12
600.0	15.758	0.9580	0.9591	+0.11
800.0	11.664	0.9455	0.9461	+0.06
1000.0	9.218	0.9340	0.9334	-0.06
1250.0	7.272	0.9210	0.9182	-0.30
1500.0	5.987	0.9100	0.9039	-0.67
1750.0	5.079	0.9006	0.8906	-1.11
2000.0	4.410	0.8937	0.8784	-1.71
2250.0	3.903	0.8898	0.8676	-2.50
2500.0	3.508	0.8887	0.8581	-3.44
2750.0	3.195	0.8903	0.8500	-4.53
3000.0	2.942	0.8943	0.8431	-5.73
3500.0	2.566	0.9099	0.8329	-8.46
4000.0	2.303	0.9334	0.8265	-11.45

TABLE XIII

SUMMARY OF CALCULATIONS FOR PROPANE USING METHOD-A*

Temperature: 100.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$**	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	403.20	0.9866	0.9875	+0.09
20.0	294.80	0.9816	0.9829	+0.13
30.0	194.60	0.9720	0.9741	+0.22
40.0	144.50	0.9622	0.9652	+0.31
50.0	114.40	0.9521	0.9561	+0.42
60.0	94.30	0.9417	0.9468	+0.54
80.0	69.10	0.9200	0.9276	+0.83
100.0	53.90	0.8966	0.9074	+1.21
125.0	41.60	0.8645	0.8805	+1.85
150.0	33.20	0.8321	0.8509	+2.26

Temperature: 130.0°F

0.0	-	1.0000	1.0000	0.00
14.7	425.70	0.9885	0.9892	+0.07
20.0	311.40	0.9842	0.9852	+0.10
30.0	205.90	0.9761	0.9777	+0.16
40.0	153.10	0.9678	0.9701	+0.24
50.0	121.40	0.9594	0.9623	+0.30
60.0	100.30	0.9508	0.9544	+0.38
80.0	73.80	0.9330	0.9382	+0.56
100.0	57.90	0.9144	0.9215	+0.78
125.0	45.10	0.8900	0.8996	+1.08
150.0	36.40	0.8637	0.8762	+1.45
200.0	25.47	0.8053	0.8247	+2.41

* Method-A: $Z_{cal.}$ is obtained using the equation (8) and generalized form for the force constants.

** $Z_{exp.}$ observed in reference (22), Reamer et al, Industrial and Engineering Chemistry, Vol. 41, 1949; p. 483.

TABLE XIII (CONTINUED)

Temperature: 160.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	448.00	0.9900	0.9906	+0.06
20.0	328.00	0.9863	0.9872	+0.09
30.0	217.10	0.9793	0.9807	+0.14
40.0	161.70	0.9722	0.9741	+0.20
50.0	128.40	0.9651	0.9674	+0.24
60.0	106.20	0.9577	0.9607	+0.31
80.0	78.40	0.9428	0.9469	+0.44
100.0	61.70	0.9274	0.9328	+0.58
125.0	48.30	0.9073	0.9144	+0.78
150.0	39.30	0.8863	0.8952	+1.00
200.0	28.00	0.8412	0.8543	+1.56
300.0	16.25	0.7330	0.7549	+2.98

Temperature: 190.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0		1.0000	1.0000	0.00
14.7	470.30	0.9913	0.9918	+0.05
20.0	344.50	0.9881	0.9888	+0.07
30.0	228.20	0.9821	0.9832	+0.11
40.0	170.10	0.9759	0.9775	+0.16
50.0	135.20	0.9698	0.9717	+0.20
60.0	112.00	0.9635	0.9659	+0.25
80.0	82.90	0.9508	0.9540	+0.34
100.0	65.40	0.9379	0.9419	+0.43
125.0	51.40	0.9211	0.9264	+0.58
150.0	42.00	0.9037	0.9102	+0.72
200.0	30.20	0.8673	0.8763	+1.04

TABLE XIII (CONTINUED)

Temperature: 190°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
300.0	18.26	0.7855	0.7997	+1.81
400.0	11.94	0.6850	0.7031	+2.64
500.0	7.59	0.5462	0.5598	+2.49

Temperature: 220.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	492.50	0.9923	0.9928	+0.05
20.0	360.90	0.9896	0.9902	+0.06
30.0	239.30	0.9846	0.9853	+0.07
40.0	178.50	0.9790	0.9803	+0.13
50.0	142.00	0.9736	0.9753	+0.17
60.0	117.70	0.9682	0.9702	+0.21
80.0	87.30	0.9572	0.9599	+0.28
100.0	69.00	0.9462	0.9495	+0.35
125.0	54.40	0.9320	0.9361	+0.44
150.0	44.60	0.9175	0.9224	+0.53
200.0	32.40	0.8873	0.8941	+0.77
300.0	19.99	0.8221	0.8318	+1.18
400.0	13.65	0.7487	0.7599	+1.50
500.0	9.66	0.6621	0.6731	+1.66
600.0	6.68	0.5496	0.5566	+1.27

Temperature: 280.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	537.00	0.9941	0.9944	+0.03
20.0	393.70	0.9919	0.9924	+0.05
30.0	261.40	0.9879	0.9886	+0.07

TABLE XIII (CONTINUED)

Temperature: 280.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
40.0	195.20	0.9838	0.9847	+0.09
50.0	155.50	0.9797	0.9808	+0.11
60.0	129.10	0.9756	0.9769	+0.13
80.0	96.00	0.9673	0.9691	+0.19
100.0	76.10	0.9591	0.9611	+0.21
125.0	60.20	0.9485	0.9510	+0.26
150.0	49.60	0.9380	0.9408	+0.30
200.0	36.40	0.9164	0.9199	+0.38
300.0	23.07	0.8720	0.8760	+0.46
400.0	16.38	0.8254	0.8290	+0.44
500.0	12.32	0.7757	0.7784	+0.35
600.0	8.56	0.7228	0.6965	-3.64
800.0	5.98	0.6023	0.5990	-0.55
1000.0	3.79	0.4773	0.4760	-0.27

Temperature: 340.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	581.30	0.9954	0.9956	+0.02
20.0	426.40	0.9937	0.9940	+0.03
30.0	283.40	0.9906	0.9910	+0.04
40.0	211.90	0.9874	0.9880	+0.06
50.0	168.90	0.9842	0.9849	+0.07
60.0	140.30	0.9811	0.9819	+0.08
80.0	104.60	0.9747	0.9758	+0.11
100.0	83.10	0.9684	0.9696	+0.12
125.0	65.90	0.9604	0.9618	+0.15
150.0	54.50	0.9524	0.9540	+0.17
200.0	40.20	0.9362	0.9382	+0.21

TABLE XIII (CONTINUED)

Temperature: 340.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
300.0	25.85	0.9037	0.9055	+0.20
400.0	18.68	0.8707	0.8717	+0.11
500.0	14.37	0.8371	0.8369	-0.02
600.0	11.48	0.8029	0.8008	-0.26
800.0	7.85	0.7320	0.7265	-0.75
1000.0	5.69	0.6627	0.6539	-1.33
1250.0	4.05	0.5898	0.5816	-1.39
1500.0	3.16	0.5523	0.5479	-0.80

Temperature: 400.0°F

0.0	-	1.0000	1.0000	0.00
14.7	625.50	0.9964	0.9965	+0.01
20.0	459.00	0.9951	0.9952	+0.01
30.0	305.30	0.9926	0.9928	+0.02
40.0	228.40	0.9902	0.9905	+0.03
50.0	182.20	0.9877	0.9880	+0.03
60.0	151.50	0.9852	0.9856	+0.04
80.0	113.10	0.9803	0.9808	+0.05
100.0	90.00	0.9754	0.9760	+0.06
125.0	71.50	0.9692	0.9699	+0.07
150.0	59.20	0.9632	0.9638	+0.06
200.0	43.90	0.9509	0.9515	+0.06
300.0	28.48	0.9262	0.9265	+0.03
400.0	20.80	0.9017	0.9012	-0.06
500.0	16.19	0.8772	0.8757	-0.17
600.0	13.12	0.8534	0.8499	-0.41
800.0	9.29	0.8058	0.7987	-0.88
1000.0	7.01	0.7600	0.7496	-1.37

TABLE XIII (CONTINUED)

Temperature: 400.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	5.24	0.7098	0.6965	-1.87
1500.0	4.15	0.6740	0.6596	-2.14
1750.0	3.45	0.6554	0.6408	-2.23
2000.0	3.01	0.6530	0.6380	-2.30

Temperature: 460.0°F

0.0	-	1.0000	1.0000	0.00
14.7	669.70	0.9972	0.9972	0.00
20.0	491.60	0.9962	0.9962	0.00
30.0	327.10	0.9942	0.9943	+0.01
40.0	244.90	0.9923	0.9924	+0.01
50.0	195.50	0.9904	0.9904	0.00
60.0	162.60	0.9885	0.9885	0.00
80.0	121.50	0.9847	0.9847	0.00
100.0	96.80	0.9809	0.9808	-0.01
125.0	77.10	0.9761	0.9760	-0.01
150.0	63.90	0.9715	0.9712	-0.03
200.0	47.50	0.9621	0.9616	-0.05
300.0	31.00	0.9434	0.9421	-0.14
400.0	22.82	0.9250	0.9228	-0.24
500.0	17.90	0.9068	0.9035	-0.36
600.0	14.63	0.8892	0.8843	-0.55
800.0	10.55	0.8548	0.8467	-0.95
1000.0	8.12	0.8227	0.8115	-1.35
1250.0	6.21	0.7870	0.7725	-1.84
1500.0	4.92	0.7471	0.7404	-0.90
1750.0	4.16	0.7373	0.7222	-2.05
2000.0	3.63	0.7355	0.7133	-3.02
2250.0	3.23	0.7376	0.7118	-3.50

TABLE XIV

SUMMARY OF CALCULATIONS FOR PROPANE USING METHOD-B*

Temperature: 100.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$ **	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	403.20	0.9866	0.9855	-0.11
20.0	294.80	0.9816	0.9802	-0.14
30.0	194.60	0.9720	0.9700	-0.21
40.0	144.50	0.9622	0.9598	-0.25
50.0	114.40	0.9521	0.9493	-0.29
60.0	94.30	0.9417	0.9386	-0.33
80.0	69.10	0.9200	0.9167	-0.36
100.0	53.90	0.8966	0.8938	-0.31
125.0	41.60	0.8645	0.8634	-0.13
150.0	33.20	0.8321	0.8302	-0.12

Temperature: 130.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$ **	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	425.70	0.9885	0.9876	-0.09
20.0	311.40	0.9842	0.9830	-0.12
30.0	205.90	0.9761	0.9744	-0.17
40.0	153.10	0.9678	0.9656	-0.23
50.0	121.40	0.9594	0.9567	-0.28
60.0	100.30	0.9508	0.9478	-0.32
80.0	73.80	0.9330	0.9294	-0.39
100.0	57.90	0.9144	0.9105	-0.43
125.0	45.10	0.8900	0.8859	-0.46
150.0	36.40	0.8637	0.8597	-0.46
200.0	25.47	0.8053	0.8029	-0.30

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* Method-B: $Z_{cal.}$ is obtained using equation (8) and also using established force constants.

** $Z_{exp.}$ observed in the reference (22), Reamer et al, *Industrial and Engineering Chemistry*, Vol. 41, 1949; p. 483.

TABLE XIV (CONTINUED)

Temperature: 160.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	448.00	0.9900	0.9892	-0.08
20.0	328.00	0.9863	0.9853	-0.10
30.0	217.10	0.9793	0.9779	-0.14
40.0	161.70	0.9722	0.9704	-0.19
50.0	128.40	0.9651	0.9628	-0.24
60.0	106.20	0.9577	0.9552	-0.26
80.0	78.40	0.9428	0.9396	-0.34
100.0	61.70	0.9274	0.9236	-0.41
125.0	48.30	0.9073	0.9031	-0.45
150.0	39.30	0.8863	0.8818	-0.51
200.0	28.00	0.8412	0.8368	-0.52
300.0	16.25	0.7330	0.7300	-0.41

Temperature: 190.0°F

0.0	-	1.0000	1.0000	0.00
14.7	470.30	0.9913	0.9907	-0.06
20.0	344.50	0.9881	0.9873	-0.08
30.0	228.20	0.9821	0.9809	-0.12
40.0	170.10	0.9759	0.9744	-0.15
50.0	135.20	0.9698	0.9679	-0.20
60.0	112.00	0.9635	0.9613	-0.23
80.0	82.90	0.9508	0.9480	-0.29
100.0	65.40	0.9379	0.9344	-0.37
125.0	51.40	0.9211	0.9171	-0.43
150.0	42.00	0.9037	0.8993	-0.49
200.0	30.20	0.8673	0.8621	-0.60

TABLE XIV (CONTINUED)

Temperature: 190.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
300.0	18.26	0.7855	0.7802	-0.67
400.0	11.94	0.6850	0.6803	-0.69
500.0	7.59	0.5462	0.5384	-1.43
Temperature: 220.0°F				
0.0	-	1.0000	1.0000	0.00
14.7	492.50	0.9923	0.9919	-0.04
20.0	360.90	0.9896	0.9889	-0.07
30.0	239.30	0.9846	0.9834	-0.12
40.0	178.50	0.9790	0.9777	-0.13
50.0	142.00	0.9736	0.9721	-0.15
60.0	117.70	0.9682	0.9664	-0.19
80.0	87.30	0.9572	0.9549	-0.24
100.0	69.00	0.9462	0.9433	-0.31
125.0	54.40	0.9320	0.9286	-0.36
150.0	44.60	0.9175	0.9135	-0.44
200.0	32.40	0.8873	0.8827	-0.52
300.0	19.99	0.8221	0.8163	-0.71
400.0	13.65	0.7487	0.7423	-0.86
500.0	9.66	0.6621	0.6562	-0.89
600.0	6.68	0.5496	0.5461	-0.64
Temperature: 280.0°F				
0.0	-	1.0000	1.0000	0.00
14.7	537.00	0.9941	0.9938	-0.03
20.0	393.70	0.9919	0.9915	-0.04
30.0	261.40	0.9879	0.9873	-0.06

TABLE XIV (CONTINUED)

Temperature: 280.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
40.0	195.20	0.9838	0.9830	-0.08
50.0	155.50	0.9797	0.9787	-0.10
60.0	129.10	0.9756	0.9744	-0.12
80.0	96.00	0.9673	0.9658	-0.16
100.0	76.10	0.9591	0.9571	-0.21
125.0	60.20	0.9485	0.9461	-0.25
150.0	49.60	0.9380	0.9350	-0.32
200.0	36.40	0.9164	0.9128	-0.39
300.0	23.07	0.8720	0.8668	-0.60
400.0	16.38	0.8254	0.8192	-0.75
500.0	12.32	0.7757	0.7698	-0.76
600.0	8.56	0.7228	0.6941	-3.97
800.0	5.98	0.6023	0.6116	+1.54
1000.0	3.79	0.4773	0.5253	+10.05

Temperature: 340.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	581.30	0.9954	0.9952	-0.02
20.0	426.40	0.9937	0.9934	-0.03
30.0	283.40	0.9906	0.9902	-0.04
40.0	211.90	0.9874	0.9869	-0.05
50.0	163.90	0.9842	0.9836	-0.06
60.0	140.30	0.9811	0.9803	-0.08
80.0	104.60	0.9747	0.9737	-0.10
100.0	83.10	0.9684	0.9671	-0.13
125.0	65.90	0.9604	0.9588	-0.17
150.0	54.50	0.9524	0.9505	-0.20
200.0	40.20	0.9362	0.9339	-0.25

TABLE XIV (CONTINUED)

Temperature: 340.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
300.0	25.85	0.9037	0.9004	-0.37
400.0	18.68	0.8707	0.8670	-0.43
500.0	14.37	0.8371	0.8337	-0.41
600.0	11.48	0.8029	0.8008	-0.26
800.0	7.85	0.7320	0.7383	+0.86
1000.0	5.69	0.6627	0.6864	+3.58
1250.0	4.05	0.5898	0.6523	+12.29
1500.0	3.16	0.5523	0.6617	+19.81

Temperature: 400.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	625.50	0.9964	0.9963	-0.01
20.0	459.00	0.9951	0.9949	-0.02
30.0	305.30	0.9926	0.9924	-0.02
40.0	228.40	0.9902	0.9898	-0.04
50.0	182.20	0.9877	0.9873	-0.04
60.0	151.50	0.9852	0.9847	-0.05
80.0	113.10	0.9803	0.9797	-0.06
100.0	90.00	0.9754	0.9746	-0.08
125.0	71.50	0.9692	0.9682	-0.10
150.0	59.20	0.9632	0.9619	-0.13
200.0	43.90	0.9509	0.9494	-0.16
300.0	28.48	0.9262	0.9245	-0.18
400.0	20.80	0.9017	0.9002	-0.17
500.0	16.19	0.8772	0.8766	-0.07
600.0	13.12	0.8534	0.8539	+0.06
800.0	9.29	0.8058	0.8124	+0.82
1000.0	7.01	0.7600	0.7787	+2.46

TABLE XIV (CONTINUED)

Temperature: 400.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	5.24	0.7098	0.7528	+6.06
1500.0	4.15	0.6740	0.7495	+11.19
1750.0	3.45	0.6554	0.7678	+17.18
2000.0	3.01	0.6530	0.7993	+22.41

Temperature: 460.0 F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	669.70	0.9972	0.9971	-0.01
20.0	491.60	0.9962	0.9960	-0.02
30.0	327.10	0.9942	0.9940	-0.02
40.0	244.90	0.9923	0.9921	-0.02
50.0	195.50	0.9904	0.9901	-0.03
60.0	162.60	0.9885	0.9881	-0.04
80.0	121.50	0.9847	0.9842	-0.05
100.0	96.80	0.9809	0.9803	-0.06
125.0	77.10	0.9761	0.9754	-0.07
150.0	63.90	0.9715	0.9706	-0.09
200.0	47.50	0.9621	0.9611	-0.10
300.0	31.00	0.9434	0.9423	-0.12
400.0	22.82	0.9250	0.9244	-0.06
500.0	17.90	0.9068	0.9073	+0.06
600.0	14.63	0.8892	0.8912	+0.23
800.0	10.55	0.8548	0.8626	+0.91
1000.0	8.12	0.8227	0.8400	+2.10
1250.0	6.21	0.7870	0.8225	+4.52
1500.0	4.92	0.7471	0.8196	+9.71
1750.0	4.16	0.7373	0.8307	+12.65
2000.0	3.63	0.7355	0.8525	+15.91
2250.0	3.23	0.7376	0.8836	+19.79

TABLE XV

SUMMARY OF CALCULATIONS FOR PROPANE USING METHOD-C*

Temperature: 100.0°F

Pressure psia.	Volume cu.ft./mole	** $Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	403.20	0.9866	0.9875	+0.09
20.0	294.80	0.9816	0.9829	+0.13
30.0	194.60	0.9720	0.9741	+0.22
40.0	144.50	0.9622	0.9652	+0.31
50.0	114.40	0.9521	0.9561	+0.42
60.0	94.30	0.9417	0.9468	+0.54
80.0	69.10	0.9200	0.9275	+0.82
100.0	53.90	0.8966	0.9074	+1.21
125.0	41.60	0.8645	0.8804	+1.84
150.0	33.20	0.8321	0.8507	+2.23

Temperature: 130.0°F

Pressure psia.	Volume cu.ft./mole	** $Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	425.70	0.9885	0.9892	+0.07
20.0	311.40	0.9842	0.9853	+0.11
30.0	205.90	0.9761	0.9777	+0.16
40.0	153.10	0.9678	0.9701	+0.24
50.0	121.40	0.9594	0.9623	+0.30
60.0	100.30	0.9508	0.9544	+0.38
80.0	73.80	0.9330	0.9382	+0.56
100.0	57.90	0.9144	0.9215	+0.78
125.0	45.10	0.8900	0.8996	+1.08
150.0	36.40	0.8637	0.8761	+1.44
200.0	25.47	0.8053	0.8245	+2.38

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* Method-C: $Z_{cal.}$ is obtained using equation (11) and also using generalized form for the force constants.

** $Z_{exp.}$ observed in reference (22), Reamer et al, <u>Industrial and Engineering Chemistry</u>, Vol. <u>41</u>, 1949; p. 483.

TABLE XV (CONTINUED)

Temperature: 160.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0		1.0000	1.0000	0.00
14.7	448.00	0.9900	0.9906	+0.06
20.0	328.00	0.9863	0.9872	+0.09
30.0	217.10	0.9793	0.9807	+0.14
40.0	161.70	0.9722	0.9741	+0.20
50.0	128.40	0.9651	0.9674	+0.24
60.0	106.20	0.9577	0.9607	+0.31
80.0	78.40	0.9428	0.9469	+0.44
100.0	61.70	0.9274	0.9327	+0.57
125.0	48.30	0.9073	0.9144	+0.78
150.0	39.30	0.8863	0.8952	+1.00
200.0	28.00	0.8412	0.8541	+1.53
300.0	16.25	0.7330	0.7541	+2.88

Temperature: 190.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	470.30	0.9913	0.9918	+0.05
20.0	344.50	0.9881	0.9888	+0.07
30.0	228.20	0.9821	0.9832	+0.11
40.0	170.10	0.9759	0.9775	+0.16
50.0	135.20	0.9698	0.9717	+0.20
60.0	112.00	0.9635	0.9659	+0.25
80.0	82.90	0.9508	0.9540	+0.34
100.0	65.40	0.9379	0.9419	+0.43
125.0	51.40	0.9211	0.9263	+0.56
150.0	42.00	0.9037	0.9102	+0.72
200.0	30.20	0.8673	0.8762	+1.02

TABLE XV (CONTINUED)

Temperature: 190.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
300.0	18.26	0.7855	0.7992	+1.74
400.0	11.94	0.6850	0.7011	+2.35
500.0	7.59	0.5462	0.5512	+0.92

Temperature: 220.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	492.50	0.9923	0.9928	+0.05
20.0	360.90	0.9896	0.9902	+0.06
30.0	239.30	0.9846	0.9853	+0.07
40.0	178.50	0.9790	0.9803	+0.13
50.0	142.00	0.9736	0.9753	+0.17
60.0	117.70	0.9682	0.9702	+0.21
80.0	87.30	0.9572	0.9599	+0.28
100.0	69.00	0.9462	0.9495	+0.35
125.0	54.40	0.9320	0.9361	+0.44
150.0	44.60	0.9175	0.9224	+0.53
200.0	32.40	0.8873	0.8940	+0.76
300.0	19.99	0.8221	0.8314	+1.13
400.0	13.65	0.7487	0.7588	+1.35
500.0	9.66	0.6621	0.6696	+1.13
600.0	6.68	0.5496	0.5453	-0.78

Temperature: 280.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	537.00	0.9941	0.9944	+0.03
20.0	393.70	0.9919	0.9924	+0.05
30.0	261.40	0.9879	0.9886	+0.07

TABLE XV (CONTINUED)

Temperature: 280.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
40.0	195.20	0.9838	0.9847	+0.09
50.0	155.50	0.9797	0.9808	+0.11
60.0	129.10	0.9756	0.9769	+0.13
80.0	96.00	0.9673	0.9691	+0.19
100.0	76.10	0.9591	0.9611	+0.21
125.0	60.20	0.9485	0.9510	+0.26
150.0	49.60	0.9380	0.9408	+0.30
200.0	36.40	0.9164	0.9199	+0.38
300.0	23.07	0.8720	0.8758	+0.44
400.0	16.38	0.8254	0.8285	+0.38
500.0	12.32	0.7757	0.7772	+0.19
600.0	8.56	0.7228	0.6925	-4.19
800.0	5.98	0.6023	0.5866	-2.61
1000.0	3.79	0.4773	0.4285	-10.22

Temperature: 340.0°F

0.0	-	1.0000	1.0000	0.00
14.7	581.30	0.9954	0.9956	+0.02
20.0	426.40	0.9937	0.9940	+0.03
30.0	283.40	0.9906	0.9910	+0.04
40.0	211.90	0.9874	0.9880	+0.06
50.0	168.90	0.9842	0.9849	+0.07
60.0	140.30	0.9811	0.9819	+0.08
80.0	104.60	0.9747	0.9758	+0.11
100.0	83.10	0.9684	0.9696	+0.12
125.0	65.90	0.9604	0.9618	+0.15
150.0	54.50	0.9524	0.9540	+0.17
200.0	40.20	0.9362	0.9381	+0.20

TABLE XV (CONTINUED)

Temperature: 340.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
300.0	25.85	0.9037	0.9054	+0.19
400.0	18.68	0.8707	0.8715	+0.09
500.0	14.37	0.8371	0.8363	-0.10
600.0	11.48	0.8029	0.7996	-0.41
800.0	7.85	0.7320	0.7223	-1.32
1000.0	5.69	0.6627	0.6424	-3.06
1250.0	4.05	0.5898	0.5502	-6.72
1500.0	3.16	0.5523	0.4894	-11.38

Temperature: 400.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	625.50	0.9964	0.9965	+0.01
20.0	459.00	0.9951	0.9952	+0.01
30.0	305.30	0.9926	0.9928	+0.02
40.0	228.40	0.9902	0.9905	+0.03
50.0	182.20	0.9877	0.9880	+0.03
60.0	151.50	0.9852	0.9856	+0.04
80.0	113.10	0.9803	0.9808	+0.05
100.0	90.00	0.9754	0.9760	+0.06
125.0	71.50	0.9692	0.9699	+0.07
150.0	59.20	0.9632	0.9638	+0.06
200.0	43.90	0.9509	0.9515	+0.06
300.0	28.48	0.9262	0.9265	+0.03
400.0	20.80	0.9017	0.9011	-0.07
500.0	16.19	0.8772	0.8755	-0.19
600.0	13.12	0.8534	0.8493	-0.48
800.0	9.29	0.8058	0.7968	-1.12
1000.0	7.01	0.7600	0.7448	-2.00

TABLE XV (CONTINUED)

Temperature: 400.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	5.24	0.7098	0.6846	-2.14
1500.0	4.15	0.6740	0.6360	-5.64
1750.0	3.45	0.6554	0.6023	-8.10
2000.0	3.01	0.6530	0.5840	-10.56

Temperature: 460.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	669.70	0.9972	0.9972	0.00
20.0	491.60	0.9962	0.9962	0.00
30.0	327.10	0.9942	0.9943	+0.01
40.0	244.90	0.9923	0.9924	+0.01
50.0	195.50	0.9904	0.9904	0.00
60.0	162.60	0.9885	0.9885	0.00
80.0	121.50	0.9847	0.9847	0.00
100.0	96.80	0.9809	0.9808	-0.01
125.0	77.10	0.9761	0.9760	-0.01
150.0	63.90	0.9715	0.9712	-0.03
200.0	47.50	0.9621	0.9616	-0.05
300.0	31.00	0.9434	0.9421	-0.14
400.0	22.82	0.9250	0.9228	-0.24
500.0	17.90	0.9068	0.9033	-0.39
600.0	14.63	0.8892	0.8839	-0.60
800.0	10.55	0.8548	0.8458	-1.05
1000.0	8.12	0.8227	0.8090	-1.67
1250.0	6.21	0.7870	0.7667	-2.58
1500.0	4.92	0.7471	0.7286	-2.48
1750.0	4.16	0.7373	0.7030	-4.65
2000.0	3.63	0.7355	0.6856	-6.78
2250.0	3.23	0.7376	0.6751	-8.48

TABLE XVI

SUMMARY OF CALCULATIONS FOR PROPANE
USING METHOD-D*

Temperature: 100.0°F

Pressure psia.	Volume cu.ft./mole	** $Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	403.20	0.9866	0.9855	-0.11
20.0	294.80	0.9816	0.9802	-0.14
30.0	194.60	0.9720	0.9700	-0.21
40.0	144.50	0.9622	0.9598	-0.25
50.0	114.40	0.9521	0.9493	-0.29
60.0	94.30	0.9417	0.9386	-0.33
80.0	69.10	0.9200	0.9167	-0.36
100.0	53.90	0.8966	0.8938	-0.31
125.0	41.60	0.8645	0.8634	-0.13
150.0	33.20	0.8321	0.8303	-0.11

Temperature: 130.0°F

0.0		1.0000	1.0000	0.00
14.7	425.70	0.9885	0.9876	-0.09
20.0	311.40	0.9842	0.9830	-0.12
30.0	205.90	0.9761	0.9744	-0.17
40.0	153.10	0.9678	0.9656	-0.23
50.0	121.40	0.9594	0.9567	-0.28
60.0	100.30	0.9508	0.9478	-0.32
80.0	73.80	0.9330	0.9294	-0.39
100.0	57.90	0.9144	0.9105	-0.43
125.0	45.10	0.8900	0.8859	-0.46
150.0	36.40	0.8637	0.8598	-0.45
200.0	25.47	0.8053	0.8031	-0.27

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* Method-D: $Z_{cal.}$ is obtained using equation (11) and also using established force constants.

** $Z_{exp.}$ observed in the reference (22) Reamer et al, <u>Industrial and Engineering Chemistry</u>, Vo. <u>41</u>, 1949; p. 483.

TABLE XVI (CONTINUED)

Temperature: 160.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	448.00	0.9900	0.9892	-0.08
20.0	328.00	0.9863	0.9853	-0.10
30.0	217.10	0.9793	0.9779	-0.14
40.0	161.70	0.9722	0.9704	-0.19
50.0	128.40	0.9651	0.9628	-0.24
60.0	106.20	0.9577	0.9552	-0.26
80.0	78.40	0.9428	0.9396	-0.34
100.0	61.70	0.9274	0.9236	-0.41
125.0	48.30	0.9073	0.9031	-0.45
150.0	39.30	0.8863	0.8818	-0.51
200.0	28.00	0.8412	0.8369	-0.51
300.0	16.25	0.7330	0.7306	-0.33

Temperature: 190.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	470.30	0.9913	0.9907	-0.06
20.0	344.50	0.9881	0.9873	-0.08
30.0	228.20	0.9821	0.9809	-0.12
40.0	170.10	0.9759	0.9744	-0.15
50.0	135.20	0.9698	0.9679	-0.20
60.0	112.00	0.9635	0.9613	-0.23
80.0	82.90	0.9508	0.9480	-0.29
100.0	65.40	0.9379	0.9344	-0.37
125.0	51.40	0.9211	0.9171	-0.43
150.0	42.00	0.9037	0.8993	-0.49
200.0	30.20	0.8673	0.8622	-0.59

TABLE XVI (CONTINUED)

Temperature: 190.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
300.0	18.26	0.7855	0.7806	-0.62
400.0	11.94	0.6850	0.6818	-0.47
500.0	7.59	0.5462	0.5446	-0.29

Temperature: 220.0°F

0.0	-	1.0000	1.0000	0.00
14.7	492.50	0.9923	0.9919	-0.04
20.0	360.90	0.9896	0.9889	-0.07
30.0	239.30	0.9846	0.9834	-0.12
40.0	178.50	0.9790	0.9777	-0.13
50.0	142.00	0.9736	0.9721	-0.15
60.0	117.70	0.9682	0.9664	-0.19
80.0	87.30	0.9572	0.9549	-0.24
100.0	69.00	0.9462	0.9433	-0.31
125.0	54.40	0.9320	0.9286	-0.36
150.0	44.60	0.9175	0.9135	-0.44
200.0	32.40	0.8873	0.8827	-0.52
300.0	19.99	0.8221	0.8166	-0.67
400.0	13.65	0.7487	0.7431	-0.75
500.0	9.66	0.6621	0.6587	-0.51
600.0	6.68	0.5496	0.5543	+0.85

Temperature: 280.0°F

0.0	-	1.0000	1.0000	0.00
14.7	537.00	0.9941	0.9938	-0.03
20.0	393.70	0.9919	0.9915	-0.04
30.0	261.40	0.9879	0.9873	-0.06

TABLE XVI (CONTINUED)

Temperature: 280.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
40.0	195.20	0.9838	0.9830	-0.08
50.0	155.50	0.9797	0.9787	-0.10
60.0	129.10	0.9756	0.9744	-0.12
80.0	96.00	0.9673	0.9658	-0.16
100.0	76.10	0.9591	0.9571	-0.21
125.0	60.20	0.9485	0.9461	-0.25
150.0	49.60	0.9380	0.9351	-0.31
200.0	36.40	0.9164	0.9128	-0.39
300.0	23.07	0.8720	0.8669	-0.58
400.0	16.38	0.8254	0.8195	-0.71
500.0	12.32	0.7757	0.7706	-0.66
600.0	8.56	0.7228	0.6969	-3.58
800.0	5.98	0.6023	0.6208	+3.07
1000.0	3.79	0.4773	0.5669	+18.76

Temperature: 340.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	581.30	0.9954	0.9952	-0.02
20.0	426.40	0.9937	0.9934	-0.03
30.0	283.40	0.9906	0.9902	-0.04
40.0	211.90	0.9874	0.9869	-0.05
50.0	168.90	0.9842	0.9836	-0.06
60.0	140.30	0.9811	0.9803	-0.08
80.0	104.60	0.9747	0.9737	-0.10
100.0	83.10	0.9684	0.9671	-0.13
125.0	65.90	0.9604	0.9588	-0.17
150.0	54.50	0.9524	0.9505	-0.20
200.0	40.20	0.9362	0.9339	-0.25

TABLE XVI (CONTINUED)

Temperature: 340.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
300.0	25.85	0.9037	0.9005	-0.35
400.0	18.68	0.8707	0.8672	-0.40
500.0	14.37	0.8371	0.8341	-0.36
600.0	11.48	0.8029	0.8017	-0.15
800.0	7.85	0.7320	0.7413	+1.27
1000.0	5.69	0.6627	0.6949	+4.86
1250.0	4.05	0.5898	0.6786	+15.06
1500.0	3.16	0.5523	0.7224	+30.80

Temperature: 400.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	625.50	0.9964	0.9963	-0.01
20.0	459.00	0.9951	0.9949	-0.02
30.0	305.30	0.9926	0.9924	-0.02
40.0	228.40	0.9902	0.9898	-0.04
50.0	182.20	0.9877	0.9873	-0.04
60.0	151.50	0.9852	0.9847	-0.05
80.0	113.10	0.9803	0.9797	-0.06
100.0	90.00	0.9754	0.9746	-0.08
125.0	71.50	0.9692	0.9682	-0.10
150.0	59.20	0.9632	0.9619	-0.13
200.0	43.90	0.9509	0.9494	-0.16
300.0	28.48	0.9262	0.9245	-0.18
400.0	20.80	0.9017	0.9003	-0.16
500.0	16.19	0.8772	0.8768	+0.05
600.0	13.12	0.8534	0.8543	+0.11
800.0	9.29	0.8058	0.8138	+0.99
1000.0	7.01	0.7600	0.7821	+2.91

TABLE XVI (CONTINUED)

Temperature: 400.0°F (cont'd)

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
1250.0	5.24	0.7098	0.7617	+7.32
1500.0	4.15	0.6740	0.7690	+14.10
1750.0	3.45	0.6554	0.8041	+22.70
2000.0	3.01	0.6530	0.8568	+31.23

Temperature: 460.0°F

Pressure psia.	Volume cu.ft./mole	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
14.7	669.70	0.9972	0.9971	-0.01
20.0	491.60	0.9962	0.9960	-0.02
30.0	327.10	0.9942	0.9940	-0.02
40.0	244.90	0.9923	0.9921	-0.02
50.0	195.50	0.9904	0.9901	-0.03
60.0	162.60	0.9885	0.9881	-0.04
80.0	121.50	0.9847	0.9842	-0.05
100.0	96.80	0.9809	0.9803	-0.06
125.0	77.10	0.9761	0.9754	-0.07
150.0	63.90	0.9715	0.9706	-0.09
200.0	47.50	0.9621	0.9611	-0.10
300.0	31.00	0.9434	0.9424	-0.10
400.0	22.82	0.9250	0.9245	-0.05
500.0	17.90	0.9068	0.9075	+0.08
600.0	14.63	0.8892	0.8915	+0.26
800.0	10.55	0.8548	0.8633	+0.99
1000.0	8.12	0.8227	0.8417	+2.31
1250.0	6.21	0.7870	0.8267	+3.77
1500.0	4.92	0.7471	0.8286	+11.91
1750.0	4.16	0.7373	0.8465	+14.81
2000.0	3.63	0.7355	0.8775	+19.30
2250.0	3.23	0.7376	0.9206	+24.83

TABLE XVII

SUMMARY OF CALCULATIONS FOR n-BUTANE USING METHOD-A*

Temperature: 100.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}^{**}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	6.802	0.9674	0.9790	+1.20
2.0	3.288	0.9352	0.9566	+2.29

Temperature: 160.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}^{**}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	7.624	0.9793	0.9843	+0.51
2.0	3.733	0.9590	0.9680	+0.94
4.0	1.787	0.9182	0.9335	+1.67
6.0	1.138	0.8771	0.8960	+2.16
8.0	0.813	0.8354	0.8552	+2.37

Temperature: 220.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}^{**}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	8.412	0.9851	0.9880	+0.29
2.0	4.143	0.9704	0.9756	+0.54
4.0	2.009	0.9411	0.9499	+0.94
6.0	1.298	0.9121	0.9228	+1.17
8.0	0.940	0.8807	0.8940	+1.51
10.0	0.725	0.8491	0.8633	+1.67
15.0	0.431	0.7571	0.7741	+2.22

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* Method-A: $Z_{cal.}$ is obtained using equation (8) and also using force constants from critical constants.

** $Z_{exp.}$ observed in reference (23), William et al, Chem. Eng. Progr., Vol. 44, 1947; p. 863-868.

TABLE XVII (CONTINUED)

Temperature: 280.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	9.189	0.9888	0.9906	+0.18
2.0	4.541	0.9773	0.9809	+0.37
4.0	2.221	0.9560	0.9612	+0.54
6.0	1.447	0.9343	0.9408	+0.70
8.0	1.058	0.9108	0.9194	+0.95
10.0	0.825	0.8878	0.8972	+1.06
15.0	0.510	0.8232	0.8363	+1.61
20.0	0.348	0.7490	0.7649	+2.13
25.0	0.245	0.6591	0.6757	+2.52

Temperature: 340.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	9.960	0.9914	0.9925	+0.11
2.0	4.938	0.9830	0.9849	+0.19
4.0	2.427	0.9663	0.9694	+0.32
6.0	1.590	0.9496	0.9535	+0.41
8.0	1.170	0.9317	0.9371	+0.58
10.0	0.919	0.9148	0.9204	+0.61
15.0	0.582	0.8690	0.8761	+0.82
20.0	0.412	0.8202	0.8279	+0.94
25.0	0.308	0.7664	0.7746	+1.07
30.0	0.237	0.7077	0.7147	+0.99
35.0	0.183	0.6375	0.6439	+1.01
37.5	0.161	0.6005	0.6047	+0.70
40.0	0.140	0.5574	0.5594	+0.36
50.0	0.068	0.3384	0.3408	+0.71

TABLE XVII (CONTINUED)

Temperature: 400.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	10.729	0.9934	0.9939	+0.05
2.0	5.329	0.9868	0.9878	+0.10
4.0	2.630	0.9741	0.9755	+0.14
6.0	1.730	0.9611	0.9629	+0.19
8.0	1.279	0.9474	0.9501	+0.29
10.0	1.009	0.9342	0.9371	+0.31
15.0	0.648	0.9000	0.9034	+0.38
20.0	0.467	0.8648	0.8680	+0.37
25.0	0.358	0.8287	0.8308	+0.25
30.0	0.284	0.7889	0.7911	+0.28
35.0	0.231	0.7486	0.7493	+0.09
37.5	0.210	0.7286	0.7280	-0.08
40.0	0.191	0.7074	0.7055	-0.27
50.0	0.133	0.6157	0.6100	-0.93
60.0	0.095	0.5278	0.5188	-1.71
80.0	0.059	0.4370	0.4366	-0.09

Temperature: 460.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	11.492	0.9946	0.9951	+0.05
2.0	5.717	0.9896	0.9901	+0.05
4.0	2.829	0.9794	0.9801	+0.07
6.0	1.867	0.9695	0.9701	+0.06
8.0	1.385	0.9590	0.9598	+0.08
10.0	1.096	0.9486	0.9495	+0.09
15.0	0.710	0.9218	0.9231	+0.14

TABLE XVII (CONTINUED)

Temperature: 460.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
20.0	0.518	0.8967	0.8962	-0.06
25.0	0.402	0.8698	0.8684	-0.16
30.0	0.324	0.8413	0.8396	-0.19
35.0	0.269	0.8147	0.8106	-0.53
37.5	0.246	0.7978	0.7952	-0.33
40.0	0.227	0.7859	0.7806	-0.67
50.0	0.168	0.7270	0.7193	-1.05
60.0	0.129	0.6696	0.6596	-1.49
80.0	0.085	0.5885	0.5727	-2.72

TABLE XVIII

SUMMARY OF CALCULATIONS FOR n-BUTANE USING METHOD-B*

Temperature: 100.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}^{**}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	6.802	0.9674	0.9853	+1.85
2.0	3.288	0.9352	0.9696	+3.68
Temperature: 160.0°F				
0.0	-	1.0000	1.0000	0.00
1.0	7.624	0.9793	0.9891	+1.00
2.0	3.733	0.9590	0.9777	+1.95
4.0	1.787	0.9182	0.9534	+3.84
6.0	1.138	0.8771	0.9267	+5.66
8.0	0.813	0.8354	0.8971	+7.38
Temperature: 220.0°F				
0.0	-	1.0000	1.0000	0.00
1.0	8.412	0.9851	0.9916	+0.66
2.0	4.143	0.9704	0.9830	+1.30
4.0	2.009	0.9411	0.9650	+2.54
6.0	1.298	0.9121	0.9459	+3.71
8.0	0.940	0.8807	0.9252	+5.05
10.0	0.725	0.8491	0.9028	+6.32
15.0	0.431	0.7571	0.8340	+10.15

* Method-B: $Z_{cal.}$ is obtained using equation (8) and also using force constants from literature.

** $Z_{exp.}$ observed in reference (23), William et al, Chem. Eng. Progr., Vol. 44, 1947; p. 863-868.

TABLE XVIII (CONTINUED)

Temperature: 280.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	9.189	0.9888	0.9935	+0.48
2.0	4.541	0.9773	0.9868	+0.97
4.0	2.221	0.9560	0.9731	+1.79
6.0	1.447	0.9343	0.9587	+2.61
8.0	1.058	0.9108	0.9436	+3.60
10.0	0.825	0.8878	0.9276	+4.49
15.0	0.510	0.8232	0.8821	+7.15
20.0	0.348	0.7490	0.8247	+10.11
25.0	0.245	0.6591	0.7448	+13.01

Temperature: 340.0°F

0.0	-	1.0000	1.0000	0.00
1.0	9.960	0.9914	0.9948	+0.34
2.0	4.938	0.9830	0.9896	+0.67
4.0	2.427	0.9663	0.9789	+1.30
6.0	1.590	0.9496	0.9678	+1.92
8.0	1.170	0.9317	0.9563	+2.64
10.0	0.919	0.9148	0.9444	+3.24
15.0	0.582	0.8690	0.9121	+4.96
20.0	0.412	0.8202	0.8750	+6.68
25.0	0.308	0.7664	0.8309	+8.40
30.0	0.237	0.7077	0.7768	+9.77
35.0	0.183	0.6375	0.7056	+10.70
37.5	0.161	0.6005	0.6628	+10.40
40.0	0.140	0.5574	0.6102	+9.49
50.0	0.068	0.3384	0.3438	+1.59

TABLE XVIII (CONTINUED)

Temperature: 400.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	10.729	0.9934	0.9959	+0.25
2.0	5.329	0.9868	0.9917	+0.50
4.0	2.630	0.9741	0.9832	+0.93
6.0	1.730	0.9611	0.9745	+1.39
8.0	1.279	0.9474	0.9656	+1.92
10.0	1.009	0.9342	0.9565	+2.39
15.0	0.648	0.9000	0.9323	+3.59
20.0	0.467	0.8648	0.9059	+4.76
25.0	0.358	0.8287	0.8766	+5.79
30.0	0.284	0.7889	0.8431	+6.87
35.0	0.231	0.7486	0.8053	+7.58
37.5	0.210	0.7285	0.7847	+7.71
40.0	0.191	0.7074	0.7621	+7.74
50.0	0.133	0.6157	0.6555	+6.46
60.0	0.095	0.5278	0.5402	+2.35
80.0	0.059	0.4370	0.4291	-1.81

Temperature: 460.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	11.492	0.9946	0.9967	+0.21
2.0	5.717	0.9896	0.9933	+0.37
4.0	2.829	0.9794	0.9865	+0.72
6.0	1.867	0.9695	0.9796	+1.04
8.0	1.385	0.9590	0.9726	+1.52
10.0	1.096	0.9486	0.9654	+1.77
15.0	0.710	0.9218	0.9468	+2.71

TABLE XVIII (CONTINUED)

Temperature: 460.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
20.0	0.518	0.8967	0.9272	+3.50
25.0	0.402	0.8698	0.9060	+4.17
30.0	0.324	0.8413	0.8829	+4.95
35.0	0.269	0.8147	0.8583	+5.33
37.5	0.246	0.7978	0.8446	+5.87
40.0	0.227	0.7859	0.8311	+5.75
50.0	0.168	0.7270	0.7697	+5.87
60.0	0.129	0.6696	0.7014	+4.71
80.0	0.085	0.5885	0.5895	+0.17

TABLE XIX

SUMMARY OF CALCULATIONS FOR n-BUTANE USING METHOD-C*

Temperature: 100.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}^{**}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	6.802	0.9674	0.9790	+1.20
2.0	3.288	0.9352	0.9566	+2.29
Temperature: 160.0°F				
0.0	-	1.0000	1.0000	0.00
1.0	7.624	0.9793	0.9843	+0.51
2.0	3.733	0.9590	0.9680	+0.94
4.0	1.787	0.9182	0.9335	+1.67
6.0	1.138	0.8771	0.8960	+2.16
8.0	0.813	0.8354	0.8551	+2.36
Temperature: 220.0°F				
0.0	-	1.0000	1.0000	0.00
1.0	8.412	0.9851	0.9880	+0.29
2.0	4.143	0.9704	0.9756	+0.54
4.0	2.009	0.9411	0.9499	+0.94
6.0	1.298	0.9121	0.9228	+1.17
8.0	0.940	0.8807	0.8939	+1.50
10.0	0.725	0.8491	0.8632	+1.66
15.0	0.431	0.7571	0.7735	+2.17

* Method-C: $Z_{cal.}$ is obtained using equation (11) and also using force constants from critical constants.

** $Z_{exp.}$ observed in reference (23), William et al, Chem Eng. Progr., Vol. 44, 1947; p. 863-868.

TABLE XIX (CONTINUED)

Temperature: 280.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	9.189	0.9888	0.9906	+0.18
2.0	4.541	0.9773	0.9809	+0.37
4.0	2.221	0.9560	0.9612	+0.54
6.0	1.447	0.9343	0.9407	+0.68
8.0	1.058	0.9108	0.9194	+0.94
10.0	0.825	0.8878	0.8971	+1.05
15.0	0.510	0.8232	0.8360	+1.56
20.0	0.348	0.7490	0.7641	+2.02
25.0	0.245	0.6591	0.6731	+2.12

Temperature: 340.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	9.960	0.9914	0.9925	+0.11
2.0	4.938	0.9830	0.9849	+0.19
4.0	2.427	0.9663	0.9694	+o.32
6.0	1.590	0.9496	0.9535	+0.41
8.0	1.170	0.9317	0.9371	+0.58
10.0	0.919	0.9148	0.9203	+0.60
15.0	0.582	0.8690	0.8759	+0.79
20.0	0.412	0.8202	0.8275	+0.89
25.0	0.308	0.7664	0.7736	+0.94
30.0	0.237	0.7077	0.7124	+0.67
35.0	0.183	0.6375	0.6385	+0.16
37.5	0.161	0.6005	0.5966	-0.65
40.0	0.140	0.5574	0.5468	-1.90
50.0	0.068	0.3384	0.2466	-27.10

TABLE XIX (CONTINUED)

Temperature: 400.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	10.729	0.9934	0.9939	+0.05
2.0	5.329	0.9868	0.9878	+0.10
4.0	2.630	0.9741	0.9755	+0.14
6.0	1.730	0.9611	0.9629	+0.19
8.0	1.279	0.9474	0.9501	+0.29
10.0	1.009	0.9342	0.9370	+0.30
15.0	0.648	0.9000	0.9033	+0.37
20.0	0.467	0.8648	0.8678	+0.35
25.0	0.358	0.8287	0.8303	+0.24
30.0	0.284	0.7889	0.7901	+0.15
35.0	0.231	0.7486	0.7473	-0.17
37.5	0.210	0.7286	0.7252	-0.47
40.0	0.191	0.7074	0.7017	-0.81
50.0	0.133	0.6157	0.5981	-2.85
60.0	0.095	0.5278	0.4862	-7.87
80.0	0.059	0.4370	0.3408	-22.05

Temperature: 460.0°F

0.0	-	1.0000	1.0000	0.00
1.0	11.492	0.9946	0.9951	+0.05
2.0	5.717	0.9896	0.9901	+0.05
4.0	2.829	0.9794	0.9801	+0.07
6.0	1.867	0.9695	0.9701	+0.06
8.0	1.385	0.9590	0.9598	+0.08
10.0	1.096	0.9486	0.9495	+0.09
15.0	0.710	0.9218	0.9231	+0.16

TABLE XIX (CONTINUED)

Temperature: 460.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
20.0	0.518	0.8967	0.8961	-0.07
25.0	0.402	0.8698	0.8681	-0.20
30.0	0.324	0.8413	0.8391	-0.26
35.0	0.269	0.8147	0.8096	-0.63
37.5	0.246	0.7978	0.7939	-0.49
40.0	0.227	0.7859	0.7788	-0.90
50.0	0.168	0.7270	0.7147	-1.69
60.0	0.129	0.6696	0.6489	-3.14
80.0	0.085	0.5885	0.5366	-8.82

TABLE XX

SUMMARY OF CALCULATIONS FOR n-BUTANE USING METHOD-D*

Temperature: 100.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}^{**}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	6.802	0.9674	0.9674	+1.85
2.0	3.288	0.9352	0.9696	+3.68

Temperature: 160.0°F

0.0	-	1.0000	1.0000	0.00
1.0	7.624	0.9793	0.9891	+1.00
2.0	3.733	0.9590	0.9777	+1.95
4.0	1.787	0.9182	0.9536	+3.86
6.0	1.138	0.8771	0.9274	+5.74
8.0	0.813	0.8354	0.8989	+7.58

Temperature: 220.0°F

0.0	-	1.0000	1.0000	0.00
1.0	8.412	0.9851	0.9916	+0.66
2.0	4.143	0.9704	0.9830	+1.30
4.0	2.009	0.9411	0.9651	+2.55
6.0	1.298	0.9121	0.9463	+3.75
8.0	0.940	0.8807	0.9261	+5.15
10.0	0.725	0.8491	0.9047	+6.55
15.0	0.431	0.7571	+11.21	

* Method-D: $Z_{cal.}$ is obtained using equation (11) and also using force constants from literature.

** $Z_{exp.}$ observed in reference (23), William et al, Chem. Eng. Progr., Vol. 44, 1947; p. 863-868.

TABLE XX (CONTINUED)

Temperature: 280.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	9.189	0.9888	0.9935	+0.48
2.0	4.541	0.9773	0.9868	+0.97
4.0	2.221	0.9560	0.9731	+1.79
6.0	1.447	0.9343	0.9589	+2.63
8.0	1.058	0.9108	0.9441	+3.66
10.0	0.825	0.8878	0.9286	+4.59
15.0	0.510	0.8232	0.8861	+7.64
20.0	0.348	0.7490	0.8357	+11.58
25.0	0.245	0.6591	0.7716	+17.10

Temperature: 340.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	9.960	0.9914	0.9948	+0.34
2.0	4.938	0.9830	0.9896	+0.67
4.0	2.427	0.9663	0.9789	+1.30
6.0	1.590	0.9496	0.9679	+1.93
8.0	1.170	0.9317	0.9566	+2.67
10.0	0.919	0.9148	0.9450	+3.30
15.0	0.582	0.8690	0.9143	+5.22
20.0	0.412	0.8202	0.8806	+7.36
25.0	0.308	0.7664	0.8430	+9.99
30.0	0.237	0.7077	0.8000	+13.05
35.0	0.183	0.6375	0.7477	+17.30
37.5	0.161	0.6005	0.7179	+19.55
40.0	0.140	0.5574	0.6822	+22.40
50.0	0.068	0.3384	0.4561	+34.73

TABLE XX (CONTINUED)

Temperature: 400.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	10.729	0.9934	0.9959	+0.25
2.0	5.329	0.9868	0.9917	+0.50
4.0	2.630	0.9741	0.9832	+0.93
6.0	1.730	0.9611	0.9746	+1.40
8.0	1.279	0.9474	0.9658	+1.94
10.0	1.009	0.9342	0.9568	+2.42
15.0	0.648	0.9000	0.9336	+3.73
20.0	0.467	0.8648	0.9091	+5.13
25.0	0.358	0.8287	0.8831	+6.57
30.0	0.284	0.7889	0.8551	+8.38
35.0	0.231	0.7486	0.8251	+10.22
37.5	0.210	0.7286	0.8096	+11.11
40.0	0.191	0.7074	0.7930	+12.10
50.0	0.133	0.6157	0.7189	+16.74
60.0	0.095	0.5278	0.6362	+20.50
80.0	0.059	0.4370	0.5167	+18.25

Temperature: 460.0°F

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
0.0	-	1.0000	1.0000	0.00
1.0	11.492	0.9946	0.9967	+0.21
2.0	5.717	0.9896	0.9933	+0.37
4.0	2.829	0.9794	0.9865	+0.72
6.0	1.867	0.9695	0.9797	+1.05
8.0	1.385	0.9590	0.9727	+1.53
10.0	1.096	0.9486	0.9657	+1.80
15.0	0.710	0.9210	0.9476	+2.80

TABLE XX (CONTINUED)

Temperature: 460.0°F (cont'd)

Pressure atm.	Volume cu.ft./lb.	$Z_{exp.}$	$Z_{cal.}$	% Dev.
20.0	0.518	0.8967	0.9291	+3.61
25.0	0.402	0.8698	0.9099	+4.62
30.0	0.324	0.8413	0.8899	+5.77
35.0	0.269	0.8147	0.8695	+6.74
37.5	0.246	0.7978	0.8585	+7.61
40.0	0.227	0.7859	0.8480	+7.89
50.0	0.168	0.7270	0.8029	+10.43
60.0	0.129	0.6696	0.7558	+12.83
80.0	0.085	0.5885	0.6715	+14.11

TABLE XXI

SECOND AND THIRD VIRIAL COEFFICIENTS
FOR ETHYLENE
AS A FUNCTION OF TEMPERATURE

Temp. °K	B(T)*	C(T)*	B(T)**	C(T)**
288.7	-149.94	7573.6	-140.80	5263.2
310.9	-129.28	7188.4	-121.98	5044.2
344.3	-104.03	6646.0	- 99.16	4686.0
377.6	- 83.83	6190.7	- 81.05	4361.4
410.9	- 67.59	5828.6	- 66.35	4089.8
444.3	- 54.55	5549.1	- 54.25	3870.0
477.6	- 42.59	5303.6	- 44.04	3692.1
510.9	- 32.96	5125.3	- 35.33	3547.9
533.2	- 27.26	5023.7	- 30.22	3467.8

* Second and third virial coefficients using force constants from literature based on experimental P-V-T data.

** Second and third virial coefficients using force constants calculated from critical constants.

TABLE XXII

SECOND AND THIRD VIRIAL COEFFICIENTS
FOR ETHANE
AS A FUNCTION OF TEMPERATURE

Temp. °K	B(T)*	C(T)*	B(T)**	C(T)**
310.9	-127.37	3591.0	-159.67	6728.2
344.3	-104.93	3432.7	-130.96	6330.8
377.6	- 87.20	3222.1	-108.22	5910.2
410.9	- 72.90	3019.6	- 89.81	5533.9
444.3	- 61.11	2842.6	- 74.60	5216.2
477.6	- 51.22	2693.2	- 61.91	4955.9
510.9	- 42.81	2569.1	- 51.02	4740.2

* Second and third virial coefficients using force constants from literature based on experimental P-V-T data.

** Second and third virial coefficients using force constants calculated from critical constants.

TABLE XXIII

SECOND AND THIRD VIRIAL COEFFICIENTS FOR PROPANE AS A FUNCTION OF TEMPERATURE

Temp. °K	B(T)*	C(T)*	B(T)**	C(T)**
310.9	-366.40	30121.3	-315.52	12631.3
327.6	-331.73	29547.7	-287.40	13149.6
344.3	-301.63	28745.2	-262.61	13291.5
360.9	-274.63	27864.8	-240.50	13186.4
377.6	-250.56	26967.6	-220.79	12985.0
410.9	-209.27	25266.9	-187.45	12354.8
444.3	-175.34	23788.1	-159.92	11676.0
477.6	-146.86	22542.6	-136.92	11040.1
510.9	-122.68	21511.8	-117.48	10478.7

* Second and third virial coefficients using force constants from literature based on experimental P-V-T data.

** Second and third virial coefficients using force constants calculated from critical constants.

TABLE XXIV

SECOND AND THIRD VIRIAL COEFFICIENTS
FOR n-BUTANE
AS A FUNCTION OF TEMPERATURE

Temp. °K	B(T)*	C(T)*	B(T)**	C(T)**
310.9	-363.16	12152.3	-519.09	12694.2
344.3	-303.14	14032.8	-434.28	19709.6
377.6	-256.15	14200.5	-368.20	21819.6
410.9	-218.30	13740.3	-315.31	21935.0
444.3	-187.21	13080.2	-272.07	21262.5
477.6	-161.38	12398.4	-236.07	20324.2
510.9	-139.46	11766.4	-205.67	19345.8

* Second and third virial coefficients using force constants from literature based on experimental P-V-T data.

** Second and third virial coefficients using force constants calculated from critical constants.

NOMENCLATURE

$B(T)$	Second Virial Coefficient
$C(T)$	Third Virial Coefficient
D	Fourth Virial Coefficient
E	Fifth Virial Coefficient
F	Sixth Virial Coefficient
H	Enthalpy
P	Pressure
P_c	Critical Pressure
R	Gas Constant
S	Entropy
T	Temperature
T_c	Critical Temperature
U	Internal Energy
V	Molar Volume
V_c	Critical Volume
Z	Compressibility Factor
Z	Critical Compressibility Factor
ϵ/k	Force Constant
b_o	Kinetic Constant
r	Collision Diameter
o	Indicates the Ideal Gaseous State
$*$	Indicates the Reduced Quantity

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