PHYSICO-CHEMICAL PROPERTIES FOR CHEMICAL ENGINEERING

化学工学物性定数

Vol. 3

Edited by Physico-Chemical Properties Committee
The Society of Chemical Engineers, Japan

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MARUZEN CO., LTD., Tokyo

PREFACE

It is our pleasure to announce the continuation of our "Physico-Chemical Properties for Chemical Engineering" series with the publication of the third volume, following Volume II published in July of 1978. The purpose of this series, as was previously stated in Volume I, is to introduce literature on experimental data, experimental methods of measurement, predictive methods, and theories on physico-chemical properties of matter related to equipment design in chemical engineering selected from about fifty major journals from around the world. Due to space limitations, it is not possible to record the raw data. However, along with each of the chapter sections, an explanation of the methods of measurement, experimental conditions and accuracy of data, and methods of calculations, together with remarks concerning the corresponding theory are included. A great effort has been made to ensure that the readers will be able to determine for themselves whether or not it is necessary to consult the original literature.

The chapter structure was designed for simplified and unified representation with data source given in Table 1 (including a review at the end of the table), specific apparatus used in the measurement reported in Table 2, and theory and correlation presented in Table 3. This volume contains approximately 1600 papers which were published in 1975～1976. Because of budget limitations, subsequent volumes will be published biennially.

The success of this publication was due to the assistance of the committee members. Typewriting service and copy correction were provided by Miss Etsuko NAKATA and Miss Yoshiko NISHIURA. We would like to express our deepest thanks to these people.

はしがき

昨年7月に出版された"化学工学物性定数"第2巻に引続いて第3巻が出版の運びとなったことは喜ばしい．本書に関する由来と目的については第1巻に詳しく記してあるが，世界各国の主要な約50誌より摘出した化学工業装置設計に関係の深い物性定数のデータ，測定装置と測定法および理論と相関についての論文を広く紹介することである．紙面の都合で原データそのものの収録は不可能になったが，各章の諸項目のそれぞれについて測定法，測定範囲と誤差および理論と相関について要点 (remarks) を記すことにより，読者が原論文を取寄せる必要があるかないかの判定ができるように極力配慮したつもりである．

各章の構成は，すべて 表1 データ源（表末にレビューを含む），表2 測定装置，表3 理論と相関とし，すっきりと統一した．本書は，1975年と1976年間に発表された約1600件の論文について収録を行ったものであるが，紙面の都合もあって引続いて2年ごとに出版する予定である．

本書がこのような形で引続いて刊行されるようになったのは，委員各位の御尽力に負うところが大きい．また，中田悦子，西浦由子の両女史には，原稿校正とかタイプの一部をお願いした．これら多くの方々に対し，ここに深甚の謝意を表する．

ACKNOWLEDGMENT

We are also indebted to the Ministry of Education of Japan for financial support in the form of a grant in aid for scientific research.

February 1979

Physico-Chemical Properties
Committee Chairman
Masahiro YORIZANE

付　記

文献調査，摘録に関し文部省科学研究費の援助に負うところが大であった．あわせて謝意を表する．

1979年2月

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NOTICE FOR USERS

1. Structure of this book:

Each chapter comprises the following tables:

Table 1 : Specific apparatus of measurement

Table 2 : Theory and correlation

Table 3 : Data and equipment

The parts (Part Ⅰ, Ⅱ, etc.) within each table are headed in such a way as to indicate the main points of the chapter.

2. Abbreviations and symbols:

Nomenclature will be explained before chapter 1.

Bibliographical notes will be placed by the following rule, and the bibliography itself will follow each individual chapter, without exception.

Chapters 1-8 will be indicated by symbols A-H.

3. For those who want to refer to the original literature:

Send requests to……

Japan Information Center of Science and Technology

2-5, Nagata 2-chome, Chiyoda-ku Tokyo, 100, Japan

Make requests on……

JICST's stipulated request form, making sure to indicate the magazine number found on the right side of page five.

(This committee does not offer copying services.)

4. Concerning the services of this committee:

Those who want more detailed information than given in the bibliograpy should send a stamped selfaddressed envelope to the address below. Replies will be made through the co-operation of the writers and reviewers mentioned elsewhere.

Physico-Chemical Properties Committee
The Society of Chemical Engineers, Japan
6-19, Kobinata 4-chome, Bunkyo-ku Tokyo, 112, Japan

凡　例

1. 本文の構成

各章とも次の3つの表で構成されている.

表1 : データ

表2 : 測定装置

表3 : 理論と相関

各表内の項 (Part I, II, etc.) は各章内の特長を生かした見出しがつけられている.

2. 略号と記号

Nomenclature は1章の前に記す.

文献記号は各章共通に下記のルールを用い, 文献は各章末に添付してある.

1~8章をA~Hの記号で代表させる.

3. 原論文の参照を希望される方へ

申込先・・・

日本科学技術情報センター (JICST)

〒100 東京都千代田区永田町2丁目5-2

申込方法・・・

JICST 指定の申込用紙使用のこと. この場合雑誌記号には5ページ右端の JICST No. を明記のこと.

(当委員会では文献コピーサービスは致しません.)

4. 本委員会のサービスについて

文献一覧表以上のことをお知りになりたい場合は, 原則として封書(返信用封書に宛名と切手同封のこと)で, 下記へ連絡下さい. 質問には, 別項に挙げた執筆, 摘録担当者が分担に応じて回答します.

宛先・・・

〒112 東京都文京区小日向4丁目6番19号

化学工学協会「物性定数委員会」

INVESTIGATED MAGAZINES AND THEIR JICST NUMBERS

No.	Full Name of Journal	JICST No.
1	Acta Chemica Scandinavica	A 314A
2	American Institute of Chemical Engineers Journal, New York	A 337A
3	American Institute of Chemical Engineers Symposium Series	B 776A
4	British Chemical Engineering $\xrightarrow{\text{see}}$ Process Technology International	B 086A
5	Bulletin of the Chemical Society of Japan	G 450A
6	Canadian Journal of Chemical Engineering	B 227A
7	Chemical Engineering	B 251A
8	Chemical Engineering Communications	D 482A
9	Chemical Engineering Journal	D 723A
10	Chemical Engineering Science	B 254A
11	Chemie-Ingenieur-Technik	B 260A
12	Chemical Reviews	B 256A
13	Collection of Czechoslovak Chemical Communications	B 288A
14	Denki Kagaku oyobi Kogyo Butsuri Kagaku	G 072A
15	Doklady Akademij Nauk S.S.S.R.	R 025A
16	Tohoku Daigaku Hisuiyoekikagaku Kenkyusho Hokoku	F 342A
17	Hydrocarbon Processing	D 303A
18	Industrial and Engineering Chemistry	(A 531B)
19	Izvestija Akademij Nauk S.S.S.R. (Seriya) Khimicheskaya	R 042A
20	Journal of the American Chemical Society	C 254A
21	Journal of Applied Chemistry and Biotechnology	C 264A
22	Journal of Chemical and Engineering Data	D 035B
23	Journal of Chemical Engineering of Japan	S 629A
24	Journal of Chemical Physics	C 275A
25	Journal of the Chemical Society Dalton Transactions	C 276A
26	Journal of Chemical Thermodynamics	D 634A
27	Journal de Chimie Physique et de Physicochimie Biologique	C 277A
28	Journal of the Indian Chemical Society	C 296A
29	Journal of Petroleum Technology	C 330A
30	Journal of Physical Chemistry	C 334A
31	Journal of Physical Chemistry of Liquid	—
32	Journal of Physical and Chemical Reference Data	—
33	Journal of Research of the National Bureau of Standards. Sec. A	C 340B
34	Kagaku Kōgaku Ronbunshu	F 099A
35	Khimiya i tekhnologiya topliva i masel	P 050A
35-S	(Chemistry and Technology of Fuels and Oils)	—
36	Khimicheskaia Promyshlennost	R 049A
37	Nippon Kagaku Kaishi	F 226B
38	Process Technology International	B 086A
39	Review of Physical Chemistry of Japan	S 091A
40	Transactions of the Faraday Society	E 274A
41	Transactions of the Institution of Chemical Engineers, London	E 282A
42	Ukrainskii khimicheskii zhurnal	R 203A
43	Uspekhi Khimii	P 117A
43-S	(Russian Chemical Reviews)	—
44	Zeitschrift für Physikalische Chemie (Frankfurt)	E 443A
45	Zeitschrift für Physikalische Chemie (Leipzig)	E 444A
46	Zhurnal Fizicheskoi Khimii	R 136A
47	Zhurnal Prikladnoi Khimii	P 140A
47-S	(Journal of Applied Chemistry of the USSR)	E 175B

Table of Symbols

a	activity
B	second virial coefficient
B_{ij}	second virial cross coefficient
c	molar concentration
C	third virial coefficient
C_p	heat capacity at constant pressure
C_v	heat capacity at constant volume
D	diffusivity
D°	self diffusivity
D^*	tracer diffusivity
E	activation energy
f	fugacity
G	free energy
H	enthalpy
h	Planck constant
ΔH_m	enthalpy of mixing
ΔH_s	enthalpy of solution
H_T	enthalpy at T
ΔH_{tr}	enthalpy of transfer
k	thermal conductivity
K	distribution coefficient, vapor liquid equilibrium ratio
L_v	heat of vaporization
M	molecular mass, atomic mass, molecular weight
m_r	molarity
m_l	molarity
P	pressure
R	gas constant
S	solubility, entropy
T	temperature (Kelvin)
t	temperature (Celsius)
U	internal energy
v	molecular volume
V	molar volume
x	liquid mole fraction
y	vapor mole fraction
z	compressibility factor

Greek Symbols

α	relative volatility
α_p	thermal expansibility
γ	activity coefficient
ε	well depth of potential function
η	viscosity
ν	frequency
ρ	density
σ	collision diameter
ϕ	fugacity coefficient, volume fraction
ω	acentric factor
κ_T	isothermal compressibility

Superscripts

$*$	standard state, radioactive tracer
$-$	partial
E	excess
L	liquid phase
V	vapor phase
o	atmospheric state
∞	infinite dilution

Subscripts

a	alcohol
app	apparent
c	critical

i	component
j	component
L	liquid phase
m	mixture
r,R	reduced
s	saturated, solution
V	vapor phase

Table of Abbreviations

abs.	absolute
alc.	alcohol, alcoholic
aliph.	aliphatic
app.	apparatus
aq.	aqueous
arom.	aromatic
av.	average
b.p.	boiling point
Bu	butyl
calcd.	calculated
calcn.	calculation
coeff.	coefficient
combn.	combination
compd.	compound
compn.	composition
concn.	concentration
conctd.	concentrated
const.	constant
cor.	corrected
c.p.	critical point
crit.	critical
deriv.	derivation
detd.	determined
detn.	determination
dev.	deviation
dil.	dilute
diln.	dilution
distn.	distillation
e.	error
emf.	electoromotive force
eq.	equation
equil.	equilibrium
equiv.	equivalent
esp.	especially
estd.	estimated
Et	ethyl
expt.	experiment
exptl.	experimentally
extn.	extraction
f.p.	freezing point
func.	function
(g)	gaseous state
illust.	illustrated
inorg.	inorganic
(l)	liquid state
liq.	liquid
lit.	literature
max.	maximum
Me.	methyl
mixt.	mixture
mol.	molecule, molecular
m.p.	melting point
neg.	negative (ly)
NMR.	nuclear magnetic resonance
no.	number
obsd.	observed
org.	organics
Pe	pentyl
pos.	positive (ly)
ppt.	precipitate
Pr.	propyl
press.	pressure
pt.	point
Ra.	radio-active
ref.	reference
(s)	solid state
sat.	saturate
satd.	saturated
satn.	saturation
soln.	solution
soly.	solubility

temp.	temperature	wt.	weight
vol.	volume		

Table of Units

Å	ängstrom	MPa	mega Paskal
atm	atmosphere	Pa	pascal
°C	degree Celsius	ppm	parts per million
cal	calorie	psi	pounds per square inch
°F	degree Fahrenheit	psia	pounds per square inch, absolute
g	gram		
K	Kelvin	psig	pounds per square inch, gage
Kg	kilogram weight		
l	liter	°R	degree Rankine
m	meter	torr	torr
mol	mole		

CONTENTS

Table 1.1 Data

Part I PVT, Compressibility Factor, Expansion Factor, Virial Coefficient				
Substance	Temperature [°C]	Pressure [atm]	Remarks	Lit. (A)
(a) Inorganic (pure)				
As	850∿1400 K	∿77	PVT(g)	168
D_2O	5∿100	∿1000 bar	PVT(l), sound speed	56
H_2O	5,15	∿1045 bar	PVT(l)	232
H_2O	0∿150	0∿1 kbar	PVT(l), sound speed	94
H_2O	323∿773 K	∿200 MPa	PVT	196
N_2	247∿321 K	∿22 kbar	PVT, sound speed	125
NbF_5	200∿400 K	1	PVT	55
SF_6	0∿50	∿200 bar	PVT(l)	95
SbF_5	150∿300 K	1	PVT	55
TaF_5	200∿400 K	"	"	"
(b) Organic (pure)				
Benzaldehyde	298∿452 K		B	2
Benzene	298∿433 K	45∿4500 bar	PVT(l)	148
Benzene	293.15,298.15 K	0.1∿10 MPa	κ_T, refractive index	27
Butanol	25∿60	∿1500 bar	PVT(l)	103
CCl_4	293.15,298.15 K	0.1∿10 MPa	κ_T, refractive index	27
CCl_4	273∿413 K	∿49010 psi.	PVT(l)	14
$CHCl_3$	293.15,298.15 K	0.1∿10 MPa	κ_T, refractive index	27
CH_2Cl_2	"	"	"	"
CHF_3	0∿200		B, Burnett	12
1,3-,1,4-Cyclohexadiene	293.15,298.15 K	0.1∿10 MPa	κ_T, refractive index	27
Cyclohexane	"	"	"	"
Cyclohexene	"	"	"	"
Dodecane			Negative press.	82
Ethane	92∿320 K	∿32 MPa	PVT	191
Ethane	25∿200	∿10 MPa	PVT, Joule-	20

Substance	Temperature [°C]	Pressure [atm]	Remarks	Lit. (A)
			Thomson coeff.	
Ethane	160∿300 K	∿70 MPa	PVT(1)	147
Ethylene	238∿448 K	∿40 MPa	PVT,B	50
[1,5-,cis,trans-2,4-,trans-1,4-] Hexadiene	293.15,298.15 K	0.1∿10 MPa	κ_T,refractive index	27
Hexane	"	"	"	"
1-Hexene	"	"	"	"
Methane	113.5∿193.05 K	∿satd. press.	PVT,sound speed	58
Octamethylcyclotetrasiloxane	237∿413 K	∿30920 psi.	PVT(1)	14
Propylene	40∿160	∿1600 psi.	Critical evaluation from lit. data	236
(c) Inorganic+Inorganic				
Air+H_2O	-20,-10,70		B_m	84
Ar+CO_2	100,200,300		B_m,B,C	21
D_2O+H_2O	2∿40	∿1000 bar	PVT(1)	53
H_2S+N_2	20,40,60,80,100	∿4500 psi.	PVT,Burnett	172
KCl+H_2O	∿350	∿1500 Kg/cm^2	PVT(1)	52
(d) Inorganic+Organic				
Ar+CH_3F	50		B,B_{12}	42
Ar+CHF_3	"		"	"
CO_2+Propane	27.4		B_{12}	24
H_2+Methane	-150∿50 °F (50 °F span)		B,B_m	159
H_2+NH_3+Propane	55.4∿80.9	11∿96	Fugacity coeff.	6
(e) Organic+Organic				
CCl_4+Octamethylcyclotetrasiloxane	273∿413 K	∿49010 psi.	PVT(1)	14
$CFCl_3$+(CF_3Cl,CF_2Cl_2,CHF_3)	27.15∿29.1		B_{12}	24
CF_2Cl_2+(CHF_2Cl,CHF_3)	"		"	"
CF_3Cl+(CHF_2Cl,CHF_3)	"		"	"
CHF_2Cl+CHF_3	"		"	"
Dimethylsulfoxide+Methanol	298∿323 K	0.1∿70 MPa	PVT(1),α_p	33
Hexane+(Neopentane,Decane)	298.15 K	∿101 kPa	κ_T	117
Part II Liquid Density				
(a) Inorganic (pure)				
$Ca(NO_2)_2$	392∿440		ρ	67
H_2O	-26∿45		κ_T	188

Substance	Temperature [°C]	Pressure [atm]	Remarks	Lit. (A)
(b) Organic (pure)				
Benzaldehyde	293∿490 K		ρ	2
Benzene	303,348,393, 433 K	1∿4000 bar	"	149
2-Bromopyridine	25∿125		"	31
1-Butanol	293∿490 K		"	75
1-Butanol	293.15,298.15 K	∿10 MPa	κ_T	174
2-Butanol	293∿490 K		ρ	75
2-Butanol	293.15,298.15 K	∿10 MPa	κ_T	174
CCl_3F	341,379,460 K	100∿2040 bar	ρ	47
2-Chloropyridine	25∿125		"	31
2-Cyanopyridine	30∿125		"	"
3-Cyanopyridine	50∿125		"	"
4-Cyanopyridine	80∿125		"	"
Cyclobutanone	20∿89		"	123
Cyclodecane	22∿131		"	"
Cyclododecane	66∿133		"	"
Cyclododecanone	70∿142		"	"
Cycloheptane	16∿114		"	"
Cycloheptanone	24∿100		"	"
Cyclooctane	29∿129		"	"
Cyclooctanone	43∿138		"	"
Cycloundecanone	28∿139		"	"
Diethylene glycol monoheptyl ether	20		"	98
2,2-Dimethylbutane	293.15,298.15 K	∿10 MPa	κ_T	174
2,3-Dimethylbutane	"	"	"	"
N,N-Dimethylethyleneurea	25∿100		ρ	173
2,2-Dimethylpentane	293.15,298.15 K	∿10 MPa	κ_T	174
N,N-Dimethylpropyleneurea	25∿100		ρ	173
Di-n-nonyl phthalate	100		"	109
Di-n-propyl tetrachloro-phthalate	90		"	"
1-Dodecanol	298∿490 K		"	75
1-Dodecanol	56		"	109
Ethane	215∿304 K		ρ at satn.	147
Ethanol	293∿455 K		ρ	75

Substance	Temperature [°C]	Pressure [atm]	Remarks	Lit. (A)
Ethanol	293.15,298.15 K	∿10 MPa	κ_T	174
Ethylene glycol monoheptyl ether	20		ρ	98
Heptane	25∿100		"	37
Lauronitrile	56		"	109
Methane	110.09,113.70, 116.30,120.00 K		V at m.p.	138
Methanol	293∿440 K		ρ	75
Methanol	293.15,298.15 K	∿10 MPa	κ_T	174
Methoxybenzylidene butylaniline	40∿50		ρ near the isotropic-nematic phase transition	70
2-Methylbutane	293.15,298.15 K	∿10 MPa	κ_T	174
2-Methyl-1-butanol	"	"	"	"
2-Methyl-2-butanol	"	"	"	"
3-Methyl-1-butanol	"	"	"	"
3-Methyl-2-butanol	"	"	"	"
Methylcyclohexane	25∿100		ρ	37
4-Methyl-N-methylpyridinium bromide	418∿498 K		"	136
2-Methylpentane	293.15,298.15 K	∿10 MPa	κ_T	174
3-Methylpentane	"	"	"	"
2-Methyl-2-pentanol	"	"	"	"
2-Methyl-1-propanol	"	"	"	"
4-Methylpyridinium bromide	410∿518 K		ρ	136
N-Methylpyridinium bromide	398∿468 K		"	"
4-Methylpyridinium chloride	410∿473 K		"	"
N-Methylpyridinium chloride	382∿433 K		"	"
1-Octanol	293∿490 K		"	75
Pentane	293.15,298.15 K	∿10 MPa	κ_T	174
1-Pentanol	293∿490 K		ρ	75
1-Pentanol	293.15,298.15 K	∿10 MPa	κ_T	174
2-Pentanol	"	"	"	"
3-Pentanol	293.15,298.15 K	∿10 MPa	κ_T	174