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

By

PILOO ERUCHSHAW ILAVIA, 1940-

A

THESIS

submitted to the faculty of
UNIVERSITY OF MISSOURI - ROLLA
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Degree of

MASTER OF SCIENCE IN PETROLEUM ENGINEERING

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Approved by

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Etter Barkf.

DEDICATED TO MY MOTHER

ABSTRACT

Experimentally determined compressibility factors of a natural gas with impurities like carbon dioxide and nitrogen are found to differ with the values computed by various methods making use of compositional breakup of the gas.

Compressibility factors for five mixtures of known composition were experimentally determined at room temperature, 100°F, 125°F, and 150°F, and at pressure ranging between 1000 psi to 4000 psi. Using the known composition of the mixtures, compressibility factors were calculated by additive volume method and by Eilerts¹ method.

The deviation between computed and experimentally determined compressibility factors are at a maximum in the lower and higher pressure ranges.

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The author would like to take the privilege of expressing his indebtedness to Dr. T. C. Wilson, his advisor, for his original idea and continued guidance and support throughout this investigation.

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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, little 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. Following their work, Sage and Lacey² presented data on binary systems, e.g. methane-nitrogen and methane-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 investigation was to provide experimental compressibility factor data on methane-nitrogen-carbon dioxide system and compare the experimental results with that computed by known methods.

1. References given are noted in the Bibliography at the end of this thesis.

II. REVIEW OF LITERATURE

Three methods are in common use for determining the compressibility of a natural gas. The direct and most reliable method is to measure the compressibility using a device similar to the one described in this work. The accuracy of the result is not affected by nitrogen, carbon dioxide or other nonhydrocarbon components of the natural gas in abnormal concentrations.

The second method requires a knowledge of specific gravity of gas referred to dry air. Standing and Katz⁴ have published charts in which the density and the pseudocritical properties of natural gases are related to gas gravity. Using these charts, the compressibility of a gas for given temperature and pressure can be estimated if the specific gravity of the gas is known.

The third and most widely used method requires knowledge of the composition of the gas. Kay⁵ applied the theorem of corresponding states for calculating Pressure-Volume-Temperature (PVT) relations of hydrocarbon mixtures, and showed how a pseudocritical pressure and temperature for a given mixture could be calculated which would be useful in estimation of the properties of the mixture in a given state from the known properties of pure components in the corresponding state. For a large number of natural gas samples, experimentally determined compressibility factors were correlated with pseudoreduced temperature and pseudoreduced pressure. These correlation charts provide a very

convenient method of computing compressibility factors.

Old, Sage and Lacey⁶ stated that a five percent error in computation of compressibility factor using "the theorem of corresponding states" is observed when a natural gas mixture has a four mole percent carbon dioxide concentration.

Eilerts et. al.¹ stated that an error of more than three percent is likely when nitrogen concentration exceeds 20 mole percent. They observed that "..... the volume of the mixture of natural gas and nitrogen at a given pressure and temperature is greater than the sum of the separate volume of natural gas and nitrogen at the same pressure and temperature". Therefore, they defined the additive compressibility factor, Z_a , as:

$$Z_a = Y_n Z_n + (1 - Y_n) Z_g \quad (1)$$

where:

Z_n = Compressibility of nitrogen

Y_n = Mole fraction of nitrogen

Z_g = Compressibility factor of the hydrocarbon fraction in mixture obtained by using "the theorem of corresponding states".

The true compressibility factor, Z , of the mixture is then defined by:

$$Z = W \times Z_a \quad (2)$$

where:

W is the additive volume correction factor which depends upon the pressure, the temperature and the nitrogen concentration in the system. The values of W for nitrogen concentration of 8.597 mole %

and 19.97 mole % for temperature between 32°F and 280°F and upto 5000 psi were evaluated by Eilerts et. al.¹.

Amyx, Bass and Whiting³ suggested that for a low concentration of carbon dioxide in a mixture of natural gas and nitrogen, the carbon dioxide can be treated as if it were a part of the hydrocarbon system. Here again, the additive volume correction factor, W , proposed by Eilerts et. al.¹, must be used to obtain corrected compressibility factors, in order to correctly account for the nitrogen.

In the study undertaken, the carbon dioxide was treated as a part of the hydrocarbon system in computing compressibility factors by Eilerts' method.

III. DISCUSSION

A. EXPERIMENTAL EQUIPMENT AND PROCEDURE

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

Before commencing the actual PVT studies, the equipment was prepared for the experiment, then calibrated and finally the mixture of desired chemical composition was prepared.

1. Equipment preparation and calibration.

The mercury pump was thoroughly cleaned and evacuated, checked for leaks and then filled with clean mercury. A known volume of mercury was then withdrawn from the pump by moving the piston forward. Knowing its mass and using the published mercury density data (given in Table 1) the volume displacement per division of the pump was obtained.

The high pressure cell was evacuated after thorough cleaning. The cell was pressurized to 4000 psig and checked for leaks. It was then calibrated for its volume at 80°F, 100°F, 125°F and 150°F and over the pressure range of 4000 psig to 1000 psig, in 500 psig decrements.

Isotherms were then drawn for cell volume against pressure, which were straight lines with a positive slope. A plot of these isotherms for Cell 1, is shown in Figure 1.

TABLE 1

COMPRESSIBILITY AND RELATIVE VOLUME OF MERCURY

Temperature in °F	Compressibility of mercury, in vol/vol, psi x 10 ⁻⁷	Volume of mercury at indicated temperature relative to volume at 60°F
70	2.750	1.001009
71	2.753	1.001110
72	2.756	1.001211
73	2.759	1.001312
74	2.762	1.001413
75	2.765	1.001513
76	2.768	1.001614
77	2.771	1.001715
78	2.774	1.001816
79	2.777	1.001917
80	2.780	1.002018
82	2.786	1.002220
84	2.792	1.002422
86	2.798	1.002624
88	2.804	1.002826
90	2.810	1.003028
100	2.840	1.004038
125	2.915	1.006566
150	3.000	1.009097

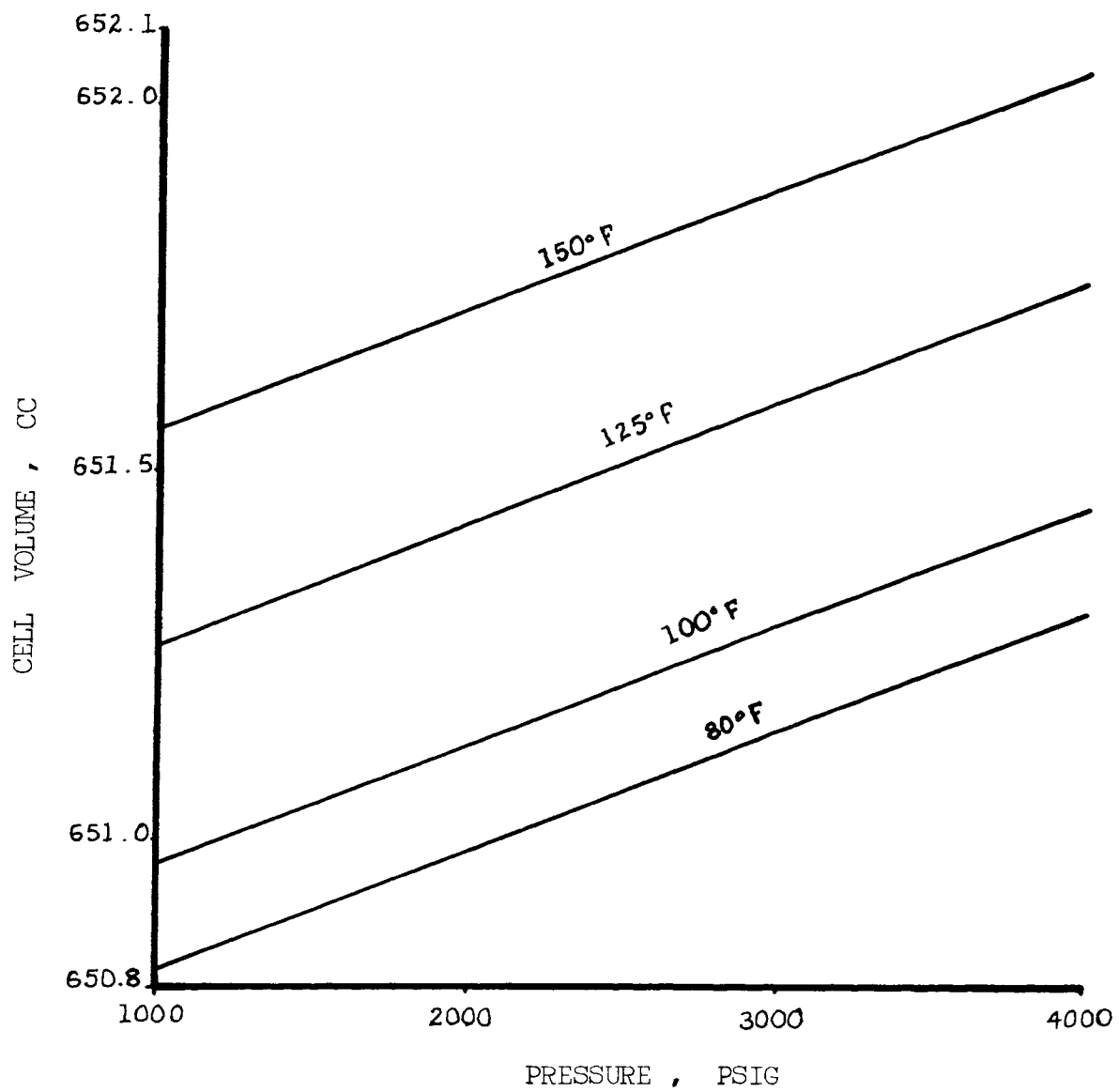


Figure 1 CALIBRATION OF CELL 1

2. Preparation of gas mixture.

Research grade, 99 mole percent (minimum), methane supplied by Philips Petroleum Company, 99.98 mole percent nitrogen and 99.9 mole percent carbon dioxide supplied by Acetelene Gas Company, were used in this study.

An approximate value of pressure required to load the desired mole fraction of each component of the mixture was calculated using the gas law relation:

$$P \times V = Z \times n \times R \times T \quad (3)$$

The volume of nitrogen was determined at 2000 psig and at room temperature by knowing the temperature, pressure, volume and the published compressibility factor for nitrogen, the number of moles of nitrogen was then calculated using (3).

Carbon dioxide was loaded in Cell 2, the number of moles was similarly determined and it was transferred to Cell 1. In a similar manner, the number of moles of methane was determined in Cell 2, and was also transferred to Cell 1.

For preparing the next mixture, only one component, after knowing its number of moles in Cell 2, was transferred to Cell 1, to yield a mixture having different mole fractions of each component. Composition of the five mixtures prepared and studied are given in Table 2. An example calculation for the mixture preparation is given in Appendix B.

TABLE 2

COMPOSITION OF THE MIXTURES

Components	<u>MIXTURE 1</u>	<u>MIXTURE 2</u>	<u>MIXTURE 3</u>	<u>MIXTURE 4</u>	<u>MIXTURE 5</u>
	mole fraction	mole fraction	mole fraction	mole fraction	mole fraction
Methane	0.60620	0.78218	0.84982	0.89604	0.87807
Ethane	-	-	-	-	0.04543
Nitrogen	0.18063	0.12390	0.08543	0.05913	0.04351
Carbon dioxide	0.21317	0.09392	0.06475	0.04483	0.03298

3. Pressure-Volume-Temperature study of the mixture.

Following the preparation of the gas mixture, the cell was placed in the constant temperature bath and the cell pressure was raised to 4000 psig. After allowing sufficient time to establish equilibrium, the initial reading on the pump was recorded. Upto this time, the volume of mercury in the cell had been accounted for and thereby the volume of the gas mixture at 4000 psig and at temperature of the bath, was known. Keeping the bath temperature constant, the cell pressure was reduced to 3500 psig by withdrawing mercury into the pump, and reading the gauge on the pump at equilibrium conditions. Subsequent readings were taken in steps of 500 psig down to 1000 psig.

Having completed one set of PVT readings, similar sets of readings were taken at stabilized cell temperatures of 100°F, 125°F and 150°F.

B. ERROR ANALYSIS.

In order to determine the accuracy of experimental procedure, PVT studies were carried out on pure methane which differed, from most recent published data ⁷, by three percent at a maximum. However, a few inevitable sources of error in the experiment may throw some light on the quality of the results achieved.

While the cell was kept in a constant temperature bath, the mercury pump was subject to temperature changes of the room which varied anywhere from 1°F to 10°F in an hour. This variation of room temperature was kept to a minimum by continuously running the exhaust fan and working at night.

The pump could be read accurately upto 0.01 cc and the third decimal place was approximated. A variation of gas volume, due to this approximation, could cause an error of 0.23 % in the calculated compressibility factor. The pressure gauge could be read accurately to 10 psig, and an error of 3 psig in pressure reading would cause a 0.16 % error in the calculated compressibility factor.

The calculational error, both round off and truncational error, were kept to a minimum by using an electronic programmable Wang calculator.

On the whole, the experimental results obtained are estimated to be in error by less than four percent.

IV. RESULTS

Compressibility factors were determined experimentally for four gas samples with varying proportions of methane, nitrogen and carbon dioxide. The fifth sample was prepared with proportions of methane and ethane identical to those in a gas condensate well having nitrogen and carbon dioxide as its other constituents.

The results of mixture preparation indicated that when definite volumes of methane, nitrogen and carbon dioxide measured at the same condition of temperature and pressure were combined, the volume of the mixture was greater than the sum of the individual volumes. This finding substantiates the observation made by Eilerts et. al.¹.

The PVT studies were conducted on the five samples at room temperature, 100°F, 125°F, and 150°F, and in the pressure range of 1000 psig to 4000 psig. For Mixture 5, a few additional data points were obtained in the pressure region from 850 psig to 1500 psig, and at 78°F to investigate the trend of isotherm which gave some indication of the two phase zone of the mixture.

For these same five mixtures, compressibility factors were computed using additiv volume method and Eilerts' method to compare them with the experimental results obtained. The experimental as well as computed compressibility factors are given in Table 3 through Table 7, and graphically presented in Figure 2 through Figure 6.

TABLE 3

EXPERIMENTAL AND COMPUTED COMPRESSIBILITY FACTOR FOR MIXTURE 1

PRESSURE PSIA	COMPRESSIBILITY FACTOR							
	78°F		100°F		125°F		150°F	
	Experi- mental	Additive volume method	Experi- mental	Additive volume method	Experi- mental	Additive volume method	Experi- mental	Additive volume method
4014.7	.84299	.84957	.96780	.86370	.99701	.88067	1.0213	.89693
3514.7	.89071	.81140	.91926	.82885	.95058	.83290	.97704	.86808
3014.7	.84475	.77895	.87767	.79950	.91027	.82327	.93595	.84505
2514.7	.80772	.75534	.84325	.77825	.87514	.80582	.89814	.83078
2014.7	.78412	.74375	.81859	.76693	.84996	.80088	.86915	.83217
1514.7	.77209	.74576	.80398	.76715	.83046	.81363	.84501	.85788
1014.7	.76628	.80901	.78932	.85658	.81320	.88231	.82811	.90667

TABLE 4

EXPERIMENTAL AND COMPUTED COMPRESSIBILITY FACTOR FOR MIXTURE 2

PRESSURE PSIA	COMPRESSIBILITY FACTOR											
	76°F			100°F			125°F			150°F		
	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method
4014.7	1.0108	.88017	.87276	1.0212	.89762	.89389	1.0363	.91612	.91377	1.0591	.93370	.92974
3514.7	.95059	.84433	.83608	.9644	.86573	.86441	.98320	.88761	.88784	1.0072	.9077	.90703
3014.7	.89355	.81551	.80928	.91247	.84060	.84463	.93320	.86548	.86864	.95752	.88779	.89023
2514.7	.84745	.79793	.79943	.86772	.82569	.83200	.88820	.85294	.86032	.91075	.87683	.88351
2014.7	.81469	.79533	.81005	.83247	.82285	.84139	.85090	.85208	.86811	.87102	.87787	.89095
1514.7	.78917	.80878	.83925	.80416	.83296	.86408	.81800	.86535	.88411	.83329	.89486	.90383
1014.7	.7697	.85683	.88670	.77569	.88931	.89683	.78382	.90900	.91393	.79345	.9268	.93063

TABLE 5

EXPERIMENTAL AND COMPUTED COMPRESSIBILITY FACTOR FOR MIXTURE 3

PRESSURE PSIA	COMPRESSIBILITY FACTOR											
	86° F			100° F			125° F			150° F		
	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method
4014.7	.96147	.88596	.88604	.99329	.90053	.89581	.99775	.91981	.91627	1.0109	.93808	.93270
3514.7	.90913	.85175	.85011	.94332	.86939	.8643	.94659	.89211	.88654	.96577	.90520	.90700
3014.7	.86225	.82492	.82972	.89774	.84541	.83563	.90110	.87108	.86809	.92220	.89395	.88845
2514.7	.82385	.81006	.82179	.85769	.83244	.83319	.86424	.86013	.85977	.88483	.88418	.88431
2014.7	.79852	.81045	.82787	.83045	.83228	.84048	.83627	.86085	.87031	.85561	.88568	.89074
1514.7	.78505	.82692	.85335	.80897	.84564	.86179	.81710	.87500	.88660	.82704	.90121	.90543
1014.7	.76961	.87554	.89140	.78980	.89492	.89878	.79111	.91340	.91351	.79892	.92984	.92704

TABLE 6

EXPERIMENTAL AND COMPUTED COMPRESSIBILITY FACTOR FOR MIXTURE 4

PRESSURE PSIA	COMPRESSIBILITY FACTOR											
	83° F			100° F			125° F			150° F		
	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method
4014.7	.96181	.88690	.88042	.96391	.89295	.89297	.97552	.92232	.92283	.99208	.94106	.94004
3514.7	.90837	.85287	.84580	.91539	.87188	.86997	.92871	.89518	.89408	.94690	.91664	.91234
3014.7	.86293	.82667	.82177	.87438	.84872	.84561	.88884	.87489	.87059	.90906	.89814	.89401
2514.7	.82366	.78135	.80874	.84054	.83703	.83552	.85731	.86504	.86333	.88009	.89692	.88567
2014.7	.79872	.78580	.81778	.81919	.83871	.84705	.83851	.86683	.87289	.86036	.89100	.89201
1514.7	.78339	.80962	.84265	.80428	.85430	.86476	.82285	.88158	.88968	.84124	.90554	.91314
1014.7	.77323	.86193	.88311	.78898	.89876	.89712	.80207	.91641	.91796	.81740	.93192	.93296

TABLE 7

EXPERIMENTAL AND COMPUTED COMPRESSIBILITY FACTOR FOR MIXTURE 5

PRESSURE PSIA	COMPRESSIBILITY FACTOR											
	88°F			100°F			125°F			150°F		
	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method	Experi- mental	Additiv. volume method	Eilerts method
4014.7	.9406	.88242	.87349	.95696	.8969	.88403	.96423	.91588	.9058	.97376	.93399	.92302
3514.7	.88702	.84662	.83818	.90813	.86418	.84961	.92036	.88668	.87486	.93327	.90736	.89890
3014.7	.84447	.81825	.81443	.86782	.83667	.82179	.88376	.86408	.85080	.89672	.88689	.88110
2514.7	.81213	.80229	.79901	.83395	.82457	.80903	.85153	.8518	.84341	.86638	.87555	.87047
2014.7	.79375	.80157	.80773	.81485	.82328	.82195	.83297	.85052	.85145	.84341	.87438	.87838
1514.7	.78645	.81676	.83356	.80105	.83536	.84338	.81842	.86156	.87080	.82659	.88572	.89561
1014.7	.78789	.85511	.87797	.79960	.87181	.88430	.80708	.89396	.90427	.81459	.91501	.92136

Figure 2 Experimental and computed compressibility factor, Z , for Mixture 1

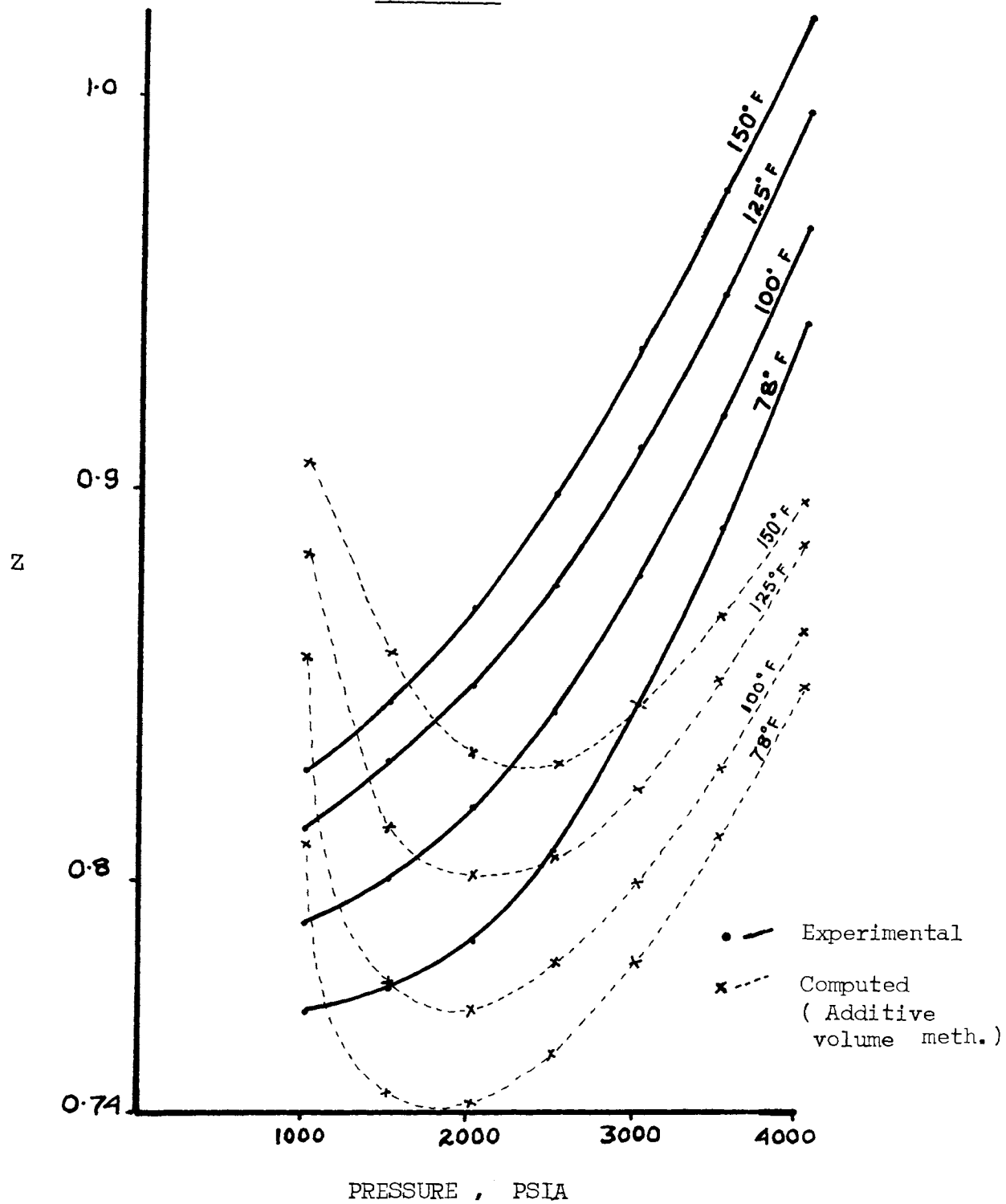


Figure 3 Experimental and computed compressibility factor, Z , for Mixture 2

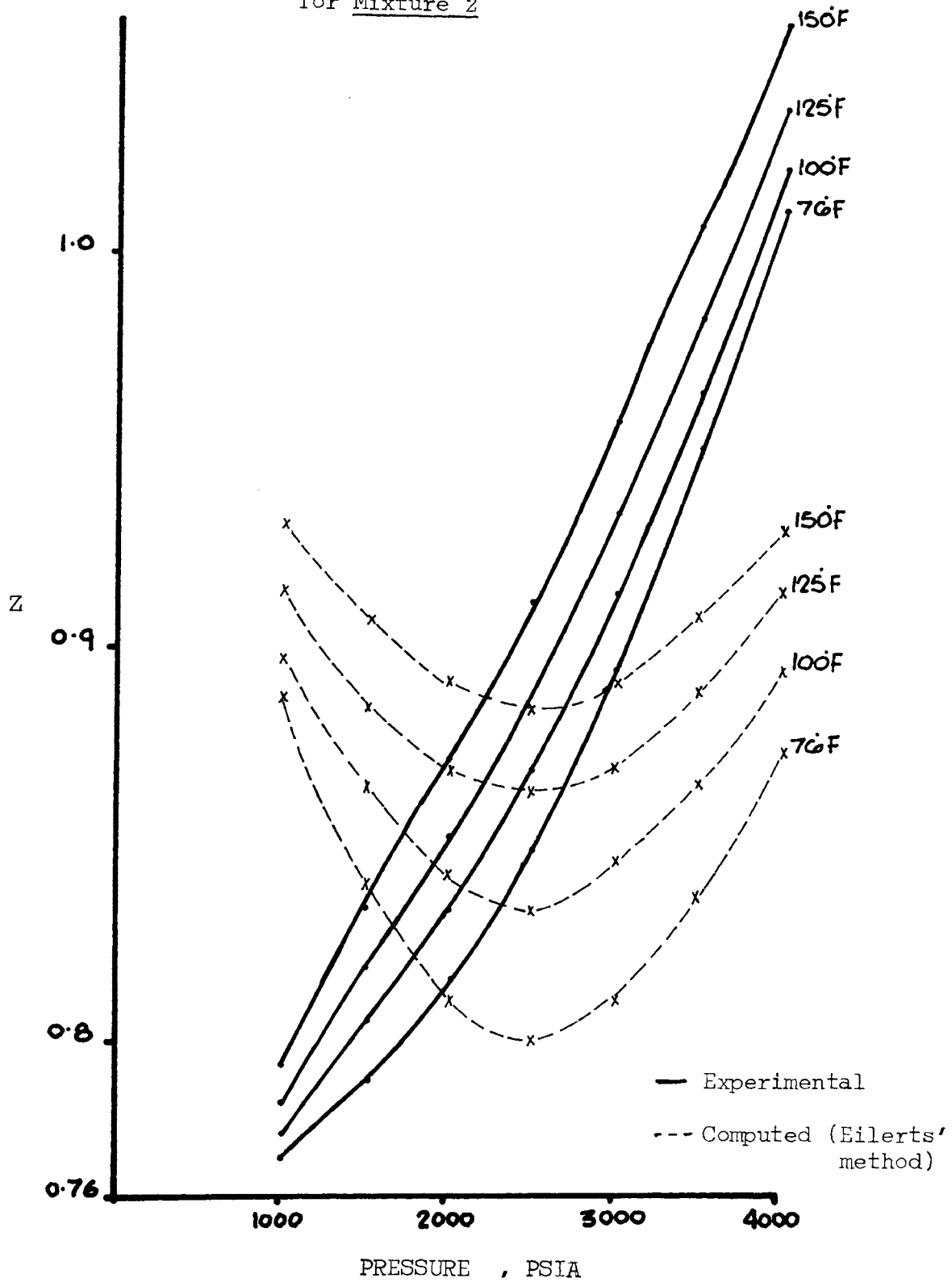


Figure 4 Experimental and computed compressibility factor, Z , for Mixture 3

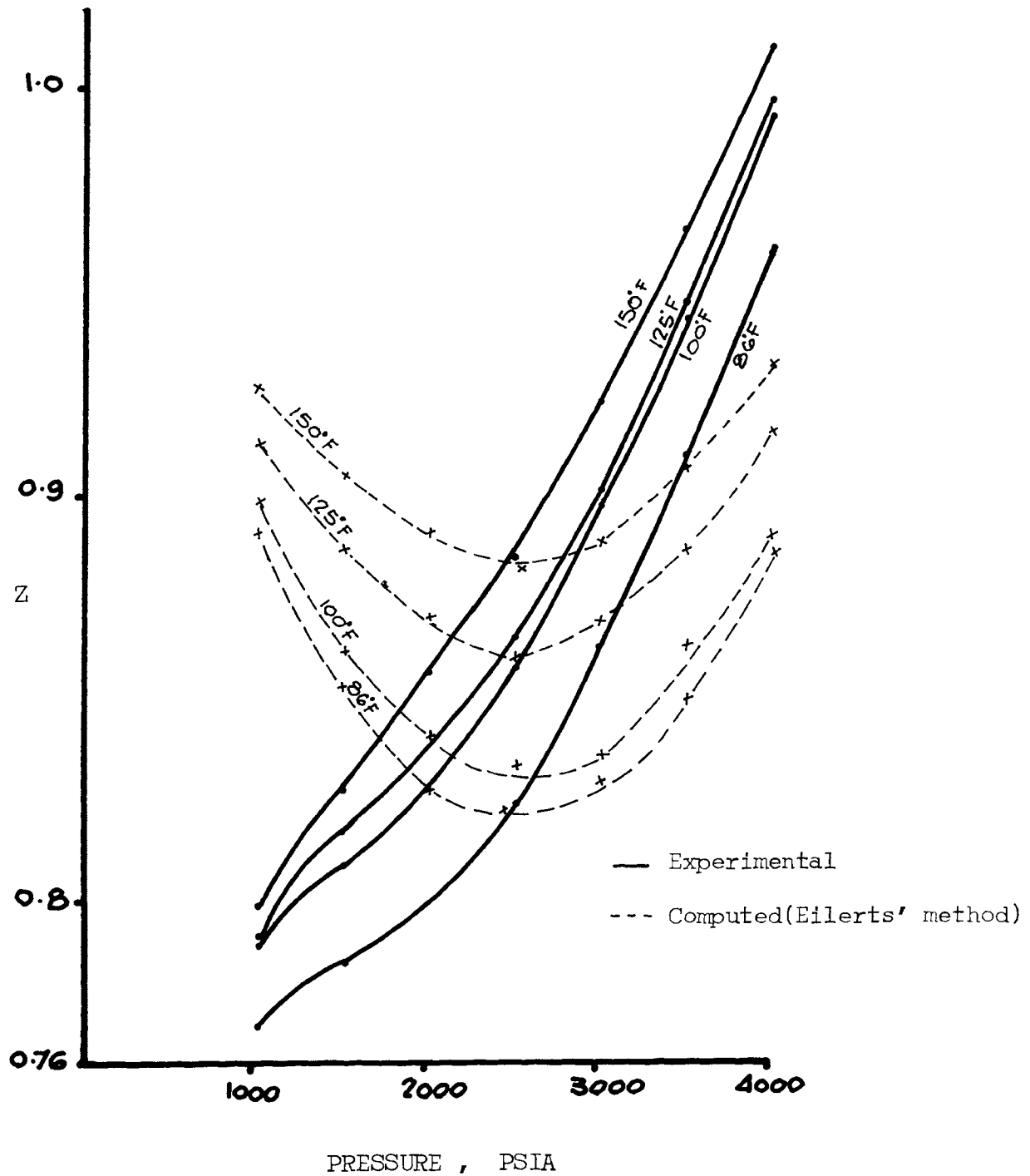


Figure 5 Experimental and computed compressibility factor, Z , for Mixture 4

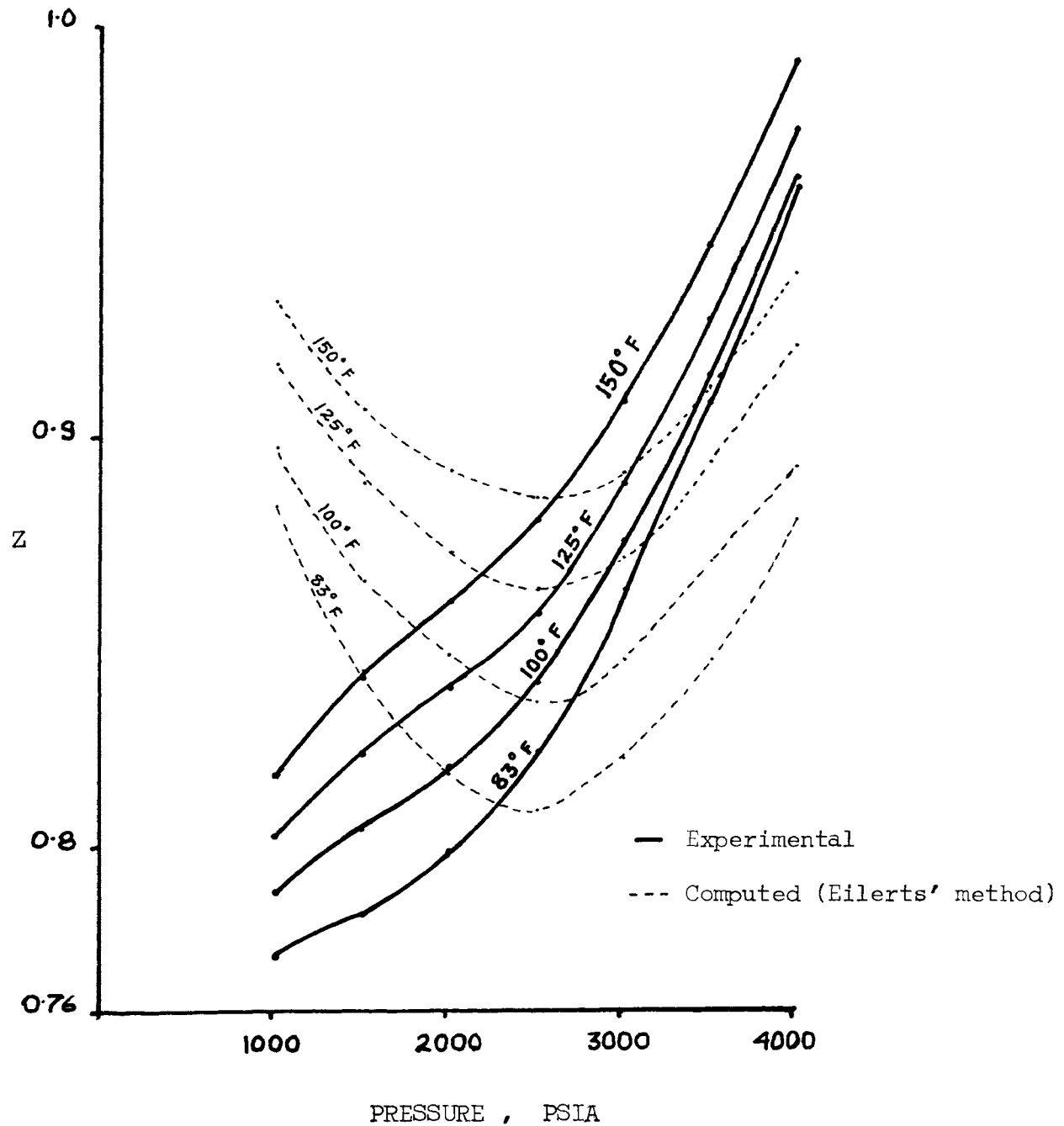
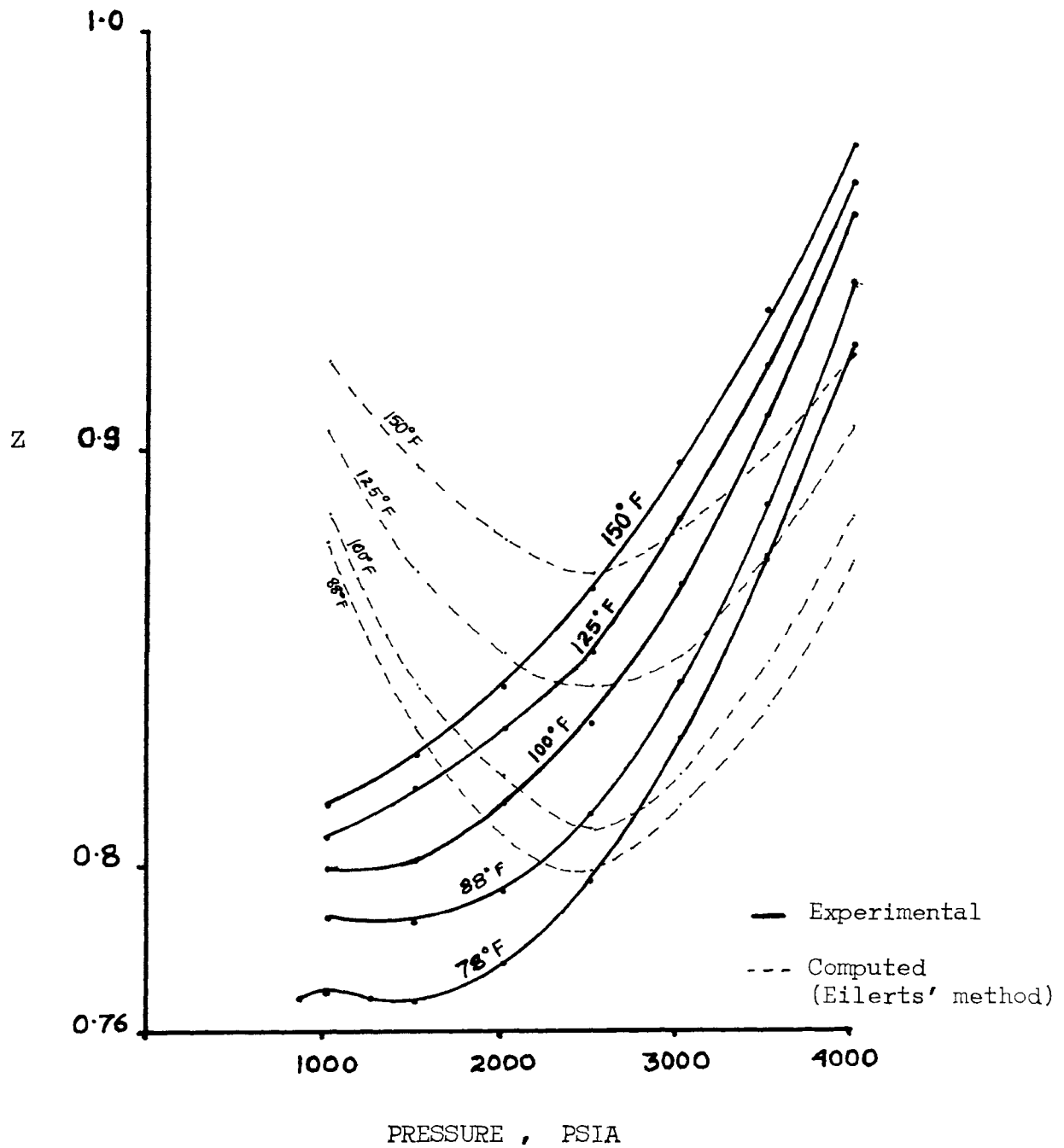


Figure 6 Experimental and computed compressibility factor, Z , for Mixture 5



From these tables and figures, it can be seen that there is poor comparison between computed and experimental compressibility factors. The deviation between them was maximum in the low pressure zone of 1500 psig to 1000 psig, and at higher temperatures. The percentage deviation of experimental values as compared to computed values of compressibility factor varied from a maximum of 15.8 % to -14.7 % for Mixture 2, and varied for Mixture 5, which had 4.5 mole percent of ethane, from 8.24 % to -9.58 %.

The critical constants for all the components and compressibility factor data on methane and ethane was obtained from A.P.I. Research Project 44⁷. Compressibility factor data on carbon dioxide and nitrogen was obtained from the work of Sage and Lacey^{2 & 8}. The additive volume correction factor, W , for the mixtures under investigation was obtained from the work of Eilerts et. al.¹. The values of W were plotted as a function of nitrogen mole percent in the gas mixture for various pressures at one temperature. Four such plots for 70°F, 100°F, 130°F and 160°F each, are shown in Figure 7 through Figure 10. The values of W were then read for the required nitrogen mole percent at desired temperature and pressure. Some extrapolation was necessary and the values of W used for 1014.7 psia were approximate. Compressibility factors for Mixture 1, which had high concentration of both nitrogen and carbon dioxide was computed by the additive volume method only.

Figure 7 Additive volume correction factor, W , as a function of pressure and concentration of nitrogen at 70°F.

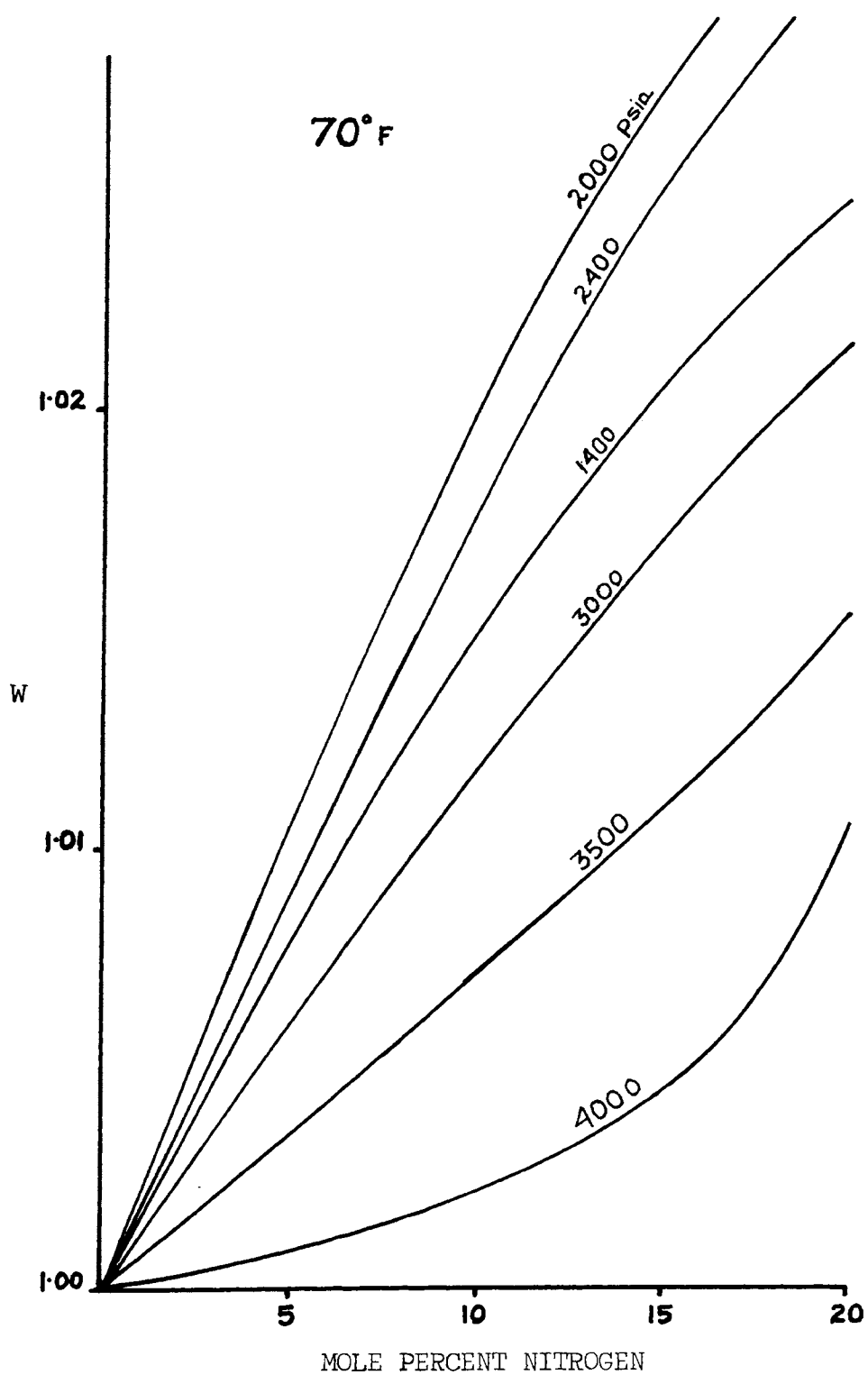


Figure 8 Additive volume correction factor, W , as a function of pressure and concentration of nitrogen at 100°F .

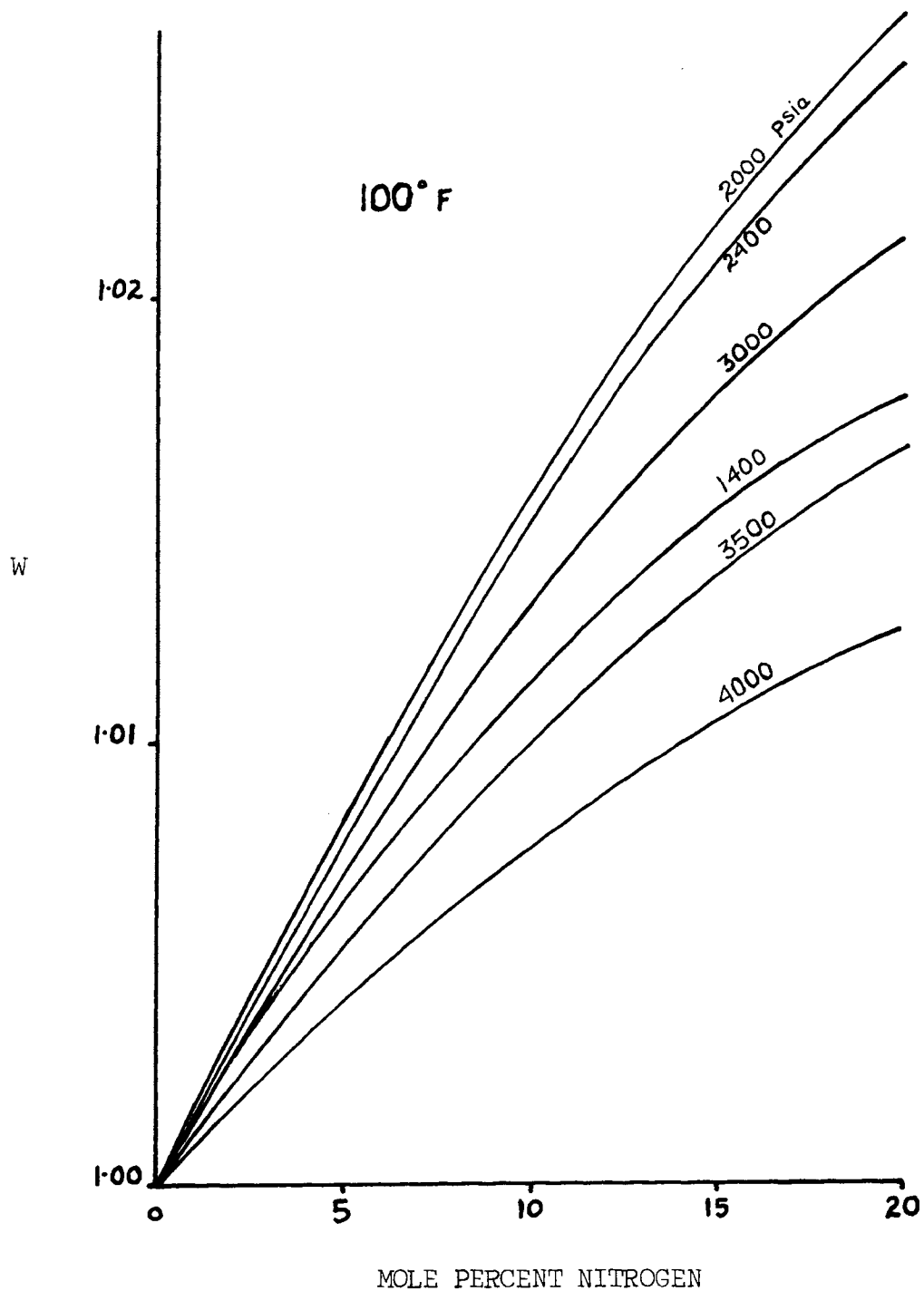


Figure 9 Additive volume correction factor, W , as a function of pressure and concentration of nitrogen at 130°F .

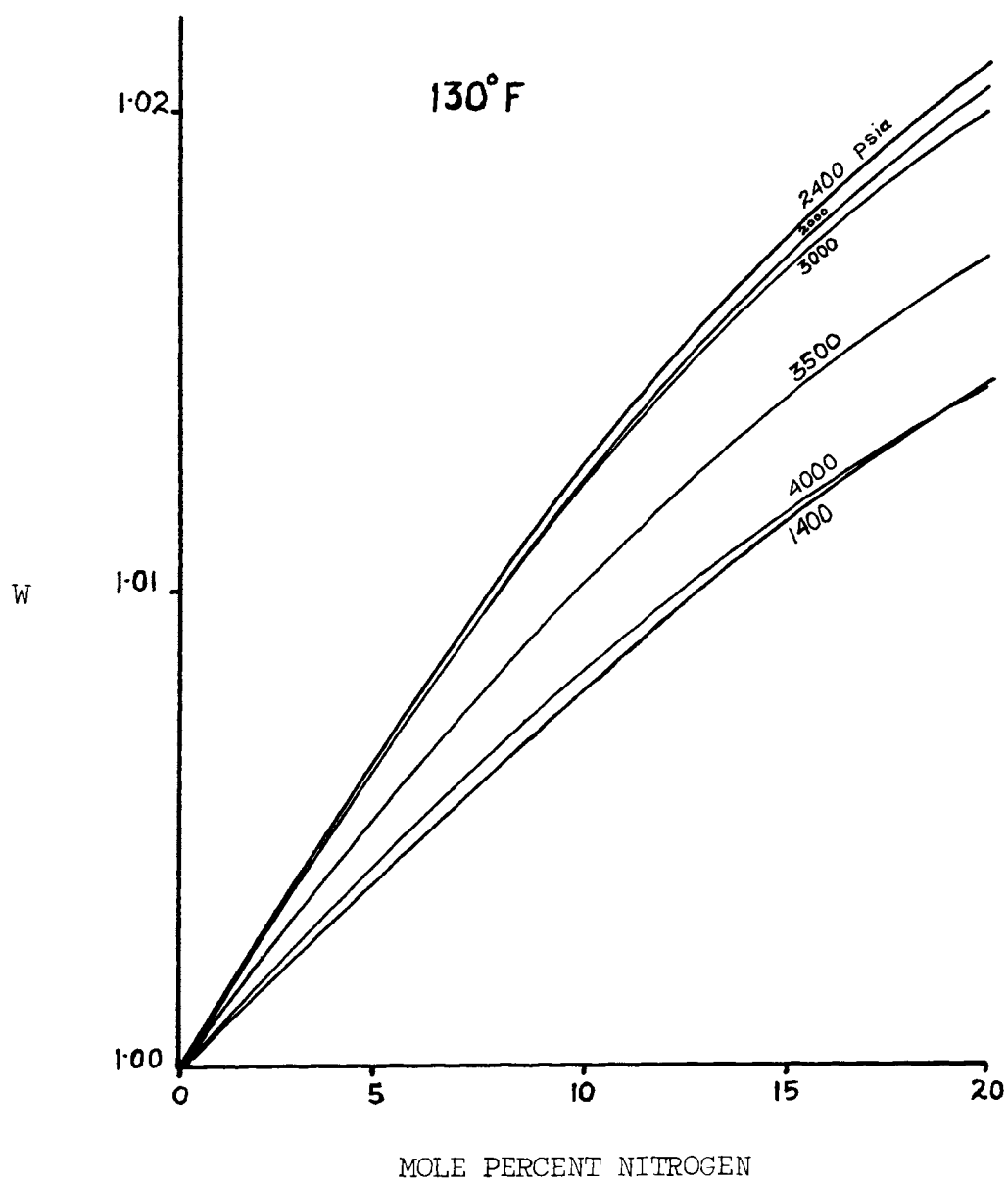
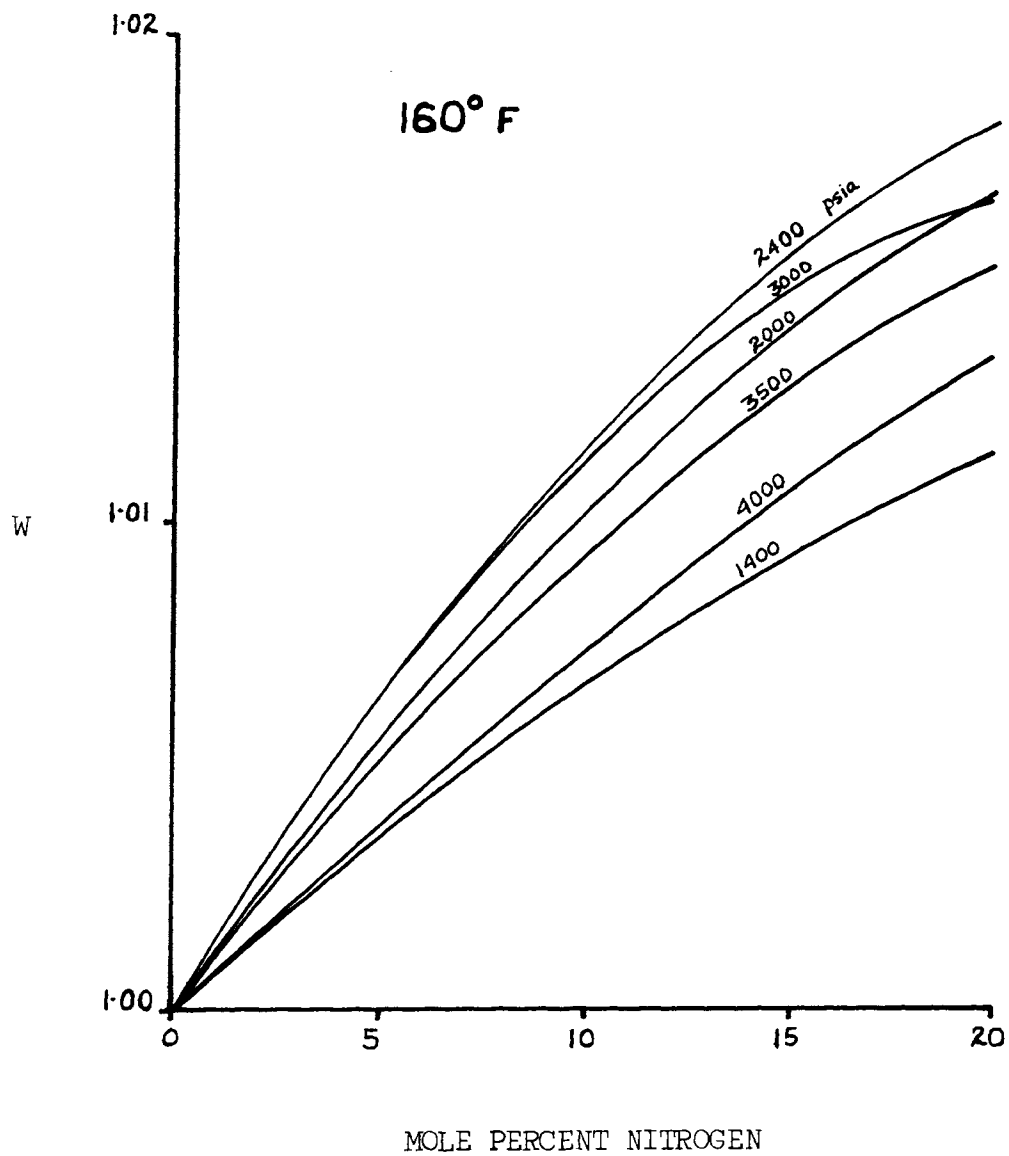


Figure 10 Additive volume correction factor, W , as a function of pressure and concentration of nitrogen at 160°F.



V. CONCLUSION AND RECOMMENDATIONS

The experimentally determined compressibility factor for mixtures containing nitrogen and carbon dioxide in varying proportion with methane as the major component have an altogether different trend than the compressibility factor computed by using the additive volume method and Eilerts et. al.¹ method. This is evident from the Figure 2 through Figure 6. The deviation between the computed and experimental compressibility factor is found to be maximum in the pressure range of 1500 psia to 1000 psia.

It is, therefore, advisable to use experimentally determined compressibility factor for a natural gas mixture containing both nitrogen and carbon dioxide in concentrations higher than one mole percent. Computation of compressibility factor using the knowledge of the composition of the gas in which nitrogen and carbon dioxide both, with appreciable to moderate concentration may lead to serious errors in reservoir engineering calculations, gas transmission and similar problems. However, this is not to imply that Eilerts' method is incorrect but that it is not suitable for the systems studied in this work.

It was beyond the capabilities of the equipment used in present investigation to carry out the study in further detail, especially for mixtures wherein the concentration of nitrogen and carbon dioxide was between one to three mole percent each, and at pressures between 100 to 1000 psia. It is, therefore, recommended that the region between 1500 to 100 psia be investigated in detail for PVT relations at various temperatures for similar gas mixtures, as investigated in this report, to provide a definite trend of 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 relation⁸ :

$$G = F - E \quad (A-1)$$

where

G = Change in cell volume

F = Expansion of original mercury

$$= V_1 \left\{ (1 + 4000 \times B_t) (1 - B_T \times P) \frac{V_T}{V_t} - 1 \right\} \quad (A-2)$$

E = Volume of mercury remaining in cell

$$= v \left\{ (1 + 4000 \times B_t) (1 - B_T \times P) \frac{V_T}{V_t} \right\} \quad (A-3)$$

where

V_1 = Cell volume at 4000 psig and room temperature.

v = Volume of mercury withdrawn in pump.

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 to volume of mercury at 60° F.

V_T = Relative volume of mercury at elevated (cell) temperature to volume of mercury at 60° F.

P = Pressure in cell.

Appendix A (continued)

Calculation of cell volume at 2000 psig. and 150°F:

Room temperature	= 79°F
Cell volume at 4000 psig. and 77°F	= 651.31081 cc
Pump reading at 4000 psig. and 77°F	= 21.76
Pump reading at 2000 psig. and 150°F	= 17.224
Pump constant	= 1.0037802
v (volume in pump)	=(21.76-17.224) x 1.0037802
	= 4.55314 cc
V_t (from Table 1)	= 1.001917
V_T (from Table 1)	= 1.009097
B_t (from Table 1)	= 2.777×10^{-7} vol/vol, psi
B_T (from Table 1)	= 3.00×10^{-7} vol/vol, psi

The change in cell volume, G, is given by:

$$G = 651.31081 \left\{ (1 + 4000 \times 2.777 \times 10^{-7}) \frac{1.009097}{1.001917} (1 - 2000 \times 3 \times 10^{-7}) - 1 \right\} - \left\{ 4.55314 (1 + 4000 \times 2.777 \times 10^{-7}) \frac{1.009097}{1.001917} (1 - 2000 \times 3 \times 10^{-7}) \right\}$$

$$\text{or } G = 0.41398 \text{ cc}$$

Therefore, volume of cell at 2000 psig. and 150°F = 651.31081 + 0.41398
= 651.72479 cc.

APPENDIX B

SAMPLE CALCULATION OF MIXTURE PREPARATION

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

$$P = \frac{ZnRT}{V} \quad \text{where } V \text{ is the volume of the cell.}$$

For nitrogen the pressure calculated to obtain 0.00018 moles was:

$$P = \frac{1 \times 0.00018 \times 10.729 \times 538 \times 28316.8}{651.5} = 45.16 \text{ psia}$$

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

$$\text{Volume of mercury pumped-in (at pump condition)} = 634.74 \text{ cc}$$

$$\text{Volume of mercury in cell condition of 2000 psig. and } 80^{\circ}\text{F} =$$

$$634.74 (1 + 4000 \times 2.78 \times 10^{-7}) (1 - 2000 \times 2.78 \times 10^{-7}) = 635.092 \text{ cc}$$

$$\text{Cell volume at 2000 psig. and } 80^{\circ}\text{F (from Figure 1)} = 651.512 \text{ cc}$$

$$\begin{aligned} \text{Volume of nitrogen at 2000 psig. and } 80^{\circ}\text{F} &= 651.512 - 635.092 \\ &= 16.4194 \text{ cc} \end{aligned}$$

Number of moles of nitrogen from (3):

$$n = \frac{2014.7 \times 16.4194}{1.1202 \times 10.729 \times 540 \times 28316.8} = 0.0001800018$$

In a similar way, the number of moles of other components of the mixture were calculated and then transferred to the cell containing nitrogen.

APPENDIX C

SAMPLE CALCULATION OF COMPRESSIBILITY FACTOR FROM EXPERIMENTAL DATA

Mixture 2:	Components	Number of moles	Mole fraction
	Methane	0.0011363880	0.78218
	Nitrogen	0.0001800018	0.12390
	Carbon dioxide	0.0001364470	0.09392

Room temperature = 84°F

Temperature of P. V. T. cell = 100°F

Pump reading at 1000 psig. and 76°F (from previous set) = 57.219

Pump reading at 4000 psig. and 100°F = 174.288

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

(Volume of mercury pumped in the cell) $\times V_T / V_t$

$$(174.288 - 57.219) \frac{1.004038}{1.002422} = 117.258 \text{ cc}$$

Volume of mercury at 1000 psig. and 76°F in cell = 471.322 cc

Volume of mercury at 4000 psig. and 100°F in cell = 471.322 + 117.258
= 588.58 cc

The cell pressure was reduced from 4000 psig. to 3500 psig. at constant temperature of 100°F and pump reading was recorded at the stabilized condition.

Appendix C (continued)

Calculation of volume of gas mixture at 3500 psig. and 100°F :

$$\text{Pump reading at 4000 psig. and 100°F} = 174.288$$

$$\text{Pump reading at 3500 psig. and 100°F} = 169.268$$

Volume of P.V.T. cell at 3500 psig. and 100°F

$$(\text{ from Figure 1 }) = 651.374 \text{ cc}$$

Volume of mercury withdrawn at cell condition will be given by :

$$\begin{aligned} \text{Volume of mercury at pump condition} & \times (1 + 4000 \times B_t)(1 - B_T \times P) \frac{V_T}{V_t} \\ = 5.02 \times (1 + 4000 \times 2.793 \times 10^{-7}) & (1 - 3500 \times 2.84 \times 10^{-7}) \frac{1.004038}{1.002422} \\ & = 5.029 \text{ cc} \end{aligned}$$

$$\begin{aligned} \text{Volume of mercury in cell at 3500 psig. and 100°F} & = 588.58 - 5.029 \\ & = 583.551 \text{ cc} \end{aligned}$$

$$\begin{aligned} \text{Volume of gas} & = \text{Volume of cell} - \text{Volume of mercury in cell} \\ & = 651.374 - 583.551 \\ & = 67.823 \text{ cc} \end{aligned}$$

Compressibility factor, Z , as given by (3), will be

$$Z = \frac{1014.7 \times 67.823}{0.0014528368 \times 10.729 \times 560 \times 28316.8} = 0.96440$$

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