UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
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EKC 234 : Kejuruteraan Pemprosesan Petroleum dan Gas

Masa: [3 jam]

ARAHAN KEPADA CALON:

Sila pastikan soalan peperiksaan ini mengandungi **LIMABELAS (15)** mukasurat bercetak dan **TUJUHBELAS (17)** mukasurat lampiran sebelum anda memulakan peperiksaan.

Kertas soalan ini mengandungi **TUJUH (7)** soalan.

Jawab **LIMA (5)** soalan. Soalan **No. 1 dalam Bahagian A ialah Wajib**. Jawab **SATU (1)** soalan dalam Bahagian B dan mana-mana **TIGA (3)** soalan dalam Bahagian C.

Bahagian A ***Part A***

1. Pilikan jawapan yang betul sahaja. Sila tuliskan jawapan anda di dalam kertas jawapan yang disediakan.

Choose the correct answer only. Write the answer in the answer script.

[a] Nombor oktana petrol adalah pengukuran bagi
- [i] kecenderungan ketukkan
- [ii] lengah pencucukan
- [iii] suhu pencucukan
- [iv] takat asap

[a] Octane number of petrol is a measure of its
- *[i] knocking tendency*
- *[ii] ignition delay*
- *[iii] ignition temperature*
- *[iv] smoke point*

[b] Nombor setana minyak diesel adalah pengukuran bagi
- [i] lengah pencucukan
- [ii] takat asap
- [iii] kelikatan
- [iv] kestabilan pengoksidaan

[b] Cetane number of a diesel fuel is the measure of its
- *[i] ignition delay*
- *[ii] smoke point*
- *[iii] viscosity*
- *[iv] oxidation stability*

[c] Indeks kelikatan
- [i] ialah pengukuran takat kilat
- [ii] ialah pengukuran perubahan kelikatan dengan suhu
- [iii] bagi minyak pelincir adalah rendah
- [iv] tiada diantara yang diatas.

[c] Viscosity index
- *[i] is the measure of flash point*
- *[ii] is the measure of variation of viscosity with temperature.*
- *[iii] of a lubricating oil should be low*
- *[iv] none of these*

[d] Takat curahan ialah
- [i] pekalian setiap 3°F
- [ii] pekalian setiap 5°F
- [iii] 5°F di bawah suhu dimana minyak berhenti mengalir
- [iv] tiada diantara yang diatas.

[d] Pour point is
- *[i] multiple of 3 ° F*
- *[ii] multiple of 5° F*
- *[iii] 5° F below the temperature at which oil ceases to flow*
- *[iv] none of these*

[e] Turus atas mentah beroperasi
- [i] pada tekanan atmosfera
- [ii] pada 10 atm
- [iii] di bawah vakum
- [iv] tiada diantara yang diatas.

[e] Crude topping column operates
- *[i] at atmospheric pressure*
- *[ii] at 10 atm*
- *[iii] under vacuum*
- *[iv] none of these*

[f] Objektif utama pemecahan bermangkin ialah untuk menghasilkan
- [i] gasolin
- [ii] kok
- [iii] minyak lub
- [iv] baki

[f] The main objective of catalytic cracking is to produce
- *[i] gasoline*
- *[ii] coke*
- *[iii] lube oil*
- *[iv] residue*

[g] Pemecahan vis
- [i] menggunakan gas asli sebagai suapan
- [ii] dilakukan pada tekanan atmosfera
- [iii] menghasilkan minyak bahan api pada kelikatan rendah
- [iv] menghasilkan gasolin sahaja

[g] Visbreaking
- *[i] uses natural gas as feed*
- *[ii] is carried out at atmospherric pressure*
- *[iii] produces fuel oil of lower viscosity*
- *[iv] produces gasoline only*

[h] Pembentukan semula menukarkan
- [i] olefin kepada parafin
- [ii] naftena kepada aromatik
- [iii] naftena kepada olefin
- [iv] naftena kepada parafin

[h] Reforming converts
- *[i] olefins into paraffins*
- *[ii] naphthenes into aromatics*
- *[iii] naphthenes into olefins*
- *[iv] naphthenes into paraffin*

[i] Suapan untuk pembentukan semula bermangkin, kebiasaannya
- [i] nafta atau gasolin
- [ii] mentah terkurang
- [iii] minyak gas vakum
- [iv] minyak gas bertekanan atmosfera

[i] Feed for catalytic reformer is generally
- *[i] naphtha or straight run gasoline*
- *[ii] reduced crude*
- *[iii] vacuum gas oil*
- *[iv] atmospheric gas oil*

[j] Kerosen mengandungi
[i] takat asap yang rendah
[ii] takat asap yang tinggi
[iii] kandungan aromatik yang tinggi
[iv] kandungan parafin yang rendah

[j] Kerosene should have
[i] low smoke point
[ii] high smoke point
[iii] high aromatics content
[iv] low paraffin content

[k] Antara nisbah petroleum di bawah, yang manakah mempunyai kandungan sulfur maksima?
[i] diesel
[ii] gasolin
[iii] nafta
[iv] baki atmosfera

[k] Which of the following fractions of petroleum contains maximum sulphur ?
[i] diesel
[ii] gasoline
[iii] naphtha
[iv] atmospheric residue

[l] Kelikatan tinggi minyak pelincir menunjukkan
[i] tekanan wap Reid yang rendah
[ii] bilangan asid yang tinggi
[iii] takat kilat dan takat nyala yang tinggi
[iv] takat kilat dan takat nyala yang rendah

[l] Higher viscosity of lubricating oil usually signifies
[i] lower Reid vapour pressure
[ii] higher acid number
[iii] higher flash point and fire point
[iv] lower flash point and fire point

[m] Takat kilat gasolin motor mungkin berada pada
[i] 30 °F
[ii] 110 °F
[iii] 240 °F
[iv] 310 °F

[m] Flash point of motor gasoline may be around
[i] 30 °F
[ii] 110 °F
[iii] 240 °F
[iv] 310 °F

[n] Antara nisbah minyak mentah dibawah, yang manakah mempunyai graviti API (ie ° API) yang maksima?
[i] minyak diesel
[ii] gasolin
[iii] minyak gas pada tekanan atmosfera
[iv] minyak gas vakum

[n] Which of the following fractions of a crude will have maximum gravity API (ie ° API) ?
[i] diesel oil
[ii] gasoline
[iii] atmospheric gas oil
[iv] vacuum gas oil

[o] Takat anilin diesel adalah pengukuran bagi
[i] kandungan aromatic
[ii] kandungan parafin
[iii] kandungan olefin
[iv] kandungan naften

[o] Aniline point of a diesel is a measure of its
[i] aromatic content
[ii] paraffin content
[iii] olefin content
[iv] naphthene content

[p] Takat didih sebenar (TBP) unit penyulingan digunakan untuk
[i] menentukan faktor pengkriteriaan
[ii] menilai stok-stok minyak
[iii] menentukan tekanan wap sebenar
[iv] Tiada diantara yang di atas

[p] True boiling point (TBP) distillation unit is used for
[i] determination of characterisation factor
[ii] evaluation of oil stocks
[iii] determination of true vapour pressures
[iv] none of these

[q] Pempelantaran ialah
[i] proses lapisan bergerak
[ii] proses lapisan terbendalir
[iii] proses tak jana semula dan lapisan tertetap
[iv] proses penjanaan semula

[q] Platforming is a
[i] moving bed process
[ii] fluidised bed process
[iii] non regenerative and fixed bed process
[iv] regenerative process

[r] Gas Petroleum Cecair (LPG) yang digunakan di rumah untuk memasak terdiri daripada:
[i] propana dan butana
[ii] butana dan etana
[iii] metana dan etana
[iv] metana dan karbon monoksida

[r] Liquified Petroleum Gas (LPG) used for house hold cooking comprises mainly of
[i] propane and butane
[ii] butane and ethane
[iii] methane and ethane
[iv] methane and carbonmonoxide

[s] Nilai kalori (kcal/N m^3) gas asli adalah lebih kurang
[i] 2500
[ii] 10,000
[iii] 25,000
[iv] 35,000

[s] The calorific value (kcal/Nm^3) of natural gas is about
[i] 2500
[ii] 10,000
[iii] 25,000
[iv] 35,000

[t] Pembentukan gas hidrat dalam gas asli bergantung kepada
[i] tekanan dan suhu gas berkenaan
[ii] tekanan gas-gas yang lain seperti nitrogen dan CO_2
[iii] tekanan air
[iv] semua (a), (b) dan (c)

(20 markah)

[t] Gas hydrate formation in natural gas depends on
[i] pressure and temperature of gas
[ii] pressure of other gases such as nitrogen and CO_2
[iii] pressure of water
[iv] all (a) , (b) and (c)

(20 marks)

Bahagian B ***Part B***

2. Bezakan antara keduanya:

[a] Penghidro dan penghidropecahan

[b] Penyingkiran gas asid melalui proses pelarut fizikal dan pelarut kimia.

[c] Penyulingan EFV dan penyulingan ASTM

[d] Penyahlilinan pelarut dan penyahlilinan bermangkin

[e] Pembentukan semula bermangkin dan pengisomeran

(20 markah)

2. *Differentiate between the followings :*

[a] Hydrotreating vs Hydrocracking

[b] Acid gas removal by Physical Solvent vs Chemical Solvent Process

[c] EFV distillation vs ASTM distillation

[d] Solvent dewaxing vs Catalytic dewaxing

[e] Catalytic Reforming vs Isomerisation

(20 marks)

3. Lukiskan gambarajah aliran yang ringkas bagi 2 proses, dengan menunjukkan pembolehubah proses-proses yang penting, ciri-ciri suapan dan produk-produk yang diperolehi.

[a] FCC (peretakan bermangkin bendalir) bagi peretakan minyak gas di dalam loji pengangkutan.

[b] Unit pengkokan terlengah bagi penghasilan gasolin.

[c] Pemisahan CO_2 dan H_2S daripada gas asli.

(20 markah)

3. *Draw a simplified flow diagram for 2 processes showing the important process variables, characteristics of feed and products obtained.*

[a] FCC (Fluid Catalytic Cracking) process for gas oil cracking in transport reactor.

[b] Delayed coker unit for production of gasoline

[c] Separation of CO_2 and H_2S from Natural Gas

(20 marks)

Bahagian C ***Part C***

4. [a] Aliran nafta yang belum pernah digunakan bersuhu antara 180°F dan 380°F dengan takat didih purata min 275°F dan 50.2°API telah ditukarkan kepada adunan gasolin jernih 96 RON. Buatkan keseimbangan bahan keseluruhan pada pembaharu itu untuk kadar suapan 10,000 BPD.

(10 markah)

[b] Stok suapan peretakan hidro mempunyai julat didih 650 - 920°F, graviti API 23.7° dan mengandungi 1.7% nisbah jisim sulfur. Jika penggunaan hidrogen untuk peretakan hidro ialah 1,500 scf/bbl daripada suapan dan kadar suapan ialah 7500 BPSD, tentukan

[i] jumlah penggunaan hidrogen
[ii] penghasilan tong-tong gasolin setiap hari.

(10 markah)

4. *[a] A 180 to 380°F virgin naphtha stream with mean average boiling point of 275°F and 50.2° API is reformed to a 96 RON clear gasoline blending stock. Make an overall material balance around the reformer for a 10,000 BPD feed rate.*

(10 marks)

[b] A hydrocracker feed stock has a boiling range of 650-920°F, an API gravity of 23.7° API and contains 1.7 wt% sulfur. If the hydrocracking hydrogen consumption is 1,500 scf/bbl of feed and the feed rate is 7,500 BPSD, determine.

[i] total hydrogen comsumption

[ii] barrels of gasoline produced per day.

[10 marks]

5. Minyak mentah telah diproses di dalam menara penyulingan mentah dan penyulingan vakum untuk diasingkan kepada pelbagai pecahan. Analisa TBP mentah telah diberi di dalam jadual Q5. Lengkapkan keseimbangan bahan pada kedua-dua menara tersebut untuk spesifikasi pecahan minyak mentah dibawah:

	IBP (° F)	EP (° F)
Gasolin	90	180
Nafta	180	380
Kerosin	380	520
LGO	520	610
AGO	610	800
VGO	800	1050

Andaikan kadar suapan minyak mentah ke dalam penyuling mentah atmosfera ialah 100,000 BPCD. Jadikan keseimbangan jisim itu kepada paun yang berhampiran.

(20 markah)

5. *Crude oil is being processed in the atmospheric crude distillation tower and vacuum distillation tower for separation into various fractions. The crude TBP analysis is given in Table Q5. make a complete material balance around an atmospheric and vacuum crude towers for crude oil fraction specifications as :*

	IBP (° F)	*EP (° F)*
Gasoline	*90*	*180*
Naphtha	*180*	*380*
Kerosene	*380*	*520*
LGO	*520*	*610*
AGO	*610*	*800*
VGO	*800*	*1050*

Assume a 100,000 BPCD crude oil feed rate to the atmospheric crude still. Make the balances to the nearest pounds. Make sulphur weight balances for the feed and products to the nearest pounds.

(20 marks)

Table Q5

CRUDE PETROLEUM ANALYSIS

GENERAL CHARACTERISTICS

Gravity, specific, 0.871 Gravity, °API, 31.0 Pour point, °F, below 5
Sulfur, percent, 0.15 Color, greenlish black
Viscosity, Saybolt Universal at 77°F, 62 sec:100°F, 55 sec. Nitrogen, percent, 0.02

DISTILLATION, BUREAU OF MINES ROUTINE METHOD

STAGE 1 - Distillation at atmospheric pressure, 743 mm. Hg
First drop, 145°F

Fraction No.	Cut temp. °F	Percent	Sum, percent	Sp. gr., 60/60°F	° API 60°F	C.I	Refractive index, n_2 at 20°C	Specific dispersion	S.U. visc., 100°F
1	122								
2	167	1.1	1.1	0.748	57.7	-	1.40061	126.1	
3	212	1.8	2.9	.753	56.4	37	1.40946	129.6	
4	257	1.7	4.6	.757	55.4	30	1.41686	131.3	
5	302	2.7	7.3	.770	52.3	28	1.42613	139.7	
6	347	3.4	10.7	.789	47.8	31	1.43860	142.8	
7	392	5.1	15.8	.813	42.6	36	1.45011	147.6	
8	437	5.9	21.7	. 829	39.2	38	1.45805	149.8	
9	482	9.8	31.5	. 846	35.8	41	1.46806	153.5	
10	527	10.7	42.2	. 860	33.0	42	1.47690	158.6	

STAGE 2 - Distillation continued at 40 mm. Hg

11	392	4.4	46.6	0.871	31.0	44	1.48289	158.7	42
12	437	8.7	55.3	.880	29.3	44	1.48436	156.3	49
13	482	6.7	62.0	.891	27.3	46	1.48938	155.1	68
14	527	5.9	67.9	.904	25.0	49	1.49414	153.0	110
15	572	6.6	74.5	.910	24.0	49			225
Residuum		23.0	97.5	.942	18.7				

Carbon residue, Conradson : Residuum, 4.3 percent; crude 1.1 percent.

APPROXIMATE SUMMARY

	Percent	Sp. gr.	°API	Viscosity
Light gasoline	2.9	0.751	56.9	
Total gasoline and naphtha	15.8	0.783	49.2	
Kerosine distillate	-	-	-	
Gas oil	35.6	.855	34.0	
Nonviscous lubricating distillate	12.1	.880-.901	29.3-25.6	50 - 100
Medium lubricating distillate	6.4	.901-.908	25.6-24.3	100 - 200
Viscous lubricating distillate	4.6	.908-.913	24.3-23.5	Above 200
Residuum	23.0	.942	18.7	
Distillation loss	2.5			

...13/-

6. [a] Gas asli yang mengandungi komposisi berikut disarikan dengan minyak gas berjisim molekular 180 dan 39 °API pada 200 psia (10,260 mm Hg) dan 90°F (32.2°C). Carikan jumlah bagi setiap sebatian tersari gallon/Mcf untuk kadar minyak 20 gallon/Mcf gas pada suhu 60°F (15.5°C) dan 14.7 psia (760 mm Hg) apabila 8 peringkat equilibria digunakan.

Tanpa mengubah nisbah $\frac{L}{V}$ bolehkah perolehan propana diperbaiki dengan menambahkan lagi peringkat-peringkat equilibria?

Komponen	**% Mol**	**Nilai K pada 90°F & 200 psia**	**Cecair gallon per 1000 kaki padu piawai**
Methane	83.19	18.2	16.9
Ethane	8.48	2.85	25.2
Propane	4.37	0.85	27.4
Isobutane	0.76	0.375	32.4
n-Butane	1.68	0.282	31.6
Isopentane	0.57	0.131	36.4
n-Pentane	0,32	0.105	36.4
Hexanes	0.63	0.038	41.1

(15 markah)

[b] Nafta dan gasolin asli akan dicampurkan. Sifat-sifat stok adalah:

Stock	**RVP, psia**	**°API**	**lb per gal**	**Mol. wt**
Naphtha	6	57	6.25	119
Natural gasoline	18	72	5.79	90

Apakah tekanan wap Reid bagi 20:80 isipadu cecair bercampur?

(5 markah)

6. [a] *A natural gas of the following composition is to be extracted with a 180 molecular weight 39 °API gas oil at 200 psia (10,260 mm Hg) and 90° F (32.2° C). Find the amount of each constituent extracted gallon/Mcf for an oil rate of 20 gallon/Mcf of gas at 60° F (15.5° C) and 14.7 psia (760 mm Hg) when 8 equilibrium stages are used.*

Without changing the $\frac{L}{V}$ *ratio, can the propane recovery be improved by adding some more equilibrium stages ?*

Component	*Mole %*	*K value at 90°F & 200 psia*	*Gallon liquid per 1000 standard cubic feet pure component*
Methane	*83.19*	*18.2*	*16.9*
Ethane	*8.48*	*2.85*	*25.2*
Propane	*4.37*	*0.85*	*27.4*
Isobutane	*0.76*	*0.375*	*32.4*
n-Butane	*1.68*	*0.282*	*31.6*
Isopentane	*0.57*	*0.131*	*36.4*
n-Pentane	*0.32*	*0.105*	*36.4*
Hexanes	*0.63*	*0.038*	*41.1*

(15 marks)

[b] *Naphtha and natural gasoline are to be blended. The properties of the stocks are*

Stock	***RVP, psia***	***°API***	***lb per gal***	***Mol. wt***
Naphtha	*6*	*57*	*6.25*	*119*
Natural gasoline	*18*	*72*	*5.79*	*90*

What is the Reid vapor pressure of a 20 : 80 liquid volume blend ?

(5 marks)

7. Gas asli yang berkandungan rendah dimampatkan daripada 30 kepada 500 psia dan disejukkan kepada 80°F sebelum ia masuk ke dalam penyerap. Analisa gas berkenaan adalah seperti berikut:

Komponen	% Mol	Nilai K pada 80°F dan 500 psia
CH_4	78.8	6.5
C_2H_6	6.5	1.2
C_3H_8	6.2	0.46
i C_4H_{10}	1.4	0.22
C_4H_{10}	2.3	0.16
i–C_5H_{12}	1.6	0.071
C_5H_{12} +	3.2	0.052

[a] Apakah komposisi terakhir gas dan hasil kondensasi?

(15 markah)

[b] Kirakan jumlah hasil kondensasi?

(5 markah)

7. *A lean natural gas is to be compressed from 30 to 500 psia and cooled to 80° F before it enters an absorber. The analysis of the gas is :*

Components	*Mole %*	*K value at 80° F & 500 psia*
CH_4	78.8	6.5
C_2H_6	6.5	1.2
C_3H_8	6.2	0.46
i C_4H_{10}	1.4	0.22
C_4H_{10}	2.3	0.16
i–C_5H_{12}	1.6	0.071
C_5H_{12} +	3.2	0.052

[a] What is the final composition of the gas and condensate ?

(15 marks)

[b] Calculate the amount of condensate ?

(5 marks)

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LAMPIRAN

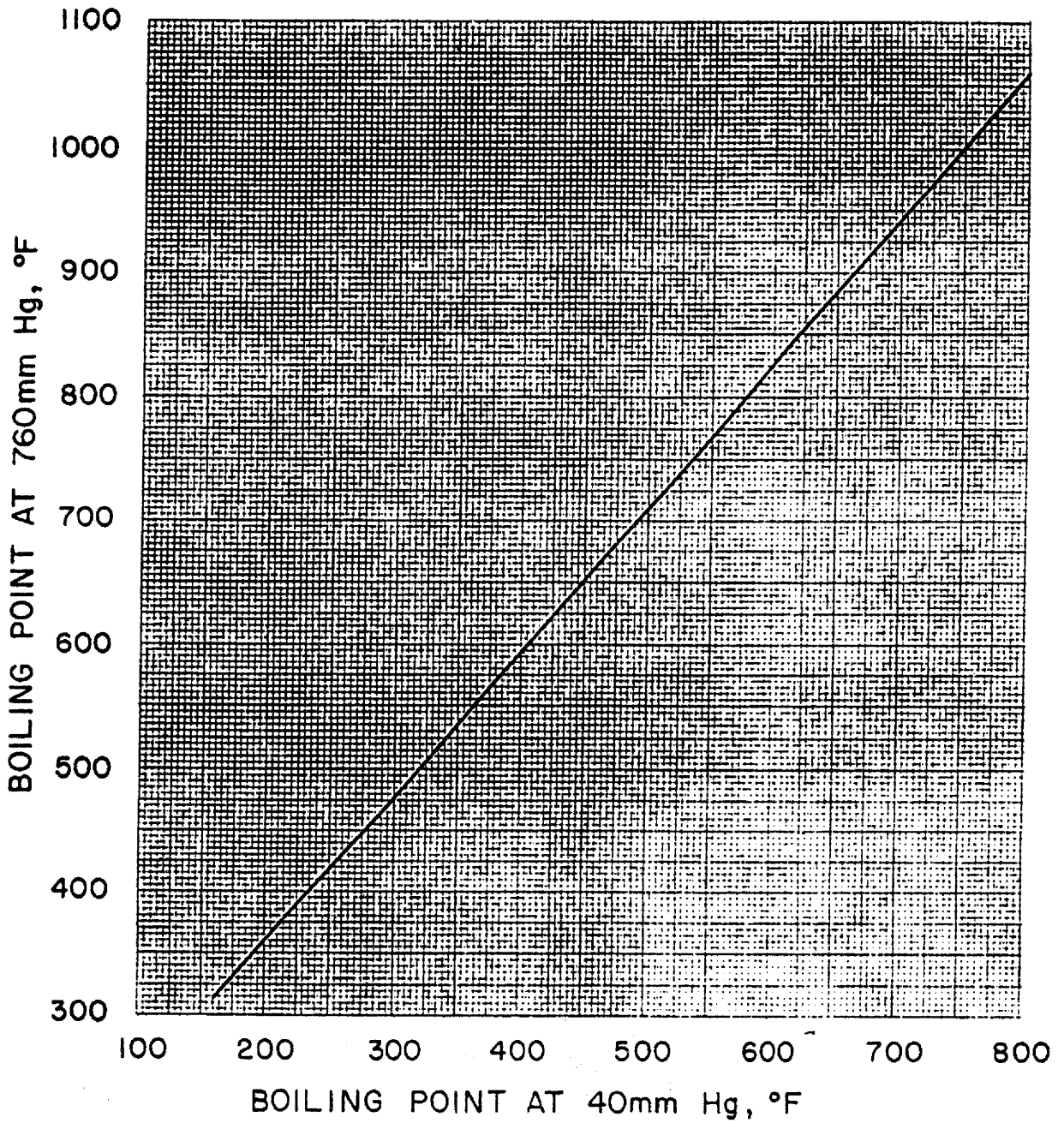


FIG. Boiling point at 760 mm Hg vs boiling point at 40 mm Hg.

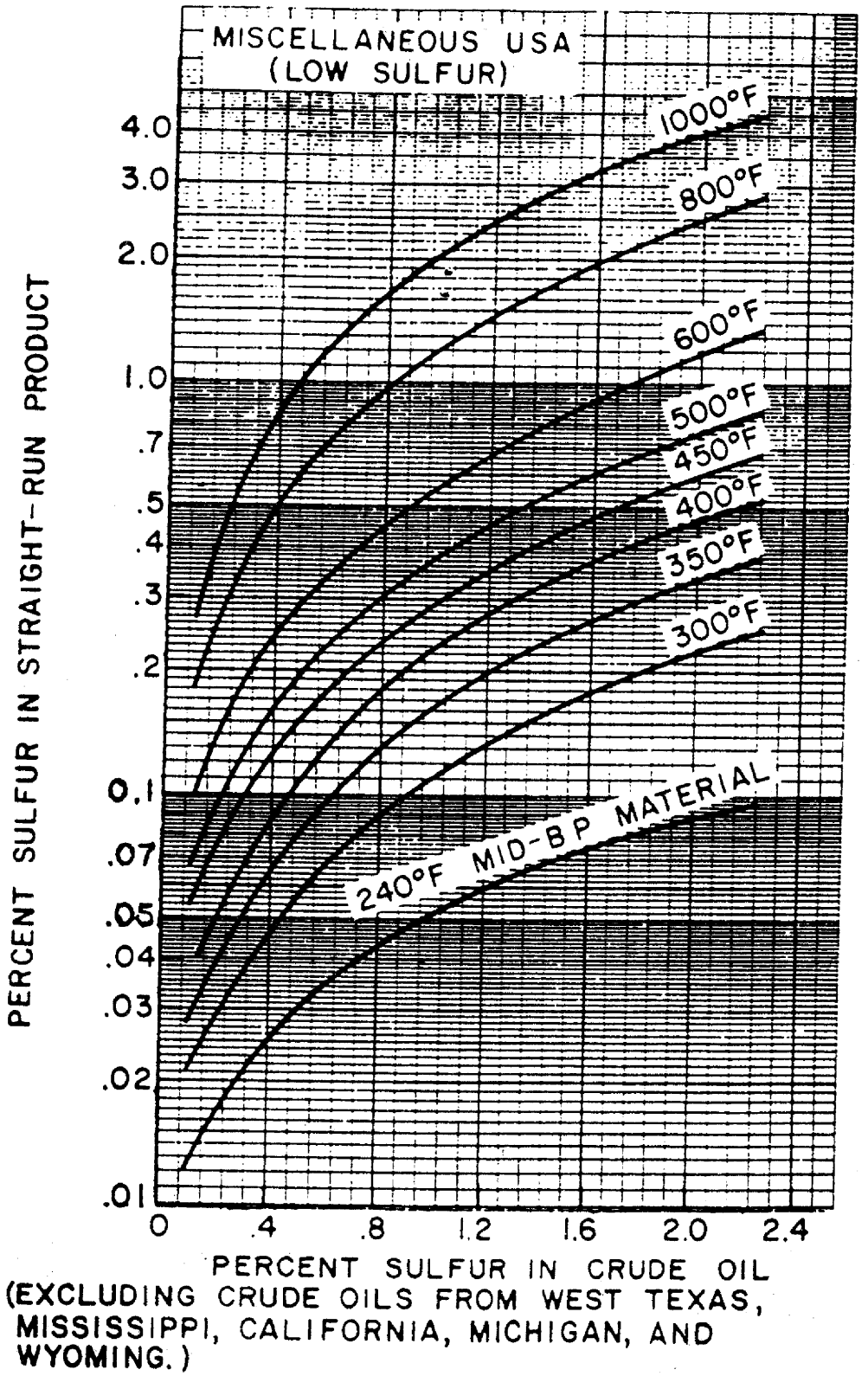


FIG. Sulfur content of products from miscellaneous U. S. crude oils

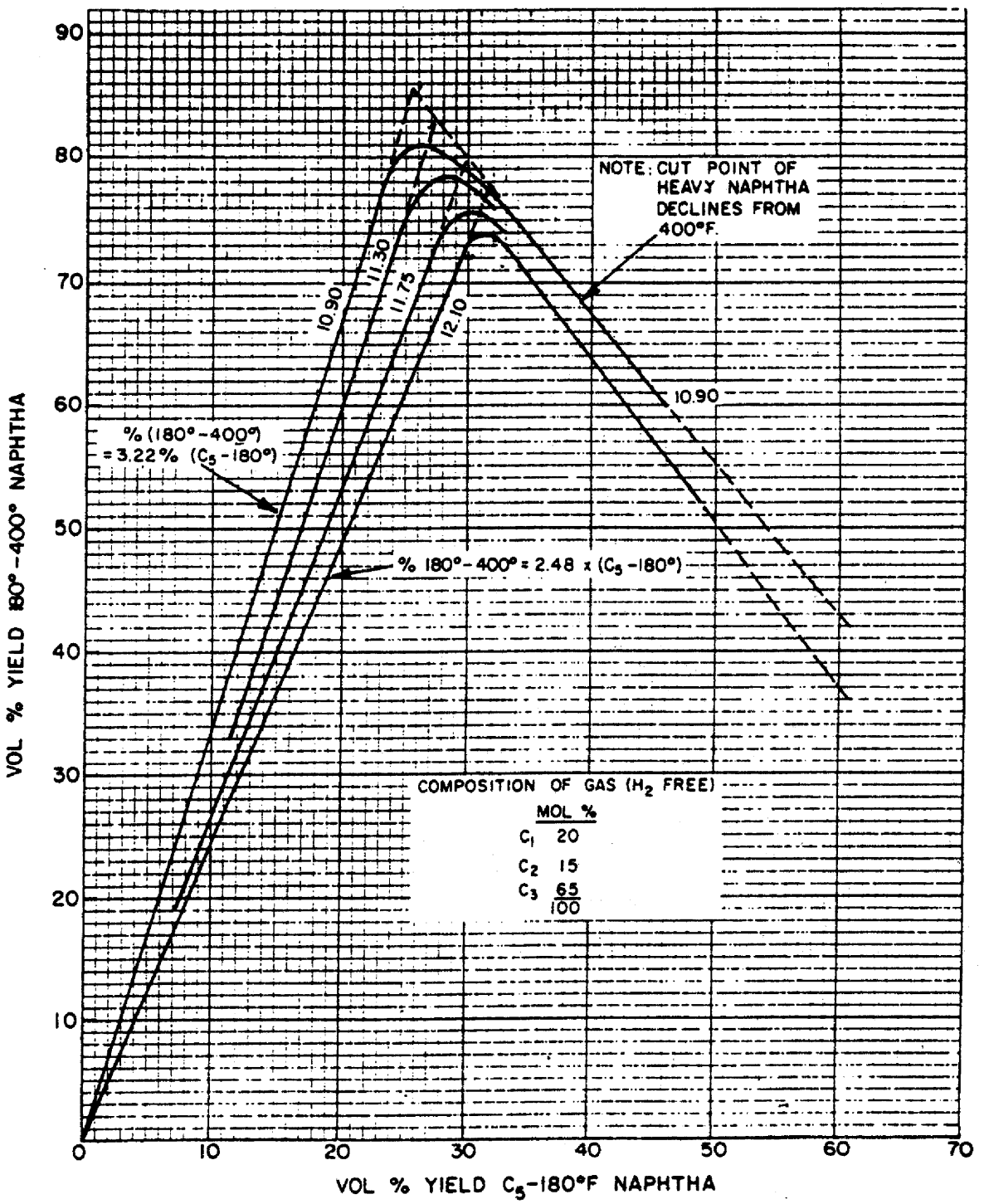


FIG. Relationship between yields of (C_5-180°F) and (180-400°F) hydrocrackates

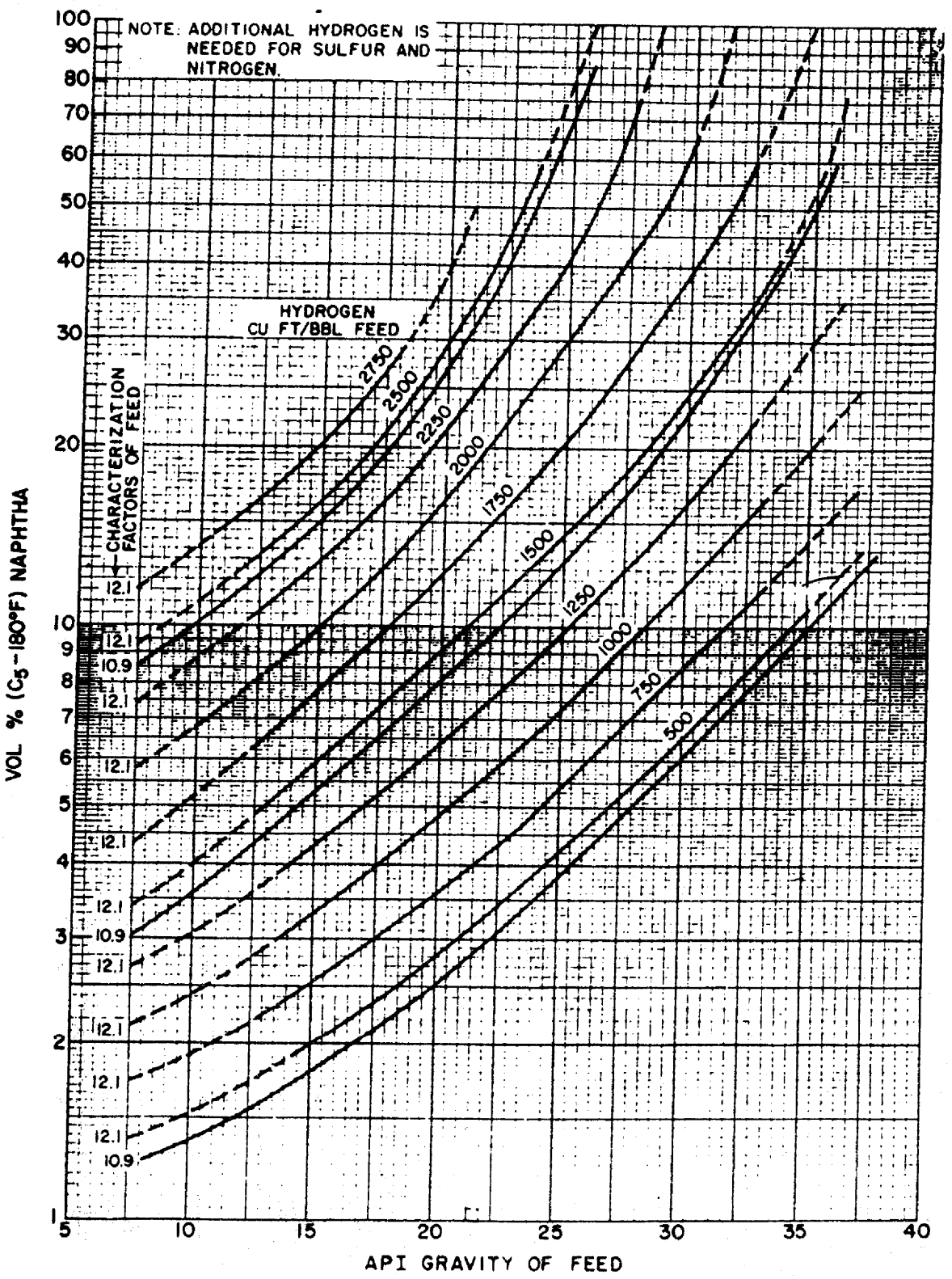


FIG. Approximate hydrogen required for hydrocracking

...5/-

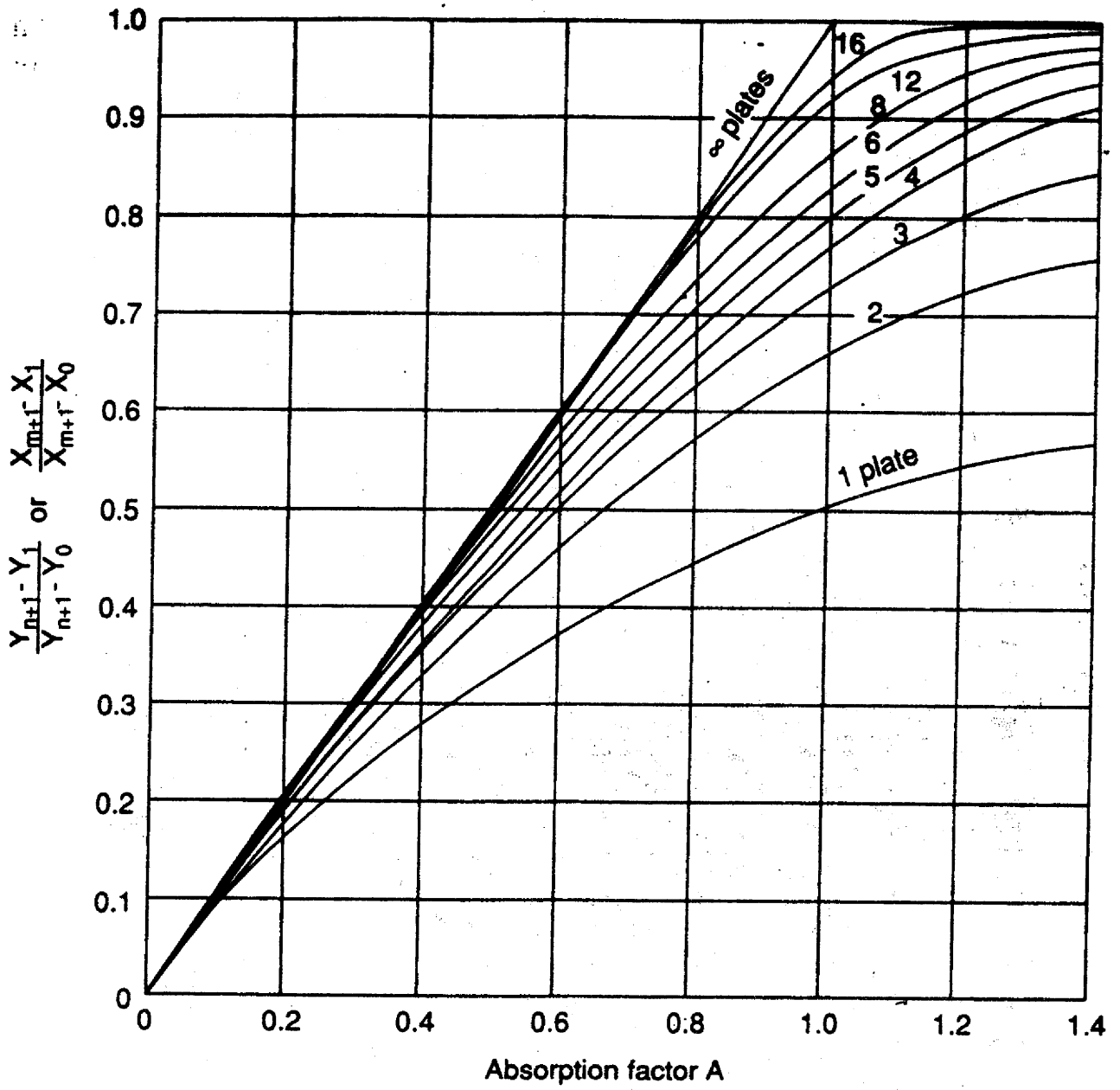


FIGURE
Solution to absorption factor and stripping factor equations

TABLE D.1

Density Conversion Table

Specific gravity	Density in vacuo			lb/hr* from	Specific gravity	Density in vacuo			lb/hr* from
60/60° F	°API	lb/bbl	lb/gal	bbl/day	60/60° F	°API	lb/bbl	lb/gal	bbl/day
1.165	-10.0	407.8	9.71	16.99	1.092	-2.0	382.6	9.11	15.94
1.163	-9.8	407.1	9.69	16.95	1.090	-1.8	382.0	9.09	15.92
1.161	-9.6	406.5	9.68	16.94	1.089	-1.6	381.4	9.08	15.89
1.159	-9.4	405.8	9.66	16.91	1.087	-1.4	380.8	9.07	15.87
1.157	-9.2	405.1	9.65	16.88	1.085	-1.2	380.3	9.05	15.85
1.155	-9.0	404.5	9.63	16.85	1.084	-1.0	379.7	9.04	15.82
1.153	-8.8	403.8	9.61	16.82	1.082	-0.8	379.1	9.03	15.80
1.151	-8.6	403.2	9.60	16.80	1.080	-0.6	378.5	9.01	15.77
1.149	-8.4	402.5	9.58	16.77	1.079	-0.4	377.9	9.00	15.75
1.147	-8.2	401.9	9.57	16.74	1.077	-0.2	377.4	8.98	15.72
1.145	-8.0	401.2	9.55	16.72	1.076	0.0	376.8	8.97	15.70
1.143	-7.8	400.6	9.54	16.69	1.074	.2	376.2	8.96	15.67
1.142	-7.6	399.9	9.52	16.66	1.073	.4	375.6	8.94	15.65
1.140	-7.4	399.3	9.51	16.64	1.071	.6	375.1	8.93	15.63
1.138	-7.2	398.6	9.49	16.61	1.070	.8	374.5	8.92	15.60
1.136	-7.0	398.0	9.48	16.58	1.068	1.0	373.9	8.90	15.53
1.134	-6.8	397.3	9.46	16.55	1.066	.2	373.4	8.89	15.56
1.132	-6.6	396.7	9.45	16.53	1.065	.4	372.8	8.88	15.53
1.131	-6.4	396.1	9.43	16.50	1.063	.6	372.3	8.86	15.51
1.129	-6.2	395.4	9.42	16.47	1.062	.8	371.7	8.85	15.49
1.127	-6.0	394.8	9.40	16.45	1.060	2.0	371.1	8.84	15.46
1.125	-5.8	394.2	9.39	16.42	1.059	.2	370.6	8.82	15.44
1.123	-5.6	393.6	9.37	16.40	1.057	.4	370.0	8.81	15.42
1.122	-5.4	392.9	9.36	16.37	1.055	.6	369.5	8.80	15.40
1.120	-5.2	392.3	9.34	16.35	1.054	.8	368.9	8.78	15.37
1.118	-5.0	391.7	9.33	16.32	1.052	3.0	368.4	8.77	15.35
1.116	-4.8	391.1	9.31	16.30	1.051	.2	367.8	8.76	15.32
1.115	-4.6	390.5	9.30	16.27	1.049	.4	367.3	8.75	15.30
1.113	-4.4	389.8	9.23	16.24	1.047	.6	366.8	8.73	15.28
1.111	-4.2	389.2	9.27	16.22	1.046	.8	366.2	8.72	15.26
1.109	-4.0	388.6	9.25	16.19	1.044	4.0	365.7	8.71	15.24
1.108	-3.8	388.0	9.24	16.17	1.043	.2	365.1	8.69	15.21
1.106	-3.6	387.4	9.22	16.14	1.041	.4	364.6	8.68	15.19
1.104	-3.4	386.8	9.21	16.12	1.040	.6	364.0	8.67	15.17
1.102	-3.2	386.2	9.19	16.09	1.038	.8	363.5	8.66	15.15
1.101	-3.0	385.6	9.18	16.07	1.037	5.0	363.0	8.64	15.12
1.099	-2.8	385.0	9.16	16.04	1.035	.2	362.4	8.63	15.10
1.097	-2.6	384.4	9.15	16.02	1.034	.4	361.9	8.62	15.08
1.096	-2.4	383.8	9.14	15.99	1.032	.6	361.4	8.60	15.06
1.094	-2.2	383.2	9.12	15.97	1.031	.8	360.9	8.59	15.04

TABLE B.1 (Continued)

Specific gravity 60/60° F	Density in vacuo °API	lb/bbl	lb/gal	lb/hr* from bbl/day	Specific gravity 60/60° F	Density in vacuo °API	lb/bbl	lb/gal	lb/hr* from bbl/day
0.922	22.0	322.8	7.69	13.45	0.876	30.0	306.8	7.30	12.78
0.921	.2	322.4	7.68	13.43	0.875	.2	306.4	7.30	12.77
0.919	.4	321.9	7.67	13.41	0.874	.4	306.0	7.29	12.75
0.918	.6	321.5	7.66	13.40	0.873	.6	305.7	7.28	12.74
0.917	.8	321.1	7.65	13.38	0.872	.8	305.3	7.27	12.72
0.916	23.0	320.7	7.64	13.36	0.871	31.0	304.9	7.26	12.70
0.915	.2	320.3	7.63	13.35	0.870	.2	304.5	7.25	12.69
0.914	.4	319.9	7.62	13.33	0.869	.4	304.2	7.24	12.67
0.912	.6	319.5	7.61	13.31	0.868	.6	303.8	7.23	12.66
0.911	.8	319.0	7.60	13.29	0.867	.8	303.4	7.22	12.64
0.910	24.0	318.6	7.59	13.27	0.865	32.0	303.0	7.21	12.62
0.909	.2	318.2	7.58	13.26	0.864	.2	302.7	7.20	12.61
0.908	.4	317.8	7.57	13.24	0.863	.4	302.3	7.19	12.60
0.907	.6	317.4	7.56	13.22	0.862	.6	301.9	7.19	12.58
0.905	.8	317.0	7.55	13.21	0.861	.8	301.6	7.18	12.57
0.904	25.0	316.6	7.54	13.19	0.860	33.0	301.2	7.17	12.55
0.903	.2	316.2	7.53	13.17	0.859	.2	300.8	7.16	12.53
0.902	.4	315.8	7.52	13.16	0.858	.4	300.5	7.15	12.52
0.901	.6	315.4	7.51	13.14	0.857	.6	300.1	7.14	12.50
0.900	.8	315.0	7.50	13.12	0.856	.8	299.7	7.14	12.49
0.898	26.0	314.6	7.49	13.11	0.855	34.0	299.4	7.13	12.47
0.897	.2	314.2	7.48	13.09	0.854	.2	299.0	7.12	12.46
0.896	.4	313.8	7.47	13.07	0.853	.4	298.7	7.11	12.45
0.895	.6	313.4	7.46	13.06	0.852	.6	298.3	7.10	12.43
0.894	.8	313.0	7.45	13.04	0.851	.8	297.9	7.09	12.41
0.893	27.0	312.6	7.44	13.02	0.850	35.0	297.6	7.09	12.40
0.892	.2	312.2	7.43	13.01	0.849	.2	297.2	7.08	12.38
0.891	.4	311.8	7.42	12.99	0.848	.4	296.9	7.07	12.37
0.889	.6	311.4	7.41	12.97	0.847	.6	296.5	7.06	12.35
0.888	.8	311.0	7.40	12.96	0.846	.8	296.2	7.05	12.34
0.887	28.0	310.6	7.40	12.95	0.845	36.0	295.8	7.04	12.32
0.886	.2	310.3	7.39	12.93	0.844	.2	295.4	7.04	12.31
0.885	.4	309.9	7.38	12.91	0.843	.4	295.1	7.03	12.30
0.884	.6	309.5	7.37	12.90	0.842	.6	294.8	7.02	12.28
0.883	.8	309.1	7.36	12.88	0.841	.8	294.4	7.01	12.27
0.882	29.0	308.7	7.35	12.86	0.840	37.0	294.0	7.00	12.25
0.881	.2	308.3	7.34	12.85	0.839	.2	293.7	6.99	12.24
0.879	.4	307.9	7.33	12.83	0.838	.4	293.4	6.99	12.21
0.878	.6	307.6	7.32	12.82	0.837	.6	293.0	6.98	12.21
0.877	.8	307.2	7.31	12.80	0.836	.8	292.7	6.97	12.20

TABLE B.1 (Continued)

Specific gravity 60/60°F	Density in vacuo °API	lb/bbl	lb/gal	lb/hr* from bbl/day	Specific gravity 60/60°F	Density in vacuo °API	lb/bbl	lb/gal	lb/hr* from bbl/day
0.835	38.0	292.3	6.96	12.18	0.797	46.0	279.1	6.64	11.63
0.834	.2	292.0	6.95	12.17	0.796	.2	278.3	6.64	11.62
0.833	.4	291.6	6.94	12.15	0.795	.4	278.5	6.63	11.60
0.832	.6	291.3	6.94	12.14	0.795	.6	278.2	6.63	11.59
0.831	.8	291.0	6.93	12.12	0.794	.8	277.9	6.62	11.58
0.830	39.0	290.6	6.92	12.11	0.793	47.0	277.6	6.61	11.57
0.829	.2	290.3	6.91	12.10	0.792	.2	277.3	6.60	11.55
0.828	.4	290.0	6.90	12.08	0.791	.4	277.0	6.59	11.54
0.827	.6	289.6	6.89	12.07	0.790	.6	276.7	6.59	11.53
0.826	.8	289.2	6.89	12.05	0.789	.8	276.3	6.58	11.51
0.825	40.0	288.9	6.88	12.04	0.788	48.0	276.0	6.57	11.50
0.824	.2	288.6	6.87	12.02	0.787	.2	275.7	6.56	11.49
0.823	.4	288.2	6.86	12.01	0.787	.4	275.4	6.56	11.47
0.822	.6	287.9	6.85	12.00	0.786	.6	275.1	6.55	11.46
0.821	.8	287.6	6.84	11.93	0.785	.8	274.1	6.54	11.45
0.820	41.0	287.2	6.84	11.97	0.784	49.0	274.5	6.54	11.44
0.819	.2	286.9	6.83	11.95	0.783	.2	274.2	6.53	11.42
0.818	.4	286.6	6.82	11.94	0.782	.4	273.9	6.52	11.41
0.817	.6	286.2	6.81	11.92	0.781	.6	273.6	6.51	11.40
0.817	.8	285.9	6.81	11.91	0.781	.8	273.3	6.51	11.39
0.816	42.0	285.6	6.80	11.90	0.780	50.0	273.0	6.50	11.37
0.815	.2	285.3	6.79	11.89	0.779	.2	272.7	6.49	11.36
0.814	.4	284.9	6.79	11.87	0.778	.4	272.4	6.49	11.35
0.813	.6	284.6	6.78	11.86	0.777	.6	272.1	6.48	11.34
0.812	.8	284.3	6.77	11.85	0.776	.8	271.8	6.47	11.32
0.811	43.0	283.9	6.76	11.83	0.775	51.0	271.5	6.46	11.31
0.810	.2	283.6	6.75	11.82	0.775	.2	271.2	6.46	11.30
0.809	.4	283.3	6.74	11.80	0.774	.4	270.9	6.45	11.29
0.808	.6	283.0	6.74	11.79	0.773	.6	270.6	6.44	11.27
0.807	.8	282.6	6.73	11.77	0.772	.8	270.3	6.44	11.26
0.806	44.0	282.3	6.72	11.76	0.771	52.0	270.0	6.43	11.25
0.805	.2	282.0	6.71	11.75	0.770	.2	269.7	6.42	11.24
0.804	.4	281.7	6.70	11.74	0.769	.4	269.4	6.41	11.22
0.804	.6	281.4	6.70	11.72	0.769	.6	269.1	6.41	11.21
0.803	.8	281.0	6.69	11.71	0.768	.8	268.8	6.40	11.20
0.802	45.0	280.7	6.69	11.70	0.767	53.0	268.5	6.39	11.19
0.801	.2	280.4	6.68	11.68	0.766	.2	268.3	6.39	11.18
0.800	.4	280.1	6.67	11.67	0.765	.4	268.0	6.38	11.17
0.799	.6	279.8	6.66	11.66	0.764	.6	267.7	6.37	11.15
0.798	.8	279.5	6.65	11.65	0.764	.8	267.4	6.37	11.14

TABLE B.1 (Continued)

Specific gravity 60/60°F	Density in vacuo °API	Density in vacuo lb/bbl	Density in vacuo lb/gal	lb/hr* from bbl/day	Specific gravity 60/60°F	Density in vacuo °API	Density in vacuo lb/bbl	Density in vacuo lb/gal	lb/hr* from bbl/day
1.029	6.0	360.3	8.58	15.01	0.973	14.0	340.5	8.11	14.19
1.028	.2	359.8	8.57	14.99	0.971	.2	340.1	8.10	14.17
1.026	.4	359.3	8.55	14.97	0.970	.4	339.6	8.09	14.15
1.025	.6	358.8	8.54	14.95	0.969	.6	339.1	8.08	14.13
1.023	.8	358.3	8.53	14.93	0.967	.8	338.7	8.06	14.11
1.022	7.0	357.7	8.52	14.90	0.966	15.0	338.2	8.05	14.09
1.020	.2	357.2	8.51	14.88	0.965	.2	337.8	8.04	14.07
1.019	.4	356.7	8.49	14.86	0.963	.4	337.3	8.03	14.05
1.017	.6	356.2	8.48	14.84	0.962	.6	336.8	8.02	14.03
1.016	.8	355.7	8.47	14.82	0.961	.8	336.4	8.01	14.02
1.014	8.0	355.2	8.46	14.80	0.959	16.0	335.9	8.00	14.00
1.013	.2	354.7	8.44	14.78	0.958	.2	335.5	7.99	13.98
1.011	.4	354.2	8.43	14.76	0.957	.4	335.0	7.98	13.96
1.010	.6	353.7	8.42	14.74	0.955	.6	334.6	7.96	13.94
1.009	.8	353.2	8.41	14.72	0.954	.8	334.1	7.95	13.92
1.007	9.0	352.7	8.40	14.70	0.953	17.0	333.7	7.94	13.90
1.006	.2	352.2	8.38	14.67	0.952	.2	333.2	7.93	13.88
1.004	.4	351.7	8.37	14.65	0.950	.4	332.8	7.92	13.87
1.003	.6	351.2	8.36	14.63	0.949	.6	332.3	7.91	13.85
1.001	.8	350.7	8.35	14.61	0.948	.8	331.9	7.90	13.83
1.000	10.0	350.2	8.34	14.59	0.947	18.0	331.4	7.89	13.81
0.999	10.2	349.7	8.33	14.57	0.945	.2	331.0	7.88	13.79
0.997	10.4	349.2	8.31	14.55	0.944	.4	330.5	7.87	13.77
0.996	10.6	348.7	8.30	14.53	0.943	.6	330.1	7.86	13.75
0.994	10.8	348.2	8.29	14.51	0.942	.8	329.7	7.85	13.74
0.993	11.0	347.7	8.28	14.49	0.940	19.0	329.2	7.84	13.72
0.992	.2	347.2	8.27	14.47	0.939	.2	328.0	7.83	13.70
0.990	.4	346.7	8.26	14.45	0.938	.4	328.4	7.82	13.68
0.989	.6	346.2	8.24	14.43	0.937	.6	327.9	7.81	13.66
0.987	.8	345.8	8.23	14.41	0.935	.8	327.5	7.80	13.65
0.986	12.0	345.3	8.22	14.39	0.934	20.0	327.1	7.79	13.63
0.985	.2	344.8	8.21	14.37	0.933	.2	326.6	7.78	13.61
0.983	.4	344.3	8.20	14.35	0.932	.4	326.2	7.77	13.59
0.982	.6	343.8	8.19	14.33	0.930	.6	325.8	7.76	13.57
0.981	.8	343.4	8.18	14.31	0.929	.8	325.3	7.75	13.55
0.979	13.0	342.9	8.16	14.29	0.928	21.0	324.9	7.74	13.54
0.978	.2	342.4	8.15	14.27	0.927	.2	324.5	7.73	13.52
0.977	.4	341.9	8.14	14.25	0.925	.4	324.0	7.72	13.50
0.975	.6	341.5	8.13	14.23	0.924	.6	323.6	7.71	13.48
0.974	.8	341.0	8.12	14.21	0.923	.8	323.2	7.70	13.47

TABLE B.2

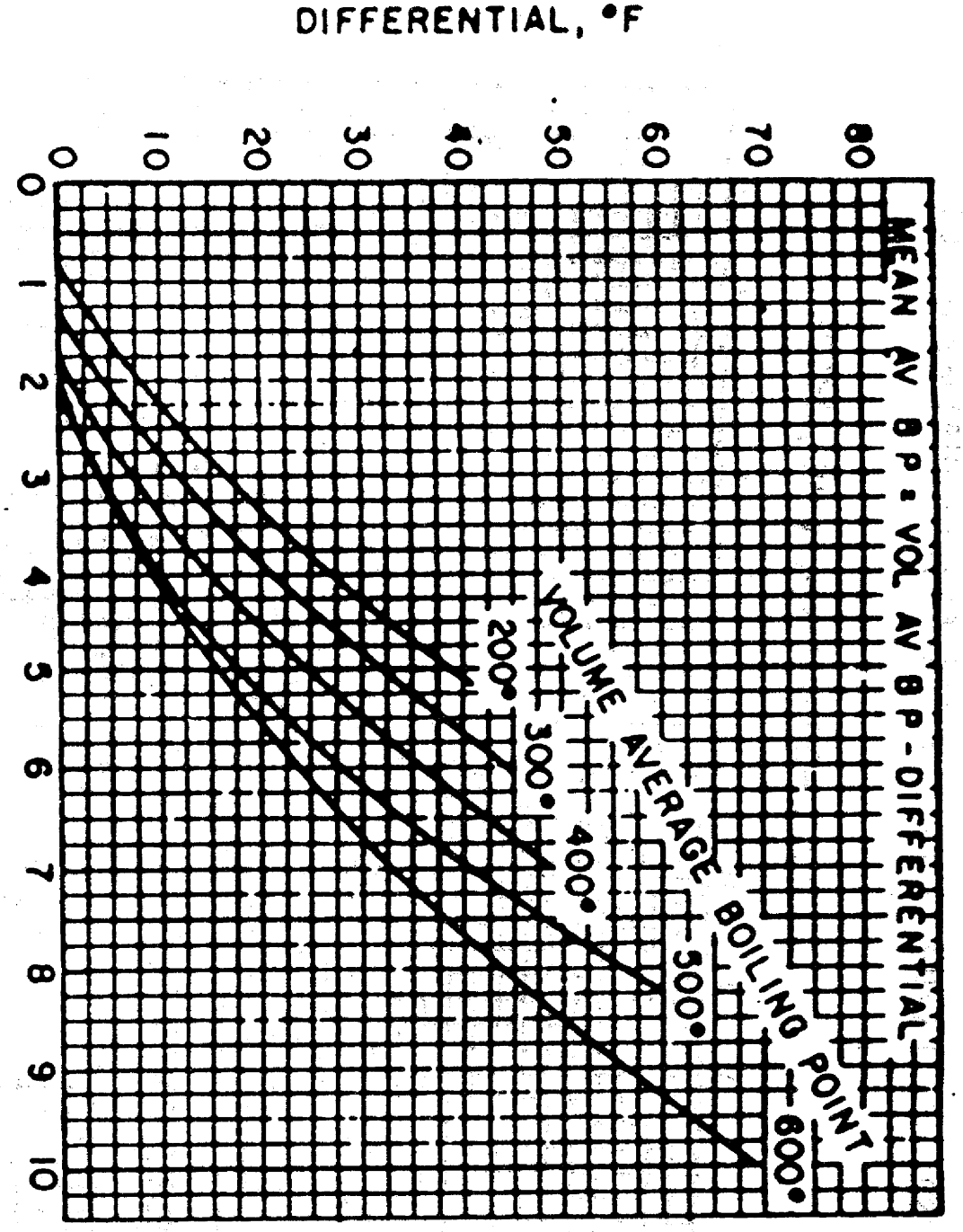
Physical Constants of Paraffin Hydrocarbons and Other Components of Natural Gas
[NGPA Publication 2145-75(1)]

Component	Notes	Methane	Ethane	Propane	Iso-Butane	N-Butane	Iso-Pentane	N-Pentane
Molecular Weight	*	16.043	30.070	44.097	58.124	58.124	72.151	72.151
Boiling Point @ 14.696 psia, °F		−258.69	−127.48	− 43.67	10.90	31.10	82.12	96.92
Freezing Point @ 14.696 psia, °F		−296.46[d]	−297.89[d]	−305.84[d]	−255.29	−217.05	−255.83	−201.51
Vapor Pressure @ 100°F, psia		(5000)	(800)	190	72.2	51.6	20.44	15.570
Density of Liquid @ 60°F & 14.696 psia								
Specific Gravity @ 60°F/60°F	a,b	0.3[i]	0.3564[h]	0.5077[h]	0.5631[h]	0.5844[h]	0.6247	0.6310
°API	* a,b	340[i]	265.5[h]	147.2[h]	119.8[h]	110.6[h]	95.0	92.7
Lb/gal @ 60°F , wt in vacuum	*	2.5[i]	2.971[h]	4.233[h]	4.695[h]	4.872[h]	5.208	5.261
Lb/gal @ 60°F, wt in air	* c	2.5[i]	2.962[h]	4.223[h]	4.686[h]	4.865[h]	5.199	5.251
Density of Gas @ 60°F & 14.696 psia								
Specific Gravity, Air = 1.00, ideal gas	*	0.5539	1.0382	1.5225	2.0068	2.0068	2.4911	2.4911
Lb/M cu ft, ideal gas	*	42.28	79.24	116.20	153.16	153.16	190.13	190.13
Volume Ratio @ 60°F and 14.696 psia								
Gal/lb mol	*	6.4[i]	10.12[h]	10.42[h]	12.38[h]	11.93[h]	13.85	13.71
Cu ft gas/gal liquid, ideal gas	*	59[i]	37.5[h]	36.43[h]	30.65[h]	31.81[h]	27.39	27.67
Gas vol/liquid vol, ideal gas	*	443[i]	280.5[h]	272.51[h]	229.30[h]	237.98[h]	204.93	207.00

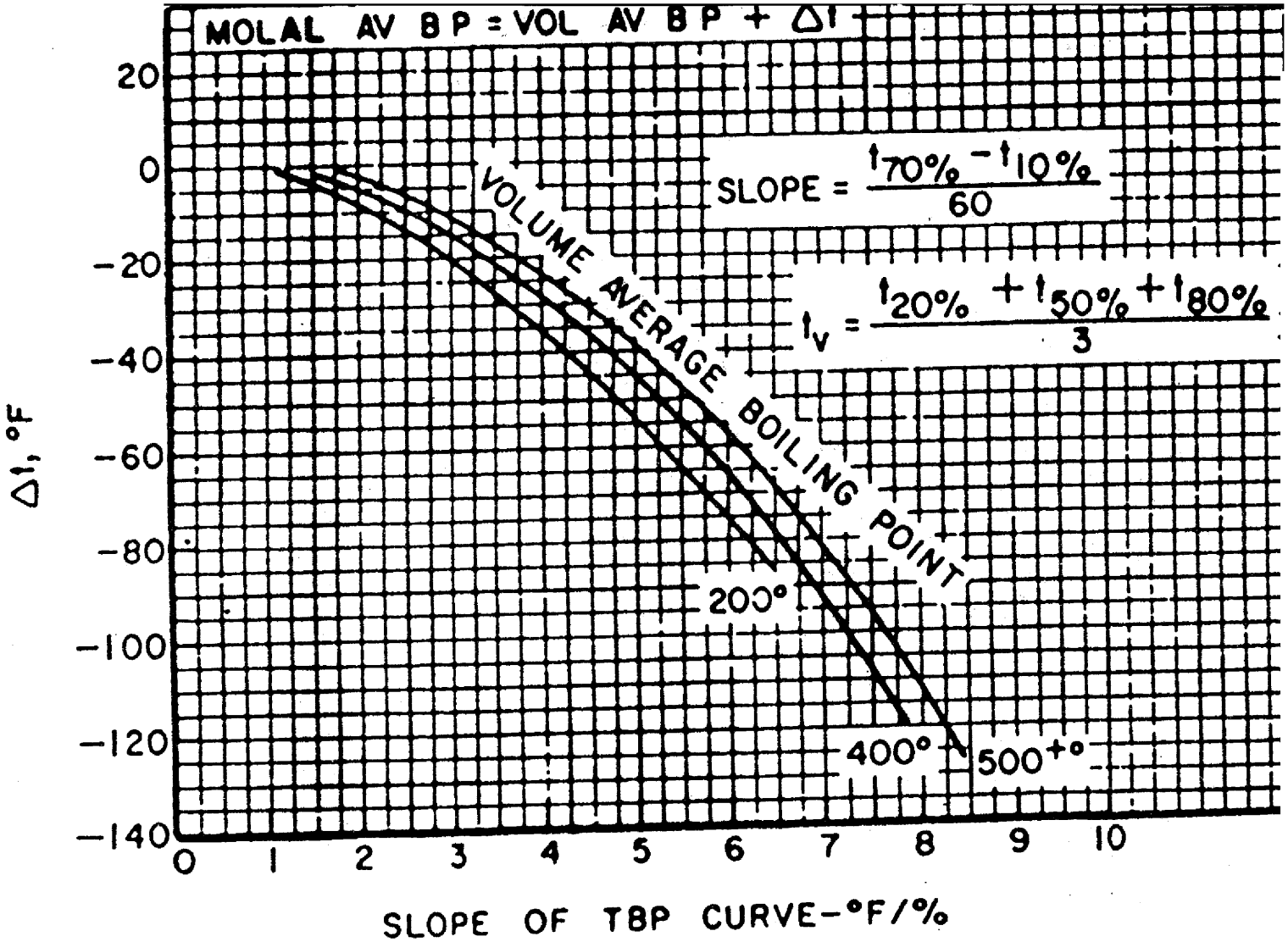
...11/-

N-Hexane	N-Heptane	N-Octane	N-Nonane	N-Decane	Carbon Dioxide	Hydrogen Sulfide	Nitrogen	Oxygen	Air	Water
86.178	100.205	114.232	128.259	142.286	44.010	34.076	28.013	31.999	28.964	18.015
155.72	209.17	258.22	303.47	345.48	−109.3[2]	− 76.6[24]	−320.4[3]	−297.4[2]	−317.6[2]	212.0
-139.58	−131.05	− 70.18	− 64.28	− 21.36	—	−117.2[7]	−346.0[24]	−361.8[24]	—	32.0
4.956	1.620	0.537	0.179	0.0597	—	394.0[6]	—	—	—	0.9492[12]
0.6640	0.6882	0.7068	0.7217	0.7342	0.827[h(6)]	0.79[h(6)]	0.808[m(3)]	1.14[m(3)]	0.856[m(8)]	1.000
81.6	74.1	68.7	64.6	61.2	39.6[h]	47.6[h]	43.6[m]	−7.4[m]	33.8[m]	10.0
5.536	5.738	5.893	6.017	6.121	6.89[h]	6.59[h]	6.74[m]	9.50[m]	7.14[m]	8.337
5.526	5.728	5.883	6.008	6.112	6.89[h]	6.58[h]	6.73[m]	9.50[m]	7.13[m]	8.328
2.9753	3.4596	3.9439	4.4282	4.9125	1.5195	1.1765	0.9672	1.1048	1.0000	0.6220
227.09	264.05	301.01	337.98	374.94	115.97	89.79	73.82	84.32	76.32	47.47
15.57	17.46	19.39	21.32	23.24	6.38[h]	5.17[h]	4.16[m]	3.37[m]	4.06[m]	2.16
24.38	21.73	19.58	17.80	16.33	59.5[h]	73.3[h]	91.3[m]	112.7[m]	93.5[m]	175.6
182.37	162.56	146.45	133.18	122.13	444.8[h]	548.7[h]	682.7[m]	843.2[m]	699.5[m]	1313.8

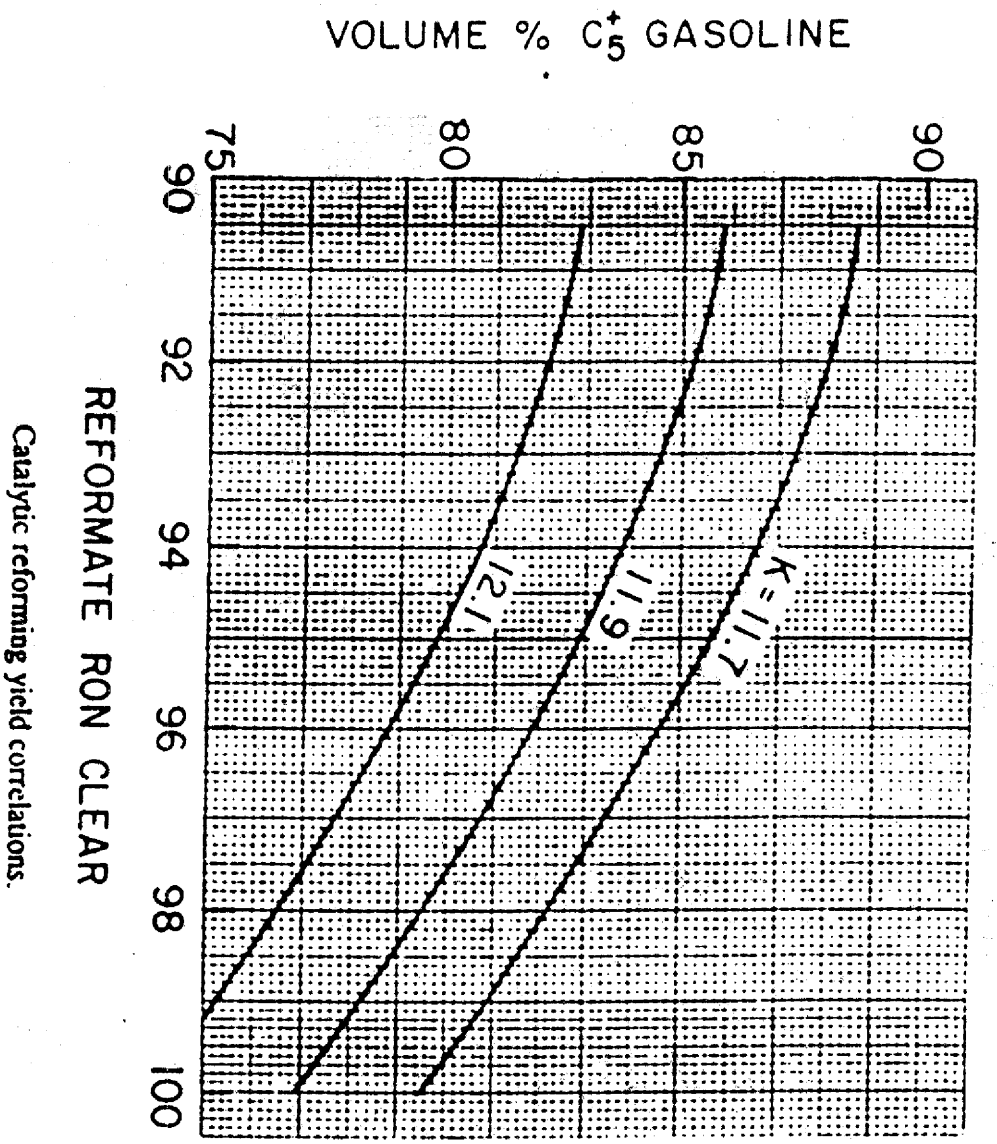
...12/-



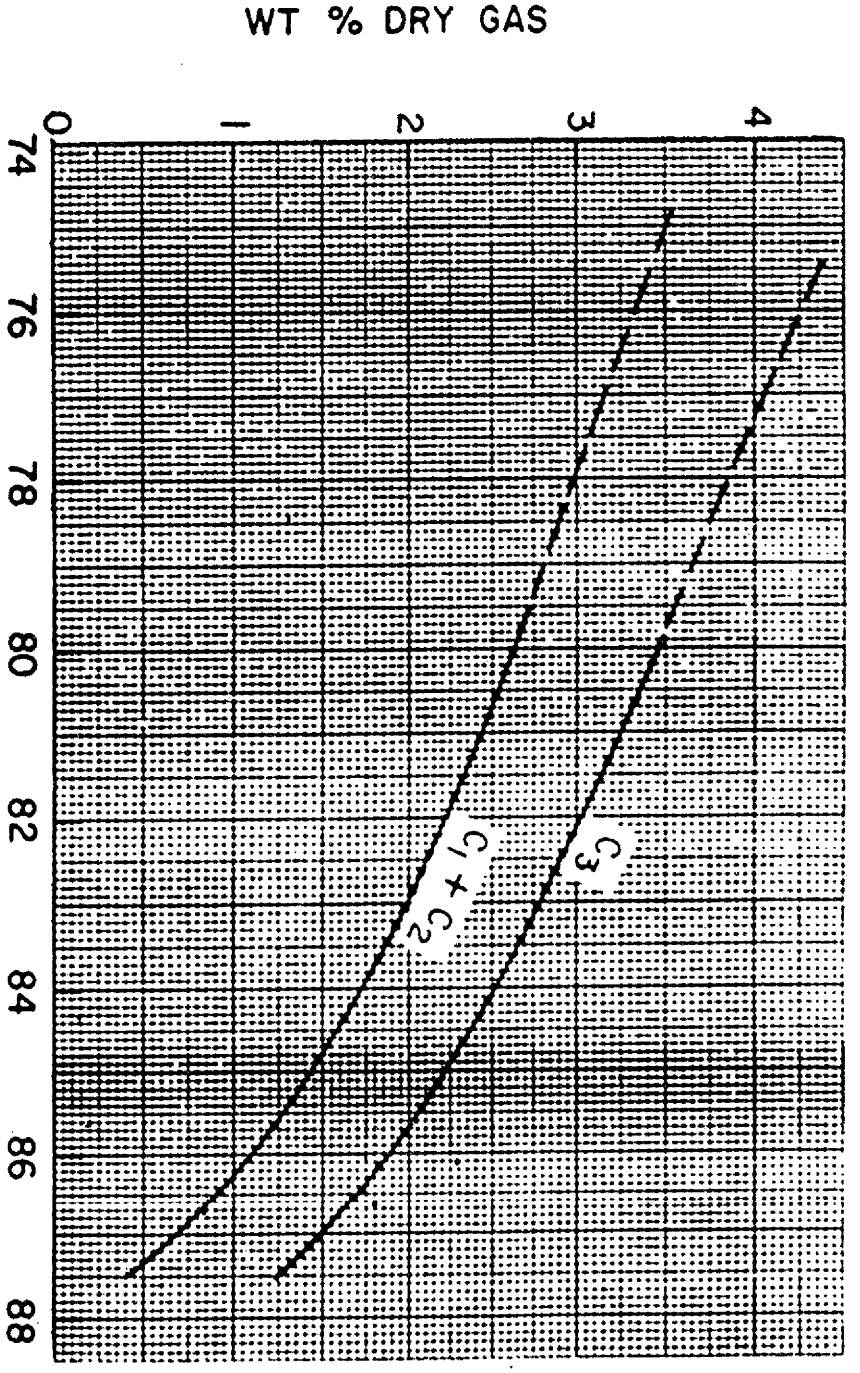
Mean average boiling point of petroleum fractions.



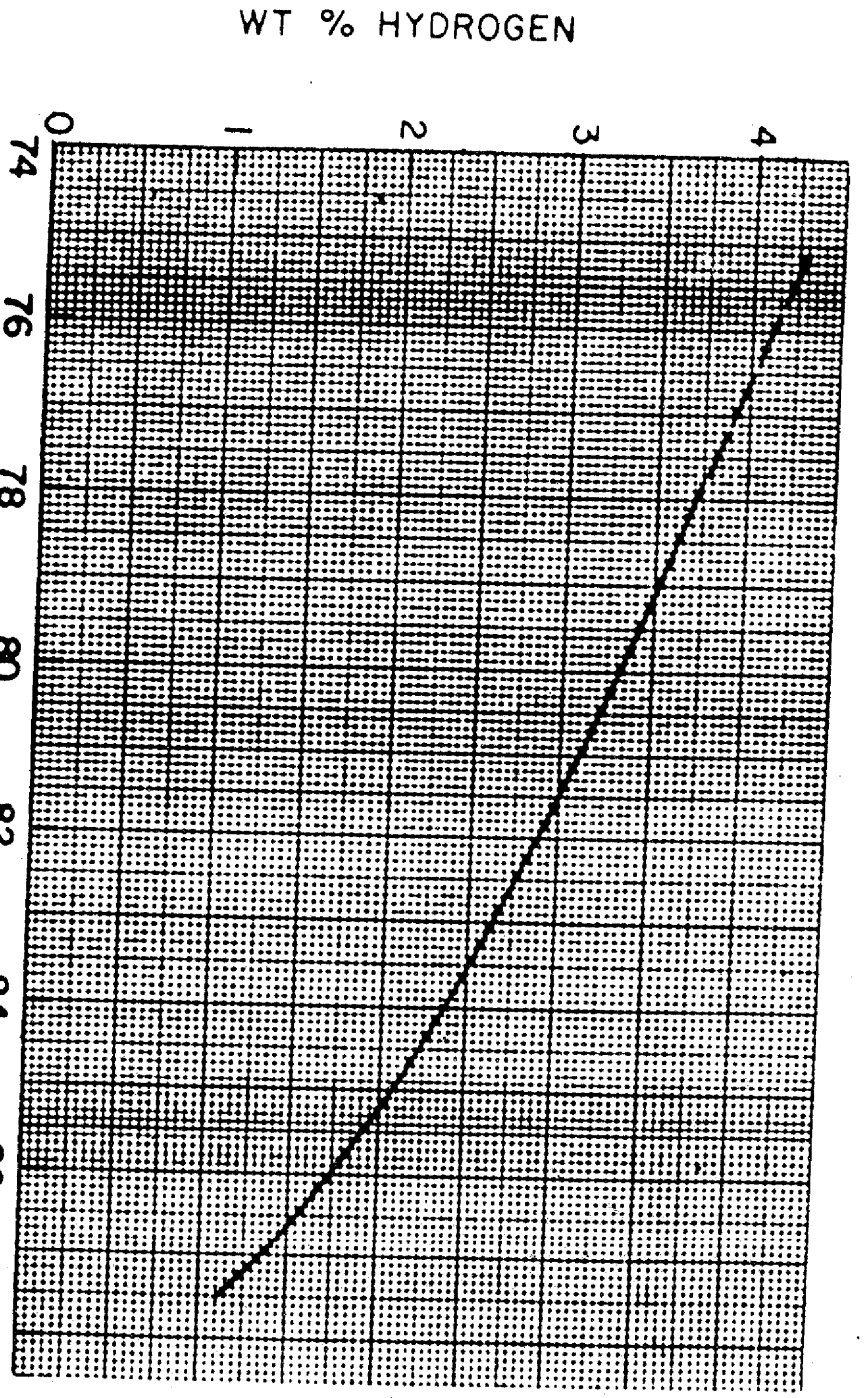
Molal average boiling point of petroleum fractions.



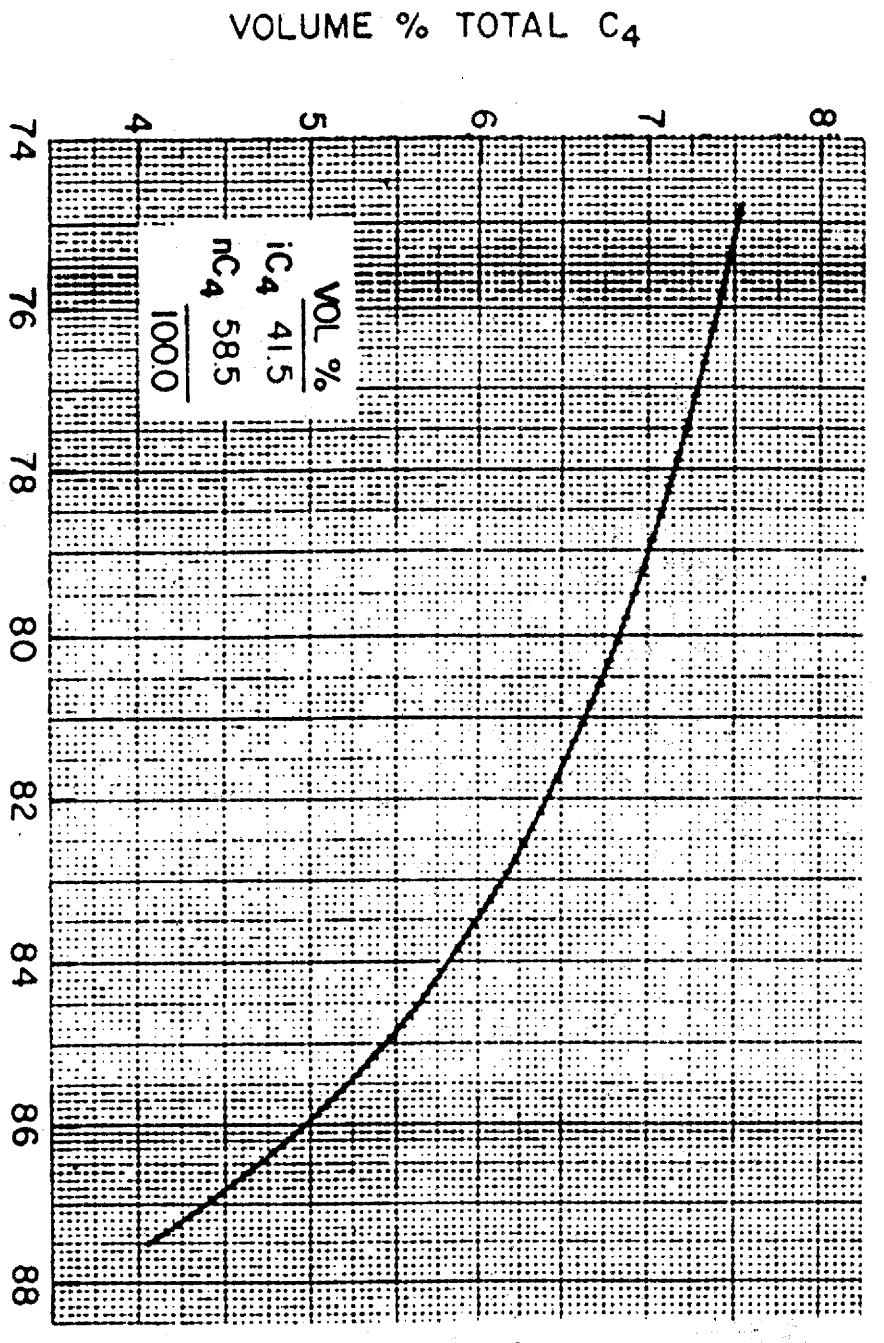
Catalytic reforming yield correlations.



Catalytic reforming yield correlations.



Catalytic reforming yield correlations.



Catalytic reforming yield correlations.