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Technical Data Book: Chapter 1 – General Data

API TECHNICAL REPORT TDB-1
1ST EDITION, XXXX 202X

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SCOPE

Technical Report TDB-1 describes the contents of the API Technical Data Book. A critically reviewed compilation of the physical and thermodynamic data that are of most interest to petroleum refiners for practical application to process evaluation and equipment design is included. Fundamental constants, conversion factors, and property definitions are provided.

Any references to other chapters within this document refer to the corresponding Technical Data Book Chapter which is published as API Technical Report TDB-x, where x is the chapter number.

0-0 Introduction to API Technical Data Book

API has sponsored this important flagship project since the first edition of the API Tech Data Book was released in 1966. For over 60 years, the project has been managed by the API Technical Data committee, whose members include the petroleum industry's leading experts in thermodynamics and chemical engineering. API member companies This is one of the many projects that API is pursuing to benefit its member companies.

Purpose

The purpose of the API Technical Data Book is to provide a critically reviewed compilation of the physical and thermodynamic data and correlations that are of most interest to petroleum refiners for practical application for process evaluation and equipment design. Chapters on the following topics are provided in electronic, searchable software format along with computer methods for implementation of recommended Data Book methods.

Introduction
Chapter 1 – General Data
Chapter 2 – Characterization of Hydrocarbons
Chapter 3 – Petroleum Fraction Distillation Interconversions
Chapter 4 – Critical Properties
Chapter 5 – Vapor Pressure
Chapter 6 – Density
Chapter 7 – Thermal Properties
Chapter 8 – Vapor-Liquid Equilibrium *K*-Values
Chapter 9 – Phase Equilibria in Systems Containing Water
Chapter 10 – Surface and Interfacial Tension
Chapter 11 – Viscosity
Chapter 12 – Thermal Conductivity
Chapter 13 – Diffusivity
Chapter 14 – Combustion
Chapter 15 – Adsorption Equilibria

The API Technical Data Book concentrates on hydrocarbons and their mixtures. Non-hydrocarbon gases and some oxygenated compounds important in petroleum processing are

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included where appropriate. Hydrocarbon systems are divided into three groups: those in the pure state, petroleum mixtures for which the compositions of all the species are known (defined mixtures), and mixtures whose composition is unknown (undefined mixtures). The undefined mixtures must usually be characterized by one or more measured physical properties, such as density, molecular weight, viscosity, and ASTM distillation, which reflect their constitution. Obviously, the treatments for these three classifications differ; thus, separate methods are given for each. Predictions for defined mixtures can often be made using correlations for undefined mixtures, but this procedure is rarely recommended.

Although some methods can be done with hand calculators, computer methods have been developed as the primary, recommended methods. Procedures are equation based, but many are also presented as figures to help illustrate these procedures and for use in educational forums. Computer methods are included for essentially all critical, volumetric, and thermodynamic properties discussed.

Data Book Organization

Each chapter is devoted to a single property or group of related properties. Within the chapters, further divisions in sections and sub-sections are made according to the property (when more than one is given in a chapter), the phase, and the state of the hydrocarbon (pure, defined mixture, or undefined mixture). Generally, non-hydrocarbons are covered in a section different from the one in which the corresponding treatment for hydrocarbons is given. Titles for the subdivisions are given in the table of contents of each chapter.

Chapter 1, “General Data,” contains information on conversion factors and pure component properties.

In Chapters 2–15, for numbering purposes, the figures, tables, and procedures that are to be used to calculate values are not treated separately according to kind but are numbered serially in order of presentation, whether Figure, Table, or Procedure. In the designation “Figure 12B1.3,” for example, “12” is the chapter number, “B” is the section designation, “1” is the sub-section number, and “3” indicates the third exhibit from the sub-section.

Comments are typically given for each figure or procedure and are normally located on the following pages. For groups of related figures, comments are given following the last figure only. Where tables and figures are used as part of a procedure, the procedure and comments for the entire unit are given first, followed by the supporting exhibits (which have no individual comments).

Included in the procedure and comments sections are some or all of the following sub-sections (shown as bold blue font in the Data Book):

Discussion
Procedure
Purpose
Limitations
Reliability
Notation
Special Comments

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Literatures Sources

Examples

To help avoid any errors or difficulties in using the Data Book correlations, it is recommended to review the Comments and Examples sections to understand their implementation and application. References to other chapters are usually no more specific than the chapter number.

Data Book Accuracy

Neither the availability of many correlations nor the endorsement of one or more of them in this book implies that any of them is totally satisfactory for all conditions of temperature, pressure, phase, composition, and hydrocarbon type. The selections were based on the available data, tempered by scientific judgment. There is no guarantee that any of the methods will be reliable for unusual compounds or conditions, and the user is cautioned against blind faith and particularly against being deceived by the rigorous appearance of a complicated correlation. The user is cautioned against using any of the methods outside the conditions stated in the limitations section. Many more experimental data are needed before our correlative knowledge can be described as satisfactory. Despite these shortcomings, the selected correlations are believed to be the best compromise among accuracy, generality, internal consistency, and ease of use that can be obtained from the readily available methods and data.

Participation in the Development of API Standards

The ongoing work of the API Technical Data Committee relies on volunteer efforts by its committee members through the support of API member companies. Your company's participation is encouraged in the ongoing development and improvement of this important API standard. Through this joint, collaborative effort, API can provide the best possible data and methods to further the profitability and safety of the refining industry.

For further information on how you can participate in the development of API Standards on behalf of your company, contact the American Petroleum Institute at 202-682-8000 (www.api.org).

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1-0 Introduction

Almost all the procedures in the API Technical Data Book require pure component physical properties. This chapter lists a collection of properties for many hydrocarbons and selected nonhydrocarbons that are provided in electronic form. The compounds and the properties that were selected for inclusion in the API Technical Data Book are those judged most useful for petroleum refining and associated industries. Further information on physical properties may be found in the Design Institute for Physical Properties (DIPPR) Data Compilation: Tables of Properties of Pure Compounds (8, 52, 53). Most data for the compounds in this chapter were taken from the following sources (in order of priority):

1. DIPPR Compilation (8, 52, 53)
2. GPA 2145 (13)
3. API Monograph Series (1-3)

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4. TRC Tables (32-34, 39-47)
5. Previous Editions of the API Technical Data Book - Petroleum Refining (9)

Unless otherwise indicated, predictions of hydrocarbon data were made using the current Data Book procedures. Predictions of nonhydrocarbon data were made using DIPPR Compilation *(8)* procedures.

The *Fundamental Constants and Conversion Factors* section contains a list of constants and lists of conversion factors. The *Letter Symbols Used in Chemical Engineering* section provides a list of letter symbols with their definitions. The *Property Definitions* section enumerates the property definitions. Other pertinent information on the pure component data sources and references properties are given following the data.

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1A Fundamental Constants and Conversion Factors

1A1 Fundamental Constants

Table 1A1.1 - Fundamental Constants

Name	Symbol	Value	Units
Basic Constants			
Velocity of light (vacuum)	c	2.99792458×10^{8}	m per sec
Avogadro constant	N_A	$6.02214076 \times 10^{23}$	molecules per gmole
Planck constant	h	$6.62607015 \times 10^{-34}$	J per Hz
Electronic charge	e	$1.602176487 \times 10^{-19}$	coulombs
Boltzmann constant	k	1.380649×10^{-16}	joules per K
Absolute temperature of the 'ice' point:			
0 °C	$T_{0°C}$	273.15	K
32 °F	$T_{32\ °F}$	491.67	deg R
Pressure-volume product for 1 mole of a gas at 0 °C (32 °F) and zero pressure (ideal gas)	$(pV)^{p=0}_{T_{0\ °C}}$	2,271.11	joules per g-mole
		22.41397	(liters) (atm) per g-mole
		2.27111×10^{6}	(m^3) (Pa) per kg-mole
		359.039	(ft^3) (atm) per lb-mol
		5,276.42	(ft^3) (psia) per lb-mol
Derived Constants			
Faraday constant	$F=eN_A$	96,485.33212	Coulombs per mole
Gas constant	N_Ak	8.31446	joules per (gmole) (K)
		1.9872	cal per (g-mole) (K)
		1.9872	Btu per (lb-mole) (°R)
		82.057	(cm^3) (atm) per (g-mole) (K)
		1,545.3	ft-lbf per (lb-mole) (°R)
		10.732	(psia) (ft^3) per (lb-mole) (°R)
		62.364	(mm Hg) (liter) per (g-mole) (K)
		0.084784	(kgf per cm^2) (liter) per (g-mole) (K)
		0.73024	(atm) (ft^3) per (lb-mole) (°R)
		554.98	(mm Hg) (ft^3) per (lb-mole) (°R)
		8,314.5	(Pa) (m^3) per (kg-mol) (K)
Boltzmann constant	$k = \frac{R}{N_A}$	1.38066×10^{-16}	ergs per (molecule) (K)
Second radiation constant	$C_2 = \frac{hc}{k}$	1.43878	cm-°C
Defined Constants			
Standard gravity	g_o	9.80665	m per sec per sec
		32.174	ft per sec per sec
Standard atmosphere	atm	1.01325×10^{6}	dynes per cm^2
		14.696	psia
		101,325	pascals
Standard millimeter of mercury pressure	mm Hg	1/760	atm
Calorie (thermochemical)	cal	4.184	joules
		4.1840×10^{7}	ergs
Calorie (International Steam Tables)	cal_{IT}; I.T. cal	4.1868	joules
Liter	l	1,000	cm^3

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Table 1A1.1 - Fundamental Constants (Continued)

Conversion Factors-Engineering Units Vs. Metric Units		
Name	**Value**	**Units**
1 in	= 2.54 cm	Definition: in = U.S. inch
1 ft	= 30.48 cm	Definition: U.S. foot (1 ft = 12 in)
1 lb	= 453.59237 g	Definition: lb = avoirdupois pound
1 gal	= 231 cu in = 0.133680556 cu ft = 3,785.412 cu cm = 3.785412 liters	Definition: gal = U.S. gallon
1 I.T. cal	= 1/860 ~~int~~ watt-hr = 4.1868 joules = 4.18605 int joules =1.00067 cal	Definition: I.T. = International Steam Tables Definition: cal = thermochemical calorie
1 Btu/ lb	= 1/1.8 I.T. cal per g	Definition: Btu = I.T. British thermal unit
1 Btu	= 251.995 I.T. cal = 1,055.06 joules = 0.293071 watt-hr = 252.164 cal	 Definition: cal = thermochemical calorie
1 hp	= 550 ft-lb [force] per sec = 745.700 watts	
1 erg	= 1 dyne-cm	
Mathematical Constants		
π = 3.141593….		
e (base of natural logarithms) = 2.71828….		
natural logarithm (base ***e***), $\log_e 10 = \ln 10$ = 2.30258509….		
Temperature Conversions		
°C = (°F – 32)/1.8		
°F = 1.8 °C + 32		
K = °C + 273.15		
°R = °F + 459.67		
°R = 1.8 K		
Where:		
°C = degrees Celsius		
°F = degrees Fahrenheit		
K = Kelvin		
°R = degrees Rankine		
Above values taken from or derived from 2022 CODATA recommended values		

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1A2 Conversion Factors

Table 1A2.1 – Length Conversions

To convert the numerical value of a property expressed in one of the units in the left-hand column of the unit conversion tables to the numerical value expressed in one of the units in the top row of the table, multiply the former value by the factor in the block common to both units.

Units	Inches	Feet	Yards	Miles	Microns	Milli-meters	Centi-meters	Meters	Kilo-meters
Inches	**1**	0.083333	0.027778	1.5783 × 10^{-5}	**25400**	**25.4**	**2.54**	**0.0254**	**2.5400 × 10^{-5}**
Feet	**12**	**1**	0.33333	1.8939 × 10^{-4}	**3.0480 × 10^{5}**	**304.8**	**30.48**	**0.3048**	**3.0480 × 10^{-4}**
Yards	**36**	**3**	**1**	5.6818 × 10^{-4}	**9.144 × 10^{5}**	**914.4**	**91.44**	**0.9144**	**9.1440 × 10^{-4}**
Miles	**63360**	**5280**	**1760**	**1**	1.609344 × 10^{9}	1.609344 × 10^{6}	1.609344 × 10^{5}	1.609344 ×10^{3}	1.609344
Microns	3.9370 × 10^{-5}	3.2808 × 10^{-6}	1.0936 × 10^{-6}	6.2137 × 10^{-10}	**1**	**10^{-3}**	**10^{-4}**	**10^{-6}**	**10^{-9}**
Millimeters	3.9370 × 10^{-2}	3.2808 ×10^{-3}	1.0936 × 10^{-3}	6.2137 × 10^{-7}	**10^{3}**	**1**	**0.1**	**0.001**	**10^{-6}**
Centimeters	0.39370	0.032808	0.010936	6.2137 × 10^{-6}	**10^{4}**	**10**	**1**	**0.01**	**10^{-5}**
Meters	39.370	3.2808	1.0936	6.2137 × 10^{-4}	**10^{6}**	**1000**	**100**	**1**	**0.001**
Kilometers	3.9370 × 10^{4}	3.2808 ×10^{3}	1.0936 × 10^{3}	0.62137	**10^{9}**	**10^{6}**	**10^{5}**	**1000**	**1**

Table 1A2.2 - Area Conversions

Units	Square Inches	Square Feet	Square Yards	Acres	Square Centimeters	Square Meters
Square Inches	**1**	6.944 × 10^{-3}	7.7160 × 10^{-4}	1.5942 × 10^{-7}	**6.4516**	**6.4516 × 10^{-4}**
Square Feet	**144**	**1**	0.11111	2.2957 × 10^{-5}	929.03	9.2903 × 10^{-2}
Square Yards	**1296**	**9**	**1**	2.0661 × 10^{-4}	8361.3	0.83613
Acres	**6.27264 × 10^{6}**	**43560**	**4840**	**1**	4.0469 × 10^{7}	4.0469 × 10^{3}
Square Centimeters	0.15500	1.0764 ×10^{-3}	1.1960 × 10^{-4}	2.4710 × 10^{-8}	**1**	**10^{-4}**
Square Meters	1550	10.764	1.196	2.4710 × 10^{-4}	**10^{4}**	**1**

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Table 1A2.3 - Volume Conversions

Units	Cubic Inches	Cubic Feet	Cubic Yards	Cubic Centimeters	Cubic Meters
Cubic Inches	**1**	5.7870×10^{-4}	2.1433×10^{-5}	16.387	1.6387×10^{-5}
Cubic Feet	**1728**	**1**	3.7037×10^{-2}	2.8317×10^{4}	2.8317×10^{-2}
Cubic Yards	**46656**	**27**	**1**	7.6455×10^{5}	0.76455
Cubic Centimeters	6.1023×10^{-2}	3.5315×10^{-5}	1.3080×10^{-6}	**1**	$\mathbf{10^{-6}}$
Cubic Meters	61023	35.315	1.308	$\mathbf{10^{6}}$	**1**

Table 1A2.4 –Liquid Volume Conversions

Units	Fluid Ounces (U.S.)	Quarts (U.S.)	Gallons (U.S.)	Imperial gallons	Barrels (Oil)	Cubic Inches	Cubic Feet	Liters	Cubic Centi-meters	Cubic Meters
Fluid Ounces (U.S.)	**1**	0.03125	7.8125×10^{-3}	6.5053×10^{-3}	1.8601×10^{-4}	1.8047	1.0444×10^{-3}	0.029574	29.574	2.9574×10^{-5}
Quarts (U.S.)	**32**	**1**	**0.25**	0.20817	5.9524×10^{-3}	57.75	0.03342	0.94635	946.35	9.4635×10^{-4}
Gallons (U.S.)	**128**	**4**	**1**	0.83267	0.023809	**231**	0.13368	3.7854	3785.4	3.7854×10^{-3}
Imperial gallons	153.72	4.8038	1.20095	**1**	0.028594	277.42	0.16054	**4.54609**	4546.1	4.5461×10^{-3}
Barrels (Oil)	**5376**	**168**	**42**	34.972	**1**	**9702**	5.6146	158.99	1.5899×10^{5}	0.15899
Cubic Inches	0.55411	0.017316	4.3290×10^{-3}	3.6047×10^{-3}	1.0307×10^{-4}	**1**	5.7870×10^{-4}	0.016387	16.387	1.6387×10^{-5}
Cubic Feet	957.51	29.922	7.4805	6.2288	0.17811	**1728**	**1**	28.317	28317	0.028317
Liters	33.814	1.0567	0.26417	0.21997	6.2898×10^{-3}	61.024	0.035315	**1**	**1000**	$\mathbf{1 \times 10^{-3}}$
Cubic Centimeters	0.033814	1.0567×10^{-3}	2.6417×10^{-4}	2.1997×10^{-4}	6.2898×10^{-6}	0.061024	3.5315×10^{-5}	**0.001**	**1**	$\mathbf{1 \times 10^{-6}}$
Cubic Meters	33814	1056.7	264.17	219.97	6.2898	61024	35.315	**1000**	$\mathbf{1 \times 10^{6}}$	**1**

Note: According to ASME Guides SI-1 (22) and SI-4 (23), 1 ml = 1 cc

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Table 1A2.5 - Mass Conversions

Units	Grains	Ounces (Avoir)*	Pounds (Avoir)*	Ounces (Troy)†	Pounds (Troy)†	Tons (Short)‡	Tons (Long)§	Grams	Kilograms	Metric Tons
Grains	**1**	2.2857 × 10^{-3}	1.4286 ×10^{-4}	2.0833 × 10^{-3}	1.7361 × 10^{-4}	7.1429 × 10^{-8}	6.3776 × 10^{-8ou}	0.064799	6.4799 × 10^{-5}	6.4799 × 10^{-8}
Ounces (Avoir)*	437.5	**1**	0.0625	0.91146	0.075955	3.125 × 10^{-5}	2.7902 × 10^{-5}	28.35	0.02835	2.8350 × 10^{-5}
Pounds (Avoir)*	**7000**	**16**	**1**	14.583	1.2153	5 × 10^{-4}	4.4643 × 10^{-4}	453.59	0.45359	4.5359 × 10^{-4}
Ounces (Troy)†	**480**	1.0971	0.068571	**1**	0.083333	3.4286 × 10^{-5}	3.0612 × 10^{-5}	31.103	0.031103	3.1103 ×10^{-5}
Pounds (Troy)†	**5760**	13.166	0.82286	**12**	**1**	4.1143 × 10^{-4}	3.6735 × 10^{-4}	373.24	0.37324	3.7324 × 10^{-4}
Tons (Short)‡	**1.400 × 10^{7}**	**32000**	**2000**	29167	2430.6	**1**	0.89286	9.0718 ×10^{5}	9.0718 × 10^{2}	0.90718
Tons (Long)§	**1.5680 × 10^{7}**	**35840**	**2240**	32667	2722.2	1.12	**1**	1.0160 ×10^{6}	1.0160 ×10^{3}	1.016
Grams	15.432	0.035274	2.2046 × 10^{-3}	0.032151	2.6792 × 10^{-3}	1.1023 × 10^{-6}	9.8421 × 10^{-7}	**1**	**0.001**	**10^{-6}**
Kilograms	1.5432 × 10^{4}	35.274	2.2046	32.151	2.6792	1.1023 × 10^{-3}	9.8421 × 10^{-4}	**1000**	**1**	**10^{-3}**
Metric Tons	1.5432 × 10^{7}	3.5274 × 10^{4}	2.2046 × 10^{3}	3.2151 × 10^{4}	2.6792 ×10^{3}	1.1023	0.98421	**10^{6}**	**1000**	**1**

* Used for ordinary commodities.
† Used for drugs, jewels, precious metals.
‡ Common in the United States and Canada.
§ Common in England.

Table 1A2.6 – Density Conversions

Units	$\frac{g}{cm^3}$	$\frac{lb}{in^3}$	$\frac{lb}{ft^3}$	$\frac{lb}{gal\ (US)}$	$\frac{kg}{m^3}$
g/cm³	**1**	0.036127	62.428	8.3454	**1000**
lb/in³	27.68	**1**	**1728**	**231**	27680
lb/ft³	0.016018	5.7870 × 10^{-4}	**1**	0.13368	16.018
lb/gal (US)	0.11983	4.3290 × 10^{-3}	7.4805	**1**	119.83
kg/m³	0.001	3.6127 × 10^{-5}	0.062428	0.0083454	**1**

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Table 1A2.7 – Pressure Conversions

Units	$\frac{\text{dynes}}{\text{cm}^2}$	Bars	Atmos-pheres	$\frac{\text{kg}}{\text{cm}^2}$	mm Hg* at 0 °C	in. Hg* at 32 °F	$\frac{\text{lbf}}{\text{in}^2}$	ft H_2O at 39.2 °F	Pascals
Dynes/ cm^2	**1**	**10^{-6}**	9.8692 × 10^{-7}	1.01972 × 10^{-6}	7.5006 × 10^{-4}	2.9530 × 10^{-5}	1.4504 × 10^{-5}	3.3456 × 10^{-5}	**0.10000**
Bars	**10^6**	**1**	0.98692	1.01972	750.06	29.530	14.504	33.456	**1 × 10^5**
Atmospheres	**1.01325 × 10^6**	**1.01325**	**1**	1.0332	**760**	29.921	14.696	33.9	**1.01325 × 10^5**
$\frac{\text{kg}}{\text{cm}^2}$	9.8067 × 10^5	0.98067	0.96784	**1**	735.56	28.959	14.223	32.809	98066.5
mm Hg* at 0 °C	1333.2	1.3332 × 10^{-3}	1.31579 × 10^{-3}	1.3595 × 10^{-3}	**1**	0.03937	0.019337	0.044604	133.32
in. Hg at 32 °F	33864	0.033864	0.033421	0.03453	**25.4**	**1**	0.49116	1.133	3386.4
$\frac{\text{lbf}}{\text{in}^2}$	68948	0.068948	0.068046	0.070307	51.715	2.036	**1**	2.3066	6894.8
ft H_2O at 39.2 °F	29890	0.029891	0.029499	0.030479	22.419	0.88265	0.43352	**1**	2988.98
Pascals	**10.000**	**1 ×10^{-5}**	9.8692 × 10^{-6}	1.0197 × 10^{-5}	7.5006 ×10^{-3}	2.9530 × 10^{-4}	1.4504 × 10^{-4}	3.3456 × 10^{-4}	**1**

* 1 Torr = 1 mm Hg.

Table 1A2.8 – Flow Conversions

Units	$\frac{\text{gal (US)}}{\text{min}}$	$\frac{\text{gal (US)}}{\text{hr}}$	$\frac{\text{ft}^3}{\text{sec}}$	$\frac{\text{ft}^3}{\text{min}}$	$\frac{\text{bbl (42)}}{\text{hr}}$	$\frac{\text{bbl (42)}}{\text{day}}$	$\frac{\text{liters}}{\text{sec}}$	$\frac{\text{m}^3}{\text{hr}}$
$\frac{\text{gal (US)}}{\text{min}}$	**1**	**60**	2.2280 ×10^{-3}	0.13368	1.4286	34.286	0.063090	0.22712
$\frac{\text{gal (US)}}{\text{hr}}$	0.016667	**1**	3.7133 × 10^{-5}	2.2280 ×10^{-3}	0.023810	0.57143	1.0515 ×10^{-3}	3.7854 × 10^{-3}
$\frac{\text{ft}^3}{\text{sec}}$	448.83	2.6930 ×10^4	**1**	**60**	641.20	1.5388 × 10^4	28.317	101.94
$\frac{\text{ft}^3}{\text{min}}$	7.4805	448.83	0.016667	**1**	10.686	256.47	0.47195	1.6990
$\frac{\text{bbl (42)}}{\text{hr}}$	**0.7000**	**42**	1.5596 × 10^{-3}	0.093576	**1**	**24**	0.044163	0.15899
$\frac{\text{bbl (42)}}{\text{day}}$	0.029167	**1.7500**	6.4984 ×10^{-5}	3.8990 × 10^{-3}	0.041667	**1**	1.8401 × 10^{-3}	6.6245 × 10^{-3}
$\frac{\text{liters}}{\text{sec}}$	15.850	951.02	0.035315	2.1189	22.643	543.44	**1**	**3.6**
$\frac{\text{m}^3}{\text{hr}}$	4.4029	264.17	0.0098096	0.58858	6.2898	150.96	0.27778	**1**

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Table 1A2.9 - Kinematic Viscosity Conversions

Units	ft^2/hr	ft^2/sec	m^2/hr	cm^2/s (Stokes)	Centistokes
ft^2/hr	**1**	2.778×10^{-4}	9.290×10^{-2}	0.2581	25.81
ft^2/sec	**3600**	**1**	3.345×10^{2}	929	9.29×10^{4}
m^2/hr	10.76	2.990×10^{-3}	**1**	2.778	277.8
cm^2/s (Stokes)	3.875	1.076×10^{-3}	**0.36**	**1**	**100**
Centistokes	3.875×10^{-2}	1.076×10^{-5}	**3.600×10^{-3}**	**0.01**	**1**

Table 1A2.10 - Absolute Viscosity Conversions

Units	$\frac{lb}{sec\text{-}ft}$	$\frac{lb}{hr\text{-}ft}$	$\frac{lbf\text{-}sec}{ft^2}$	Centipoise	$\frac{kg}{hr\text{-}m}$
$\frac{lb}{sec\text{-}ft}$	**1**	**3600**	0.03108	1488	5357
$\frac{lb}{hr\text{-}ft}$	2.778×10^{-4}	**1**	8.634×10^{-6}	0.4134	1.488
$\frac{lbf\text{-}sec}{ft^2}$	32.17	1.158×10^{5}	**1**	47880	1.724×10^{5}
Centipoise	6.720×10^{-4}	2.419	2.089×10^{-5}	**1**	**3.600**
$\frac{kg}{hr\text{-}m}$	1.867×10^{-4}	0.672	5.802×10^{-6}	0.2778	**1**

* 1 poise = 100 centipoises = 1 g/sec-cm. Kinematic viscosity, in centistokes, times density (g/cm^3) at same temperature equals centipoises.

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Table 1A2.11 - Energy Conversions

Units	Joules	Calories	I. T. Calories	British Thermal Units	Kilowatt-Hours	Horse-power-Hours	Foot-Pounds [Force]	$\frac{ft^3\text{-}lbf}{in^2}$	Liter Atmos-pheres	Centigrade Heat Units
Joules	**1**	0.23901	0.23885	9.4782×10^{-4}	2.7778×10^{-7}	3.7251×10^{-7}	0.73756	5.1220×10^{-3}	9.8692×10^{-3}	5.2657×10^{-4}
Calories	**4.184**	**1**	0.99933	3.9657×10^{-3}	1.1622×10^{-6}	1.5586×10^{-6}	3.0860	2.1430×10^{-2}	4.1293×10^{-2}	2.2031×10^{-3}
I. T. Calories	**4.1868**	1.0007	1	3.9683×10^{-3}	1.1630×10^{-6}	1.5596×10^{-6}	3.0880	2.1445×10^{-2}	4.1321×10^{-2}	2.2046×10^{-3}
British Thermal Units	1055.1	252.16	252.00	**1**	2.9307×10^{-4}	3.9301×10^{-4}	778.17	5.4040	10.413	0.55556
Kilowatt-Hours	**3.600×10^6**	8.6042×10^5	8.5985×10^5	3412.2	**1**	1.341	2.6552×10^6	18439	35529	1895.6
Horsepower-Hours	2.6845×10^6	6.4162×10^5	6.4119×10^5	2544.4	0.7457	**1**	1.9800×10^6	13750	26494	1413.6
Foot-Pounds [Force]	1.3558	0.32405	0.32383	1.2851×10^{-3}	3.7662×10^{-7}	5.0505×10^{-7}	**1**	6.9444×10^{-3}	1.3381×10^{-2}	7.1393×10^{-4}
ft3-lbf/in^2	195.24	46.663	46.632	0.18505	5.4233×10^{-5}	7.2727×10^{-5}	**144**	**1**	1.9268	0.10281
Liter Atmospheres	101.32	24.217	24.201	0.096038	2.8146×10^{-5}	3.7744×10^{-5}	74.733	0.51898	**1**	5.3354×10^{-2}
Centigrade Heat Units	1899.1	453.90	453.59	**1.8**	5.2753×10^{-4}	7.0743×10^{-4}	1400.7	9.7271	18.743	**1**

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Table 1A2.12 - Power Conversions

Units	Btu / min	Btu / hr	ft-lb / sec	ft-lb / min	Horse-power	Metric Horsepower	Watts	cal / sec	I.T. cal / sec
Btu / min	**1**	**60.00**	12.969	778.17	0.023581	0.023908	17.584	4.2027	4.1999
Btu / hr	0.016667	**1**	0.21616	12.969	3.9301×10^{-4}	3.9847×10^{-4}	0.29307	0.070046	0.069999
ft-lb / sec	7.7104×10^{-2}	4.6262	**1**	60.00	1.8182×10^{-3}	1.8434×10^{-3}	1.3558	0.32405	0.32383
ft-lb / min	1.2851×10^{-3}	0.077104	0.016667	**1**	3.0303×10^{-5}	3.0723×10^{-5}	0.022597	5.4008×10^{-3}	5.3972×10^{-3}
Horsepower	42.407	2544.4	**550**	**33000**	**1**	1.0139	745.70	178.23	178.11
Metric Horsepower	41.827	2509.6	542.48	32549	0.98632	**1**	735.50	175.79	175.67
Watts	0.056869	3.4121	0.73756	44.254	1.3410×10^{-3}	1.3596×10^{-3}	**1**	0.23901	0.23885
cal / sec	0.23794	14.276	3.0860	185.16	5.6108×10^{-3}	5.6887×10^{-3}	**4.1840**	**1**	0.99933
I.T. cal / sec	0.23810	14.286	3.0880	185.28	5.6146×10^{-3}	5.6925×10^{-3}	**4.1868**	1.0007	**1**

Table 1A2.13 - Specific Energy Conversions

Units	joules / g	cal / g	I.T. cal / g	Btu / lb
joules / g	**1**	0.23901	0.23885	0.42992
cal / g	**4.1840**	**1**	0.99933	1.7988
I.T. cal / g	**4.1868**	1.0007	**1**	1.8
Btu / lb	2.3260	0.55593	0.55556	**1**

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Table 1A2.14 – Specific Energy per Degree Conversions

Units	joules / g-K	cal / g-K	I.T. cal / g-K	Btu / lb-°F
joules / g-K	**1**	0.23901	0.23885	0.23885
cal / g-K	**4.1840**	**1**	0.99933	0.99933
I.T. cal / g-K	**4.1868**	1.0007	**1**	**1**
Btu / lb-°F	**4.1868**	1.0007	**1**	**1**

Table 1A2.15 – Heat Flux Conversions

Units	Btu / hr-ft^2	cal / sec-cm^2	kcal / hr-m^2	watts / cm^2	joules / sec-m^2
Btu / hr-ft^2	**1**	7.5397×10^{-5}	2.714	3.1546×10^{-4}	3.1546
cal / sec-cm^2	13263	**1**	36000	**4.1840**	**41840**
kcal / hr-m^2	0.3684	2.7778×10^{-5}	**1**	1.1622×10^{-4}	1.1622
watts / cm^2	3170.0	0.23901	8604.2	**1**	**10000**
joules / sec-m^2	0.31700	2.3901×10^{-5}	0.86042	$\mathbf{1 \times 10^{-4}}$	**1**

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Table 1A2.16 – Heat Transfer Coefficient Conversions

Units	$\frac{Btu}{hr\text{-}ft^2\text{-}^oF}$	$\frac{cal}{sec\text{-}cm^2\text{-}K}$	$\frac{kcal}{hr\text{-}m^2\text{-}K}$	$\frac{watts}{cm^2\text{-}K}$	$\frac{joules}{sec\text{-}m^2\text{-}K}$
$\frac{Btu}{hr\text{-}ft^2\text{-}^oF}$	**1**	1.3571×10^{-4}	4.8857	5.6783×10^{-4}	5.6783
$\frac{cal}{sec\text{-}m^2\text{-}K}$	7368.5	**1**	**36000**	**4.184**	**41840**
$\frac{kcal}{hr\text{-}m^2\text{-}K}$	0.20468	2.7778×10^{-5}	**1**	1.1622×10^{-4}	1.1622
$\frac{watts}{cm^2\text{-}K}$	1761.1	0.23901	8604.2	**1**	**10000**
$\frac{joules}{sec\text{-}m^2\text{-}K}$	0.17611	2.3901×10^{-5}	0.86042	$\mathbf{1 \times 10^{-4}}$	**1**

Table 1A2.17 – Thermal Conductivity Conversions

Units	$\frac{Btu}{hr\text{-}ft^2\text{-}^oF\text{ per in}}$	$\frac{Btu}{hr\text{-}ft^2\text{-}^oF\text{ per ft}}$	$\frac{cal}{sec\text{-}cm^2\text{-}K\text{ per cm}}$	$\frac{kcal}{hr\text{-}m^2\text{-}K\text{ per m}}$	$\frac{watts}{cm^2\text{-}K\text{ per cm}}$	$\frac{joules}{sec\text{-}m^2\text{-}K\text{ per m}}$
$\frac{Btu}{hr\text{-}ft^2\text{-}^oF\text{ per in}}$	**1**	0.08333	3.4471×10^{-4}	0.12410	1.4423×10^{-3}	0.14423
$\frac{Btu}{hr\text{-}ft^2\text{-}^oF\text{ per ft}}$	**12.000**	**1**	4.1366×10^{-3}	1.4892	0.017307	1.7307
$\frac{cal}{sec\text{-}cm^2\text{-}K\text{ per cm}}$	2901.0	241.75	**1**	**360**	**4.184**	**418.40**
$\frac{kcal}{hr\text{-}m^2\text{-}K\text{ per m}}$	8.0582	0.67152	2.7778×10^{-3}	**1**	0.011622	1.1622
$\frac{watts}{cm^2\text{-}K\text{ per cm}}$	693.35	57.779	0.23901	86.042	**1**	**100**
$\frac{joules}{sec\text{-}m^2\text{-}K\text{ per m}}$	6.9335	0.5778	2.3901×10^{-3}	0.86042	**0.01**	**1**

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1B Letter Symbols Used in Chemical Engineering

The letter symbols for the concepts most widely used in chemical engineering are listed in tables 1B1.1 (by category) and 1B1.2 (alphabetically). A letter symbol is a single letter used to represent a primary concept for a physical quantity, and it may be used with a subscript or superscript. A subscript may designate a place in space or time, a system of units, or a constant or reference value. A superscript may designate a dimensionless form, a reference or equilibrium value, a sequence in time or space, or a mathematical identification (average value, derivative, tensor index).

These lists have been adapted from the official tables of the American Institute of Chemical Engineers and of the American National Standards Institute. Suitable modifications have been made in the units to conform with the editorial policies of the American Petroleum Institute. Several additions have been made for symbols used frequently in this book. Listing is alphabetical by concept within each category. Illustrative units or definitions are supplied where appropriate.

Greek Alphabet

A	α	Alpha	I	ι	Iota	P	ρ	Rho
B	β	Beta	K	κ	Kappa	∑	σ	Sigma
Γ	γ	Gamma	Λ	λ	Lambda	T	τ	Tau
Δ	δ, ∂	Delta	M	μ	Mu	Y	υ	Upsilon
E	ε	Epsilon	N	ν	Nu	Φ	φ	Phi
Z	ζ	Zeta	Ξ	ξ	Xi	X	χ	Chi
H	η	Eta	O	ο	Omicron	Ψ	ψ	Psi
Θ	θ	Theta	Π	π	Pi	Ω	ω	Omega

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1B1 Letter Symbols for the Principal Concepts Used in Chemical Engineering

Table 1B1.1 Letter Symbols for the Principal Concepts Used in Chemical Engineering

General Symbols		Unit or Definition	General Symbols		Unit or Definition
Acceleration	a	ft per sec per sec	Newton law of motion,		$g_c = ma/F$
of gravity	g	ft per sec per sec	conversion factor	g_c	$(lb)(ft/s^2)/lbf$
Acentric factor	ω		Number		
Base of natural			in general	N	
logarithms	e		of moles	n	
Coefficient	C		Pressure	p	lbf/ft^2; atm
Difference, finite	Δ				lbf/in^2 (abs)
Differential operator	d		Quantity, in general	Q	
Partial	∂		Radius of gyration	$\overline{R}$	
Efficiency	η		Ratio, in general	R	
Energy, dimension	E	BTU; ft-lb [force]	Refractive index	n	
Enthalpy	H	BTU	Resistance	R	
Entropy	S	BTU per deg R	Shear stress	τ	lb [force] per sq ft
Force	F	lb [force]	Temperature		
Fugacity Coefficient	ϕ		absolute	T	K; deg R
Function	ϕ, ψ, χ		dimension of	θ	
Gas constant,			in general	T, t	deg C; deg F
universal	R	To distinguish, use R_o	Temperature difference,		
Gibbs free energy	G, F	$G = H - TS$, BTU	logarithmic mean	$\bar{\theta}$	deg F
Heat	Q	BTU	Time		
Helmholtz free energy	A	$A = U - TS$, BTU	dimension of	T	sec
Internal energy	U	BTU	in general	t, τ	sec; hr
Mass, dimension of	m	lb	Watson characterization		
Mechanical equivalent			factor	K	
of heat	J	ft-lb [force] per BTU	Work	W	Btu
Moment of inertia	I	$lb\text{-}ft^2$			

Geometric Property Symbols		Unit or Definition	Geometric Property Symbols		Unit or Definition
Angle	α, θ, ϕ		In general	A	sq ft
in x,y plane	α		Projected	A_P	sq ft
in y,z plane	ϕ		Surface		
in z,x plane	θ		per unit mass	A_w, s	sq ft per lb
solid angle	ω		per unit volume	A_v, a	sq ft per cu ft
Area			Linear dimension		
cross-section	S	sq ft	breadth	b	ft
fraction free cross-			diameter	D	ft
section	σ		distance along path	s, x	ft
Height above			mean free path	λ	cm; ft
datum plane	Z	ft	radius	r	ft
Height equivalent	H	ft (Use subscript p for	thickness		
		equilibrium stage and	in general	B	ft
		t for transfer unit)	of film	B_f	ft
Hydraulic radius	r_H	ft; sq ft per ft	wavelength	λ	cm; ft
Lateral distance from			Other		
datum plane	Y	ft	Particle-shape factor	ϕ_s	
Length, distance or			Volume		
dimension of	L	ft	Fraction voids	ε	
Longitudinal distance			Humid volume	v_H	cu ft per lb dry air
from datum plane	X	ft	In general	V	cu ft

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Table 1B1.1 Letter Symbols for the Principal Concepts used in Chemical Engineering (Continued)

Intensive Property Symbols		Unit or Definition	Intensive Property Symbols		Unit or Definition
Absorptivity for radiation	α		At constant volume	c_v	Btu/lb-°F
Activity	a		Heat capacities, ratio of	γ	
Activity coefficient, molar basis	γ		Helmholtz free energy	A	Btu/ lb
Coefficient of expansion			Humid heat	c_s	Btu /lb dry air-°F
Linear	α	ft per ft per deg F	Internal energy	U	Btu/lb
Volumetric	β	cu ft per cu ft per deg F	Latent heat, phase change	λ	Btu/lb
Compressibility factor	z	$z = pV/RT$	Molecular weight	MW	
Density	ρ	lb per cu ft	Reflectivity for radiation	ρ	
Diffusivity			Surface tension	σ	lb [force] per ft
Molecular, volumetric	D_v, δ	cu ft per (hr) (ft); sq ft per hr	Thermal conductivity	k	Btu/hr-ft^2-°F-ft
Thermal	α	α = k/cρ, sq ft per hr	Transmissivity of radiation	τ	
Emissivity ratio for radiation	ε				
Enthalpy	H	Btu per lb	Vapor pressure	p^*	lbf/ft^2; atm; lbf/in^2 (abs)
Entropy	S	Btu per (lb) (deg R)			
Fugacity	f	lb [force] per sq ft; atm	Viscosity		
Gibbs free energy	G, F	Btu per lb	Absolute or coefficient of	μ	lb per (sec) (ft)
Heat capacity	c	Btu per (lb) (deg F)	Kinematic	ν	sq ft per sec
at constant pressure	c_p	Btu per (lb) (deg F)	Volume, per mole	V	cu ft per lb-mole

Concentration Symbols		Unit or Definition	Concentration Symbols		Unit or Definition
Absorption factor	A	$A=L/KV$	Mole or mass fraction		
Concentration, mass or moles per unit volume	c	lb per cu ft; lb-moles per ft^3	In heavy or extract phase	X	
			In light or raffinate phase	y	
Fraction			Mole or mass ratio		
By volumes	x_v		In heavy or extract phase	X	
By weight	x_w		In light or raffinate phase	Y	
Cumulative beyond a given size	ϕ		Number concentration of particles	n_p	number per cu ft
Humidity	H, Y_H	lb per lb dry air	Phase equilibrium ratio	K	$K = y^*/x$
At adiabatic saturation temperature	H_a, Y_a	lb per lb dry air	Relative distribution of two components		
At saturation	H_s, Y^*	lb per lb dry air	Between two phases in equilibrium	α	$\alpha = K_i/K_j$
At wet-bulb temperature	H_w, Y_w	lb per lb dry air	Between successive stages	β	$\beta_n = \frac{(y_i/y_j)_n}{(x_j/x_i)_{n+1}}$
Mass concentration of particles	c_p	lb per cu ft	Relative humidity	H_R, R_H	
Moisture content			Slope of equilibrium curve	m	$m = dy^*/dx$
Equilibrium water to bone dry stock	X^*	lb per lb dry stock	Stripping factor	S	$S=KV/L$
Free water to bone dry stock	X	lb per lb dry stock			
Total water to bone dry stock	X_T	lb per lb dry stock			

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Table 1B1.1 Letter Symbols for the Principal Concepts used in Chemical Engineering (Continued)

Rate Concept Symbols		Unit or Definition	Rate Concept Symbols		Unit or Definition
Mass transfer coefficient			Quantity per unit time, unit area		
Individual	k	lb-moles per (hr) (ft^2) (driving force)	Emissive power, total	W	Btu per (hr) (ft^2)
			Mass velocity, average	G	G = w/S, lb per (sec)(ft^2)
Gas film	k_G	To define driving force,	Vapor or light phase	$G, \overline{G}$	lb per (hr) (ft^2)
Liquid film	k_L	use subscript:	Liquid or heavy phase	$L, \overline{L}$	lb per (hr) (ft^2)
Overall	K	*c* for lb-moles per cu ft	Radiation, intensity of	I	Btu per (hr) (ft^2)
Gas film basis	K_G	*p* for atm	Velocity		
Liquid film basis	K_L	*x* for mole fraction	Nominal, basis total cross-section of packed vessel	v_s	ft per sec
Quantity per unit time in general	q		Volumetric average	$V, \overline{V}$	(ft^3) per (sec) (ft^2); ft per sec
Angular velocity	ω		Quantity per unit time, unit volume		
Feed rate	F	lb per hr; lb-moles per hr			
Frequency	f, N_f		Quantity reacted per unit time, reactor volume	N_R	mole per (sec) (cu ft)
Friction velocity	u^*	$u^* = (g_c \tau_w \rho)^{1/2}$, ft per sec			
Heat transfer rate	q	Btu per hr	Space velocity, volumetric	Λ	cu ft per (sec) (cu ft)
Heavy of extract phase rate	L	lb per hr; lb-moles per hr	Quantity per unit time, unit area, unit driving force, in general	k	
Heavy or extract product rate	B	lb per hr; lb-moles per hr			
Light or raffinate phase rate	V	lb per hr; lb-moles per hr	Eddy diffusivity	δ_E	(ft^2) per hr
Light or raffinate product rate	D	lb per hr; lb-moles per hr	Eddy viscosity	v_E	(ft^2) per hr
Mass rate of flow	w	lb per sec; lb per hr	Eddy thermal diffusivity	α_E	(ft^2) per hr
Molar rate of transfer	N	lb-moles per hr	Heat transfer coefficient		
Power	P	ft-lb [force] per sec	Individual	H	Btu per (hr) (ft^2) (°F)
Revolutions per unit time	n		Overall	U	Btu per (hr) (ft^2) (°F)
Velocity, in general	u	ft per sec	Stefan-Boltzmann constant	σ	0.173×10^{-8} Btu per (hr) (ft^2) ($°R)^4$
Instantaneous local					
Longitudinal (x) component of	u	ft per sec			
Lateral (y) component of	v	ft per sec			
Normal (z) component of	w	ft per sec			
Volumetric rate of flow	q	cu ft per sec; cu ft per hr			

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Table 1B1.2 - Alphabetical Index of Symbols Used in Chemical Engineering

Primary Concept		Subscript Concept
a	Acceleration	Acoustic
	Activity	Adiabatic
	Area, alternate for surface per unit volume	Arithmetic
A	Absorption factor	Absolute
	Area	Area Basis
	Helmholtz free energy	Component A
b	Breadth	Baffle
		Base
		Normal boiling point
B	Heavy product rate	Black body
	Thickness	Boiling point
		Component B
c	Concentration, mass or moles per unit volume	Concentration basis
		Contraction
	Specific heat, heat capacity	Conversion factor
		Critical
		Cutoff size
C	Coefficient	Component C
d	Differential operation	Discharge
		Disperse
		Drop
		Dry
D	Diameter	Component D
	Diffusivity	Distillate
	Light or raffinate product rate	
e	Base of natural logarithms	Effective
		Exit
E	Energy	Component E
	Dimension of	Eddy
	In general	Entrainment
f	Frequency	Film
	Fanning friction factor	Fluid
	Fugacity	Frequency
		Friction
F	Feed rate	Feed
	Force	
g	Acceleration of gravity	Gage
		Gravity
		Vapor
G	Gibbs free energy	Vapor
	Mass velocity, Vapor in general	Vapor film basis
h	Individual coefficient	Heat
	of heat transfer	Heated
H	Enthalpy	Heat basis
	Height equivalent	Humidity
	Humidity	Hydraulic
i		Generalized component
		Interface
		Internal or inner
I	Intensity of radiation	
	Moment of inertia	
j	Transfer factor	Generalized component
J	Mechanical equiv. of heat	
k	Mass transfer coefficient, individual	
	Quantity per unit time, unit area, unit driving force, in general	
	Thermal conductivity	
K	Watson characterization factor	
	Overall mass transfer coefficient	
	Phase concentration ratio	
L	Heavy or extract phase rate	Liquid
	Length	Liquid film basis
	Mass velocity of liquid or heavy phase	
m	Mass	Mass
	Dimension of, in general	Mean
	Slope of equilibrium curve	
M		Mass basis
		Molecular
MW	Molecular weight	
n	Number concentration	Generalized stage
	Number of moles	Number
	Refractive index	
	Revolutions per unit time	
N	Molar rate	
	Number, in general	
o		Initial
		Outer
O		Overall
p	Pressure	Constant pressure
		Particle
		Plate or stages
		Pressure basis
		Projected
P	Power	
pc		Pseudocritical
q	Quantity per unit time in general	Rate basis
	Rate of heat flow	
	Rate of volumetric flow	

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Table 1B1.2 - Alphabetical Index of Symbols Used in Chemical Engineering (Continued)

Primary Concept		Subscript Concept	Primary Concept		Subscript Concept
Q	Heat		α	Absorptivity for radiation	
	Quantity, in general			Angle	
r	Radius	Radius or radial		Angle in x, y plane	
		Reduced		Coefficient of linear expansion	
R	Gas constant	Radiation		Relative distribution of two components between two phases at equilibrium	
	Ratio, in general	Reactor volume basis			
	Reflux ratio	Relative value			
	Resistance			Thermal diffusivity	
$\overline{R}$	Radius of gyration		β	Coefficient of volumetric expansion	
s	Distance along path	Saturation			
	Specific surface	Shape		Relative distribution of two components between successive stages	
		Stress			
		Surface basis			
S	Cross-section	Cross-section basis	γ	Activity coefficient, molar basis	
	Entropy	Solid			
	Stripping factor	Solvent		Ratio of heat capacities	
t	Temperature	Tangential	∂	Differential operator, partial	
	Time	Terminal	δ	Diffusivity, volumetric	Film basis
		Transfer unit or units	Δ	Difference, finite	
T	Absolute temperature	Constant temperature	ε	Emissivity ratio for radiation	
	Temperature, in general	Total		Fraction voids	
u	Longitudinal component of local velocity	Upper	η	Efficiency	
			θ	Angle	
	Velocity, in general			Angle in z, x plane	
U	Heat transfer coefficient, overall			Temperature, dimension of	
	Internal energy		$\overline{\theta}$	Log mean temperature difference	
v	Lateral component of local velocity	Constant volume			
		Velocity basis	λ	Latent heat of phase change	
	Nominal velocity	Volumetric		Mean free path	
	Specific volume			Wavelength	
V	Light or raffinate phase rate	Vapor	Λ	Volumetric space velocity	At constant viscosity
	Volume, in general		μ	Viscosity, absolute	
	Volumetric average velocity		ν	Viscosity, kinematic	
w	Mass flow rate	Mass basis	ρ	Density	Density basis
	Normal component of local velocity	Wet bulb		Reflectivity for radiation	
			σ	Fraction free cross-section	
W	Work			Stefan-Boltzmann constant	
	Total emissive power			Surface tension	
x	Distance along path	Mole fraction basis	τ	Shear stress	
	Fraction			Time, alternate for	
	Mole or mass fraction in heavy or extract phase			Transmissivity for radiation	
			Φ	Angle	
X	Longitudinal distance from datum plane	Mole ratio basis		Angle in y, z plane	
				Fraction cumulative, larger than a given size	
	Mole or mass ratio in heavy or extract phase			Particle factor	
y	Mole or mass fraction in light or raffinate phase			Function	
				Fugacity coefficient	
Y	Humidity			Particle factor	
	Lateral distance from datum plane		χ	Function	
			ψ	Function	
Y	Mass or mole ratio in light or raffinate phase		ω	Acentric factor	
				Angular frequency	
z	Compressibility factor			Angular velocity	
Z	Height above datum plane			Solid angle	

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1C Property Definitions

A list of physical properties in the API Technical Data Book as well as a definition of the property and any other pertinent information follows.

Acentric Factor

The acentric factor is calculated from the definition:

$$\omega = -\log(p_r^*) - 1.000$$

Where:

p_r^* = reduced pressure, p^*/p_c

p^* = vapor pressure at T = 0.7 Tc, in psia

p_c = critical pressure in psia

T = temperature, °R

T_c = critical temperature, °R

When vapor pressure data were not available at T, = 0.7, Procedure 2A1.1 was used. Further information on the acentric factor is given in Chapter 2.

Aniline Point

The aniline point of a petroleum product is the critical solution temperature of a mixture of equal volumes of aniline and the hydrocarbon. It is the lowest temperature at which a petroleum product is completely miscible with an equal volume of freshly distilled aniline.

ASTM Octane Numbers

The octane number of a motor fuel indicates its relative tendency to knock under specified conditions of laboratory engine operation. It is equal to the percentage of iso-octane in the reference fuel whose knock characteristics equal those of the sample under test.

Octane numbers are reported for both the motor method and the research method of testing.

Boiling Point

The normal boiling point of a liquid is defined as the temperature at which its vapor pressure is equal to one atmospheric pressure in °F.

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Chemical Formula

The chemical formula is listed as defined by DIPPR (8, 52, 53).

Coefficient of Expansion

The coefficient of expansion is calculated by the definition:

$$\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$$

Values are reported at 60 °F in units of (°F) $^{-1}$

Compound Name

The compound name or component name is listed by “Common Name” name convention as defined by DIPPR (8, 52, 53).

Critical Properties

The conditions of equilibrium for coexisting vapor and liquid phases of a pure substance are defined on a pressure-temperature diagram by the vapor pressure curve. This curve starts at the triple point, where vapor, liquid, and solid phases are in equilibrium, and ends at the critical point. As the critical point is approached by the coexisting phases, their properties approach each other until they become identical at the critical temperature and pressure, where a single homogeneous phase is present.

Values of critical temperature in degrees Fahrenheit, pressure in pounds per square inch absolute, volume in cubic feet per pound, and compressibility factor are given. Further information on critical properties is given in Chapter 4.

Density of Liquids

$$specific\ gravity, 60\ °\mathrm{F}/60\ °\mathrm{F} = \frac{\rho(60\ °\mathrm{F}, lb/gal)}{\rho(water, 60\ °\mathrm{F}, lb/gal)}$$

$$sp\ gr = \frac{\rho(60\ °\mathrm{F}, lb/gal)}{8.33718}$$

Where:

ρ = liquid density

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Liquid densities at 60 °F are given in pounds per gallon at one atmosphere when 60 °F is below the normal boiling point or at saturation pressure when 60 °F is at or above the normal boiling point. For compounds that are solid at 60 °F, the liquid density is the liquid value extrapolated back to 60 °F.

Densities at other temperatures can be calculated from the density at 60 °F by

$$\rho\,(T\ deg\ F) = \frac{\rho\,(60\ °\mathrm{F})}{1 + \left[\frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P (T - 60)\right]}$$

Where:

T = *temperature, in degrees Fahrenheit.*

$\frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$ = *coefficient of expansion, in degrees Fahrenheit.*

API gravity is defined as:

$$deg\ API = \frac{141.5}{sp\ gr} - 131.5$$

Further information on liquid density is given in Chapter 6.

Description	Symbol	SI (kg/m^3)	US Customary [a] (lb/gal)
Density at 60 °F (15.5556 °C)	$\rho_{w,60}$	999.016	8.337 19
Density at 15 °C (59 °F)	$\rho_{w,15}$	999.102	8.337 91
Density at 20 °C (68 °F)	$\rho_{w,20}$	998.206	8.330 43

Dielectric Constant

The dielectric constant is the ratio of the permittivity of the dielectric to the permittivity of a vacuum. An alternative definition is the ratio of the capacitance of a capacitor containing the dielectric to that of an identical but empty capacitor.

Flammability Limits

Lower and upper limits of flammability are reported as volume percent in a mixture with air.

When experimental data were not available, lower flammability limits were predicted by the method of Shebeko et al. (36), and upper flammability limits were predicted by the DIPPR Compilation method (8, 52, 53).

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Flash Point Temperature

The flash point of a liquid or solid is the lowest temperature at which sufficient vapor is given off through evaporation or sublimation to form an ignitable mixture with the air near the surface of the liquid or in the vessel used.

Freezing Point

The temperature at which a substance changes from liquid phase to solid phase at 1 atmosphere pressure.

Gibbs Free Energy of Formation

The Gibbs free energy of formation for the ideal gas state is reported at 77 °F in units Btu/lb.

Heat Capacity of the Liquid and Gas

Heat capacities at constant pressure are reported for the liquid and ideal gas at 60 °F and 1 atm pressure. These are related to the enthalpy by:

$$C_P = \left(\frac{\partial H}{\partial T}\right)_P$$

The observed heat capacity for a saturated liquid or vapor is C_s. This may be converted to the heat capacity at constant pressure by:

$$C_P = T\left(\frac{\partial V}{\partial T}\right)_P \frac{dp^*}{dT} + C_s$$

Where:

dp/dT* = *the temperature derivative of the vapor pressure, in pounds per square inch absolute per °R.*

When values of the ideal gas heat capacity calculated from spectroscopic data were not available, they were predicted by the second order method of Benson using the CHETAH program (31). Heat capacities are reported in units of British thermal units per pound degree F. For compounds where the normal boiling point is below 60 °F, liquid heat capacity is reported at the saturation pressure. Further information on heat capacity is given in Chapter 7.

Heat of Formation

Heat of formation of a hydrocarbon C_aH_b in the ideal gas state is reported at 77 °F in units of Btu/lb. Heats of formation of the hydrocarbon in the liquid state are related to those in the ideal gas state by the following equation:

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$$\Delta H_f^{liq}(Btu/lb) = \Delta H_f^{gas}(Btu/lb) - \lambda(Btu/lb)$$

Where:

λ = *the heat of vaporization at 77 °F*

To derive a liquid heat of formation of a hydrocarbon, C_aH_b, from a heat of combustion, the following equations, which neglect pressure corrections, can be used:

$$\Delta H_f^{liq}(Btu/lb) = \Delta H_c(net, Btu/lb) + a\frac{MW(CO_2)}{MW(C_aH_b)}\Delta H_f(CO_2, gas) + \frac{b}{2}\frac{MW(H_2O)}{MW(C_aH_b)}\Delta H_f(H_2O, gas)$$

$$\Delta H_f^{liq}(Btu/lb) = \Delta H_c(net, Btu/lb) + a\frac{(44)(-3844.28)}{MW(C_aH_b)} + \frac{b}{2}\frac{(18)(-5770.9)}{MW(C_aH_b)}$$

ΔH_c	*= net heat of combustion, in Btu/lb*
MW	*= molecular weight, in lb/lb-mol*
ΔH_f	*= heat of formation at 77 ° F.*
–3844.28 Btu/lb	*= heat of formation of CO_2 gas, in Btu/lb.*
–5770.9	*= heat of formation of H_2O gas, in Btu/lb (20).*

The heats of formation of nonhydrocarbons are obtained using the same techniques with standard products of combustion as given earlier. Values are taken from DIPPR Compilation where available. For compounds where heats of formation were not derived from experimental data, heats of formation were predicted by the second order method of Benson using the CHETAH program (31).

Heat of Fusion

The heat of fusion, reported at the melting point, is the heat required to convert a substance from the solid phase to the liquid phase at 1 atmosphere pressure.

Heat of Vaporization

The heat of vaporization λ, is defined as the enthalpy of the real gas at the equilibrium vapor pressure, minus the enthalpy of the liquid at the same pressure and temperature. When experimental data were not available, λ was predicted at the normal boiling point by the Clapeyron Equation:

$$\lambda = \left(\frac{dP^*}{dT}\right)T\left(V_g - V_L\right)(144/778)$$

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Where:

λ	=	*latent heat of vaporization, in Btu/lb*
p^*	=	*pure substance vapor pressure, in psia*
T	=	*temperature, in °R*
V_g	=	*specific volume of saturated vapor, in ft3/lb*
V_L	=	*specific volume of saturated liquid, in ft3/lb*
(144/778)	=	*conversion factor*

Further information on heat of vaporization is given in Chapter 7.

Molecular Weight

The molecular weight (MW) reported is based on IUPAC "Atomic Weights of the Elements," 1986 (102).

Net Heat of Combustion of the Liquid

Hydrocarbons:

The net heat of combustion at 77 °F, ΔH_c, is the change in enthalpy for the reaction:

$$C_aH_b(\text{liquid, 77 °F, 1 atm}) + (a+b/4)\ O_2(\text{gas, 77 °F, 1 atm}) =$$

$$a\ CO_2\ (\text{gas, 77 °F, 1 atm}) + (b/2)\ H_2O(\text{gas, 77 °F, 1 atm})$$

Net heat of combustion is related to gross heat of combustion by the relationship:

$$\Delta H_c\ (net, Btu/lb) = \Delta H_c\ (gross, Btu/lb) - \left(\frac{b}{2}\right) * \lambda_w \frac{MW(H_2O)}{MW(C_aH_b)}$$

Where:

λ_w	=	*heat of vaporization of water at 77 °F and saturation pressure = 1,050.0 Btu/lb (20).*

For compounds which are gaseous at 77 °F and 1 atm (i.e., C_1 to C_4 hydrocarbons), the net heat of combustion of the vapor is given. This is related to the net heat of combustion of the liquid as follows:

$$\Delta H_c\ (vapor) = \Delta H_c\ (liquid) + \lambda$$

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Where:

λ = *heat of vaporization at 77 °F, in Btu/lb.*

Nonhydrocarbons:

For nonhydrocarbons, the standard combustion products are:

CO_2 (gas)

H_2O (gas)

F_2 (gas)

Cl_2 (gas)

Br_2 (gas)

I_2 (gas)

SO_2 (gas)

N_2 (gas)

For compounds where the heat of formation was not available, the net heat of formation was predicted by the second order method of Benson using the CHETAH program (31) after which the heat of combustion as calculated from the definition.

The heat of combustion is defined as heat evolved, therefore, the values for heat of combustion that are reported are positive. Further information on heat of combustion is given in Chapter 14.

Refractive Index of Liquids

Values of the refractive index, n_D, of the air saturated hydrocarbon relative to air at the sodium D-line (5892.6A) are reported at 77 °F.

Solubility Parameter

The solubility parameter is defined by

$$\delta = \left(\frac{\Delta U^{vap}}{\underline{V^L}} \right)^{1/2}$$

Where:

ΔU^{vap} = *internal energy change on vaporization to the ideal gas, in cal/mol*

$\underline{V^L}$ = *liquid molar volume at 25 °C, in cm^3/mole*

An approximation of the internal energy change yields:

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$$\delta = \left(\frac{\lambda - RT}{\underline{V^L}}\right)^{1/2}$$

Where:

λ	=	*heat of vaporization at 25 ℃, in cal/mole*
$\underline{V^L}$	=	*liquid molar volume at 25 ℃, in cm^3/mole*
R	=	*gas constant = 1.9872 cal/mole-K*
T	=	*absolute temperature, 298.15 K*

The above equation was used to calculate solubility parameters in units of (cal/cm^3)$^{1/2}$.

Specific Gravity

Specific gravity is the ratio of the density at 60 °F relative to water at 60 °F.

Surface Tension

Surface tension is the tension exhibited by the free surface of a liquid. The liquid surface tension at 77 °F is reported in units of dynes per centimeter. Further information on surface tension is given in Chapter 10.

Vapor Pressure

Vapor pressure is the pressure at which the vapor phase of a substance is in equilibrium with the liquid phase of that substance at a specified temperature. Values of vapor pressure at 100 degrees °F are reported in units of pounds per square inch absolute. Further information on vapor pressure is given in Chapter 5.

Viscosity of Liquids

The kinematic viscosity in centistokes is reported at 100 °F and 210 °F and 1 atmosphere pressure. The kinematic viscosity, *v*, is related to the absolute viscosity, μ, by:

$$v\ (stokes) = \frac{\mu\ (poise)}{\rho\ (gm/cu\ cm)}$$

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Where:

ρ = *liquid density.*

Further information on viscosity is given in Chapter 11.

Watson K Factor

The Watson characterization factor, K, is defined by the equation:

$$K = \frac{(MeABP)^{1/3}}{SG}$$

Where MeABP must be in °R and SG is the relative density at 60 °F relative to water at 60 °F.

Further information on the Watson characterization factor is given in Chapter 2.

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Table 1C1.1 illustrates the 35 pure component properties that are available in a complimentary datasheet named “TDB-1 Datasheet” for over 850 components. The data is sorted by both component name and pure component property. Data references are given in the datasheet and data type information is also given. The data was taken from Chapter 1 API Technical Data Book 1997

Table 1C1.1

Name		METHANE			ETHANE			PROPANE			n-BUTANE			ISOBUTANE		
API ID		1			2			3			4			5		
Formula		CH4			C2H6			C3H8			C4H10			C4H10		
Class		n-Paraffins			n-Paraffins			n-Paraffins			n-Paraffins			i-Isoparaffin		
	Units	value	ref.	type	value	ref.	type	value	ref.	type	value	ref.	type	value	ref.	type
Molecular Weight	lb/lbmol	16.043	82B	D	30.069	82B	D	44.096	102	D	58.123	102	D	58.123	102	D
Critical Temperature	°F	-116.67	82B	X	90.09	82B	X	205.97	82B	X	305.58	82B	X	274.46	82	X
Critical Pressure	psia	666.7	82B	X	707.8	82B	X	615.0	82B	X	548.8	82B	X	527.9	82	X
Critical Volume	ft^3/lb	0.09907	50A	X	0.07877	50A	X	0.07458	50A	X	0.07041	50A	X	0.07194	50A	X
Critical Compressibility		0.288	(P)	D	0.284	(P)	D	0.280	(P)	D	0.274	(P)	D	0.282	(P)	D
Solubility Parameter at 77 °F	$(cal/cm^3)^{0.5}$	5.680	50A	D	6.050	50A	D	6.400	50A	D	7.066	50A	D	6.146	50A	D
Normal Boiling Point	°F	-258.73	82B	X	-127.49	82	X	-43.75	82	X	31.08	82	X	10.78	82	X
Acentric Factor		0.01115	50A	D	0.09896	(P)	D	0.14985	50A	D	0.19769	50A	D	0.17702	(P)	D
Melting Point at 1 atm	°F	-296.44	82B	Z	-297.25	50A	Z	-305.77	50A	E	-217.05	82	X	-255.28	82	X
Ideal Gas Heat of Formation 77°F	BTU/lb	-2008.7	50A	X	-1203.8	50A	X	-1018.9	50A	X	-932.6	50A	X	-997.0	50A	X
Ideal Gas Gibbs Free Energy of Formation 77°F	BTU/lb	-1362.0	50A	X	-460.4	50A	X	-234.6	50A	X	-123.8	50A	X	-156.0	50A	X
Heat of Fusion at 77°F	BTU/lb	25.127	50A	X	30.090	50A	X	34.332	50A	X	34.550	50A	X	33.651	50A	X
Net Heat of Combustion of Lquid 77 °F	BTU/lb	21530.7	50A	Y	20469.9	50A	Y	19966.2	50A	Y	19693.8	50A	Y	19633.0	50A	Y
Refractive Index at 77 °F		1.0004	181	X	1.1849	50A	X	1.2861	50A	X	1.3293	50A	X	1.3345	50A	X
Flash Point Temperature	°F	N/A			N/A			N/A			N/A			N/A		
Lower Flammability Limit, % Vol in Air		5	82	X	3	82	X	2	82	X	2	82	X	2	82	X
Upper Flammability Limit, % Vol in Air		15	82	X	13	82	X	10	82	X	9	82	X	9	82	X
Vapor Pressure at 100 °F	psia	5000	82	Z	800	82	Z	189	82	X	52	82	X	73	82	X
Liquid Heat Capacity 60°F, 1 atm	BTU/(lb °F)	N/A			0.9723	82	Z	0.6200	82	X	0.5701	50	X	0.5707	82	X
Ideal Gas Heat Capacity 60°F, 1 atm	BTU/(lb °F)	0.5267	82	X	0.4078	82	X	0.3885	82	X	0.3950	82	X	0.3867	82	X
Specific Gravity at 60/60 °F		0.2999	50A	D	0.3562	50A	D	0.5070	50A	D	0.5840	(P)	D	0.5629	50A	D
API Gravity at 60 °F		340.38	50A	D	265.76	50A	D	147.60	50A	D	110.79	(P)	D	119.89	50A	D
Liquid Density at 60 °F	lb/ft^3	18.701	82	Z	22.214	82	F	31.619	82	F	36.423	82	F	35.104	82	F
Liquid Kinematic Viscsity 100 °F	cSt	N/A			N/A			0.1864	50A	T	0.2662	50A	T	0.2845	50A	T
Liquid Kinematic Viscsity 210 °F	cSt	N/A			N/A			N/A			0.1452	50A	T	0.1561	50A	T
Heat of Vaporization at NBP	BTU/lb	219.45	82	X	211.14	82	X	183.01	82	X	165.93	82	X	157.23	82	X
Surface Tension at 77 °F	dyne/cm	N/A			0.54	233		7.03	189	T	11.89	189	T	9.83	189	T
Coefficient of Expansion at 60 °F	1/°F	N/A			N/A			0.00152	51	E	0.00117	51	X	0.00119	51	X
Dielectric Constant		1.6	234		1.33	234		1.67	234		1.77	234		1.75	234	
Aniline Point	°F	N/A			N/A			N/A			181.6	51	X	225.7	51	X
Octane Number (Motor) D357		N/A			+ 0.1	82	K	97.1	82	X	89.6	82		97.6	82	
3 ml TEL per gallon		N/A			N/A			N/A			+ 0.4	51	K	N/A		
Octane Number (Research) D908		N/A			+ 1.6	82	K	+ 1.8	82	K	93.8	82		+ 0.1	82	K
3 ml TEL per gallon		N/A			N/A			N/A			+ 0.4	51	K	N/A		
Watson K Factor		19.53	50A	D	19.44	(P)	D	14.72	50A	D	13.51	50A	D	13.82	50A	D

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Data Type

B = Pseudocritical value.
C = Absolute values from weights in vacuum.
D = Calculated from the definition.
E = At saturation pressure (triple point).
F = At saturation pressure and 60 F.
G = At boiling point.
H = Critical solution temperature instead of aniline point.
J = Evaluated at -148 F.
K = The + sign and the number following signify that the octane number of the compound corresponds to that of 2,2,4-trimethylpentane with the indicated number of milliliters of tetraethyl lead added.
L = Evaluated at -54 F.
M = Evaluated at -193.3 F.
N = Too volatile to run as a liquid in the CFR engine.
P = Predicted.
Q = Specific gravity - 119.2 F/60 F (sublimation point).
R = For the undercooled liquid below the normal freezing point.
S = Unknown whether predicted or experimental.
T = Extrapolated.
U = Evaluated at -13.27 F.
V = Predicted and extrapolated. W = Sublimation temperature.
Y = Net heat of combustion of the gas.
Z = Estimated value.
a= Net heat of combustion of the solid.

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{Insert Addendum HERE}

Annex A

Development Summary

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First Edition (1966)

The preparation of the First Edition of the API Technical Data Book covered a period of more than four years from 1959 to 1964. During that time, the work of the Penn State staff, led by the late Dr. M. R. Fenske, Dr. W. G. Braun, and Mr. W. H. Thompson, was guided and coordinated by the API Subcommittee on Technical Data with assistance from the Contractors' Advisory Subcommittee, under the sponsorship of the API Refining Department. [For more details, see A. S. Lehmann, "API Technical Data Book Project," *Proc.* AP144(III) 278 (1964). The general pattern followed by Penn State in preparing each phase of each section of the book is outlined below:

The literature was searched for pertinent data and correlations. When there were many applicable correlations, some were eliminated from further consideration on the basis of such factors as complexity, lack of generality, failure to be internally consistent, and available of improved forms.

A set of data was assembled for comparison with the predictions of the correlations. The correlations were evaluated for accuracy, generality, ease of use and other characteristics. The evaluation results, conclusions and recommendations were reported to the subcommittees for review. Occasionally, reevaluations or further checking was performed, based on comments from the reviewers.

The recommended data and correlations, along with descriptive comments, were prepared in final form for subcommittee review. The draft chapters were modified to satisfy reviewers' criticisms and were submitted for publication. As implied, no attempt was made to develop new correlations for the First Edition of the API Technical Data Book.

During the literature searches, approximately 10,000 articles were reviewed. Of these, 3000 were useful enough to include in reports, and approximately 750 are cited in the book. Four bibliographies of data were prepared and published as incidental by-products of this effort:

Fenske, M. R., Braun, W. G., Holmes, A. S., *Bibliography of Vapor-Liquid Equilibrium Data for Hydrocarbon Systems Bibliography No. 1,* Am Petrol. Inst., New York (1963).

Holmes, A. S., Braun, W. G., Fenske, M. R., *Bibliography of Vapor Pressure Data for Hydrocarbons, Bibliography No. 2,* Am. Petrol. Inst., New York (1964).

Jeter, L. T., Thompson, W. H., Braun, W. G., Fenske, M. R., *Bibliography of Volumetric and Thermodynamic Data for Pure Hydrocarbons and Their Mixtures, Bibliography No. 3,* Am. Petrol. Inst., New York (1964).

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Wilson, R. F., Thompson, W. H., Braun, W. G., Fenske, M. R., *Bibliography of Vapor-Liquid Equilibrium Data for Hydrocarbon-Nonhydrocarbon Gas Systems, Bibliography No. 4,* Am Petrol. Inst., New York (1964).

These bibliographies, documentation reports (see below), and the tables of data issued by API Research Project *44* extended the usefulness of this book to unusual hydrocarbons and systems.

One of the most difficult tasks was narrowing the evaluations to reasonable sizes, consistent with the importance of the property under consideration and the available time and funds. It was neither possible nor justifiable, for example, to examine in detail more than 80 correlations that are available for the vapor pressure or the heat of vaporization of pure hydrocarbons. For many properties, extensive databases have been assembled.

Selecting a single method for use with all hydrocarbons at all temperatures and pressures was often difficult because different correlations normally excelled in different areas. Furthermore, the results of error analyses were occasionally complicated, for example, when different correlations were applicable to different groups of data points and the difficulty of the non-common points varied. If only common data points were compared, the set was usually so small and restricted that the effects of temperature, pressure, system, and/or hydrocarbon type could not be studied. The intangible criteria of generality and ease of use were always considered, along with the more concrete error analysis results.

Although there were usually too many applicable correlations, occasionally none were available for technically important circumstances. Notable examples of this are correlations for mixtures containing hydrogen or high concentrations of unsaturated or aromatic hydrocarbons. Methods are given for these mixtures, but data were rarely available to confirm the methods' validity.

After the evaluations were completed, the results and recommendations were reported to the subcommittee members in 85 different documents, including 29 formal reports. Fourteen more formal reports were draft chapters, which contained draft copies of the figures in the *Technical Data Book.* Most figures had previously been redrawn from their original sources to unify style, to make them more convenient and useful for a quantitative application, and in some cases, to correct errors. Comments from the subcommittee members resulted in the elimination of many troublesome errors and obstacles for the inexperienced user.

After the publication of the *Technical Data Book,* the American Petroleum Institute made Documentation Report Nos. 2-66 through 14-66 to holders of the book. These reports are an organization of the evaluation reports and document the selection of the correlations in this data book on a chapter-by-chapter basis. In addition to providing answers to many questions about the selection of the contents of the data book, the information was useful in estimating the reliability of the various correlations in specific situations. These reports are now unavailable.

The extensive literature surveys, correlation evaluations and the review procedure outlined above make this data book the most complete and reliable work yet compiled specifically for general use in the evaluation of petroleum refining processing and related equipment.

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The direct product of the work described above is, of course, the data book. The project also resulted in partial or total support for a number of undergraduate and graduate students and for professional staff. Many of the students have completed their academic work and have since entered industry, and an unusually large proportion have entered the petroleum industry. All have an increased understanding of and sympathy for the problems of the petroleum industry.

Second Edition (1970)

Since the literature search for the First Edition was completed, a large number of new correlations and an even larger amount of experimental data of potential use in the *Technical Data Book* have appeared in the open literature. This information prompted further studies, also supported by the American Petroleum Institute as a vital part of its continuing program to provide the best current data and correlations for the practicing engineer, which ultimately resulted in publication of the second and third editions.

Revisions for the Second Edition, published in 1970, were made in Chapters 1, 7, 8, 9, and 11. In Chapter 1, the physical property tables of the C_1-C_{10} hydrocarbons were extensively revised based on the changes in, or additions to, the tables of API Research Project 44. Also included were tables for the physical properties of biphenyls, diphenyls, tetrahydronaphthalenes, and decahydronaphthalenes. In Chapter 7, the tables of coefficients for the calculations of ideal gas enthalpies, the enthalpy-temperature diagrams, and the enthalpy-entropy diagrams for methane, ethane, propane, and ethene were revised. In Chapter 8, material was added on the solubility of gases in water and the water content of natural gases. Chapters 9 and 11 concerning water-hydrocarbon phase equilibria and viscosity, respectively, were completely revised.

The numerical solutions of all of the example problems in the book were changed to reflect the revisions of the properties that were made in Chapter 1. Inadvertent errors in chapters, which were listed in Revision Sheet 1 (July 1, 1967) and Revision Sheet 2 (December 1, 1969), were corrected.

Third Edition (1976)

For the Third Edition, published in 1976, Chapters 4, 6, and 7 were completely revised, and necessary changes were made in Chapters 1 and 2. Chapter 4 was expanded in 1974 to include procedures to calculate critical properties for all types of hydrocarbon systems. Chapter 6, as revised in 1972, included new methods for saturated liquid densities for pure hydrocarbons, defined hydrocarbon mixtures, and non-hydrocarbons. In the 1976 publication, the vapor density section of Chapter 6 and all of Chapter 7 were revised. Vapor densities and thermodynamic properties for pure hydrocarbons and defined hydrocarbon mixtures were all predicted by the modified Pitzer corresponding-states method of Lee and Kesler. Desk and computer methods were made consistent. New methods for predicting thermodynamic properties of petroleum fractions were included that use the methods of Chapter 4 to predict critical properties. The acentric factors of Chapter 2 were revised for consistency with Chapters 6 and 7. Certain properties in Chapter 1, as revised by API Research Project 44, were updated.

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Fourth Edition (1982)

For the Fourth Edition, Chapter 5 on vapor pressure, Chapter 8 on vapor-liquid equilibria, Chapter 12 on thermal conductivity, and Chapter 13 on diffusivity were completely revised, with a large amount of new material added. Chapter 2 on characterization and Chapter 3 on distillation relationships were partially revised with new procedures for estimating properties. Chapter 4 on critical properties was updated. Chapter 9 on water-hydrocarbon equilibria and gas hydrates was completely revised and substantially expanded. Data and correlations for water-hydrocarbon systems previously in Chapter 8 were updated and included in Chapter 9. Chapter 10 on surface tension was revised, and methods for prediction of interfacial tension were included for the first time.

Fifth Edition (1992)

For the Fifth Edition, a revision package was issued in 1985 that completely revises Chapter 14 on combustion, Chapter 11 on viscosity, and the liquid portion of Chapter 6 on density. A new Chapter 15 on gas-solid and liquid-solid adsorption equilibria was added. In addition, the procedure for computer calculation of vapor-liquid equilibria in Chapter 8 was revised. The ninth revision package, released in 1988, included complete revisions of Chapters 1–4 covering general data, characterization, distillation, and critical properties. The tenth revision package contains a complete update of Chapter 7 on thermal properties. Numerous other changes to the entire book make is consistent with changes previously published (primarily in Chapter 1).

Sixth Edition (1997)

The eleventh revision package (1994) included complete revisions of Chapter 3 on petroleum fraction distillation inter-conversions, Chapter 5 on vapor pressure, and Chapter 8 on vapor-liquid equilibrium K-values. Substantive additions and improvements were made in Chapters 3, 5, and 8.

The twelfth revision package (1996) included complete revisions of Chapter 9 on water-hydrocarbon equilibria, Chapter 11 on viscosity, and Chapter 12 on thermal conductivity as well as an update of all property values and addition of some important compounds in Chapter 1. Ideal gas tables of Chapter 7 and revised procedures to predict Reid vapor pressure in Chapter 5 were also included.

The thirteenth revision package (1998) contained:

(1) a revised Chapter 2 containing routines for additional inspection properties as well as updates of previous routines,

(2) an updated Chapter 4 procedure for calculation of critical properties from an equation of state,

(3) a revised Reid vapor pressure prediction method in Chapter 5,

(4) changes in Chapter 7 procedures for heat capacity of petroleum fractions,

(5) new heat of formation and combustion tables in Chapters 7 and 14,

(6) totally revised and updated values and correlations for interaction coefficients for hydrocarbon-non-hydrocarbon systems for the Soave equation of state, and

(7) additional revisions and additions to the hydrocarbon-water portion of Chapter 9.

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Seventh Edition (2005)

A number of technical improvements are provided in the Seventh Edition as a result of research efforts by Wiltec designed to improve data and correlations of Sulfur containing compounds and through consultation provided by Costa Tsonopoulos to revise Chapter 9. Each chapter of the Sixth Edition of the API Technical Data Book was reviewed and revised by the API Technical Data Committee except for Chapter 15 which remains the same as the Sixth Edition.

Eighth Edition (2006)

A detailed, comprehensive review of the printed Data Book was performed by the API Tech Data Book committee members.

This review process focused on providing a consistent convention of terminology throughout the Data Book while correcting any errors from past editions

Ninth Edition (2013)

All chapters have been reformatted to include the section letter designation both in the text and the table of contents.

Chapter 6 was completely rewritten, updated and new methods have been added throughout the Data Book as indicated in each chapter Preface.

Tenth Edition (2016)

Chapter 7 was completely rewritten and updated, and Chapter 2 was also updated.

Eleventh Edition (2019)

Chapter 12 – This chapter has been revised and expanded with new data and correlations. Available methods for predicting thermal conductivities of liquid and gas hydrocarbons and their mixtures were tested before selecting a recommended method in each category. Work on the Eleventh Edition revision was performed by Dr. Richard L. Rowley with Dale Embry of ConocoPhillips as the chapter coordinator for the Technical Data Committee.

Chapter 4 – New regressed P_c were added for Alkylcyclohexane C13, C15 and C17-C22 (Carl Fitz).

Chapter 6 – Regressed ZRA values were added for C25-C30 to table 6A1.2 (Carl Fitz). Additionally, the API Database was updated for ZRA's.

Chapter 5 – Vapor Pressure data was updated to match with DIPPR (Carl Fitz).

Chapters 8 and 9 – Interaction parameters were updated.

Chapter 10 – Surface tension data was updated (Carl Fitz).

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