INTERNATIONAL STANDARD

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Crude petroleum and petroleum products — Compressibility factors for hydrocarbons in the range 638 kg/m³ to 1 074 kg/m³

Pétrole brut et produits pétroliers — Facteurs de compressibilité des hydrocarbures dans la plage de 638 kg/m³ à 1 074 kg/m³

Reference number
ISO 9770 : 1989 (E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 9770 was prepared by ISO/TC 28, *Petroleum and petroleum products.*

Annex A of this International Standard is for information only.

International Organization for Standardization
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Crude petroleum and petroleum products — Compressibility factors for hydrocarbons in the range 638 kg/m^3 to 1 074 kg/m^3

The following standard[1)] is adopted as International Standard ISO 9770 : 1989:

Manual of Petroleum Measurement Standards
Chapter 11.2.1M — Compressibility Factors for Hydrocarbons: 638-1074 Kilograms per Cubic Metre Range

published August 1984 by

American Petroleum Institute
1220 L Street, Northwest
WASHINGTON, D.C. 20005
USA

NOTES

1 It has been agreed by the API that they will give the ISO Central Secretariat at least 12 months' notice of any intention to amend, revise or withdraw this standard.

2 It should be noted that API has published an erratum to the August 1984 publication and this also forms part of this International Standard. This erratum is as follows (the corrections have been included in the French-language version of the API standard appended to the French-language version of this International Standard):

ERRATUM

Page 3, Change the first full sentence and the example at the top of the page to read as follows:

From the compressibility table, the F factor is 0.649 divided by 1,000,000 or 0.000000649. Then,

$$V_e = 1000/(1 - 0.000000649 * 3450)$$
$$= 1002.2 \text{ cubic metres}$$

3 In 11.2.1M of the referenced standard the term "molecular volume" is used. The corresponding term in ISO 31-8 : 1980 (E) is "molar volume" (8-6.1). However, later text and the calculation procedure (11.2.1.5.2M) relates the quantity to the reciprocal of density, i.e. "specific volume" [3.1 in ISO 31-3 : 1978 (E)], which should be understood.

4 An extract from the referenced standard is reproduced in annex A for information. To illustrate the presentation of the table, one page (p. 129) has been reproduced, the title being the same for all the other pages.

5 In the French-language version of this International Standard, a translation of the text of the API standard is provided.

1) Copies of the API standard may be obtained through API at the above address.

Annex A
(informative)

Extract from API *Manual of Petroleum Measurement Standards*

CONTENTS

CHAPTER 11.2.1M—COMPRESSIBILITY FACTORS FOR HYDROCARBONS: 638–1074 KILOGRAMS PER CUBIC METRE RANGE

Chapter 11—Physical Properties Data

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

11.2.1M Compressibility Factors for Hydrocarbons: 638–1074 Kilograms per Cubic Metre Range

11.2.1.1M 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 meter temperature and density (15°C) of metered material. The corresponding version in customary units is Chapter 11.2.1.

11.2.1.2M HISTORY AND DEVELOPMENT

The previous compressibility standard (API Standard 1101, Appendix B, Table II) for hydrocarbons in the 0–90°API gravity range was developed in 1945 by Jacobson, et al [1]. It is based on limited data obtained mostly on pure compounds and lubricating oil type materials. Also, Standard 1101 was developed without the aid of a mathematical model.

In 1981, a working group of the Committee on Static Petroleum Measurement was set up to revise the compressibility tables of Standard 1101. This group performed an extensive literature search and found only three sources of compressibility information. The resulting data base is broader than that used in the previous standard. Unfortunately, it is not large enough to cover the range of current commercial operations. When new data are available, they will be incorporated into an expanded standard. This standard now replaces the discontinued Standard 1101, Appendix B, Table II, 0–100°API gravity portion.

11.2.1.3M DATA BASE AND LIMITS OF THE STANDARD

The actual standard is the printed table that follows this text. The mathematical model and computer steps used to generate this standard should not be considered the standard. They can be used to develop computer subroutines for various languages and machines to duplicate the results in the printed table. Also, a computer tape is available through API, which contains the same information as the printed table. The tape can be used in the development of various computer subroutines.

The data base (see Table 1) for this standard was obtained from Jessup [2], Downer and Gardiner [3], and Downer [4]. It consists of seven crude oils, five gasolines, and seven middle distillate-gas oils. The lubricating oil data from these sources were not included. Modeling results showed that lubricating oils are a different population than crude oils and other refined products. Their inclusion increases the compressibility correlation uncertainty by a factor of two. Also, lubricating oils are not normally metered under pressure and do not require the use of this standard.

The limits of the experimental data are 681 to 934 kilograms per cubic metre, 0 to 150°C, and 0 to 4902 kilopascals. As a result of a Committee on Static Petroleum Measurement (COSM) and Committee on Petroleum Measurement (COPM) survey, the actual limits of the standard are broader: 638 to 1074 kilograms per cubic metre, −30 to 90°C, and 0 to 10300 kilopascals. Hence, certain portions of the standard represent extrapolated results (Figure 1). In these extrapolated portions, the uncertainty analysis discussed in 11.2.1.5M may not be valid.

The increments of this standard are 0.25°C and 2 kilograms per cubic metre. Interpolation to smaller increments is not recommended.

11.2.1.4M EXAMPLE USE OF THE STANDARD

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

$$V_e = V_m/[1 - F*(P_m - P_e)]$$

Where:

V_e = volume at equilibrium (bubble point) pressure, P_e.

V_m = volume at the meter pressure, P_m.

As an example, calculate the volume of 1000 cubic metres (V_m) of a 933.6 kilograms per cubic metre (15°C) fuel oil metered under a pressure of 3450 kilopascals (P_m) and 37.85°C. Assume a P_e value of 0 kilopascals. First, the density and temperature are rounded to the nearest 2 kilograms per cubic metre and 0.25°C, in this

Table 1—Data Base and Experimental Conditions for Chapter 11.2.1M

Sample Name and Origin	Density kg/m³ at 15°C	Temperature °C	Pressure kPa	Number of Data Points	Reference
Crude Oils					
ADMEG (Zakum) export	825.2	4.44–76.67	0–3503	5	3
Barrow Island	839.5	4.44–76.67	0–3503	5	3
Libyan (Tobruk) export	842.5	37.78–76.67	0–3503	3	3
Iranian Light export	856.4	4.44–76.67	0–3503	5	3
Kuwait export	870.4	4.44–76.67	0–3503	5	3
Iranian Heavy export	872.7	4.44–76.67	0–3503	5	3
Alaskan (North Slope)	890.9	15.56–76.67	0–3503	4	3
Gasolines					
Light catalytic cracked	680.9	4.44–37.78	0–3399	3	4
Straight run	734.4	4.44–60.0	0–3399	4	4
Cracked	768.0	0.0–65.0	0–4902	5	2
Fighting aviation	697.0	0.0–70.0	0–4902	5	2
Fighting aviation	695.0	0.0–70.0	0–4902	5	2
Kerosine and Light Fuel Oil					
Kerosine (odorless)	789.7	4.44–76.67	0–3399	5	4
DERV	847.6	4.44–76.67	0–3399	5	4
Gas Oils and Heavy Fuels Oils					
Gas oil	833.6	4.44–76.67	0–3399	5	4
Commercial fuel oil	934.1	37.78–60.0	0–3399	2	4
Los Angeles basin gas oil	873.4	0.0–150.0	0–4902	3	2
Oklahoma gas oil	880.7	0.0–150.0	0–4902	3	2
Midcontinent gas oil	883.0	0.0–150.0	0–4902	3	2

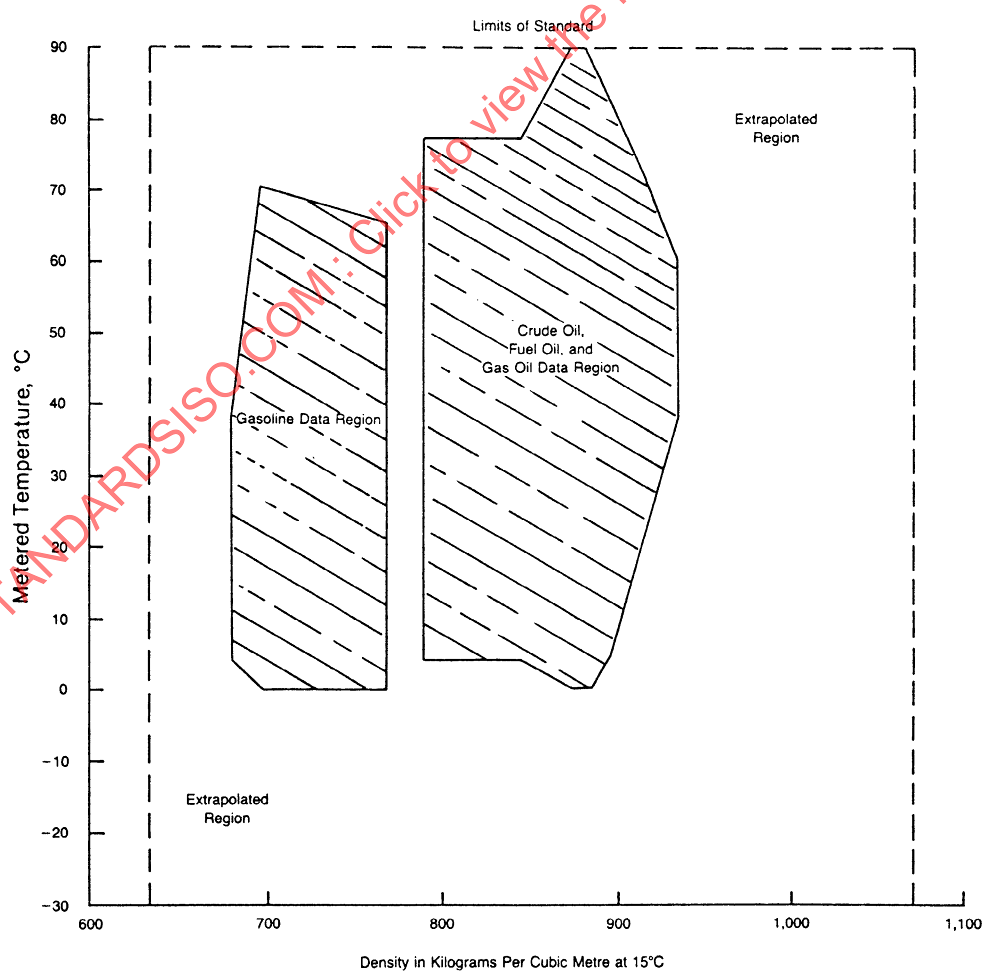

Figure 1—Comparison of Data Base and Extrapolated Regions for Chapter 11.2.1M

case 934 kilograms per cubic metre and 37.75°C. From the compressibility table, the F factor is 0.643 divided by 1,000,000 or 0.000000643. Then,

$$V_e = 1000/(1 - 0.000000643 * 3450) = 1002.2 \text{ cubic metres}$$

For additional examples and more details, see *Manual of Petroleum Measurement Standards*, Chapter 12.2.

11.2.1.5M MATHEMATICAL MODEL FOR THE STANDARD

11.2.1.5.1M Basic Model and Uncertainty Analysis

The basic mathematical model, used to develop this standard, relates the compressibility factor exponentially (EXP) to temperature and the square of molecular volume. That is,

$$F = \text{EXP}\ (A + B*T + C/\text{RHO}^2 + D*T/\text{RHO}^2)$$

Where:

A, B, C, and D = constants.
T = temperature, in °C.
RHO = density, in grams per cubic centimetre at 15°C. 1/RHO is proportional to molecular volume.

Hence, compressibility is the result of the interaction of two molecular volumes and temperature. The above equation is consistent with the development of API Standard 2540 (*Manual of Petroleum Measurement Standards*, Chapter 11.1) for the thermal expansion of hydrocarbons. The use of higher powers of T and RHO does not yield further significant minimization of compressibility factor uncertainty.

Using the above equation and data base, maximum compressibility factor uncertainty is ±6.5 percent at the 95 percent confidence level. Hence at worst, one should expect that the real compressibility factor for a given material could be either 6.5 percent higher or 6.5 percent lower than the value in the standard. This statement is only true within the limits of the data base. It may not be true for the extrapolated portions of the standard.

To assess the possible uncertainty in the calculated volume at equilibrium pressure using the above data base and equation, two approaches were taken. First, it was assumed that only the correlation uncertainty in mean compressibility of ±6.5 percent was significant. With this approach, volumetric uncertainty should be in the range of 0.02 to 0.10 percent, depending on operating conditions (Table 2, Basis A). These uncertainties are in agreement with the maximum uncertainty of 0.10 percent recommended by a COSM and COPM survey.

The first volumetric uncertainty analysis assumes that mean compressibility is not a function of pressure. For low pressures, this assumption is adequate. For higher pressures, mean compressibility will decrease with increasing pressure. At what pressure this effect becomes significant for the materials of this standard is not definitely known. However, analysis of the Jessup [2] data indicates that mean compressibility could possibly decrease by about 0.00073 percent per kilopascal with increasing pressure. Incorporating both the compressibility correlation uncertainty and the potential pressure uncertainty yields volumetric uncertainties in the range of 0.03 to 0.21 percent (Table 2, Basis A + B). Hence, the use of this standard with operating pressures greater than the experimental limit of 4902 kilopascals could double the uncertainty in calculated volume over the uncertainty based on available data.

Table 2—Volumetric Uncertainty Analysis for Chapter 11.2.1M

Mean Compressibility kPa^{-1}	Percent Uncertainty in Volume for Various Pressures, kPa					
	Correlation Uncertainty Only Basis A			Correlation + Pressure Uncertainty Basis A + B		
	3447	6895	10342	3447	6895	10342
$1.45 \cdot 10^{-6}$ (Note 1)	0.03	0.07	0.10	0.05	0.12	0.21
$0.87 \cdot 10^{-6}$ (Note 2)	0.02	0.04	0.06	0.03	0.08	0.13

BASIS: A. 6.5 percent correlation uncertainty in mean compressibility prediction.
B. 0.00073 percent/kPa uncertainty in mean compressibility due to effect of pressure [2].

NOTES:
1. Typical compressibility value for 720 kg/m^3 (15°C) gasoline at 38°C or 800 kg/m^3 fuel oil at 93°C.
2. Typical compressibility value for 738 kg/m^3 gasoline at −7°C or 850 kg/m^3 crude oil at 38°C.

11.2.1.5.2M Calculation Procedure

This procedure is recommended for computers with 6 to 7 floating point digits of precision or greater.

Step 1: Initialize temperature in °C.

T = XX.XX: $-30.00 \le T \le 90.00$, rounded to nearest 0.25°C. by
TT = INT(T): i.e., truncation
DIFF = $T - TT$.
If DIFF $\ge$ 0 then SIGN = 1.0 else SIGN = $-$1.0.
DIFF = ABS(DIFF): i.e., absolute value.
If DIFF < 0.125 then $T = TT$.
If 0.125 ≤ DIFF < 0.375 then $T = TT$ + 0.25*SIGN
If 0.375 ≤ DIFF < 0.625 then $T = TT$ + 0.50*SIGN
If 0.625 ≤ DIFF < 0.875 then $T = TT$ + 0.75*SIGN
If DIFF ≥ 0.875 then $T = TT$ + 1.00*SIGN

Step 2: Initialize the density in kilograms per cubic metre.

RHO = XXXX: 638 ≤ RHO ≤ 1074, rounded to the nearest 2 by
RHOH = INT(RHO/2.0).
DIFF = RHO − 2*RHOH.
If DIFF ≥ 1.0 then RHO = 2 + 2*RHOH.
Else RHO = 2*RHOH.

Step 3: Calculate the density in grams per cubic centimetre and the square of density.

RHO = RHO*0.001.
RHOSQR = RHO*RHO = X.XXXXX, rounded to the nearest 0.00001 by
RHOSQR = INT(RHOSQR*100000.0 + 0.5) *0.00001.

Step 4: Calculate the compressibility factor.

F = EXP (− 1.62080 + 0.00021592*T + 0.87096/ RHOSQR + 0.0042092*T/RHOSQR)
by rounding each term to the nearest 0.00001 as follows:

If T < 0 then SIGN = − 1.0 else SIGN = 1.0.
TERM1 = − 1.62080.
TERM2 = INT(21.592*T + 0.5*SIGN) * 0.00001.
TERM3 = INT(87096.0/RHOSQR + 0.5)*0.00001.
TERM4 = INT(420.92*T/RHOSQR + 0.5*SIGN) *0.00001
F = EXP (TERM1 + TERM2 + TERM3 + TERM4) = X.XXXX.
Then round F to the nearest 0.001 by
F = INT(F*1000.0 + 0.5)*0.001.
F is now the table value.

The INT intrinsic function returns an integer by truncating all digits to the right of the decimal point. The exponential intrinsic EXP must return a result accurate to the nearest 0.0001.

11.2.1.6M REFERENCES

1. Jacobson, E. W., Ambrosius, E. E., Dashiell, J. W., and Crawford, C. L., "Second Progress Report on Study of Existing Data on Compressibility of Liquid Hydrocarbons," Report of the Central Committee on Pipe-Line Transportation, Vol. 2 (IV), p. 39–45, American Petroleum Institute, Washington, D.C., 1945.
2. Jessup, R. S., "Compressibility and Thermal Expansion of Petroleum Oils in the Range 0° to 300°C," *Bureau of Standards Journal of Research,* Vol. 5, July to December 1930, p. 985–1039, National Bureau of Standards, Washington, D.C.
3. Downer, L., and Gardiner, K. E. S., "Bulk Oil Measurement Compressibility Measurements on Crude Oils Deviations from API Standard 1101," BP Research Centre Report No. 20 587/M (8 pages), October 28, 1970.
4. Downer, L. "Bulk Oil Measurement Compressibility Data on Crude Oils and Petroleum Products Viewed as a Basis for Revised International Tables (API Standard 1101 Tables)," BP Research Centre Report No. 20 639 (21 pages), January 17, 1972.

CHAPTER 11.2.1(M) OF THE API MANUAL OF

PETROLEUM MEASUREMENT STANDARDS

COMPRESSIBILITY FACTORS FOR HYDROCARBONS

IN THE 638-1074 KILOGRAMS PER CUBIC METRE

RANGE RELATED TO DENSITY(15 DEG C) AND

METERING TEMPERATURE(DEGREES CELSIUS)