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**PHYSICO-CHEMICAL PROPERTIES
FOR CHEMICAL ENGINEERING**

化学工学物性定数

Vol. 2

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



MARUZEN CO., LTD., Tokyo

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PREFACE

It is our delightness to publish the second volume in succession after the publication of the first volume of "Physico-Chemical Properties for Chemical Engineering" in March of the last year. The origin and the purpose of this book, which were written clearly in the first volume, are to introduce literatures on experimental data, experimental method of measurements, predictive method and theory of physico-chemical properties of matter related to equipment design in chemical engineering from about fifty main journals in the world. Due to printing limitations, it is not possible to record the raw data. However, along with each of the chapter sections, an explanation of the means of measurement, margin of error on experimental data, method of calculation, and remarks concerning the theory behind these will be included. Great pains have been taken to make sure that the reader will be able to tell whether or not it is necessary to consult the original literature.

The chapter structure is all constructed with simplified and unified representation and that is as follows ; data in Table 1 (including review in the end of Table 1), the specific apparatus of measurement in Table 2, and theory and correlation in Table 3. This book includes about 1500 theses published in two years from 1973 to 1974. Because of the limitation of page, the subsequent book will be published every other year.

The fact that this publication has turned out so well is due to the help of the first chairman Professor Kazuo SATO, and the following committee members. We owe typewriting service and correction of the copy to Miss Etsuko NAKATA and Mrs. Chikako SHINTAKU. We would like to express our deepest thanks to these people.

は し が き

昨年3月に出版された“化学工学物性定数”第1巻に引続いて第2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(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1973年と1974年間に発表された約1500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今のところ引続いて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、初代委員長の佐藤一雄教授およびその後を継がれた委員各位の御尽力に負うところが大きい。また、中田悦子、新宅千賀子の両女史には原稿の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 also express our thanks to the financial support of a Grant-in-Aid for Scientific Research from the Ministry of Education of Japan.

June 1978

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きであった．あわせて謝意を表する．

1978年6月

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NOTICE FOR USERS

凡 例

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 bibliography should send a stamped self-addressed 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

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)

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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 314 A
2	American Institute of Chemical Engineers Journal, New York	A 337 A
3	American Institute of Chemical Engineers Symposium Series	B 776 A
4	British Chemical Engineering $\xrightarrow{\text{see}}$ Process Technology International	B 086 A
5	Bulletin of the Chemical Society of Japan	G 450 A
6	Canadian Journal of Chemical Engineering	B 227 A
7	Chemical Engineering	B 251 A
8	Chemical Engineering Communications	D 482 A
9	Chemical Engineering Journal	D 723 A
10	Chemical Engineering Science	B 254 A
11	Chemie-Ingenieur-Technik	B 260 A
12	Chemical Reviews	B 256 A
13	Collection of Czechoslovak Chemical Communications	B 288 A
14	Denki Kagaku oyobi Kogyo Butsuri Kagaku	G 072 A
15	Doklady Akademij Nauk S.S.S.R.	R 025 A
16	Tohoku Daigaku Hisuiyoeikagaku Kenkyusho Hokoku	F 342 A
17	Hydrocarbon Processing	D 303 A
18	Industrial and Engineering Chemistry	(A 531 B)
19	Izvestija Akademij Nauk S.S.S.R. (Seriya) Khimicheskaya	R 042 A
20	Journal of the American Chemical Society	C 254 A
21	Journal of Applied Chemistry and Biotechnology	C 264 A
22	Journal of Chemical and Engineering Data	D 035 B
23	Journal of Chemical Engineering of Japan	S 629 A
24	Journal of Chemical Physics	C 275 A
25	Journal of the Chemical Society	C 276 A
26	Journal of Chemical Thermodynamics	D 634 A
27	Journal de Chimie Physique et de Physicochimie Biologique	C 277 A
28	Journal of the Indian Chemical Society	C 296 A
29	Journal of Petroleum Technology	C 330 A
30	Journal of Physical Chemistry	C 334 A
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 340 B
34	Kagaku Kōgaku	F 099 A
35	Khimiya i tekhnologiya topliva i masel	P 050 A
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40	Transactions of the Faraday Society	E 274 A
41	Transactions of the Institution of Chemical Engineers, London	E 282 A
42	Ukrainskii khimicheskii zhurnal	R 203 A
43	Uspekhi Khimii	P 117 A
44	Zeitschrift für Physikalische Chemie (Frankfurt)	E 443 A
45	Zeitschrift für Physikalische Chemie (Leipzig)	E 444 A
46	Zhurnal Fizicheskoi Khimii	R 136 A
47	Zhurnal Prikladnoi Khimii	P 140 A

Table of Symbols

a	activity	x	liquid mole fraction
B	second virial coefficient	y	vapor mole fraction
B_{ij}	second virial cross coefficient	z	compressibility factor
c	molar concentration	Greek Symbols	
C	third virial coefficient	α	relative volatility
C_p	heat capacity at constant pressure	γ	activity coefficient
C_v	heat capacity at constant volume	ϵ	well depth of potential function
D	diffusivity	η	viscosity
D°	self diffusivity	ν	frequency
D^*	tracer diffusivity	ρ	density
f	fugacity	σ	collision diameter
G	free energy	ϕ	fugacity coefficient,
H	enthalpy		volume fraction
h	Planck constant	ω	acentric factor
ΔH_m	enthalpy of mixing	Superscripts	
ΔH_s	enthalpy of solution	*	standard state, radio-
H_T	enthalpy at T		active tracer
ΔH_{tr}	enthalpy of transfer	-	partial
k	thermal conductivity	E	excess
K	distribution coefficient, vapor liquid equilibrium ratio	L	liquid phase
L_v	heat of vaporization	V	vapor phase
M	molecular mass, atomic mass, molecular weight	o	atmospheric state
m_r	molarity	∞	infinite dilution
m_l	molality	Subscripts	
P	pressure	c	critical
R	gas constant	i	component
S	solubility, entropy	j	component
T	temperature (Kelvin)	m	mixture
t	temperature (Celsius)	r	reduced
U	internal energy	s	saturated, solution
v	molecular volume		
V	molar volume		

Table of Abbriviations

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

Table of Units

°		°F	degree Fahrenheit
Å	Angstrom	g	gram
atm	atmosphere	K	Kelvin
°C	degree Celsius	Kg	kirogram weight
cal	calorie		

Table of Units

l	liter	psia	pounds per square inch, absolute
m	meter		
mol	mole	psig	pounds per square inch, gage
ppm	parts per million		
psi	pounds per square inch	°R	degree Rankine

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CHAPTER 1 P-V-T RELATION AND LIQUID DENSITY

Table 1.1 Data

Part I PVT, Compressibility Factor, Expansion Factor, Virial Coefficient

Substance	Temperature [°C]	Pressure [atm]	Remarks	Lit. [A]
(a) Inorganic (pure)				
Ar	101~138 K		B,C	214
Ar	-120~110	~190	Joule-Thomson coeff.	268
BF ₃	0~225	~250 bar	PVT,B	293
ClF ₃	20~180		B	197
H ₂ O	0~100	0~1000 bar	Z	85
MoF ₆	40~180		B	196
NH ₃	25~125	~500	Z,PVT	48
NH ₃	100,150,200	2~9.5 kbar	PVT,α	287
NH ₃	131~134	109~117	PVT,Z	49
NO	300 K		B,C	73
SF ₆	273~374 K		B	114
S ₂ ~S ₈	823~1273 K	0.68~144	PVT	226
Se ₂ ~Se ₈	1073~1373 K	1~40	"	225
UF ₆	55~190		B	196
WF ₆	40~180		"	"
Xe	165~289.74 K	22~3815	PVT,Z,B,C	271
(b) Organic (pure)				
n-Butane	296~511.1 K		B	242
CF ₃ Cl	50~200	2~8 kbar	P-V eq.	243
Diethylether	20~188.6	~40 bar	PVT	72
2,2-Dimethylpropane	70~225	~310	"	53
n-Dodecane	15~35	negative	"	119
Ethane	296~510.6 K		B	242
Ethane	209~306 K		B,C	214
Ethane	238~305 K	9~48	Z	63
Fluorobenzene-d ₅	30~350	60~3500 bar	PVT	57
(o-,m-,p-)Fluorotoluene	100~180		B	198
Methane, deuterated- methane	111~302 K		"	82
Methane	126~191 K		B,C	214
2-Methylbutane	22	0~24000 bar	PVT	116

Substance	Temperature [°C]	Pressure [atm]	Remarks	Lit. [A]
Pentane	22	0~24000 bar	PVT	116
Propane	271~322 K	66~3057 psi.	P-ρ-T	7
Propane	296~511.8 K		B	242
Propanol	286~321 K		"	6
Propyleneoxide	38.5~215.3	1.73~44.4	PVT	236
Tetrahydrofurane	25		B	282
Toluene	100~220		"	144
Toluene	140~310		B,PVT	209
Vinylacetate	-30~100	0~800 bar	PVT	188
Vinylchloride	0~75	0.52~10.2	Z	107
(c) Inorganic+Inorganic				
Ar+CO ₂	-120~120	190	Joule-Thomson coeff.	268
Ar+NH ₃	50	~50	PVT,Z	50
CO ₂ +N ₂ O	30~50	50~85	PVT-y	137
CO ₂ +SF ₆		crit.	y vs. (∂P/∂V) _T	177
H ₂ +Ne	25~31.14 K	1~34	PVT	269
H ₂ +N ₂ +NH ₃	15~400	71~611	"	154
He+CO ₂	100	1~300	PVT, B _m , B _{ij}	283
He+CO ₂	150	25~300	"	284
N ₂ +NH ₃	50	~50	PVT,Z	50
N ₂ +NH ₃	98	2895~6233 bar	PVT at gas-gas equilibria	285
(d) Inorganic+Organic				
Ar+Butane, Ar+Ethane, Ar+ Propane	296.2~511 K		B _{ij}	242
CO ₂ +n-Pentane	40.1~220°F	~1397 psi.	PVT	17
N ₂ +Benzene, N ₂ +Cyclo- hexane, N ₂ +n-Hexane	30~70	~6	B _{ij}	132
NH ₃ +Ethane	24~38	46~65	PVT-y	136
SF ₆ +Propane		crit.	y vs. (∂P/∂V) _T	177
Tetrahydrofurane	25		B _{ij}	242
Xe+H ₂ O	375~500	200~3000 bar	PVT	87
(e) Organic+Organic				
Benzene+n-Hexane,	210, 220		B _m , B _{ij}	16
Benzene+n-Hexane,	170~220		"	"
Benzene+n-Heptane,				
Benzene+n-Pentane,				
Benzene+n-Octane				
Benzene+Toluene	180~220	4.6~7.03	PVT-y	15
n-Decane+Tetradecane	25~85	1~4244	PVT	258

Substance	Temperature [°C]	Pressure [atm]	Remarks	Lit. [A]
n-Decane+Tetradecane+ Hexadecane, n-Dodecane+Hexadecane	25~85	1~3543	PVT	258
Ethane+n-Heptane	35~84	supercrit.	"	300
Ethane+n-Heptane	50~122	~85	Z	68
Ethylene+Vinylacetate	~423 K	~120 MN/m ²	"	309
Fluorobenzene+n-Octane	170~220		B _m , B _{ij}	275
Fluorobenzene+n-Pentane	"		PVT-y, B _{ij}	14
m-Fluorotoluene+Toluene	100~185		B _m , B _{ij}	199
Hexane+Octadecane, Hexane+1-Octadecene, Hexane+Hexadecane, trans-1,3-Hexadiene+ Octadecane,trans-1,3- Hexadiene+1-Octadecene,	35,50 " 35		B _{ij} ,GLC method " "	164 " "
trans-1,3-Hexadiene+ Hexadecane,trans-1,3- Hexadiene+1-Hexadecene, trans-1,4-Hexadiene+ Octadecane,trans-1,4- Hexadiene+1-Octadecene,	" " " "		" " " "	" " " "
trans,trans-2,4-Hexa- diene+Octadecane,trans, trans-2,4-Hexadiene+ 1-Octadecene,trans, trans-2,4-Hexadiene+ Hexadecane,trans,trans- 2,4-Hexadiene+1-Hexa- decene,	" " " "		" " " "	" " " "
1,5-Hexadiene+Octa- decane,1,5-Hexadiene+ 1-Octadecene,cis-1,3,5- Hexatriene+Octadecane, cis-1,3,5-Hexatriene+ 1-Octadecene,cis-1,3,5- Hexatriene+Hexadecane, cis-1,3,5-Hexatriene+ 1-Hexadecene,	35,50 " 35		" " "	" " "
1-Hexene+Octadecane, 1-Hexene+1-Octadecene, trans-3-Hexene+Octa- decane,	35,50 35		" " "	" " "

Substance	Temperature [°C]	Pressure [atm]	Remarks	Lit. [A]
trans-3-Hexene+1-Octa- decene, trans-3-Hexene+ Hexadecane, trans-3- Hexene+1-Hexadecene, trans-2-Hexene+Octa- decane, trans-2-Hexene+ 1-Octadecene	35 "		B_{ij} , GLC method "	164 "
Kerosene+Transformer oil	20,100,150	1~8000 bar	PVT	184
Methanol+Dimethylamine, Methanol+Methylamine, Methanol+Triethylamine, Methanol+Trimethylamine	25~45		"	190
2-Methylbutane+Pentane	22	0~24000 bar	PVT	116
Octadecane+Pentane, Octadecane+1,4-Penta- diene, Octadecane+cis-1, 3-Pentadiene, Octadecane +trans-2-Pentene, 1-Octadecene+Pentane	35 "		B_{ij} , GLC method "	164 "
(f) Review and Survey Ethane, Ethene			Survey of PVT data	51
He			Survey of B, PVT data	187
Isobutane	261~408 K		PVT review	47
N ₂			Survey of B, PVT data	121
Propane, Propene			Survey of PVT data	51

Part II Liquid Density

(a) Inorganic (pure)				
AgNO ₃	~312		$-(\partial V/\partial P)_T/V$ eq.	37
AlBr ₃	92~319		ρ and V eqs.	208
D ₂ O	-30~5		ρ	221
H ₂ O	0~100	0~1000 bar	ρ , $-(\partial V/\partial P)_T/V$, $(\partial V/\partial T)_P/V$	85
H ₂ O	-40~0		ρ	221
H ₂ O	25	1	$-(\partial V/\partial P)_T/V$ and consts. of Tait eq.	142
KBr	over 100 °C above the melting point		$-(\partial V/\partial P)_T/V$ eq.	37