A comparative study of experimental and computed compressibility factors of ethane-carbon dioxide-nitrogen system

Brij Raj Misra

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A COMPARATIVE STUDY OF EXPERIMENTAL AND COMPUTED COMPRESSIBILITY FACTORS OF ETHANE-CARBON DIOXIDE-NITROGEN SYSTEM

By

BRIJ RAJ MISRA, 1940 -

A THESIS submitted to the faculty of UNIVERSITY OF MISSOURI - ROLLA in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN PETROLEUM ENGINEERING Rolla, Missouri 1970

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The purpose of this study was to provide compressibility factor data on the ethane - carbon dioxide - nitrogen system. Compressibility factors were experimentally determined for 5 mixtures at room temperature, 100°F, 125°F, 150°F and pressures ranging between 1000 psig to 4000 psig.

An attempt was also made to compare the experimental data with the compressibility factors obtained by the additive volume method. The deviation of the computed compressibility factor from the experimental data was found to be in accordance with the general view of previous workers. However, the deviation was found to be a maximum in the pressure range 1500 psig to 1000 psig.
ACKNOWLEDGEMENTS

The author wishes to express his grateful appreciation to Dr. T. C. Wilson for his guidance and encouragement throughout this investigation. Special thanks are due to Professor J. P. Govier for his valuable suggestions and providing facilities to carry out this work.

The author would like to express his sincere appreciation to Dr. E. L. Park for his constructive suggestions after going through the manuscript. The author is indebted to fellow graduate student P. E. Ilavia for his valuable help during experiment. Particular appreciation is due to Mr. Everett M. Ragan for his help in fixing the experimental equipments as and when needed.
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I. INTRODUCTION

While considerable theoretical and experimental work is available on the compressibility factors of the pure hydrocarbon gases and hydrocarbon mixtures, less is known about the added effect of nitrogen and carbon dioxide occurring with the natural hydrocarbon mixtures.

Eilerts et. al.\(^1\), have investigated the effect of added nitrogen in a hydrocarbon mixture and proposed a procedure for calculating the effect of nitrogen on the compressibility factor.

The work of Eilerts et. al.\(^1\), was followed by Sage and Lacey\(^2\) who, have presented data on binary systems e.g., ethane - nitrogen and ethane - carbon dioxide systems. However, no experimental work is available for a hydrocarbon system containing nitrogen and carbon dioxide together in varying proportions. The object of this experimental investigation was to provide compressibility factor data on ethane - carbon dioxide - nitrogen system and compare the experimental results with the additive volume compressibility factors suggested by Eilerts et. al.\(^1\), and adopted for nitrogen and carbon dioxide occurring together with hydrocarbon mixtures, by Amyx, Bass and Whiting\(^3\).

\(^1\)References given at the end of thesis.
II. LITERATURE REVIEW

Various methods have been developed for computing the compressibility factor of lean natural hydrocarbon gases from the knowledge of its chemical composition or density. Of all these methods, Kay's method is worth mentioning. Kay suggested that for mixtures of lower hydrocarbons, the pseudocritical temperature, $p_{Tc}$ and pseudocritical pressure, $p_{Pc}$, of the mixture may be obtained with sufficient accuracy applying Amagat's law of partial volumes for mixtures to the critical properties of individual constituents of the mixture. The pseudocritical temperature and pressure is defined as follows:

$$p_{Tc} = \sum_{i=1}^{n} Y_i T_{ci}$$  \hspace{1cm} (1)

$$p_{Pc} = \sum_{i=1}^{n} Y_i P_{ci}$$  \hspace{1cm} (2)

where $Y_i$ is the mole fraction of the $i$th component and $T_{ci}$ and $P_{ci}$ are critical temperature and pressure of the $i$th component in the mixture.

Kay also introduced the concept of pseudoreduced pressure and temperature based on the theorem of corresponding states. The pseudoreduced pressure, $p_{Pr}$, and pseudoreduced temperature, $p_{Tr}$, are defined as:

$$p_{Pr} = \frac{P}{p_{Pc}}$$  \hspace{1cm} (3)

$$p_{Tr} = \frac{T}{p_{Tc}}$$  \hspace{1cm} (4)
where P and T are the absolute pressure and temperature of the system. For a large number of natural gas samples, experimentally determined compressibility factors were correlated with pseudo-reduced temperature and pressure. The results of these correlations are presented in a number of charts and provide a very convenient method of computing compressibility factors when calculated $pPr$ and $pTr$ are known.

The methods devised for computing the compressibility factor of a lean natural gas from its composition provide a dependable solution for low nitrogen and carbon dioxide concentrations. But when nitrogen or carbon dioxide or both are associated with hydrocarbon gases in considerable quantity, these methods do not yield satisfactory results. This is true because, nitrogen and carbon dioxide are chemically unlike hydrocarbon gases, hence, will have a different compressibility character. As a result, if these gases are present in considerable quantity in natural gas, computing methods that give due consideration to their nature should be used.

Eilerts et. al.\(^1\) who studied the effect of added nitrogen on the compressibility of natural gases concluded that the compressibility factor of natural hydrocarbon - nitrogen mixture determined by assuming that law of corresponding states holds good, has an error of less than 1% for a mixture having 10 mole % nitrogen concentration or less. The error in compressibility factor was expected to be greater than 3% for a natural gas having 20 mole % nitrogen or more.

Old, Sage and Lacey\(^5\) stated that for a mixture containing 4 mole % carbon dioxide concentration, a 5% error in compressibil-
lity factor computation may be obtained using theorem of corresponding states. However, as per Standing up to 2 mole % carbon dioxide in a gas mixture allows the theorem of corresponding states to be used.

Eilerts et. al. suggested a procedure for computing the compressibility factor of mixtures containing high concentration of nitrogen. They defined an additive compressibility factor $Z_a$ as follows:

$$Z_a = Z_n Y_n + (1 - Y_n) Z_g$$  \hspace{1cm} (5)$$

where $Z_n$ is the compressibility factor of nitrogen, $Z_g$ is the compressibility factor of the hydrocarbon fraction in mixture and $Y_n$ is the mole fraction of nitrogen. The true compressibility factor $Z$ of the mixture is then defined by:

$$Z = C Z_a$$  \hspace{1cm} (6)$$

where $C$ is the additive volume correction factor which depends upon the temperature, the pressure and nitrogen concentration in the system. The value of $C$ is obtained from published data over various temperature and pressure ranges.

Sage and Lacey have also suggested a computation procedure to correct the volume calculation for impurities such as carbon dioxide based on the partial residual volume. As suggested by Amyx, Bass and Whiting, analogous to the work of Eilerts et. al., the compressibility factor of carbon dioxide can be utilized to calculate, by method of additive volumes, the compressibility factor of a mixture containing carbon dioxide. The additive volume compressibility factor $Z_a$ is given by:
where $Y_{CO_2}$ is the mole fraction of carbon dioxide in the mixture.

$Z_g$ is the compressibility factor of the hydrocarbon fraction.

Amyx, Bass and Whiting\textsuperscript{3} have concluded that when both carbon dioxide and nitrogen are present, for a low concentration of carbon dioxide and moderate concentration of nitrogen, the correction of the additive compressibility factor can be made as if carbon dioxide were a part of the hydrocarbon system; thus $C$ corrects nitrogen only and additive compressibility factor $Z_a$ is defined by:

$$Z_a = Y_{CO_2} (Z_{CO_2}) + (1 - Y_{CO_2}) Z_g$$

and the corrected compressibility factor, $Z$, of the mixture will be:

$$Z = C Z_a$$

where $C$ is the additive volume correction factor for nitrogen.

A similar procedure to the one suggested by Amyx, Bass and Whiting\textsuperscript{3} for a mixture containing nitrogen and carbon dioxide was used to correlate the experimental results.
A. EXPERIMENTAL EQUIPMENT AND PROCEDURE

The equipment used in the experiment consists primarily of a high pressure cell, a mercury pump with gauge, a constant temperature oil bath and associated miscellaneous equipment.

The entire experimental procedure was set in the following sequence. Preparing the equipment for study, calibration of pump and cell, preparing gas mixtures and determining P.V.T. relationships for various temperature and pressure ranges.

1. Preparing equipment for study.

The pump, cells and connecting lines were thoroughly cleaned. They were separately connected with the vacuum pump and completely evacuated. This preliminary step was observed throughout each experimental run. The cell was pressurized to 4000 psig and checked for leaks.

2. Calibration of pump and cell.

The mercury pump was calibrated by withdrawing known volumes of mercury from the pump and calculating its volume with the use of a chemical balance and published mercury density data.

The high pressure cells were calibrated at temperatures of 80°F, 100°F, 125°F, 150°F and over the pressure range of 1000 psig to 4000 psig, in 500 psig increments. A linear relation was obtained by plotting the cell volume as a function of pressure at constant temperature. This relationship is shown in Figure 1.
Figure 1  CELL CALIBRATION
<table>
<thead>
<tr>
<th>Temperature in °F</th>
<th>Compressibility of mercury, vol/vol, psi $\times 10^{-7}$</th>
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<td>2.765</td>
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</tr>
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<td>76°F</td>
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<td>150°F</td>
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<td>1.009097</td>
</tr>
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</table>
3. Preparation of gas mixtures.

The pure grade 99 mole % (minimum), ethane used in preparing the mixtures, was obtained from Phillips Petroleum Company. Nitrogen and carbon dioxide were obtained from Acetelene Gas Company.

Using the ideal gas law relation an approximate value of pressure required to load the desired mole fraction of each component of the mixture was calculated. Nitrogen was first loaded at the desired pressure in Cell 1. The volume of nitrogen was then measured at 2000 psig. By knowing the pressure, volume, temperature and published compressibility factor values of nitrogen, the number of moles of nitrogen could be calculated.

Carbon dioxide was loaded in Cell 2 the number of moles was similarly determined and it was transferred to Cell 1. Finally, ethane was loaded in the thoroughly cleaned and evacuated Cell 2. After establishing the mole content ethane was transferred in Cell 1.

The procedure such as one employed in this study will not give the exact desired mixture but it was found to work very well for approximating the desired mixture. An example calculation for a mixture preparation is given in Appendix B.

4. P. V. T. measurements of the mixture:

Following the preparation of desired gas mixture the Cell was placed in constant temperature bath at room temperature. The Cell pressure was raised to 4000 psig. After allowing sufficient time to establish equilibrium, the initial reading on the pump was recorded. The subsequent pump readings were taken at 3500, 3000, 2500, 2000, 1500
and 1000 psig Cell pressures.

Having completed one set of P . V . T . readings the temperature of the bath was raised to 100°F, 125°F and 150°F and pressure - volume readings were taken at stabilized temperature and pressure conditions.

B . ERROR ANALYSIS

In order to compare the experimental results with the published data, P . V . T . studies were carried out on a sample of nitrogen at 100°F and pressures ranging between 4000 psig and 1000 psig. A comparison between the experimental values of compressibility factors and the ones obtained from the work of Sage and Lacey showed a difference of 3%. A small deviation of the experimental results with the published data provided encouragement to work on mixtures. However, the following sources of error in the experiment might throw some light on the quality of results achieved.

At times the room temperature varied anywhere from 1°F to 10°F in an hour duration. Therefore, some precaution was used to stabilize the room temperature so as to limit the variation to a maximum of two degrees Fahrenheit. However, an error of 1°F in temperature would cause a maximum change in compressibility factor of 0.183%.

The pump could be read accurately up to 0.01 cc and the readings at third decimal place were approximated. The reading of the third decimal place introduces a negligible error affecting a change in calculated compressibility factor.

The calculational error (the round off error and truncation error) was kept to a minimum by using an electronic programmable Wang calculator:
IV. RESULTS

Four gas samples, with varying proportions of ethane, carbon-dioxide and nitrogen were prepared and studied to determine compressibility factor. After initial studies were performed, a mixture was prepared to simulate a possible natural gas sample composed of methane, ethane, carbon dioxide and nitrogen, designated as Mixture 5.

P. V. T. relations of the samples were studied at room temperature 100°F, 125°F and 150°F and over the pressure range 1000 psig to 4000 psig. Results of the investigation are presented in Tables 2 through Table 5. Figures 2 through 6 graphically represent pressure-compressibility factor relations at 4 isotherms. Three additional data points were obtained on Mixture 4 to investigate the trend of isotherms in the region 1000 psig to 2000 psig.

In order to compare the experimentally determined compressibility factor of the mixtures, the compressibility factor for the same mixtures were computed using Eilerts' method and is presented in Table 6. The results on mixture preparation at room temperature and 2000 psig indicated that when definite volumes of carbon dioxide, nitrogen and ethane measured at the same condition of temperature and pressure were combined, the volume of the mixture of the three gases measured at the same condition of temperature and pressure, was found to be smaller than the sum of the volumes of individual gases. This is due to the fact that since the critical temperature of carbon dioxide and ethane are at 88°F and at 90°F, a portion of ethane - carbon dioxide - nitrogen system goes into liquid phase at room temperature and 2000 psig.

A comparative study of the experimentally determined and computed compressibility factors at 125°F and pressure between 1000 psig to
4000 psig is available in Figures 7 through Figure 10. From these figures it can be seen that deviation from the experimental values increases gradually from an average of 2.14% for Mixture 4 to 7.25% for Mixture 3. See table 7. The maximum deviation, in the region 1000 psig to 1500 psig, for Mixture 4 and Mixture 3 were 7.95% and 16.16%, respectively.

The order of deviation for Mixture 5, which, contained methane was different than ethane - carbon dioxide - nitrogen system. The deviation was a minimum at 2000 psig. See Figure 10.

It is also interesting to note that the percentage deviation decreased, for all the samples, at comparatively higher temperature where, the samples were above their critical temperatures. This feature can also be visualised from the published work of Sage and Lacey\(^2\) on ethane - carbon dioxide system, (Figure 11), which, indicates that with increasing temperature the deviation from an ideal solution reduces to a minimum.

The revised compressibility factor data on single components ethane and methane was obtained from A. P. I. Research Project \(^{11}\). Compressibility factors of nitrogen and carbon dioxide were available from Sage and Lacey's\(^{10}\) work. The computed compressibility factors could be calculated only for temperatures 125°F and 150°F from the available chart on the compressibility factor of natural gases\(^{11}\). The additive volume correction factor C for the mixtures under investigation was selected from the closest available data. Since, Mixture 2 contains 19.197 mole % carbon dioxide its compressibility factor was not computed using Eilerts method.
## Table 2

### Composition of the Mixtures

<table>
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<tr>
<th>Components</th>
<th>Mixture 1 (mole frac.)</th>
<th>Mixture 2 (mole frac.)</th>
<th>Mixture 3 (mole frac.)</th>
<th>Mixture 4 (mole frac.)</th>
<th>Mixture 5 (mole frac.)</th>
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<td>0.84963</td>
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</tr>
<tr>
<td>1514.7</td>
<td>0.75822</td>
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<tr>
<td>1014.7</td>
<td>0.74922</td>
<td>0.77599</td>
<td>0.78596</td>
<td>0.80318</td>
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</tr>
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</table>
Figure 2 EXPERIMENTAL COMPRESSIBILITY FOR MIXTURE 1
Figure 3 EXPERIMENTAL COMPRESSIBILITY FOR MIXTURE: 2
Figure 4 EXPERIMENTAL COMPRESSIBILITY FOR MIXTURE 3
Figure 5 EXPERIMENTAL COMPRESSIBILITY FOR MIXTURE 4.
Figure 6 EXPERIMENTAL COMPRESSIBILITY FOR MIXTURE 5
<table>
<thead>
<tr>
<th>Pressure (psia)</th>
<th>Mixture 1</th>
<th>Mixture 2</th>
<th>Mixture 3</th>
<th>Mixture 4</th>
<th>Mixture 5</th>
</tr>
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<tr>
<td>4014.7</td>
<td>0.79319</td>
<td>0.79452</td>
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<td>0.76960</td>
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<td>3514.7</td>
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<td>0.71511</td>
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<td>0.68776</td>
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<td>0.65566</td>
<td>0.62457</td>
<td>0.64259</td>
<td>0.60709</td>
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<tr>
<td>2514.7</td>
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<td>0.58590</td>
<td>0.54681</td>
<td>0.57297</td>
<td>0.52504</td>
</tr>
<tr>
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<td>0.51906</td>
<td>0.47422</td>
<td>0.50752</td>
<td>0.44857</td>
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<tr>
<td>1514.7</td>
<td>0.42139</td>
<td>0.48813</td>
<td>0.40940</td>
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<td>0.45847</td>
<td>0.577658</td>
<td>0.45327</td>
<td>0.57351</td>
<td>0.41741</td>
</tr>
<tr>
<td>Mixture</td>
<td>Carbon Dioxide (mole %)</td>
<td>Nitrogen (mole %)</td>
<td>Average Dev. (2000-4000 psig) %</td>
<td>Maximum Dev. (at 1000 psig) %</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------------------</td>
<td>-------------------</td>
<td>---------------------------------</td>
<td>-------------------------------</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>6.556</td>
<td>13.009</td>
<td>5.00</td>
<td>12.09</td>
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</tr>
<tr>
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<td>16.16</td>
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<tr>
<td>4</td>
<td>5.782</td>
<td>7.299</td>
<td>2.14</td>
<td>7.95</td>
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</tr>
<tr>
<td>5</td>
<td>4.222</td>
<td>5.569</td>
<td>5.00</td>
<td>1.04 (min.)</td>
<td>14.44</td>
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Figure 7 EXPERIMENTAL AND COMPUTED COMPRESSIBILITY FACTORS MIXTURE 1
Figure 8. EXPERIMENTAL AND COMPUTED

COMPRESSIBILITY FACTORS MIXTURE 3
Figure 9  EXPERIMENTAL AND COMPUTED

COMPRESSIBILITY FACTORS  MIXTURE 4
Figure 10 EXPERIMENTAL AND COMPUTED

COMPRESSIBILITY FACTORS MIXTURE 5
Figure 11. VOLUMETRIC DEVIATION FROM IDEAL SOLUTIONS

ETHANE - CARBON DIOXIDE (0.6 mole fraction ethane)
V. CONCLUSION AND RECOMMENDATIONS

The results of experimentally determined compressibility factors for ethane - carbon dioxide - nitrogen system and computed compressibility factors for the same system, using Eilerts' method, indicated gradual increase in deviation from experimental value with increasing percentage of carbon dioxide and nitrogen in the mixture. This is in accordance with the general view of Olds et al.\(^5\) and Eilerts and co-workers\(^1\).

The deviation was found to reach maximum in the pressure range 1500 psig to 1000 psig, where the carbon dioxide and ethane have their critical region, at the temperatures under study.

Due to limitation of equipment it was not possible to carry out the present investigation in further detail, namely, in the pressure ranges from 0 psig to 2000 psig. It is, therefore, recommended that the critical region for ethane - carbon dioxide - nitrogen system should be investigated in detail. Also, it would be interesting to study P. V. T. relations in the pressure region 0 psig to 1000 psig which will provide a definite guide to the isotherms in this region.
VI. APPENDICES
APPENDIX A

SAMPLE CALCULATION OF CELL CALIBRATION

At any pressure, \( P \), and cell temperature, \( T \), the change in cell volume was calculated by the following relation:\(^1\)

Change in Cell volume, \( G \), = Expansion of original mercury, \( F \), minus volume in Cell, \( E \).

\( E \) and \( F \) are further defined as:

\[
E = v \left( 1 + 4000 \frac{B_t}{V_t} \right) \frac{V_T}{V_t} - \left( 1 - B_T P \right)
\]

\[
F = V_1 \left[ \left( 1 + 4000 \frac{B_t}{V_t} \right) \frac{V_T}{V_t} - \left( 1 - B_T P \right) \right] - 1
\]

where \( v \) = volume in pump
\( V_1 \) = cell volume at 4000 psig and room temperature.
\( B_t \) = compressibility of mercury at room temperature.
\( B_T \) = compressibility of mercury at elevated cell temperature.
\( V_t \) = relative volume of mercury at room temperature.
\( V_T \) = relative volume of mercury at elevated cell temperature.

Calculation of cell volume at 3500 psig and 150°F:

Room temperature
Cell volume at 4000 psig and 77°F = 651.3108 cc
Pump reading at 4000 psig and 77°F = 21.760
Pump reading at 3500 psig and 150°F = 17.758
Pump constant = 1.0037802
Volume in pump, \( v \) = 4.002 x 1.0037802
= 4.01713 cc
Appendix A (continued)

\[ V_t \text{ (from Table 1 )} = 1.001917 \]
\[ V_T \text{ (from Table 1 )} = 1.009097 \]
\[ B_t \text{ (from Table 1 )} = 2.777 \times 10^{-7} \text{ vol/vol.psi} \]
\[ B_T \text{ (from Table 1 )} = 3.000 \times 10^{-7} \text{ vol/vol.psi} \]

Change in cell volume, \( G \),

\[
651.3108 \left[ \left( 1 + 4000 \times 2.777 \times 10^{-7} \right) \frac{1.009097}{1.001917} \left( 1 - 3500 \times 3 \times 10^{-7} \right) - 1 \right]
- 4.0171 \left( 1 + 4000 \times 2.777 \times 10^{-7} \right) \frac{1.009097}{1.001917} \left( 1 - 3500 \times 3 \times 10^{-7} \right)
\]

\[ = 0.66042 \text{ cc} \]

Volume of cell at 3500 psig and 150°F

\[ = 651.3108 + 0.66048 \]

\[ = 651.971 \text{ cc} \]
APPENDIX B

SAMPLE CALCULATION OF MIXTURE PREPARATION

To obtain the individual volume of each gas for preparing the mixture of desired mole fraction, the pressure at which gas could be loaded in the cell was calculated from the gas law relation:

\[ P = \frac{ZnRT}{V} \quad (12) \]

where, \( V \), is the volume of the cell.

For nitrogen the pressure calculated to obtain 0.00035 moles was:

\[ P = \frac{1x0.00035x10.729x544x28316.8}{661.5} = 88.788 \text{ psia} \]

The exact volume of nitrogen loaded in the cell at the above calculated pressure was found by pumping - in known quantity of mercury to a pressure of 2000 psig.

Volume of mercury pumped in cell (at pump condition) = 617.139 cc

Volume of mercury in cell condition at 2000 psig and 84°F:

\[ 617.139 \left(1 + 4000 \times 2.792 \times 10^{-7}\right) \left(1 - 2000 \times 2.792 \times 10^{-7}\right) = 617.483 \text{ cc} \]

Cell volume at 2000 psig and 84°F (from Figure 1) = 651.530

Volume of nitrogen at 2000 psig and 84°F = 651.53 - 617.483 = 34.047 cc

Number of moles of nitrogen from (12):

\[ n = \frac{2014.7 \times 34.047}{1.121 \times 10.729 \times 544 \times 28316.8} = 0.0003703019 \]

In the similar procedure as above the number of moles of carbon dioxide, ethane and methane were also determined and the gases were transferred to the cell containing nitrogen.
APPENDIX C

SAMPLE CALCULATION OF COMRESSIBILITY FACTOR

FROM EXPERIMENTAL DATA:

<table>
<thead>
<tr>
<th>Mixture 4</th>
<th>Components</th>
<th>Mole fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethane</td>
<td>0.86918</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.07299</td>
<td></td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>0.05780</td>
<td></td>
</tr>
</tbody>
</table>

Room temperature = 80°F

Temperature of P. V. T. cell = 100°F

Pump reading at 1000 psig and 86°F (at prev. set) = 179.847 cc

Pump reading at 4000 psig and 100°F = 246.510 cc

Volume of mercury added in cell to raise the pressure to 4000 psig and 100°F will be given by:

\[
\frac{(\text{Volume of mercury pumped in cell}) \times \frac{V_t}{V_t}}{V_t} = 66.797 \text{ cc}
\]

Volume of mercury in cell at 1000 psig and 84°F

( from prev. calcul) = 418.168 cc

Volume of mercury in cell at 4000 psig and 100°F = 418.168 + 66.797 = 484.965 cc

The cell pressure was reduced from 4000 psig to 1000 psig in steps of 500 psig at constant temperature of 100°F and pump reading was recorded at each pressure step at stabilized conditions.
Calculation of volume of gas mixture at 1000 psig and 100°F.

Pump reading at 1000 psig and 100°F  = 125.790 cc

Volume of P. V. T. cell at 1000 psig and 100°F

( read from Figure 1 ) = 650.968 cc

Volume of mercury withdrawn when cell pressure
was lowered to 1000 psig ( at pump conditions ) = 246.51 - 125.790

= 120.720 cc

Volume of mercury in cell conditions will be given by:

Volume of mercury in pump conditions. ( \( 1 + 4000x_{B_t} \) ) \( \frac{V_T}{V_t} \) ( 1 - \( B_T \) ) =

\[ 120.72 \left( 1 + 4000 \times 2.78 \times 10^{-7} \right) \frac{1.004038}{1.002018} \left( 1 - 1000 \times 2.84 \times 10^{-7} \right) \]

= 121.064 cc

Volume of mercury at 1000 psig and 100°F

= 484.965 - 121.064

= 363.901 cc

Volume of gas = Volume of cell - Volume of mercury

650.968 - 363.901 = 287.067 cc

Compressibility factor, \( Z \), will be given by (12):

\[ Z = \frac{1014.7 \times 287.067}{0.0050730147 \times 10.729 \times 560 \times 28316.8} = 0.33749 \]
VII. BIBLIOGRAPHY


12. Through personal communications with Prof. Govier.
VIII • VITA

Brij Raj Misra was born on May 24, 1940, in Ghazipur, U. P., India. He received his primary and secondary education in his home town. He has received his college education from Banaras Hindu University, India, where he received his bachelor of science and Master of Science degree in Geology in 1960.

Prior to joining the University of Missouri - Rolla, he served the Oil and Natural Gas Commission, India, for 8 years, in various capacities. He has been enrolled in the graduate school of the University of Missouri - Rolla, since January, 1969.