PETROLEUM ENGINEERING

FLUID PROPERTIES

DATA BOOK

Compiled by

Curtis H. Whitson
(May 1994)

Based in Part on the Original Compilation by
M.B. Standing (August 1974)

PREFACE

The original **Petroleum Engineering Data Book** compiled by M.B. Standing during his work at our institute in 1973 and 1974 has been and is still used by many hundreds of practicing petroleum engineers in Norway and around the world. I personally use it almost daily for quick (and accurate) estimates of fluid properties.

Yes, Standing's Data Book has survived the computer! And I suppose until every petroleum engineer has HyperText access to such charts and tables on their computers, the Data Book will continue to survive.

What I've done here is to create a new Data Book that is limited to Fluid Properties. Quite a few new charts and tables have been added to the original Standing charts, and a few of the original fluid-related charts have been replaced or omitted. The original charts from Standing's Data Book included here are referenced as such. Otherwise, all of the original Standing charts for relative permeability, transient flow, and other miscellaneous charts have been removed.

As I tell my students when they ask *"should we use the charts in this-or-that text book, or should we use the Standing Data Book?"* my reply is simply *"if you want a property that you can be sure is reliable, use the Data Book."* I realize that replacing some of Standing's original charts, for the sake of improved print quality, may introduce less reliable (or at worst erroneous) information, but I hope these changes result in an overall improvement.

C.H. Whitson
Trondheim
May 31, 1994

TABLE OF CONTENTS

GENERAL PROPERTIES, UNITS, AND CONSTANTS

PROPERTIES OF GASES

PROPERTIES OF CARBON DIOXIDE

PROPERTIES OF OILS

PROPERTIES OF WATER-HYDROCARBON SYSTEMS

PROPERTIES OF INTERFACES

REFERENCES

PHYSICAL PROPERTIES OF PURE COMPOUNDS IN CUSTOMARY UNITS

Compound		Molecular Weight M	Specific Gravity γ	Liquid Density ρ_{sc}	CRITICAL CONSTANTS				Acentric Factor ω	Normal Boiling Point T_b	Ideal Liquid Yield L	Gross Heating Value H
					p_c	T_c	v_c	Z_c				
		lb/lbmol	*water=1*	*lb/ft³*	*psia*	*°R*	*ft³/lbmol*			*°R*	*gal/Mscf*	*Btu/scf*
NITROGEN	N_2	28.02	0.4700	29.31	493.0	227.3	1.443	0.2916	0.0450	139.3		
CARBON DIOXIDE	CO_2	44.01	0.5000	31.18	1070.6	547.6	1.505	0.2742	0.2310	350.4		
HYDROGEN SULPHIDE	H_2S	34.08	0.5000	31.18	1306.0	672.4	1.564	0.2831	0.1000	383.1		672
METHANE	C_1	16.04	0.3300	20.58	667.8	343.0	1.590	0.2884	0.0115	201.0		1012
ETHANE	C_2	30.07	0.4500	28.06	707.8	549.8	2.370	0.2843	0.0908	332.2		1783
PROPANE	C_3	44.09	0.5077	31.66	616.3	665.7	3.250	0.2804	0.1454	416.0	27.4	2557
ISO BUTANE	iC_4	58.12	0.5613	35.01	529.1	734.7	4.208	0.2824	0.1756	470.6	32.7	3354
BUTANE	nC_4	58.12	0.5844	36.45	550.7	765.3	4.080	0.2736	0.1928	490.8	31.4	3369
ISO PENTANE	iC_5	72.15	0.6274	39.13	490.4	828.8	4.899	0.2701	0.2273	541.8	36.3	4001
PENTANE	nC_5	72.15	0.6301	39.30	488.6	845.4	4.870	0.2623	0.2510	556.6	36.2	4009
HEXANE	nC_6	86.17	0.6604	41.19	436.9	913.4	5.929	0.2643	0.2957	615.4	41.2	4756
HEPTANE	nC_7	100.20	0.6828	42.58	396.8	972.5	6.924	0.2633	0.3506	668.8	46.3	5503
OCTANE	nC_8	114.20	0.7086	44.19	360.6	1023.9	7.882	0.2587	0.3978	717.9	50.9	6250
NONANE	nC_9	128.30	0.7271	45.35	332.0	1070.3	8.773	0.2536	0.4437	763.1	55.7	6996
DECANE	nC_{10}	142.30	0.7324	45.68	304.0	1111.8	9.661	0.2462	0.4902	805.2	61.4	7743
AIR		28.97	0.4700	29.31	547.0	239	1.364	0.2910	0.0400	141.9		
WATER	H_2O	18.02	1.0000	62.37	3206.0	1165	0.916	0.2350	0.3440	671.6		
OXYGEN	O_2	32.00	0.5000	31.18	732.0	278	1.174	0.2880	0.0250	162.2		

PHYSICAL PROPERTIES OF PURE COMPOUNDS IN SI UNITS

Compound		Molecular Weight M	Specific Gravity γ	Liquid Density ρ_{sc}	CRITICAL CONSTANTS				Acentric Factor ω	Normal Boiling Point T_b	Ideal Liquid Yield L	Gross Heating Value H
					p_c	T_c	v_c	Z_c				
		kg/kmol	*water=1*	*kg/m³*	*bar*	*K*	*m³/kmol*			*K*	*m³/ 1000 m³*	*MJ/std m³*
NITROGEN	N_2	28.02	0.4700	469.5	33.99	126.3	0.0901	0.2916	0.0450	77.39		
CARBON DIOXIDE	CO_2	44.01	0.5000	499.5	73.82	304.2	0.0940	0.2742	0.2310	194.67		
HYDROGEN SULPHIDE	H_2S	34.08	0.5000	499.5	90.05	373.6	0.0976	0.2831	0.1000	212.83		25.04
METHANE	C_1	16.04	0.3300	329.7	46.04	190.6	0.0993	0.2884	0.0115	111.67		37.71
ETHANE	C_2	30.07	0.4500	449.6	48.80	305.4	0.1479	0.2843	0.0908	184.56		66.43
PROPANE	C_3	44.09	0.5077	507.2	42.49	369.8	0.2029	0.2804	0.1454	231.11	3.67	95.27
ISO BUTANE	iC_4	58.12	0.5613	560.7	36.48	408.2	0.2627	0.2824	0.1756	261.44	4.37	125.0
BUTANE	nC_4	58.12	0.5844	583.8	37.97	425.2	0.2547	0.2736	0.1928	272.67	4.20	125.5
ISO PENTANE	iC_5	72.15	0.6274	626.8	33.81	460.4	0.3058	0.2701	0.2273	301.00	4.86	149.1
PENTANE	nC_5	72.15	0.6301	629.5	33.69	469.7	0.3040	0.2623	0.2510	309.22	4.83	149.4
HEXANE	nC_6	86.17	0.6604	659.7	30.12	507.4	0.3701	0.2643	0.2957	341.89	5.51	177.2
HEPTANE	nC_7	100.20	0.6828	682.1	27.36	540.3	0.4322	0.2633	0.3506	371.56	6.20	205.0
OCTANE	nC_8	114.20	0.7086	707.9	24.86	568.8	0.4920	0.2587	0.3978	398.83	6.80	232.9
NONANE	nC_9	128.30	0.7271	726.4	22.89	594.6	0.5477	0.2536	0.4437	423.94	7.45	260.7
DECANE	nC_{10}	142.30	0.7324	731.7	20.96	617.7	0.6031	0.2462	0.4902	447.33	8.20	288.5
AIR		28.97	0.4700	469.5	37.71	132.8	0.0852	0.2910	0.0400	78.83		
WATER	H_2O	18.02	1.0000	999.0	221.05	647.2	0.0572	0.2350	0.3440	373.11		
OXYGEN	O_2	32.00	0.5000	499.5	50.47	154.4	0.0733	0.2880	0.0250	90.11		

SINGLE CARBON NUMBER PROPERTIES OF C_{7+} FRACTIONS IN CUSTOMARY UNITS

(after Katz and Firoozabadi)

	Katz-Firoozabadi Generalized Properties						Defined	Lee-Kesler/Kesler-Lee Correlations			Riazi	Defined
	Normal Boiling Point Interval at 1 atm		Average Normal Boiling Point, T_b									
Carbon Number Fraction	Lower Boiling Point °C	Upper Boiling Point °C	°C	°R	Specific Gravity γ water=1	Molecular Weight M	Watson Factor K_w	Critical Temperature T_c °R	Critical Pressure p_c psia	Acentric Factor ω	Critical Volume V_c ft³/lbmol	Critical Z-factor Z_c
6	36.5	69.2	63.9	606.7	0.690	84	12.27	914	476	0.271	5.6	0.273
7	69.2	98.9	91.9	657.1	0.727	96	11.96	976	457	0.310	6.2	0.272
8	98.9	126.1	116.7	701.7	0.749	107	11.86	1027	428	0.349	6.9	0.269
9	126.1	151.3	142.2	747.6	0.768	121	11.82	1077	397	0.392	7.7	0.266
10	151.3	174.6	165.8	790.1	0.782	134	11.82	1120	367	0.437	8.6	0.262
11	174.6	196.4	187.2	828.6	0.793	147	11.84	1158	341	0.479	9.4	0.257
12	196.4	216.8	208.3	866.6	0.804	161	11.86	1195	318	0.523	10.2	0.253
13	216.8	235.9	227.2	900.6	0.815	175	11.85	1228	301	0.561	10.9	0.249
14	235.9	253.9	246.4	935.2	0.826	190	11.84	1261	284	0.601	11.7	0.245
15	253.9	271.1	266.0	970.5	0.836	206	11.84	1294	268	0.644	12.5	0.241
16	271.1	287.0	283.0	1001.1	0.843	222	11.87	1321	253	0.684	13.3	0.236
17	287.0	303.0	300.0	1031.7	0.851	237	11.87	1349	240	0.723	14.0	0.232
18	303.0	317.0	313.0	1055.1	0.856	251	11.89	1369	230	0.754	14.6	0.229
19	317.0	331.0	325.0	1076.7	0.861	263	11.90	1388	221	0.784	15.2	0.226
20	331.0	344.0	338.0	1100.1	0.866	275	11.92	1408	212	0.816	15.9	0.222
21	344.0	357.0	351.0	1123.5	0.871	291	11.94	1428	203	0.849	16.5	0.219
22	357.0	369.0	363.0	1145.1	0.876	305	11.94	1447	195	0.879	17.1	0.215
23	369.0	381.0	375.0	1166.7	0.881	318	11.95	1466	188	0.909	17.7	0.212
24	381.0	392.0	386.0	1186.5	0.885	331	11.96	1482	182	0.936	18.3	0.209
25	392.0	402.0	397.0	1206.3	0.888	345	11.99	1498	175	0.965	18.9	0.206

SINGLE CARBON NUMBER PROPERTIES OF C_{7+} FRACTIONS IN CUSTOMARY UNITS (continued)

(after Katz and Firoozabadi)

	Katz-Firoozabadi Generalized Properties						Defined	Lee-Kesler/Kesler-Lee Correlations			Riazi	Defined
	Normal Boiling Point Interval at 1 atm		Average Normal Boiling Point, T_b									
Carbon Number Fraction	Lower Boiling Point °C	Upper Boiling Point °C	°C	°R	Specific Gravity γ water=1	Molecular Weight M	Watson Factor K_w	Critical Temperature T_c °R	Critical Pressure p_c psia	Acentric Factor ω	Critical Volume V_c ft³/lbmol	Critical Z-factor Z_c
26	402.0	413.0	408.0	1226.1	0.892	359	12.00	1515	168	0.992	19.5	0.203
27	413.0	423.0	419.0	1245.9	0.896	374	12.01	1531	163	1.019	20.1	0.199
28	423.0	432.0	429.0	1263.9	0.899	388	12.03	1545	157	1.044	20.7	0.196
29	432.0	441.0	438.0	1280.1	0.902	402	12.04	1559	152	1.065	21.3	0.194
30	441.0	450.0	446.0	1294.5	0.905	416	12.04	1571	149	1.084	21.7	0.191
31	450.0	459.0	455.0	1310.7	0.909	430	12.04	1584	145	1.104	22.2	0.189
32	459.0	468.0	463.0	1325.1	0.912	444	12.04	1596	141	1.122	22.7	0.187
33	468.0	476.0	471.0	1339.5	0.915	458	12.05	1608	138	1.141	23.1	0.185
34	476.0	483.0	478.0	1352.1	0.917	472	12.06	1618	135	1.157	23.5	0.183
35	483.0	491.0	486.0	1366.5	0.920	486	12.06	1630	131	1.175	24.0	0.180
36			493.0	1379.1	0.922	500	12.07	1640	128	1.192	24.5	0.178
37			500.0	1391.7	0.925	514	12.07	1650	126	1.207	24.9	0.176
38			508.0	1406.1	0.927	528	12.09	1661	122	1.226	25.4	0.174
39			515.0	1418.7	0.929	542	12.10	1671	119	1.242	25.8	0.172
40			522.0	1431.3	0.931	556	12.10	1681	116	1.258	26.3	0.170
41			528.0	1442.1	0.933	570	12.11	1690	114	1.272	26.7	0.168
42			534.0	1452.9	0.934	584	12.13	1697	112	1.287	27.1	0.166
43			540.0	1463.7	0.936	598	12.13	1706	109	1.300	27.5	0.164
44			547.0	1476.3	0.938	612	12.14	1716	107	1.316	27.9	0.162
45			553.0	1487.1	0.940	626	12.14	1724	105	1.328	28.3	0.160

RECOMMENDED BINARY INTERACTION PARAMETERS FOR THE PENG-ROBINSON (PR) AND SOAVE-REDLICH-KWONG (SRK) EQUATIONS OF STATE FOR NONHYDROCARBON-HYDROCARBON COMPONENT PAIRS

	PR EOS			SRK EOS		
	N2	**CO2**	**H2S**	**N2**	**CO2**	**H2S**
N2	-	-	-	-	-	-
CO2	0.000	-	-	0.000	-	-
H2S	0.130	0.135	-	0.120	0.120	-
C1	0.025	0.105	0.070	0.020	0.120	0.080
C2	0.010	0.130	0.085	0.060	0.150	0.070
C3	0.090	0.125	0.080	0.080	0.150	0.070
IC4	0.095	0.120	0.075	0.080	0.150	0.060
C4	0.095	0.115	0.075	0.080	0.150	0.060
IC5	0.100	0.115	0.070	0.080	0.150	0.060
C5	0.110	0.115	0.070	0.080	0.150	0.060
C6	0.110	0.115	0.055	0.080	0.150	0.050
C7+	0.110	0.115	0.050[a]	0.080	0.150	0.030[a]

a. Should decrease gradually with increasing carbon number.

RECOMMENDED VOLUME TRANSLATION PARAMETERS s_i FOR THE PENG-ROBINSON (PR) AND SOAVE-REDLICH-KWONG (SRK) EQUATIONS OF STATE

$$s_i = c_i/b_i$$

$$b_i = \Omega_b \frac{RT_{ci}}{p_{ci}}$$

Component	PR EOS (Ω_b=0.07780)	SRK EOS (Ω_b=0.08664)
N2	-0.193	-0.008
CO2	-0.082	0.083
H2S	-0.129	0.047
C1	-0.159	0.023
C2	-0.113	0.060
C3	-0.086	0.082
IC4	-0.084	0.083
C4	-0.067	0.097
IC5	-0.061	0.102
C5	-0.039	0.121
C6	-0.008	0.147
C_{7+} Fractions	Determine s_i by forcing the EOS to fit exactly the measured specific gravity of each C_{7+} fraction.	

PHYSICAL CONSTANTS AND VALUES*
(from Earlougher)

Triple point of water	273.16 exactly 0.01 exactly 491.688 exactly 32.018 exactly	**K** °C °R °F
Absolute zero	0.00 exactly -273.15 exactly 0.00 exactly -459.67 exactly	**K** °C °R °F
Gas Constant (R)	8.3143 10.732	**$J \cdot mol^{-1} \cdot K^{-1}$** $psia \cdot ft^3 \cdot (lbmol)^{-1} \cdot {}^oR^{-1}$
Density of water at 60°F (15.56 °C, 288.71 K)	999.014 0.999 014 62.366 4	**$kg \cdot m^{-3}$** $g \cdot cm^{-3}$ $lb \cdot ft^{-3}$
Standard atmosphere	1.013 25 E+05 1.013 25 14.695 9	**Pa** bar psia
Density of air at 1 atm, 60°F (15.56 °C, 288.71 K)	1.223 2 1.223 2 E-03 0.076 362	**$kg \cdot m^{-3}$** $g \cdot cm^{-3}$ $lb \cdot ft^{-3}$
Earth's gravitational acceleration, g	9.806 650 980.665 0 32.174 05	**$m \cdot s^{-2}$** $cm \cdot s^{-2}$ $ft \cdot s^{-2}$
g_c	1.000 000 1.000 000 32.174 05	**$kg \cdot m \cdot N^{-1} \cdot s^{-2}$** $g \cdot cm \cdot dyne^{-1} \cdot s^{-2}$ $lb_m \cdot ft \cdot lb_f^{-1} \cdot s^{-2}$
π	3.141 593	
°API (γ_{API})	$\frac{141.5}{\gamma(60^oF)} - 131.5$	

* SI values are in boldface type. All quantities are consistent with conversion factors for the current SI system.

UNIVERSAL GAS CONSTANT FOR VARIOUS UNITS

Pressure Unit	Volume Unit	Temperature Unit	Mass(mole) Unit	Gas Constant R
psia	ft^3	°R	lb	10.7315
psia	cm^3	°R	lb	303880
psia	cm^3	°R	g	669.94
bar	ft^3	°R	lb	0.73991
atm	ft^3	°R	lb	0.73023
atm	cm^3	°R	g	45.586
Pa	m^3	K	kg	8314.3
Pa	m^3	K	g	8.3143
kPa	m^3	K	kg	8.3143
kPa	cm^3	K	g	8314.3
bar	m^3	K	kg	0.083143
bar	cm^3	K	g	83.143
atm	m^3	K	kg	0.082055
atm	cm^3	K	g	82.055
Energy Unit				
Btu		°R	lb	1.9858
Btu		°R	g	0.0043780
cal		°R	lb	500.76
cal		°R	g	1.1040
kcal		°R	lb	0.50076
kcal		°R	g	0.0011040
cal		K	kg	1985.8
cal		K	g	1.9858
erg		K	kg	8.3143E+10
erg		K	g	8.3143E+07
J		K	kg	8314.3
J		K	g	8.3143

GREEK ALPHABET

Upper Case	Lower Case	Name
Α	α	alpha
Β	β	beta
Γ	γ	gamma
Δ	δ	delta
Ε	ε	epsilon
Ζ	ζ	zeta
Η	η	eta
Θ	θ	theta
Ι	ι	iota
Κ	κ	kappa
Λ	λ	lambda
Μ	μ	mu
Ν	ν	nu
Ξ	ξ	xi
Ο	ο	omicron
Π	π	pi
Ρ	ρ	rho
Σ	σ	sigma
Τ	τ	tau
Υ	υ	upsilon
Φ	ϕ	phi
Χ	χ	chi
Ψ	ψ	psi
Ω	ω	omega

SI SYSTEM UNITS
(from Earlougher)

Base SI Units Used in Phase Behavior

Quantity	Name	Symbol
length	metre	m
time	second	s
mass	kilogram	kg
temperature	kelvin	K
amount of substance	mole	mol

Units That Are Multiples or Submultiples of SI Base Units Given Special Names

Quantity	Name of Unit	Symbol	Definition	SI Term
mass	tonne	t	1 t = 10^3 kg	Mg
volume	litre	l	1 l = 1 dm^3	dm^3

SI PREFIXES
(from Earlougher)

Factor	Prefix	Symbol*
10^{12}	tera	T
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^2	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

* Only the symbols T (tera), G (giga), and M (mega) are capital letters. Compound prefixes are not allowed - for example, use nm (nano metre) rather than mμm (milli micro metre).

USEFUL CONVERSION FACTORS
(from Earlougher)

SI conversions are in boldface type. All quantities are current to SI standards as of 1974. An asterisk (*) after the sixth decimal indicates the conversion factor is exact and all following digits are zero. All other conversion factors have been rounded. The notation E+03 is used in place of 10^3, and so on.

To Convert From	To	Multiply by	Inverse
AREA			
acre	**metre² (m²)**	4.046 856 E+03	2.471 054 E−04
	foot²	4.356 000* E+04	2.295 684 E−05
darcy	**metre² (m²)**	9.869 23 E−13	1.013 25 E+12
	centimetre² (cm²)	9.869 23 E−09	1.013 25 E+08
	micrometre² (μm²)	9.869 23 E−01	1.013 25 E+00
	millidarcy	1.000 000* E+03	1.000 000*E−03
	cm²·cp·sec⁻¹·atm⁻¹	1.000 000* E+00	1.000 000*E+00
foot²	**metre² (m²)**	9.290 304* E−02	1.076 391 E+01
	centimetre²	9.290 304* E+02	1.076 391 E−03
	inch²	1.440 000* E+02	6.944 444 E−03
hectare	**metre² (m²)**	1.000 000* E+04	1.000 000*E−04
	acre	2.471 054 E+00	4.046 856 E−01
mile²	**metre² (m²)**	2.589 988 E+06	3.861 022 E−07
	acre	6.400 000* E+02	1.562 500*E−03
DENSITY			
gram/centimetre³	**kilogram/metre³ (kg·m⁻³)**	1.000 000* E+03	1.000 000*E−03
	pound-mass/foot³	6.242 797 E+01	1.601 846 E−02
	pound-mass/gallon	8.345 405 E+00	1.198 264 E−01
	pound-mass/barrel	3.505 070 E+02	2.853 010 E−03
pound-mass/foot³	**kilogram/metre³ (kg·m⁻³)**	1.601 846 E+01	6.242 797 E−02
	pound-mass/gallon	1.336 805 E−01	7.480 520 E+00
	pound-mass/barrel	5.614 583 E+00	1.781 076 E−01
pound-mass/gallon	**kilogram/metre³ (kg·m⁻³)**	1.198 264 E+02	8.345 406 E−03
	pound-mass/barrel	4.200 000 E+01	2.380 952 E−02
FORCE			
dyne	**newton (N)**	1.000 000* E−05	1.000 000*E+05
	pound-force	2.248 089 E−06	4.448 222 E+05
kilogram-force	**newton (N)**	9.806 650* E+00	1.019 716 E−01
	pound-force	2.204 622 E+00	4.535 924 E−01
pound-force	**newton (N)**	4.448 222 E+00	2.248 089 E−01
LENGTH			
angstrom	**metre (m)**	1.000 000* E−10	1.000 000*E+10
centimetre	**metre (m)**	1.000 000* E−02	1.000 000*E+02
foot	**metre (m)**	3.048 000* E−01	3.280 840 E+00
	centimetre	3.048 000* E+01	3.280 840 E−02
inch	**metre (m)**	2.540 000* E−02	3.937 008 E+01
	centimetre	2.540 000* E+00	3.937 008 E−01
micron	**metre (m)**	1.000 000* E−06	1.000 000*E+06
mile (U.S. statute)	**metre (m)**	1.609 344* E+03	6.213 712 E−04
	foot	5.280 000* E+03	1.893 939 E−04
MASS			
gram-mass	**kilogram (kg)**	1.000 000* E−03	1.000 000*E+03
ounce-mass (av)	**kilogram (kg)**	2.834 952 E−02	3.527 397 E+01
	gram	2.834 952 E+01	3.527 397 E−02
pound-mass	**kilogram (kg)**	4.535 923 7*E−01	2.204 623 E+00
	ounce-mass	1.600 000* E+01	6.250 000*E−02
slug	**kilogram (kg)**	1.459 390 E+01	6.852 178 E−02
	pound-mass	3.217 405 E+01	3.108 095 E−02
ton (U.S. short)	**kilogram (kg)**	9.071 847 E+02	1.102 311 E−03
	pound-mass	2.000 000* E+03	5.000 000*E−04
ton (U.S. long)	**kilogram (kg)**	1.016 047 E+03	9.842 064 E−04
	pound-mass	2.240 000* E+03	4.464 286 E−04
ton (metric)	**kilogram (kg)**	1.000 000* E+03	1.000 000*E−03
tonne	**kilogram (kg)**	1.000 000* E+03	1.000 000*E−03

USEFUL CONVERSION FACTORS
(from Earlougher)

To Convert From	To	Multiply by	Inverse
PRESSURE			
atmosphere (normal—760 mm Hg)	**pascal (Pa)**	1.013 25 E+05	9.869 23 E−06
	mm Hg (0 °C)	7.600 000*E+02	1.315 789 E−03
	feet water (4 °C)	3.389 95 E+01	2.949 90 E−02
	psi	1.469 60 E+01	6.804 60 E−02
	bar	1.013 25 E+00	9.869 23 E−01
bar	**pascal (Pa)**	1.000 000*E+05	1.000 000*E−05
	psi	1.450 377 E+01	6.894 757 E−02
centimetre of Hg (0 °C)	**pascal (Pa)**	1.333 22 E+03	7.500 64 E−04
	psi	1.933 67 E−01	5.171 51 E+00
dyne/centimetre²	**pascal (Pa)**	1.000 000*E−01	1.000 000*E+01
	psi	1.450 377 E−05	6.894 757 E+04
feet of water (4 °C)	**pascal (Pa)**	2.988 98 E+03	3.345 62 E−04
	psi	4.335 15 E−01	2.306 73 E+00
kilogram-force/centimetre²	**pascal (Pa)**	9.806 650*E+04	1.019 716 E−05
	bar	9.806 650*E−01	1.019 716 E+00
	psi	1.422 334 E+01	7.030 695 E−02
psi	**pascal (Pa)**	6.894 757 E+03	1.450 377 E−04
TIME			
day	**second (s)**	8.640 000*E+04	1.157 407 E−05
	minute	1.440 000*E+03	6.944 444 E−04
	hour	2.400 000*E+01	4.166 667 E−02
hour	**second (s)**	3.600 000*E+03	2.777 778 E−04
	minute	6.000 000*E+01	1.666 667 E−02
minute	**second (s)**	6.000 000*E+01	1.666 667 E−02
VISCOSITY			
centipoise	**pascal-second (Pa·s)**	1.000 000*E−03	1.000 000*E+03
	dyne-second/centimetre²	1.000 000*E−02	1.000 000*E+02
	pound-mass/(foot-second)	6.719 689 E−04	1.488 164 E+03
	pound-force-second/foot²	2.088 543 E−05	4.788 026 E+04
	pound-mass/(foot-hour)	2.419 088 E+00	4.133 789 E−01
centistoke	**metre²/second (m²/s)**	1.000 000*E−06	1.000 000*E+06
	centipoise/(gram/centimetre³)	1.000 000*E+00	1.000 000*E+00
poise	**pascal-second (Pa·s)**	1.000 000*E−01	1.000 000*E+01
pound-mass/(foot-second)	**pascal-second (Pa·s)**	1.488 164 E+00	6.719 689 E−01
pound-mass/(foot-hour)	**pascal-second (Pa·s)**	4.133 789 E−04	2.419 088 E+03
pound-force-second/foot²	**pascal-second (Pa·s)**	4.788 026 E+01	2.088 543 E−02
VOLUME			
acre-foot	**metre³ (m³)**	1.233 482 E+03	8.107 131 E−04
	foot³	4.356 000*E+04	2.295 684 E−05
	barrel	7.758 368 E+03	1.288 931 E−04
barrel	**metre³ (m³)**	1.589 873 E−01	6.289 811 E+00
	foot³	5.614 583 E+00	1.781 076 E−01
	gallon	4.200 000*E+01	2.380 952 E−02
foot³	**metre³ (m³)**	2.831 685 E−02	3.531 466 E+01
	inch³	1.728 000 E+03	5.787 037 E−04
	gallon	7.480 520 E+00	1.336 805 E−01
gallon	**metre³ (m³)**	3.785 412 E−03	2.641 720 E+02
	inch³	2.310 001 E+02	4.329 003 E−03
litre	**metre³ (m³)**	1.000 000*E−03	1.000 000*E+03
VOLUMETRIC RATE			
barrel/day	**metre³/sec (m³/s)**	1.840 131 E−06	5.434 396 E+05
	metre³/hour (m³/h)	6.624 472 E−03	1.509 554 E+02
	metre³/day (m³/d)	1.589 873 E−01	6.289 810 E+00
	centimetre³/second	1.840 131 E+00	5.434 396 E−01
	foot³/minute	3.899 016 E−03	2.564 750 E+02
	gallon/minute	2.916 667 E−02	3.428 571 E+01
foot³/minute	**metre³/sec (m³/s)**	4.719 474 E−04	2.118 880 E+03
foot³/second	**metre³/sec (m³/s)**	2.831 685 E−02	3.531 466 E+01
gallon/minute	**metre³/sec (m³/s)**	6.309 020 E−05	1.585 032 E+04

USEFUL CONVERSION FACTORS

(additional unit conversions)

To Convert From	To	Multiply by	Inverse
AMOUNT OF SUBSTANCE			
mol	lbmol	2.204 623 E-03	4.535 923 E+02
	gmol	1.000 000*E+00	1.000 000*E+00
	kmol	1.000 000*E-03	1.000 000*E+03
kmol	mol	1.000 000*E+03	1.000 000*E-03
	gmol	1.000 000*E+03	1.000 000*E-03
	lbmol	2.204 623 E+00	4.535 923 E-01
DIFFUSIVITY			
cm^2/s	m^2/s	1.000 000*E-04	1.000 000*E+04
	mm^2/s	1.000 000*E+02	1.000 000*E-02
	ft^2/s	1.076 390 E-03	9.290 304 E+02
	ft^2/hr	3.875 000 E+00	2.580 640 E-01
SURFACE TENSION			
mN/m	dyne/cm	1.000 000*E+00	1.000 000*E+00
ENERGY			
Btu	kJ	1.055 056 E+00	9.478 160 E-01
	cal	2.521 640 E+02	3.965 660 E-03
	kcal	2.521 640 E-01	3.965 660 E+00
	erg	1.055 056 E+10	9.478 160 E-11

* Exact conversion.

TEMPERATURE SCALE CONVERSIONS*

(from Earlougher)

To Convert	To	Solve
degree Fahrenheit (T_F)	kelvin (T_K)	$T_K = (T_F + 459.67)/1.8$
degree Rankine (T_R)	kelvin (T_K)	$T_K = T_R/1.8$
degree Fahrenheit (T_F)	degree Rankine (T_R)	$T_R = T_F + 459.67$
degree Fahrenheit (T_F)	degree Celcius (T_C)	$T_C = (T_F - 32)/1.8$
degree Celsius (T_C)	kelvin (T_K)	$T_K = T_C + 273.15$

* The SI standard, the kelvin (K), is defined so the triple point of water is 273.16 K exactly. The SI temperature symbol is written K, without a degree symbol. The cgs (and common) temperature unit is degree Celcius, °C; the common oilfield unit is degree Fahrenheit, °F, or degree Rankine, °R.

5A1.3

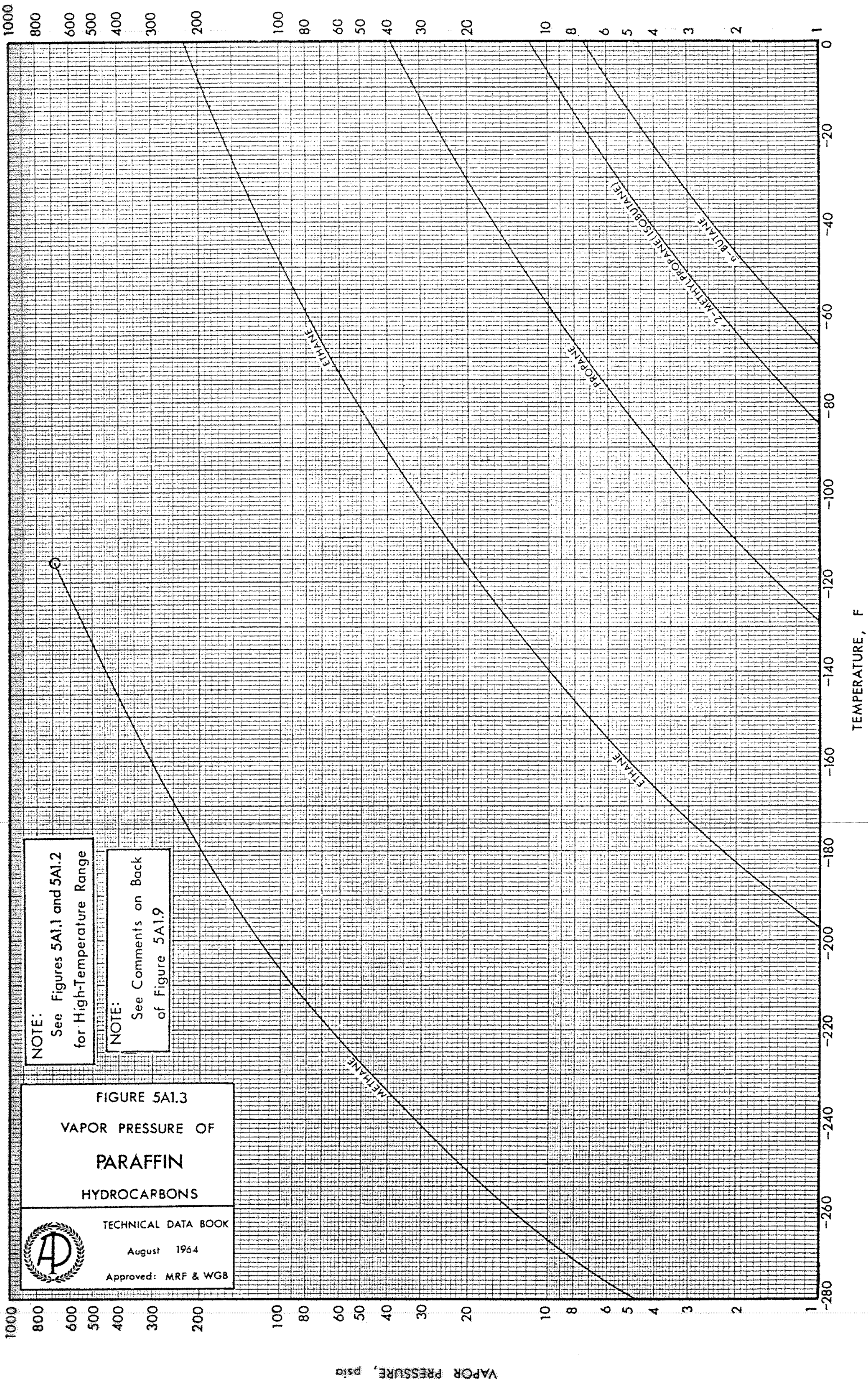


FIGURE 5A1.3
VAPOR PRESSURE OF
PARAFFIN
HYDROCARBONS
TECHNICAL DATA BOOK
August 1964
Approved: MRF & WGB
NOTE: See Figures 5A1.1 and 5A1.2 for High-Temperature Range
NOTE: See Comments on Back of Figure 5A1.9
METHANE
ETHANE
PROPANE
2-METHYLPROPANE (ISOBUTANE)
n-BUTANE
TEMPERATURE, F
VAPOR PRESSURE, psia

5A1.1

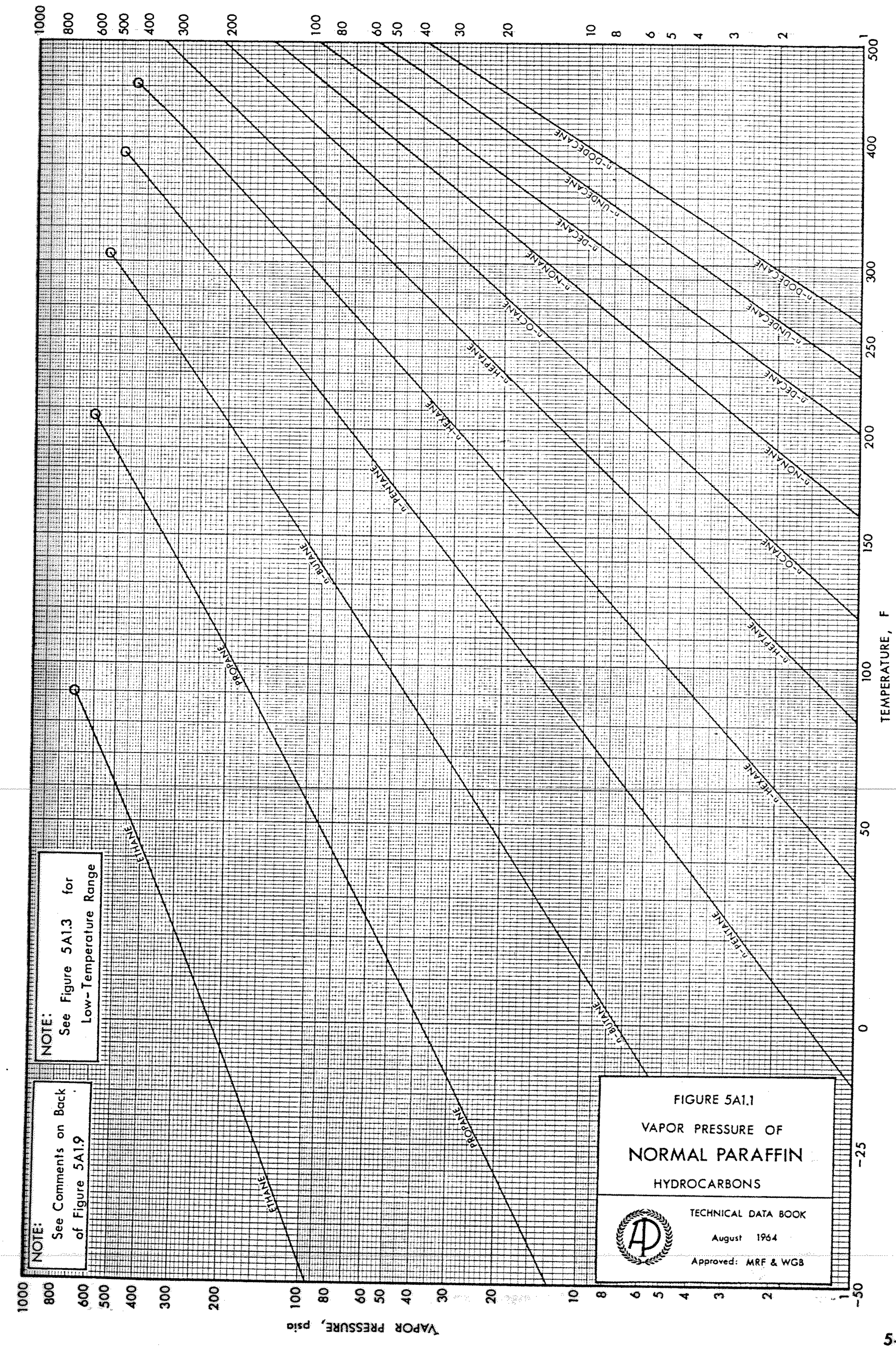
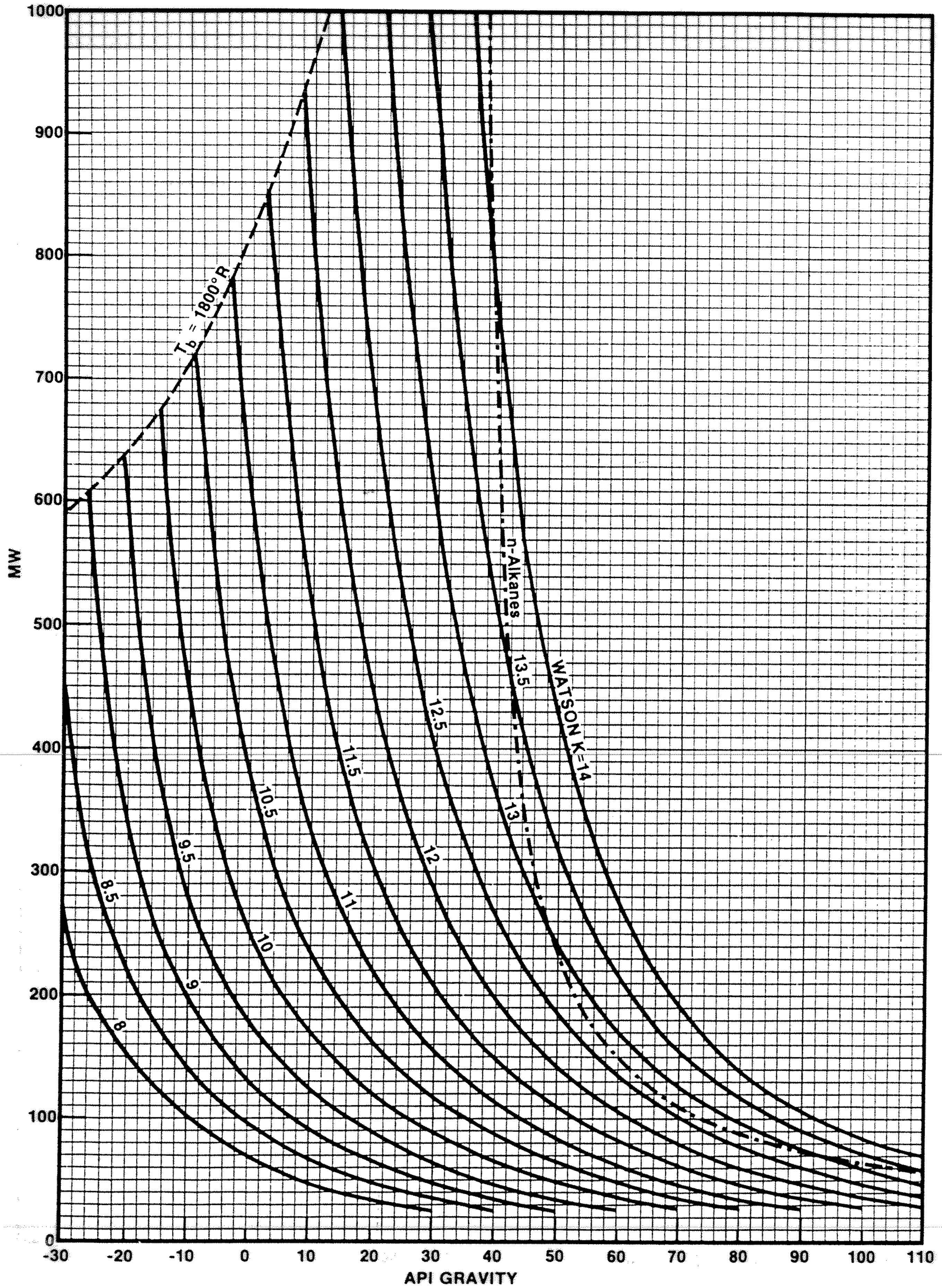
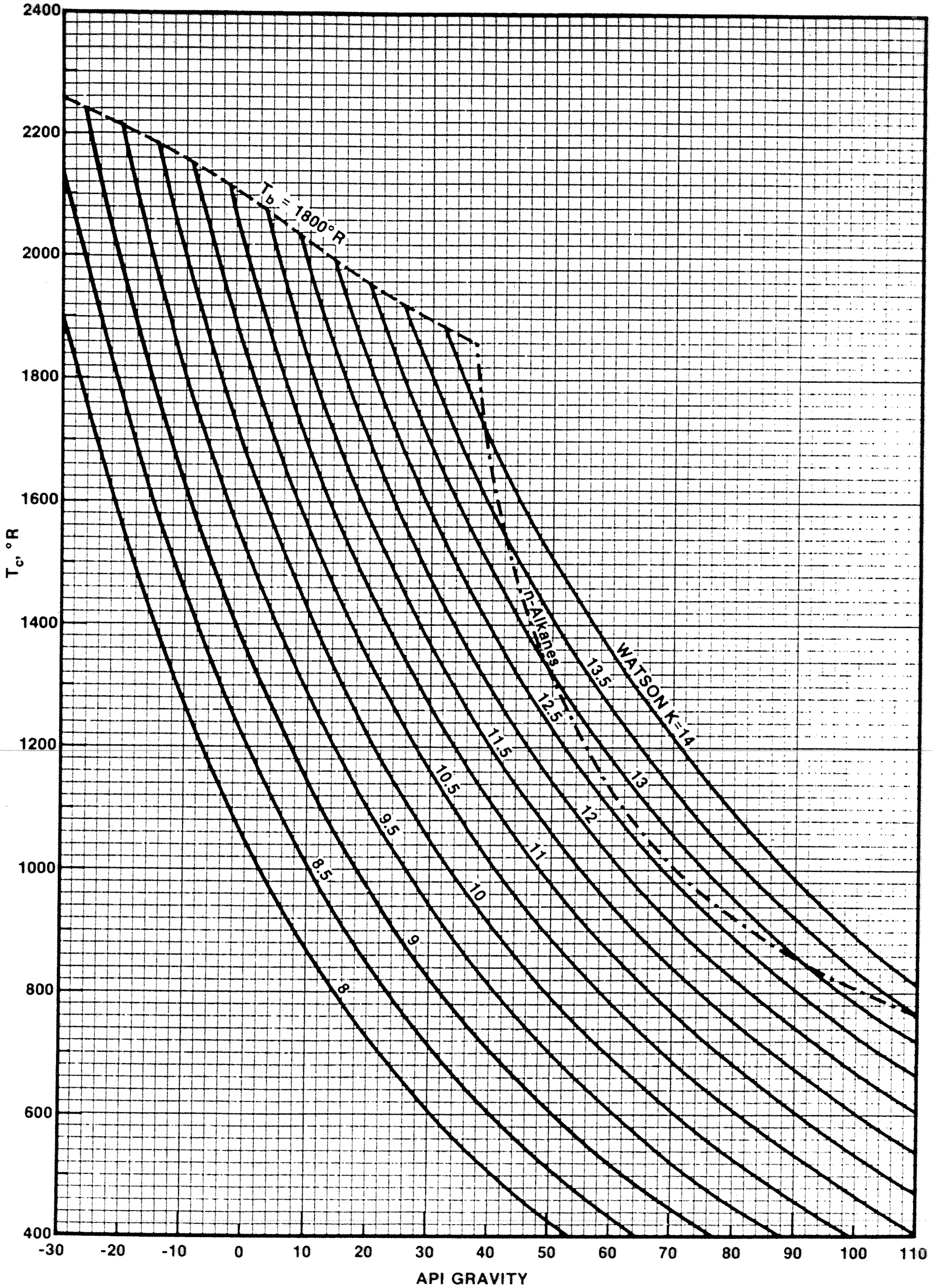


FIGURE 5A1.1
VAPOR PRESSURE OF
NORMAL PARAFFIN
HYDROCARBONS
TECHNICAL DATA BOOK
August 1964
Approved: MRF & WGB
NOTE: See Comments on Back of Figure 5A1.9
NOTE: See Figure 5A1.3 for Low-Temperature Range
VAPOR PRESSURE, psia
TEMPERATURE, F
ETHANE
PROPANE
n-BUTANE
n-PENTANE
n-HEXANE
n-HEPTANE
n-OCTANE
n-NONANE
n-DECANE
n-UNDECANE
n-DODECANE

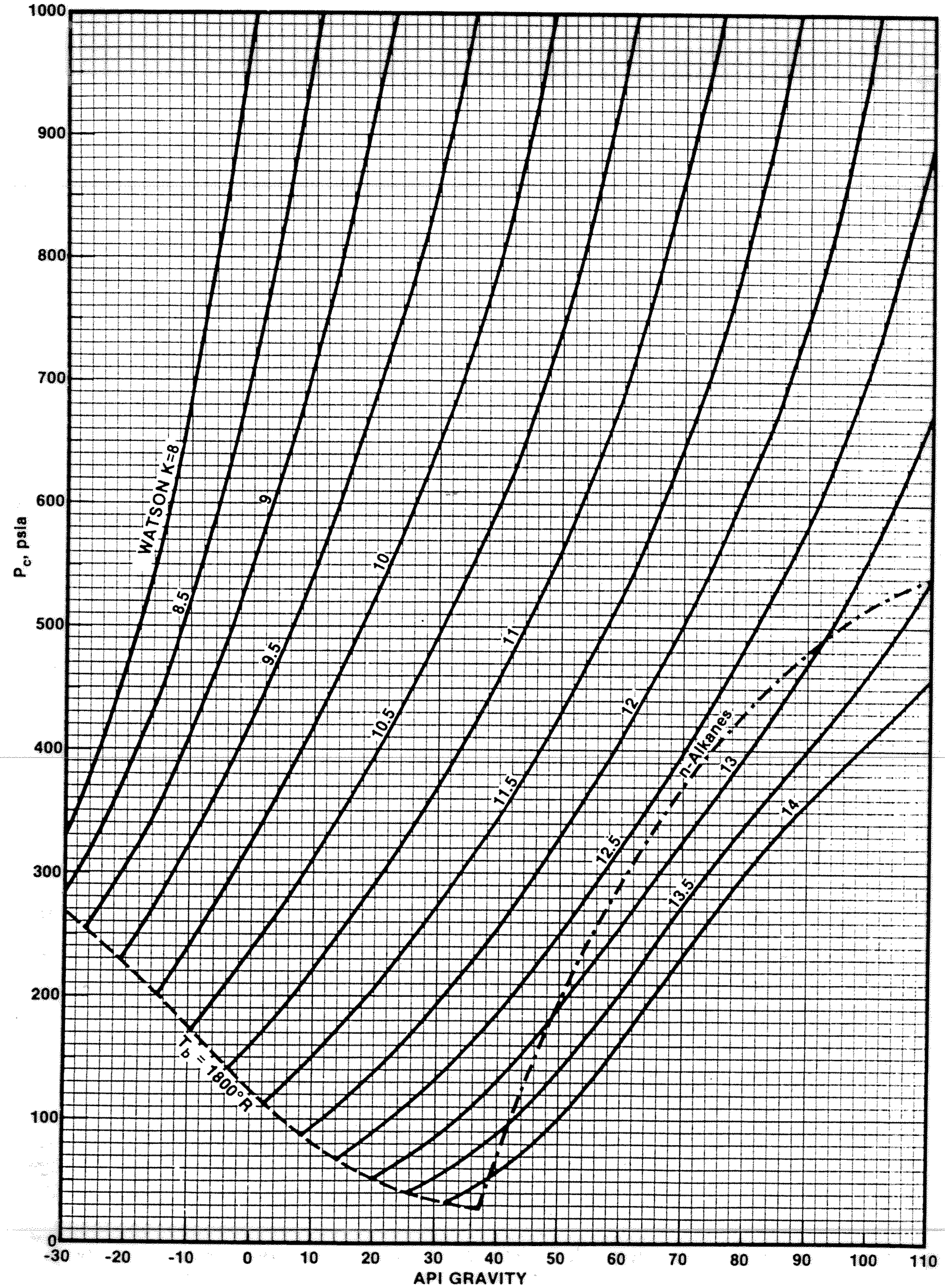
Twu Correlations



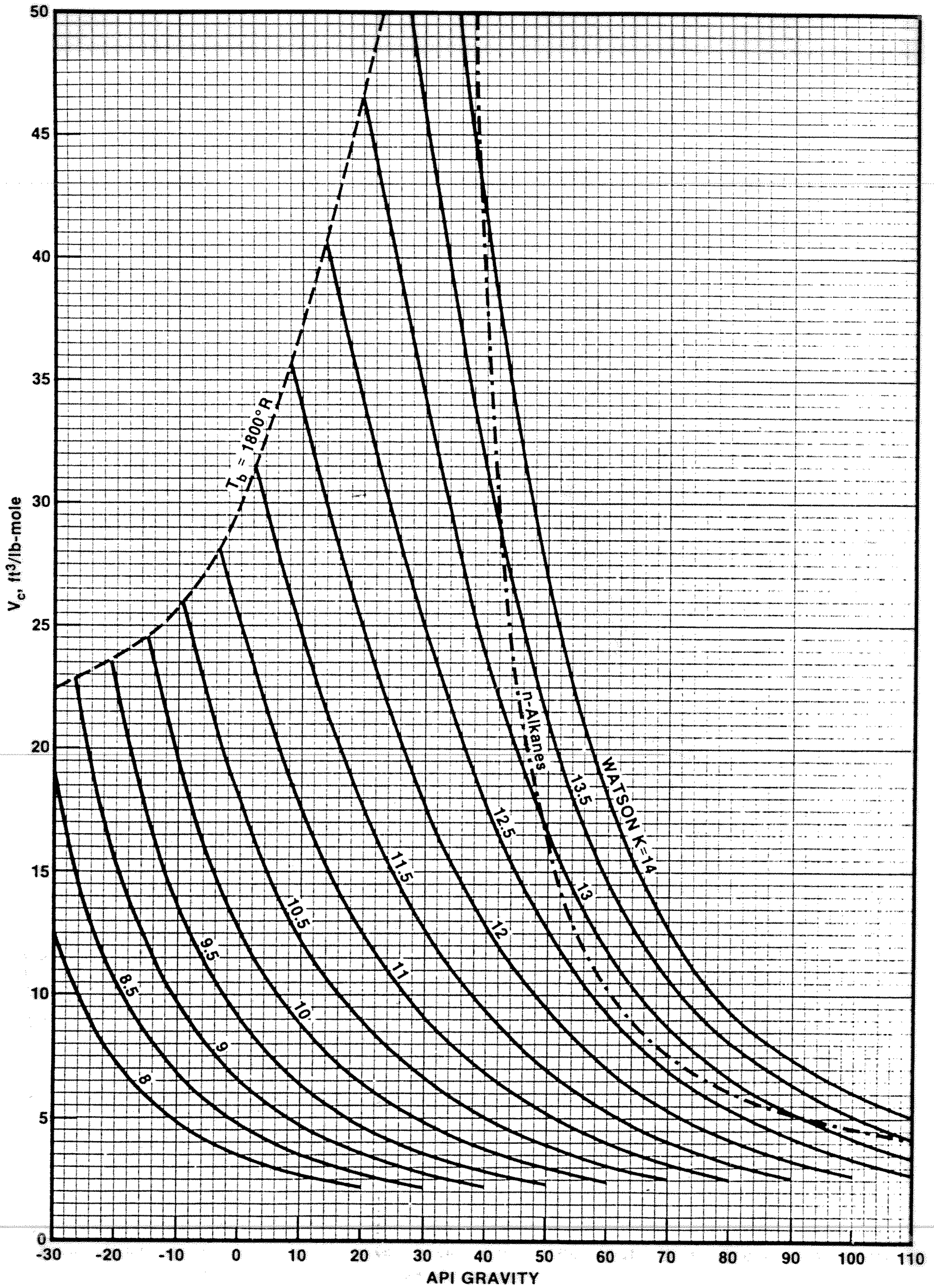
Twu Correlations

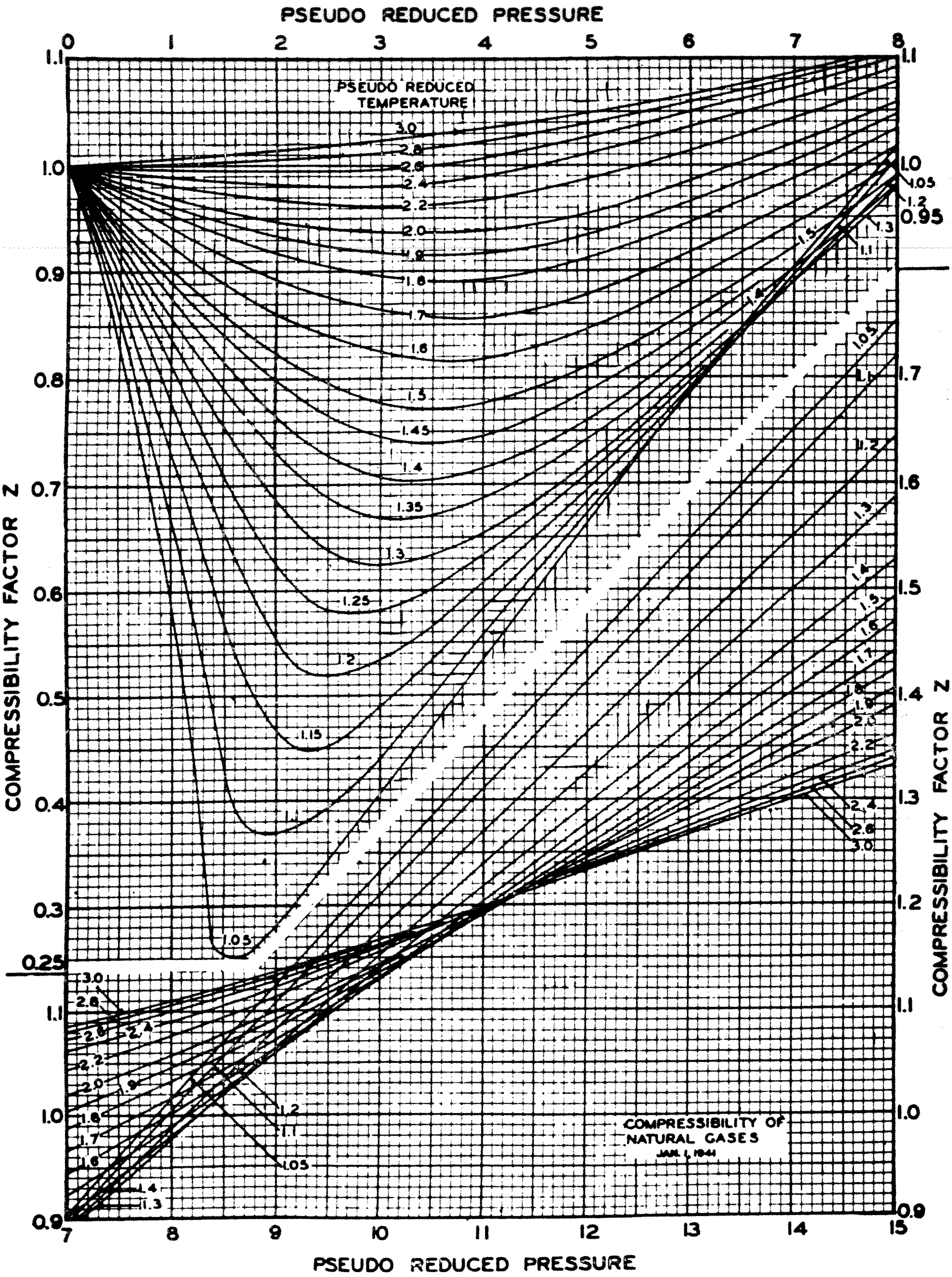


Twu Correlations

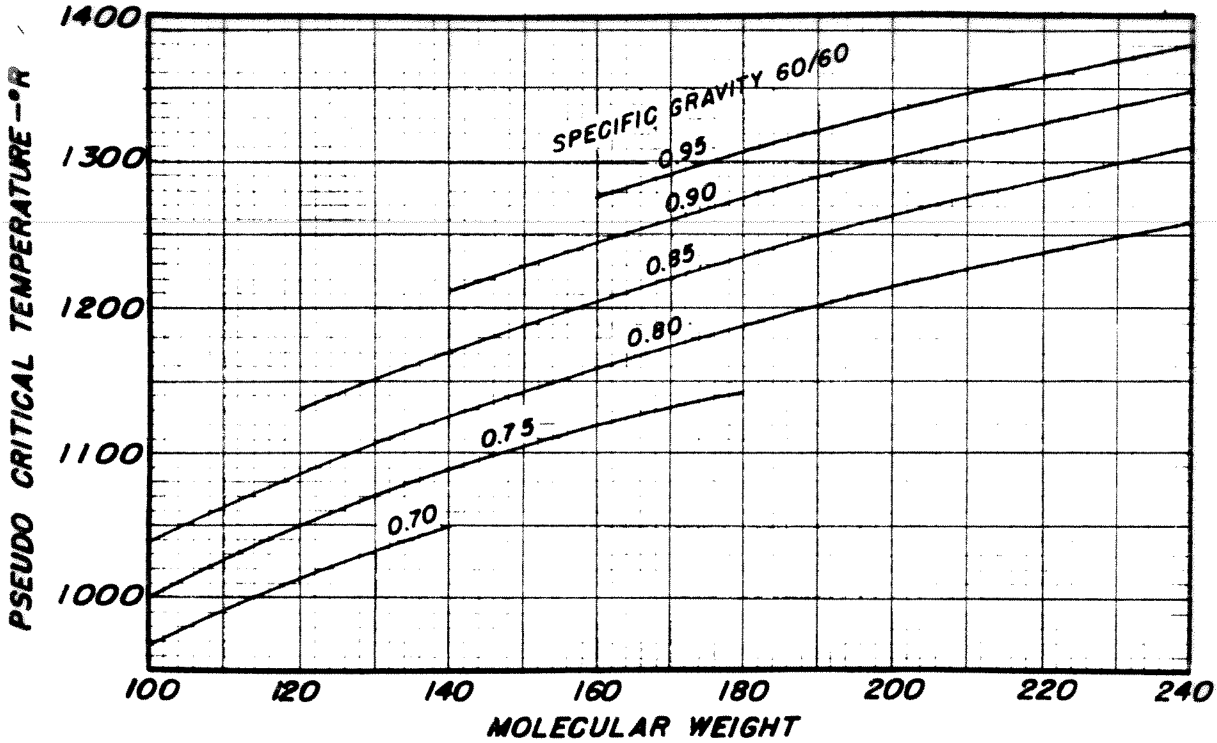


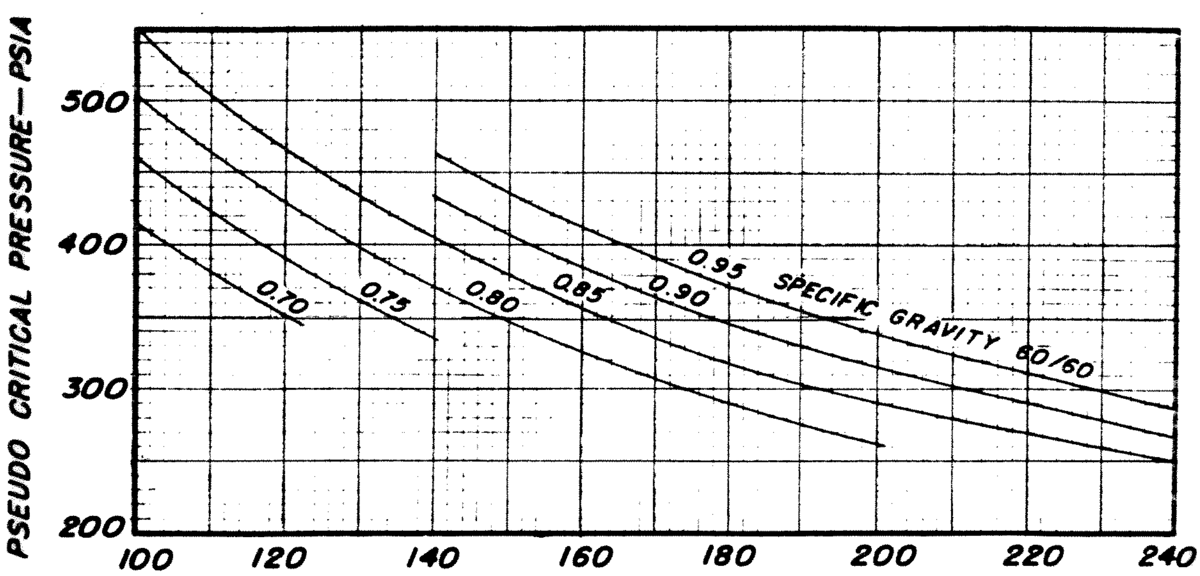
Twu Correlations



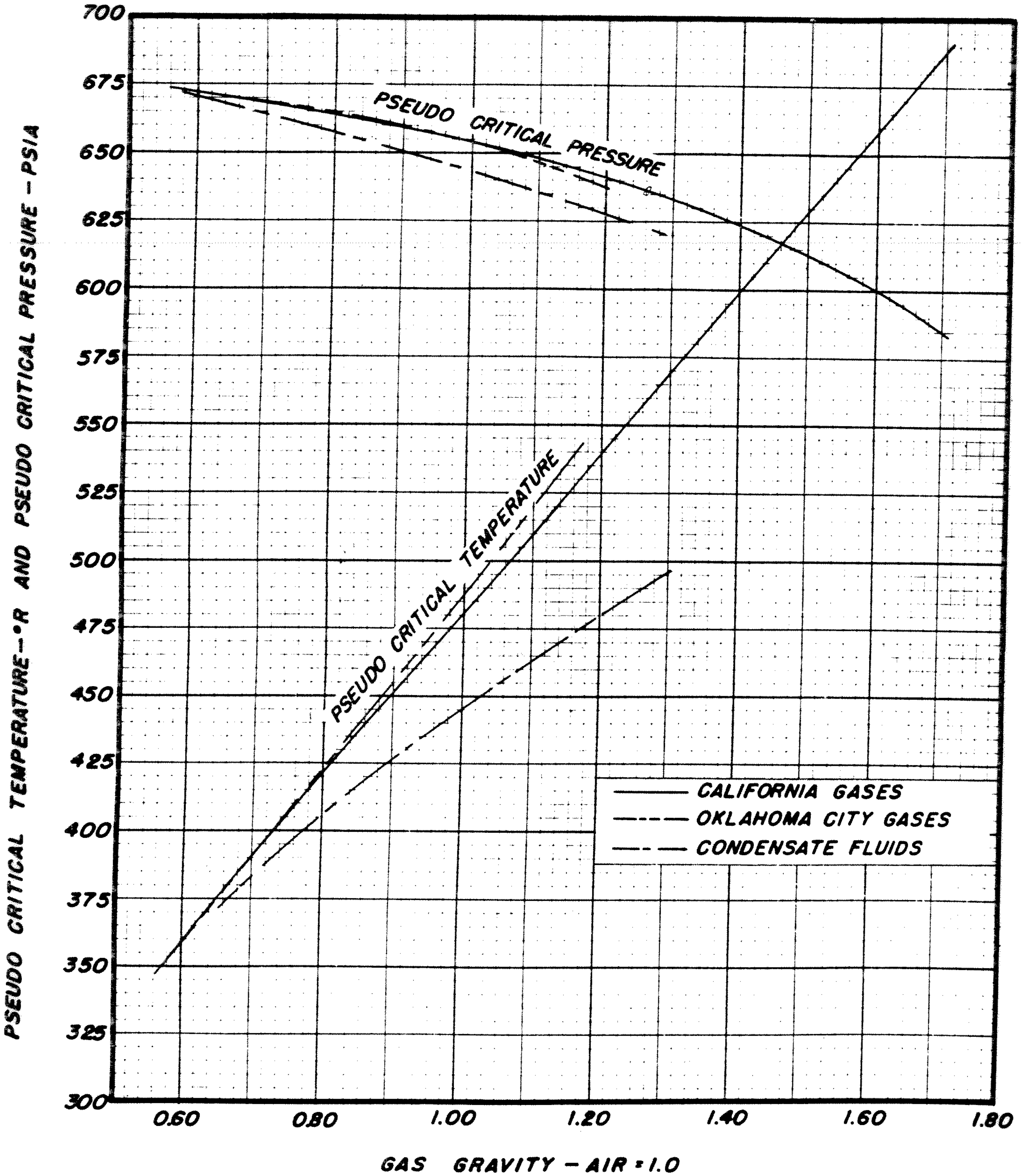


COMPRESSIBILITY FACTOR, Z, OF NATURAL GASES VS.
PSEUDOREDUCED PRESSURE AND PSEUDOREDUCED TEMPERATURE
(After Standing and Katz, Trans AIME, 1942)

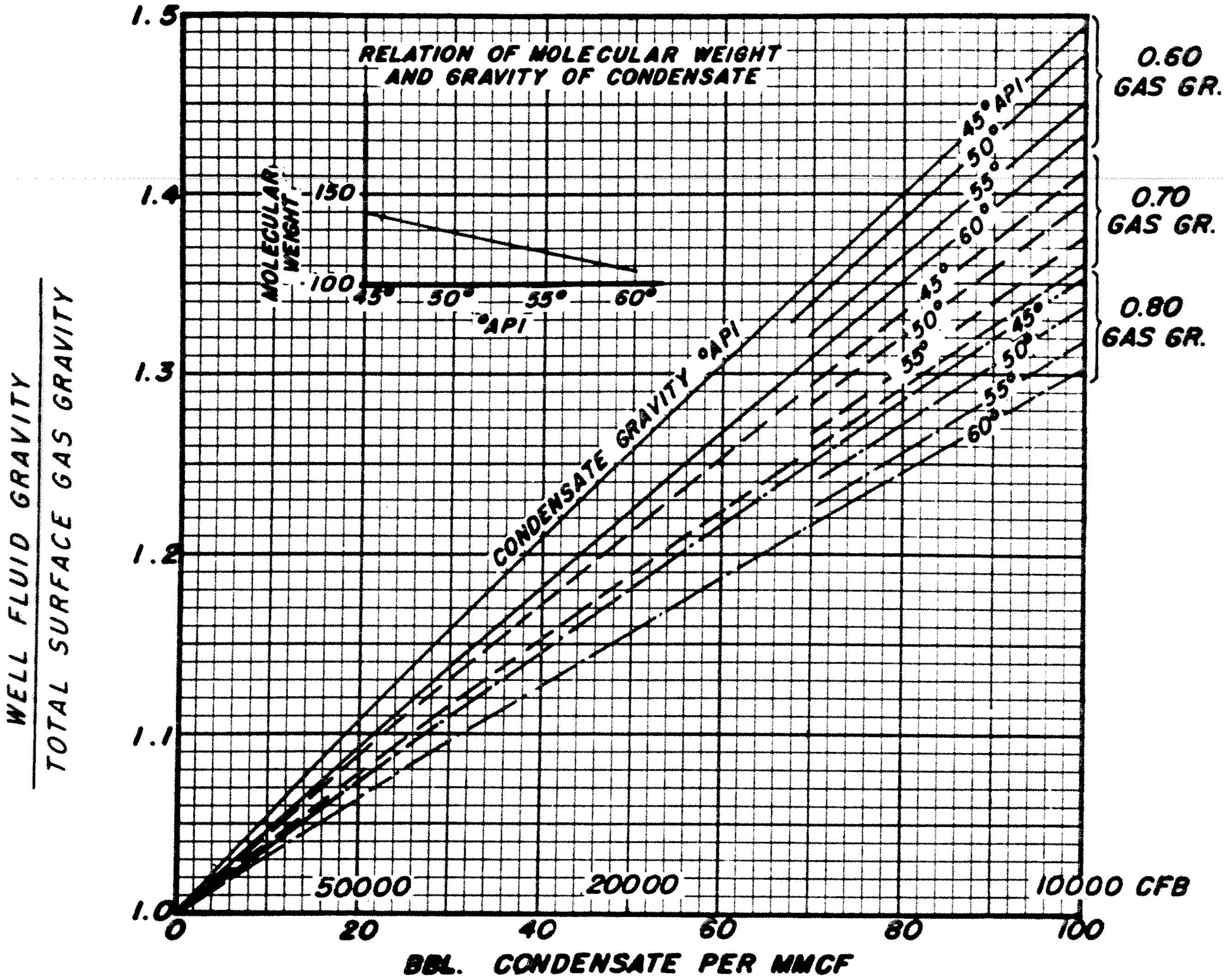




PSEUDOCRITICAL TEMPERATURE AND PRESSURE
VS. MOLECULAR WEIGHT AND SPECIFIC GRAVITY
FOR HEPTANES AND HEAVIER FRACTION
IN GAS AND GAS CONDENSATE SYSTEMS
(After Mathews, Roland and Katz. Proceeding NGAA, 1942)

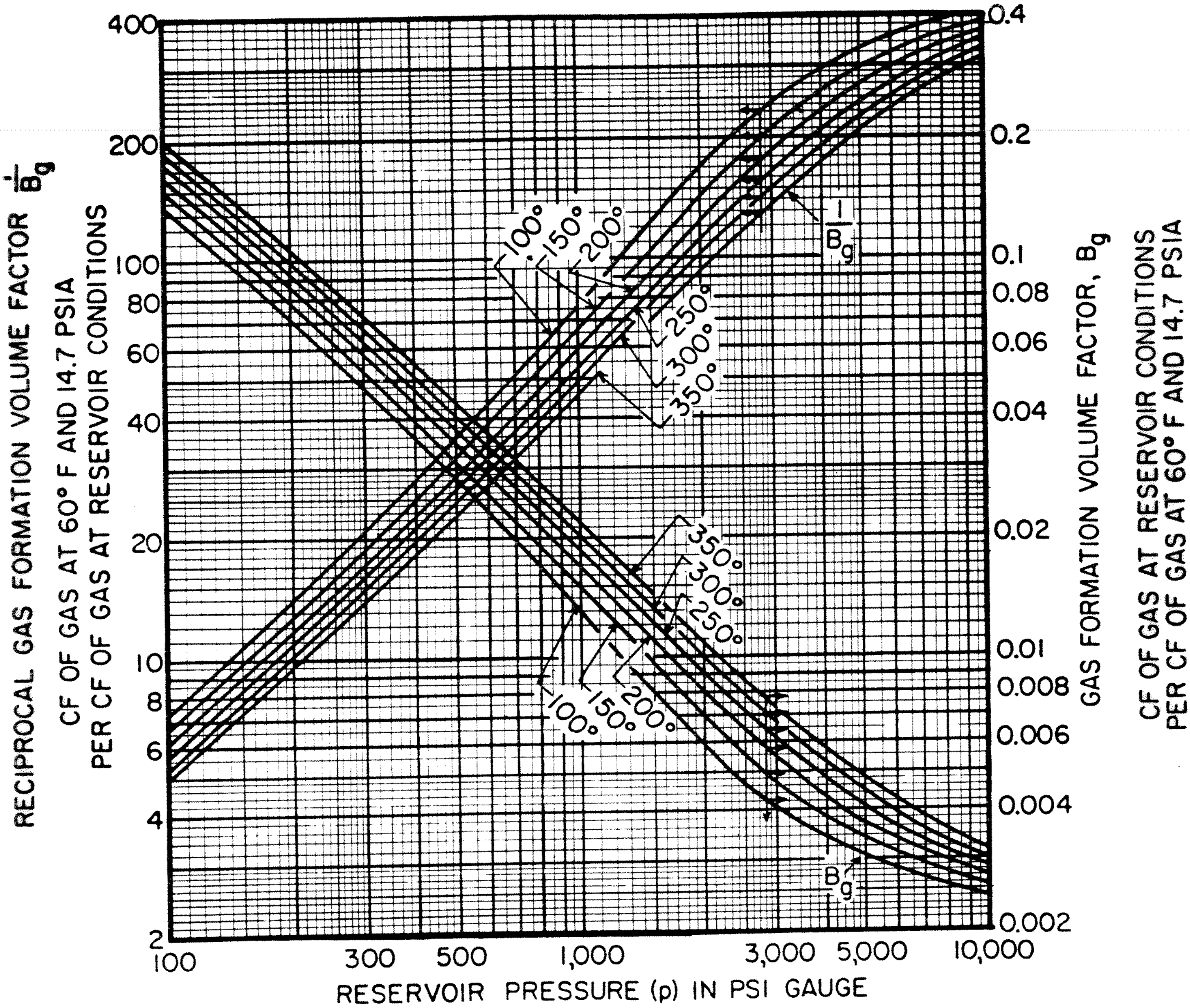


PSEUDOCRITICAL PRESSURE AND TEMPERATURE OF NATURAL GAS AND GAS CONDENSATE FLUIDS VS. GAS GRAVITY
(After Standing, Oil Field Hydrocarbon Systems, Reinhold Publishing, 1952)



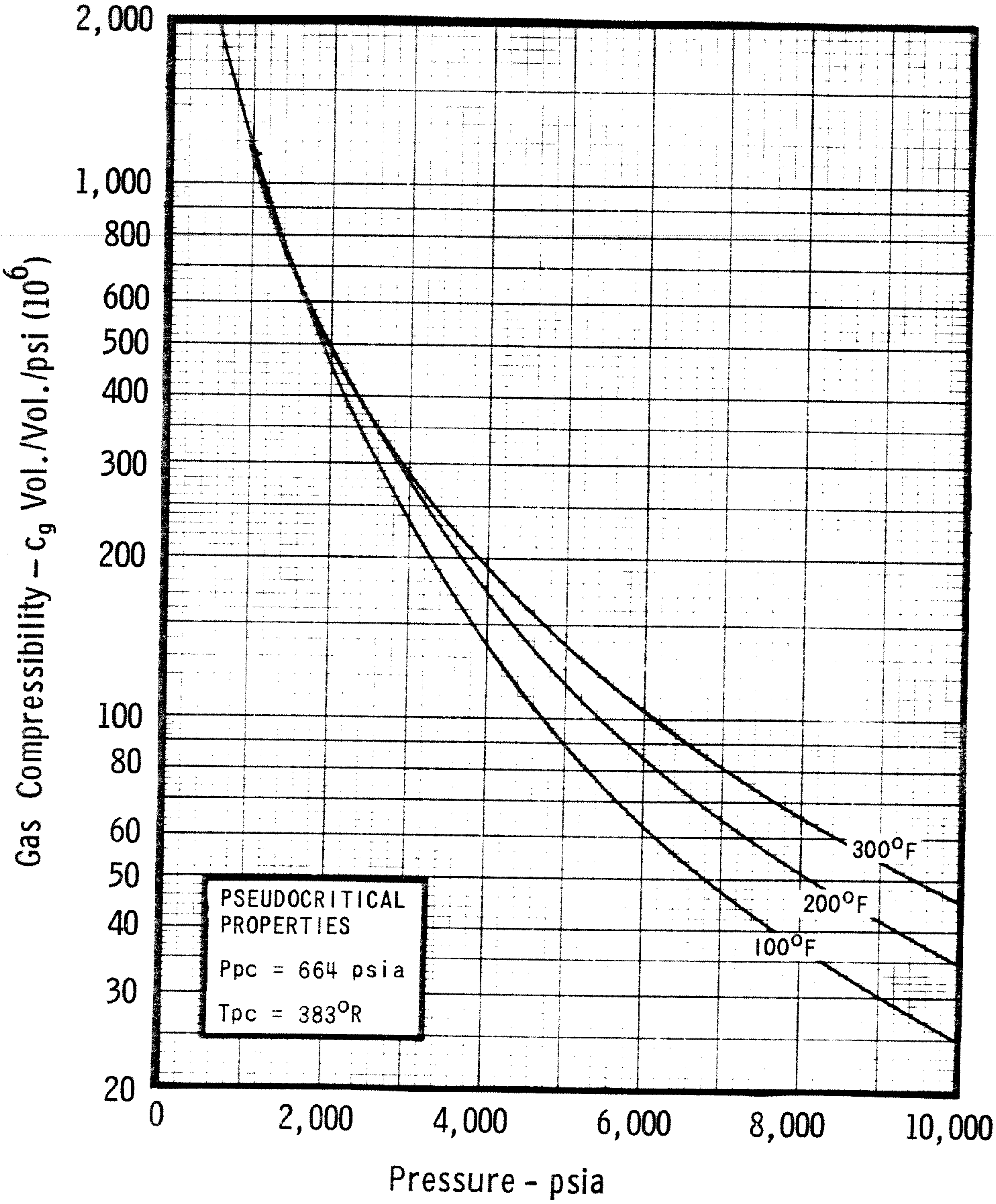
RATIO OF WELL FLUID GRAVITY TO TOTAL SURFACE GAS GRAVITY
VS. BARRELS OF CONDENSATE PER M Mcf
(After Standing, Oil Field Hydrocarbon Systems,
Reinhold Publishing, 1952)

Gas gravity 0.7 (air 1.0).

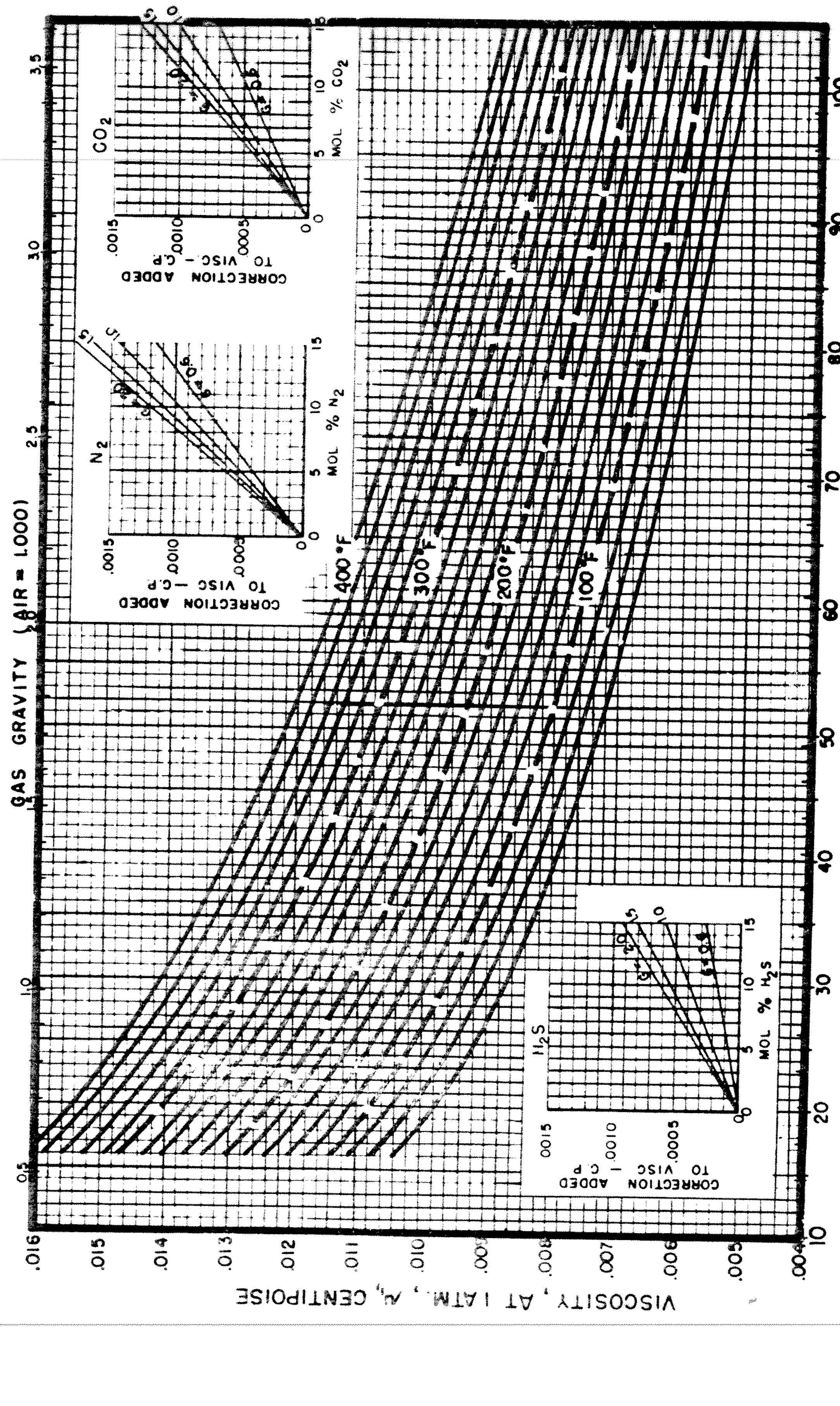


Gas-formation volume factor, B_g, and reciprocal gas-formation volume $\frac{1}{B_g}$ vs. pressure and temperature. Gas gravity = 0.7. To calculate gas density use relationship:

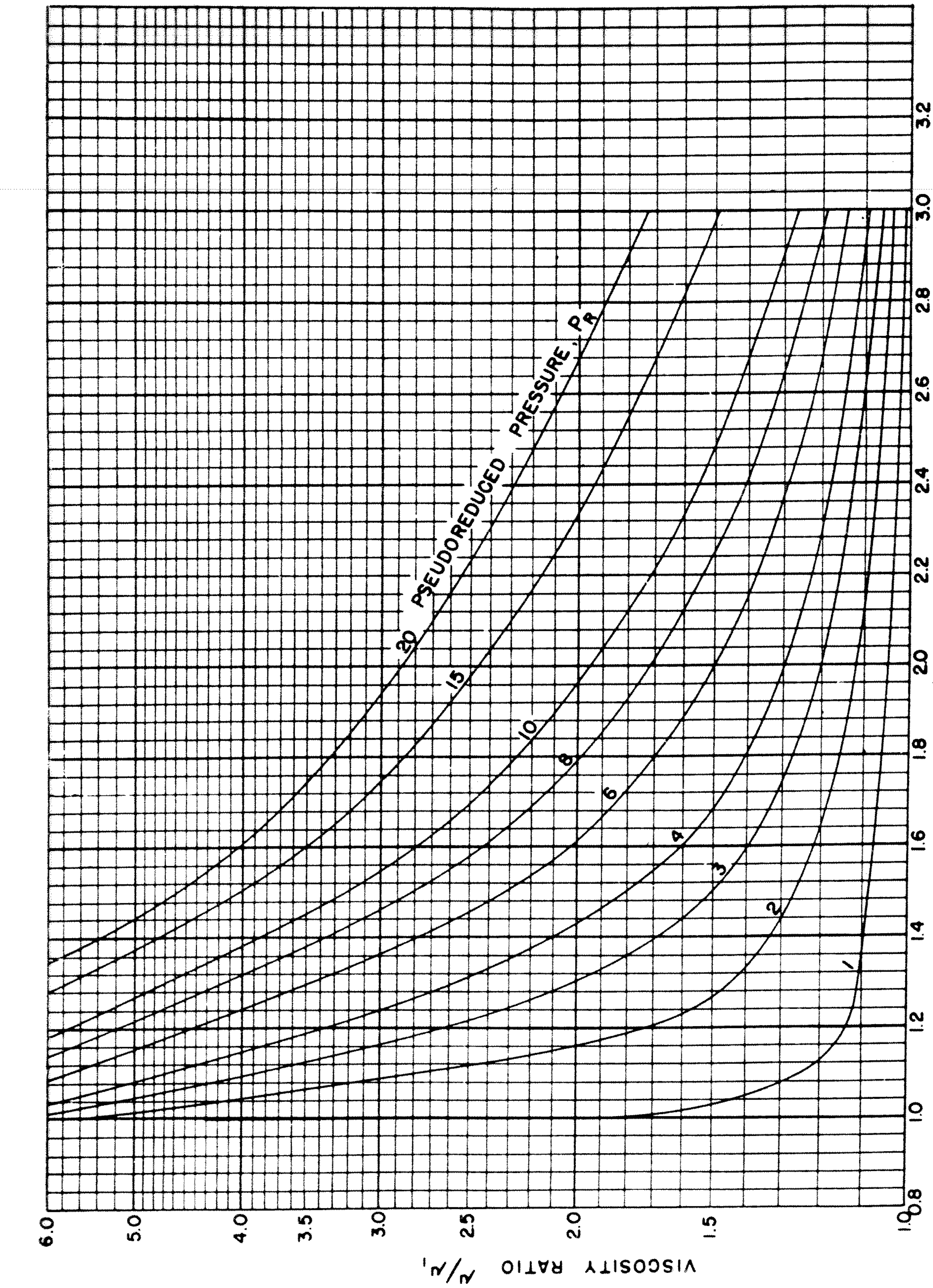
$$\rho_g \text{ (lbs./ft.}^3) = 0.0535 \cdot \frac{1}{B_g}$$



COMPRESSIBILITY, c_g OF NATURAL GAS
VS. PRESSURE AND TEMPERATURE
GAS GRAVITY = 0.7



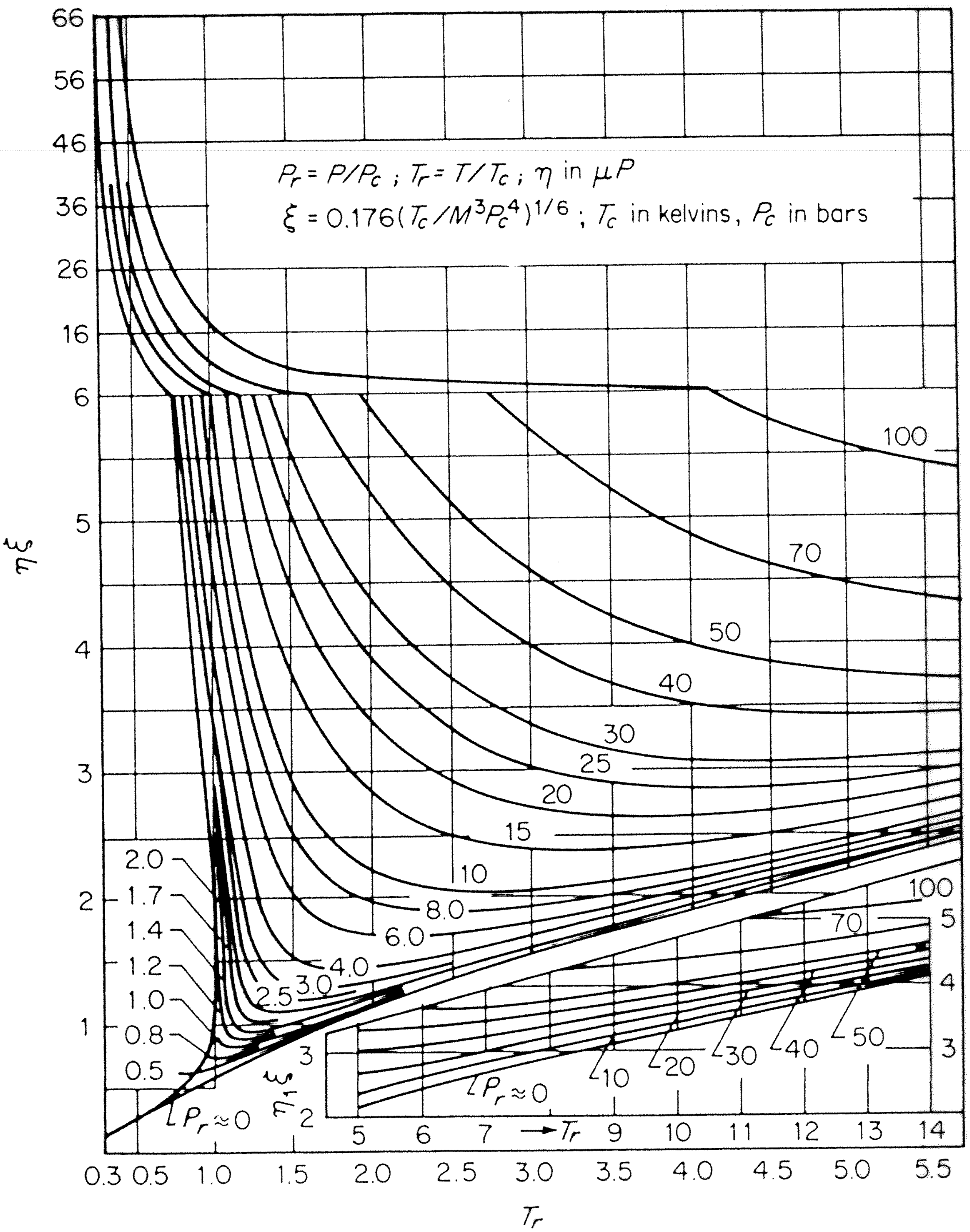
VISCOSITY OF PARAFFIN HYDROCARBON GASES AT ATMOSPHERIC PRESSURE AND ELEVATED TEMPERATURE (After Carr, Kobayashi and Burrows, Trans AIME, 1954)



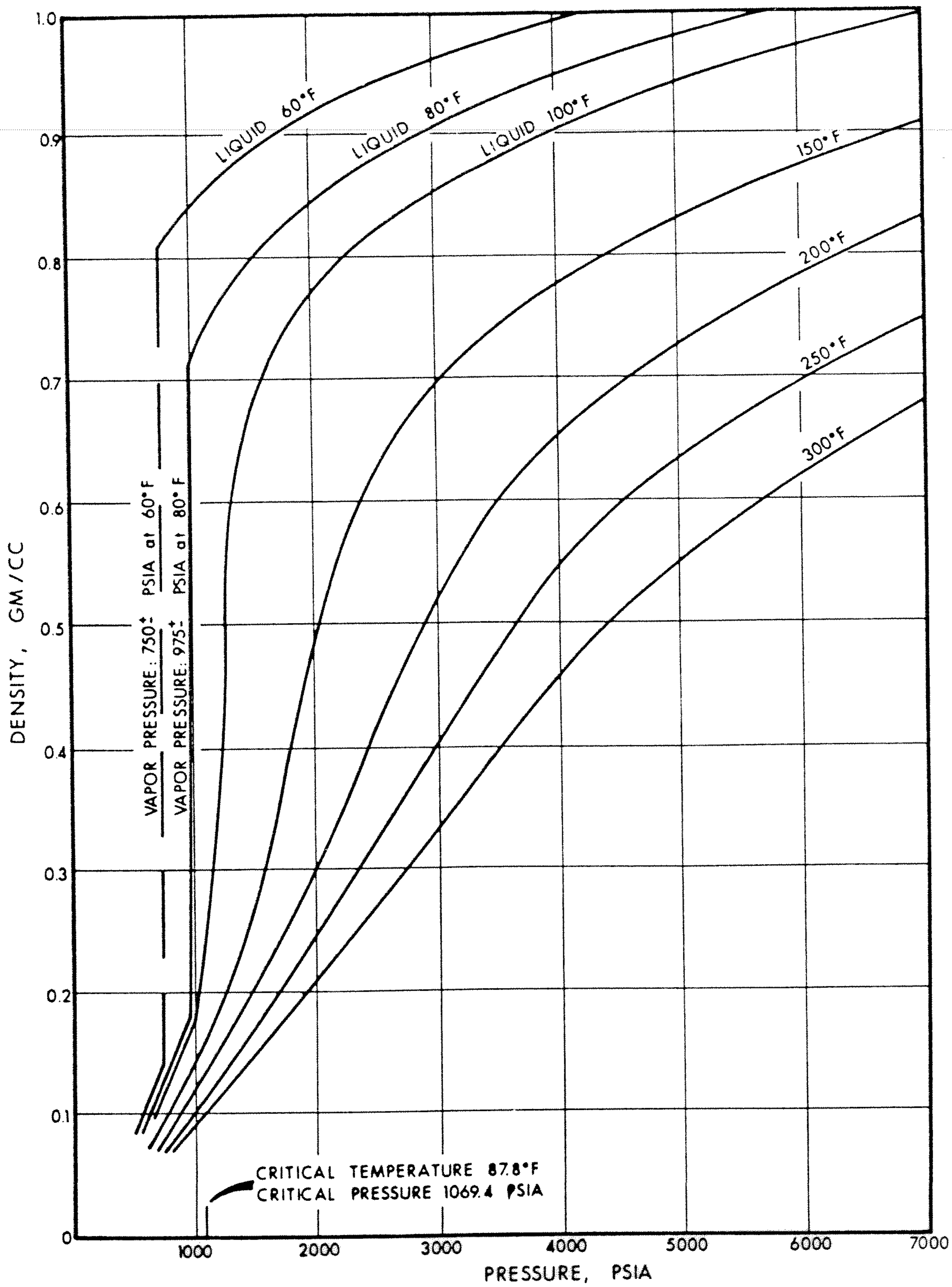
RATIO OF GAS VISCOSITY AT ELEVATED PRESSURE TO VISCOSITY AT ATMOSPHERIC PRESSURE VS. PSEUDOREDUCED TEMPERATURE AND PRESSURE

(After Carr, Kobayashi and Burrows, Trans AIME, 1954)

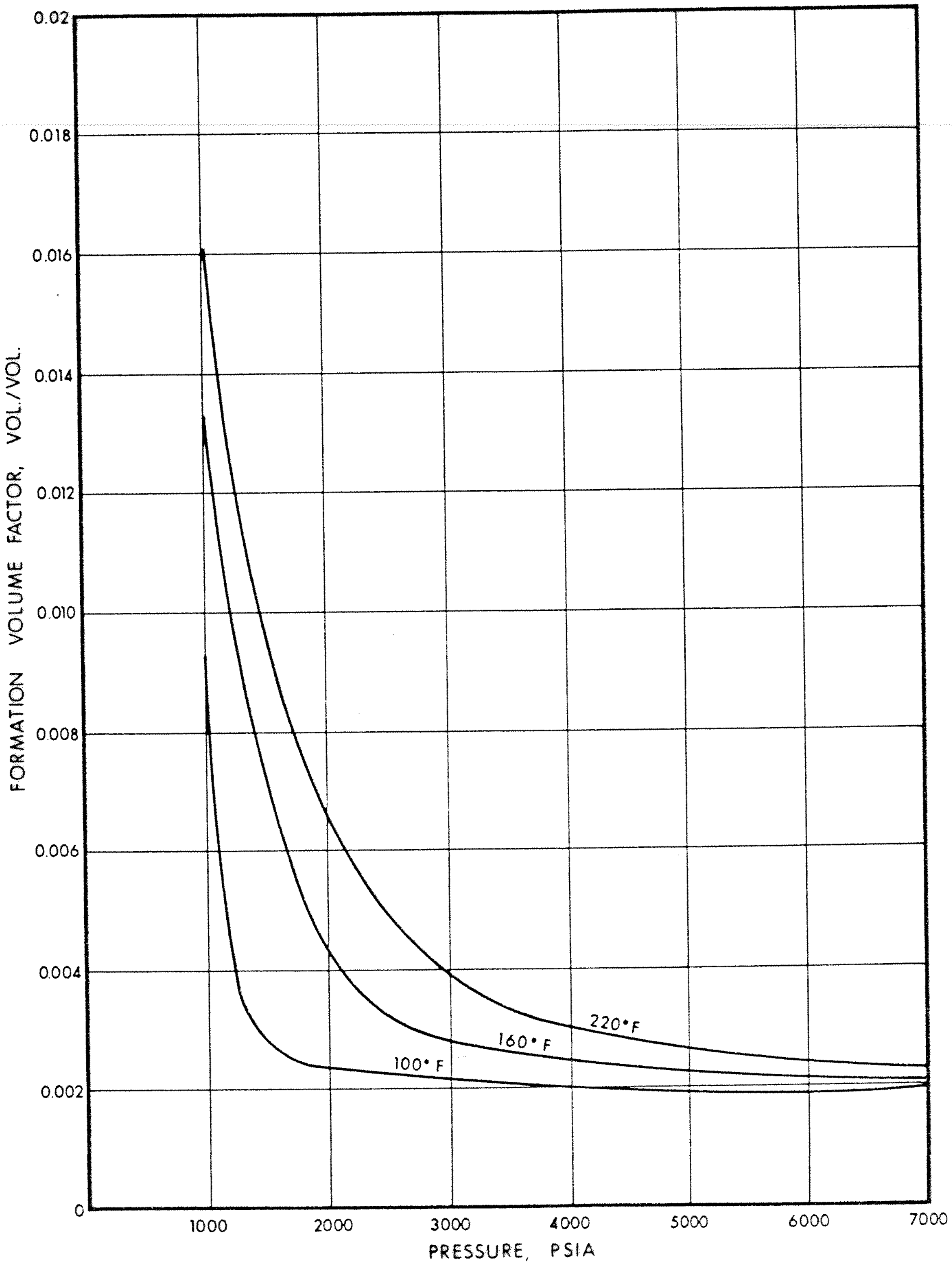
Lucas Corresponding-States Gas Viscosity Correlation



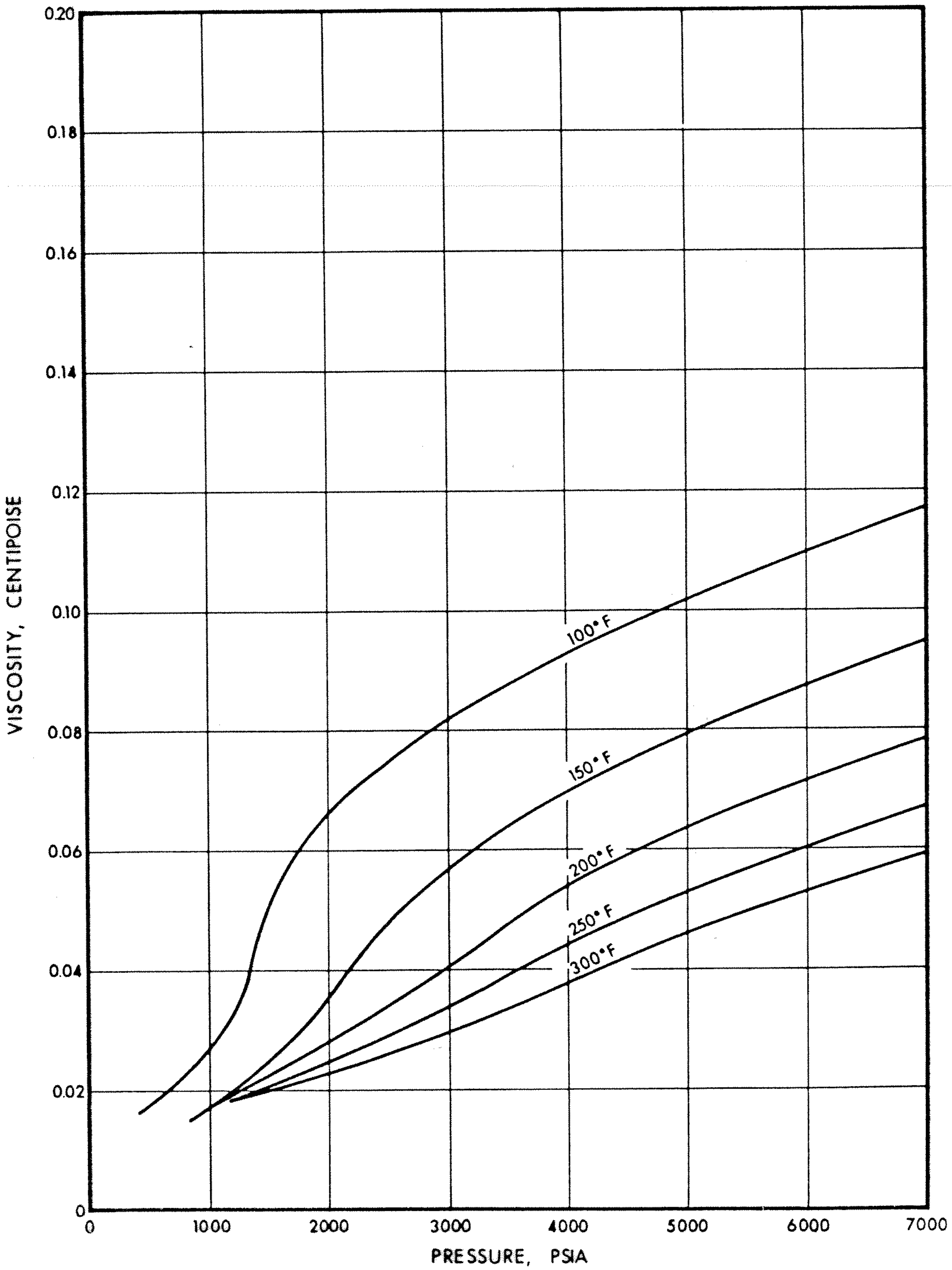
Carbon Dioxide Density



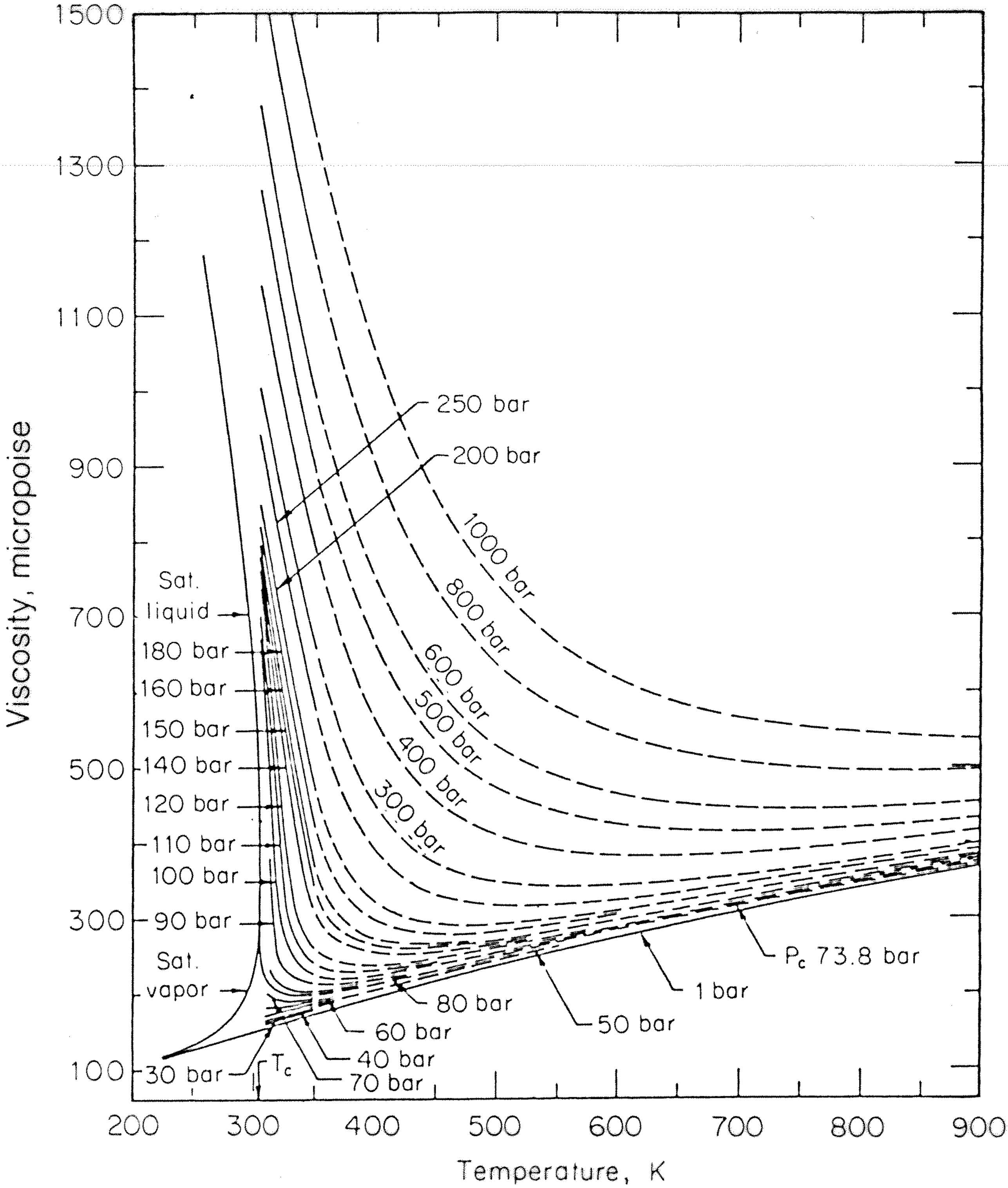
Carbon Dioxide Formation Volume Factor



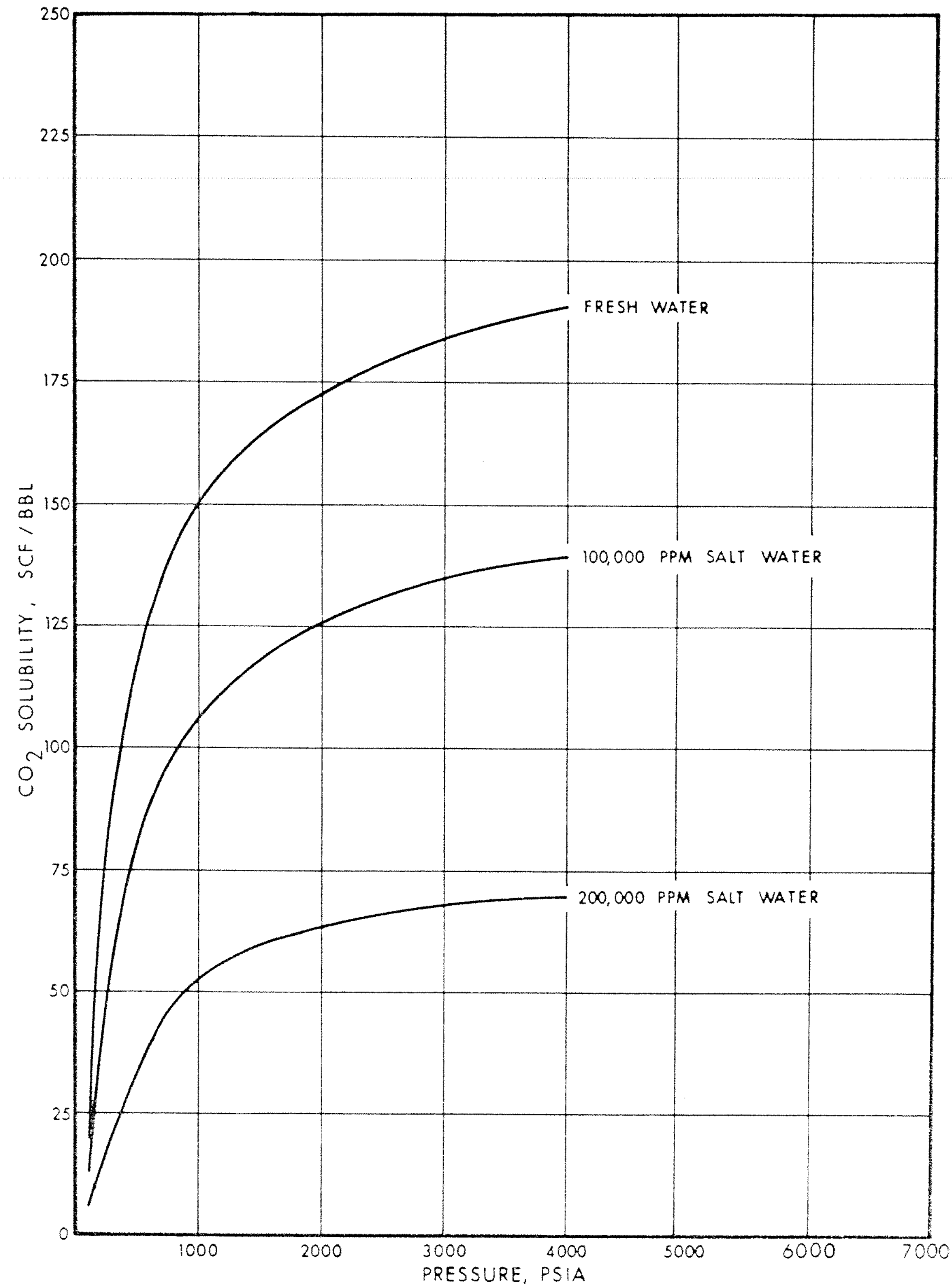
Carbon Dioxide Gas Viscosity (Customary Units)

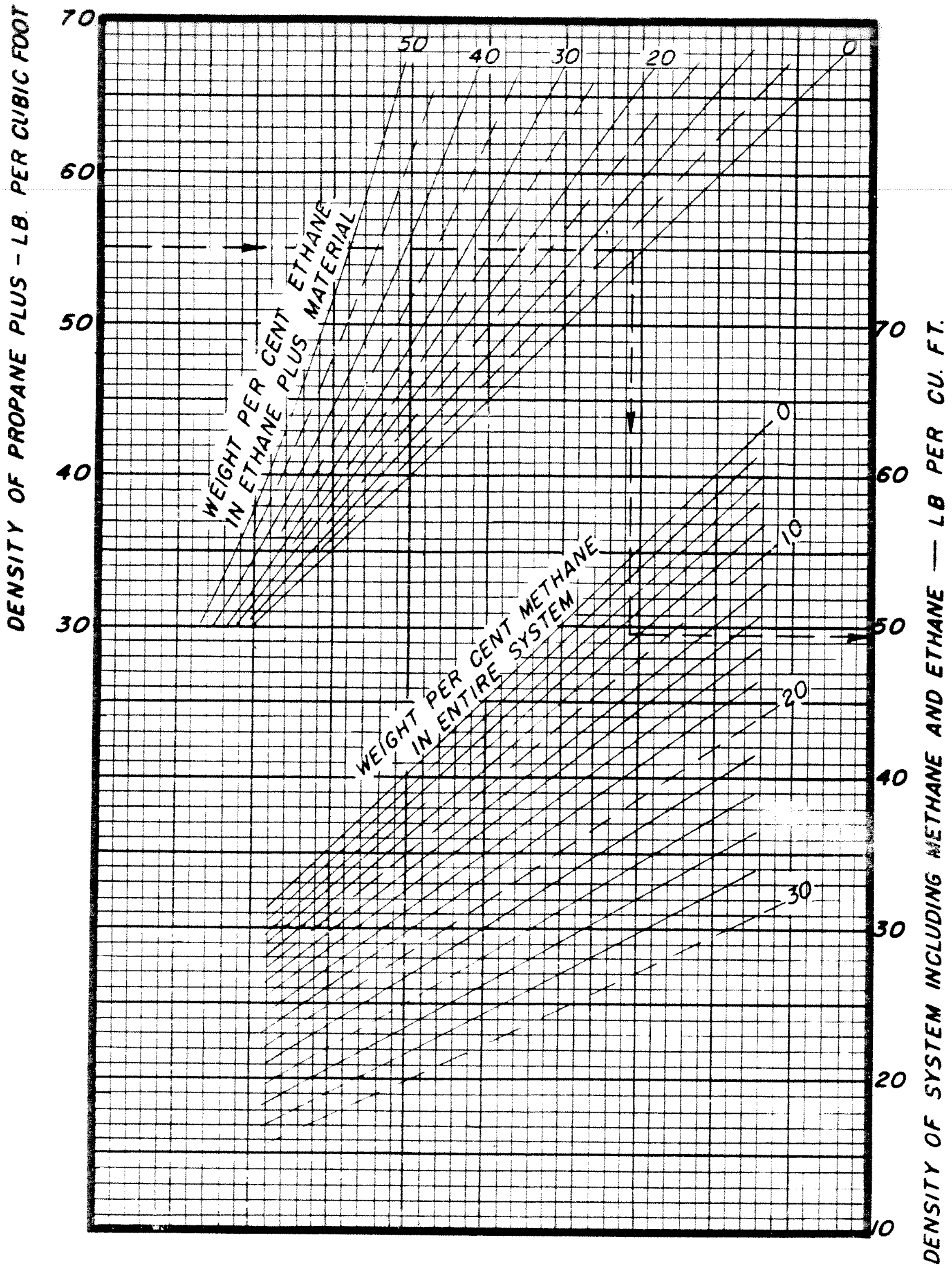


Carbon Dioxide Gas Viscosity (SI Units)

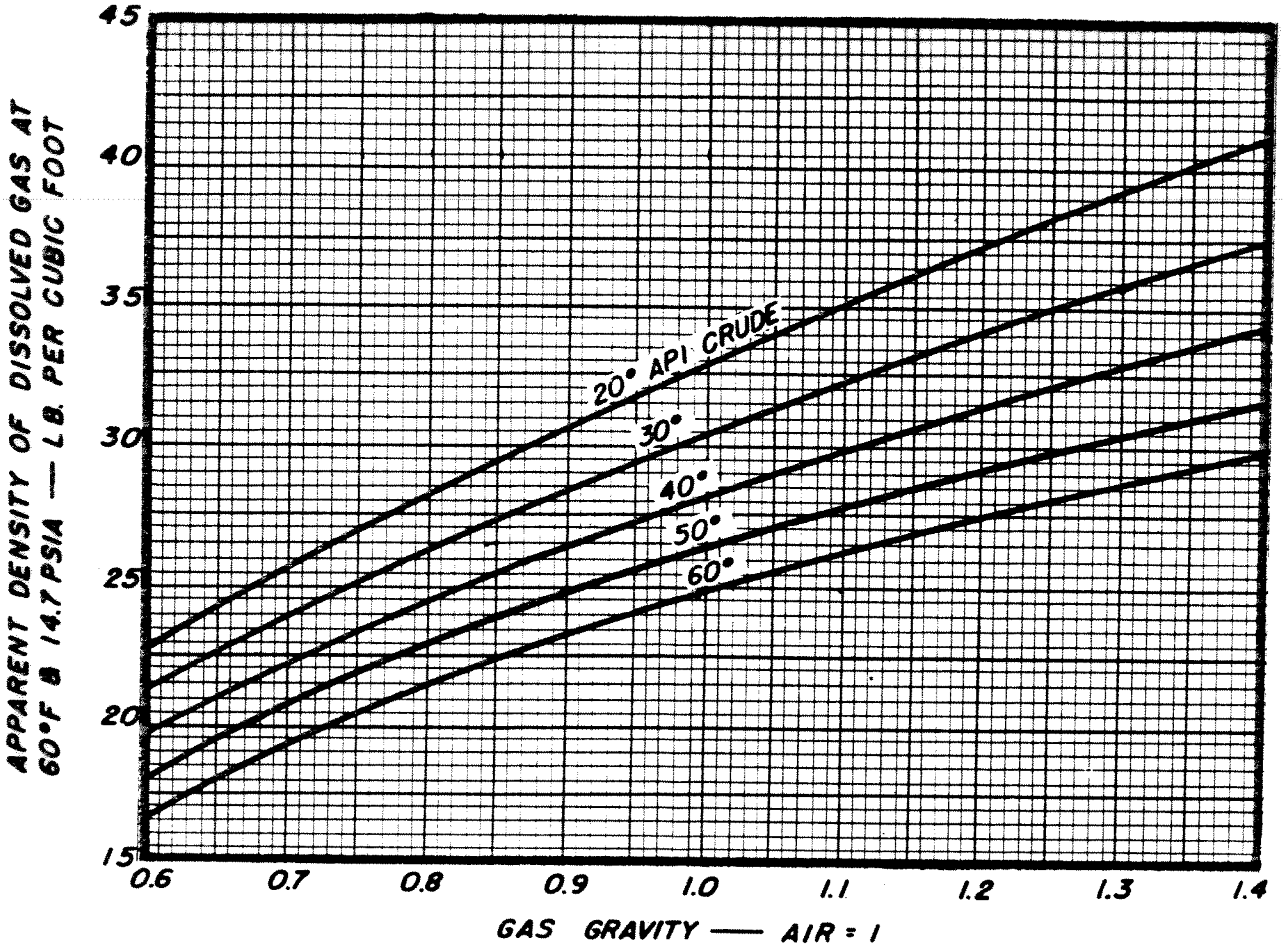


Carbon Dioxide Solubility in Water/Brine

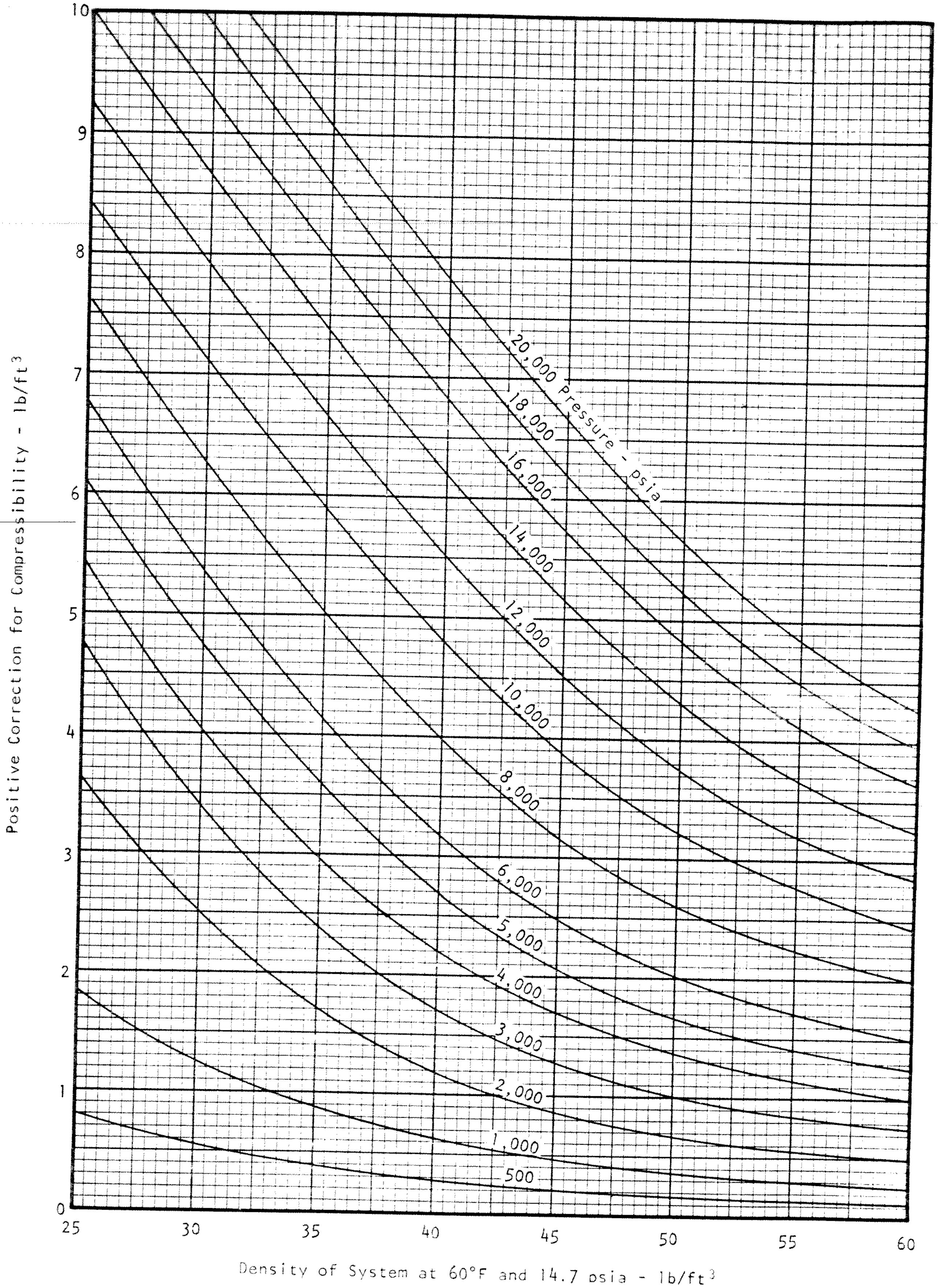




PSEUDO LIQUID DENSITY (14.7 psia/60°F)
OF HYDROCARBON MIXTURES CONTAINING METHANE
AND ETHANE VS. DENSITY OF PROPANE PLUS FRACTION
(After Standing, Oil Field Hydrocarbon Systems,
Reinhold Publishing, 1952)

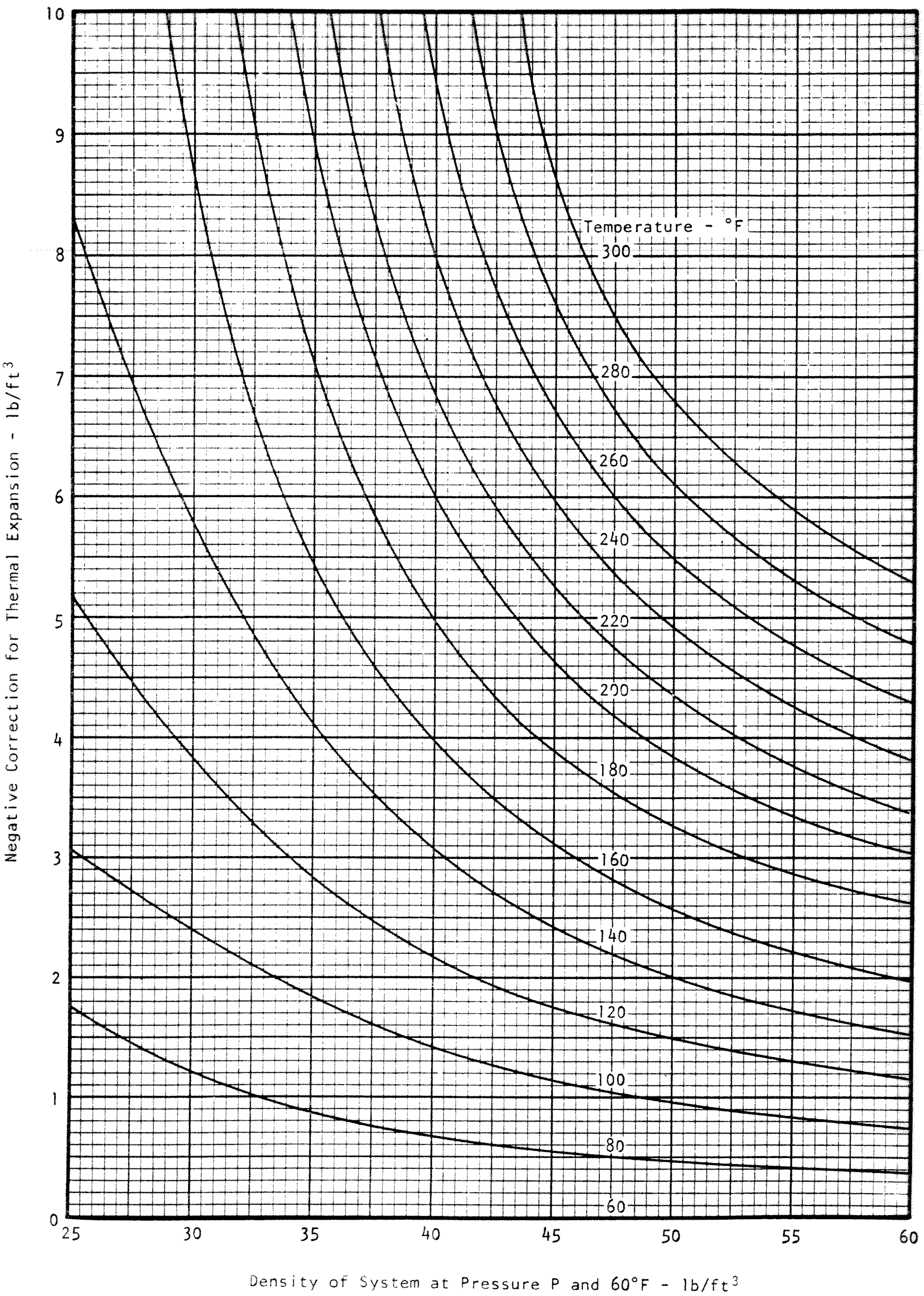


APPARENT LIQUID DENSITY OF NATURAL GASES
WHEN DISSOLVED IN VARIOUS GRAVITY CRUDE OILS
(After Katz, API Drilling and Production Practice, 1942)



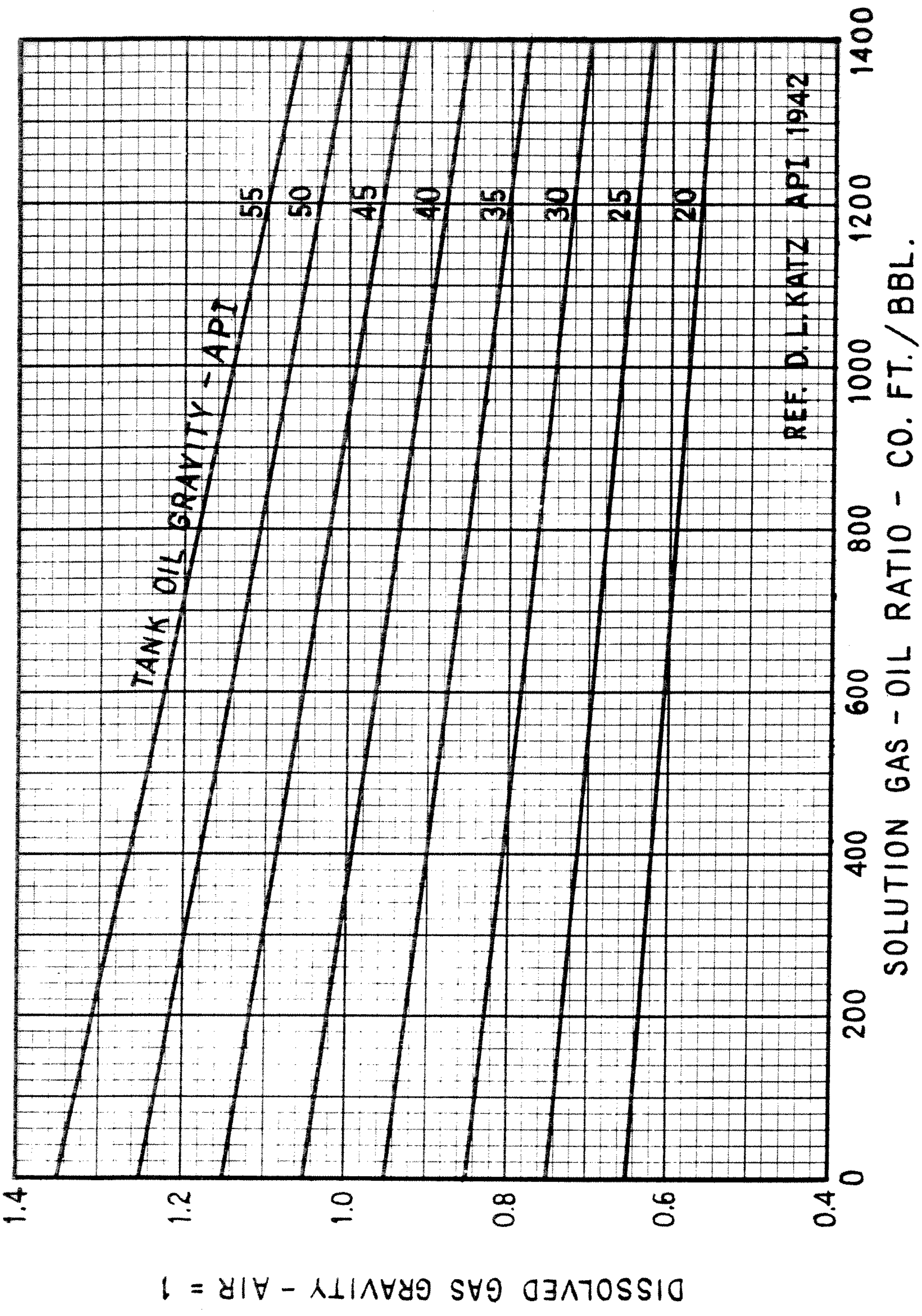
DENSITY UNITS (POUNDS PER CUBIC FEET) TO ADD TO ATMOSPHERIC PSEUDO LIQUID DENSITY TO OBTAIN PSEUDO LIQUID DENSITY AT ELEVATED PRESSURE AND 60°F

(After Madrazo, Trans AIME 1960)

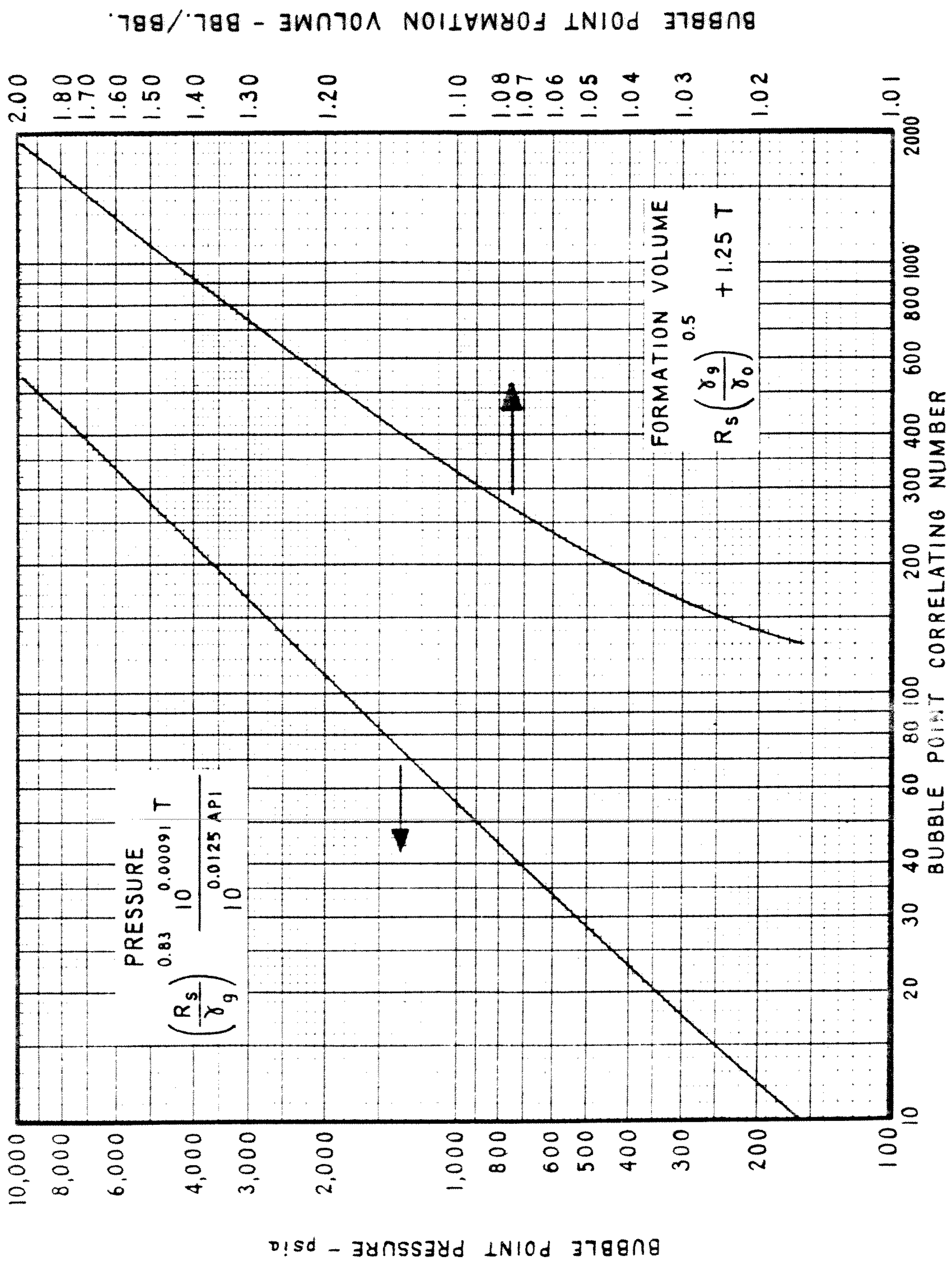


DENSITY UNITS (POUNDS PER CUBIC FEET) TO SUBTRACT FROM ELEVATED PRESSURE/60°F PSEUDO LIQUID DENSITY TO OBTAIN TRUE LIQUID DENSITY AT ELEVATED PRESSURE AND TEMPERATURE.

(After Madrazo, Trans AIME, 1960)



GENERALIZED CORRELATION OF DISSOLVED GAS GRAVITY, SOLUTION GAS-OIL RATIO, AND TANK OIL GRAVITY



GENERALIZED CORRELATIONS OF BUBBLE POINT PROPERTIES

REF. API 1947

PROPERTIES OF NATURAL HYDROCARBON MIXTURES OF GAS AND LIQUID

BUBBLE POINT PRESSURE

EXAMPLE

REQUIRED:

Bubble point pressure at 200°F of a liquid having a gas-oil ratio of 350 CFB, a gas gravity of 0.75, and a tank oil gravity of 30°API.

PROCEDURE:

Starting at the left side of the chart, proceed horizontally along the 350 CFB line to a gas gravity of 0.75. From this point drop vertically to the 30°API line. Proceed horizontally from the tank oil gravity scale to the 200°F line. The required pressure is found to be 1930 PSIA.

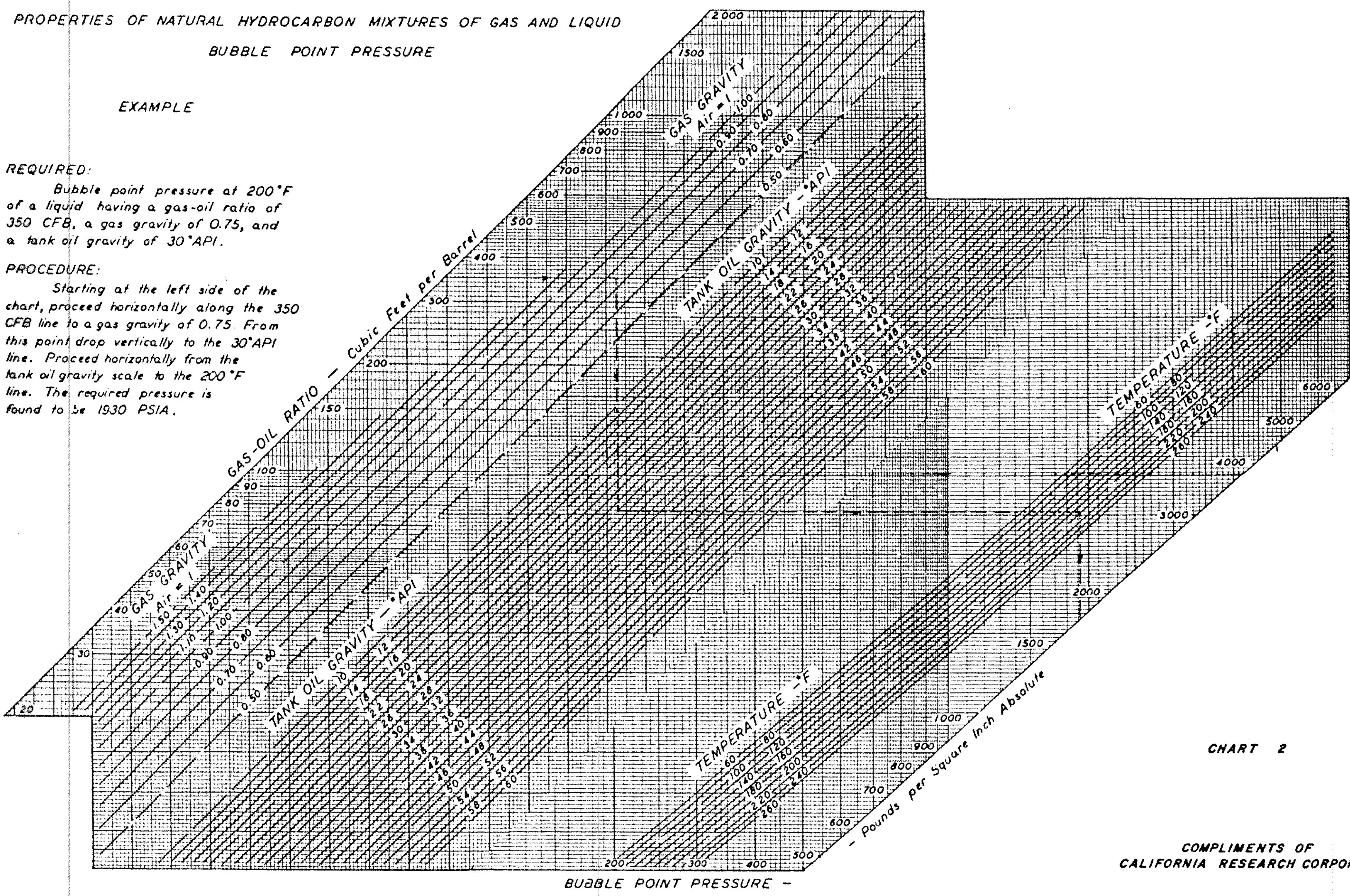


CHART 2

COMPLIMENTS OF
CALIFORNIA RESEARCH CORPORATION

PROPERTIES OF NATURAL HYDROCARBON MIXTURES OF GAS AND LIQUID

FORMATION VOLUME of GAS PLUS LIQUID PHASES

EXAMPLE

REQUIRED:

Formation volume of the gas plus liquid phases of a 1500 CFB mixture, gas gravity = 0.80, tank oil gravity = 40 °API, at 200 °F and 1000 PSIA

PROCEDURE:

Starting at the left side of the chart, proceed horizontally along the 1500 CFB line to the 0.80 gas gravity line. From this point drop vertically to the 40 °API line. Proceed horizontally to 200 °F. and from that point drop to the 1000 PSIA pressure line. The required formation volume is found to be 5.0 barrels per barrel of tank oil.

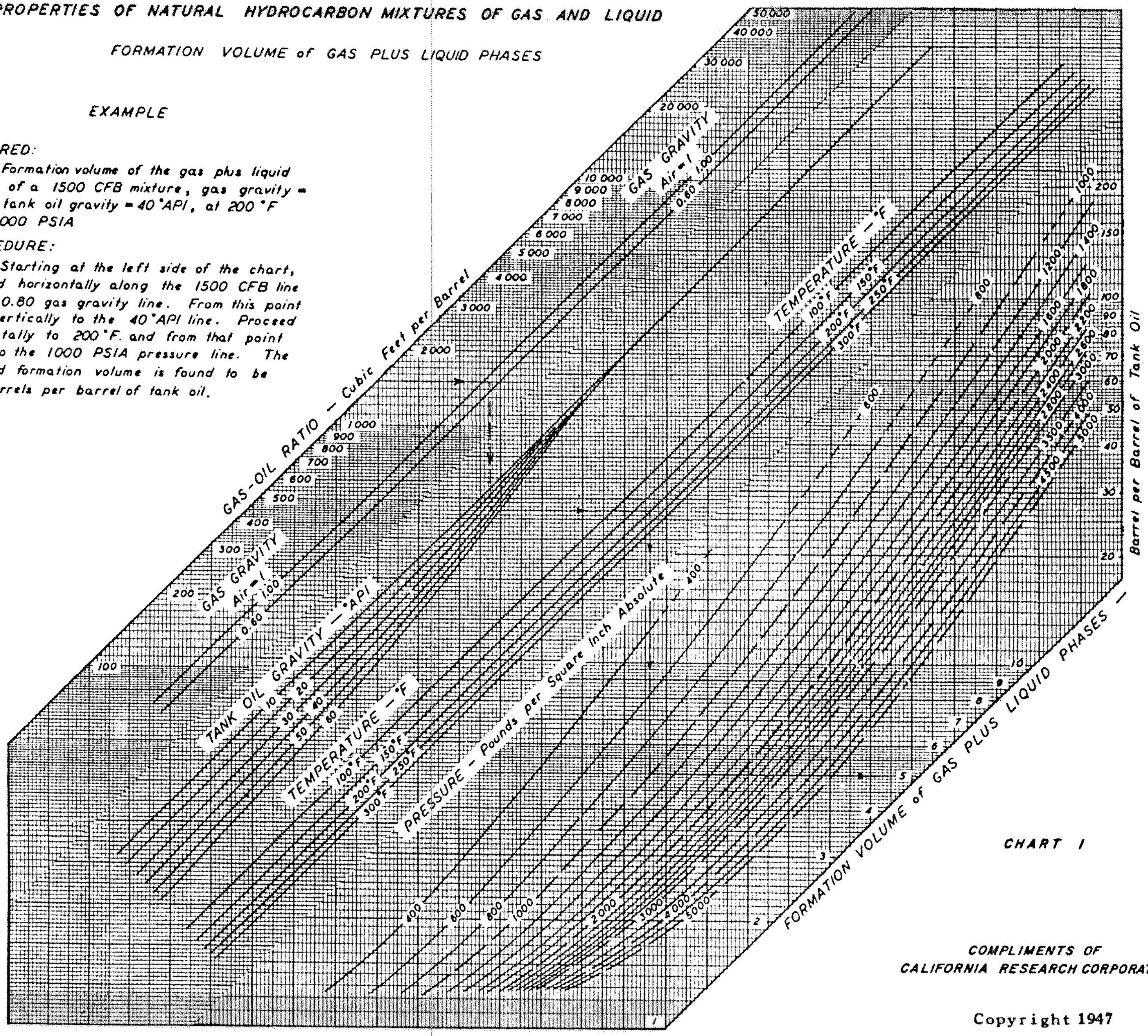


CHART I

COMPLIMENTS OF
CALIFORNIA RESEARCH CORPORATION

PROPERTIES OF NATURAL HYDROCARBON MIXTURES OF GAS AND LIQUID

FORMATION VOLUME of BUBBLE POINT LIQUIDS

EXAMPLE

REQUIRED:

Formation volume at 200°F of a bubble point liquid having a gas-oil ratio of 350 CFB, a gas gravity of 0.75, and a tank oil gravity of 30 °API.

PROCEDURE:

Starting at the left side of the chart, proceed horizontally along the 350 CFB line to a gas gravity of 0.75. From this point drop vertically to the 30°API line. Proceed horizontally from the tank oil gravity scale to the 200°F line. The required formation volume is found to be 1.22 barrel per barrel of tank oil.

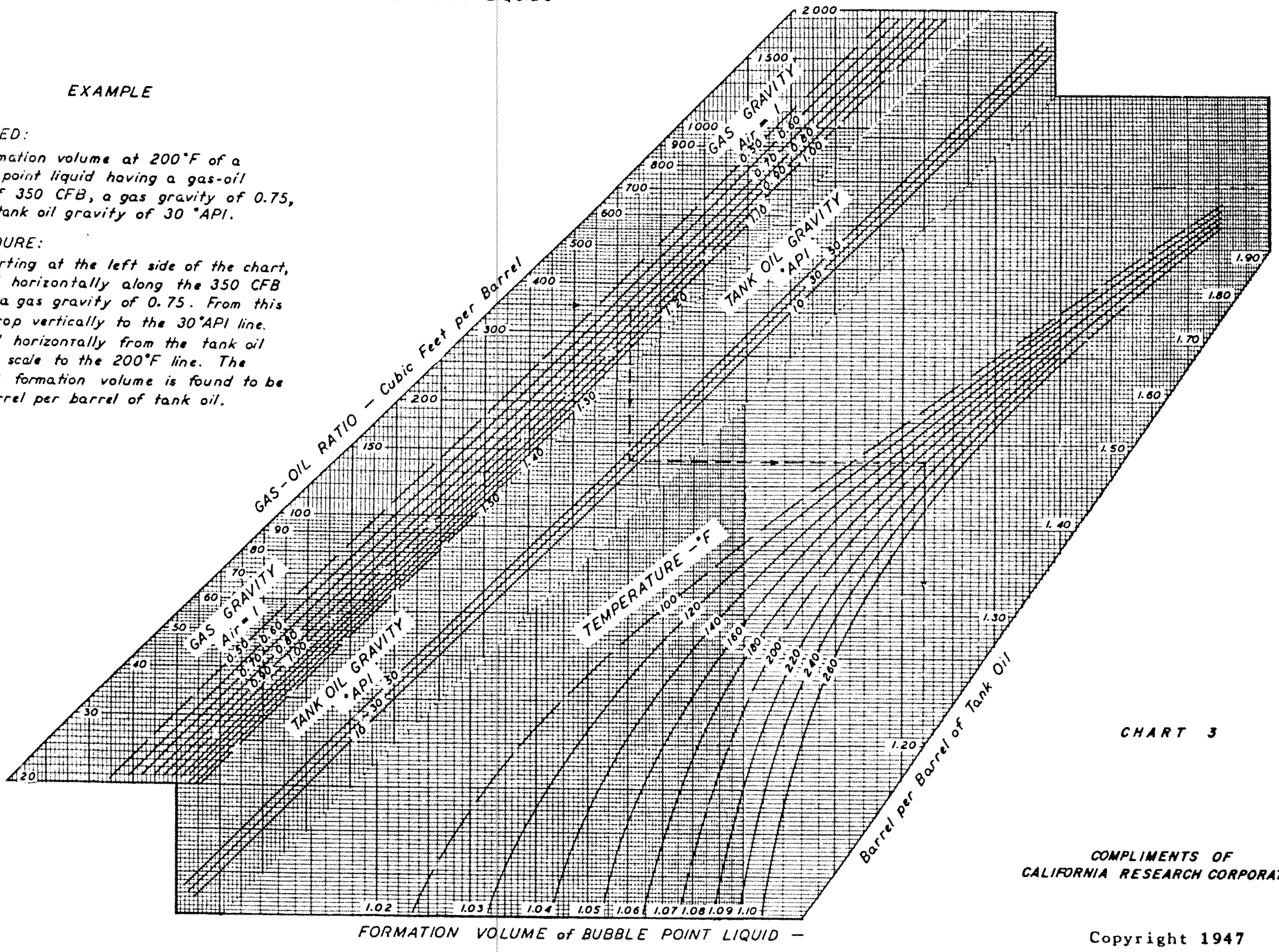
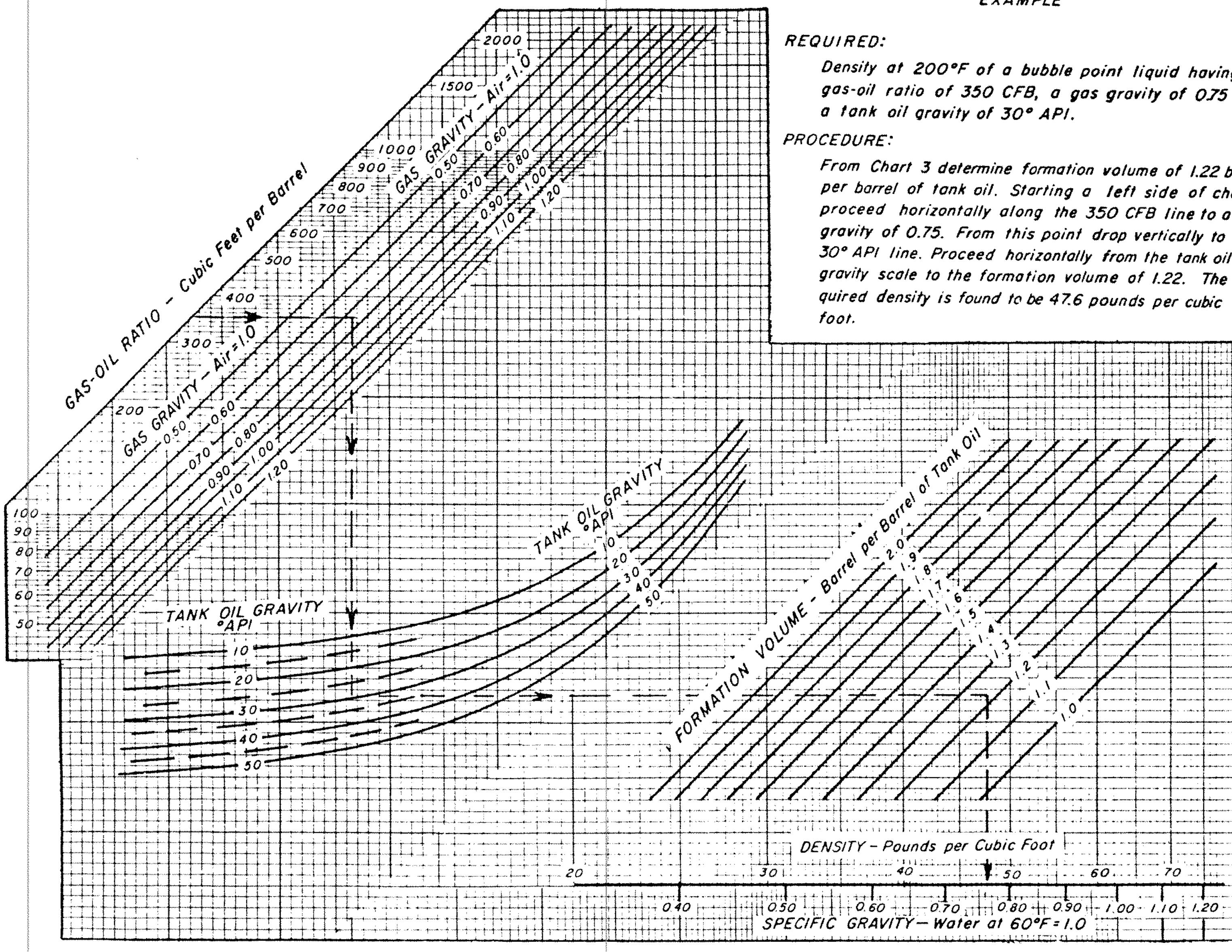


CHART 3

COMPLIMENTS OF
CALIFORNIA RESEARCH CORPORATION

PROPERTIES OF NATURAL HYDROCARBON MIXTURES OF GAS AND LIQUID

DENSITY and SPECIFIC GRAVITY of MIXTURES



EXAMPLE

REQUIRED:

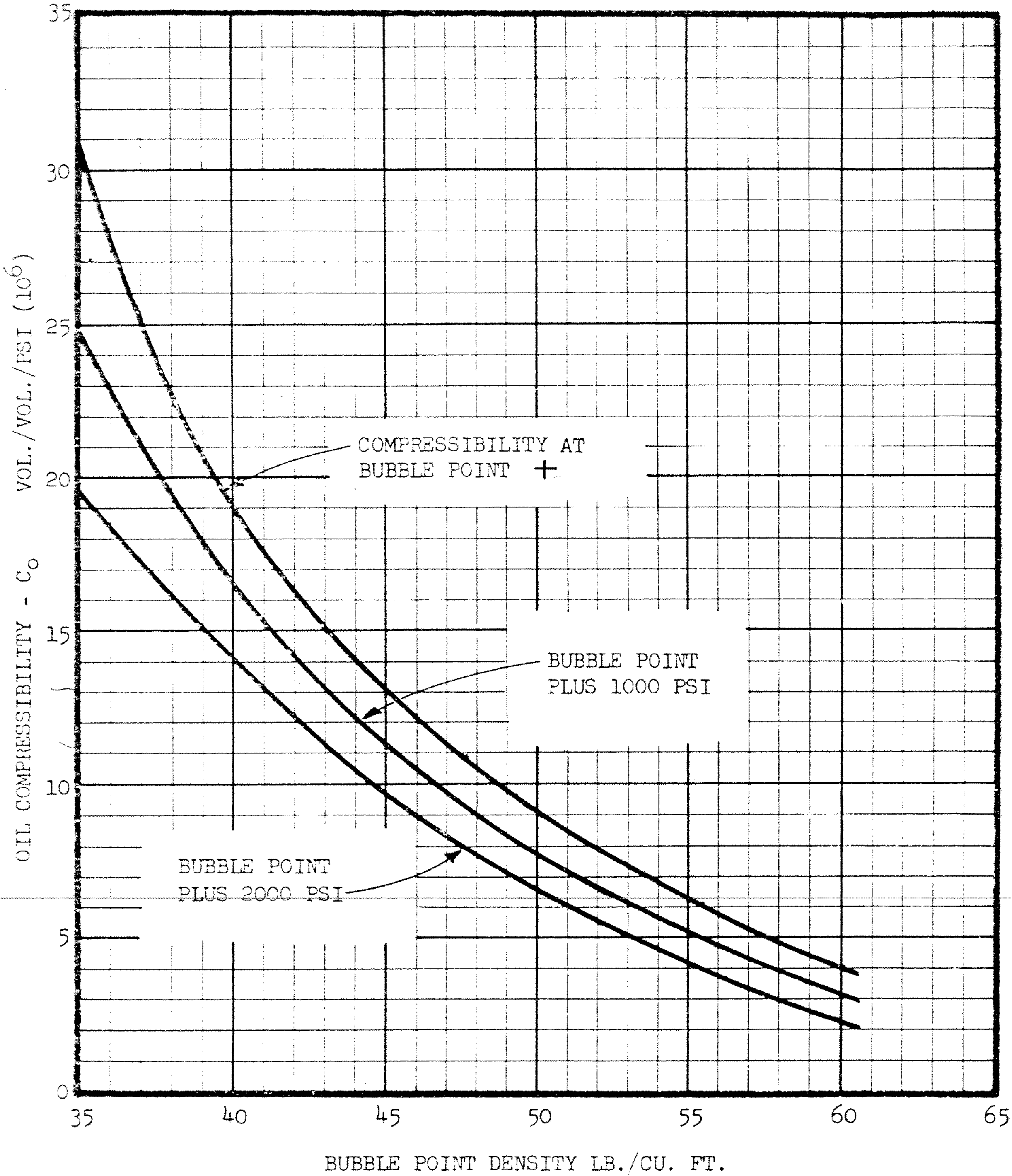
Density at 200°F of a bubble point liquid having a gas-oil ratio of 350 CFB, a gas gravity of 0.75 and a tank oil gravity of 30° API.

PROCEDURE:

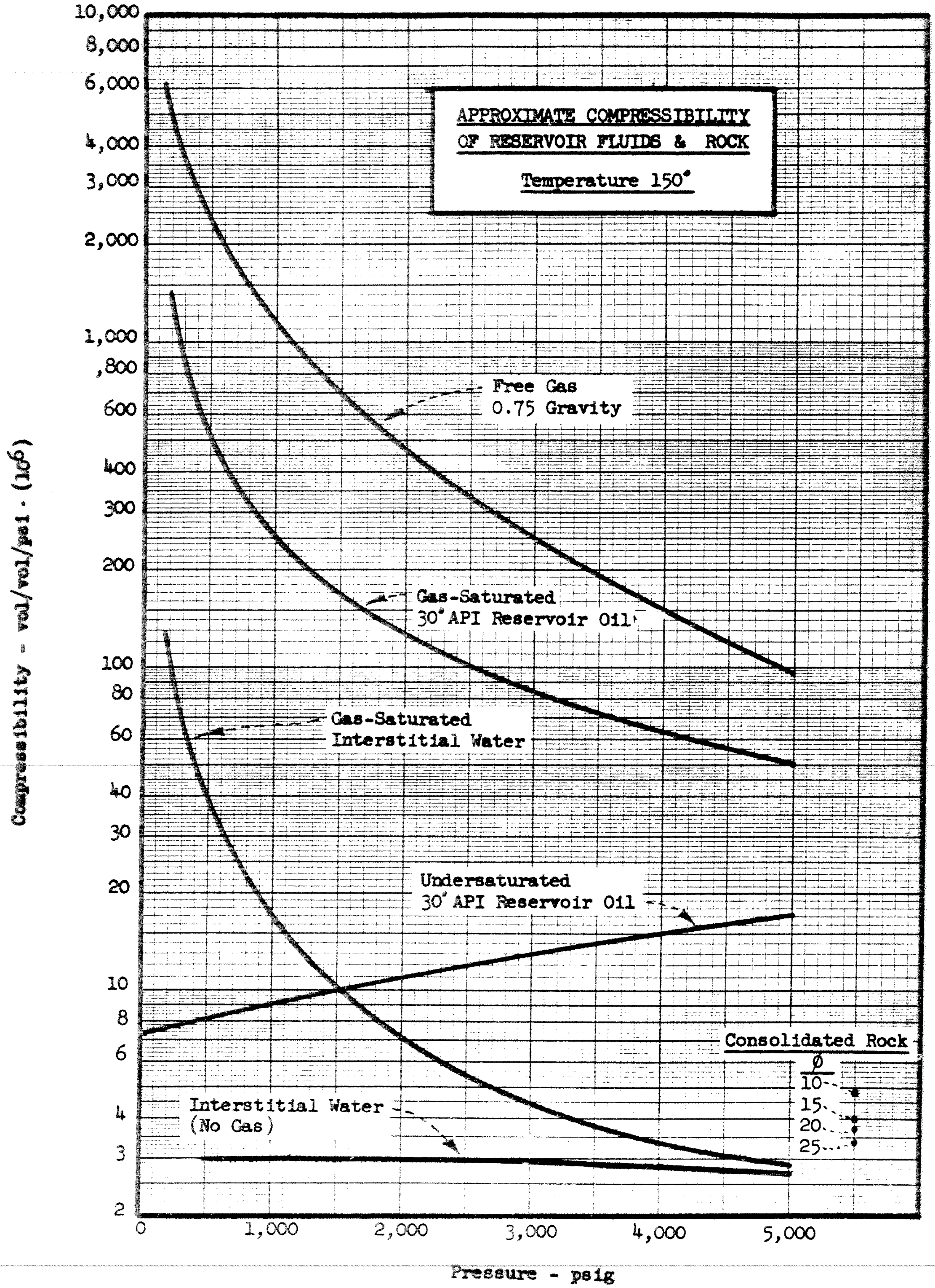
From Chart 3 determine formation volume of 1.22 barrels per barrel of tank oil. Starting a left side of chart proceed horizontally along the 350 CFB line to a gas gravity of 0.75. From this point drop vertically to the 30° API line. Proceed horizontally from the tank oil gravity scale to the formation volume of 1.22. The required density is found to be 47.6 pounds per cubic foot.

CHART 4

COMPLIMENTS OF
CALIFORNIA RESEARCH CORPORATION

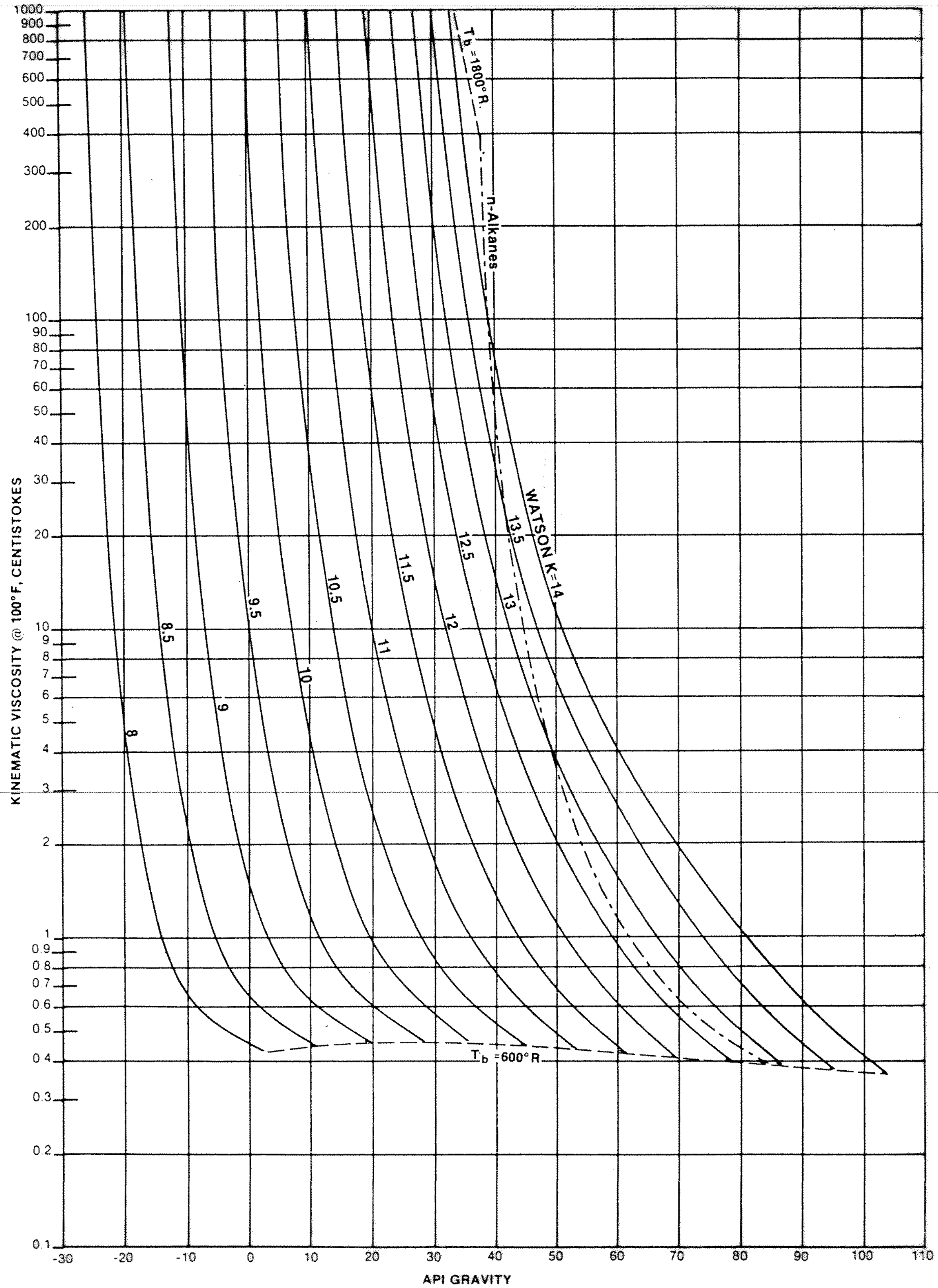


COMPRESSIBILITY OF RESERVOIR OILS
ABOVE THEIR BUBBLE POINT
VS. DENSITY AT THE BUBBLE POINT


APPROXIMATE COMPRESSIBILITY
OF RESERVOIR FLUIDS & ROCK
Temperature 150°
Free Gas
0.75 Gravity
Gas-Saturated
30° API Reservoir Oil
Gas-Saturated
Interstitial Water
Undersaturated
30° API Reservoir Oil
Interstitial Water
(No Gas)
Consolidated Rock
Ø
10
15
20
25
Compressibility - vol/vol/psi · (10^6)
10,000
8,000
6,000
4,000
3,000
2,000
1,000
,800
600
400
300
200
100
80
60
40
30
20
10
8
6
4
3
2
0
1,000
2,000
3,000
4,000
5,000
Pressure - psig

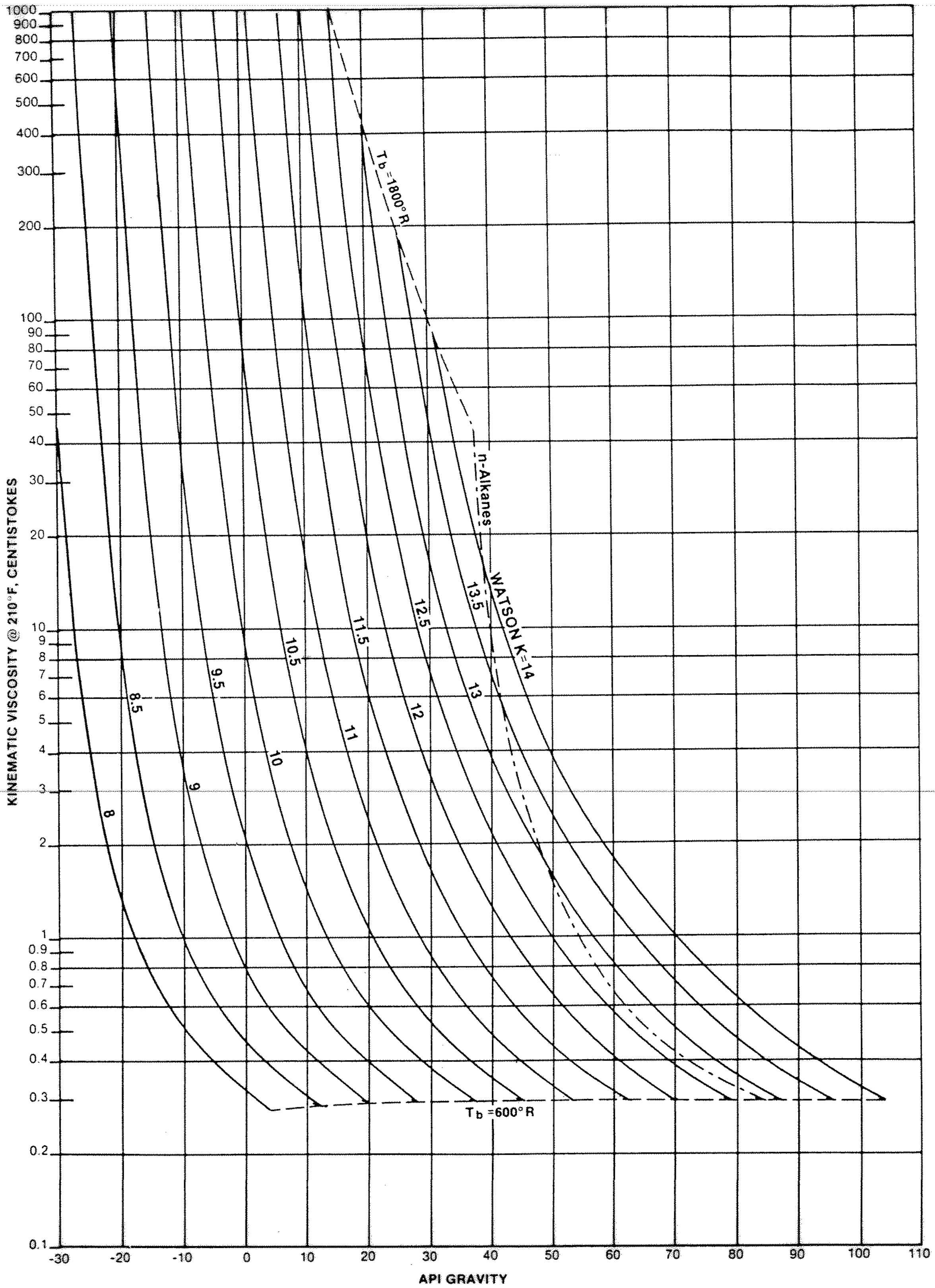
Twu Correlation

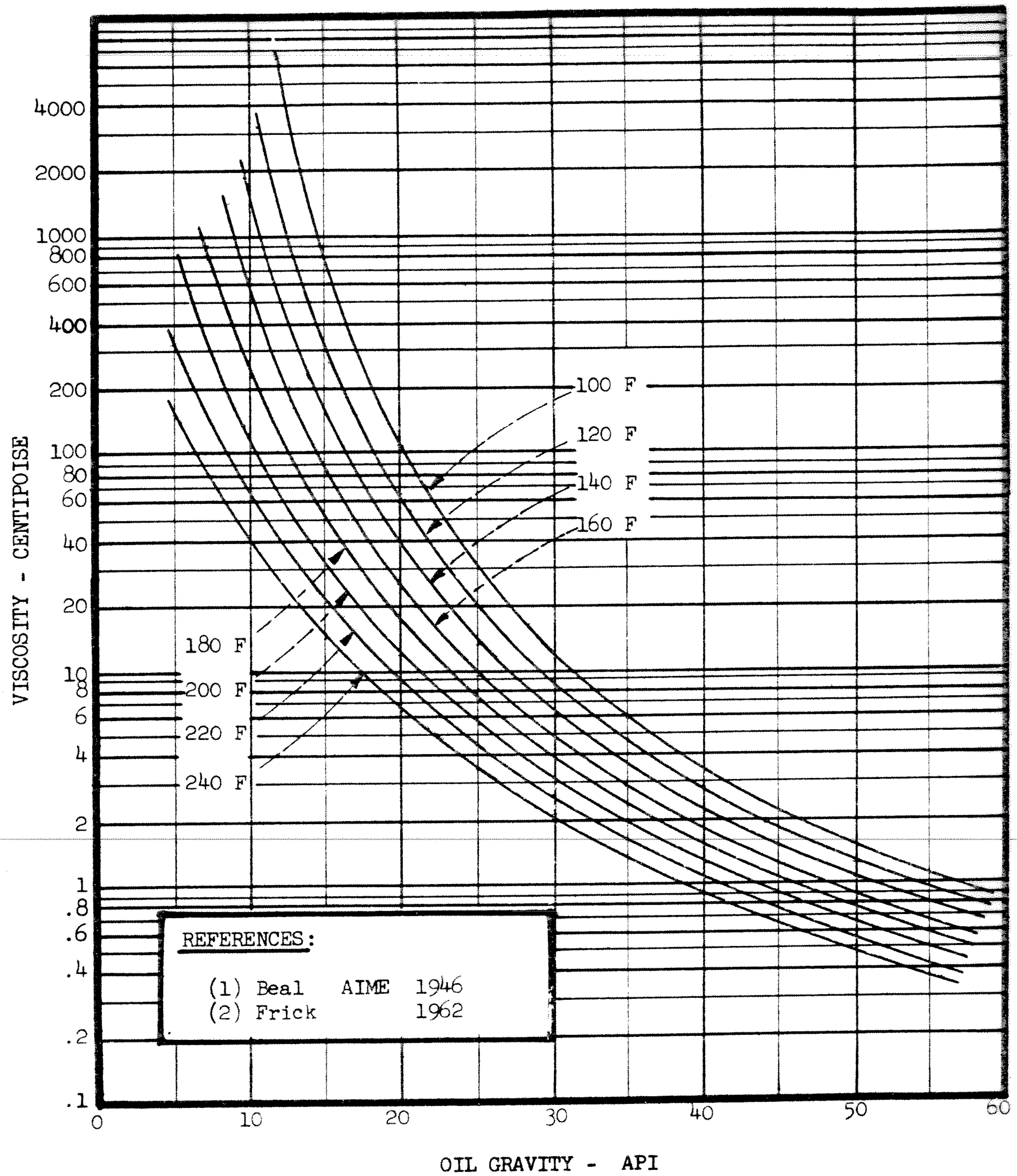
Note: $\mu(cp)=\nu(cSt)\rho(g/cm^3)$; $\rho=0.999\gamma$; $\gamma=141.5/(131.5+{}^oAPI)$



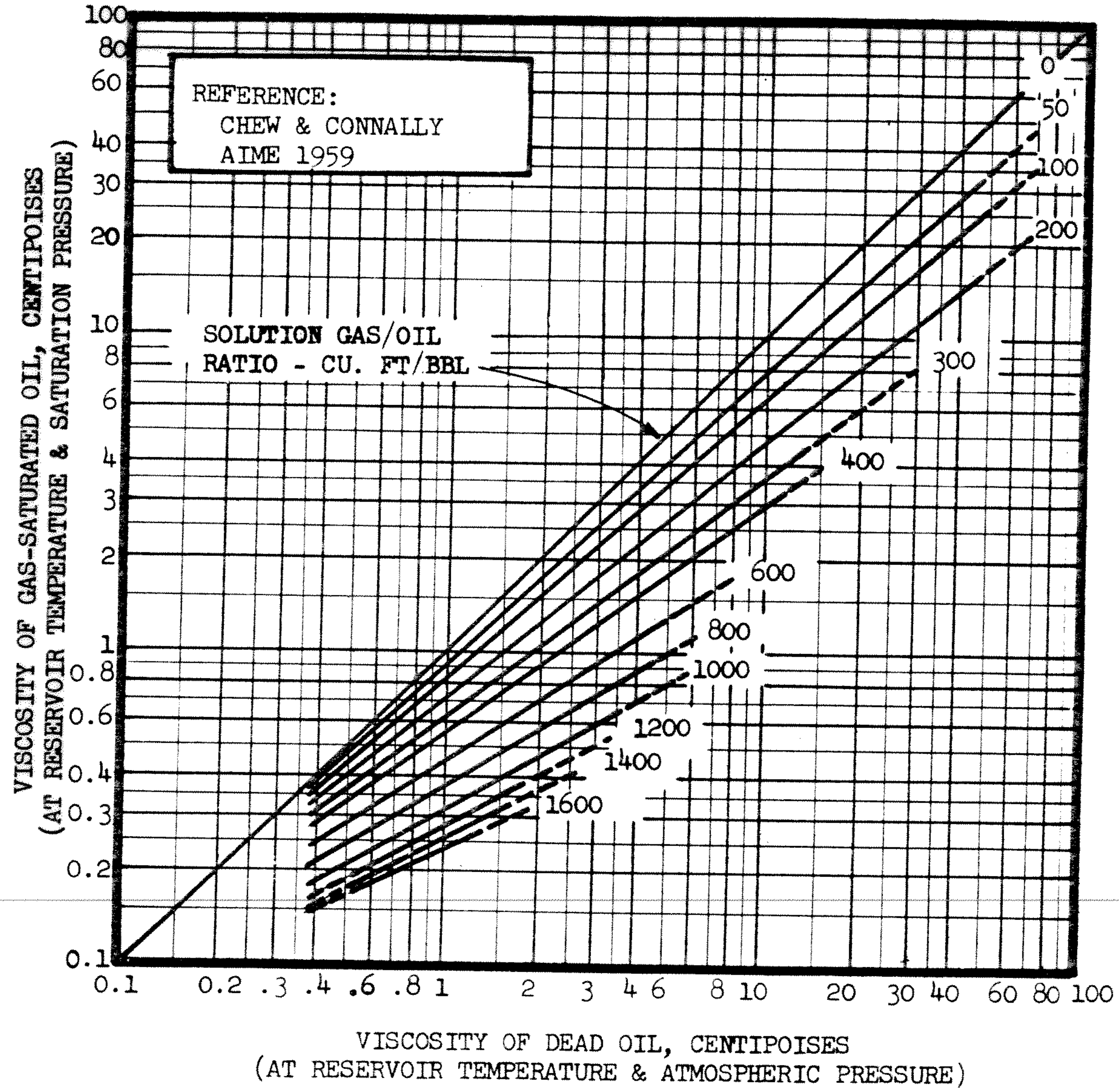
Twu Correlation

Note: $\mu(cp)=\nu(cSt)\rho(g/cm^3)$; $\rho=0.999\gamma$; $\gamma=141.5/(131.5+^{o}API)$

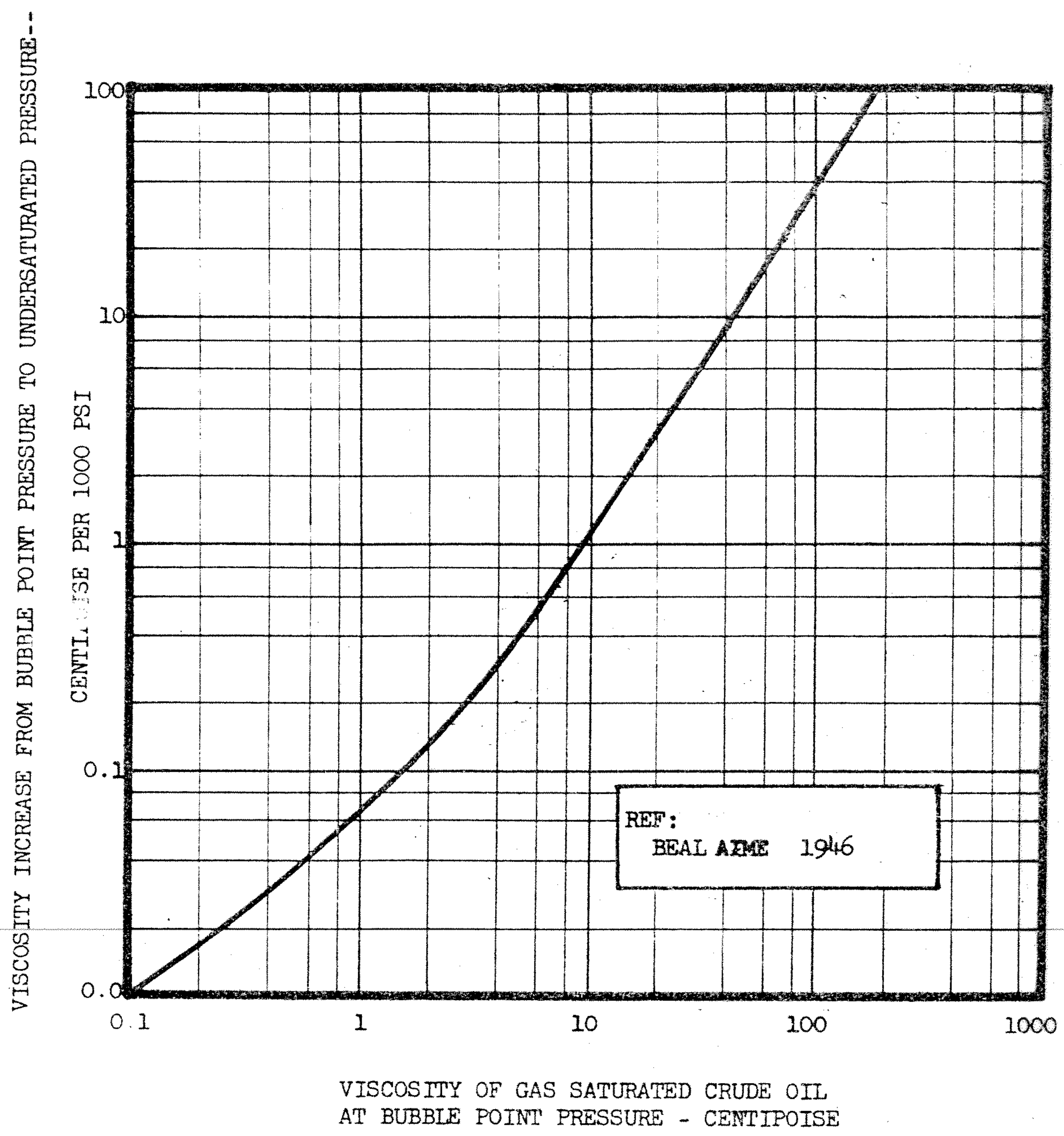




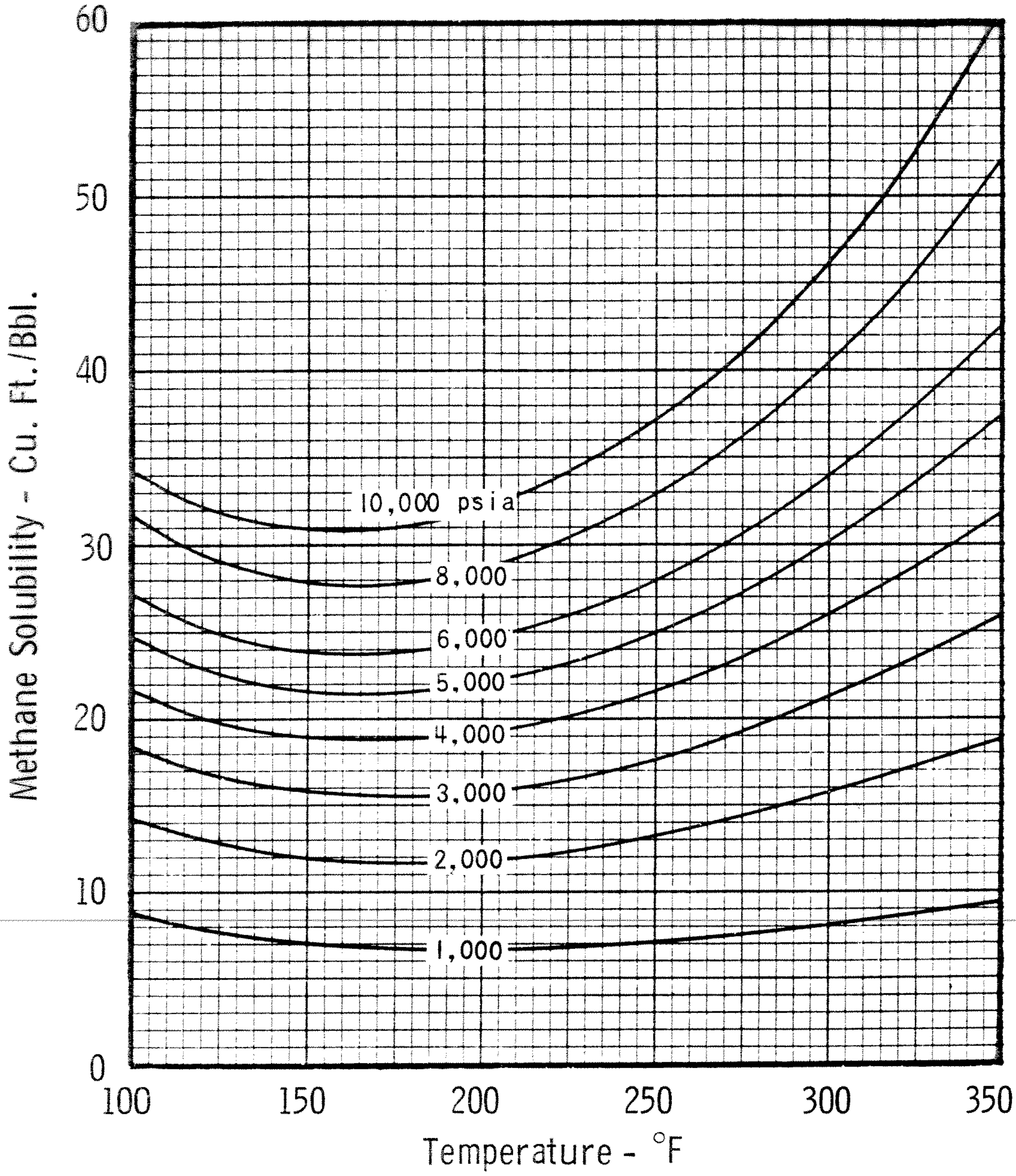
VISCOSITY OF GAS-FREE CRUDE OILS AT ATMOSPHERIC PRESSURE VS. API



VISCOSITY OF GAS SATURATED CRUDE OIL
AT RESERVOIR TEMPERATURE & PRESSURE
VS. VISCOSITY OF THE GAS-FREE OIL AT
RESERVOIR TEMPERATURE & ATMOSPHERIC PRESSURE

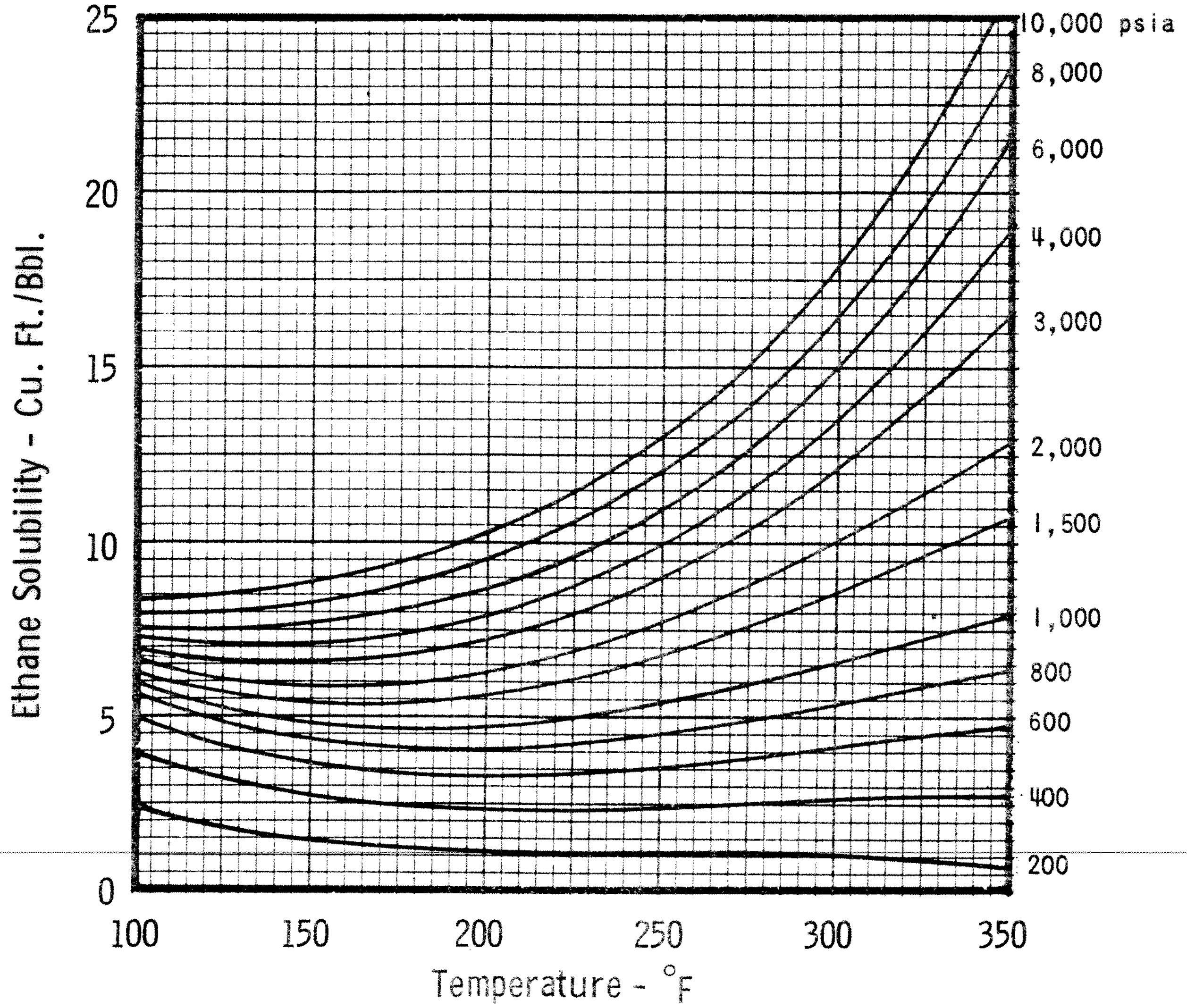


EFFECT OF PRESSURE ON OIL VISCOSITY
AT PRESSURES ABOVE THE BUBBLE POINT PRESSURE



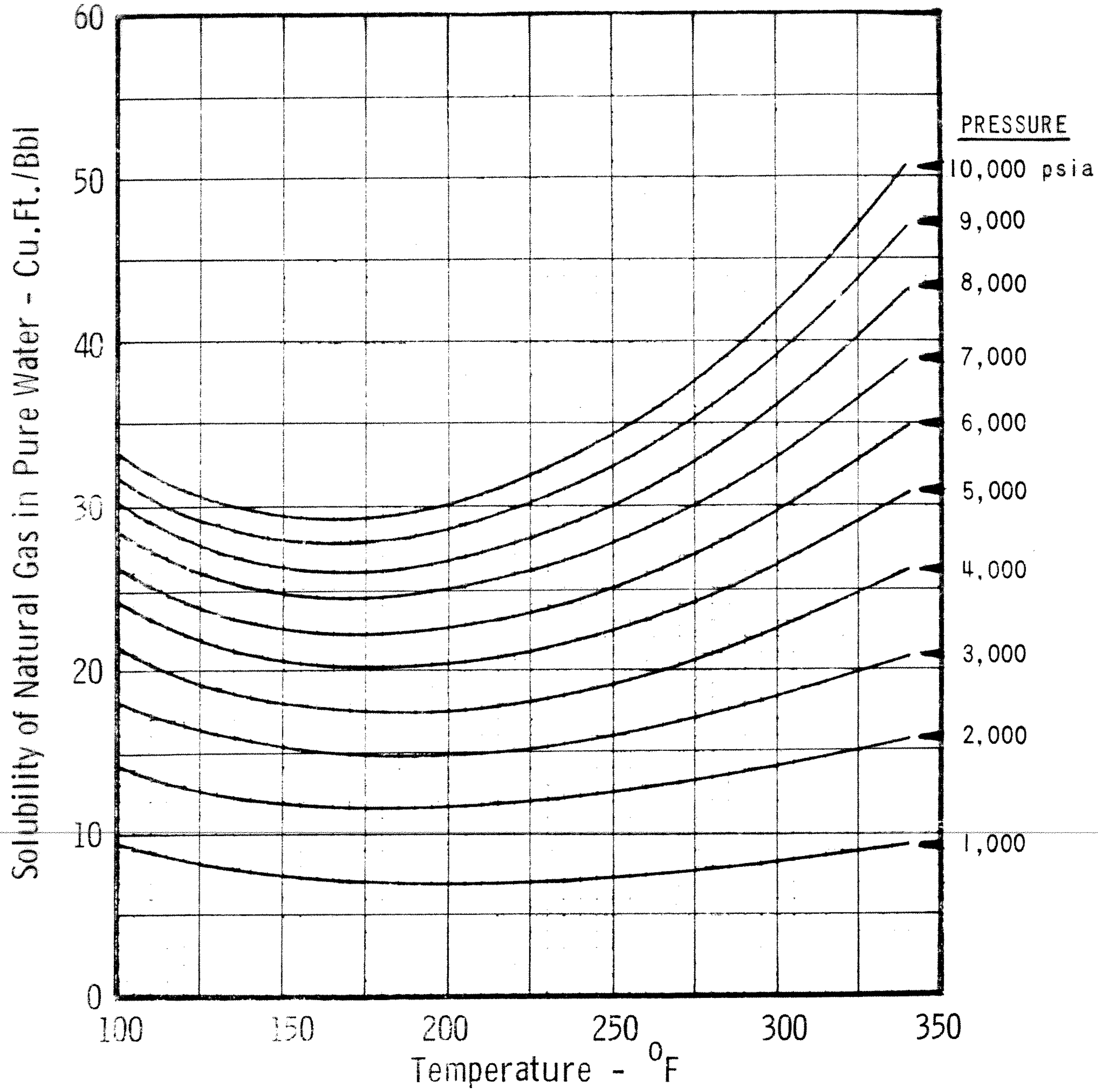
SOLUBILITY OF METHANE IN WATER

REFERENCE: CULBERSON & McKETTA
TRANS AIME 192(1951)223

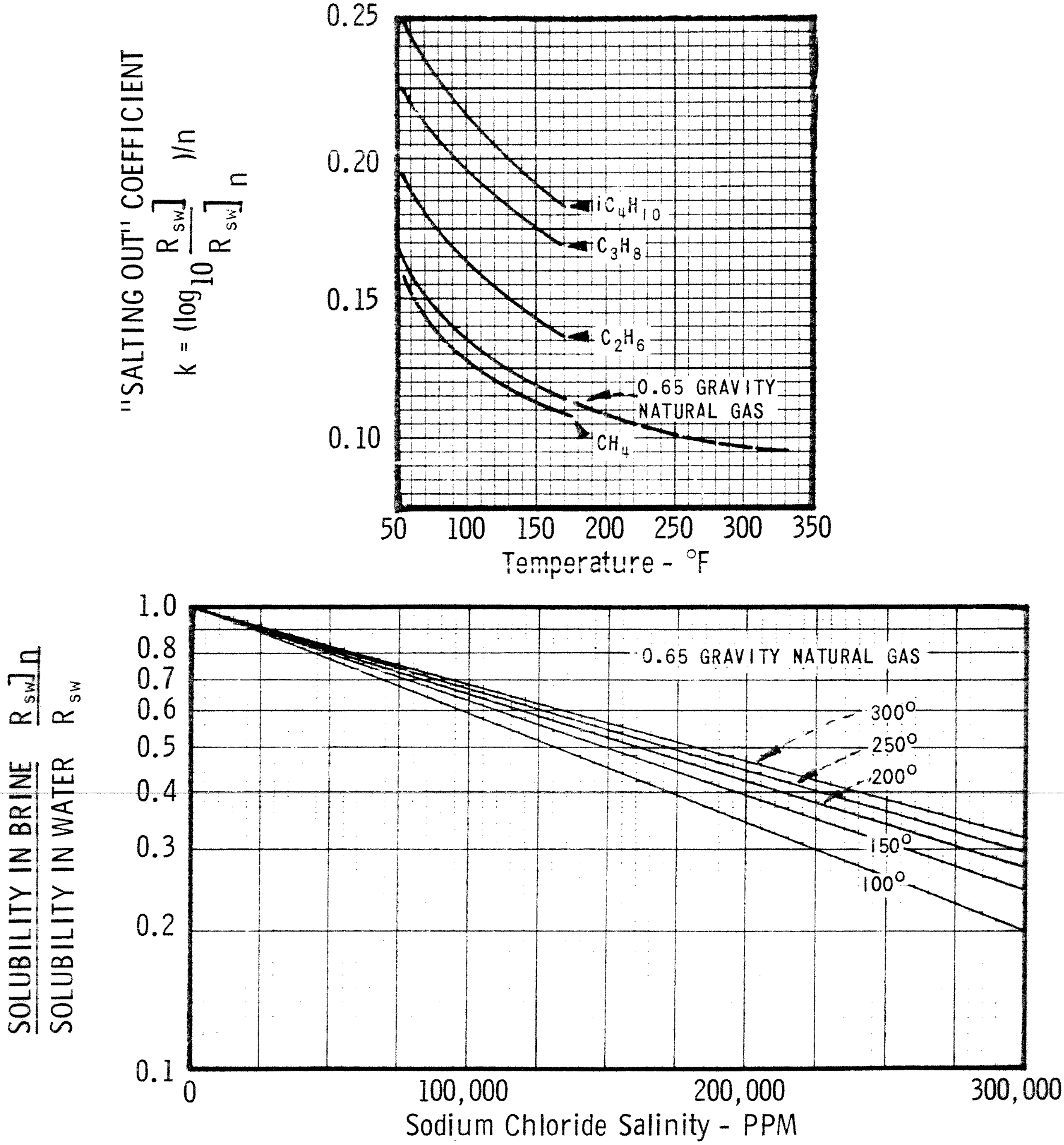


SOLUBILITY OF ETHANE IN WATER

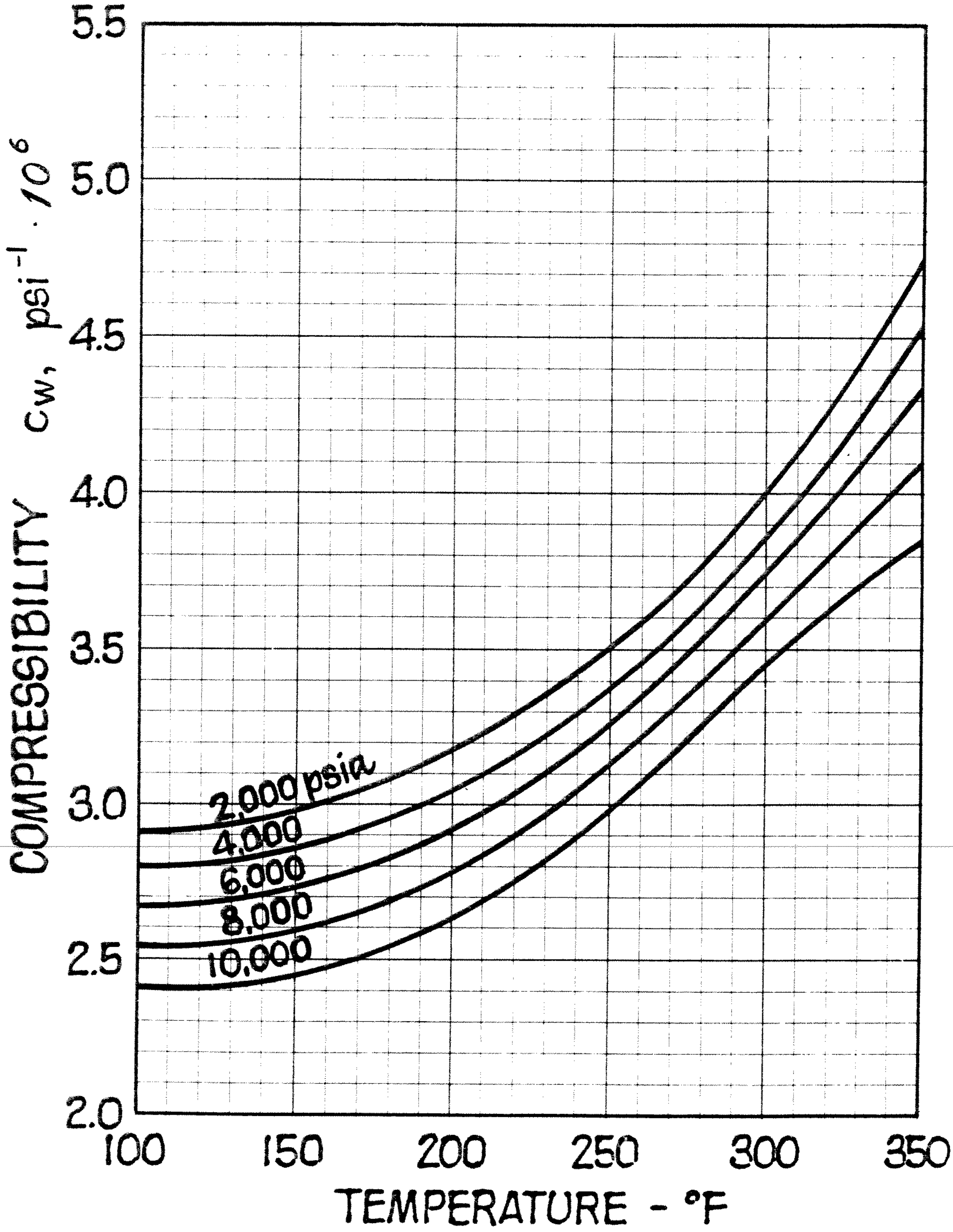
REFERENCE: CULBERSON & McKETTA
TRANS AIME 189(1950)319



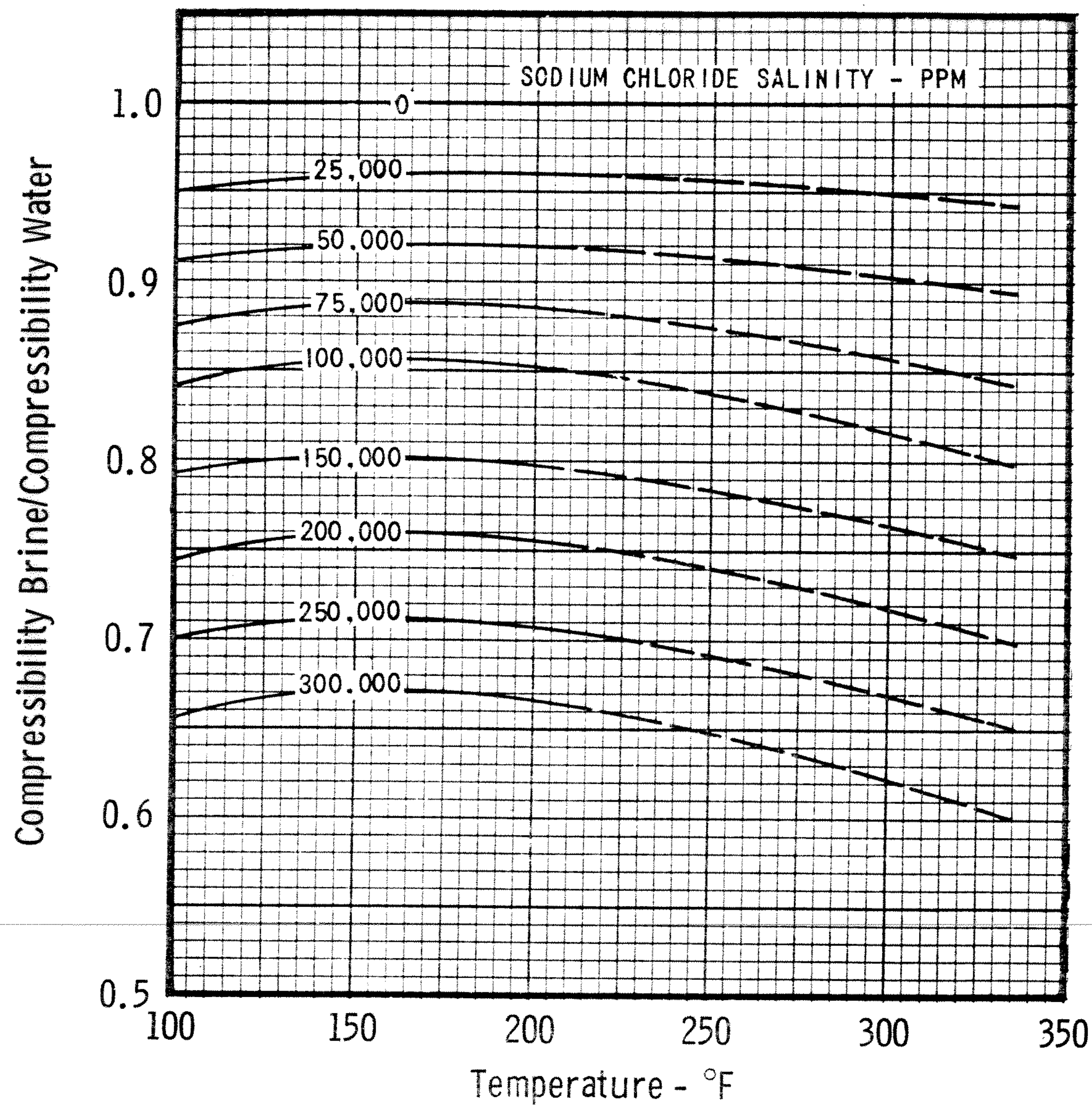
SOLUBILITY OF 0.65 GRAVITY NATURAL GAS IN PURE WATER



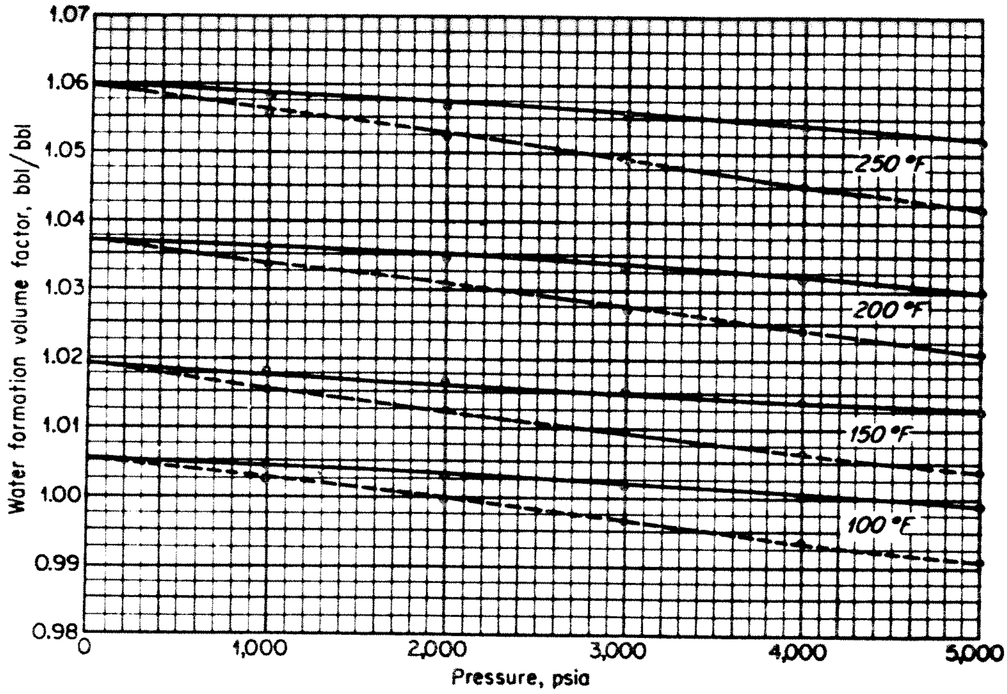
REDUCTION IN GAS SOLUBILITY
DUE TO DISSOLVED SALT CONTENT



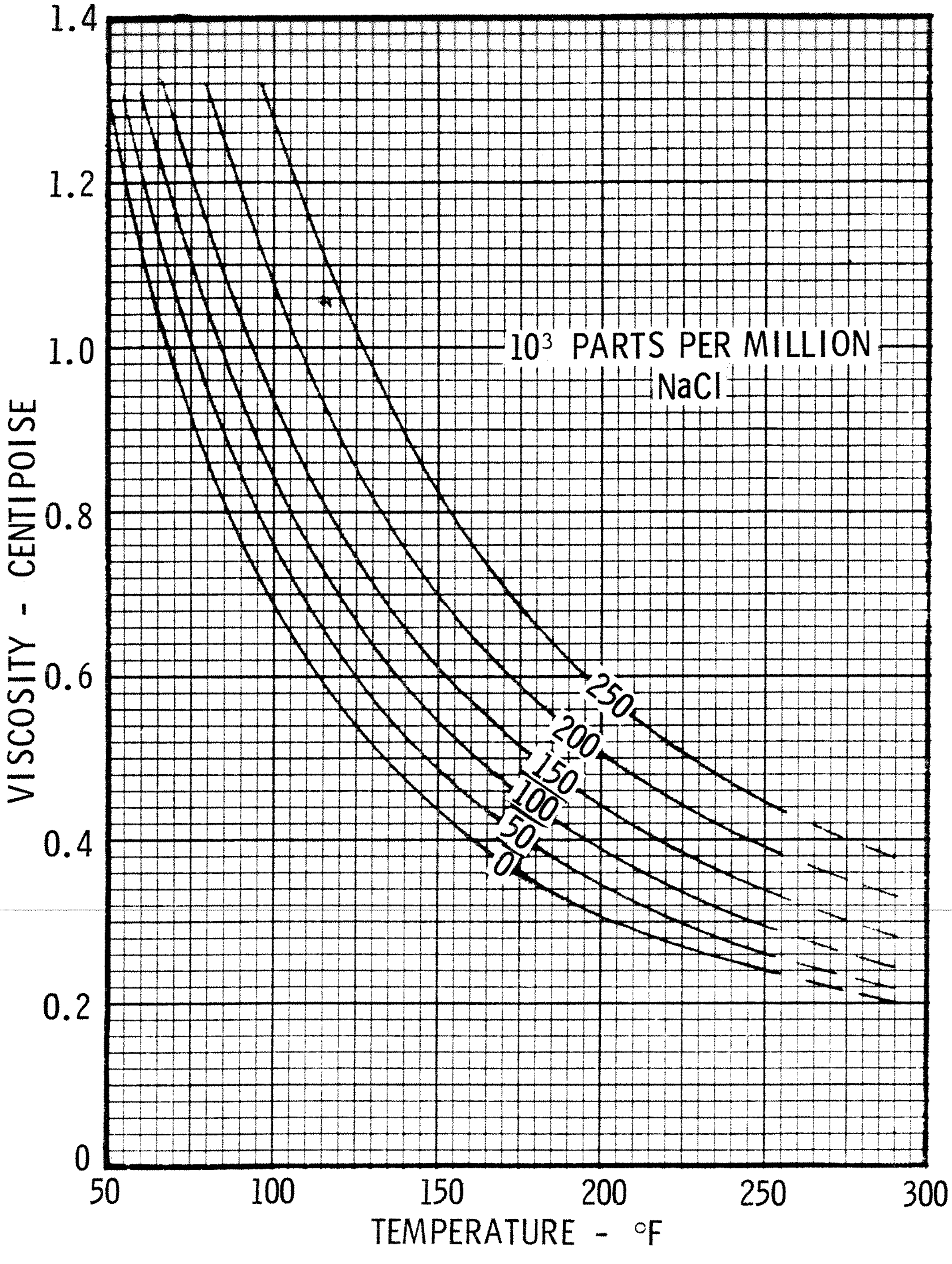
COMPRESSIBILITY OF PURE WATER



REDUCTION IN WATER COMPRESSIBILITY
DUE TO DISSOLVED SALTS

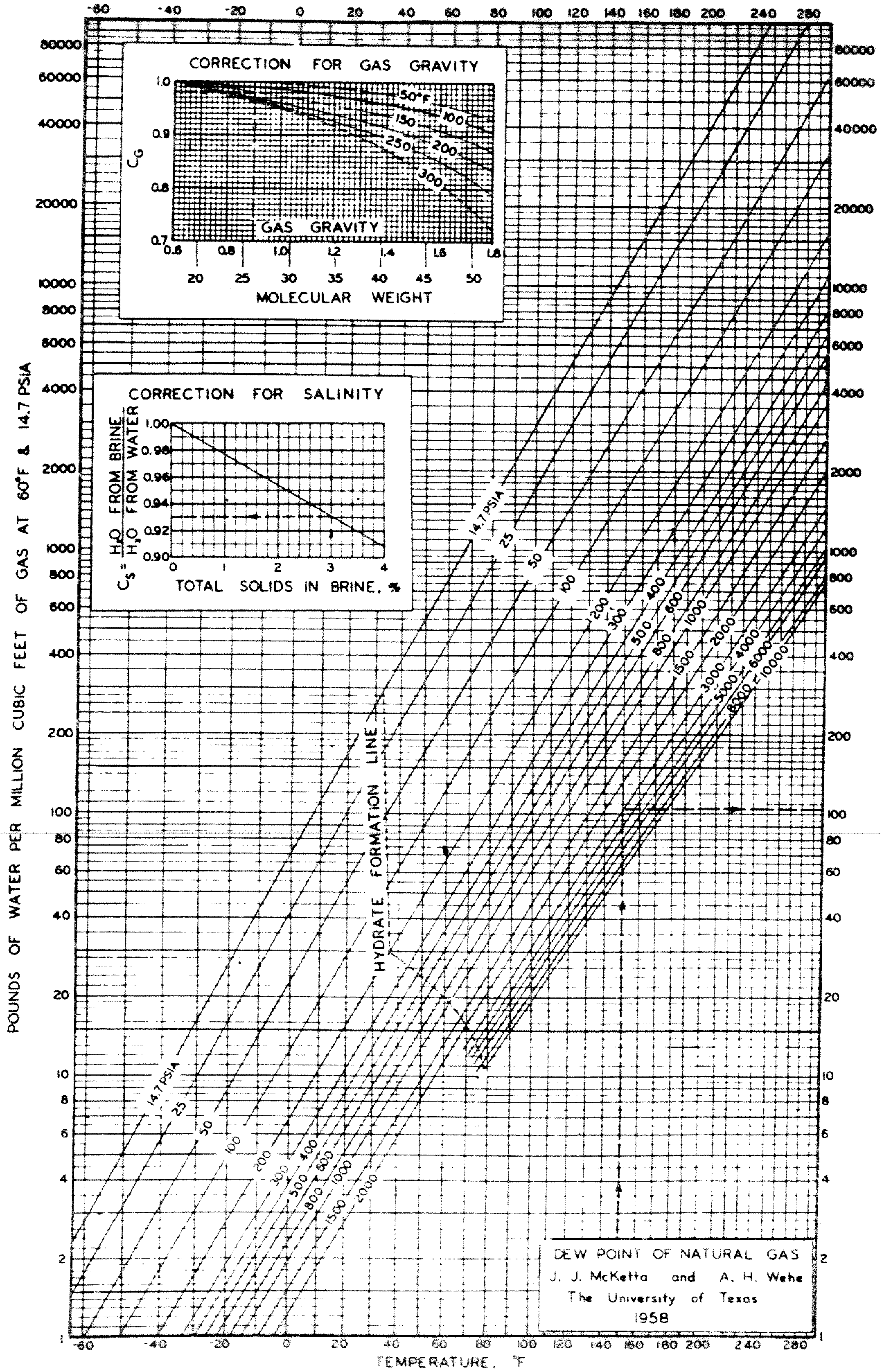


WATER-FORMATION VOLUME FACTOR FOR PURE WATER (DASHED LINES) AND PURE WATER SATURATED WITH NATURAL GAS (SOLID LINES) AS A FUNCTION OF PRESSURE AND TEMPERATURE. (AFTER DODSON AND STANDING, API, 1944).



VISCOSITY OF SODIUM CHLORIDE BRINES

(Interpolated from International Critical Tables)


CORRECTION FOR GAS GRAVITY
GAS GRAVITY
MOLECULAR WEIGHT
CORRECTION FOR SALINITY
TOTAL SOLIDS IN BRINE, %
POUNDS OF WATER PER MILLION CUBIC FEET OF GAS AT 60°F & 14.7 PSIA
HYDRATE FORMATION LINE
TEMPERATURE, °F
DEW POINT OF NATURAL GAS
J. J. McKetta and A. H. Wehe
The University of Texas
1958

INTERFACIAL TENSION (IFT) VALUES AT ATMOSPHERIC PRESSURE
(after Standing Chart 40)

Fluids	Temperature °C	Temperature °F	IFT mN/m	IFT lb_f/in
Water - Air (Natural Gas)	21 60 100	70 140 212	73 66 59	0.00042 0.00038 0.00034
Mercury - Air "clean" "dirty"	24±	75±	 465 400±	 0.00265 0.00228
Kerosene - Air Kerosene - Water	24 24	75 75	24 50	0.00014 0.00029
Crude Oils - Air (Tank Oils)	25	78	10-35 Avg. 21	 0.00012

$lb/in = 5.71 \cdot 10^{-6}\ dynes/cm$

$1.0\ mN/m = 1.0\ dynes/cm$

INTERFACIAL TENSION (IFT) AND CONTACT ANGLES TO USE IN CAPILLARY PRESSURE CALCULATIONS

(after Standing Chart 41)

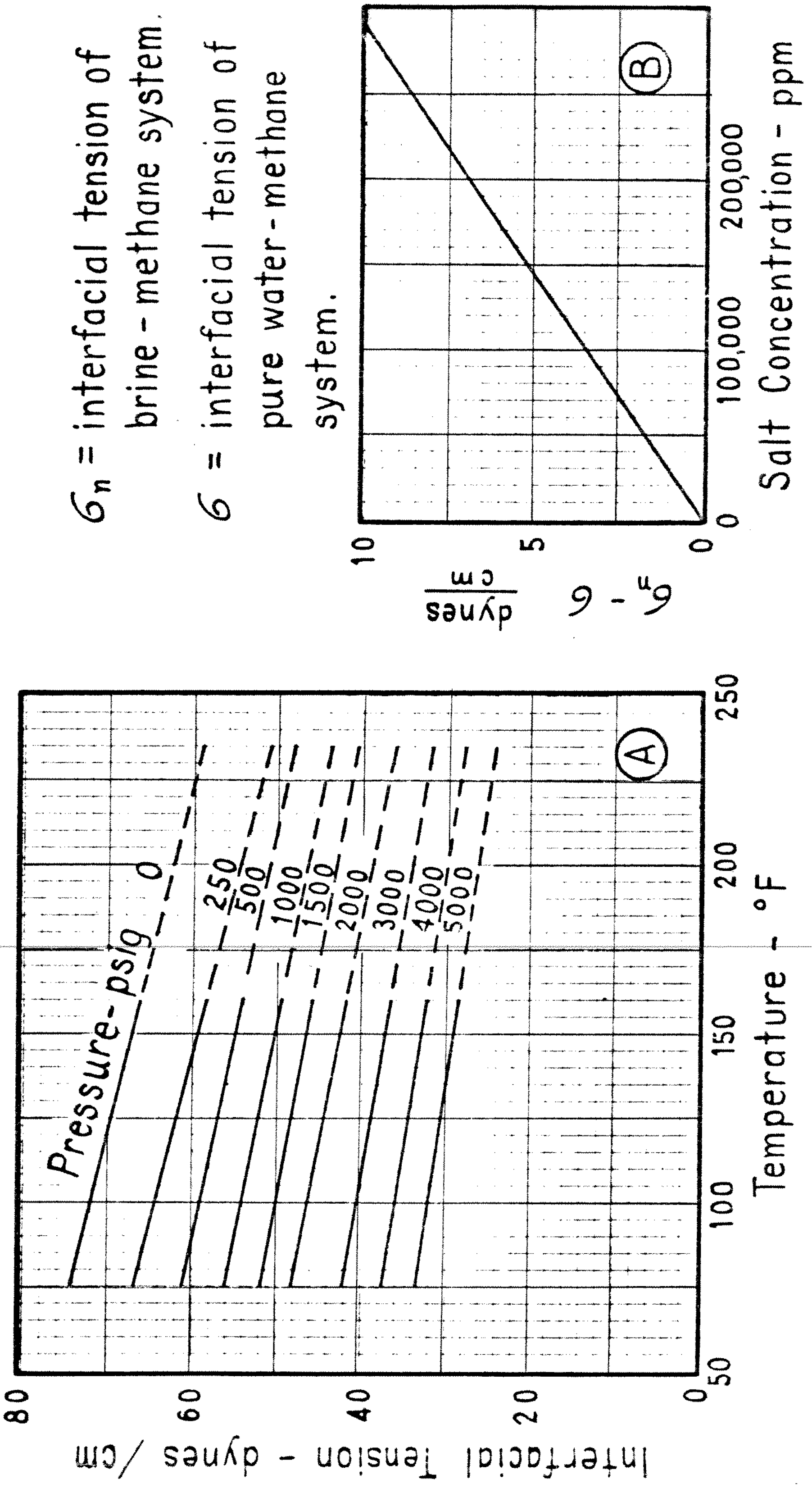
The following values are recommended when direct information is not available.

INTERFACIAL TENSION

Fluids	Reservoir		Laboratory
Water - Gas	(1) Use Methane-Water Chart (2) Use 35 mN/m		(1) Use 73 mN/m for fresh water. Apply salinity correction from Methane-Water chart
Water - Oil	(1) Use 30-35 mN/m		(1) Use 50 mN/m for kerosene-water
Oil - Gas	Pressure psia	IFT mN/m	
	<1000	10	
	2000	3	
	3000	1	
	>3000	0.5	

CONTACT ANGLE, θ (Wettability)

Fluids	Reservoir	Laboratory
Water - Gas	(1) $\theta = 0^o$	(1) $\theta = 0^o$
Water - Oil	(1) $\theta = 30^o$	(1) $\theta = 60^o$
Oil - Gas	(1) $\theta = 0^o$	(1) $\theta = 0^o$



Pressure - temperature - interfacial tension of brine - methane systems.

Reference List

1. *Technical Data Book--Petroleum Refining*, 3rd ed., API, New York City (1977).

2. Earlougher, R.C., Jr.: *Advances in Well Test Analysis*, Monograph, SPE, Dallas (1977).

3. Goodrich, J.H.: "Target Reservoirs for CO_2 Miscible Flooding," U.S. DOE (1980) **DOE/MC/08341-17**.

4. Lucas, K.: *Chem. Ing. Tech.* (1981) **53**, 959.

5. Nagy, Z. and Shirkovskiy, A.I.: "Mathematical Simulation of Natural Gas Condensation Processes Using the Peng-Robinson Equation of State," paper SPE 10982 presented at the 1982 SPE Annual Technical Conference and Exhibition, New Orleans, Sept. 26-29.

6. Reid, R.C., Prausnitz, J.M., and Polling, B.E.: *The Properties of Gases and Liquids*, 4th ed., McGraw-Hill, New York (1987).

7. Standing, M.B.: *Petroleum Engineering Data Book*, Norwegian Institute of Technology, Department of Petroleum Engineering and Applied Geophysics, Trondheim (1974).

8. Stephan, K. and Lucas, K.: *Viscosity of Dense Fluids*, Plenum, New York (1979).

9. Twu, C.H.: "Prediction of Thermodynamic Properties of Normal Paraffins Using Only Normal Boiling Point," *Fluid Phase Equilibria* (1983) **11**, 65-81.

10. Twu, C.H.: "An Internally Consistent Correlation for Predicting the Critical Properties and Molecular Weights of Petroleum and Coal-Tar Liquids," *Fluid Phase Equilibria* (1983) **16**, 137-150.

11. Whitson, C.H. and Brule, M.R.: *Phase Behavior*, Monograph, SPE of AIME, Dallas (1994) **(in print)**.

REFERENCES

Table Cross-Reference

Chart	Ref.	Original Standing Chart	Chart	Ref.	Original Standing Chart	Chart	Ref.	Original Standing Chart
1	11		**31**	6,8		**61**	7	(42)
2	11		**32**	3				
3	11		**33**	7	(15)			
4	11		**34**	7	(16)			
5	5,6,11		**35**	7	(17)			
6	2		**36**	7	(18)			
7	2		**37**	7	(20)			
8	-		**38**	7	(19)			
9	2		**39**	7				
10	2		**40**	7				
11	2		**41**	7				
12	2,11		**42**	7				
13	1		**43**	7	(25)			
14	1		**44**	7	(26)			
15	9		**45**	10				
16	9		**46**	10				
17	9		**47**	7	(28)			
18	9		**48**	7	(29)			
19	7	(3)	**49**	7	(30)			
20	7	(4)	**50**	7	(31)			
21	7	(5)	**51**	7	(32)			
22	7	(6)	**52**	7	(33)			
23	7	(8)	**53**	7	(34)			
24	7	(11)	**54**	7	(35)			
25	7	(13)	**55**	7	(36)			
26	7	(14)	**56**	7	(37)			
27	4,6		**57**	7	(38)			
28	3		**58**	7	(39)			
29	3		**59**	7	(40)			
30	3		**60**	7	(41)			