Manual of Petroleum Measurement Standards

Chapter 11.2.2—Compressibility Factors for Hydrocarbons: 350–637 Relative Density (60°F/60°F) and –50°F to 140°F MeteringTemperature

SECOND EDITION, OCTOBER 1986

REAFFIRMED, SEPTEMBER 2017

energy API

AMERICAN PETROLEUM INSTITUTE

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ERRATA

Page 22, mid-page, correct the following code:

Old code: A = 6.4837D0
Corrected code: A = 6.4827D0

Page 22, near the bottom of the page, correct the following code:

Old code: A = 2.085371D1
Corrected code: A = 2.08537D1

Page 23, Line 12, correct the following code:

Old code: K = (C+D*RDEN) / 553.0D0 * 1.0D5
Corrected code: K = (C+D*RDEN) / 543.0D0 * 1.0D5

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FOREWORD

This publication provides tables to correct hydrocarbon volumes metered under pressure to corresponding volumes at the equilibrium pressure for the metered temperature. The parallel publication in metric (SI) units is the *Manual of Petroleum Measurement Standards*, Chapter 11.2.2M.

The table presented in this volume is also available from API as a computer tape, along with a manual containing the text information in this publication.

Suggested revisions are invited and should be submitted to the director, Measurement Coordination Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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CONTENTS

CHAPTER 11.2.2—COMPRESSIBILITY FACTORS FOR HYDROCARBONS: 0.350–0.637 RELATIVE DENSITY (60°F/60°F) AND −50°F TO 140°F METERING TEMPERATURE

PAGE

11.2.2.1 Scope 1
11.2.2.2 History and Development 1
11.2.2.3 Type of Standard and Limits 1
11.2.2.4 Example Use of the Standard 1
11.2.2.5 Data Base 2
11.2.2.6 Basic Model 5
11.2.2.7 Uncertainty Analysis 6
11.2.2.8 Calculation Procedure 8
11.2.2.9 References 10

Table of Compressibility Factors for Hydrocarbons: 0.350–0.637 Relative Density (60°F/60°F) and −50°F to 140°F Metering Temperature 11

Text Tables
1—Summary of Data Base 2
2—Data Mixture Compositions (Mole Percent) 4
3—Effect of Pressure on Compressibility Factors 6
4—Expected Frequency of Errors When Using Temperatures to the Nearest 0.25°C Versus the Nearest 0.5°F 6

Figures
1—Limits of Data Base by Relative Density and Temperature 3
2—Uncertainties (95-Percent Confidence Level) in Volume Versus Temperature and Relative Density 7

Chapter 11—Physical Properties Data

SECTION 2—VOLUME CORRECTION FACTORS FOR METER PROVING AND HYDROCARBON COMPRESSIBILITY

11.2.2 Compressibility Factors for Hydrocarbons: 0.350–0.637 Relative Density (60°F/60°F) and −50°F to 140°F Metering Temperature

11.2.2.1 SCOPE

The purpose of this standard is to correct hydrocarbon volumes metered under pressure to the corresponding volumes at the equilibrium pressure for the metered temperature. This standard contains compressibility factors related to the meter temperature and relative density (60°F/60°F) of the metered material. The corresponding metric (SI) version is Chapter 11.2.2M.

11.2.2.2 HISTORY AND DEVELOPMENT

The previous API standard for hydrocarbon compressibility, Standard 1101, *Measurement of Petroleum Liquid Hydrocarbons by Positive Displacement Meter*, was developed from graphical correlations prepared in 1945. This standard was based on limited data with only a few points for pure fluids in the range from propane to pentane. No lighter mixtures and no effect of pressure on the compressibility factor were considered.

In 1981, the Committee on Static Petroleum Measurement formed a subcommittee, the Hydrocarbon Compressibility Group, to revise the compressibility tables of Standard 1101. As a result of an extensive literature survey, the data base found for the relative density portion of the table covers a broader range than that used in Standard 1101 but is lacking in data for unsaturated hydrocarbons. The data base was used to develop a mathematical model that includes the effect of pressure on the compressibility factor. The printed table produced from the model is the standard. This standard replaces the discontinued Standard 1101 and the first edition of Chapter 11.2.2, *Compressibility Factors for Hydrocarbons: 0.500–0.611 Relative Density Range and 20–128°F*.

11.2.2.3 TYPE OF STANDARD AND LIMITS

The actual standard is the printed table of 224 pages that follows this text. The increments used in the table are 0.5°F and 0.002 relative density. Interpolation to 0.001 relative density is allowed. Compressibilities are in the usual units of reciprocal pounds per square inch but are calculated from two terms, A and B, and the pressure difference from equilibrium, D_p. This is necessary to obtain the desired accuracy in volume because of the important effect of pressure on the compressibility factor for light hydrocarbons. The range of the table is from −50°F to 140°F and from 0.350 to 0.637 relative density (60°F/60°F), for use with pressure differences above equilibrium from 0 to 2200 pounds per square inch.

The equation used to generate the table is given for those who wish to duplicate the table using their specific computer and language. Identical table information is available on a computer tape. The use of this computer tape to verify individually developed computer subroutines is highly recommended.

11.2.2.4 EXAMPLE USE OF THE STANDARD

In this standard, the compressibility factor (F) is used in the normal manner for volume correction (* denotes multiplication):

$$C_{pl} = V_e/V_m = 1/(1 - F * D_p)$$

Where:

C_{pl} = correction factor for pressure.
V_e = volume at the equilibrium (bubble point) pressure, P_e.
V_m = volume at the meter pressure, P_m.
$D_p = P_m - P_e$.

P_e and P_m may be in either pounds per square inch gage or pounds per square inch absolute, but both must be in the same units.

As an example, calculate the volume at equilibrium pressure of 1000 barrels (V_m) of a material with a relative density (60°F/60°F) of 0.5297 metered under a pressure of 500 pounds per square inch at a temperature of 55.1°F. The equilibrium pressure (P_e) for this material at 55.1°F is 45 pounds per square inch. The rounded relative density and temperature values of 0.530 and 55.0°F yield an A factor of 35,641 and a B factor of 5.516. The compressibility factor (F) is calculated as follows:

$$\begin{aligned} F &= 1/(A + D_p * B) \\ &= 1/[35{,}641 + (500 - 45) * 5.516] \\ &= 0.00002621 \end{aligned}$$

The value for F is rounded to the eighth decimal place, to the maximum of four significant digits.

Then,

$$C_{pl} = 1/[1.0 - 0.00002621 * (500 - 45)]$$
$$= 1.0121$$

The value for C_{pl} is rounded to the maximum of four decimal places.

$$V_e = V_m * C_{pl}$$
$$= 1000 * 1.0121$$
$$= 1012 \text{ barrels}$$

The value for V_e is rounded to the nearest whole barrel.

For additional examples and more details, see Chapter 12.2, *Calculation of Liquid Petroleum Quantities Measured by Turbine or Displacement Meters*.

11.2.2.5 DATA BASE

An initial 2278 data points were obtained from the literature for pure fluid compounds and mixtures of light hydrocarbon liquids. These data were examined to eliminate data for gases, data with large errors, and data with other abnormalities. The final data base used in this standard consists of 1724 data points from 13 sources (see Table 1).

The ranges of the experimental data were relative densities (60°F/60°F) from 0.3477 to 0.6312, temperatures from −28°F to 160°F, and pressure differences from 41 to 2036 pounds per square inch gage (see Figure 1). The actual ranges for the standard, as determined by an API survey, are relative densities (60°F/60°F) from 0.350 to 0.637, temperatures from −50°F to 140°F, and pressure differences from 0 to 2200 pounds per square inch gage. Hence, some portions of the standard represent extrapolated results. The uncertainty analysis presented in 11.2.2.7 may not be valid for these extrapolated portions. For the lower relative densities, 140°F is above the pseudocritical temperature at which liquid exists. For these fluids, the range is restricted to 96 percent of the pseudocritical temperature.

The data set contains 46 different mixtures of normal hydrocarbons from methane to decane. The compositions of the mixtures are listed in Table 2. The use of the standard for compositions not close to those in the data base represents an extrapolation whose results may have a greater uncertainty.

Table 1—Summary of Data Base

Sample	Relative Density (60°/60°F)	Temperature (°F)	Pressure (pounds per square inch gage)	Number of Data Points	References
NGPA/TP2	0.35–0.61	32–140	180–2000	455	12
NGPA/TP1	0.35–0.51	40–130	150–2000	218	21
Cal Tech	0.50–0.63	70–160	100–2000	157	9, 10, 13, 14, 15, 16, 17
Tulsa	0.35–0.51	−20–120	100–1500	542	1
Manley/Swift	0.508	−20–100	300–1600	13	8
Pope	0.356	−25–63	198–1788	36	11
Straty	0.356	−28–66	320–2200	67	18
Douslin	0.356	−13–32	460–2100	5	3
Dittmar	0.508	32–140	140–2120	33	2
Haynes	0.51–0.58	−28–80	242–2040	81	5, 6, 7
Ely	0.508	−28–100	121–2130	57	4
Thomas	0.508	32–122	121–1477	50	20
Teichmann	0.508	122–149	400–1465	10	19

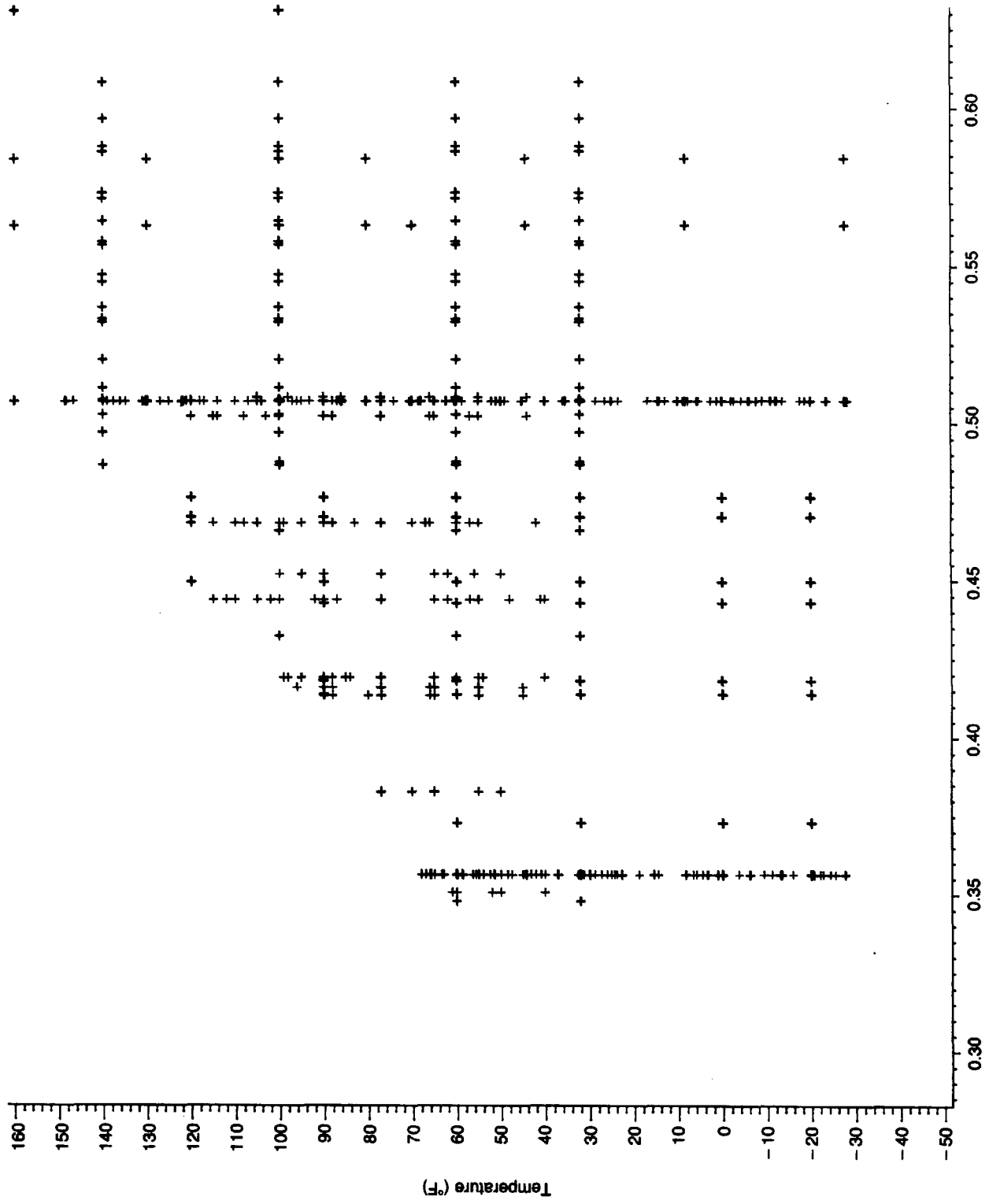


Figure 1—Limits of Data Base by Relative Density and Temperature

Table 2—Data Mixture Compositions (Mole Percent)

Sample	C_1	C_2	C_3	nC_4	iC_4	nC_5	iC_5	C_6	C_7	C_8	C_9	C_{10}
1	3.10	96.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.02	35.29	19.80	8.11	6.70	5.74	6.54	6.88	5.71	3.18	2.03
3	0.28	8.83	32.08	18.00	7.37	6.09	5.22	5.95	6.25	5.19	2.89	1.85
4	0.52	16.17	29.41	16.50	6.76	5.58	4.78	5.45	5.73	4.76	2.65	1.69
5	0.89	27.70	25.21	14.14	5.79	4.79	4.10	4.67	4.91	4.08	2.27	1.45
6	1.16	36.33	22.06	12.38	5.07	4.19	3.59	4.09	4.30	3.57	1.99	1.27
7	1.55	48.45	17.64	9.90	4.06	3.35	2.87	3.27	3.44	2.86	1.59	1.02
8	1.88	58.83	13.87	7.78	3.19	2.63	2.26	2.57	2.70	2.24	1.25	0.80
9	0.00	0.02	50.13	18.20	7.17	4.46	3.82	4.35	4.58	3.80	2.12	1.35
10	0.28	8.83	45.59	16.54	6.52	4.05	3.47	3.95	4.16	3.45	1.93	1.23
11	0.52	16.17	41.77	15.17	5.97	3.72	3.18	3.62	3.82	3.17	1.77	1.12
12	0.89	27.70	35.81	13.00	5.12	3.19	2.73	3.11	3.27	2.71	1.51	0.96
13	1.16	36.34	31.33	11.38	4.48	2.79	2.39	2.72	2.86	2.38	1.33	0.84
14	1.55	48.44	25.07	9.10	3.59	2.23	1.91	2.18	2.29	1.90	1.06	0.68
15	1.88	58.84	19.70	7.15	2.82	1.75	1.50	1.71	1.80	1.49	0.83	0.53
16	0.00	0.00	63.77	17.74	6.21	2.90	1.97	2.91	2.62	0.93	0.95	0.00
17	0.29	8.93	57.89	16.11	5.64	2.63	1.79	2.64	2.38	0.84	0.86	0.00
18	0.52	16.15	53.17	14.78	5.17	2.42	1.62	2.43	2.18	0.77	0.79	0.00
19	0.89	27.68	45.55	12.67	4.44	2.07	1.41	2.08	1.87	0.66	0.68	0.00
20	1.16	36.34	39.86	11.09	3.88	1.81	1.23	1.82	1.64	0.58	0.59	0.00
21	1.55	48.45	31.86	8.87	3.11	1.45	0.99	1.46	1.31	0.47	0.48	0.00
22	1.88	58.83	25.06	6.97	2.44	1.14	0.77	1.14	1.03	0.37	0.37	0.00
23	2.33	72.67	15.93	4.44	1.55	0.73	0.49	0.73	0.66	0.23	0.24	0.00
24	0.00	0.08	99.85	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	2.42	0.00	97.58	0	0	0	0	0	0	0	0	0
27	0.00	0.00	99.11	0.89	0	0	0	0	0	0	0	0
28	0.00	37.00	63.00	0.00	0	0	0	0	0	0	0	0
29	0.00	49.89	50.11	0.00	0	0	0	0	0	0	0	0
30	3.23	48.28	48.49	0.00	0	0	0	0	0	0	0	0
31	0.00	71.71	28.29	0.00	0	0	0	0	0	0	0	0
32	2.31	70.05	27.64	0.00	0	0	0	0	0	0	0	0
33	2.18	69.52	27.47	0.83	0	0	0	0	0	0	0	0
34	0.00	89.97	10.03	0.00	0	0	0	0	0	0	0	0
35	0.00	100.00	0.00	0.00	0	0	0	0	0	0	0	0
36	2.26	97.74	0.00	0.00	0	0	0	0	0	0	0	0
37	0.00	0.00	0.00	100.00	0	0	0	0	0	0	0	0
38	0.00	0.00	0.00	0.00	0	100	0	0	0	0	0	0
39	0.00	0.00	100.00	0.00	0	0	0	0	0	0	0	0
40	0.00	0.00	0.00	0.00	100	0	0	0	0	0	0	0
44	0.00	0.00	100.00	0.00	0	0	0	0	0	0	0	0
45	0.00	30.13	69.87	0.00	0	0	0	0	0	0	0	0
46	0.00	51.28	48.72	0.00	0	0	0	0	0	0	0	0
47	0.00	71.60	28.40	0.00	0	0	0	0	0	0	0	0
48	0.00	100.00	0.00	0.00	0	0	0	0	0	0	0	0
49	2.55	28.90	68.55	0.00	0	0	0	0	0	0	0	0
50	2.70	49.17	48.13	0.00	0	0	0	0	0	0	0	0
51	2.52	67.76	29.72	0.00	0	0	0	0	0	0	0	0
52	2.51	87.76	9.73	0.00	0	0	0	0	0	0	0	0
68	0.00	0.00	100.00	0.00	0	0	0	0	0	0	0	0
70	0	100	0	0	0	0	0	0	0	0	0	0
71	0	100	0	0	0	0	0	0	0	0	0	0
72	0	100	0	0	0	0	0	0	0	0	0	0
73	0	0	100	0	0	0	0	0	0	0	0	0
74	0	0	100	0	0	0	0	0	0	0	0	0
75	0	0	100	0	0	0	0	0	0	0	0	0
76	0	0	100	0	0	0	0	0	0	0	0	0
77	0	0	100	0	0	0	0	0	0	0	0	0
78	0	0	100	0	0	0	0	0	0	0	0	0
79	0	0	0	0	100	0	0	0	0	0	0	0
80	0	0	0	0	100	0	0	0	0	0	0	0
81	0	0	0	100	0	0	0	0	0	0	0	0
82	0	0	0	100	0	0	0	0	0	0	0	0