# VOLUMETRIC AND PHASE BEHAVIOR OF PROPENE-1-BUTENE SYSTEM

Thesis by

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In Partial Fulfillment of the Requirements
For the Degree of
Chemical Engineer

California Institute of Technology
Pasadena, California
1948

# ACKNOWLEDGEMENT

This investigation was sponsored by the Socony-Vacuum Oil Company. The advice and guidance of Professors B. H. Sage and W. N. Lacey have been most helpful. The assistance of H. H. Reamer in connection with the experimental work is greatly appreciated. W. M. McCardell and J. W. Schmit assisted with some of the calculations necessary for the preparation of the data. Helpful advice was received from P. S. Farrington and G. P. Guill.

# ABSTRACT

The volumetric behavior of an 81.739 mole % 1-butene mixture of propene and 1-butene was investigated at seven temperatures from 40°F to 280°F over a pressure range from about 40 pounds per square inch absolute to 10,000 pounds per square inch absolute. Tabulations of single-phase and two-phase data interpolated to even values of pressure are presented.

Revised volumetric data for three mixtures of propene and 1-butene previously investigated by Farrington are presented in tabular form over similar ranges of temperature and pressure. Variations of actual volumetric behavior from ideal behavior are shown graphically for the system.

The compositions of bubble-point liquid and dew-point gas were established experimentally throughout the two-phase region for temperatures between 40° and 280°F. Values of specific volume and composition for coexisting liquid and gas phases are tabulated. Equilibrium constants are given for propene and 1-butene. Properties for the critical region are estimated.

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# I. INTRODUCTION

Olefins are becoming of increasing industrial importance as raw materials because of their susceptability to varied chemical reactions. A growing synthetic chemical industry makes use of olefins as a starting point in the production of a relatively large number of organic compounds. The petroleum industry is a source of vast quantities of unsaturated hydrocarbons which result from cracking operations. Natural gas can be converted in part to olefins by cracking or catalytic dehydrogenation.

Propene and 1-butene are two of the more common and important olefins. Together they enter into many polymerization reactions. Because propene and 1-butene are very similar in their physical and chemical properties, an accurate knowledge of the phase equilibrium for the system is needed for separation processes. Reliable volumetric and phase equilibrium data concerning 1-butene and propene may serve to illustrate the behavior of other closely related olefins.

Almost no experimental volumetric and phase equilibria data are to be found in the literature concerning combinations of unsaturated aliphatic compounds. The behavior of mixtures of propene and 1-butene does not appear to have been investigated previously. However, the two individual components have been investigated in some detail. Olds, Sage, and Lacey (1), in this laboratory, have established the volumetric behavior of 1-butene at pressures up to 10,000 pounds per square inch and in the temperature interval between 100° and 340°F. The results of other investigations of 1-butene may be found in the literature (2)(3)(4)(5). The volumetric behavior of propene was studied recently in this laboratory by Farrington (5)(6), who used pressures up to 10,000 pounds per square inch throughout the temperature interval between 40°and 460°F. Other investigations of the volumetric behavior of propene are reported in the literature (8)(9)(10)(11).

Farrington began the study of the propene-1-butene system and reported his results in a thesis(6). He investigated the volumetric properties of 17.050, 33.153, and 69.050 mole % 1-butene mixtures. The initial smoothing of his primary data was accomplished by Farrington. The final smoothing of Farrington's results against composition of the system was carried out by the author. The data are included in the present thesis.

The inconsistencies of data found by different investigators are expected to be more in the case of olefins than with paraffins, due to greater instability and difficulty of preparation. The present work was restricted to a maximum temperature of 280°F as a result of a previous investigation of 1-butene which reported a marked deterioration above 300°F. No appreciable decomposition, polymerization, or isomerization were detected during the investigation.

## II. MATERIALS

The propene employed in this investigation was obtained from the Phillips Petroleum Company with an analyzed purity of greater than 0.995 mole fraction propene. Further purification of the propene was carried out by a fractionation at atmospheric pressure in a column packed with small glass helices. A reflux ratio of approximately 40 to 1 was used, and the first tenth and the last fifth of the material were discarded in the course of the fractionation. The purity of the propene was checked in the volumetric apparatus by means of an isothermal vaporization from bubble point to dew point at 100°F. Several batch lots of purified propene were prepared during the course of the investigation, and the maximum change of vapor pressure found in going isothermally at 100°F from bubble point to dew point was 0.8 pound per square inch.

The 1-butene was prepared by dehydration of n-butanol with activated alumina as a catalyst. A description of apparatus, preparation procedure, and method of purification used may be found in the literature (1). A modification of the apparatus was made in that the 4-8 mesh catalyst as described in the literature had been replaced with 8-14 mesh granular alumina. As a result the optimum flow rate of liquid n-butanol was increased from 35 to about 60 drops per minute. The maximum change in vapor pressure in going isothermally at 130°F from bubble point to dew point for any of the batches of 1-butene was 0.7 pound per square inch. Quantities of 1-butene were prepared as above shortly before use in the volumetric apparatus. The time of storage of the 1-butene was held to a minimum to reduce the possibility of an isomerization to 2-butene.

## III. EXPERIMENTAL METHOD AND ACCURACY OF RESULTS

The pressure-volume-temperature apparatus employed in the volumetric studies has been described in detail in the literature (12). However, it is felt that a brief description of the equipment is warranted here. In principle the apparatus (Figure 1) consists of a stainless steel chamber within which a sample of known weight and composition is introduced by a weighing bomb technique which has been described (12). The weight of sample is known within 0.1% and the composition to within 0.001 mole fraction. The sample is confined within the chamber, and simultaneous measurements of pressure, temperature, and volume of the sample are made after equilibrium has been attained. The equilibrium condition of the contents of the chamber is provided by mechanical agitation using a cylindrical cage of inclined paddles attached to vertical rods, activated by means of an electromagnet rotating about the outside of the chamber. The equilibrium chamber is submerged in an agitated oil bath whose temperature is controlled to within 0.03°F of the desired value. The temperature is measured with a strain-free platinum resistance thermometer in connection with a Müeller bridge. A cooling unit which draws kerosene from the oil bath, passes it over freon-cooled coils, and returns the kerosene to the oil bath is used at temperatures below 100°F. The volume of the sample in the chamber is varied by introduction or withdrawal of mercury. The quantity of mercury added to the equilibrium chamber is established from the change in elevation of a mercury-air interface within an interconnected air chamber as measured by an electric probe. The measurement of volume is possible with less accuracy than either the measurement of pressure or of temperature, and the volumes are estimated to be known within 0.2-0.3%. The pressure is measured by a balance of the piston-cylinder type (12) which is calibrated against the vapor pressure of carbon dioxide at the ice point (13). The equilibrium pressure may be measured within 0.1 pound per square inch or 0.05%, whichever is larger in magnitude.

The method used in obtaining volumetric data may be summarized as follows:

1) After the sample has been introduced into the chamber, the pressure is raised to the greatest desired value by injecting mercury into the chamber.

2) The oil bath is maintained at a predetermined temperature and frequent readings are taken to see that no deviations occur from the desired temperature.

3) A sufficient period of time before taking measurements is allowed for equilibrium to be attained as shown by constancy of pressure and temperature with time.

4) Measurements of volume and pressure are made.

5) The pressure is decreased, equilibrium is re-established, and the process of making measurements of pressure and volume is repeated until that time at which the maximum working volume of the chamber is reached.

6) The temperature of the oil bath is changed to another desired value, and the entire process of measurements is repeated at the new temperature.

7) After completion of the highest temperature, a volumetric check is made at 100°F to determine any possible changes which have

occurred in the sample or apparatus during the run. The changes must amount to less than 0.2% or lie within the accuracy of the experimental results.

8) In order to obtain data in the low-pressure range, the sample is reduced to approximately one-eighth of its former size by removing a known weight of sample from the chamber by means of a weighing bomb technique. The sample size reduction must necessarily be done with the sample in a homogeneous state in order to avoid a change in composition of the sample. After the reduction of sample size, a check of the bubble-point pressure at 100°F is made to show that no change in composition has resulted. At each temperature, measurements are made with the small sample in the same manner as with the large sample, except that a lower pressure range is used.

The composition of coexisting phases in the propene-1-butene system was determined by removing a sample of dew-point gas at a given equilibrium pressure and temperature from the PVT chamber and analyzing the sample. Various methods of analyzing the composition of gaseous samples of 1-butene and propene were investigated including the use of a mass-spectrometer (14)(15). Four different mixtures of propene and 1-butene were prepared with known compositions and were used to test the accuracy possible with a mass-spectrometer analysis. Of the four mixtures analyzed with the mass-spectrometer of the General Petroleum Corporation, Torrance, California, two analyses agreed within 0.1% of the known compositions. The other two analyses deviated by approximately 1% from the known compositions, and the reproducibility of the analyses varied over a range of several per cent. The Consolidated

Engineering Corporation, Pasadena, California, advised that analysis accuracies of the order of 0.1-0.2% could be obtained for approximately equimolal mixtures only with difficulty and by use of special techniques. As these facts discouraged the use of the mass spectrometer, it was decided to employ a gas density method which had proven successful in this laboratory in the analysis of dew-point gas for the methane-propane system.

Samples of propene and 1-butene were added to the PVT chamber by weighing bomb techniques, with the composition of the mixture adjusted to lie somewhere in the two-phase region at the prescribed pressure and temperature. After equilibrium had been attained in the PVT chamber as shown by constancy of pressure and volume readings, the equilibrium pressure was recorded; approximately a one-gram sample of dew-point gas was withdrawn from the chamber and throttled into an evacuated 500 milliliter glass sample bulb, as shown schematically in Figure 1. During the withdrawal of the sample, the phase equilibrium within the chamber must not be disturbed and the equilibrium pressure must be maintained. Withdrawals were made with the agitator within the chamber turned off, and the period of time required for withdrawal was kept at a minimum. The displacement pressure of the dew-point gas was maintained at a relatively constant value during a withdrawal through the use of an auxiliary air chamber of approximately two cubic feet capacity. This vessel was connected to the air chamber of the PVT apparatus, and the pressure adjusted to the equilibrium value desired for the withdrawal. The relatively small change in volume of the total system caused by the withdrawal of the sample resulted in variations in pressure of less than three pounds per square inch from the equilibrium value. It is believed that the withdrawal technique did not cause significant changes in the composition of the dew-point gas from the equilibrium conditions. The volumes of the glass sample bulbs had been determined by previous calibrations with pure hydrocarbons. The estimated uncertainty in volume was within 0.15%. The pressure of the gas in the sample bulbs was approximately one atmosphere and was measured by means of a mercury manometer and a cathetometer to within ±.02 centimeters of mercury. The sample bulbs were brought to a constant temperature in a box through which air was circulated at room temperature. After a constant temperature had been reached by the sample bulb as shown by a mercury-in-glass thermometer calibrated to 0.1°F, values of pressure and temperature were recorded for the gas sample and the bulb stopcock closed. Duplicate samples of dew-point gas were withdrawn for each phase analysis.

The density of the gas mixture in the sample bulb was determined with a Christian-Becker analytical balance of the chainomatic type and with calibrated stainless steel weights. The method of substitution was employed in all weighings. That is, the calibrated weights and sample bulb were placed on the same pan of the balance and a tare weight was placed on the other pan. After the evacuated weight of the sample bulb had been increased by the weight of the sample, an equivalent weight had to be removed from that pan since the same tare weight was being used for both weighings. Errors due to unequal balance arm lengths were cancelled out in this weighing procedure. An identical glass sample bulb filled with air at atmospheric pressure was used as a tare weight to eliminate buoyancy corrections. The tare bulb was handled and conditioned in exactly the same manner as the sample bulbs in order to compensate for conditioning errors. From the known PVT properties of propene and 1-butene and the weight of sample, the composition of the dew-point gas could be determined. This method of calculation is described in detail in the appendix and did not make use of the assumption of ideal solutions. The average value obtained from the duplicate analyses was the one reported. It is believed that the experimental results have an accuracy within 0.25%. As a check on the method, analyses of dew-point gas of a known composition were made with agreement within 0.2%.

## IV. EXPERIMENTAL RESULTS

The volumetric properties of the propene-1-butene system in the single phase region are presented in Table I. Four experimental mixtures were employed for gathering data for the system. The experimental data for the 17.050, 33.153, and 69.050 mole % 1-butene mixtures were obtained by Farrington (6). After the fourth mixture had been completed, Farrington's data were rechecked and smoothed against the composition of the system to assure consistency among all mixtures and the pure components. This procedure resulted in minor corrections to the data tabulated in Farrington's thesis and in addition allowed his data to be augmented in the low-pressure region.

The experimental results for the 81.739% 1-butene mixture were obtained by the author. The volumetric data in the liquid region were smoothed against pressure and temperature in a manner similar to that described by Farrington (6). After the results for the mixture were consistent, smoothing against composition of the system was employed. In the dew-point and attenuated-gas region the experimental data were used to construct isothermal curves on residual volume-pressure plots for each experimentally studied mixture. The isotherms were extrapolated to zero pressure. The values of residual volume obtained at zero pressure were smoothed by the use of a method attributed to Dr. R. H. Olds, formerly of this laboratory. This method makes use of equations of the following form:

At $P = 0$ :

$$1)\quad \underset{\sim}{V} = \frac{\alpha}{T} + \beta$$

$$2)\quad \underset{\sim}{V} = A\underline{n}_k^2 + B\underline{n}_k + C$$

Where $\alpha$ and $\beta$ are empirical coefficients dependent upon the composition of the system; A, B, and C are empirical coefficients dependent upon the temperature of the system.

From smooth isothermal curves joining the $\underset{\sim}{V}$ values at zero pressure with the experimentally determined values at higher pressures, the volumetric behavior of the mixtures at intervening pressures were determined. All experimental data were obtained at irregular pressures and have been interpolated to even values of pressure for convenience in use. The graphical methods employed were carried out on 50 x 75 centimeter size millimeter coordinate paper with scales chosen consistent with the accuracy of the data. It is believed that no uncertainties greater than 0.1% were introduced by these methods and that the smoothing operations should have the effect of increasing, rather than decreasing, the accuracy of the data. The accuracy of the data in the single phase region is thought to be of the order of 0.2% except in the vicinity of the critical region where an added uncertainty of as much as 0.1% may be expected. Figure 2 shows the effect of change of composition within the system on the relation of compressibility factor to pressure.

Values of specific volume and compressibility factor within the heterogeneous region of the 81.739 mole % 1-butene mixture are presented in Table II. Isothermal curves of compressibility factor versus pressure were used for smoothing the data and for making interpolations to even values of pressure. Experience has shown the compressibility factor to be of the most value in relating volumetric properties within the two-phase region. Because the data in the two-phase region could not be smoothed against temperature, greater uncertainties may be expected in the two-phase region than in the single-phase region. Also the scattering of experimental data was greater in the two-phase region than in the single-phase region, which fact indicates difficulty in attaining equilibrium in the time allowed. It is thought that the recorded values of two-phase specific volume may involve uncertainties up to 0.5%.

Table III lists the experimental coexisting-phase data obtained from the volumetric studies and from the dew-point gas analyses. It is of interest to note that for the 81.739 mole % 1-butene mixture the phenomenon of retrograde dew-point was observed at 280°F. The values of bubble-point pressure and volume were determined from the volumetric data by the method described by Sage, Backus, and Lacey (16), and the dew-point values were obtained by a similar method employing the abrupt discontinuity which occurs with the compressibility factor at the dew point. The properties of coexisting liquid and gas phases in the propene-1-butene system are presented in Table IV. These properties have been interpolated to correspond with even values of pressure for convenience in use.

In cases where experimental results were not available, graphical methods were employed to obtain the necessary values from other experimental data. Volumetric values for the pure components at 250°F were obtained by graphical interpolation between 220° and 280°F values. The vapor pressures of 1-butene at 40°F and 70°F were obtained from the literature (5), and the volumes of bubble-point liquid at these temperatures were obtained by extrapolation of isothermal curves on volume-pressure plots and checked by cross plotting against temperature and against composition of the system. Approximate values of compressibility factor at 40°F and 70°F were obtained for the dew-point gas of 1-butene by extrapolation of the isothermal curves of pressure versus compressibility factor for the pure substance. These values of compressibility factor were checked by cross plotting against temperature and against composition of the system. Values of residual volume were calculated from the compressibility factors by means of the equation:

$$\underset{\sim}{V} = (1 - Z)\frac{bT}{P}$$

The dew-point locus for 1-butene was drawn on a pressure-$\underset{\sim}{V}$ plot and extrapolated to values of $\underset{\sim}{V}$ at 70°F and 40°F. These extrapolated values of $\underset{\sim}{V}$ had to agree with the values of $\underset{\sim}{V}$ calculated from the above equation. By working back and forth between Z and $\underset{\sim}{V}$ plots, consistent values were obtained for the dew points at 40°F and 70°F. Because of the high sensitivity of the residual volume function, it was thought that satisfactory accuracy was obtained.

The dew-point properties of all mixtures at 40°F, of all mixtures except the 17.050% mixture at 70°F, and of the 81.739% mixture at 100°F had to be determined by graphical methods. The dew-point pressures were obtained from isothermal curves on pressure-composition plots and checked on a pressure-temperature diagram. Values of dew-point compressibility factor were derived by plotting diagrams of Z versus pressure and Z versus temperature for each mixture and by cross plotting against composition. The three plots were made mutually consistent and values of residual volume were calculated from the compressibility factor values. The dew-point locus for each mixture was plotted on a pressure-V diagram and extrapolated to the value at 40°F. The procedure used in obtaining consistent values of Z and of V was similar to the one employed with pure 1-butene.

All experimental coexisting-phase data were plotted as isothermal curves on pressure-composition diagrams as illustrated in Figure 3. Cross plots were made of temperature-composition at pressures of 50, 100, 200, 300, 500, 588, and 610 pounds per square inch absolute, and also of pressure-temperature for the experimental compositions used. Figures 4 and 5 show these diagrams. Smooth curves were obtained with all plots, which showed that the data were consistent. Values of the gas-liquid equilibrium constant ($K = \frac{y}{x}$) were calculated from bubble-point and dew-point compositions at various selected pressures which were taken from the pressure-composition plots. Figure 6 shows a plot of PK versus P for propene and 1-butene. The product of pressure and equilibrium constant was chosen as a coordinate in order to provide a magnified scale for the plotting of equilibrium constants. The PK versus P plot has been smoothed in conjunction with the curves on the pressure-composition diagram so that the two plots are mutually consistent. The smoothing of the above-mentioned curves also resulted in a small amount of additional smoothing performed on the temperature-composition and pressure-temperature plots to make all diagrams consistent.

Isothermal curves on specific volume-composition plots were constructed which allowed values of specific volume to be obtained for any desired composition of bubble-point liquid or dew-point gas.

The properties in the critical region have been estimated since insufficient experimental data were available within this region. These properties are presented in Table V. It is believed that the critical envelope of the system was established within 1% uncertainty.

The critical values of propene and 1-butene were available from the literature (7)(1), and the critical pressure at 280°F was known within narrow limits. The critical envelope could be drawn through these points on the pressure-temperature diagram as a smooth curve. This critical locus determined points by intersection at 220°F and 250°F. The dew-point and bubble-point curves were extrapolated on the pressure-composition and pressure-temperature diagrams, keeping the curves mutually consistent at all times. This extrapolation on the pressure-temperature diagram determined the critical points of the mixtures within narrow limits. Plots of P versus Z and Z versus composition were constructed to aid in further delineating the critical region. Critical volumes of the mixtures were obtained by applying the rule of rectilinear diameters (17) to each mixture. The loci of the critical volumes plotted versus temperature and versus composition were in the form of smooth curves.

Each cricondentherm, or value of maximum temperature at which two coexisting phases occur for a given mixture composition, was obtained by drawing in a smooth locus on the pressure-temperature diagram. The cricondentherm volumes were obtained from the density versus pressure plots constructed for use with the method of rectilinear diameters.

The propene-1-butene system results may be compared with calculated ideal values. The deviations of the actual bubble-point pressures of mixtures from predictions by Raoult's Law are shown at 160°F in Figure 7. From the assumptions of Raoult's and Dalton's Laws, the following "ideal vapor pressure" is obtained:

$$P''_r = x_3P''_3 + x_4P''_4$$

The deviation of the actual vapor pressure from the ideal vapor pressure of the mixture is given by the expression:

$$\underset{\sim}{P''} = P''_r - P''$$

The percentage deviation of actual specific volumes from those volumes calculated on the basis of ideal solutions is presented in Figure 8 for pressures of 100, 600, and 10,000 pounds per square inch absolute at 160°F. The ordinate for this figure is defined by the equation:

$$\%\text{ deviation} = \frac{(V_{ideal} - V)(100)}{V_{ideal}}$$

The values of $V_{ideal}$ are given by the relation:

$$V_{ideal} = x_3V_3 + x_4V_4$$

It is interesting to note that the liquid mixtures at 10,000 pounds per square inch are more nearly ideal solutions than are the gaseous mixtures at 100 pounds per square inch.

Equilibrium constant values may be calculated from consideration of Raoult's and Dalton's Laws which may be combined to give:

$$(1) \quad x_kP''_k = y_kP$$

or

$$(2) \quad K_k = \frac{y_k}{x_k} = \frac{P''_k}{P}$$

and

$$(3) \quad PK_k = P''_k$$

Equation (3) indicates that for a given temperature the calculated value of $PK_k$ will be equal to the vapor pressure of the pure component. A horizontal line for each temperature and for each component will result on the PK versus P plot shown in Figure 6.

Hadden (18) has presented values of ideal gas-liquid equilibrium constants for a number of hydrocarbons as a result of correlations of experimental data and fugacities. It is of interest to compare his ideal K values, read from a nomogram, for propene and 1-butene with the actual experimental values.

| T | P | Experimental | | Hadden (18) | |
|---|---|---|---|---|---|
| °F | PSI abs. | $K_3$ | $K_4$ | $K_3$ | $K_4$ |
| 40 | 50 | 1.772 | .485 | 2.00 | .55 |
| 70 | 100 | 1.420 | .439 | 1.61 | .44 |
| 100 | 200 | 1.096 | .43 | 1.20 | .37 |
| 160 | 300 | 1.299 | .619 | 1.37 | .52 |
| 220 | 400 | 1.428 | .834 | 1.60 | .71 |
| 250 | 500 | 1.342 | .896 | 1.55 | .74 |
| 280 | 600 | 1.172 | .966 | 1.50 | .75 |

The deviations from ideal behavior shown above for the system are between 0 - 28%. As pressures approach the critical region, ideal equilibrium constants become less valid.

## V. NOMENCLATURE

b = specific gas constant $= \frac{R}{M}$, $(lb/in^2)(ft^3/lb)/^{\circ}R$

$R = 10.73185$ $M_3 = 42.079$ $M_4 = 56.105$

Propene b = 0.25504

Mixture containing 17.050% 1-butene b = 0.24133

Mixture containing 33.153% 1-butene b = 0.22966

Mixture containing 69.050% 1-butene b = 0.20732

Mixture containing 81.739% 1-butene b = 0.20043

1-Butene b = 0.19128

K = gas-liquid equilibrium constant $= \frac{y}{x}$

$\underline{n}$ = mol fraction of a component

P = pressure, lb./sq. in. abs.

$\underset{\sim}{P}''$ = residual vapor pressure, lb./sq. in. abs.

$P''$ = vapor pressure of pure component at a given temperature, lb./sq. in. abs.

$P''_r$ = reference vapor pressure, lb./sq. in. abs.

T = absolute temperature, °F absolute, °R

V = specific volume, cu. ft./lb.

$\underset{\sim}{V}$ = residual volume $= \frac{bT}{P} - V$, cu. ft./lb.

x = mol fraction of a component in liquid phase

y = mol fraction of a component in gas phase

Z = compressibility factor $= \frac{PV}{bT}$

Subscripts

3 refers to propene

4 refers to 1-butene

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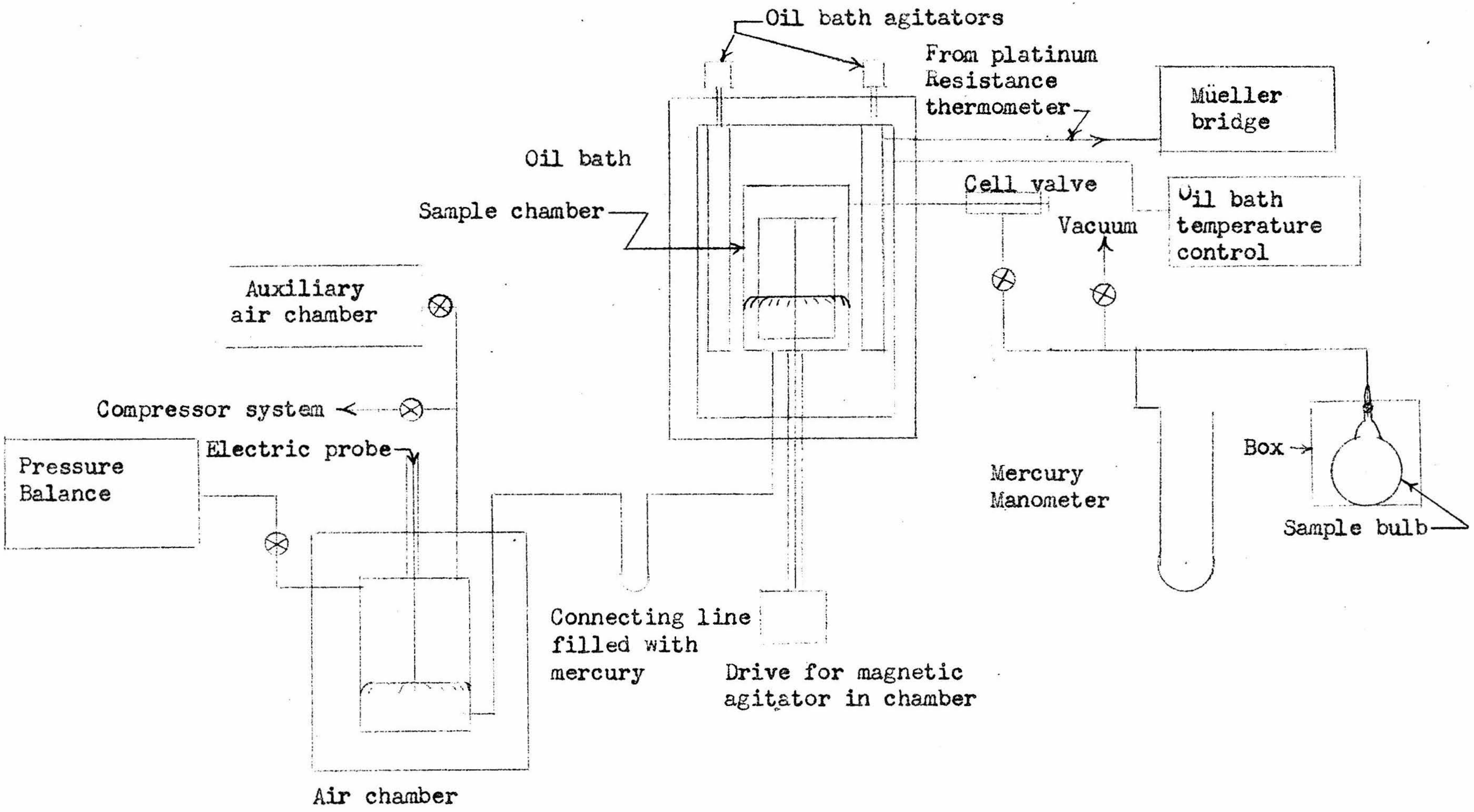

Figure 1. Schematic Diagram of Apparatus

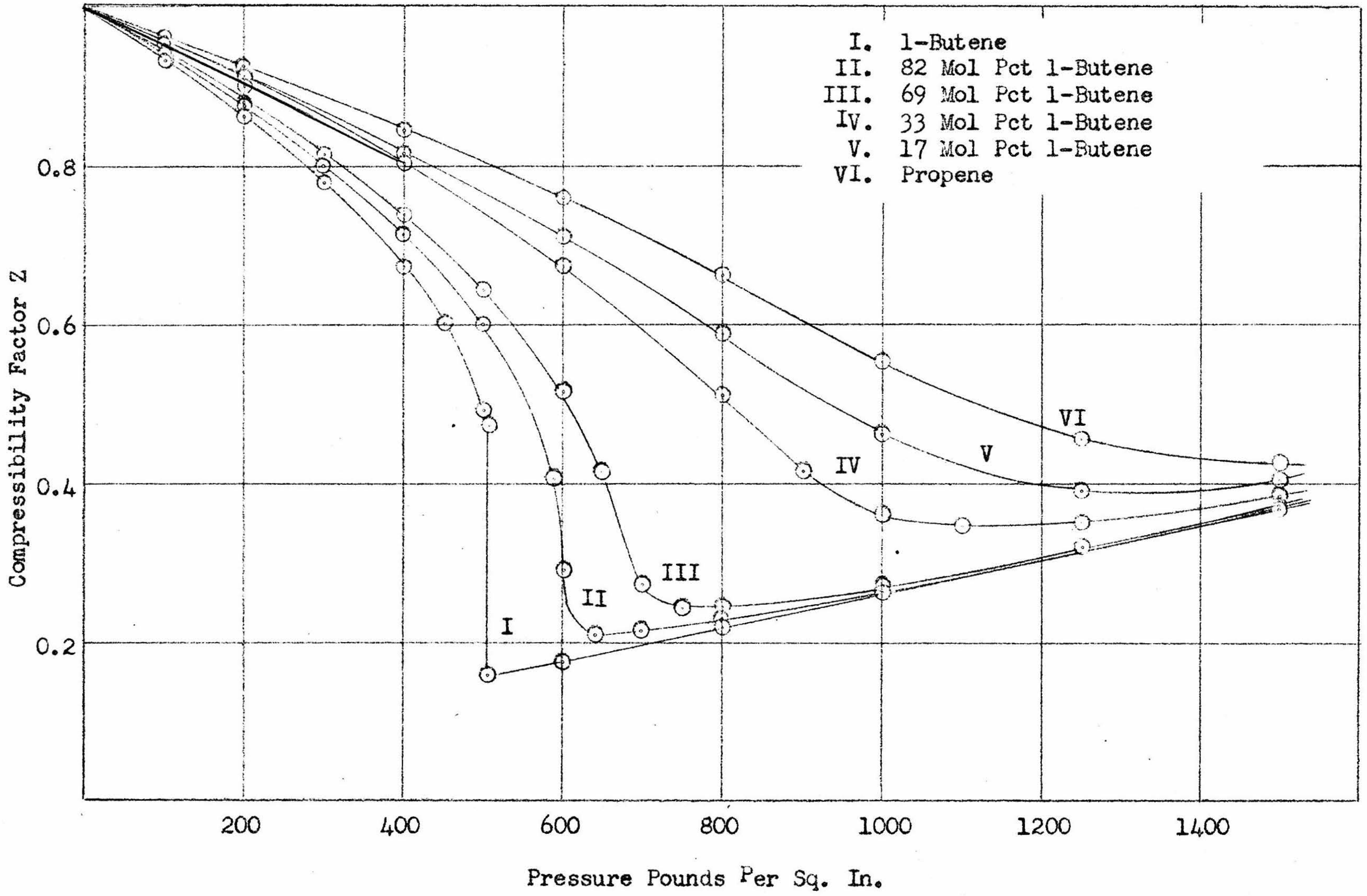

Figure 2. Compressibility Factor for the Propene-1-Butene System at 280°F.

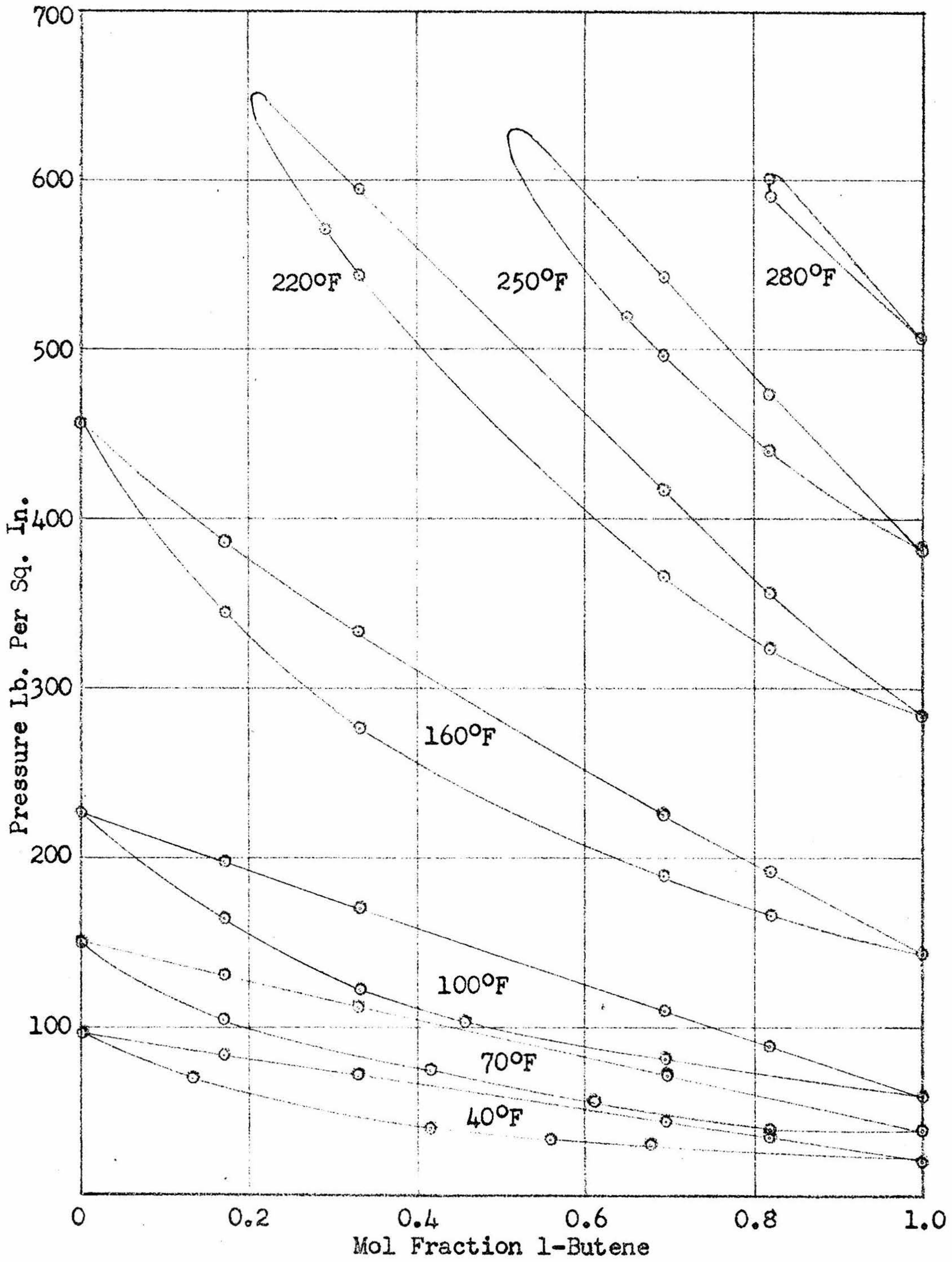

Figure 3. Pressure-Composition Diagram for the Propene-1-Butene System

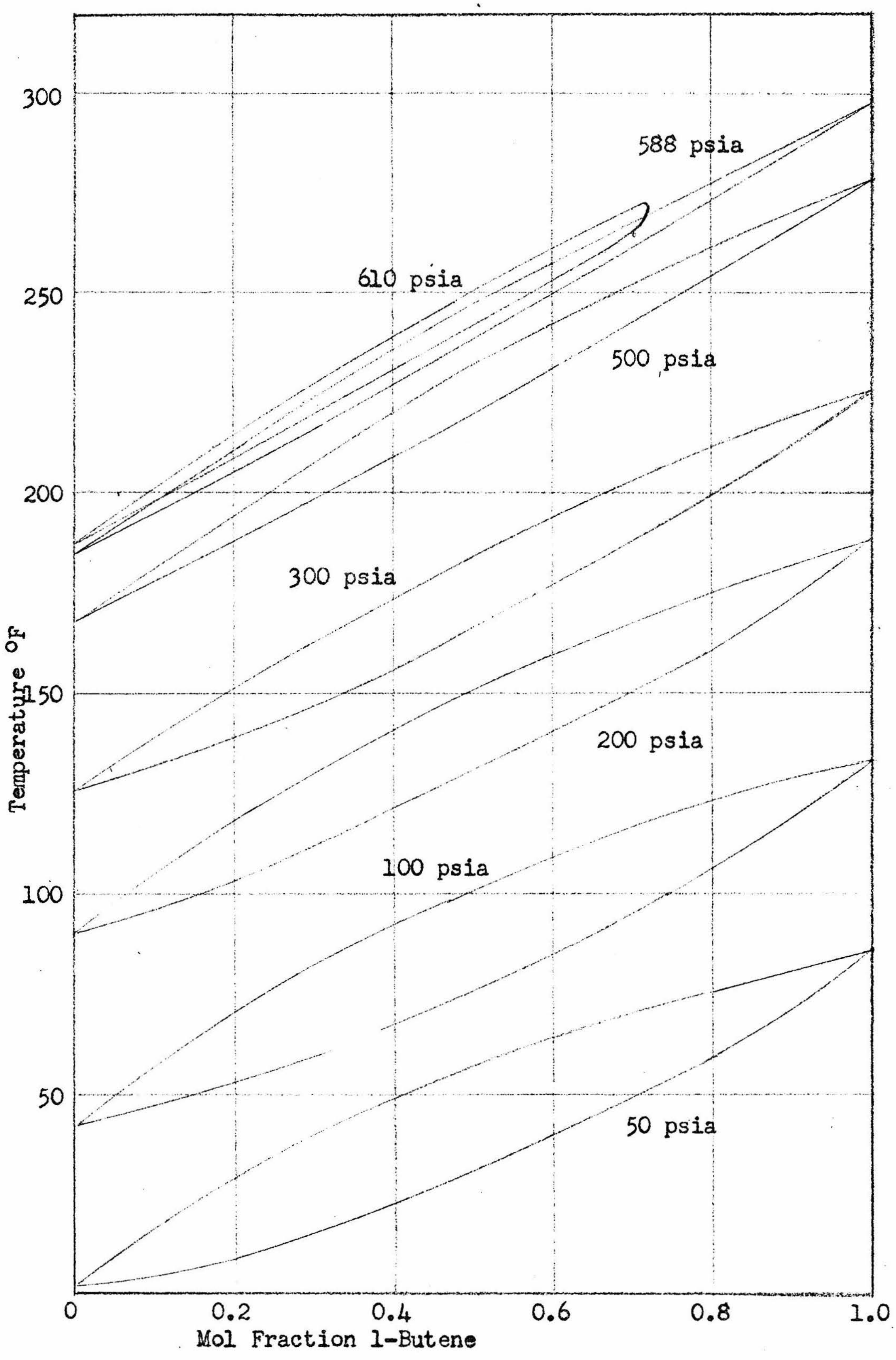

Figure 4. Temperature-Composition Diagram for the Propene-1-Butene System

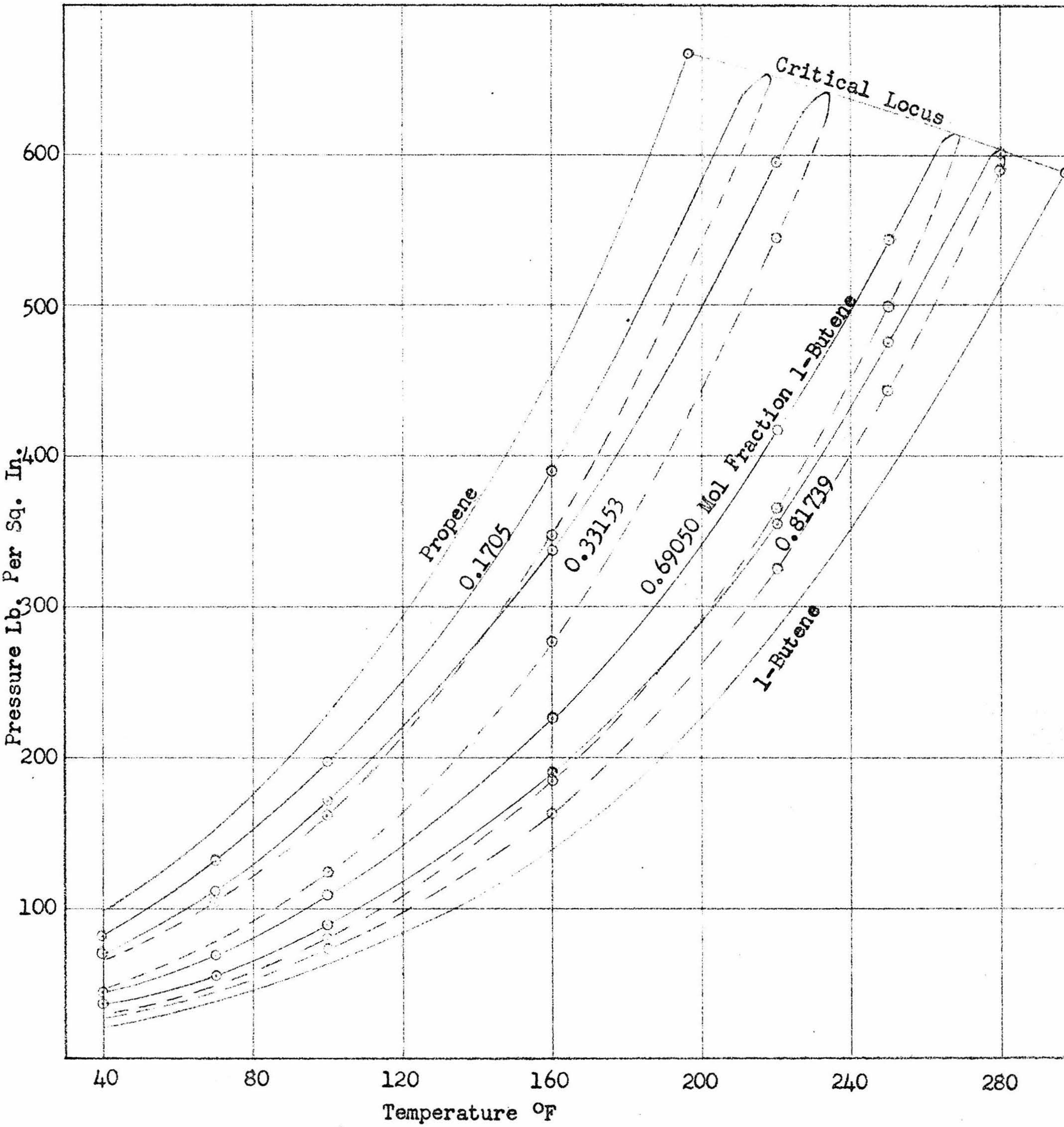

Figure 5. Pressure-Temperature Diagram for the Propene-1-Butene System

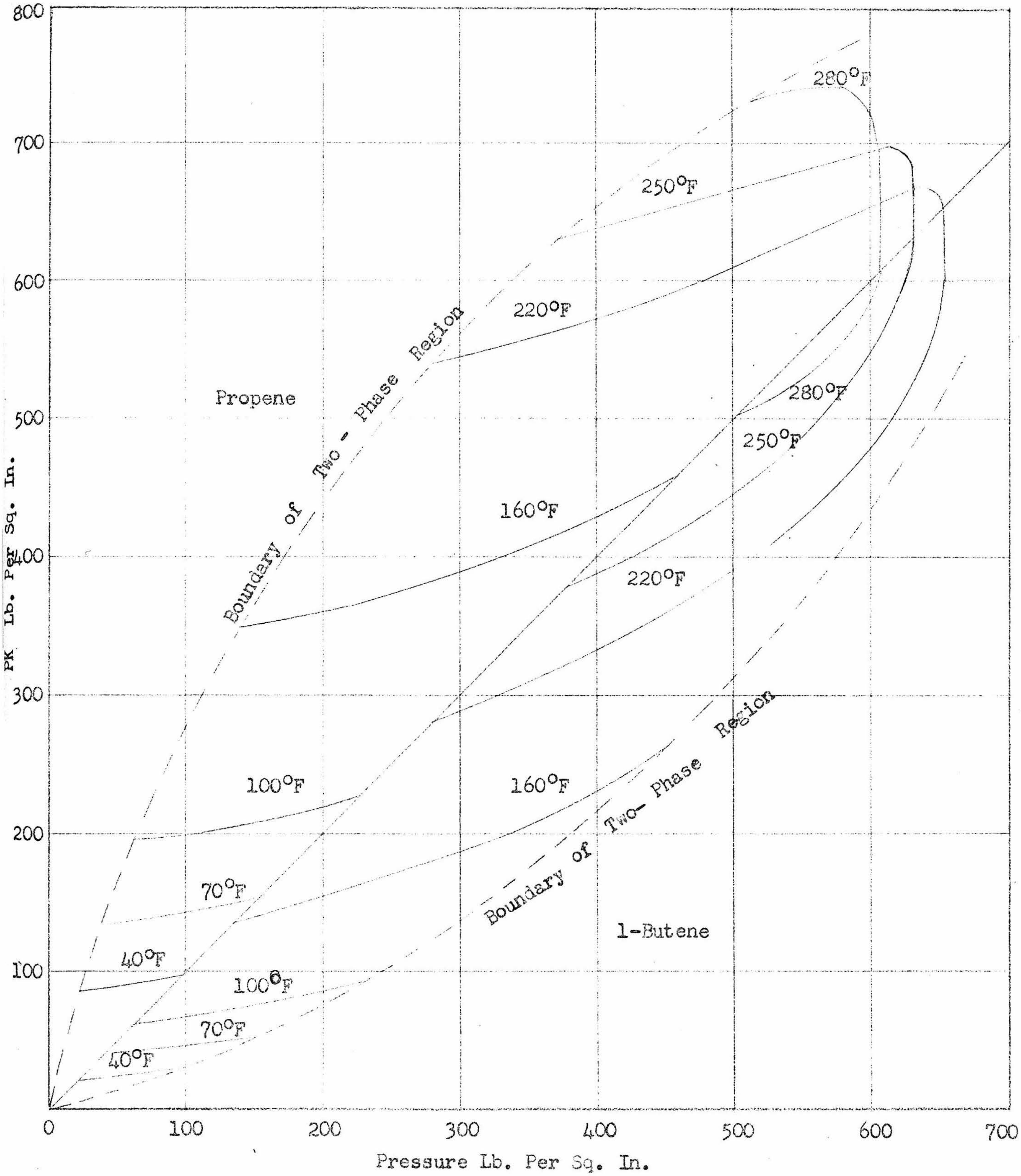

Figure 6. Equilibrium Constants for Propene and 1-Butene in the Propene-1-Butene System

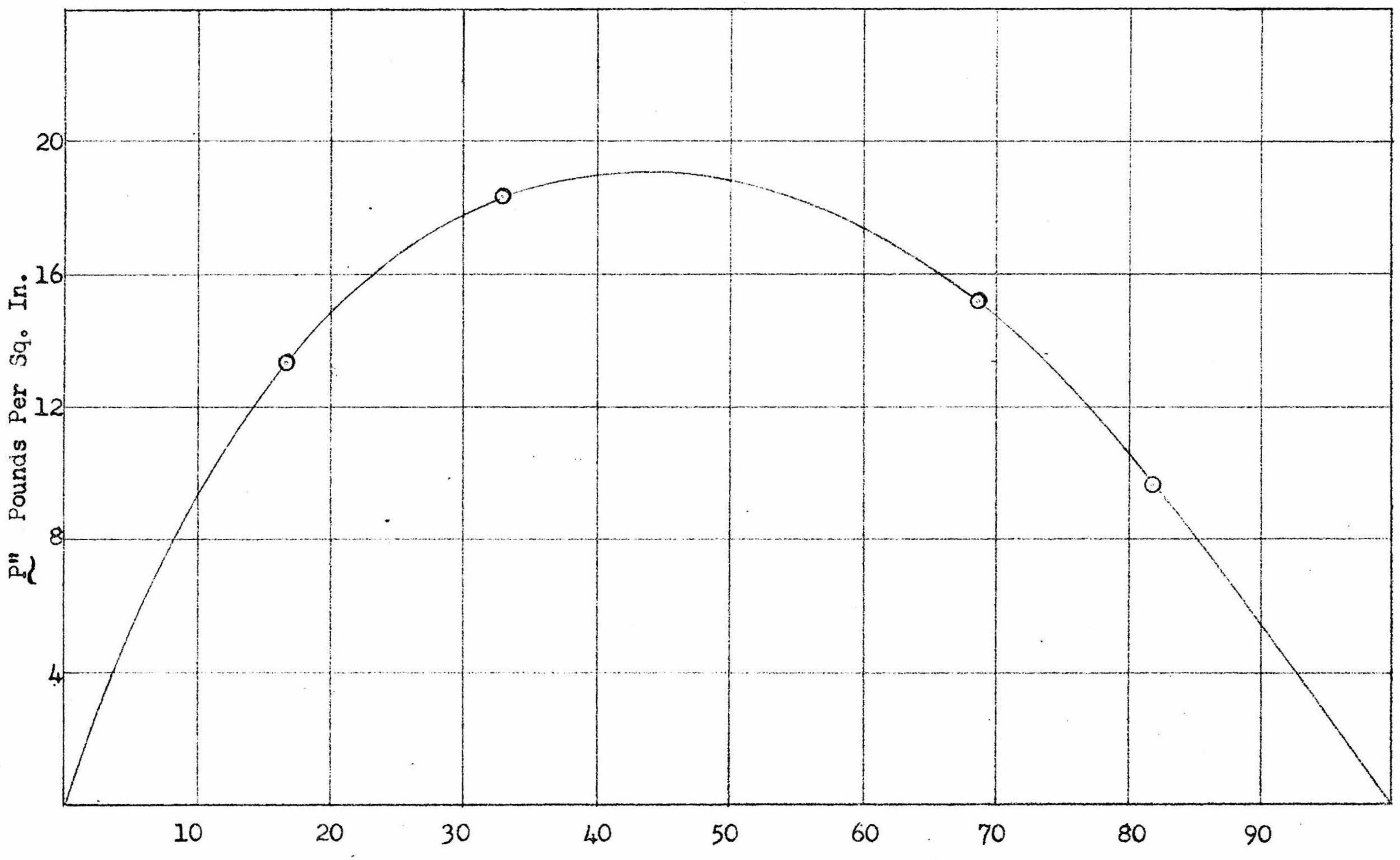

Figure 7. Deviation of Bubble-Point Pressure from Raoult's Law for Propene-1-Butene Mixtures at 160°F.

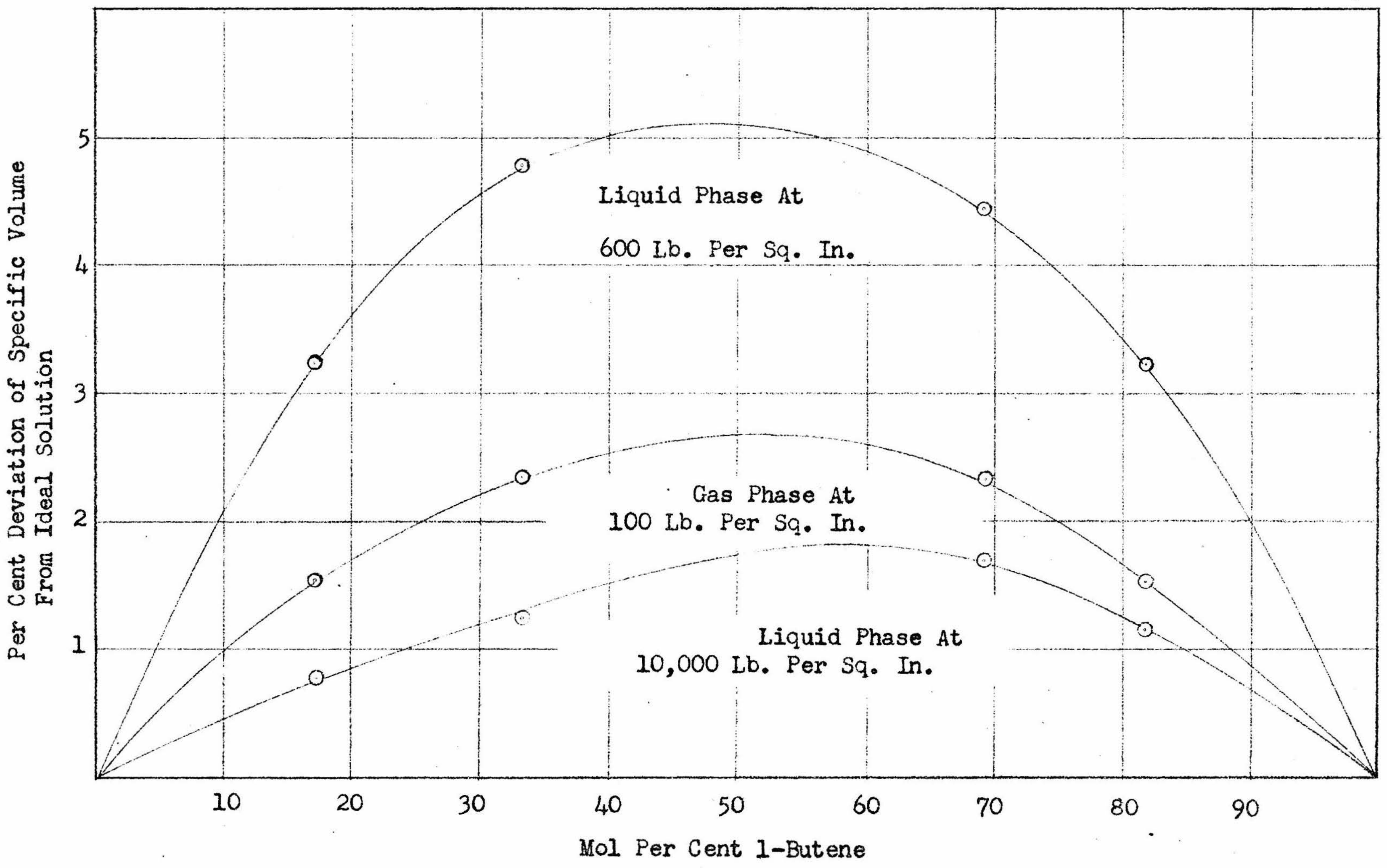

Figure 8. Deviation of Actual Specific Volume From Ideal Solution for Propene-1-Butene Mixtures at 160°F

TABLE I. Single-Phase Volumetric Behavior of Four Experimental Mixtures of Propene-1-Butene

Temperature 40° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.17050 | | 0.33153 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| D. P. | 1.815 (60.0)[a] | 0.903 | 2.3155 (45.6) | 0.9201 |
| B. P. | 0.02874 (82.8) | 0.0197 | 0.02814 (70.5) | 0.1729 |
| 0 | — | 1.000 | — | 1.000 |
| 14.7 | 8.039 | 0.9796 | 7.627 | 0.9768 |
| 20 | 5.860 | 0.9719 | 5.554 | 0.9679 |
| 30 | 3.845 | 0.9565 | 3.635 | 0.9502 |
| 40 | 2.8336 | 0.9399 | 2.6714 | 0.9311 |
| 50 | 2.2238 | 0.9220 | — | — |
| 60 | — | — | — | — |
| 80 | — | — | 0.02804 | 0.0196 |
| 100 | 0.02877 | 0.0239 | 0.02802 | 0.0244 |
| 125 | 0.02875 | 0.0298 | 0.02800 | 0.0305 |
| 150 | 0.02873 | 0.0357 | 0.02799 | 0.0366 |
| 200 | 0.02870 | 0.0476 | 0.02796 | 0.0487 |
| 300 | 0.02863 | 0.0712 | 0.02790 | 0.0729 |
| 400 | 0.02857 | 0.0948 | 0.02785 | 0.0971 |
| 500 | 0.02850 | 0.1182 | 0.02779 | 0.1211 |

[a] Figures in parentheses are dew-point or bubble-point pressures expressed as pounds per square inch.

## TABLE I CONT'D

Temperature 40° F

|  | Mole Fraction 1-Butene as Follows: |  |  |  |
|---|---|---|---|---|
|  | 0.17050 |  | 0.33153 |  |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compress-ibility Factor | Sp Volume Cu Ft/Lb | Compress-ibility Factor |
| 600 | 0.02844 | 0.1415 | 0.02774 | 0.1450 |
| 800 | 0.02831 | 0.1878 | 0.02763 | 0.1926 |
| 1000 | 0.02820 | 0.2339 | 0.02752 | 0.2398 |
| 1250 | 0.02806 | 0.2909 | 0.02741 | 0.2986 |
| 1500 | 0.02792 | 0.3473 | 0.02730 | 0.3568 |
| 1750 | 0.02780 | 0.4034 | 0.02719 | 0.4146 |
| 2000 | 0.02768 | 0.4591 | 0.02708 | 0.4719 |
| 2250 | 0.02756 | 0.5142 | 0.02698 | 0.5290 |
| 2500 | 0.02744 | 0.5689 | 0.02688 | 0.5856 |
| 2750 | 0.02733 | 0.6232 | 0.02678 | 0.6417 |
| 3000 | 0.02724 | 0.6777 | 0.02670 | 0.6980 |
| 3500 | 0.02703 | 0.7845 | 0.02652 | 0.8088 |
| 4000 | 0.02683 | 0.8900 | 0.02634 | 0.9181 |
| 4500 | 0.02665 | 0.9945 | 0.02616 | 1.0258 |
| 5000 | 0.02647 | 1.0975 | 0.02600 | 1.1328 |
| 6000 | 0.02615 | 1.3011 | 0.02570 | 1.3437 |
| 7000 | 0.02586 | 1.5011 | 0.02545 | 1.5524 |
| 8000 | 0.02561 | 1.6990 | 0.02518 | 1.7553 |
| 9000 | 0.02537 | 1.8934 | 0.02495 | 1.9567 |
| 10000 | 0.02516 | 2.0864 | 0.02475 | 2.1567 |

## TABLE I CONT'D

Temperature 40° F

| | Mole Fraction 1-Butene as Follows: | | | |
| --- | --- | --- | --- | --- |
| | 0.69050 | | 0.81739 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| D. P. | 3.280 (29.7) | 0.9403 | 3.626 (26.1) | 0.945 |
| B. P. | 0.02695 (43.6) | 0.0113 | 0.02659 (34.9) | 0.0093 |
| 0 | — | 1.000 | — | 1.000 |
| 14.7 | 6.848 | 0.9713 | 6.609 | 0.9698 |
| 20 | 4.976 | 0.9606 | 4.799 | 0.9584 |
| 30 | — | — | — | — |
| 40 | — | — | 0.02659 | 0.0106 |
| 50 | 0.02695 | 0.0130 | 0.02658 | 0.0133 |
| 60 | 0.02694 | 0.0156 | 0.02657 | 0.0159 |
| 80 | 0.02692 | 0.0208 | 0.02656 | 0.0212 |
| 100 | 0.02690 | 0.0260 | 0.02654 | 0.0265 |
| 125 | 0.02687 | 0.0324 | 0.02653 | 0.0331 |
| 150 | 0.02685 | 0.0389 | 0.02651 | 0.0397 |
| 200 | 0.02680 | 0.0517 | 0.02647 | 0.0529 |
| 300 | 0.02675 | 0.0775 | 0.02643 | 0.0792 |
| 400 | 0.02667 | 0.1030 | 0.02637 | 0.1053 |
| 500 | 0.02662 | 0.1285 | 0.02633 | 0.1315 |
| 600 | 0.02657 | 0.1539 | 0.02628 | 0.1574 |

## TABLE I CONT'D

Temperature 40° F

| Pressure Lb/Sq In Absolute | Mole Fraction 1-Butene as Follows: 0.69050 | | 0.81739 | |
|---|---|---|---|---|
| | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| 800 | 0.02648 | 0.2045 | 0.02619 | 0.2092 |
| 1000 | 0.02640 | 0.2548 | 0.02612 | 0.2608 |
| 1250 | 0.02630 | 0.3173 | 0.02601 | 0.3246 |
| 1500 | 0.02619 | 0.3792 | 0.02591 | 0.3881 |
| 1750 | 0.02610 | 0.4409 | 0.02583 | 0.4513 |
| 2000 | 0.02601 | 0.5021 | 0.02576 | 0.5144 |
| 2250 | 0.02594 | 0.5634 | 0.02569 | 0.5772 |
| 2500 | 0.02586 | 0.6240 | 0.02561 | 0.6393 |
| 2750 | 0.02579 | 0.6846 | 0.02554 | 0.7013 |
| 3000 | 0.02571 | 0.7445 | 0.02546 | 0.7627 |
| 3500 | 0.02557 | 0.8639 | 0.02531 | 0.8845 |
| 4000 | 0.02542 | 0.9815 | 0.02515 | 1.0045 |
| 4500 | 0.02528 | 1.0981 | 0.02500 | 1.1233 |
| 5000 | 0.02514 | 1.2133 | 0.02487 | 1.2416 |
| 6000 | 0.02488 | 1.4409 | 0.02461 | 1.4744 |
| 7000 | 0.02465 | 1.6655 | 0.02442 | 1.7068 |
| 8000 | 0.02445 | 1.8880 | 0.02424 | 1.9363 |
| 9000 | 0.02426 | 2.1075 | 0.02404 | 2.1604 |
| 10000 | 0.02410 | 2.3263 | 0.02390 | 2.3864 |

## TABLE I CONT'D

Temperature 70° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.17050 | | 0.33153 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| D. P. | 1.060 (103.6) | 0.859 | 1.363 (78.8) | 0.8830 |
| B. P. | 0.03013 (130.6) | 0.0308 | 0.02942 (111.3) | 0.0269 |
| 0 | — | 1.000 | — | 1.000 |
| 14.7 | 8.551 | 0.9830 | 8.118 | 0.9806 |
| 20 | 6.243 | 0.9767 | 5.921 | 0.9734 |
| 30 | 4.110 | 0.9645 | 3.891 | 0.9595 |
| 40 | 3.042 | 0.9519 | 2.8743 | 0.9451 |
| 50 | 2.4000 | 0.9387 | 2.2628 | 0.9300 |
| 60 | 1.9711 | 0.9252 | 1.8539 | 0.9144 |
| 80 | 1.4321 | 0.8962 | — | — |
| 100 | 1.1057 | 0.8650 | — | — |
| 125 | — | — | 0.2941 | 0.0302 |
| 150 | 0.03013 | 0.0354 | 0.02939 | 0.0362 |
| 200 | 0.03010 | 0.0353 | 0.02935 | 0.0483 |
| 300 | 0.02998 | 0.0704 | 0.02925 | 0.0721 |
| 400 | 0.02990 | 0.0936 | 0.02916 | 0.0959 |
| 500 | 0.02981 | 0.1166 | 0.02907 | 0.1195 |
| 600 | 0.02971 | 0.1395 | 0.02899 | 0.1430 |

## TABLE I CONT'D

Temperature 70° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.17050 | | 0.33153 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| 800 | 0.02955 | 0.1849 | 0.02883 | 0.1896 |
| 1000 | 0.02938 | 0.2298 | 0.02866 | 0.2356 |
| 1250 | 0.02919 | 0.2854 | 0.02848 | 0.2926 |
| 1500 | 0.02900 | 0.3403 | 0.02830 | 0.3490 |
| 1750 | 0.02883 | 0.3947 | 0.02815 | 0.4050 |
| 2000 | 0.02867 | 0.4486 | 0.02800 | 0.4603 |
| 2250 | 0.02850 | 0.5016 | 0.02785 | 0.5151 |
| 2500 | 0.02835 | 0.5544 | 0.02773 | 0.5617 |
| 2750 | 0.02821 | 0.6069 | 0.02761 | 0.6241 |
| 3000 | 0.02808 | 0.6590 | 0.02750 | 0.6782 |
| 3500 | 0.02784 | 0.7623 | 0.02729 | 0.7852 |
| 4000 | 0.02763 | 0.8646 | 0.02710 | 0.8911 |
| 4500 | 0.02743 | 0.9656 | 0.02691 | 0.9954 |
| 5000 | 0.02725 | 1.0659 | 0.02675 | 1.0995 |
| 6000 | 0.02690 | 1.2626 | 0.02641 | 1.3026 |
| 7000 | 0.02659 | 1.4561 | 0.02610 | 1.5018 |
| 8000 | 0.02630 | 1.6459 | 0.02579 | 1.6960 |
| 9000 | 0.02602 | 1.8320 | 0.02553 | 1.8888 |
| 10000 | 0.02574 | 2.0136 | 0.02530 | 2.0797 |

## TABLE I CONT'D

Temperature 70° F

| | Mole Fraction 1-Butene as Follows: 0.69050 | | 0.81739 | |
|---|---|---|---|---|
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compress-ibility Factor | Sp Volume Cu Ft/Lb | Compress-ibility Factor |
| D. P. | 1.9702 (50.6) | 0.9078 | 2.158 (45.0) | 0.914 |
| B. P. | 0.02795 (70.9) | 0.0180 | 0.02760 (57.4) | 0.0149 |
| 0 | — | 1.000 | — | 1.000 |
| 14.7 | 7.292 | 0.9758 | 7.039 | 0.9743 |
| 20 | 5.308 | 0.9666 | 5.121 | 0.9646 |
| 30 | 3.473 | 0.9488 | 3.346 | 0.9456 |
| 40 | 2.5527 | 0.9298 | 2.4560 | 0.9253 |
| 50 | 1.9976 | 0.9095 | — | — |
| 60 | — | — | — | — |
| 80 | 0.02795 | 0.0204 | 0.02757 | 0.0208 |
| 100 | 0.02793 | 0.0254 | 0.02755 | 0.0259 |
| 125 | 0.02791 | 0.0318 | 0.02753 | 0.0324 |
| 150 | 0.02790 | 0.0381 | 0.02751 | 0.0389 |
| 200 | 0.02786 | 0.0507 | 0.02746 | 0.0517 |
| 300 | 0.02780 | 0.0759 | 0.02740 | 0.0774 |
| 400 | 0.02774 | 0.1010 | 0.02733 | 0.1030 |
| 500 | 0.02767 | 0.1260 | 0.02726 | 0.1284 |
| 600 | 0.02760 | 0.1508 | 0.02722 | 0.1538 |

TABLE I CONT'D

Temperature 70° F

| Pressure Lb/Sq In Absolute | Mole Fraction 1-Butene as Follows: 0.69050 Sp Volume Cu Ft/Lb | 0.69050 Compressibility Factor | 0.81739 Sp Volume Cu Ft/Lb | 0.81739 Compressibility Factor |
|---|---|---|---|---|
| 800 | 0.02749 | 0.2003 | 0.02710 | 0.2042 |
| 1000 | 0.02737 | 0.2492 | 0.02700 | 0.2543 |
| 1250 | 0.02723 | 0.3099 | 0.02688 | 0.3165 |
| 1500 | 0.02710 | 0.3702 | 0.02677 | 0.3782 |
| 1750 | 0.02697 | 0.4298 | 0.02666 | 0.4394 |
| 2000 | 0.02685 | 0.4890 | 0.02656 | 0.5003 |
| 2250 | 0.02674 | 0.5479 | 0.02646 | 0.5608 |
| 2500 | 0.02664 | 0.6064 | 0.02636 | 0.6207 |
| 2750 | 0.02653 | 0.6643 | 0.02627 | 0.6804 |
| 3000 | 0.02644 | 0.7223 | 0.02616 | 0.7392 |
| 3500 | 0.02626 | 0.8369 | 0.02600 | 0.8571 |
| 4000 | 0.02610 | 0.9506 | 0.02584 | 0.9735 |
| 4500 | 0.02595 | 1.0633 | 0.02569 | 1.0889 |
| 5000 | 0.02580 | 1.1746 | 0.02554 | 1.2028 |
| 6000 | 0.02550 | 1.3932 | 0.02524 | 1.4264 |
| 7000 | 0.02523 | 1.6082 | 0.02500 | 1.6483 |
| 8000 | 0.02499 | 1.8204 | 0.02476 | 1.8657 |
| 9000 | 0.02476 | 2.0291 | 0.02455 | 2.0811 |
| 10000 | 0.02456 | 2.2364 | 0.02436 | 2.2944 |

## TABLE I CONT'D

Temperature 100° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.17050 | | 0.33153 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compress-ibility Factor | Sp Volume Cu Ft/Lb | Compress-ibility Factor |
| D. P. | 0.6767 (161.4) | 0.8086 | 0.8752 (124.4) | 0.847 |
| B. P. | 0.03185 (195.3) | 0.0461 | 0.03090 (166.9) | 0.0401 |
| 0 | — | 1.000 | — | 1.000 |
| 14.7 | 9.058 | 0.9856 | 8.604 | 0.9837 |
| 20 | 6.621 | 0.9803 | 6.285 | 0.9778 |
| 30 | 4.369 | 0.9704 | 4.142 | 0.9666 |
| 40 | 3.243 | 0.9603 | 3.070 | 0.9554 |
| 50 | 2.5667 | 0.9501 | 2.4268 | 0.9440 |
| 60 | 2.1157 | 0.9398 | 1.9974 | 0.9324 |
| 80 | 1.5507 | 0.9184 | 1.4595 | 0.9083 |
| 100 | 1.2100 | 0.8958 | 1.1346 | 0.8827 |
| 125 | 0.9344 | 0.8647 | — | — |
| 150 | 0.7458 | 0.8282 | — | — |
| 200 | 0.03184 | 0.0471 | 0.03085 | 0.0480 |
| 300 | 0.03170 | 0.0704 | 0.03073 | 0.0717 |
| 400 | 0.03156 | 0.0935 | 0.03061 | 0.0953 |
| 500 | 0.03142 | 0.1163 | 0.03050 | 0.1186 |
| 600 | 0.03129 | 0.1390 | 0.03039 | 0.1419 |

## TABLE I CONT'D

Temperature 100° F

Mole Fraction 1-Butene as Follows:

| | 0.17050 | | 0.33153 | |
|---|---|---|---|---|
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compress-ibility Factor | Sp Volume Cu Ft/Lb | Compress-ibility Factor |
| 800 | 0.03104 | 0.1838 | 0.03017 | 0.1878 |
| 1000 | 0.03081 | 0.2281 | 0.02997 | 0.2332 |
| 1250 | 0.03055 | 0.2827 | 0.02974 | 0.2892 |
| 1500 | 0.03030 | 0.3365 | 0.02952 | 0.3445 |
| 1750 | 0.03007 | 0.3896 | 0.02931 | 0.3990 |
| 2000 | 0.02985 | 0.4420 | 0.02913 | 0.4532 |
| 2250 | 0.02965 | 0.4939 | 0.02895 | 0.5067 |
| 2500 | 0.02945 | 0.5451 | 0.02878 | 0.5597 |
| 2750 | 0.02928 | 0.5961 | 0.02863 | 0.6125 |
| 3000 | 0.02911 | 0.6466 | 0.02847 | 0.6645 |
| 3500 | 0.02882 | 0.7468 | 0.02820 | 0.7679 |
| 4000 | 0.02857 | 0.8461 | 0.02795 | 0.8698 |
| 4500 | 0.02834 | 0.9442 | 0.02774 | 0.9711 |
| 5000 | 0.02811 | 1.0406 | 0.02753 | 1.0709 |
| 6000 | 0.02770 | 1.2305 | 0.02715 | 1.2673 |
| 7000 | 0.02734 | 1.4169 | 0.02679 | 1.4589 |
| 8000 | 0.02700 | 1.5992 | 0.02645 | 1.6462 |
| 9000 | 0.02668 | 1.7777 | 0.02615 | 1.8309 |
| 10000 | 0.02636 | 1.9516 | 0.02586 | 2.0118 |

## TABLE I CONT'D

Temperature 100° F

| Pressure Lb/Sq In Absolute | Mole Fraction 1-Butene as Follows: 0.69050 |  |  | 0.81739 |  |  |
|---|---|---|---|---|---|---|
|  | Sp Volume Cu Ft/Lb |  | Compress-ibility Factor | Sp Volume Cu Ft/Lb |  | Compress-ibility Factor |
| D. P. | 1.2501 | (80.8) | 0.8705 | 1.3622 | (72.3) | 0.878 |
| B. P. | 0.02920 | (108.4) | 0.0273 | 0.02865 | (89.4) | 0.0228 |
| 0 | — |  | 1.000 | — |  | 1.000 |
| 14.7 | 7.734 |  | 0.9796 | 7.467 |  | 0.9783 |
| 20 | 5.639 |  | 0.9720 | 5.442 |  | 0.9702 |
| 30 | 3.704 |  | 0.9576 | 3.570 |  | 0.9546 |
| 40 | 2.7344 |  | 0.9426 | 2.6319 |  | 0.9385 |
| 50 | 2.1511 |  | 0.9270 | 2.0674 |  | 0.9215 |
| 60 | 1.7604 |  | 0.9103 | 1.6888 |  | 0.9032 |
| 80 | 1.2652 |  | 0.8723 | — |  | — |
| 100 | — |  | — | 0.02865 |  | 0.0255 |
| 125 | 0.02918 |  | 0.0314 | 0.02863 |  | 0.0319 |
| 150 | 0.02915 |  | 0.0377 | 0.02861 |  | 0.0383 |
| 200 | 0.02910 |  | 0.0502 | 0.02859 |  | 0.0510 |
| 300 | 0.02900 |  | 0.0750 | 0.02848 |  | 0.0762 |
| 400 | 0.02890 |  | 0.0996 | 0.02840 |  | 0.1013 |
| 500 | 0.02881 |  | 0.1241 | 0.02832 |  | 0.1262 |
| 600 | 0.02873 |  | 0.1486 | 0.02825 |  | 0.1511 |

## TABLE I CONT'D

Temperature 100° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.69050 | | 0.81739 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| 800 | 0.02856 | 0.1969 | 0.02810 | 0.2004 |
| 1000 | 0.02841 | 0.2449 | 0.02796 | 0.2492 |
| 1250 | 0.02824 | 0.3042 | 0.02782 | 0.3100 |
| 1500 | 0.02806 | 0.3628 | 0.02768 | 0.3701 |
| 1750 | 0.02790 | 0.4208 | 0.02753 | 0.4295 |
| 2000 | 0.02775 | 0.4783 | 0.02740 | 0.4885 |
| 2250 | 0.02761 | 0.5354 | 0.02726 | 0.5468 |
| 2500 | 0.02749 | 0.5923 | 0.02714 | 0.6048 |
| 2750 | 0.02737 | 0.6487 | 0.02703 | 0.6626 |
| 3000 | 0.02726 | 0.7049 | 0.02693 | 0.7202 |
| 3500 | 0.02705 | 0.8160 | 0.02674 | 0.8343 |
| 4000 | 0.02685 | 0.9256 | 0.02656 | 0.9470 |
| 4500 | 0.02667 | 1.0343 | 0.02638 | 1.0582 |
| 5000 | 0.02650 | 1.1419 | 0.02618 | 1.1669 |
| 6000 | 0.02616 | 1.3528 | 0.02588 | 1.3842 |
| 7000 | 0.02585 | 1.5595 | 0.02559 | 1.5968 |
| 8000 | 0.02558 | 1.7637 | 0.02534 | 1.8071 |
| 9000 | 0.02532 | 1.9640 | 0.02509 | 2.0129 |
| 10000 | 0.02508 | 2.1615 | 0.02488 | 2.2179 |

## TABLE I CONT'D

Temperature 160° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.17050 | | 0.33153 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compress-ibility Factor | Sp Volume Cu Ft/Lb | Compress-ibility Factor |
| D. P. | 0.2864 (346.9) | 0.6643 | 0.3709 (276.3) | 0.7200 |
| B. P. | 0.03705 (389.7) | 0.0965 | 0.03509(334.3) | 0.0824 |
| 0 | — | 1.000 | — | 1.000 |
| 14.7 | 10.068 | 0.9894 | 9.568 | 0.9880 |
| 20 | 7.369 | 0.9855 | 7.000 | 0.9837 |
| 30 | 4.876 | 0.9782 | 4.628 | 0.9755 |
| 40 | 3.630 | 0.9708 | 3.442 | 0.9673 |
| 50 | 2.8814 | 0.9634 | 2.7300 | 0.9591 |
| 60 | 2.3823 | 0.9558 | 2.2554 | 0.9508 |
| 80 | 1.7581 | 0.9405 | 1.6619 | 0.9342 |
| 100 | 1.3829 | 0.9247 | 1.3053 | 0.9172 |
| 125 | 1.0821 | 0.9045 | 1.0194 | 0.8953 |
| 150 | 0.8807 | 0.8834 | 0.8279 | 0.8726 |
| 200 | 0.6266 | 0.8379 | 0.5851 | 0.8222 |
| 300 | 0.3640 | 0.7302 | — | — |
| 400 | 0.03698 | 0.0989 | 0.03483 | 0.0979 |
| 500 | 0.03646 | 0.1219 | 0.03448 | 0.1211 |
| 600 | 0.03601 | 0.1448 | 0.03417 | 0.1441 |

## TABLE I CONT'D

### Temperature 160° F

|  | Mole Fraction 1-Butene as Follows: |  |  |  |
|---|---|---|---|---|
|  | 0.17050 |  | 0.33153 |  |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| 800 | 0.03527 | 0.1887 | 0.03363 | 0.1890 |
| 1000 | 0.03466 | 0.2318 | 0.03318 | 0.2331 |
| 1250 | 0.03404 | 0.2845 | 0.03277 | 0.2878 |
| 1500 | 0.03351 | 0.3361 | 0.03236 | 0.3411 |
| 1750 | 0.03306 | 0.3869 | 0.03202 | 0.3937 |
| 2000 | 0.03267 | 0.4369 | 0.03167 | 0.4451 |
| 2250 | 0.03232 | 0.4863 | 0.03137 | 0.4959 |
| 2500 | 0.03201 | 0.5351 | 0.03110 | 0.5467 |
| 2750 | 0.03172 | 0.5833 | 0.03084 | 0.5959 |
| 3000 | 0.03146 | 0.6311 | 0.03059 | 0.6448 |
| 3500 | 0.03099 | 0.7253 | 0.03019 | 0.7424 |
| 4000 | 0.03059 | 0.8182 | 0.02984 | 0.8387 |
| 4500 | 0.03023 | 0.9096 | 0.02950 | 0.9328 |
| 5000 | 0.02991 | 1.0000 | 0.02920 | 1.0259 |
| 6000 | 0.02935 | 1.1775 | 0.02868 | 1.2091 |
| 7000 | 0.02886 | 1.3509 | 0.02824 | 1.3890 |
| 8000 | 0.02842 | 1.5203 | 0.02782 | 1.5638 |
| 9000 | 0.02802 | 1.6863 | 0.02742 | 1.7340 |
| 10000 | 0.02765 | 1.8489 | 0.02703 | 1.8992 |

## TABLE I CONT'D

### Temperature 160° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.69050 | | 0.81739 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| D. P. | 0.5428 (184.1) | 0.7778 | 0.6009 (163.7) | 0.7920 |
| B. P. | 0.03233 (224.9) | 0.0566 | 0.03156 (190.6) | 0.0484 |
| 0 | — | 1.000 | — | 1.000 |
| 14.7 | 8.612 | 0.9851 | 8.320 | 0.9843 |
| 20 | 6.293 | 0.9797 | 6.078 | 0.9876 |
| 30 | 4.152 | 0.9695 | 4.007 | 0.9678 |
| 40 | 3.081 | 0.9591 | 2.9713 | 0.9568 |
| 50 | 2.4374 | 0.9486 | 2.3494 | 0.9457 |
| 60 | 2.0084 | 0.9380 | 1.9346 | 0.9345 |
| 80 | 1.4712 | 0.9161 | 1.4148 | 0.9112 |
| 100 | 1.1476 | 0.8933 | 1.1015 | 0.8868 |
| 125 | 0.8868 | 0.8628 | 0.8483 | 0.8537 |
| 150 | 0.7133 | 0.8328 | 0.6755 | 0.8157 |
| 200 | — | — | 0.03153 | 0.0508 |
| 300 | 0.03215 | 0.0751 | 0.03133 | 0.0757 |
| 400 | 0.03192 | 0.0994 | 0.03115 | 0.1003 |
| 500 | 0.03173 | 0.1235 | 0.03099 | 0.1247 |
| 600 | 0.03153 | 0.1473 | 0.03084 | 0.1490 |

## TABLE I CONT'D

Temperature 160° F

| Pressure Lb/Sq In Absolute | Mole Fraction 1-Butene as Follows: 0.69050 | | 0.81739 | |
|---|---|---|---|---|
| | Sp Volume Cu Ft/Lb | Compress-ibility Factor | Sp Volume Cu Ft/Lb | Compress-ibility Factor |
| 800 | 0.03119 | 0.1942 | 0.03056 | 0.1968 |
| 1000 | 0.03092 | 0.2407 | 0.03033 | 0.2442 |
| 1250 | 0.03062 | 0.2979 | 0.03003 | 0.3022 |
| 1500 | 0.03031 | 0.3539 | 0.02977 | 0.3595 |
| 1750 | 0.03007 | 0.4096 | 0.02953 | 0.4160 |
| 2000 | 0.02983 | 0.4644 | 0.02931 | 0.4719 |
| 2250 | 0.02964 | 0.5191 | 0.02913 | 0.5277 |
| 2500 | 0.02945 | 0.5731 | 0.02895 | 0.5827 |
| 2750 | 0.02925 | 0.6261 | 0.02879 | 0.6374 |
| 3000 | 0.02907 | 0.6788 | 0.02863 | 0.6915 |
| 3500 | 0.02874 | 0.7830 | 0.02833 | 0.7983 |
| 4000 | 0.02843 | 0.8852 | 0.02805 | 0.9033 |
| 4500 | 0.02815 | 0.9860 | 0.02779 | 1.0068 |
| 5000 | 0.02790 | 1.0859 | 0.02755 | 1.1090 |
| 6000 | 0.02743 | 1.2811 | 0.02713 | 1.3105 |
| 7000 | 0.02703 | 1.4728 | 0.02675 | 1.5075 |
| 8000 | 0.02670 | 1.6626 | 0.02645 | 1.7036 |
| 9000 | 0.02638 | 1.8431 | 0.02614 | 1.8941 |
| 10000 | 0.02608 | 2.0300 | 0.02590 | 2.0852 |

## TABLE I CONT'D

Temperature 220° F

| Pressure Lb/Sq In Absolute | Mole Fraction 1-Butene as Follows: 0.17050 | | 0.33153 | |
|---|---|---|---|---|
| | Sp Volume Cu Ft/Lb | Compress-ibility Factor | Sp Volume Cu Ft/Lb | Compress-ibility Factor |
| D. P. | — | — | 0.1488 (543.7) | 0.5183 |
| B. P. | — | — | 0.04598 (594.5) | 0.1751 |
| 0 | — | 1.000 | — | 1.000 |
| 14.7 | 11.073 | 0.9921 | 10.527 | 0.9911 |
| 20 | 8.113 | 0.9892 | 7.710 | 0.9879 |
| 30 | 5.379 | 0.9838 | 5.109 | 0.9818 |
| 40 | 4.012 | 0.9783 | 3.808 | 0.9757 |
| 50 | 3.191 | 0.9728 | 3.027 | 0.9696 |
| 60 | 2.6442 | 0.9672 | 2.5067 | 0.9635 |
| 80 | 1.9601 | 0.9560 | 1.8560 | 0.9512 |
| 100 | 1.5493 | 0.9445 | 1.4654 | 0.9388 |
| 125 | 1.2203 | 0.9300 | 1.1526 | 0.9230 |
| 150 | 1.0007 | 0.9151 | 0.9439 | 0.9070 |
| 200 | 0.7254 | 0.8844 | 0.6822 | 0.8741 |
| 300 | 0.4478 | 0.8189 | 0.4173 | 0.8020 |
| 400 | 0.3054 | 0.7447 | 0.27925 | 0.7156 |
| 500 | 0.2158 | 0.6577 | 0.18620 | 0.5964 |
| 600 | 0.1478 | 0.5406 | 0.04570 | 0.1757 |

## TABLE I CONT'D

Temperature 220° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.17050 | | 0.33153 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compress-ibility Factor | Sp Volume Cu Ft/Lb | Compress-ibility Factor |
| 800 | 0.04681 | 0.2283 | 0.04090 | 0.2096 |
| 1000 | 0.04242 | 0.2586 | 0.03903 | 0.2500 |
| 1250 | 0.03992 | 0.3042 | 0.03745 | 0.2999 |
| 1500 | 0.03844 | 0.3515 | 0.03650 | 0.3507 |
| 1750 | 0.03743 | 0.3993 | 0.03569 | 0.4001 |
| 2000 | 0.03658 | 0.4460 | 0.03502 | 0.4487 |
| 2250 | 0.03538 | 0.4922 | 0.03441 | 0.4960 |
| 2500 | 0.03530 | 0.5380 | 0.03396 | 0.5439 |
| 2750 | 0.03480 | 0.5834 | 0.03352 | 0.5906 |
| 3000 | 0.03435 | 0.6282 | 0.03313 | 0.6367 |
| 3500 | 0.03357 | 0.7163 | 0.03247 | 0.7280 |
| 4000 | 0.03293 | 0.8030 | 0.03191 | 0.8177 |
| 4500 | 0.03236 | 0.8878 | 0.03143 | 0.9061 |
| 5000 | 0.03187 | 0.9715 | 0.03100 | 0.9930 |
| 6000 | 0.03106 | 1.1361 | 0.03028 | 1.1639 |
| 7000 | 0.03042 | 1.2982 | 0.02971 | 1.3323 |
| 8000 | 0.02986 | 1.4563 | 0.02921 | 1.4970 |
| 9000 | 0.02936 | 1.6109 | 0.02870 | 1.6547 |
| 10000 | 0.02893 | 1.7637 | 0.02828 | 1.8117 |

## TABLE I CONT'D

Temperature 220° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.69050 | | 0.81739 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| D. P. | 0.2458 (365.4) | 0.6375 | 0.2794 (324.2) | 0.6650 |
| B. P. | 0.03777 (413.1) | 0.1107 | 0.03622 (357.3) | 0.0950 |
| 0 | — | 1.000 | — | 1.000 |
| 14.7 | 9.483 | 0.9891 | 9.163 | 0.9885 |
| 20 | 6.940 | 0.9851 | 8.704 | 0.9843 |
| 30 | 4.592 | 0.9776 | 4.434 | 0.9763 |
| 40 | 3.417 | 0.9699 | 3.298 | 0.9684 |
| 50 | 2.7122 | 0.9624 | 2.6165 | 0.9603 |
| 60 | 2.2422 | 0.9547 | 2.1621 | 0.9523 |
| 80 | 1.6543 | 0.9392 | 1.5935 | 0.9358 |
| 100 | 1.3011 | 0.9234 | 1.2517 | 0.9188 |
| 125 | 1.0180 | 0.9030 | 0.9776 | 0.8970 |
| 150 | 0.8286 | 0.8821 | 0.7940 | 0.8743 |
| 200 | 0.5902 | 0.8376 | 0.5618 | 0.8247 |
| 300 | 0.3441 | 0.7326 | 0.3186 | 0.7016 |
| 400 | — | — | 0.03595 | 0.1056 |
| 500 | 0.03699 | 0.1313 | 0.03543 | 0.1300 |
| 600 | 0.03640 | 0.1550 | 0.03498 | 0.1541 |

## TABLE I CONT'D

### Temperature 220° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.69050 | | 0.81739 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| 800 | 0.03544 | 0.2012 | 0.03426 | 0.2012 |
| 1000 | 0.03470 | 0.2463 | 0.03368 | 0.2472 |
| 1250 | 0.03400 | 0.3016 | 0.03308 | 0.3035 |
| 1500 | 0.03340 | 0.3555 | 0.03256 | 0.3585 |
| 1750 | 0.03290 | 0.4086 | 0.03213 | 0.4127 |
| 2000 | 0.03246 | 0.4607 | 0.03175 | 0.4661 |
| 2250 | 0.03208 | 0.5122 | 0.03141 | 0.5188 |
| 2500 | 0.03173 | 0.5629 | 0.03110 | 0.5707 |
| 2750 | 0.03141 | 0.6130 | 0.03083 | 0.6223 |
| 3000 | 0.03113 | 0.6628 | 0.03059 | 0.6736 |
| 3500 | 0.03062 | 0.7606 | 0.03013 | 0.7741 |
| 4000 | 0.03018 | 0.8567 | 0.02973 | 0.8729 |
| 4500 | 0.02979 | 0.9514 | 0.02937 | 0.9702 |
| 5000 | 0.02945 | 1.0450 | 0.02905 | 1.0662 |
| 6000 | 0.02886 | 1.2289 | 0.02850 | 1.2552 |
| 7000 | 0.02835 | 1.4083 | 0.02801 | 1.4393 |
| 8000 | 0.02793 | 1.5857 | 0.02760 | 1.6208 |
| 9000 | 0.02753 | 1.17584 | 0.02724 | 1.7996 |
| 10000 | 0.02715 | 1.9268 | 0.02687 | 1.9724 |

## TABLE I CONT'D

Temperature 250° F

Mole Fraction 1-Butene as Follows:

| | 0.17050 | | 0.33153 | |
|---|---|---|---|---|
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| D. P. | — | — | — | — |
| B. P. | — | — | — | — |
| 0 | — | 1.000 | — | 1.000 |
| 14.7 | 11.575 | 0.9932 | 11.006 | 0.9923 |
| 20 | 8.484 | 0.9907 | 8.064 | 0.9895 |
| 30 | 5.629 | 0.9860 | 5.348 | 0.9843 |
| 40 | 4.202 | 0.9813 | 3.989 | 0.9790 |
| 50 | 3.345 | 0.9766 | 3.174 | 0.9737 |
| 60 | 2.7742 | 0.9719 | 2.6308 | 0.9685 |
| 80 | 2.0602 | 0.9623 | 1.9514 | 0.9578 |
| 100 | 1.6316 | 0.9526 | 1.5437 | 0.9471 |
| 125 | 1.2886 | 0.9404 | 1.2174 | 0.9337 |
| 150 | 1.0597 | 0.9281 | 0.9998 | 0.9201 |
| 200 | 0.7731 | 0.9027 | 0.7274 | 0.8925 |
| 300 | 0.4849 | 0.8494 | 0.4530 | 0.8338 |
| 400 | 0.3390 | 0.7917 | 0.3134 | 0.7691 |
| 500 | 0.2494 | 0.7282 | 0.22518 | 0.6908 |
| 600 | 0.1873 | 0.6560 | 0.16105 | 0.5929 |

## TABLE I CONT'D

Temperature 250° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.17050 | | 0.33153 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| 800 | 0.09743 | 0.4551 | 0.05629 | 0.2763 |
| 1000 | 0.05405 | 0.3156 | 0.04529 | 0.2779 |
| 1250 | 0.04579 | 0.3342 | 0.04157 | 0.3188 |
| 1500 | 0.04250 | 0.3722 | 0.03957 | 0.3642 |
| 1750 | 0.04070 | 0.4159 | 0.03818 | 0.4099 |
| 2000 | 0.03935 | 0.4595 | 0.03719 | 0.4563 |
| 2250 | 0.03823 | 0.5022 | 0.03644 | 0.5030 |
| 2500 | 0.03740 | 0.5459 | 0.03578 | 0.5488 |
| 2750 | 0.03670 | 0.5893 | 0.03522 | 0.5942 |
| 3000 | 0.03609 | 0.6322 | 0.03471 | 0.6389 |
| 3500 | 0.03509 | 0.7171 | 0.03386 | 0.7271 |
| 4000 | 0.03426 | 0.8001 | 0.03315 | 0.8135 |
| 4500 | 0.03358 | 0.8823 | 0.03255 | 0.8987 |
| 5000 | 0.03300 | 0.9634 | 0.03202 | 0.9823 |
| 6000 | 0.03200 | 1.1210 | 0.03116 | 1.1471 |
| 7000 | 0.03123 | 1.2764 | 0.03050 | 1.3099 |
| 8000 | 0.03061 | 1.4298 | 0.02993 | 1.4690 |
| 9000 | 0.03009 | 1.5812 | 0.02941 | 1.6240 |
| 10000 | 0.02960 | 1.7283 | 0.02892 | 1.7743 |

## TABLE I CONT'D

Temperature 250° F

Mole Fraction 1-Butene as Follows:

| | 0.69050 | | 0.81739 | |
|---|---|---|---|---|
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| D. P. | 0.1560 (497.7) | 0.5278 | 0.1827 (442.0) | 0.5678 |
| B. P. | 0.04356 (540.8) | 0.1601 | 0.04050 (472.5) | 0.1345 |
| 0 | --- | 1.000 | --- | 1.000 |
| 14.7 | 9.918 | 0.9906 | 9.583 | 0.9901 |
| 20 | 7.263 | 0.9872 | 7.016 | 0.9865 |
| 30 | 4.810 | 0.9808 | 4.645 | 0.9797 |
| 40 | 3.584 | 0.9743 | 3.460 | 0.9729 |
| 50 | 2.8477 | 0.9677 | 2.7481 | 0.9660 |
| 60 | 2.3570 | 0.9612 | 2.2737 | 0.9591 |
| 80 | 1.7432 | 0.9479 | 1.6802 | 0.9450 |
| 100 | 1.3747 | 0.9343 | 1.3238 | 0.9307 |
| 125 | 1.0794 | 0.9171 | 1.0381 | 0.9123 |
| 150 | 0.8822 | 0.8994 | 0.8471 | 0.8933 |
| 200 | 0.6345 | 0.8624 | 0.6064 | 0.8526 |
| 300 | 0.3827 | 0.7804 | 0.3603 | 0.7600 |
| 400 | 0.24953 | 0.6784 | 0.22710 | 0.6386 |
| 500 | --- | --- | 0.04000 | 0.1406 |
| 600 | 0.04193 | 0.1710 | 0.03885 | 0.1639 |

## TABLE I CONT'D

Temperature 250° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.69050 | | 0.81739 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compress-ibility Factor | Sp Volume Cu Ft/Lb | Compress-ibility Factor |
| 800 | 0.03906 | 0.2124 | 0.03725 | 0.2095 |
| 1000 | 0.03758 | 0.2451 | 0.03619 | 0.2544 |
| 1250 | 0.03641 | 0.3093 | 0.03520 | 0.3093 |
| 1500 | 0.03550 | 0.3619 | 0.03443 | 0.3631 |
| 1750 | 0.03476 | 0.4134 | 0.03383 | 0.4162 |
| 2000 | 0.03414 | 0.4641 | 0.03332 | 0.4685 |
| 2250 | 0.03361 | 0.5140 | 0.03287 | 0.5199 |
| 2500 | 0.03315 | 0.5633 | 0.03246 | 0.5705 |
| 2750 | 0.03273 | 0.6118 | 0.03211 | 0.6208 |
| 3000 | 0.03236 | 0.6598 | 0.03179 | 0.6705 |
| 3500 | 0.03173 | 0.7548 | 0.03120 | 0.7677 |
| 4000 | 0.03119 | 0.8480 | 0.03070 | 0.8633 |
| 4500 | 0.03072 | 0.9396 | 0.03026 | 0.9573 |
| 5000 | 0.03031 | 1.0300 | 0.02989 | 1.0507 |
| 6000 | 0.02963 | 1.2083 | 0.02925 | 1.2338 |
| 7000 | 0.02905 | 1.3821 | 0.02867 | 1.4109 |
| 8000 | 0.02856 | 1.5529 | 0.02819 | 1.5855 |
| 9000 | 0.02813 | 1.7207 | 0.02773 | 1.7577 |
| 10000 | 0.02775 | 1.8861 | 0.02740 | 1.9263 |

## TABLE I CONT'D

Temperature 280° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.17050 | | 0.33153 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| D. P. | — | — | — | — |
| 0 | — | 1.000 | — | 1.000 |
| 14.7 | 12.075 | 0.9941 | 11.483 | 0.9934 |
| 20 | 8.854 | 0.9919 | 8.418 | 0.9910 |
| 30 | 5.878 | 0.9879 | 5.586 | 0.9865 |
| 40 | 4.391 | 0.9838 | 4.171 | 0.9820 |
| 50 | 3.498 | 0.9797 | 3.321 | 0.9775 |
| 60 | 2.9025 | 0.9756 | 2.7548 | 0.9730 |
| 80 | 2.1583 | 0.9672 | 2.0469 | 0.9639 |
| 100 | 1.7115 | 0.9588 | 1.6221 | 0.9549 |
| 125 | 1.3539 | 0.9480 | 1.2820 | 0.9433 |
| 150 | 1.1153 | 0.9371 | 1.0553 | 0.9318 |
| 200 | 0.8167 | 0.9150 | 0.7714 | 0.9082 |
| 300 | 0.5168 | 0.8686 | 0.4864 | 0.8589 |
| 400 | 0.3658 | 0.8196 | 0.3424 | 0.8062 |
| 500 | 0.27392 | 0.7672 | 0.25416 | 0.7481 |
| 600 | 0.21182 | 0.7120 | 0.19313 | 0.6821 |

## TABLE I CONT'D

Temperature 280° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.17050 | | 0.33153 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| 800 | 0.13174 | 0.5904 | 0.10896 | 0.5131 |
| 1000 | 0.08233 | 0.4612 | 0.06172 | 0.3633 |
| 1250 | 0.05595 | 0.3915 | 0.04835 | 0.3558 |
| 1500 | 0.04839 | 0.4066 | 0.04403 | 0.3888 |
| 1750 | 0.04473 | 0.4385 | 0.4164 | 0.4290 |
| 2000 | 0.04261 | 0.4774 | 0.04001 | 0.4710 |
| 2250 | 0.04099 | 0.5166 | 0.03891 | 0.5153 |
| 2500 | 0.03973 | 0.5565 | 0.03792 | 0.5580 |
| 2750 | 0.03882 | 0.5980 | 0.03713 | 0.6011 |
| 3000 | 0.03810 | 0.6403 | 0.03645 | 0.6437 |
| 3500 | 0.03677 | 0.7209 | 0.03533 | 0.7279 |
| 4000 | 0.03570 | 0.8000 | 0.03444 | 0.8109 |
| 4500 | 0.03483 | 0.8780 | 0.03370 | 0.8927 |
| 5000 | 0.03411 | 0.9554 | 0.03308 | 0.9736 |
| 6000 | 0.03298 | 1.1085 | 0.03206 | 1.1323 |
| 7000 | 0.03209 | 1.2584 | 0.03128 | 1.2889 |
| 8000 | 0.03138 | 1.4063 | 0.03064 | 1.4429 |
| 9000 | 0.03077 | 1.5513 | 0.03006 | 1.5925 |
| 10000 | 0.03025 | 1.6946 | 0.02953 | 1.7383 |

## TABLE I CONT'D

Temperature 280° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.69050 | | 0.81739 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| D. P. | -- | -- | 0.0715 (603.5) | 0.291 |
| -- | -- | -- | 0.1015 (590)[b] | 0.404 |
| 0 | -- | 1.000 | -- | 1.000 |
| 14.7 | 10.351 | 0.9920 | 10.003 | 0.9915 |
| 20 | 7.583 | 0.9890 | 7.327 | 0.9884 |
| 30 | 5.027 | 0.9835 | 4.856 | 0.9826 |
| 40 | 3.749 | 0.9779 | 3.620 | 0.9767 |
| 50 | 2.9820 | 0.9723 | 2.8786 | 0.9708 |
| 60 | 2.4705 | 0.9666 | 2.3841 | 0.9648 |
| 80 | 1.8309 | 0.9551 | 1.7657 | 0.9527 |
| 100 | 1.4469 | 0.9435 | 1.3942 | 0.9404 |
| 125 | 1.1394 | 0.9288 | 1.0967 | 0.9246 |
| 150 | 0.9340 | 0.9136 | 0.8980 | 0.9085 |
| 200 | 0.6767 | 0.8825 | 0.6485 | 0.8748 |
| 300 | 0.4170 | 0.8157 | 0.3958 | 0.8009 |
| 400 | 0.28368 | 0.7400 | 0.26465 | 0.7141 |
| 500 | 0.19870 | 0.6479 | 0.17832 | 0.6013 |
| 600 | 0.13258 | 0.5187 | -- | -- |

[b] Retrograde Dew Point

TABLE I CONT'D

Temperature 280° F

| | Mole Fraction 1-Butene as Follows: | | | |
|---|---|---|---|---|
| | 0.69050 | | 0.81739 | |
| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor | Sp Volume Cu Ft/Lb | Compressibility Factor |
| 800 | 0.04739 | 0.2472 | 0.04240 | 0.2288 |
| 1000 | 0.04234 | 0.2761 | 0.03975 | 0.2681 |
| 1250 | 0.03942 | 0.3213 | 0.03785 | 0.3191 |
| 1500 | 0.03783 | 0.3700 | 0.03663 | 0.3706 |
| 1750 | 0.03687 | 0.4208 | 0.03573 | 0.4217 |
| 2000 | 0.03606 | 0.4703 | 0.03505 | 0.4728 |
| 2250 | 0.03533 | 0.5183 | 0.03440 | 0.5220 |
| 2500 | 0.03470 | 0.5657 | 0.03390 | 0.5716 |
| 2750 | 0.03417 | 0.6128 | 0.03341 | 0.6197 |
| 3000 | 0.03371 | 0.6595 | 0.03301 | 0.6679 |
| 3500 | 0.03293 | 0.7516 | 0.03232 | 0.7630 |
| 4000 | 0.03229 | 0.8423 | 0.03174 | 0.8563 |
| 4500 | 0.03174 | 0.9314 | 0.03125 | 0.9485 |
| 5000 | 0.03126 | 1.0192 | 0.03080 | 1.0387 |
| 6000 | 0.03045 | 1.1914 | 0.03005 | 1.2161 |
| 7000 | 0.02980 | 1.3603 | 0.02940 | 1.3881 |
| 8000 | 0.02924 | 1.5254 | 0.02890 | 1.5594 |
| 9000 | 0.02873 | 1.6861 | 0.02845 | 1.7270 |
| 10000 | 0.02828 | 1.8441 | 0.02800 | 1.8886 |

TABLE II. Two-Phase Volumetric Data for a Mixture of Propene and 1-Butene with 81.739 Mole % 1-Butene

| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor |
|---|---|---|
| | 40°F | |
| 34.9[b] | 0.02659 | 0.0093 |
| 30 | 0.9074 | 0.2718 |
| 31 | 0.6542 | 0.2025 |
| 32 | 0.4438 | 0.1418 |
| 33 | 0.27314 | 0.0900 |
| 34 | 0.13108 | 0.0445 |
| | 70°F | |
| 57.4[b] | 0.02760 | 0.0149 |
| 48 | 0.9754 | 0.4410 |
| 50 | 0.6837 | 0.3220 |
| 52 | 0.4522 | 0.2215 |
| 54 | 0.26444 | 0.1345 |
| 56 | 0.11129 | 0.0587 |
| | 100°F | |
| 89.4[b] | 0.02865 | 0.0228 |
| 74 | 1.0157 | 0.6700 |
| 76 | 0.7882 | 0.5340 |
| 78 | 0.6038 | 0.4198 |
| 80 | 0.4512 | 0.3218 |
| 82 | 0.3264 | 0.2386 |
| 84 | 0.22650 | 0.1696 |
| 86 | 0.14349 | 0.1100 |
| 88 | 0.07164 | 0.0562 |
| | 160°F | |
| 190.6[b] | 0.03156 | 0.0484 |
| 163.7[d] | 0.6009 | 0.7922 |
| 165 | 0.5544 | 0.7365 |
| 167 | 0.4946 | 0.6550 |
| 169 | 0.4232 | 0.5758 |
| 171 | 0.3643 | 0.5015 |
| 175 | 0.26652 | 0.3755 |
| 179 | 0.18888 | 0.2722 |
| 183 | 0.12469 | 0.1837 |
| 187 | 0.07054 | 0.1062 |

| Pressure Lb/Sq In Absolute | Sp Volume Cu Ft/Lb | Compressibility Factor |
|---|---|---|
| | 220°F | |
| 357.3[b] | 0.03622 | 0.0950 |
| 324.2[d] | 0.2794 | 0.6650 |
| 325 | 0.27246 | 0.6500 |
| 330 | 0.22622 | 0.5480 |
| 335 | 0.18361 | 0.4515 |
| 340 | 0.14476 | 0.3613 |
| 345 | 0.11056 | 0.2800 |
| 350 | 0.07932 | 0.2038 |
| 355 | 0.04943 | 0.1288 |
| | 250°F | |
| 472.5[b] | 0.04050 | 0.1345 |
| 442.0[d] | 0.1827 | 0.5678 |
| 445 | 0.15940 | 0.4987 |
| 450 | 0.12960 | 0.4100 |
| 455 | 0.09396 | 0.3441 |
| 460 | 0.08726 | 0.2822 |
| 465 | 0.06837 | 0.2235 |
| 470 | 0.04963 | 0.1640 |
| | 280°F | |
| 603.5[b] | 0.0715 | 0.291 |
| 590.0[rd] | 0.1015 | 0.404 |

[b] Bubble Point
[d] Dew Point
[rd] Retrograde Dew Point

## TABLE III. Experimental Data for Coexisting Phases in the Propene-1-Butene System

| Mole Fraction 1-Butene | Dew Pt. Pressure PSI Absolute | Bubble Pt. Pressure PSI Absolute |
|---|---|---|
| | 40 Deg F | |
| 0.00 | 97.5 | 97.5 |
| 0.1302 | 69.1 | — |
| 0.17050 | — | 82.8 |
| 0.33153 | — | 70.5 |
| 0.4131 | 40.8 | — |
| 0.5576 | 34.3 | — |
| 0.69050 | — | 43.6 |
| 0.81739 | — | 34.9 |
| 1.00 | 21.9 | 21.9 |
| | 70 Deg F | |
| 0.00 | 152.1 | 152.1 |
| 0.17050 | 103.6 | 130.6 |
| 0.33153 | — | 111.3 |
| 0.4154 | 69.5 | — |
| 0.6078 | 54.9 | — |
| 0.69050 | — | 70.9 |
| 0.81739 | — | 57.4 |
| 1.00 | 38.2 | 38.2 |
| | 100 Deg F | |
| 0.00 | 227.3 | 227.3 |
| 0.17050 | 161.4 | 195.3 |
| 0.33153 | 124.4 | 166.9 |
| 0.4582 | 104.0 | — |
| 0.69050 | 80.8 | 108.4 |
| 0.81739 | — | 89.4 |
| 1.00 | 62.5 | 62.5 |
| | 160 Deg F | |
| 0.00 | 456.6 | 456.6 |
| 0.17050 | 346.9 | 389.7 |
| 0.33153 | 276.3 | 334.3 |
| 0.69050 | 184.1 | 224.9 |
| 0.81739 | 163.7 | 190.6 |
| 1.00 | 142.9 | 142.9 |

| Mole Fraction 1-Butene | Dew Pt. Pressure PSI Absolute | Bubble Pt. Pressure PSI Absolute |
|---|---|---|
| | 220 Deg F | |
| 0.2920 | 571.8 | — |
| 0.33153 | 543.7 | 594.5 |
| 0.69050 | 365.4 | 413.1 |
| 0.81739 | 324.2 | 357.3 |
| 1.00 | 282.6 | 282.6 |
| | 250 Deg F | |
| 0.6472 | 519.4 | — |
| 0.69050 | 497.7 | 540.8 |
| 0.81739 | 442.0 | 472.5 |
| 1.00 | 381.9 | 381.9 |
| | 280 Deg F | |
| 0.81739 | 603.5 | — |
| 0.81739 | 590.0* | — |
| 1.00 | — | — |

| | $T_c$ Deg F | $P_c$ Pressure PSI Absolute |
|---|---|---|
| 1-Butene | 297.0 | 588.0 |
| Propene | 196.5 | 667.2 |

*Retrograde dew point

TABLE IV. Properties of Coexisting Phases in Propene-1-Butene System

| Temp., °F | Pressure PSI Absolute | Mole Fraction 1-Butene Liquid | Mole Fraction 1-Butene Gas | Sp. Vol., Cu Ft/Lb Liquid | Sp. Vol., Cu Ft/Lb Gas | Equilibrium Constants Propene | Equilibrium Constants 1-Butene |
|---|---|---|---|---|---|---|---|
| 40 | 21.9 [a] | 1.000 | 1.000 | 0.02610 | 4.146 | 3.954 | 1.000 |
| | 30 | 0.887 | 0.674 | 0.02639 | 3.234 | 2.908 | 0.759 |
| | 40 | 0.743 | 0.436 | 0.02680 | 2.603 | 2.190 | 0.587 |
| | 50 | 0.600 | 0.291 | 0.02720 | 2.197 | 1.772 | 0.485 |
| | 60 | 0.467 | 0.199 | 0.02761 | 1.910 | 1.502 | 0.426 |
| | 70 | 0.336 | 0.126 | 0.02813 | 1.648 | 1.315 | 0.375 |
| | 80 | 0.207 | 0.071 | 0.02860 | 1.422 | 1.171 | 0.341 |
| | 90 | 0.086 | 0.027 | 0.02918 | 1.238 | 1.064 | 0.316 |
| | 97.5 [b] | 0.000 | 0.000 | 0.02969 | 1.123 | 1.000 | 0.303 |
| 70 | 38.2 [a] | 1.000 | 1.000 | 0.02720 | 2.445 | 3.521 | 1.000 |
| | 40 | 0.983 | 0.943 | 0.02721 | 2.355 | 3.364 | 0.959 |
| | 50 | 0.888 | 0.698 | 0.02740 | 1.980 | 2.700 | 0.785 |
| | 60 | 0.793 | 0.531 | 0.02764 | 1.713 | 2.264 | 0.670 |
| | 80 | 0.606 | 0.319 | 0.02824 | 1.339 | 1.730 | 0.526 |
| | 100 | 0.429 | 0.188 | 0.02900 | 1.094 | 1.420 | 0.439 |
| | 125 | 0.216 | 0.080 | 0.02995 | 0.8795 | 1.174 | 0.370 |
| | 150 | 0.017 | 0.006 | 0.03107 | 0.7315 | 1.011 | 0.333 |
| | 152.1 [b] | 0.000 | 0.000 | 0.03121 | 0.7207 | 1.000 | 0.330 |
| 100 | 62.5 [a] | 1.000 | 1.000 | 0.02821 | 1.5245 | 3.136 | 1.000 |
| | 80 | 0.880 | 0.702 | 0.02850 | 1.262 | 2.472 | 0.798 |
| | 100 | 0.746 | 0.491 | 0.02900 | 1.055 | 2.002 | 0.658 |
| | 125 | 0.587 | 0.329 | 0.02960 | 0.8723 | 1.625 | 0.560 |
| | 150 | 0.404 | 0.213 | 0.03053 | 0.7295 | 1.382 | 0.494 |
| | 175 | 0.284 | 0.129 | 0.03119 | 0.6260 | 1.218 | 0.454 |
| | 200 | 0.144 | 0.062 | 0.03202 | 0.5454 | 1.096 | 0.431 |
| | 227.3 [b] | 0.000 | 0.000 | 0.03318 | 0.4718 | 1.000 | 0.411 |
| 160 | 142.9 [a] | 1.000 | 1.000 | 0.03092 | 0.6736 | 2.500 | 1.000 |
| | 150 | 0.970 | 0.930 | 0.03100 | 0.6450 | 2.337 | 0.959 |
| | 200 | 0.781 | 0.608 | 0.03178 | 0.5030 | 1.791 | 0.778 |
| | 250 | 0.604 | 0.410 | 0.03280 | 0.4110 | 1.491 | 0.679 |
| | 300 | 0.440 | 0.272 | 0.03402 | 0.3400 | 1.299 | 0.619 |
| | 350 | 0.284 | 0.166 | 0.03560 | 0.2838 | 1.165 | 0.585 |
| | 400 | 0.142 | 0.082 | 0.03745 | 0.2408 | 1.070 | 0.574 |
| | 456.6 [b] | 0.000 | 0.000 | 0.03983 | 0.2002 | 1.000 | 0.581 |

## TABLE IV. CONT'D

| Temp., °F | Pressure PSI Absolute | Mole Fraction 1-Butene | | Sp. Vol., Cu Ft/Lb | | Equilibrium Constants | |
|---|---|---|---|---|---|---|---|
| | | Liquid | Gas | Liquid | Gas | Propene | 1-Butene |
| 220 | 282.6 [a] | 1.000 | 1.000 | 0.03472 | 0.3220 | 1.918 | 1.000 |
| | 300 | 0.954 | 0.917 | 0.03502 | 0.3016 | 1.817 | 0.961 |
| | 350 | 0.835 | 0.735 | 0.03603 | 0.2568 | 1.590 | 0.880 |
| | 400 | 0.720 | 0.601 | 0.03738 | 0.2180 | 1.428 | 0.834 |
| | 450 | 0.610 | 0.490 | 0.03865 | 0.1855 | 1.309 | 0.803 |
| | 500 | 0.508 | 0.399 | 0.04010 | 0.1630 | 1.221 | 0.786 |
| | 550 | 0.411 | 0.324 | 0.04222 | 0.1450 | 1.151 | 0.790 |
| | 600 | 0.320 | 0.255 | 0.04690 | 0.130 | 1.096 | 0.797 |
| | 625 | 0.276 | 0.224 | 0.05200 | 0.120 | 1.073 | 0.810 |
| | 645 | 0.241 | 0.200 | 0.0588 | 0.105 | 1.054 | 0.830 |
| | 653 [c] | 0.218 | 0.218 | 0.0691 | 0.0691 | 1.000 | 1.000 |
| 250 | 381.9 [a] | 1.000 | 1.000 | 0.03800 | 0.2220 | 1.652 | 1.000 |
| | 400 | 0.961 | 0.938 | 0.03555 | 0.2076 | 1.592 | 0.976 |
| | 450 | 0.860 | 0.797 | 0.03984 | 0.1778 | 1.453 | 0.926 |
| | 500 | 0.766 | 0.686 | 0.04120 | 0.1550 | 1.342 | 0.896 |
| | 550 | 0.674 | 0.593 | 0.04440 | 0.134 | 1.245 | 0.880 |
| | 600 | 0.585 | 0.519 | 0.0528 | 0.115 | 1.159 | 0.887 |
| | 615 | 0.560 | 0.502 | 0.0580 | 0.108 | 1.132 | 0.896 |
| | 625 | 0.539 | 0.492 | 0.0618 | 0.0950 | 1.104 | 0.913 |
| | 630 [c] | 0.514 | 0.514 | 0.0688 | 0.0688 | 1.000 | 1.000 |
| 280 | 506 [a] | 1.000 | 1.000 | 0.4497 | 0.1327 | 1.443 | 1.000 |
| | 525 | 0.966 | 0.952 | 0.0450 | 0.127 | 1.400 | 0.986 |
| | 550 | 0.920 | 0.893 | 0.0450 | 0.119 | 1.347 | 0.970 |
| | 575 | 0.878 | 0.842 | 0.0503 | 0.109 | 1.294 | 0.959 |
| | 600 | 0.835 | 0.807 | 0.0645 | 0.087 | 1.172 | 0.966 |
| | 604 [c] | 0.822 | 0.822 | 0.0683 | 0.0683 | 1.000 | 1.000 |

[a] Vapor pressure of 1-Butene

[b] Vapor pressure of Propene

[c] Critical state

TABLE V. Properties of Propene-1-Butene System in the Critical Region

| Mole Fraction of 1-Butene | 1.00 | 0.8174 | 0.6905 | 0.3315 | 0.1705 | 0 |
|---|---|---|---|---|---|---|
| Critical State | | | | | | |
| Pressure (lb/in$^2$abs) | 588.0 | 604.0 | 615.0 | 643.0 | 654.0 | 667.2 |
| Temperature ($^\circ$F) | 297.0 | 280.0 | 268.0 | 233.0 | 218.0 | 196.5 |
| Volume (cu. ft/lb) | 0.0686 | 0.0683 | 0.0685 | 0.0690 | 0.0692 | 0.0694 |
| Point of Max. Temp. | | | | | | |
| Pressure (lb/in$^2$abs) | | 602.0 | 612.5 | 640.2 | 651.5 | |
| Temperature ($^\circ$F) | | 281.0 | 269.0 | 234.5 | 219.5 | |
| Volume (cu. ft/lb) | | 0.0826 | 0.0824 | 0.0813 | 0.0775 | |

# IX. APPENDIX

## I. METHOD OF CALCULATION EMPLOYED IN THE DETERMINATION OF DEW-POINT GAS COMPOSITION.

1) Calculate $bZ = \frac{PV}{mT}$

   where $P$ = pressure of gas in sample bulb

   $V$ = volume of sample bulb

   $m$ = weight of gas in sample bulb

   $T$ = absolute temperature of gas in bulb

   $b$ = specific gas constant for sample of gas

2) Assume an approximate composition of the mixture being analyzed.

3) Using assumed value of mixture composition, obtain value of Z from a graph of Z vs mole fraction 1-butene plotted with isothermal curves at a pressure of one atmosphere. This graph was constructed from experimental PVT data for the propene-1-butene system.

4) Calculate $b = \frac{bZ}{Z}$

5) Substitute the calculated value of b into equation $n_4 = \frac{.76514}{b} - 3.001$ to obtain an approximate value of $n_4$

   The above equation may be derived from the relations:

   $b = \frac{R}{n_3M_3 + n_4M_4}$ and $n_3 = 1 - n_4$

6) Repeat steps 2 through 5 using new value of composition for second trial. Make as many trial calculations as needed.