UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Pertama
Sidang Akademik 1997/98

September 1997

EKC 333 Kejuruteraan Pemprosesan Petroleum dan Gas

Masa: [3 jam]

ARAHAN KEPADA CALON:

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

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

Terdapat **TIGA (3)** bahagian di dalam kertas ini iaitu, **Bahagian A, Bahagian B** dan **Bahagian C**.

Jawab **LIMA (5)** soalan semuanya.

Soalan Nombor 1 Bahagian A adalah wajib dan jawab **DUA (2)** soalan dari **Bahagian B** dan **DUA (2)** soalan dari **Bahagian C**.

Soalan dari Bahagian B **MESTILAH** dijawab dalam Bahasa Malaysia.

...2/-

Bahagian A

1. Pilih 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] Juzuk utama yang terdapat di dalam gas asli ialah
The main constituent of natural gas is

[i] CO_2
[ii] C_2H_6
✓ [iii] CH_4
[iv] C_2H_2

[b] Minyak mentah masam mengandungi
Sour crude contains

[i] Tiada sebatian sulfur
No sulfur compounds

✓ [ii] Sebatian sulfur
Sulfur compounds

[iii] Lilin
Wax

[iv] Sebatian nitrogen
Nitrogen compounds

[c] Nombor oktana bagi gasolin premium ialah
Octane number of premium gasoline is

[i] rendah daripada gasolin biasa
lower than regular gasoline

✓ [ii] tinggi daripada gasolin biasa
higher than regular gasoline

[iii] sama seperti gasoline LSR
same as LSR gasoline

...3/-

[iv] sama seperti nafta.
same as naphtha

[d] Kualiti penyalaan untuk minyak diesel ditentukan di dalam
The ignition quality of a diesel fuel is measured in terms of

[i] indek diesel
diesel index

[ii] indek kelikatan
viscosity index

√ [iii] indek setana
cetane index

[iv] indek sekaitan
correlation index

[e] Takat kilat (flash) sesuatu minyak itu diukur dengan
Flash point of an oil is measured by

[i] Kalorimeter bomb
Bomb calorimeter

[ii] Perkakas Pensky Mertens
Pensky Mertens apparatus

[iii] Kalorimeter boy
Boy's calorimeter

√ [iv] Viscometer say bolt
Say bolt viscometer

[f] Pemangkin yang digunakan di dalam pemecahan bermangkin ialah
Catalyst used in catalytic cracking is

[i] Silika *Silica*
[ii] Alumina *Alumina*
√ [iii] Zeolit ultra stabil Y. *Ultra stable Y zeolite*
[iv] Pt/Al_2O_3

...4/-

[g] Pada kebiasaannya, suapan untuk pembentukan semula bermangkin adalah
Feed for catalytic reformer is usually

[i] bahan mentah terturun
reduced crude

[ii] minyak bergas atmosfera
atmospheric gas oil

[iii] nafta atau gasoline larian lurus
naphtha or straight run gasoline

[iv] minyak bergas hampagas
vacuum gas oil

[h] Nombor setana untuk diesel yang digunakan oleh trak adalah
Cetane number of diesel used in trucks may be

[i] 10
[ii] 35
[iii] 60
[iv] 85

[i] Minyak pelincir berkelikatan tinggi menunjukkan
Higher viscosity of lubricating oil usually signifies

[i] nombor asid yang tinggi
higher acid number

[ii] RVP yang rendah
lower RVP

[iii] takat kilat dan takat nyala yang rendah
lower flash point and fire point

[iv] takat kilat dan takat nyala yang tinggi
higher flash point and fire point

...5/-

[j] Minyak mentah berasaskan parafin kalau dibandingkan dengan minyak mentah berasas asfalt memberi
Paraffins base crude as compared to asphalt base crude gives

[i] gasolin nilai octana yang tinggi
higher octane value gasoline

[ii] minyak pelincir hasil rendah
poor yield of lube oil

[iii] minyak pelincir yang rendah indek kelikatannya
lower viscosity index lube oil

[iv] gasolin larian lurus yang tinggi hasilnya
higher yield of straight run gasoline

[k] Faktor ciri minyak mentah dikira sebagai 12.5. Ini bermakna ia adalah
The characterisation factor of crude oil is calculated as 12.5. It means that it is

√[i] berparafin
paraffinic

[ii] bernafta
naphthenic

[iii] pertengahan
intermediate

[iv] tiada seperti di atas
none of the above

[l] Berikut adalah petrol (gasolin) yang disarankan tetapi tidak untuk kerosin.
Which of the following is desirable in petrol (gasoline) but undesirable in kerosene.

[i] parafin
paraffins

/[ii] aromatik
aromatics

...6/-

[iii] merkaptan
mercaptans

[iv] asid bernafta
naphthenic acid

[m] Manakah yang memberi nilai graviti °API yang tinggi
Which has the maximum °API gravity of all

[i] Diesel
Diesel

[ii] Nafta
Naphtha

[iii] Petrol (gasoline)
Petrol (gasoline)

[iv] Kerosin
Kerosene

[n] Sebahagian besar air daripada gas asli disesarkan dengan cara
Large amounts of water from natural gas is removed by

[i] Penjerapan
Adsorption

[ii] Penjerapan/perlucutan
Adsorption/stripping

[iii] Pengewapan kilat
Flash vaporistion

[iv] Tiada antara yang di atas
None of the above

[o] Nilai kalori (kcal/Nm^3) untuk gas asli dianggarkan
The calorific value (kcal/Nm^3) of natural gas is about

[i] 2500
[ii] 10,000
[iii] 25,000
[iv] 35,000

...7/-

[p] 95% daripada LPG mengandungi butana (C_4) yang menyejat pada 760 mm Hg dan pada suhu

95% of LPG containing mostly butane (C_4) will evaporate at 760 mm Hg at a temperature of

[i] 20°F
[ii] 34°F
[iii] 44°F
[iv] 60°F

[q] Takat kilat untuk diesel automatif adalah lebih kurang.
The flash point of an automative diesel is about

[i] 100°F
[ii] 125°F
[iii] 150°F
[iv] 80°F

[r] Cara yang biasa digunakan untuk menyikirkan H_2S dan CO_2 dari gas asli ialah:

The most common method for the removal of H_2S and CO_2 from the natural gas is:

[i] Unit Merawat Amine
Amine Treating Unit

[ii] Penjerapan Tekanan Berayun (PSA)
Pressure Swing Adsorption (PSA)

[iii] Proses membran
Membrane process

[iv] Proses Claus
Claus process

...8/-

[s] Titik potong TBP untuk gasoline LSR normal diberikan
TBP cut point for normal LSR gasoline cut is given as

[i] 70°F(IBP) - 160°F(EP)
[ii] 90°F(IBP) - 190°F(EP)
[iii] 70°F(IBP) - 180°F(EP)
[iv] 90°F(IBP) - 150°F(EP)

[t] Mana di antara berikut merupakan sifat terpenting untuk bahanapi jet?
Which of the following is the most important property for a jet fuel?

[i] takat awan
cloud point

[ii] takat curahan
pour point

[iii] warna
colour

[iv] takat beku
freezing point

(20 markah)

Bahagian B

2. Secara ringkas, definisikan maksud perkataan berikut:
Define the following terms (in brief)

[a] Indek kelikatan
Viscosity index

[b] Gas sekutu
Associated gas

[c] Gasolin asli
Natural gasoline

[d] Takat awan dan curahan
Cloud and Pour Point

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[e] Sulingan pertengahan
Middle distillates

[f] Nilai pemanasan bersih
Net heating value

[g] Stok pusingan bermangkin
Catalytic cycle stock

[h] Tekanan Wap Reid (RVP)
Reid Vapor Pressure (RVP)

[i] Unit penghabisan ringan
Light end unit

[j] Hidrat gas
Gas Hydrate

(20 markah)

3. Bezakan antara keduanya:
Differentiate between the followings:

[a] Penguraian bermangkin dan Penghidropecahan
Catalytic cracking vs. Hydrocracking

[b] Pengkokan terlengah dan Visbreaking
Delayed coking vs. Visbreaking

[c] Penyulingan ASTM dan penyulingan TBP
ASTM distillation vs. TBP distillation

[d] Bahan mentah parafin dan bahan mentah aromatik
Paraffinic vs. Aromatic crude

[e] Kendalian dan penyimpanan Gas Cecair Mentah (LN6) dan Kendalian dan penyimpanan Gas Cecair Petroleum (LPG).

Liquified Natural Gas (LNG) storage and handling vs. Liquified Petroleum Gas (LPG) storage and handling.

(20 markah)

...10/-

4. Lukiskan satu gambarajah aliran yang ringkas berdasarkan mana-mana dua (2) proses di bawah di mana anda dikehendaki menunjukkan pembolehubah proses yang penting seperti suhu, tekanan, kadar aliran (WHSV/LHSV) dan sebagainya. Ini termasuk juga ciri-ciri suapan, hasil penukaran keluaran (produk) dengan spesifikasinya.

Draw a simplified flow diagram for 2 (two) of the following processes showing the important process variables like temperature, pressure, flow rate (WHSV/LHSV) etc. and characteristics of feed, yield/conversion of product with its specifications.

[a] Penyingkiran CO_2 dan H_2S daripada gas asli dengan kaedah proses penyerapan.

Removal of CO_2 and H_2S from natural gas using Absorption process.

[b] Penukaran gas asli kepada etilena dan propilena.
Natural gas conversion to ethylene and propylene.

[c] Pembentukan semula nafta bermangkin.
Catalytic reforming of naphtha.

(20 markah)

BAHAGIAN C

5. Minyak mentah telah diproses di dalam menara penyulingan mentah atmosfera untuk diasingkan kepada pelbagai pecahan. Analisa TBP mentah telah diberi di dalam jadual Q5. Lengkapkan keseimbangan bahan pada menara tersebut untuk spesifikasi pecahan minyak mentah di bawah:

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

...11/-

	IBP (°F)	EP(°F)
Gasolin *Gasoline*	90	180
Nafta *Naphtha*	190	380
Kerosin *Kerosene*	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 sulfur untuk suapan dan produk kepada paun yang berhampiran.

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

(20 markah)

6. [a] Aliran nafta dara 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. Jadikan keseimbangan bahan keseluruhannya pada pembentukan semula untuk kadar suapan 10,000 BPD.

A 180 to 380°F virgin naphtha stream with a 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 markah)

[b] Satu loji menerima 25 MMcf/hari gas asli bergraviti 0.6 pada suhu 80°F dan tekanan 250 psi. Untuk tujuan pemerosesan, gas asli tersebut perlu dimampat sehingga 1000 psi. Pendingin antara dan pendingin lanjut digunakan untuk menurunkan gas tersebut kepada 100°F.

A plant receives 25 MMcf/day of 0.6 gravity natural gas at 80°F and 250 psi. It is to be compressed to 1000 psi for processing. Intercoolers and after coolers are used to lower the gas to 100°F.

...12/-

[i] Berapakah jumlah kuasa kuda yang diperlukan untuk mampatan. Kecekapan mampatan ialah 0.8.

What is total horse power required for compression. The compression efficiency is 0.8.

[ii] Apakah tugas haba pendingin antara dan/atau pendingin lanjut untuk gas itu?. Sila gunakan Graf Enthalpy-entropy di dalam Lampiran untuk tujuan pengiraan entalpi.

What is the corresponding heat duty of inter - and/or after coolers for the gas? Use Enthalpy-entropy given in the Appendix diagram for the calculation of enthalpy.

(10 markah)

Gunakan data *Useful data* 1 MMcf/ hari *day* = $2638.5 \frac{lbmol}{\text{hari } day}$

Kuasa kuda untuk *Horsepower required for* 1 MMcf/hari *day* = 0.432 x Δh

...13/-

Table Q5

GENERAL CHARACTERISTIC

Gravity, specific, 0.853 Gravity, °API, 34.4 Pour point, °F., below 5
Sulfur, percent, 0.19 Color, brownish green
Viscosity, Saybolt Universal at 100°F. 46 sec. Nitrogen, percent, 0.04

DISTILLATION, BUREAU OF MINES ROUTINE METHOD

STAGE 1 - Distillation at atmospheric pressure, 758 mm. Hg
First drop 113 °F

Fraction No.	Cut temp. °F	Percent	Sum. percent	Sp. gr., 60/60°F	° API. 60°F.	C.I.	Refractive index, n_D at 20°C.	Specific dispersion	S.U. vise., 100° F.	Cloud test. °F
1.....	122									
2.....	167									
3.....	212	2.6	2.6	0.706	68.9	-	1.39971	129.4		
4.....	257	3.1	5.7	.739	60.0	21	1.41235	132.0		
5.....	302	3.7	9.4	.762	54.2	25	1.42308	135.4		
6.....	347	4.2	13.6	.780	49.9	26	1.43298	137.1		
7.....	392	5.8	19.4	.796	46.3	28	1.44076	138.4		
8.....	437	4.9	24.3	.807	43.8	27	1.44701	139.1		
9.....	482	7.6	31.9	.820	41.1	28	1.45389	140.8		
10....	527	9.1	41.0	.834	38.1	30	1.46161	143.0		
STAGE 2 - Distllation continued at 40 mm. Hg										
11.....	392	6.0	47.0	0.846	35.8	32	1.46906	148.8	40	below 5
12.....	437	8.3	55.3	.854	34.2	32	1.47238	147.4	46	20
13.....	482	6.8	62.1	.866	31.9	34	1.47868	144.0	58	50
14.....	527	5.8	67.9	.881	29.1	38	1.48434	-	81	60
15.....	572	6.1	74.0	.892	27.1	40			135	70
Residuum.	.....	24.5	98.5	.940	19.0					

Carbon residue, Conradson: Residuum. 4.6 percent; crude 1.2 percent.

APPROXIMATE SUMMARY

	Percent	Sp.gr.	°API	Viscosity
Light gasoline	2.6	0.706	68.9	
Total gasoline and naphtha	19.4	0.765	53.5	
Kerosine distillate	12.5	.815	42.1	
Gas oil	21.9	.843	36.4	
Nonviscous lubricating distillate	12.9	.585-.884	33.4-28.6	50-100
Medium lubricating distillate	7.3	.884-.898	28.6-26.1	100-200
Viscous lubricating distillate	-	-	-	Above 200
Residuum	24.5	.940	19.0	
Distillation loss	1.5			

...14/-

7. Campuran hidrokarbon mengandungi rencaman dalam peratusan mol:
A mixture of hydrocarbons has the following composition in mol %:

	Mol %
CH_4	1.0
C_2H_6	15.0
C_3H_8	25.0
i-C_4H_{10}	14.0
n-C_4H_{10}	25.0
n-C_5H_{12}	20.0
Total	100.0

Campuran tersebut wujud dalam fasa wap pada tekanan 100 psia (5170 mm Hg)

The mixture exists at a pressure of 100 psia (5170 mm Hg) and is all in the vapor phase.

[a] Berapakah peratusan dalam mole wap yang telah dipeluwapkan jika campuran tersebut disejukkan sehingga 90°F (32.2°C).

What mole % of the vapor is condensed in if the mixture is cooled to 90°F (32.2°C).

[b] Apakah rencaman cecair dan wap di dalam bahagian [a].
What is the composition of liquid and vapor in part [a].

Andaikan bahawa graviti tentu cecair adalah sama pada suhu 60°F dan 90°F.
Assume that the liquid specific gravities are same at 60°F and 90°F.

(20 markah)

...15/-

Nilai K pada 90°F (32.2°C)
K values at 90°F (32.2°C)

Komponen *Component*, i	K_i	Ketumpatan *Density*, $\frac{m^3}{kg}$
CH_4	19.0	6.16×10^{-3}
C_2H_6	5.2	4.709×10^{-3}
C_3H_8	1.5	2.077×10^{-3}
i-C_4H_{10}	0.69	1.84×10^{-3}
n-C_4H_{10}	0.51	1.76×10^{-3}
n-C_5H_{12}	0.18	1.59×10^{-3}

Nilai pemalar gas *Value of gas constant* $R = \frac{0.082\ m^3.atm}{kmol.K}$

-ooo0ooo-

LAMPIRAN

TABLE B.1

Density Conversion Table

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
1.165	-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	1.053	.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	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.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

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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

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[2]	−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

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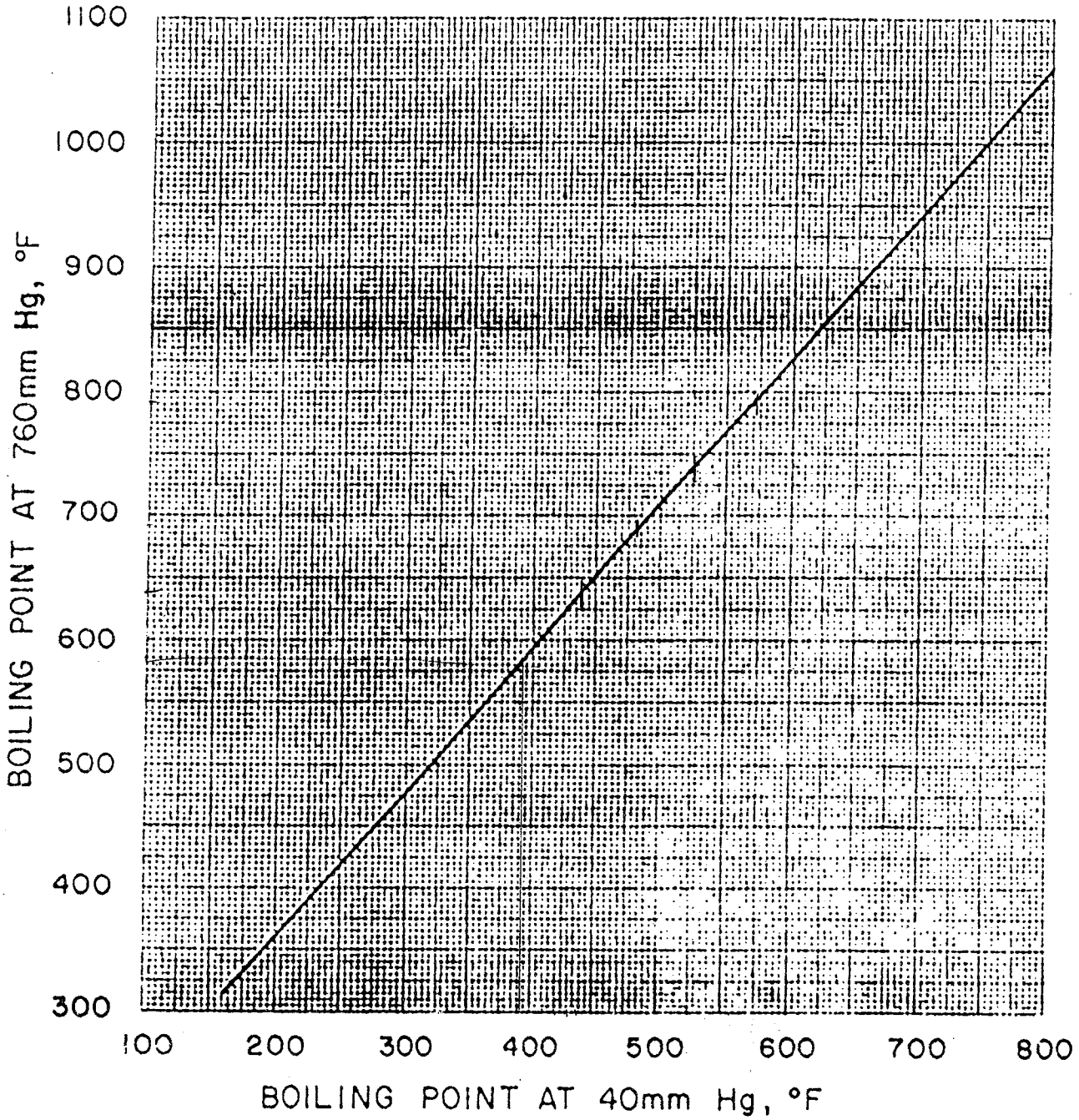
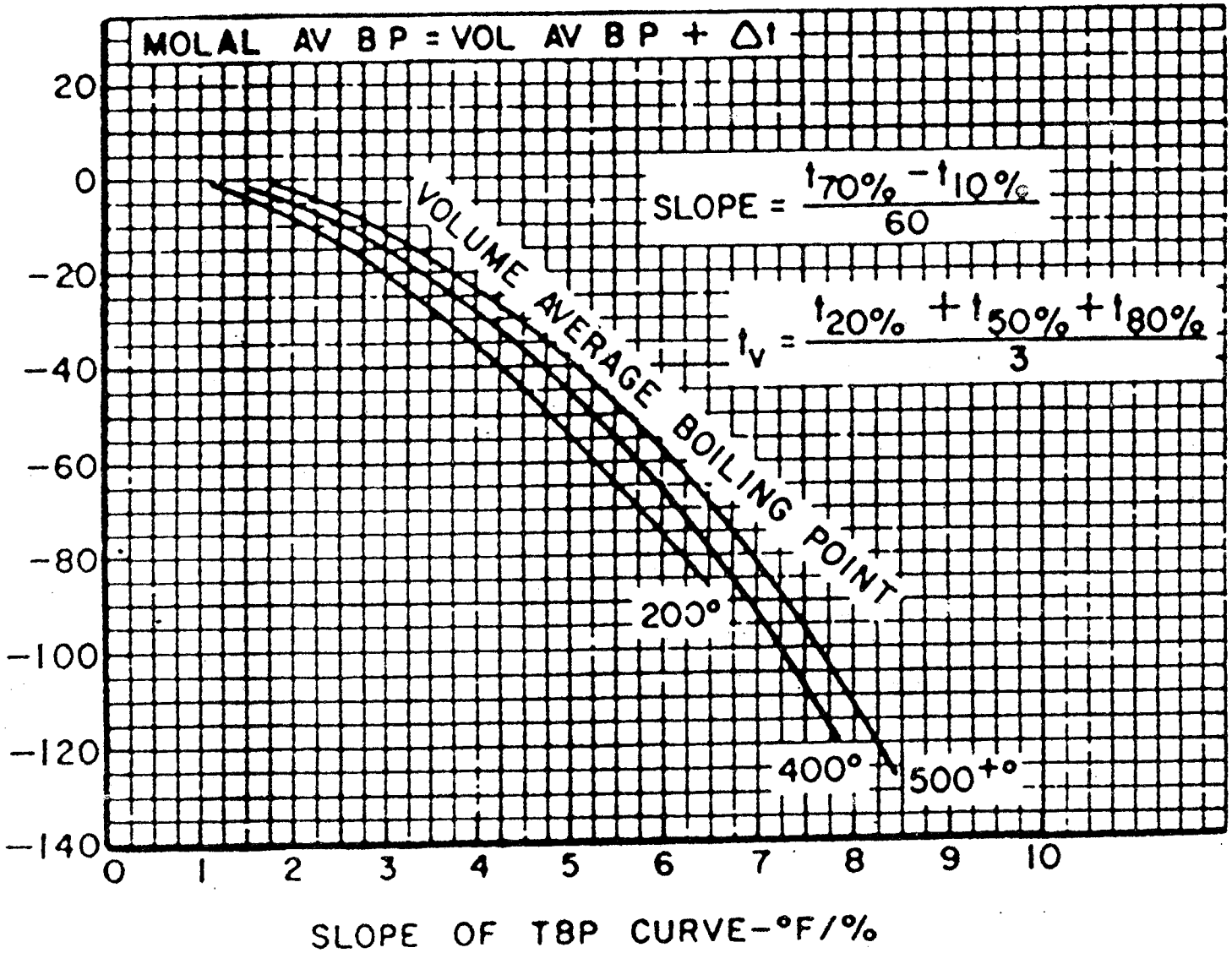
../7/-



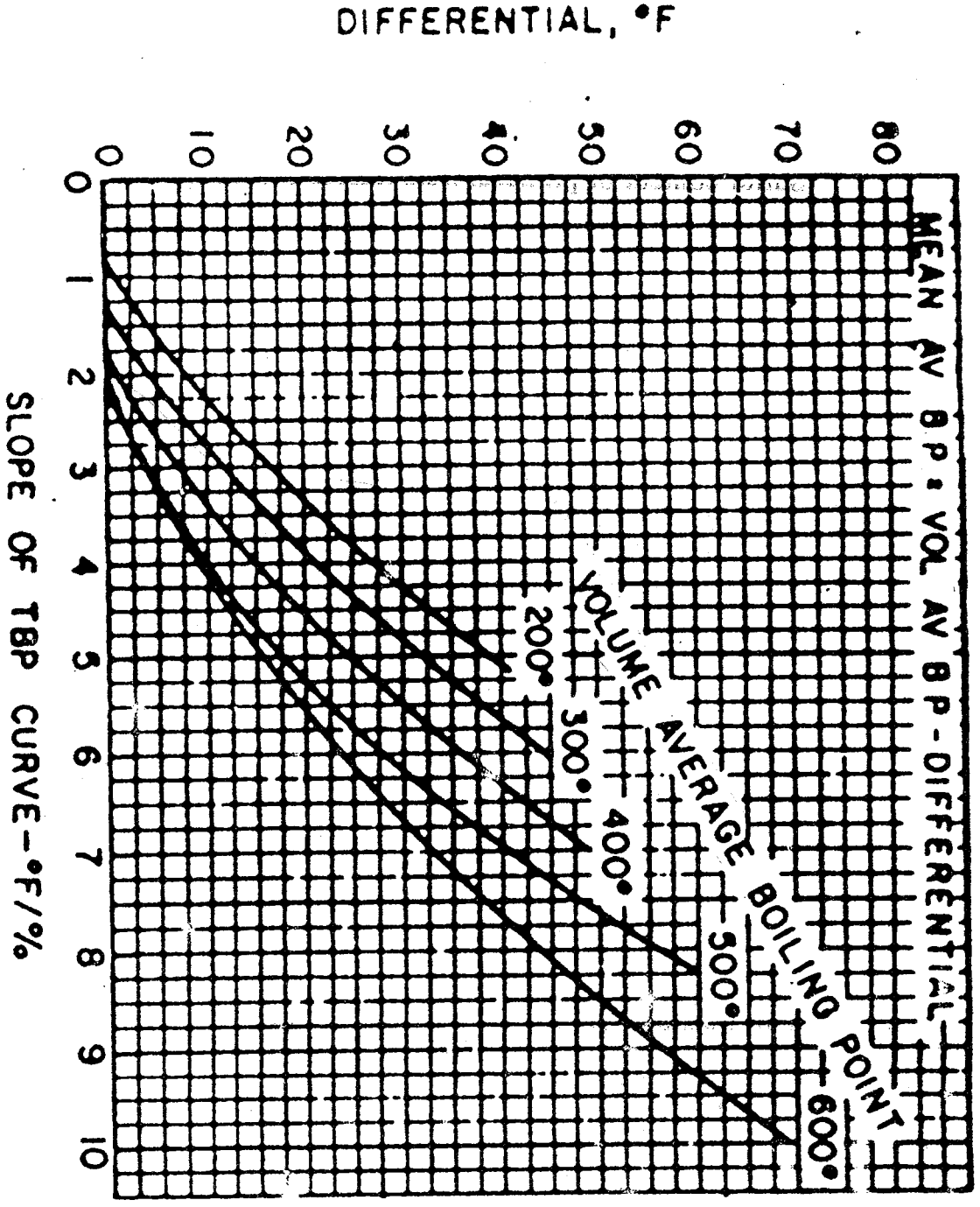
Boiling point at 760 mm Hg vs boiling point at 40 mm Hg.

...8/-



Molal average boiling point of petroleum fractions.

[EKC 333]



Mean average boiling point of petroleum fractions.

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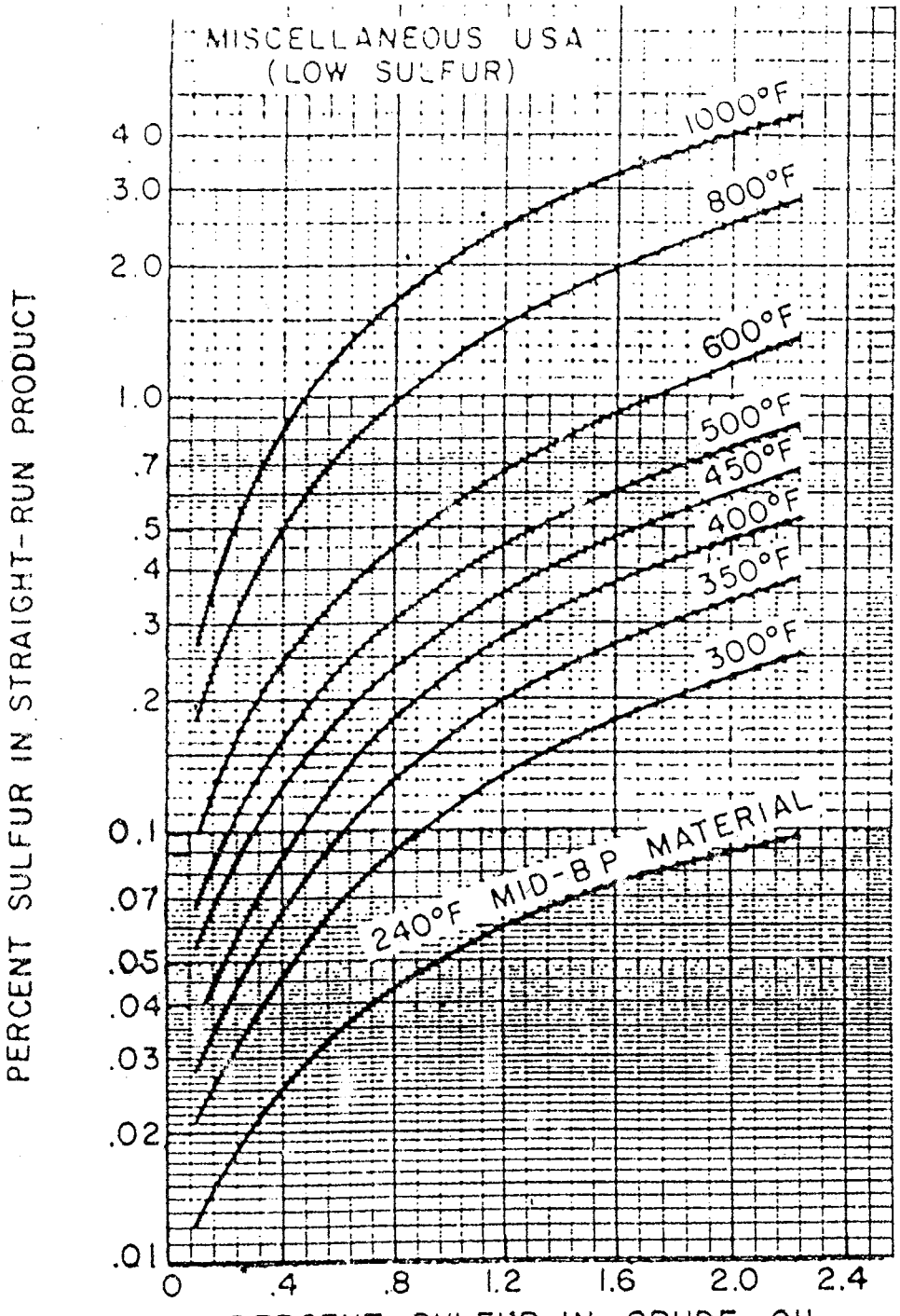
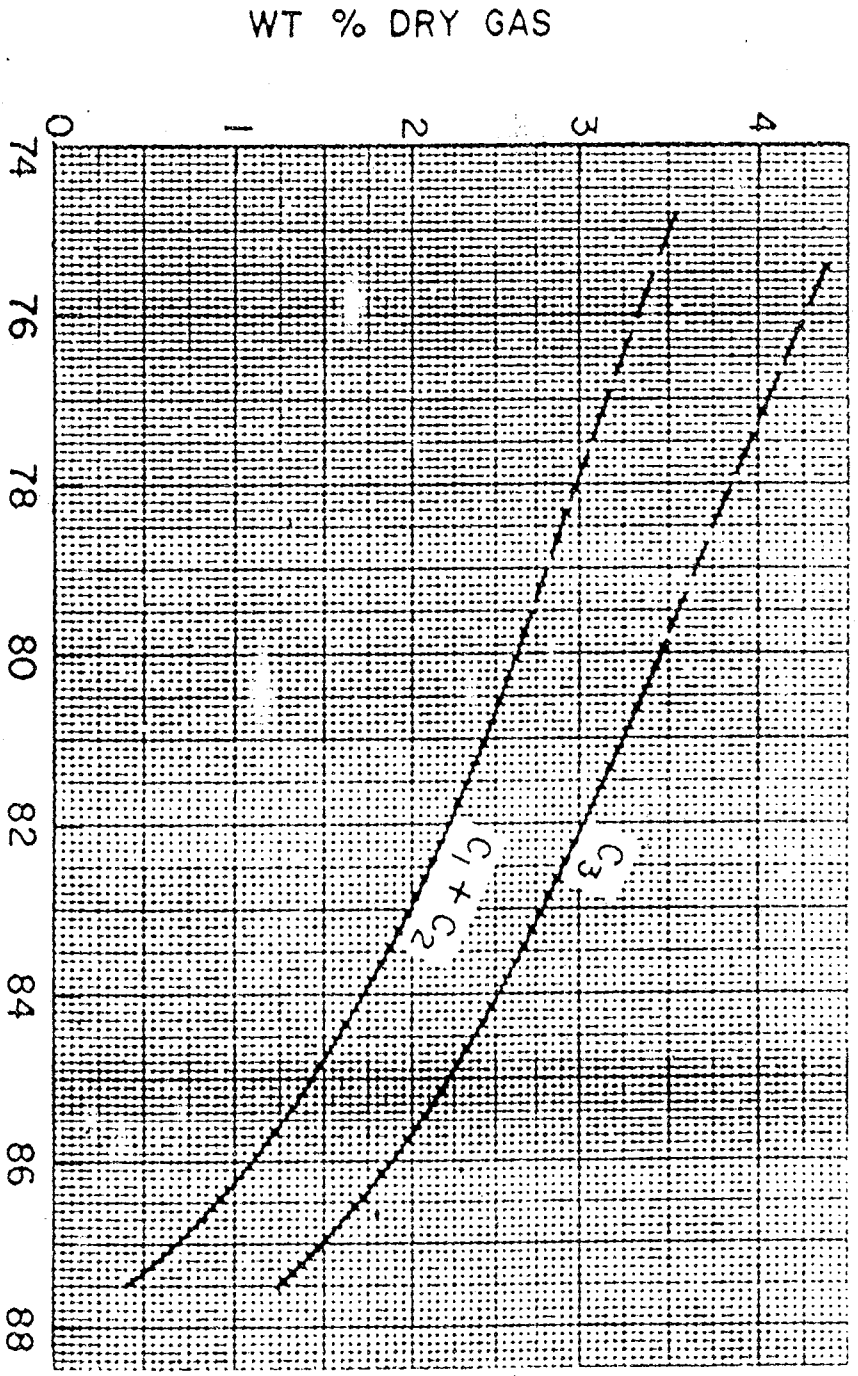
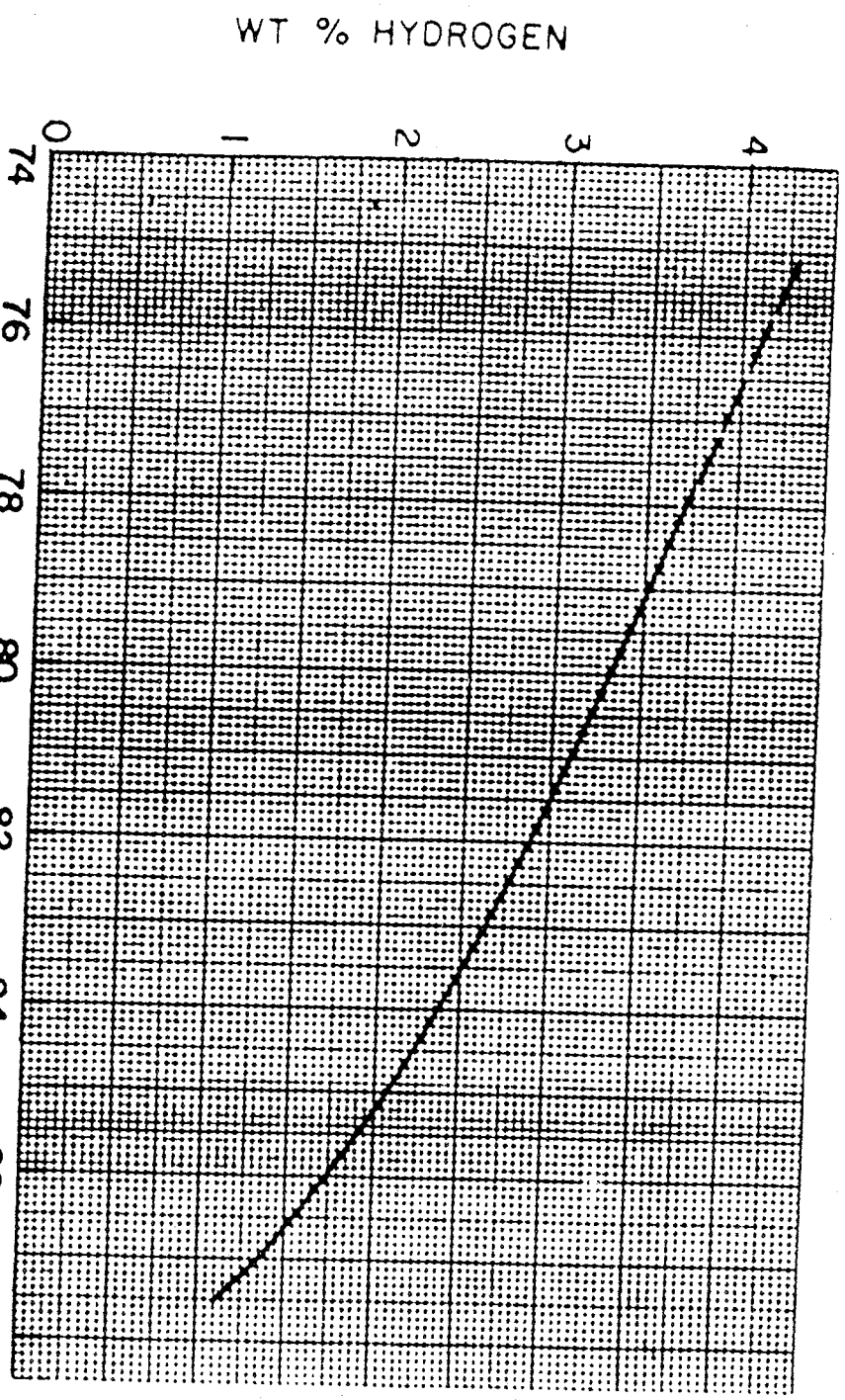


(EXCLUDING CRUDE OILS FROM WEST TEXAS, MISSISSIPPI, CALIFORNIA, MICHIGAN, AND WYOMING.)

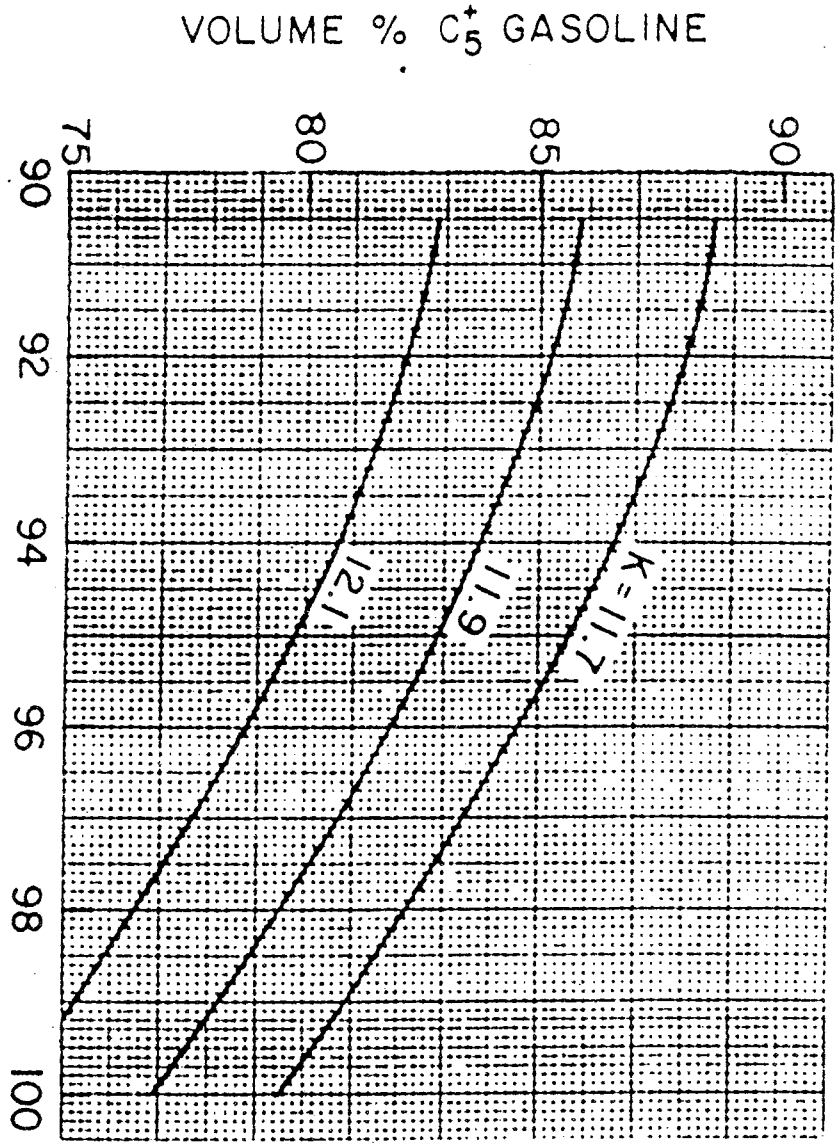


Catalytic reforming yield correlations.

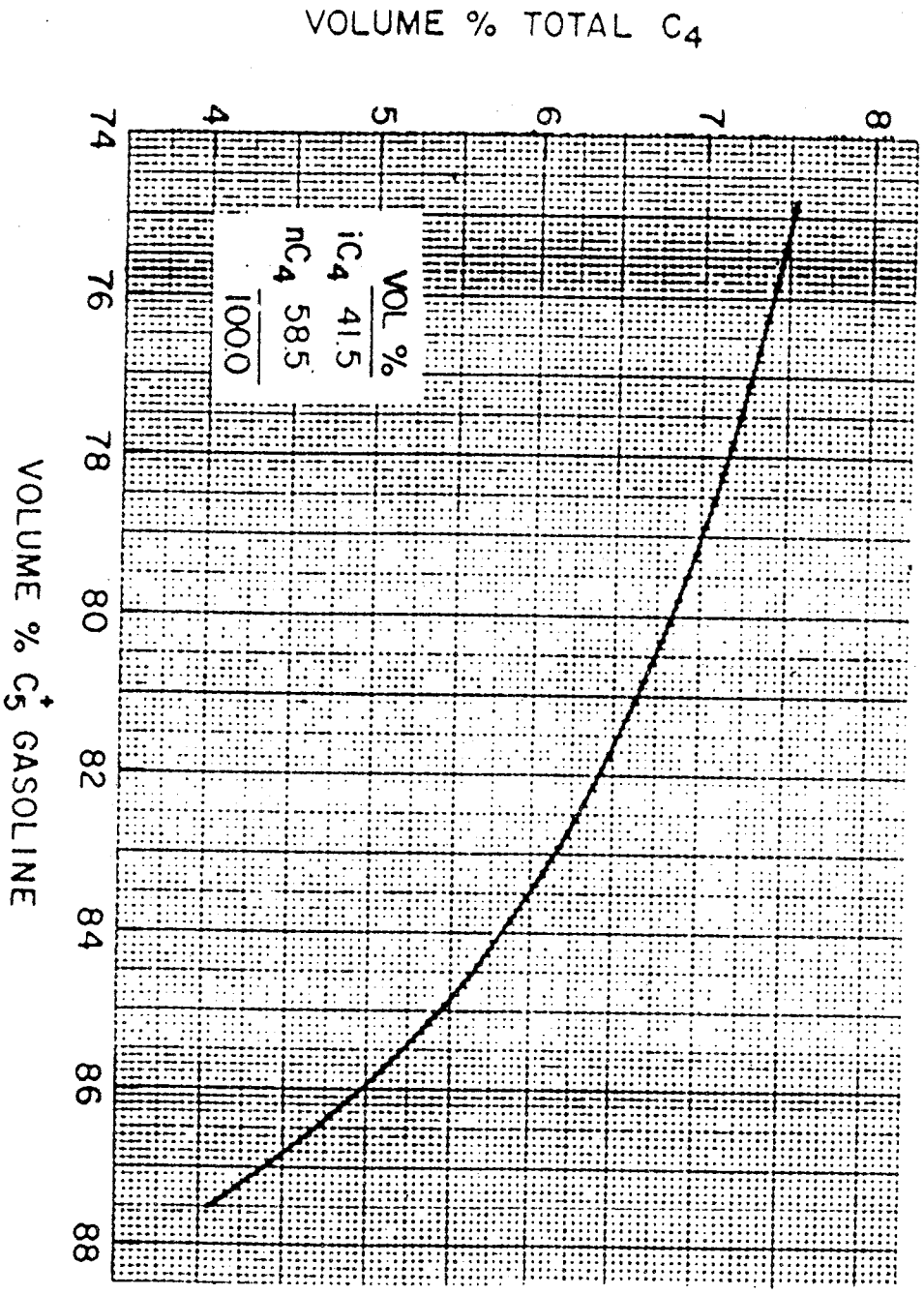


Catalytic reforming yield correlations.

...13/-

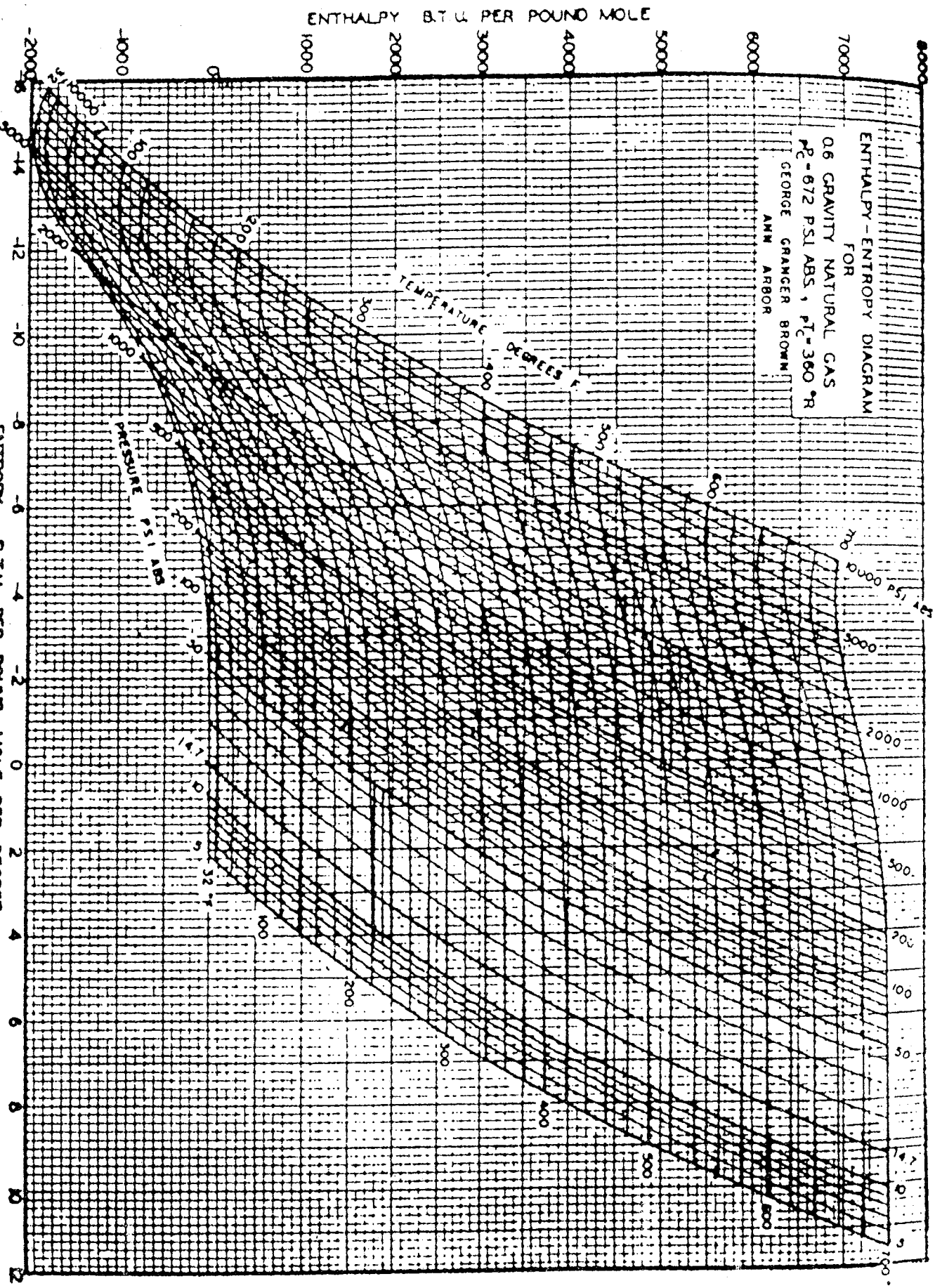


Catalytic reforming yield correlations.



Catalytic reforming yield correlations.

...15/-


ENTHALPY B.T.U. PER POUND MOLE
ENTROPY B.T.U. PER POUND MOLE PER DEGREE
ENTHALPY-ENTROPY DIAGRAM FOR 0.6 GRAVITY NATURAL GAS
P_C = 672 P.S.I. ABS., T_C = 360 °R
GEORGE GRANGER BROWN
ANN ARBOR
TEMPERATURE DEGREES F
PRESSURE P.S.I. ABS.
32 °F

FIGURE