

uop
engineering design seminar

asphalt oxidizer
design

design engineering seminar

asphalt oxidizer

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outline

- definitions
- introduction
- asphalt properties
- asphalt oxidizers
- process flow diagram
- asphalt properties vs. oxidizer residence time
- design problem -part 1
 - solution
- design problem -part 2
 - solution
- typical blowing curves
- process variables
- composition of asphalt
- changes in asphalt during blowing
- specifications for asphalt materials

america
name

asphalt =

asphalt =
oxidation

oxidizer =

oxidized asphalt = blown bitumen

oxidized =

world wide
name

bitumen

bitumen
blowing

blowing column
or blowing still

blown

Introduction

Asphalt or bitumen is a dark, viscous to almost solid material consisting of high molecular weight hydrocarbons, mostly heavy aromatics and naphthenes. It is the residue remaining in certain types of crude oils after the more volatile components have been removed, usually by vacuum distillation. Most asphalts will contain little or no olefins, unless the asphalt has been subjected to cracking conditions during the distillation.

The properties of the asphalts produced will depend on the method of preparation, even though they come from the same crude source. The properties of the virgin asphalt can be modified considerably by air blowing. This is called asphalt oxidation, but the principal chemical reaction is probably dehydrogenation. Blowing will lower penetration, and increase softening point and will lower ductility.

The principal uses for asphalts are for road building (this is by far the major use), for roofing materials, for flooring materials (asphalt tiles) and some specialty uses. Each of these uses requires special handling.

The roofing and flooring asphalts usually require very high softening points, and almost always are blown asphalts.

Asphalt Properties:

Because it is different from most other hydrocarbons, a special set of tests are used to define asphalt properties.

a) Penetration

The commonest control specification is called penetration. In this test, a standardized needle is allowed to penetrate a sample of asphalt in a container at specified conditions of time, temperature and load. The penetration is expressed in penetration units (tenths of a millimeter). The commonest imposed conditions are a temp. of 77 °F (25°C), a loading of 100 grams and a test time of 5 secs.

Other conditions are occasionally used, and it is customary to specify the parameters when specs. are written. If nothing is said, the 77°F, 100 G., 5 sec. parameters may be assumed.

A typical paving asphalt will be 100 penetration. A 500 pen. material is sticky and viscous and a 5 pen. material hard and brittle at ambient temperatures.

b) Softening Point

Physically speaking, even the hardest grades of asphalt are viscous liquids, and therefore have no melting point. As asphalt is heated it becomes softer and its viscosity decreases. The softening point is determined by a standardized arbitrary method, the ball and ring method. In this method a brass ring of specified diameter is filled with molten asphalt and cooled to room temperature. A steel ball weighing 3.5 grams is placed on the asphalt and the whole assembly

problem -part 2

Size the wash tower & K.O. pot for the asphalt oxidizer just designed.

*assume no condensation of any part of the flue gas
in the wash tower or K.O. pot.*

*assume we will cool the flue gas to 325°F (163°C)
and the wash oil will heat up from 300°F (149°C) to 400°F (204°C)>*

*assume gas inlet to wash tower is 5 PSIG (0.35 Kg/cm² g)
& the K.O. pot is @ 3 PSIG (0.21 Kg/cm² g).*

*~ 90 Bbls. of hot wash oil inventory in bottom of wash tower
is desired.*

(ignore volume of the bottom head in your calculations)

*Note: side-to-side pans
curtain area $\geq$ open area of the pan
min. spacing-24" (610 mm)*

UOP K - CABP
 MW - MABP

API°

K
 API°

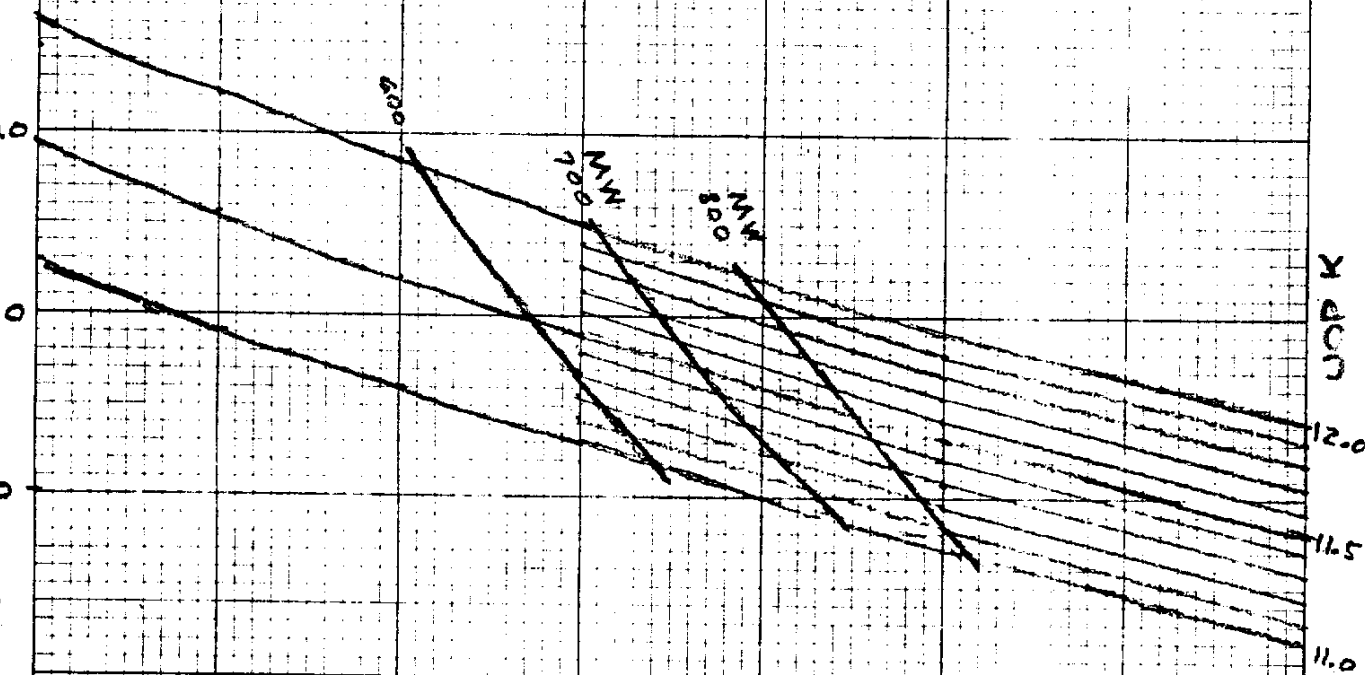
800

1000

1200

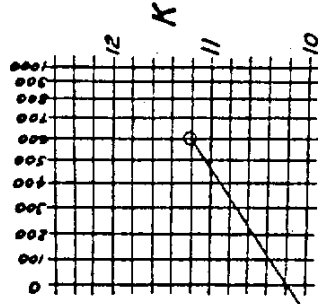
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BOILING POINT OF



ENTHALPY OF PETROLEUM LIQUIDS

CUBIC AVERAGE
BOILING POINT, °F



R.E. CHART F-6
MAY 2, 1939

EXAMPLE: ENTHALPY OF
A STOCK HAVING A B.P. 500°
AND $K=11.2$ AT 750°F
IS 411 BTU/LB.

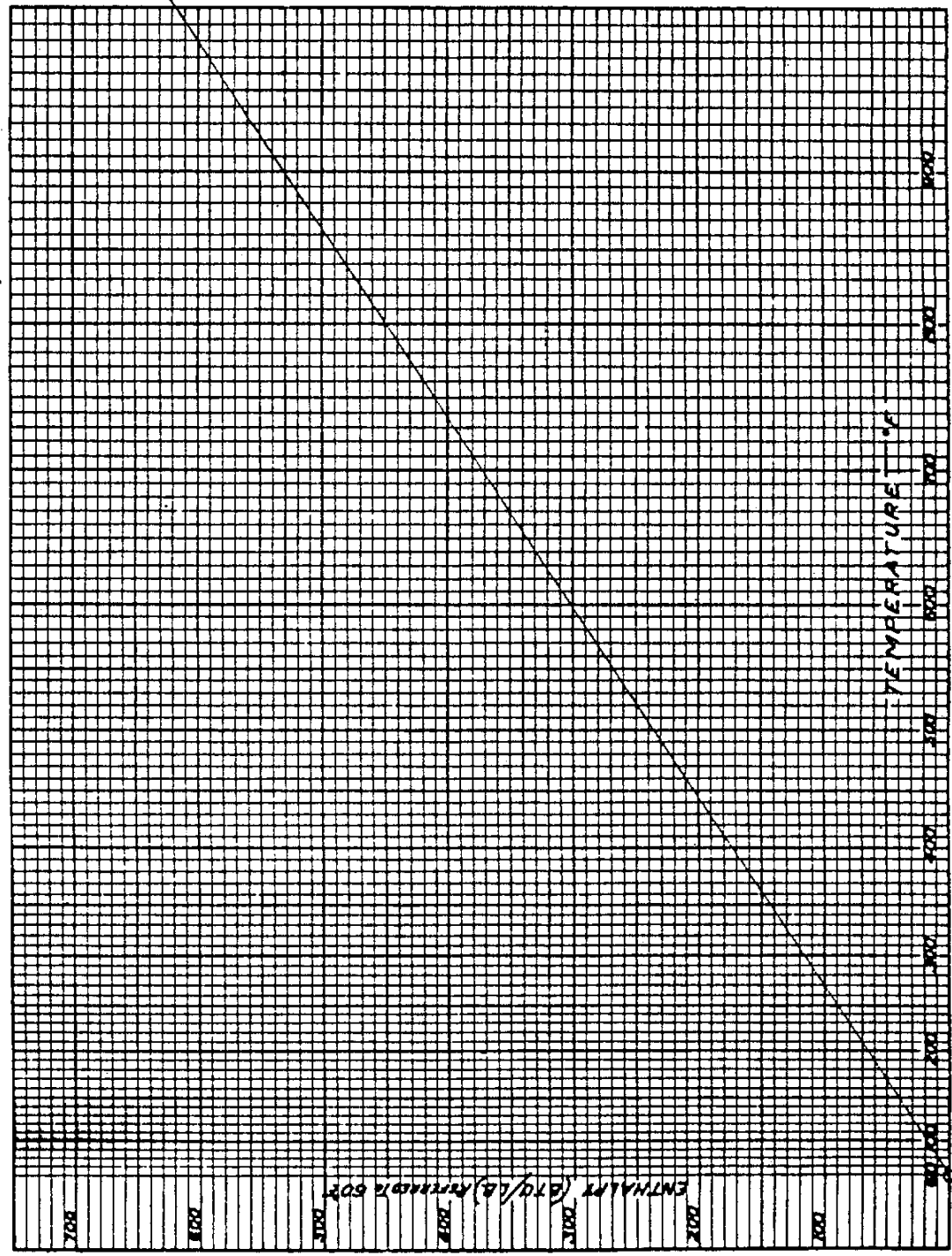


Fig. 9

Asphalt Oxidizer Problem

JW Jr

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SOLUTION

$$\left[2 \text{ Kcal/Kg} \times 17146 \times 44.4 = 1.53 \times 10^6 \text{ Kcal/Hr} \right]$$

$$\text{Heat of Reaction} = 2 \text{ BTU/LB} \times 37800 \times 80 = 6.05 \times 10^6 \text{ BTU/Hr.}$$

COMPRESSOR CALCULATIONS:

$$\text{TOP PRESSURE} = 5 \text{ PSIG (0.35)}$$

$$\text{LINE, SPIDER AND CONTROL VALVE } \Delta P = 8.2 \text{ (0.57)}$$

STATIC HEAD

$$\frac{42.6}{2.31} (.91) = \frac{16.8}{30.0 \text{ PSIG (2.1)}}$$

$$\text{COMPRESSOR DISCHARGE} = 30 \text{ PSIG (2.1 Kg/cm}^2\text{g)}$$

$$\text{COMPRESSION RATIO} = \frac{30 + 14.7}{14.7} = 3.04$$

$$T_2 = T_{\text{INLET}} \left(\text{C.R.}^{k-1/k} \right) \quad T_{\text{INLET}} \text{ IN } ^\circ \text{R}$$

$$\text{THEOR. DISCH. TEMP.} = T_2, ^\circ \text{R}$$

$$T_2 = (100 + 460) (3.04^{1.4-1/1.4}) = 560 (3.04^{0.2857})$$

$$= 560 (1.408) = 769 ^\circ \text{R} \quad \text{OR} \quad 309 ^\circ \text{F}$$

Asphalt Oxidizer Problem

JW Jr

SOLUTION

Heat & Weight balance
CHECK

	IN lb/HR	100 BTU/HR.	OUT lb/HR	100 BTU/HR
Asphalt	37800 (17146)	2.47 (0.61)		
AIR	8015 (3636)	0.52 (0.14)		
OXID. Asp.			37576 (17044)	8.10 (2.04)
FLUE GAS		(1.53)	8239 (3738)	0.94 (0.24)
HT. OF REACTION -		6.05		
TOTAL	45815 (20827) Kg/HR	9.04 (2.28) 100 Kcal/HR	45815 (20827) Kg/HR	9.04 (2.28) 100 Kcal/HR

Asphalt Oxidizer Problem

||

SOLUTION

$$(179.55 \times 16.56 = 2974 \text{ M}^3/\text{hr})$$

$$\text{NORMAL AIR REQUIREMENT} = 0.7 \times 2500 = 1750 \text{ SCFM}$$

$$\frac{(2974)}{1750} \times 60 = 8015 \text{ LB/HR} \quad (3636 \text{ Kg/HR})$$

$$\frac{13.1}{(0.818)} \times 8015 = 276.4 \text{ lb-MOLS/HR} \quad (125.4 \text{ Kg-MOLS/HR})$$

$$\text{NORMAL FLUE GAS} = 1.028 \times 8015 = 8239 \text{ LB/HR} \quad [(3636) = 3738 \text{ Kg/HR}]$$

$$\left(\frac{[3738 \text{ Kg/HR}]}{25.4} = 147.2 \text{ Kg-MOLS/HR} \right)$$

$$\frac{8239}{25.4} = 324.4 \text{ lb-MOLS/HR}$$

$$\text{@ } 5 \text{ PSIG AND } 500^\circ\text{F} \quad (0.35 \text{ Kg/cm}^2\text{g}) \quad (260^\circ\text{C})$$

$$P_v = \frac{19.7 \times 25.4}{10.73 \times 960} = 0.0486 \text{ LB/FT}^3 \quad (0.7785 \text{ Kg/M}^3)$$

$$\therefore \text{Vapor Volume At Top} = \frac{(3738 \text{ Kg/hr})}{0.0486 \times 3600} = 47.1 \text{ CFS} \quad (1.334 \text{ M}^3/\text{sec})$$

$$\text{MAX. AIR RATE} = 1.25 \times 8015 = 10019 \text{ LB/HR}$$

$$\text{MAX. FLUE GAS RATE} = 1.25 \times 8239 = 10299 \text{ LB/HR} \quad (3738) \quad (4673 \text{ Kg/HR})$$

$$47.1 \times 1.25 = 58.9 \text{ CFS}$$

$$(1.334 \times 1.25 = 1.667 \text{ M}^3/\text{sec})$$

ASPHALT OXIDIZER PROBLEM

JW JR

SOLUTION

(0.229 M/sec.)

AREA REQ'D FOR 0.75 FT./sec. VEL.

$$= \frac{58.9}{0.75} = 78.5 \text{ FT}^2 \quad \left[\frac{1.667}{0.229} = 7.28 \text{ M}^2 \right]$$

$$10'0'' \text{ } \phi \text{ TOWER} \approx 78.5 \text{ FT}^2$$

$$10'6'' \text{ } \phi \text{ TOWER} \approx 86.6$$

LETS USE 10'0" ϕ TOWER (or 3100 MM ϕ TOWER)

$$(16.56 \text{ M}^3/\text{HR} @ 15.5^\circ\text{C} = \frac{16.56}{0.875} = 18.93 \text{ M}^3/\text{HR} @ 260^\circ\text{C})$$

$$2500 \text{ BPSD} @ 60^\circ\text{F} = \frac{2500}{0.875} = 2857 \text{ BPSD}$$

LIQ EXPANSION TO 500°F

@ 500°F

$$\frac{2857}{24} \times 5 = 595 \text{ BBLS FOR 5 HOUR}$$

(94.65 M³) RESIDENCE TIME

LEVEL IN 10'0" I.D. VESSEL (OR 3100 MM ϕ VESSEL)

$$= \frac{595 \times 5.614}{78.5} = 42.6 \text{ FT.}$$

$$\frac{42.6}{0.75} \text{ (VOL 25\% RESIDUO VACIO)} = 56.8 \text{ FT. SAY } 60' \text{ FT.}$$

$\therefore$ Vessel is 10'0" I.D. X 60 FT TANGENT-TANGENT
(3100MM ϕ X 18000MM) LENGTH

$$\frac{94.65 \text{ M}^3}{7.55 \text{ M}^2} = 12.54 \text{ M (A LITTLE DIFFERENT DUE TO DIFFERENT } \phi \text{ - ENGLISH VS METRIC)}$$



Process Division

UOP Inc.
20 UOP Plaza—Algonquin & Mt. Prospect Roads
Des Plaines, Illinois 60016 • 312-391-2000

HEAT AND WEIGHT BALANCES

DESIGN ENGINEERING SEMINAR

ASPHALT OXIDIZER PROBLEM

PAGE NO. 11

DATE

PROJECT

BY J.W. JR

ENGINEERING DEPARTMENT

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OXIDIZER SECTION

STREAM	° API (LB/GAL)	K	MW	FLOWING SP. GR. (LB/CF)	° F	PSIG (MM HG ABS)	BPSD @ 60°F (10 ⁶ SCF/D)	FLOWING GPM (CFS)	MOLS PER HR.	LB/HR	BTU/ LB	10 ⁶ BTU/HR
ASPHALT TO EXCH	5	11.3	620	0.91	450		2500	83	61	37800	183	7.11
EXCH. DUTY												4.64
ASPHALT TO OXIDIZER	5	11.3	620	0.99	212		2500	76	61	37800	65	2.47
AIR TO COMPRESSOR			29	(0.07)	100	0	(2.52)	(32)	276.4	8015	10	0.08
AIR TO OXIDIZER			29	(0.157)	309	30	(2.52)	(14)	276.4	8015	65	0.52
FLUE GAS TO WASH TOWER			25.4	(0.049)	500	5	(2.95)	(47)	324.4	8239	114	0.94
OXIDIZED ASPHALT TO COOLER	3	11.5	800	0.92	500		2448	82	47	37576	215	8.10
COOLER DUTY												3.14
OXIDIZED ASPHALT TO STORAGE	3	11.5	800	0.96	350		2448	78	47	37576	132	4.96
HEAT OF REACTION												6.05

110P17.1022H



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HEAT AND WEIGHT BALANCES (MKS Units)

DESIGN ENGINEERING SEVENAR

ASPHALT OXIDIZER PROBLEM

ENGINEERING DEPARTMENT

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PROJECT

BY JWS JT

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STREAM	gm/cc @ 15.6°C (°API)	K	MW	FLOWING SP. GR. (kg/m ³)	°C	Kg/cm ² (MM HG ABS)	(m ³ /DAY) Nm ³ /HR.	FLOWING m ³ /HR.	Kg MOLS. PER HR.	Kg/HR.	Kcal/Kg	10 ⁶ Kcal/HR.
ASPHALT TO EXCH	(5)	11.3	620		232		16.56	18.8	27.7	17146	104	1.79
EXCH DUTY												1.18
ASPHALT TO OXIDIZER	(5)	11.3	620		99		16.56	17.3	27.7	17146	36	0.61
AIR TO COMPRESSOR			29	(1.14)	38	0	2813	3246	125.4	3636	6	0.02
AIR TO OXIDIZER			29	(1.68)	164	2.1	2813	1357	125.4	3636	39	0.14
FLUE GAS TO WASH TOWER			25.4	(0.78)	260	0.35	3293	4802	147.1	3738	63	0.24
OXIDIZED ASPHALT TO COOLER	(3)	11.5	800	0.92	260		16.21		21.3	17044	119	2.04
COOLER DUTY												0.79
OXIDIZED ASPHALT TO STORAGE	(3)	11.5	800	0.96	177		16.22		21.3	17044	73	1.25
HEAT OF REACTION												1.53

UOP17-2

asphalt oxidizer program

design parameters

starting with 300 pen. asphalt (95°F [35°C]) soft. pt.

DESIRED PRODUCT

softening point	50	175°F (79.4°C)
penetration		30
Air, SCFM/BPSD of charge		0.7 (179.55 M ³ /hr/M ³ /hr)
oxidizer temp.		500°F (260°C)
residence time		5 hrs

charge losses per lb. of air = 0.028 lb.

wet flue gas per lb. of air = 1.028 lb.

mol. wt. of wet flue $\cong$ 25.4

mol. wt. of air $\cong$ 29.0

set max. air rate at 125 % of normal

vapor velocity at top @ max. flue gas rate = 0.75 ft./sec. (0.229 M/sec.)

@ 60°F (15.6°C) and 14.7 PSIA, 1 lb of air = 13.1 ft³ (1 kg. of air = 0.818 M³)

sp. ht. of both air & flue gas = 0.26

heat capacity ratio for air (k value) = 1.4

HEAT OF REACTION = 2 BTU/lb of asphalt feed per $^{\circ}\text{F}$, soft. pt. change
(2 Kcal/kg of asphalt feed per $^{\circ}\text{C}$, soft. pt. change)

Set liquid height in oxidizer @ 75 % of the total tangent length
(disregard the volume in the bottom head in the calculations)

Asphalt Oxidizer Problem

Design an asphalt oxidizer to blow 2500 BSPD of 300 pen., 95°F soft. pt.
ARABIAN asphalt down to 30 pen. and 175°F soft. pt.

assume charge is 5 API and 11.3 UOP K.

assume 5 PSIG and 500°F at top of OXIDIZER

assume oxidized asphalt is 3 API and 11.5 UOP K

assume bottom product out of oxidizer is at 500°F (260°C)

assume air to compressor @ 100°F (38°C) and 0 % relative hum. @ sea level

(1 barrel = 5.614 ft³ = 0.159 M³)

cool product to 350°F (177°C)

asphalt feed enters the unit at 450°F (232°C)

assume pressure drop from air compressor outlet to air distributor ✓

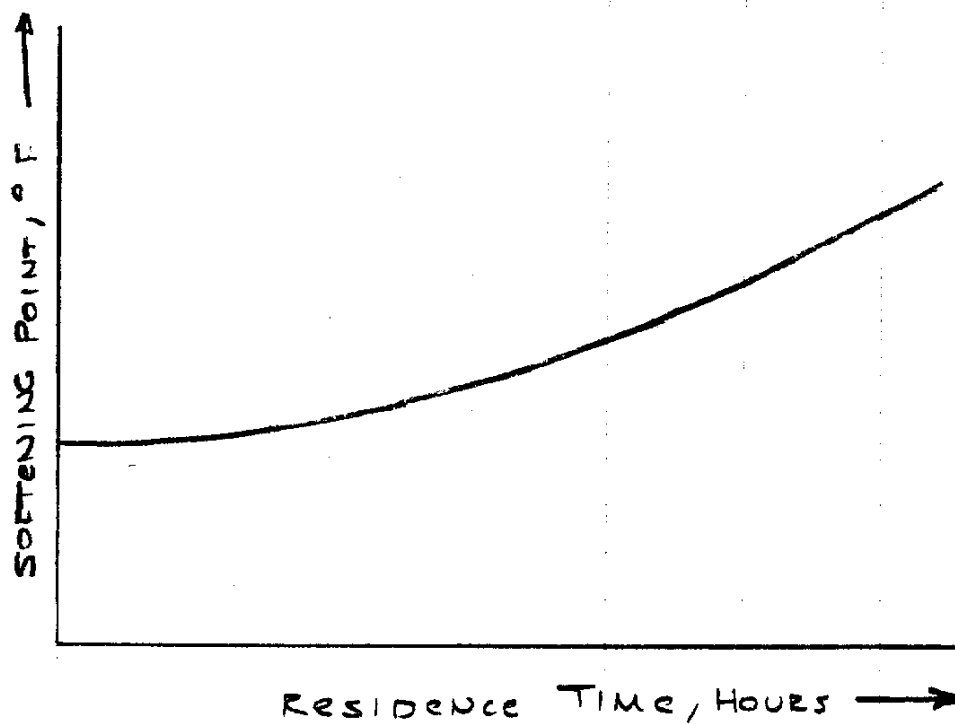
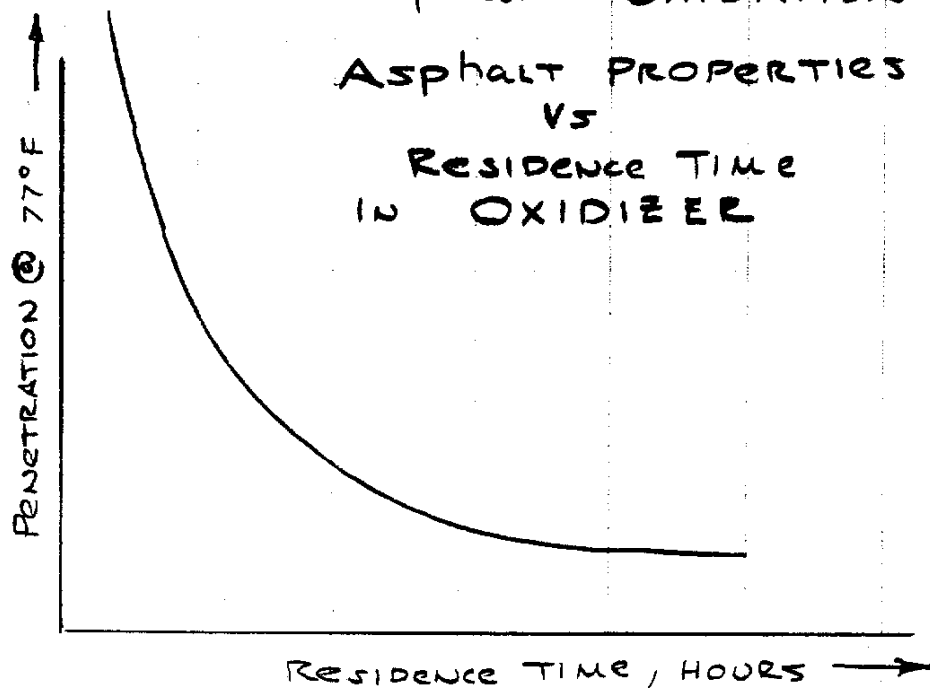
outlet is 8.2 PSI (0.56 Kg/cm²)

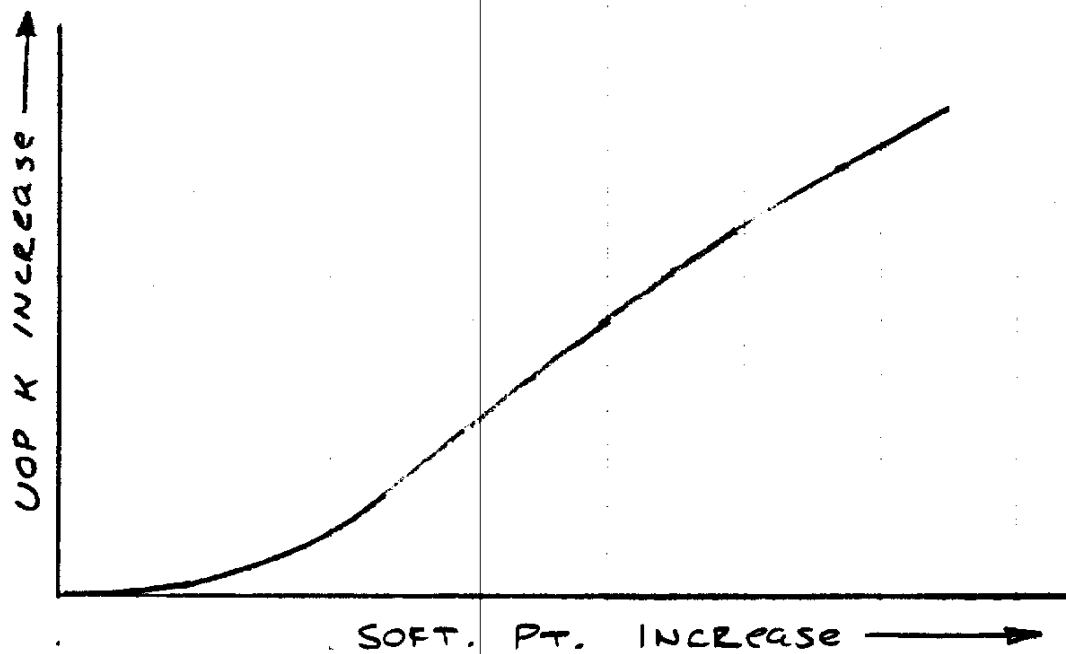
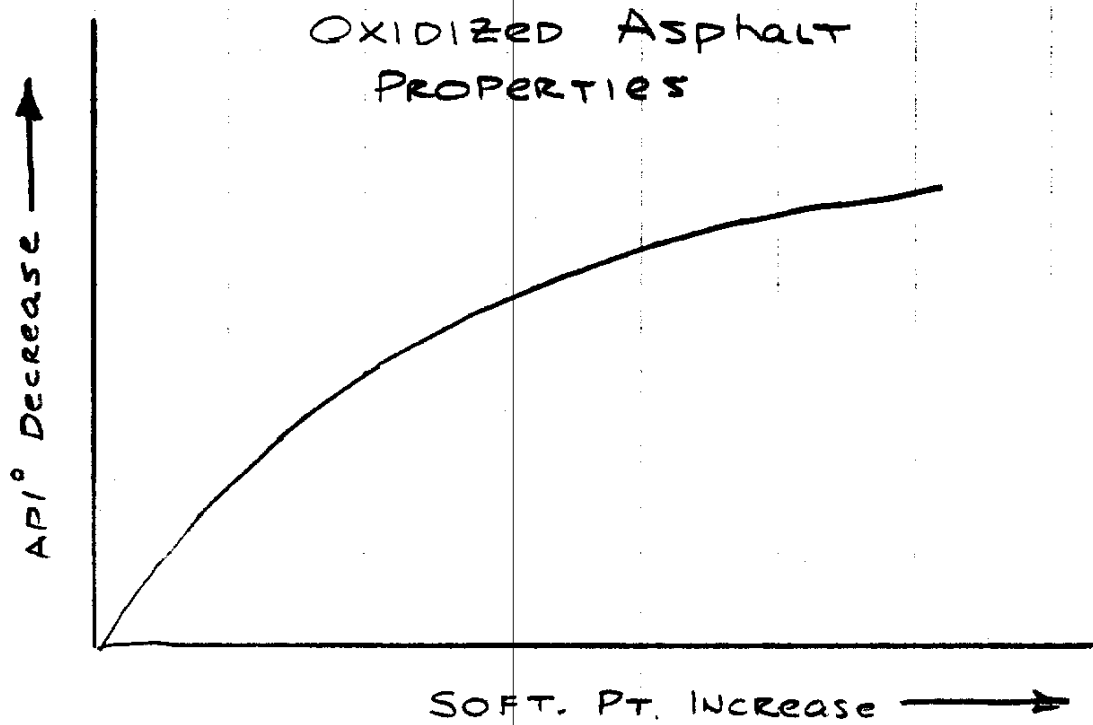
NOTE; temp. disch = temp. suction (C.R. ^{$k-1/k$}) temp in °R

C.R. = comp. ratio = press, disch / press, suction ; in PSIA

k = 1.4 (for air)

Asphalt Oxidation Asphalt Properties vs Residence Time in Oxidizer



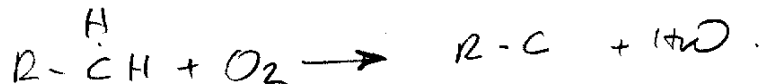


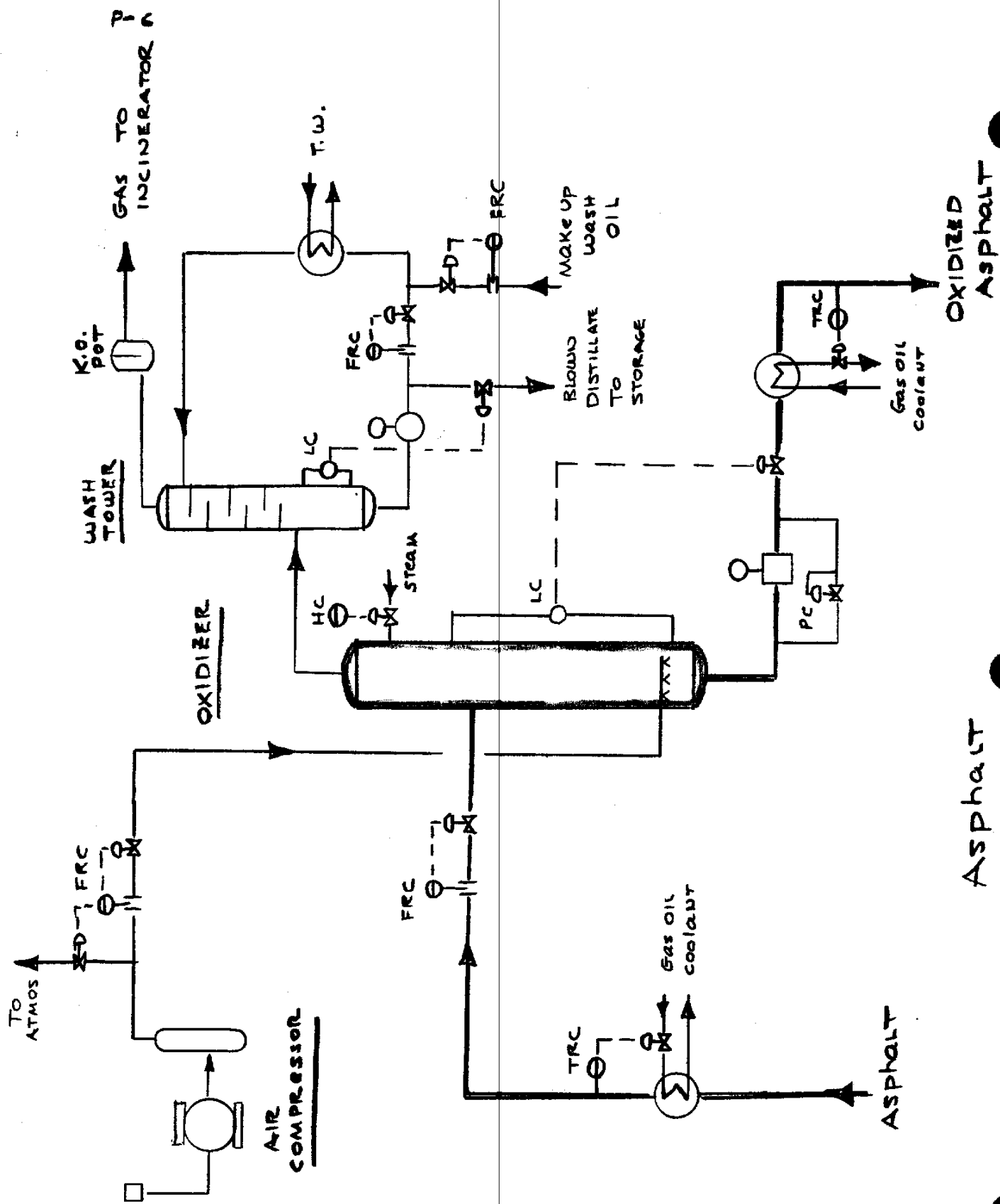
Asphalt Oxidizers (Cont'd.)

The polymerization reaction in air blowing proceeds because of the dehydrogenation of the asphalt, resulting from hydrogen removal by the oxygen in the air (to form water). This is an exothermic reaction (gives off heat).

The oxidized asphalt is a product with higher softening point for a given penetration as compared to asphalt produced by other processes.

Rx





Oxidized Asphalt

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b) Softening Point (Cont'd.)

is heated in a water bath at a constant rate of 5°C per min. until the ball and asphalt fall. The temp. at which the softened asphalt touches the bottom of the water bath is reported as the softening point, ball and ring. The test is highly standardized, and it is important that the lab follows the prescribed cooling and heating rates.

A typical paving asphalt could have a 120°F softening point while fully blown grades have softening points of up to 300°F . (49°C) (149°C)

c) Ductility

The ductility test consists of stretching, in a suitable apparatus, an asphalt briquette constricted in the middle to a cross-section of 1 sq. cm. in a water bath at 25°C at a rate of 5 cm/min. Under these conditions, ductilities of over 100 cm. may be obtained, the briquette being pulled out into a very thin thread before it snaps.

d) Other Tests

Other tests which are used in asphalt specifications include

- 1) Solubility in Organic Solvents, usually CCl_4 , CS_2 , or NC_7
- 2) Ash Content
- 3) Flash Point
- 4) Viscosity
- 5) Oliensis (Spot) Test

Asphalt Oxidizers

Blowing oxygen through the asphalt increases the asphaltene content of the asphalt, primarily by dehydrogenation. The higher the asphaltene content, the higher will be the softening point and the lower will be the penetration.

Originally, asphalt oxidizers were built as batch operated units; a vessel was filled with virgin asphalt, and air was blown through it until the specified product was produced. Blowing times often were in the neighborhood of 12 hours.

The present philosophy is to build continuous oxidizers, in which feed is being steadily introduced and product simultaneously removed. The continuous units have much more flexibility and blowing time is reduced to 4-8 hours.

In the oxidizing column, the temperature is usually maintained between (232°C) (260°C) (329°C) 450°F and 500°F, though temperatures as high as 625°F have been used.

If the temperature is too low, a longer residence time is required and the oxygen content of the flue gas may be so high as to increase the risk of explosion. On the other hand, too high a temperature at the residence times required (4-8 Hrs.) may result in the occurrence of some cracking and coking in the overhead vapor lines.

PART 1

GETTING STARTED

— AIR RATE

$[M^3/hr]$

$= [M^3/hr]$

$$Feed\ BPSD \times Air\ Factor = SCFM$$

— CONVERT $\frac{M^3}{hr}$ SCFM TO $\frac{kg}{hr}$ lb/hr

$$\frac{SCFM}{13.1} \times 60 = lb/hr \quad \frac{M^3/hr}{0.818} = kg/hr$$

— CALC FLUE GAS RATE

$$Air\ Rate \times 1.028 = Flue\ Gas\ Rate$$

— CALC DENSITY OF FLUE GAS

$$\rho_v = \frac{MW \times (14.7 + Top\ Press)}{10.73 \times (460 + Top\ Temp)} = lb/ft^3$$

Calc cu ft/sec of FLUE GAS

$$\frac{lb/hr}{\rho_v (3600)} = CFS$$

$$MAX\ CFS = Normal\ CFS \times 1.25$$

CALC HT OF REACTION

$$\begin{aligned}
 & 2 \text{ Kcal/Kg (Kg/hr)} (\Delta \text{ S.P. } ^\circ \text{C}) = \text{Kcal/hr} \\
 - & 2 \text{ BTU/lb (lb/hr OF FEED)} (\Delta \text{ S.P.}) \\
 & = \text{BTU/hr} \quad \Delta \text{ SOFTENING POINT}
 \end{aligned}$$

COMPRESSOR CALCS

TWR TOP PRESS
 + LINE, SPIDEE, C.V. DP +
 STATIC HD OF LIQUID IN TOWER
 $\hat{=}$ COMPRESSOR DISCH PRESSURE

$$\text{C.R.} = \frac{\text{DISCH PRESS} + 14.7}{14.7}$$

$$T_2 = T_{\text{INLET}} \times \text{C.R.}^{k-1/k}$$

$$T_2, ^\circ \text{F} = T_2, ^\circ \text{R} - 460$$

PART 2

GETTING STARTED

- MAX FLUE GAS RATE FROM PART 1

$$\frac{16/\text{hr} \cdot \text{Kg}/\text{hr}}{3600 \times \text{PV.}} = \frac{\text{M}^3/\text{SEC}}{\text{CU FT}/\text{SEC}}$$

FROM PART 1

$$\frac{\text{CFS}}{2 \text{ ft}^2} = 59 \text{ FT REQ'D}$$

$$\frac{\text{M}^3/\text{SEC}}{0.61} = \text{MA}$$

(CROSS SECTIONAL AREA OF WASH TOWER)

→ CALC

CURTAIN AREA

= CHORD LT. OF PAN X TRAY SPACING

(TO CHECK TRAY SPACING)

PART 2 (CONT'D)

- size K.O. POT
- calc P_v - @ 3 psig & 325°F (163°C)
(.21 Kg/cm²g)
- calc P_L

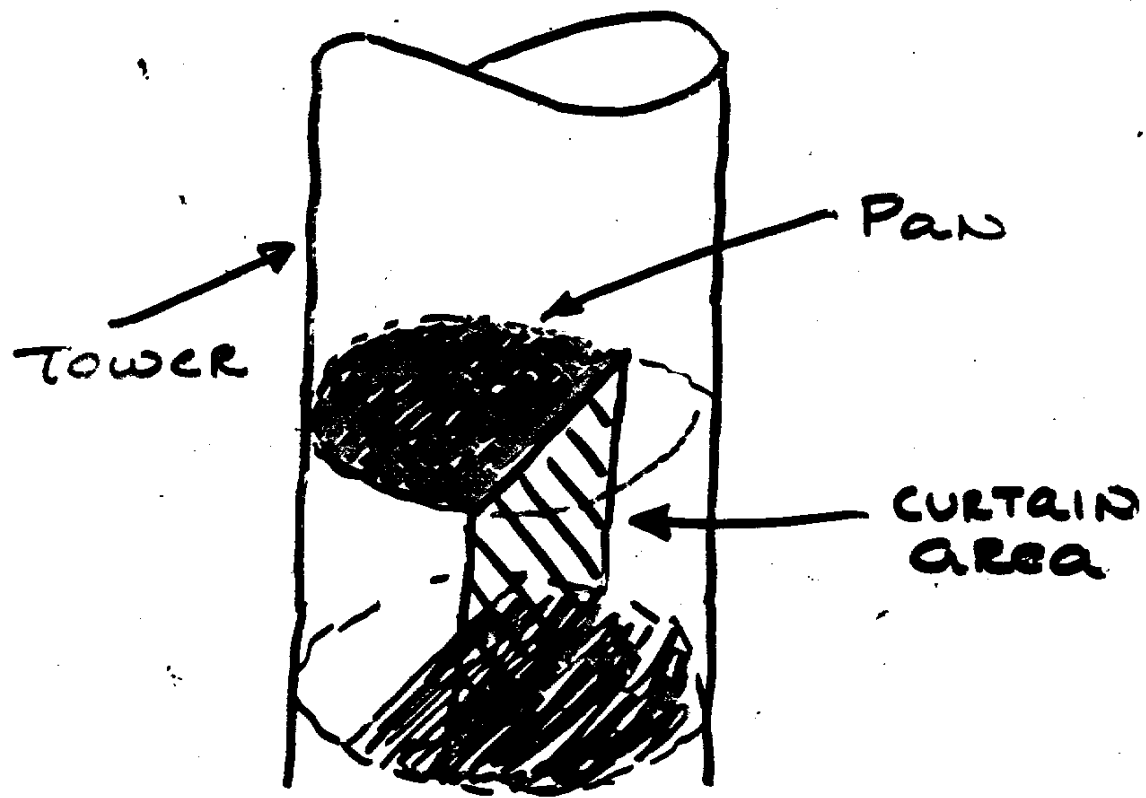
- calc Max FPS — Max M/sec

$$= 0.157 \left(\frac{P_L}{P_v} \right)^{1/2} \quad 0.048 \left[\frac{\text{IN}}{\text{METRIC UNITS}} \right]$$

- USING MAX FLOW GAS RATE

$$\frac{\text{lb/hr}}{3600 (P_v)} = \text{CFS} \quad \frac{\text{Kg/hr}}{3600 (P_v)} = \text{M/sec}$$

$$\frac{\text{CFS}}{\text{Max FPS}} = \text{SQ FT OF K.O. POT}$$



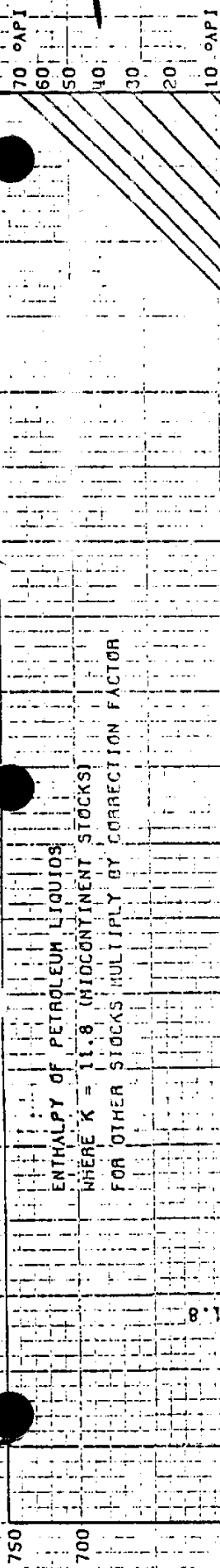
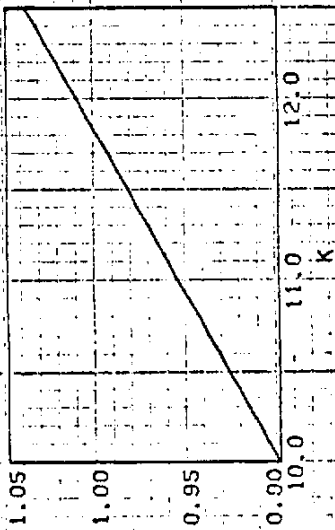
ENTHALPY (BTU/LB) REFERRED TO 60°F

CORRECTION FACTOR FOR STOCKS WITH K OTHER THAN 11.8

ENTHALPY OF PETROLEUM LIQUIDS

WHERE $K = 11.8$ (MIDCONTINENT STOCKS)

FOR OTHER STOCKS MULTIPLY BY CORRECTION FACTOR



UNIVERSAL OIL PRODUCTS COMPANY

09-10-71 OSO

Replaces R.E.-F.6

HEAT AND WEIGHT BALANCES

DESIGN ENGINEERING SEMINAR
ASPHALT PAVING PAVEMENT
WATER TOWER

ENGINEERING DEPARTMENT

PAGE NO. _____
DATE _____
PROJECT _____
BY _____

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HEAT AND WEIGHT BALANCES (MKS Units)

DESIGN ENGINEERING SEMINAR
ASPHALT OXIDIZER PROBLEM

ENGINEERING DEPARTMENT

PAGE NO. 18 METRIC

DATE

PROJECT

BY JUL JT

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STREAM	gm/cc @ 15.6°C (°API)	K	MW	FLOWING SP. GR. (kg/m ³)	°C	Kg/cm ² (MM HG ABS)	(m ³ /DAY) Nm ³ /HR.	FLOWING m ³ /HR.	Kg MOL. PER HR.	Kg/HR.	Kcal/Kg	10 ⁶ Kcal/HR.
FLUE GAS TO WASH TOWER			25.4	(0.78)	260	0.35	3293	4802	147.1	3737	63	0.24
FLUE GAS TO K.O. POT			25.4	(0.85)	163	0.21	3293	4396	147.1	3737	38	0.14
WASH OIL PA TO COOLER COOLER DUTY	(20)	11.7			204			3.7		3024	97	0.29
WASH OIL PA RETURN TO TWR	(20)	11.7			149			3.6		3024	65	0.19

UOP17-

SOLUTION

Flue Gas Ht. IN - Ht. OUT

$$(0.24) - (0.14) = (0.10 \times 10^6 \text{ Kcal/HR})$$

$$0.94 - 0.57 = 0.37 \times 10^6 \text{ BTU/HR}$$

$$\frac{0.37 \times 10^6}{175 - 118} = 6667 \text{ lb/HR wash oil REQUIRED}$$

$$\left[\frac{0.10 \times 10^6}{97 - 65} \approx 3024 \text{ Kg/hr} \right]$$

SOLUTION

WASH TOWER

$$\frac{\text{MAX FLUE GAS}}{[3737]} [4671 \text{ Kg/Hr}]$$

$$8239 \times 1.25 = 10299 \text{ LB/Hr}$$

AT INLET $P_v = 0.0486 \text{ LB/FT}^3$ or 0.7785 Kg/M^3

$$\frac{10299}{3600(0.0486)} = 58.9 \text{ FT}^3/\text{SEC}$$

$$\left[\frac{4671}{3600(0.7785)} = 1.667 \text{ M}^3/\text{SEC} \right]$$

$$\frac{58.9}{2} = 29.45 \text{ SQ FT REQ'D}$$

$$\left[\frac{1.667}{0.61} = 2.733 \text{ M}^2 \text{ REQ'D} \right]$$

6' DIA. TOWER = 28.27 SQ FT

6'6" DIA TOWER = 33.18 SQ FT

LET'S USE 6'6" DIA TOWER (1981 MM)

$$\frac{90 \text{ Bbls} \times 5.614}{33.18} = \frac{505.3}{33.18} = 15.2 \text{ FT}$$

$$\frac{1800 \text{ MM } \phi \text{ TWR}}{1900} = 2.54 \text{ M}^2$$

$$= 2.83 \leftarrow \text{LET'S USE THIS TOWER}$$

SOLUTION

CURTAIN AREA

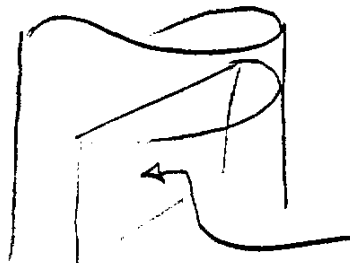
[2.83 M² FOR 1900 MM Ø TOWER]

$$A_{\text{TOTAL}} = 33.18 \text{ FT}^2$$

CROSS SECTIONAL AREA
OF 6'6" Ø TOWER

$$A_{\text{OPEN}} = 0.292 (33.18) = 9.69 \text{ FT}^2$$

$$[0.292 (2.83) = 0.83 \text{ M}^2]$$



CURTAIN AREA

CURTAIN AREA = CHORD LENGTH X TRAY SPACING
[610 MM]

CHECK AT 24" TRAY SPACING

$$\text{Dia} = 6.5' \text{ OR } 1900 \text{ MM} = \text{CHORD LT} = 1.79 \text{ M}$$

$$\text{CHORD LENGTH} = 0.94 \times \text{Dia} = 0.94 \times 6.5 = 6.1 \text{ FT}$$

$$6.1 \times 2 = 12.2 \text{ Sq FT (CURTAIN AREA)}$$

$$12.2 \geq 9.69 \quad \leftarrow \text{OK}$$

TRAY SPACING - 24"

$$1.79 \times 0.61 = 1.09 \text{ M}^2 \text{ (CURTAIN AREA)}$$

$$1.09 \geq 0.83$$

SOLUTION

K.O. POT

$$\text{Max FPS} = 0.157 \left(\frac{e_L}{e_v} \right)^{1/2} \quad 0.048 \text{ (FOR MAX M/sec)}$$

$$\text{ASSUME } e_L = 0.85 \times 62.4 = 53 \text{ LB/FT}^3 \quad [1000] = 850 \text{ Kg/M}^3$$

$$e_v = 0.053 \text{ LB/FT}^3 \quad [0.849 \text{ Kg/M}^3] \quad (163^\circ\text{C}) \quad @ 3 \text{ PSIG AND } 325^\circ\text{F}$$

$$\text{Max FPS} = 0.157 \left(\frac{53}{0.053} \right)^{1/2} = 0.157 (31.62) = 5.0 \text{ FPS OR } 1.53 \text{ M/sec}$$

$$\text{Max Flue Gas} = 8239 \times 1.25 = 10299 \quad [3783] = [4729 \text{ Kg/Hr}]$$

$$\frac{10299}{3600(0.053)} = 54 \text{ CFS} \quad \left[\frac{4729}{3600(0.849)} = 1.55 \text{ M}^3/\text{sec} \right]$$

$$\frac{54}{5} = 10.8 \text{ FT}^2$$

$$4'0'' \text{ DIA POT} = 12.6 \text{ SQ FT}$$

$$3'6'' \text{ DIA POT} = 9.6 \text{ SQ FT}$$

Let's Use 4'0" DIA POT.

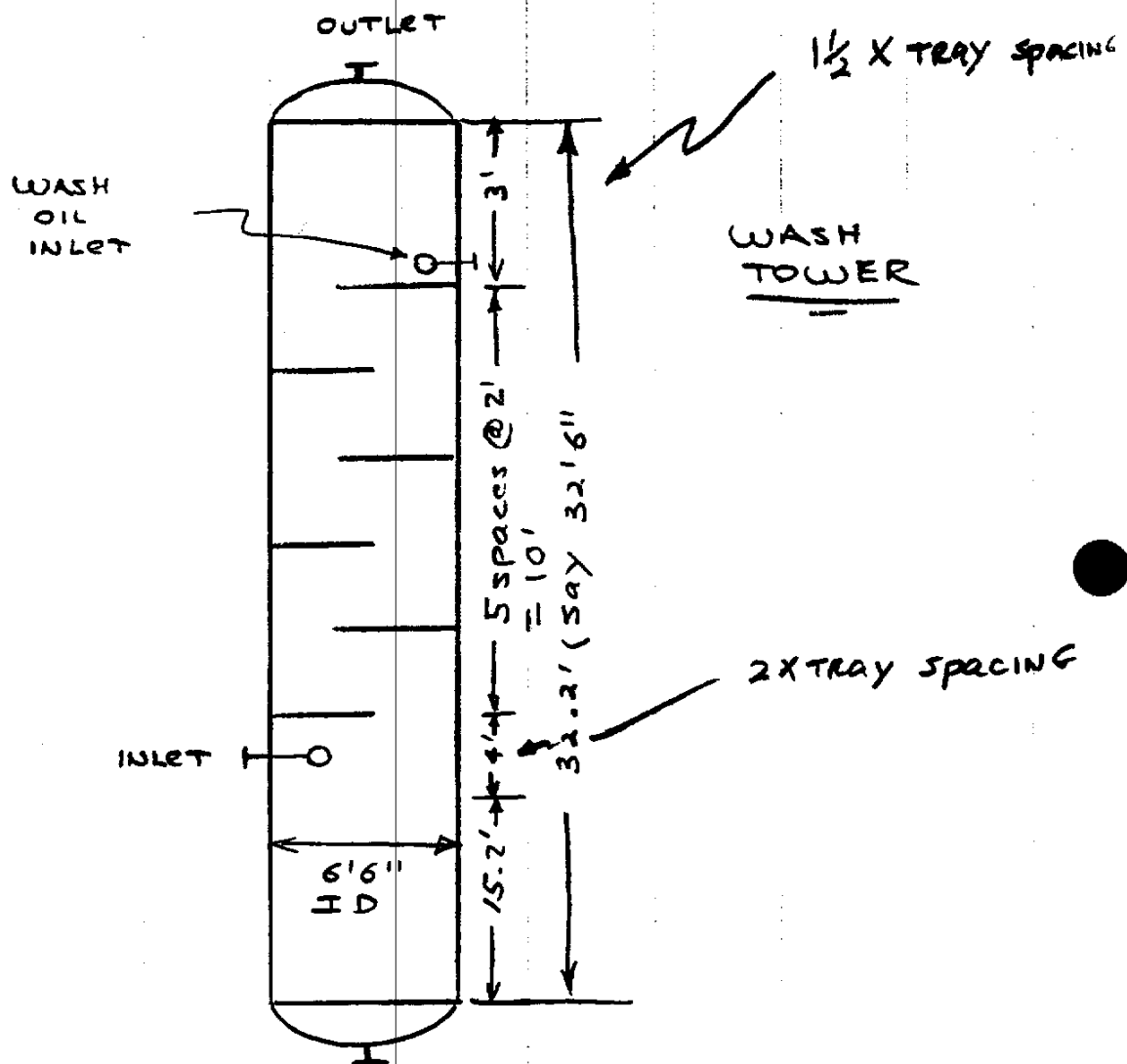
$$\frac{1.55}{1.53} = 1.01 \text{ M}^2$$

$$1200 \text{ MM } \phi = 1.13 \text{ M}^2 \leftarrow \text{OK}$$

Heat & Weight Balance CHECK

	<u>IN</u>	^{10⁶}	<u>OUT</u>	^{10⁶}
	LB/HR	BTU/HR	LB/HR	BTU/HR
FLUE Gas	8239	0.94	8239	0.57
WASH OIL	6667	0.79	6667	1.16
TOTAL	<u>14906</u>	<u>1.73</u>	<u>14906</u>	<u>1.73</u>
	Kg/HR	^{10⁶}	Kg/HR	^{10⁶}
	3737	Kcal/HR	3737	Kcal/HR
		0.24		0.14
	<u>3024</u>	<u>0.19</u>	<u>3024</u>	<u>0.29</u>
	6761	0.43	6761	0.43

SKETCH



BPSD @ 60°F

F. EXP. @ 500°F 0.875

$$\frac{\text{COLD BARRELS}}{0.875} =$$

HOT BARRELS =

DROD CALCULUS
DRL VESSEL

AIR RATE

- FEED BPSD x AIR FACTOR

$$2500 \text{ BPS} \times 0.7 = 1750 \text{ SCFH}$$

- SCFH TO lb/hr.

$$\frac{\text{SCFH} \times 60}{13.1} \Rightarrow \text{LB/HR.} \quad \frac{1750 \text{ SCFH} \times 60}{13.1}$$

AIR RATE $\Rightarrow$ 8015 lb/hr AIR.

$$\text{MAX AIR RATE} = 1.25 \times 8015 = 10019 \text{ lb AIR}$$

- FUEL GAS FUEL GAS / LB AIR = 1.028

$$\text{AIR RATE} \times 1.028 \Rightarrow 10019 \text{ lb AIR} \times 1.028 \frac{\text{LB FUEL GAS}}{\text{LB AIR}} = 10300 \text{ LB/HR.}$$

DENSITY OF FUEL GAS.

$$\rho_v = \frac{17.44 (14.7 + \text{TOP PRESS})}{10.73 (460 + \text{TOP TEMP})} = \frac{25.4 \times (14.7 + 5)}{10.73 \times (460 + 500)} = 0.048810 / \text{ft}^3$$

$$\text{MAX CFS OF FUEL GAS: } \frac{10300}{0.048810 \times 3600} = 58.89 \text{ CFS.}$$

$$\text{AREA REQD. } \frac{58.89 \text{ CFS}}{0.75 \text{ FPS}} = 78.52 \text{ FT}^2$$

GALLO
GOLLO

29

(2)

$$\text{HOT BPSD} = \frac{2500}{0.875} = 2857 \text{ BPSD}$$

VOL REQD

$$\frac{\text{HOT BPSD} \times \text{TH RES}}{24} = \frac{2857 \times 5 \text{ HOURS}}{24 \text{ HOURS}} = 595 \text{ BBLs}$$

HEIGHT OF OIL

$$\frac{\text{HOT BBLs} \times 5.614}{\text{AREA}} = \frac{595 \times 5.614}{78.72} = 42.6 \text{ FEET}$$

HEAT OF RX

2 BTU/LB OF SOFT

$$\text{LB/H OF FEED} = 2500 \text{ BPSD} \times 8.634 \frac{\text{LB}}{\text{GAL}} \times \frac{42.6 \text{ FEET}}{24 \text{ H}} \times \text{DAY} = 37774$$

$$\text{SPEC} = 8.634 \frac{\text{POUNDS}}{\text{GAL}}$$

$$\text{SPEC} = 1.0366$$

$$\text{HEAT OF RX} = 2 \text{ BTU} \times 37774 \text{ LB/H} \left(\frac{175 - 95}{\text{LB OF SOFT}} \right)$$

$$= 6.044 \times 10^6 \text{ BTU/HR}$$

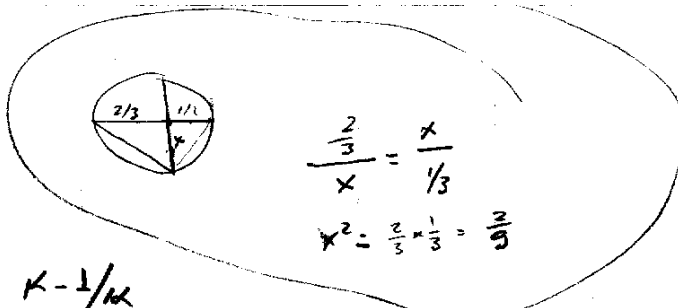
COMPRESSOR CALCS.

$$\text{COMP DISCH PRESS} = 5 \text{ PSIG} + 8.2 \text{ +}$$

$$\text{STATIC HEAD OF LIQ} = \frac{42.6 \text{ FEET} \times 1.0366 \text{ SPEC}}{2.31} = 16.5 \text{ PSIG}$$

$$\text{COMP DISC} = 5 + 8.2 + 16.5 = 29.7 \text{ PSIG}$$

$$\text{COMP RATIO} = \frac{14.7 + 29.7}{14.7} = 3.02$$



$$T_2 = T_1 \times CR^{K-1/K}$$

$$K = 1.4$$

$$T_1 = 100 + 460 = 560^\circ R$$

$$T_2 = 560 \times 3.023^{\frac{0.4}{1.4}}$$

$$T_2 = 768^\circ R = 308^\circ F$$

$$\text{MAX PLUG GAS RATE} = 58.89 \text{ CFS}$$

POR

CROSS SECTIONAL AREA WASH TOWER

CFS

MAX VEL ALLOW

$$\frac{\text{CFS}}{2} = 29.5 \text{ FT}^2$$

MAX VEL 2 FT/SEC

COURTAIN AREA

$$D = \sqrt{4A/\pi}$$

$$D = 6.12 \text{ FEET}$$

$$\text{CHORD LENGTH} = 0.94 D = 5.75 \text{ FEET}$$

$$\text{COURTAIN AREA} = 5.75 \text{ FEET} \times 2 \text{ FEET} = 11.5 \text{ FEET}^2$$

NO POT

$$P_v = \frac{MW \times (14.7 + \text{PRESS})}{10.73 \times (460 + \text{TEMP})} =$$

$$P_v = \frac{28.4 (14.7 + 3)}{10.73 (460 + 325)} = 0.0533$$

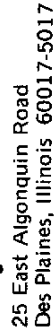
$$P_L = 0.9333$$

$$\text{MAX ALL VEL} = 0.157 (P_L / P_v)^{1/2}$$

$$= 0.6572, \text{ VEL FACTOR FEET/SEC.}$$

$$\text{MIN ALL AREA} = 58.89 / 0.6572$$

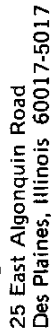
$$= 89.60 \text{ FT}^2 \quad D = 10.68 \text{ FT}$$



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PROJECT _____
BY _____

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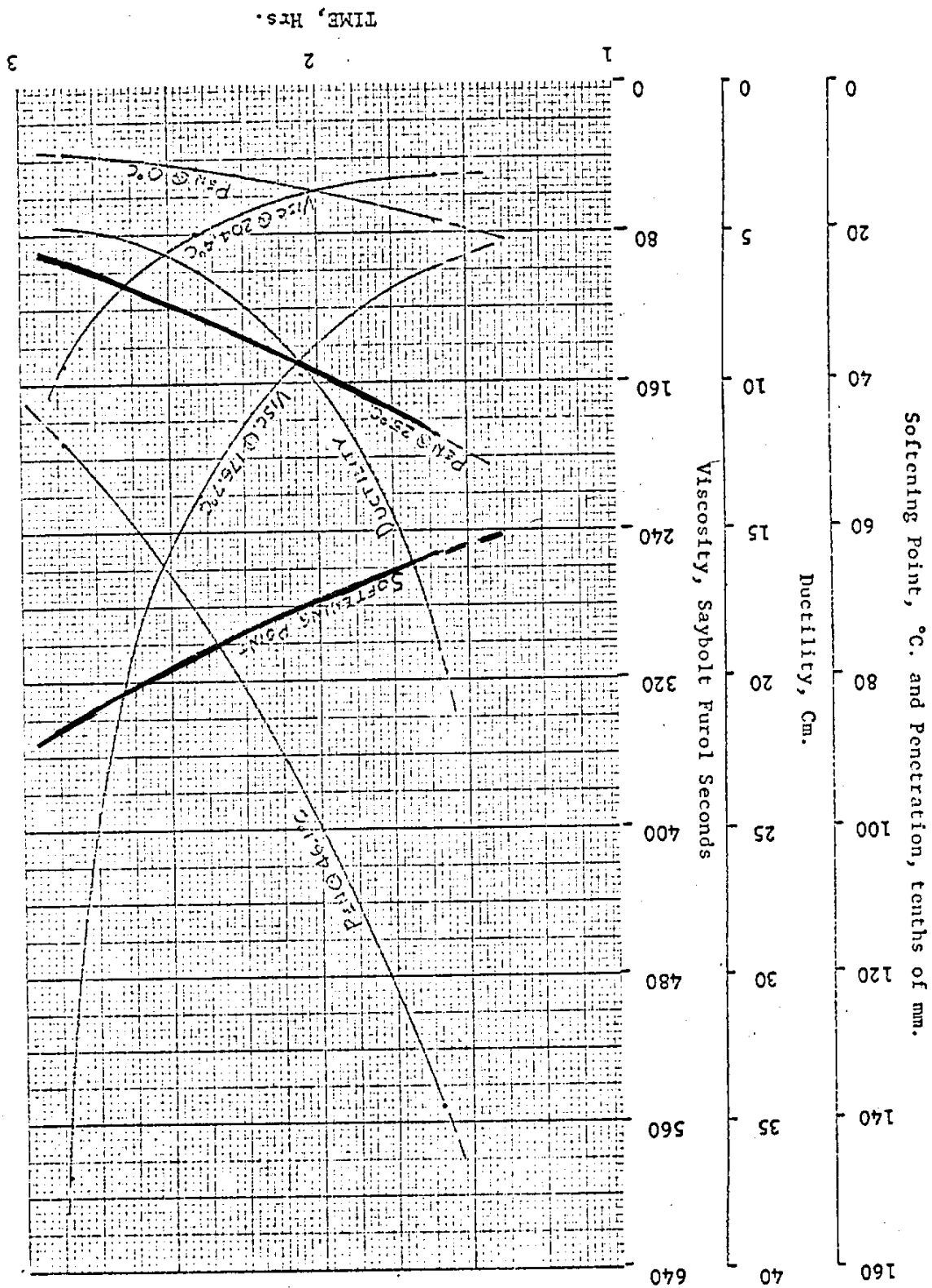
[illegible]

PLOT PLANT

Softening Point, Penetration, Ductility,
and Viscosity versus Time for 200/300 Pen
Cyrus Asphalt at 237.8°C (460°F) Blown
with Air at 7.0 SCF/Hr/Lb of Charge.
S.P. - 39°C
Pen - 240
sp gr 1.025 @ 25°C/25°C

P-26

Figure 1



TYPICAL FLUE GAS COMPOSITION

page-25
jbw jr

oxidizer	data on calif	oxidizer	data on european
MOL%	MOL %	MOL%	MOL%
nitrogen	66.0	64.6	64.6
oxygen	2.8	4.6	4.6
CO2	0.8	0.3	0.3
CO	0.3	---	---
H2S	0.01		
ammonia	0.04		
hydrocarbons	0.05		
water vapor	30		~30

0.5 * }

* mainly lt. hcbn. C1,C2,C3,&C4's

PENETRATION AT 77°F
(100 GM - 5 SEC)

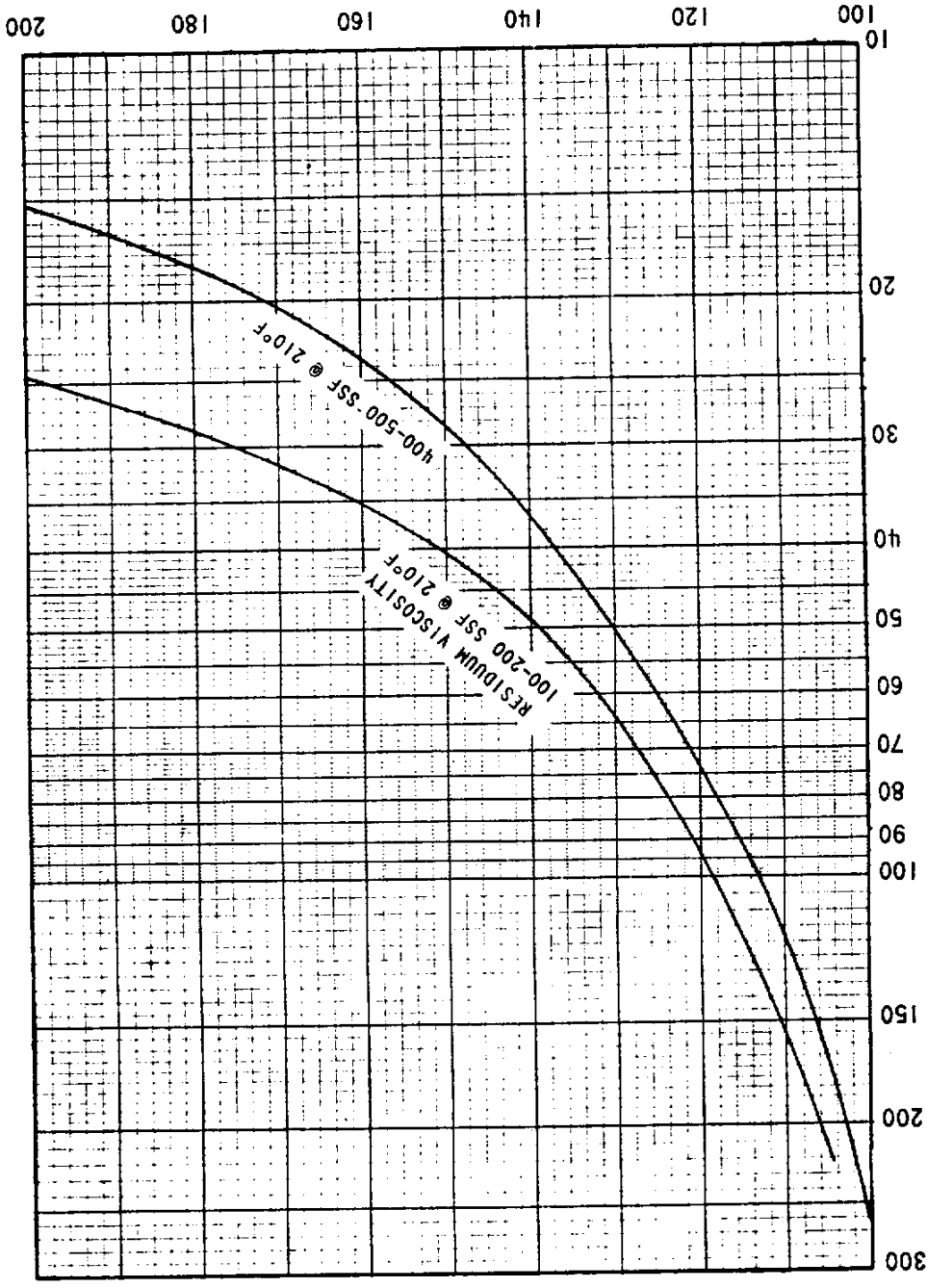


CHART H-1
ARABIAN CRUDE OIL
PROPERTIES OF COMMERCIALY PRODUCED ASPHALTS
BY AIR BLOWING HEAVY RESIDUUM
SOFTENING POINT VS. PENETRATION

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RE 574678

TYPICAL SOFTENING POINT - PENETRATION RELATIONSHIPS FOR BLOWN ASPHALTS

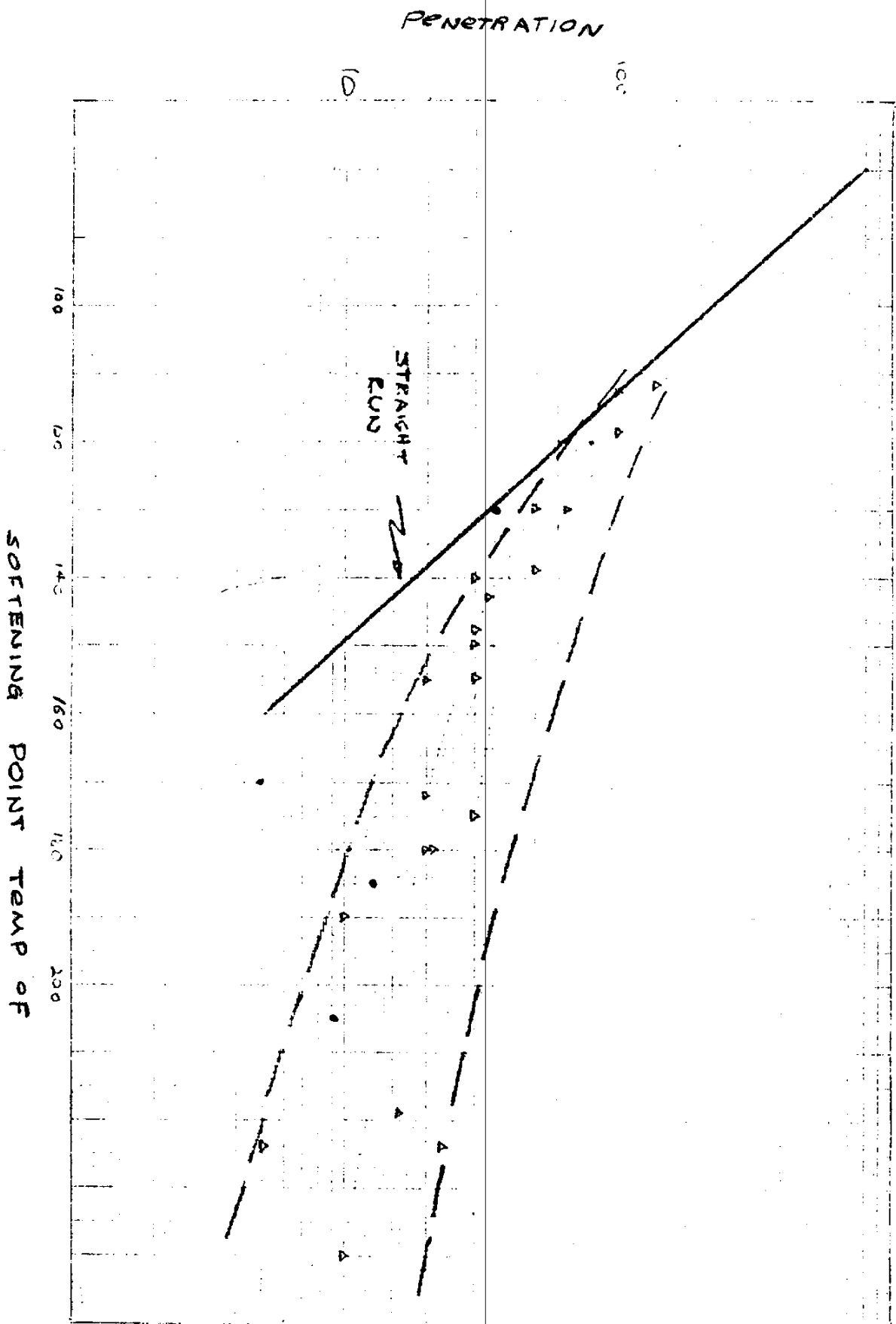


Figure 4

SPECIFICATIONS

Asphalt for Dampproofing and Waterproofing

soft. pt., °F	pen., @77°F
115-145 (46-63°C)	50-100
145-170 (63-77°C)	25-50
180-200 (82-93°C)	20-40

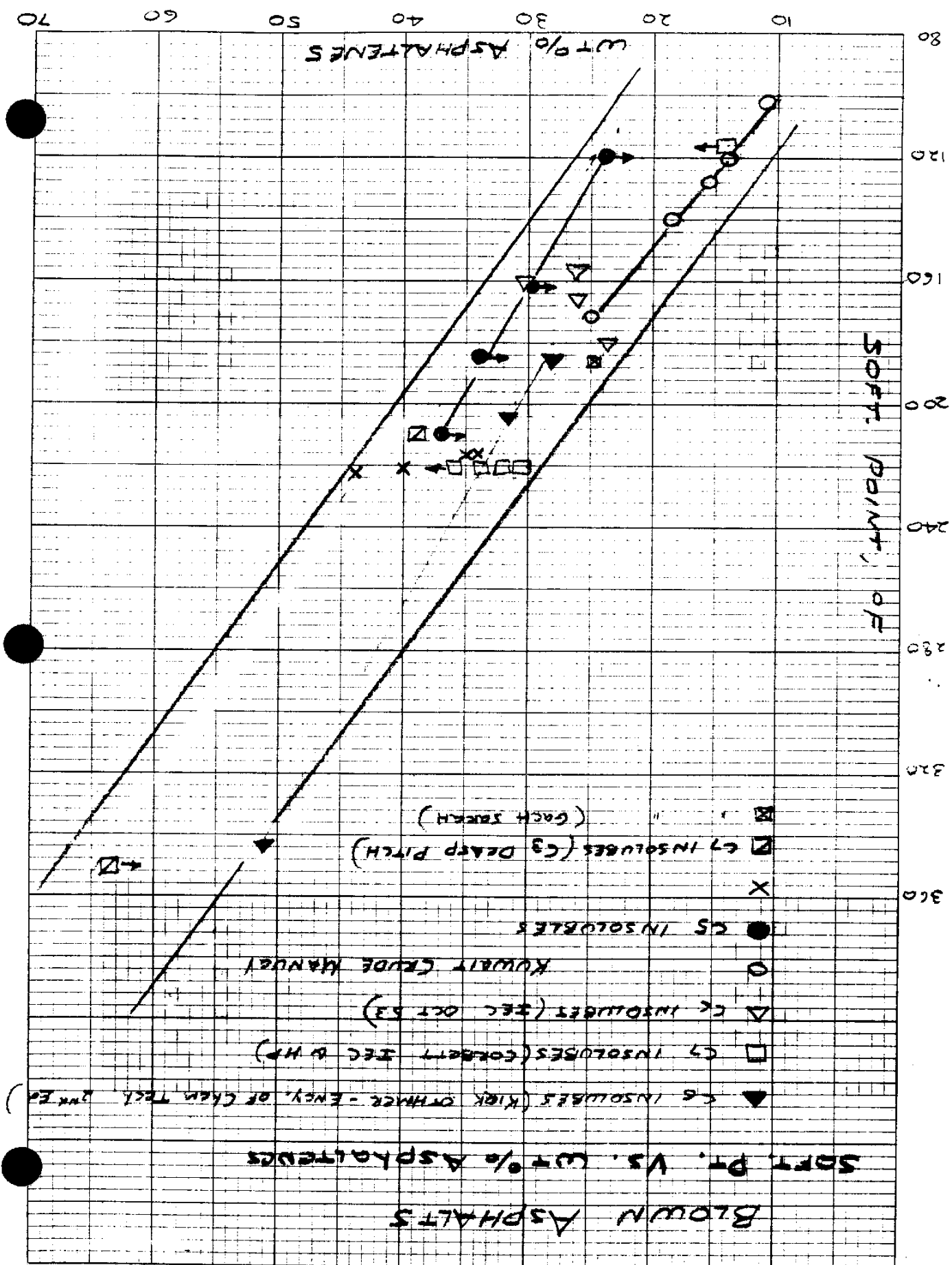
SPECIFICATIONS

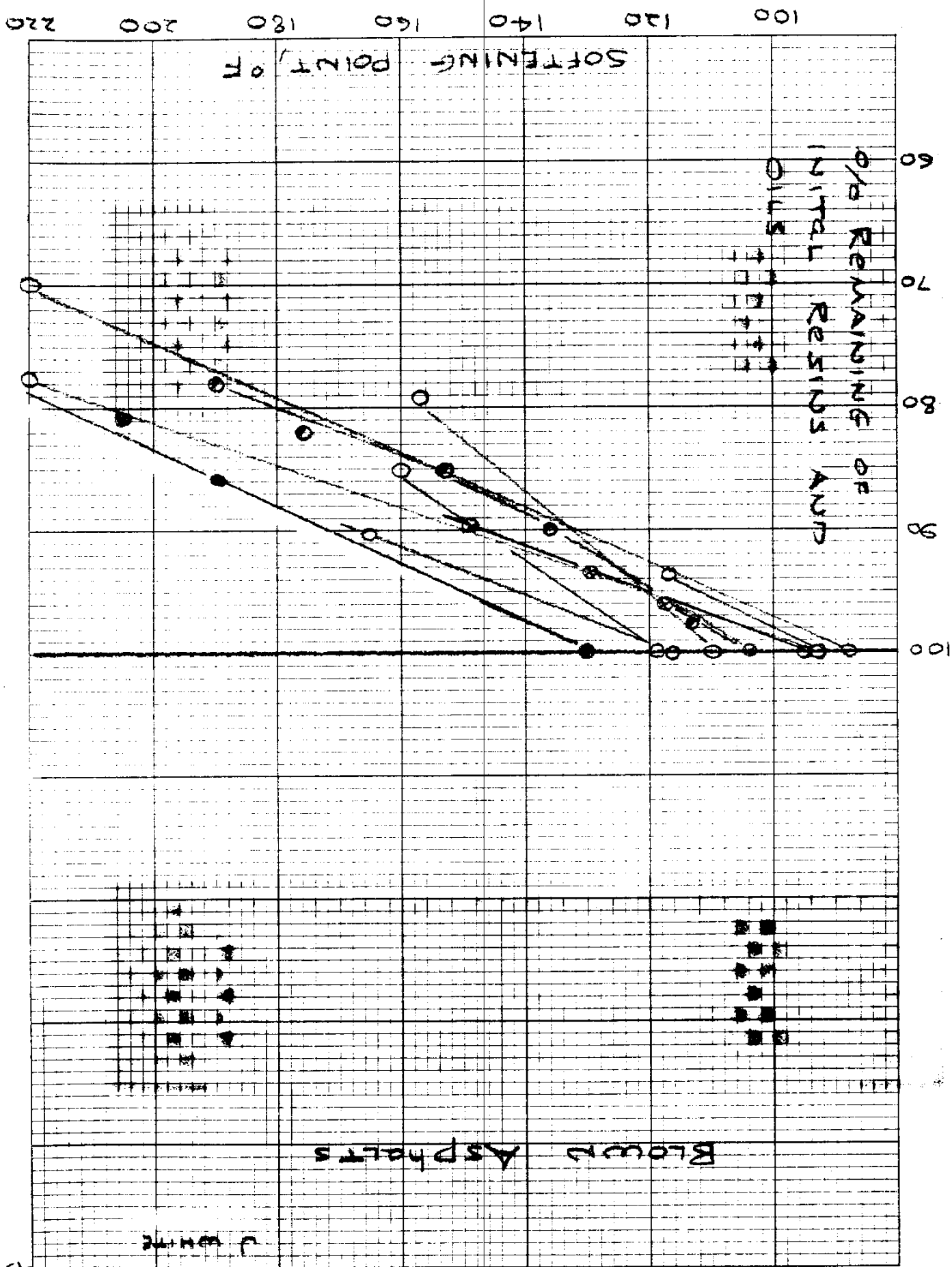
Roll and Shingle Saturant

- air blown asphalt
- soft. pt. 110-140°F (43-60°C)
- saturating roofing felts
- for shingles & roll roofing

Roll and Shingle Coating

- air blown asphalt
- soft. pt. 180-240°F (82-116°C)
- coating saturated felts to provide an
adhesive for the surfacing granules





P-48

43

RUSSIAN

A	23	26	28	31
R	47	47	46	45
O	30	27	26	24

SOFT. PT. 104 → 118 → 131 → 149 ° F
(40 → 48 → 55 → 65 ° C)

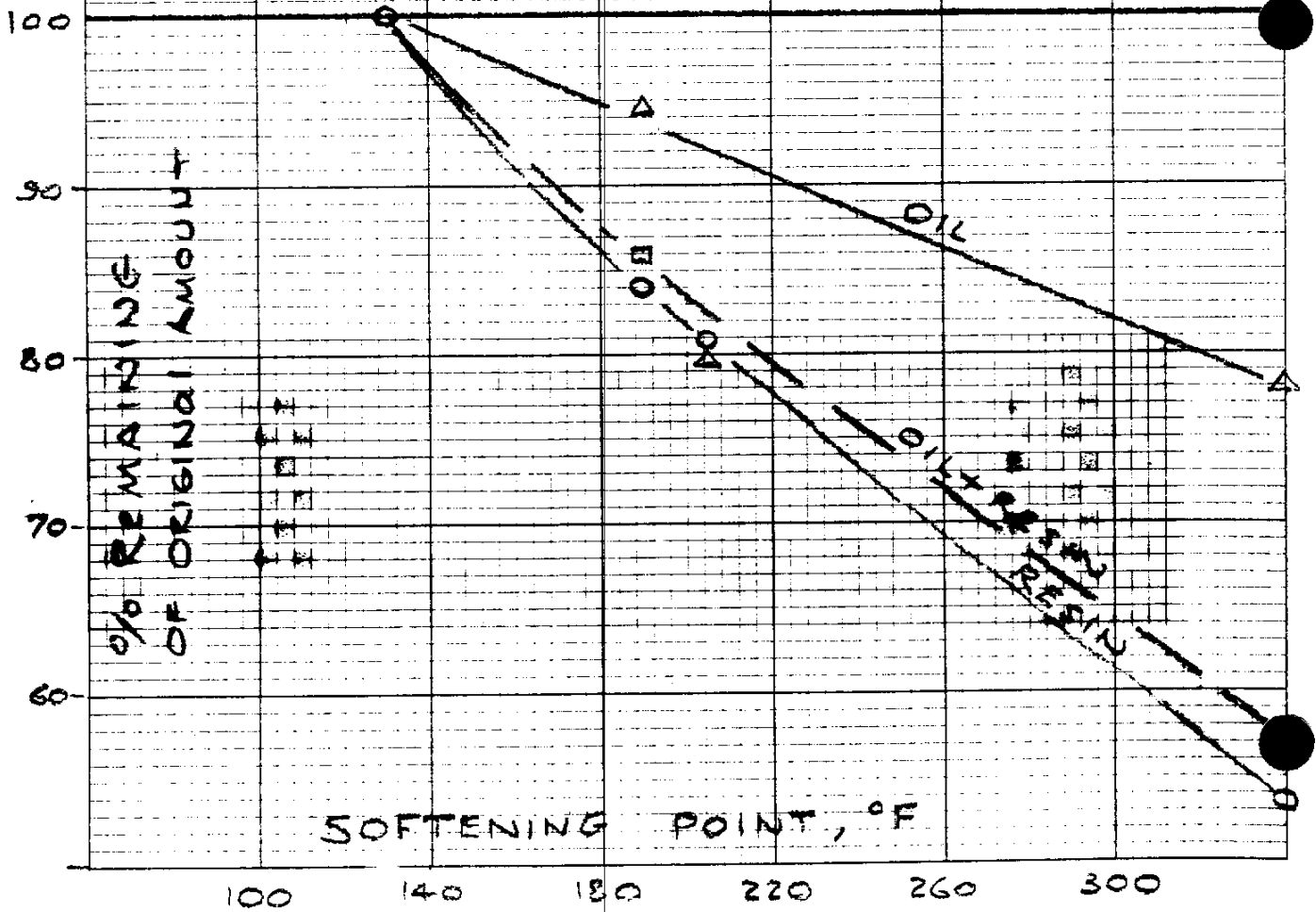
RUSSIAN

A	22	24	30	34	36	39
R	48	49	44	43	42	40
O	30	27	26	23	22	21

SOFT. PT. 104 → 113 → 136 → 153 → 176 → 190 ° F
(40 → 45 → 58 → 67 → 80 → 88 ° C)

J. WHITE

BLOWN ARKANSAS ASPHALT



TYPICAL ST. RUN ASPHALTS

A = ASPHALTENE

R = RESIN

O = OIL

	KUWAIT	KANSAS	Venezuela	Calif.
A	14	16.6	17.8	4.5
R	67	53.5	50.8	40.5
O	19	29.8	31	55.8
	SANTA MARIA	ARKANSAS	WYOMING	WEST TEXAS
A	33.7	14.8	22	16
R	17.6	70.4	46	59
O	48.7	14.8	32	25

CHANGES IN ASPHALT DURING BLOWING

CALIFORNIA

A	4.5	25.8
R	40.5	30.9
O	55.8	44.7

SOFT. PT. 110 → 157°F
(43 → 69°C)

KANSAS

A	16.6	25.0
R	53.5	52.5
O	29.8	22.9

SOFT. PT. 118 → 165°F
PEN. (48 → 74°C)

VENEZUELAN

17.8	30.5
50.8	40.6
31.6	29.3

119 → 160°F
(48 → 71°C)

ARKANSAS

14.8	26.9	31.4	51.3
70.4	59.1	56.8	37.2
14.8	14.0	11.8	11.5

(54 → 85 → 96 → 173°
130 → 185 → 205 → 344°
36 → 13 → 9 → 1 pc

A	11	30
R	89	70
O		

SOFT PT 93 → 220°F
(34 → 104°C)

7	35	9	14
93	65	91	86

88 → 220°F
(31 → 104°C)

95 → 117°F
(35 → 47°C)

COMPOSITION OF ASPHALT

ASPHALTENES

- Insoluble in pentane or hexane
- high MW (3000-100,000)
- weakly bound large complex layerlike cluster
- exists as a highly dispersed colloid in the oil phase

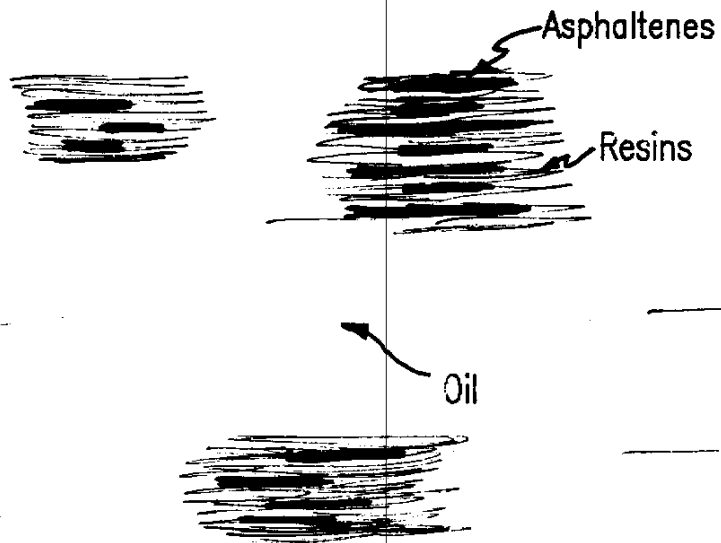
RESINS

- after the asphaltenes are removed
- the material that is absorbed on activated Fuller's Earth
- high MW (2500-4500?)
- aromatic-like (somewhat reactive)
- surrounds the asphaltene clusters
- some asphaltene-like properties

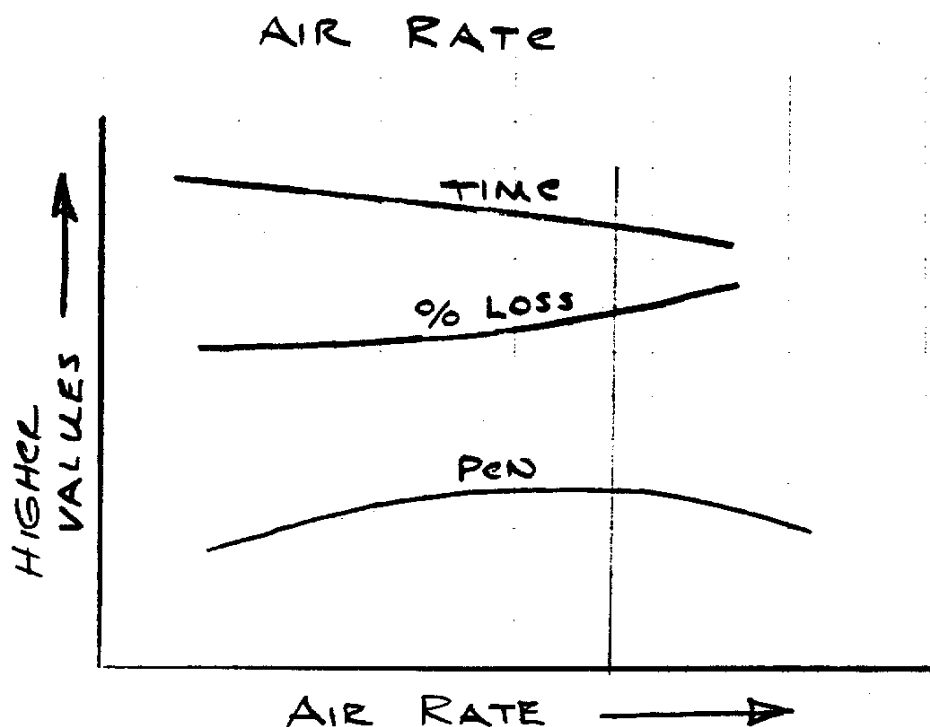
OILS

- what's left
- heavy distillate (like vacuum gas oil in properties)

MAGNIFIED LOOK AT ASPHALT



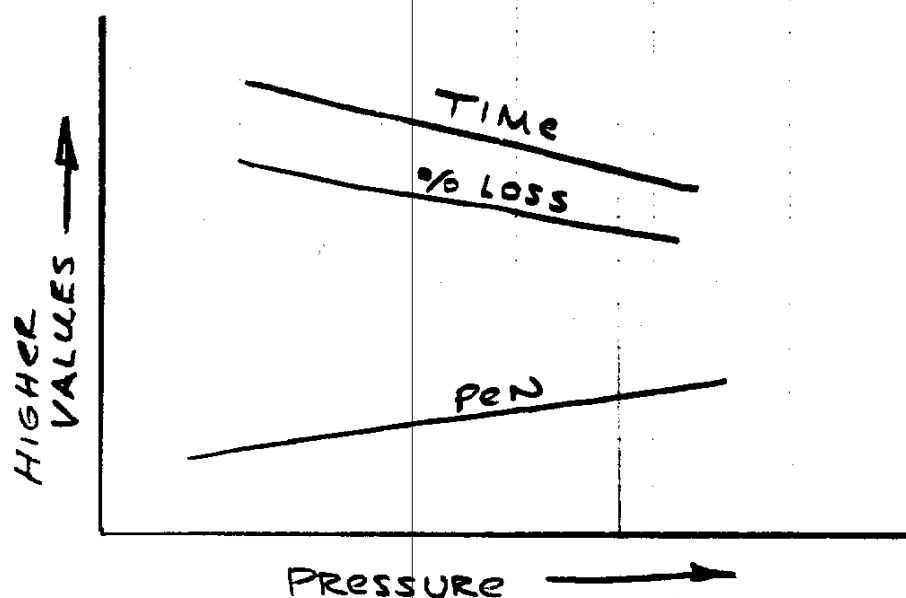
COLLOID SUSPENSION



BLOWING TO THE SAME SOFT. PT.
PRODUCT FROM THE SAME FEED AT
A HIGHER AIR RATE

- TIME WILL BE SHORTER
- % LOSS WILL BE GREATER
- PEN ?

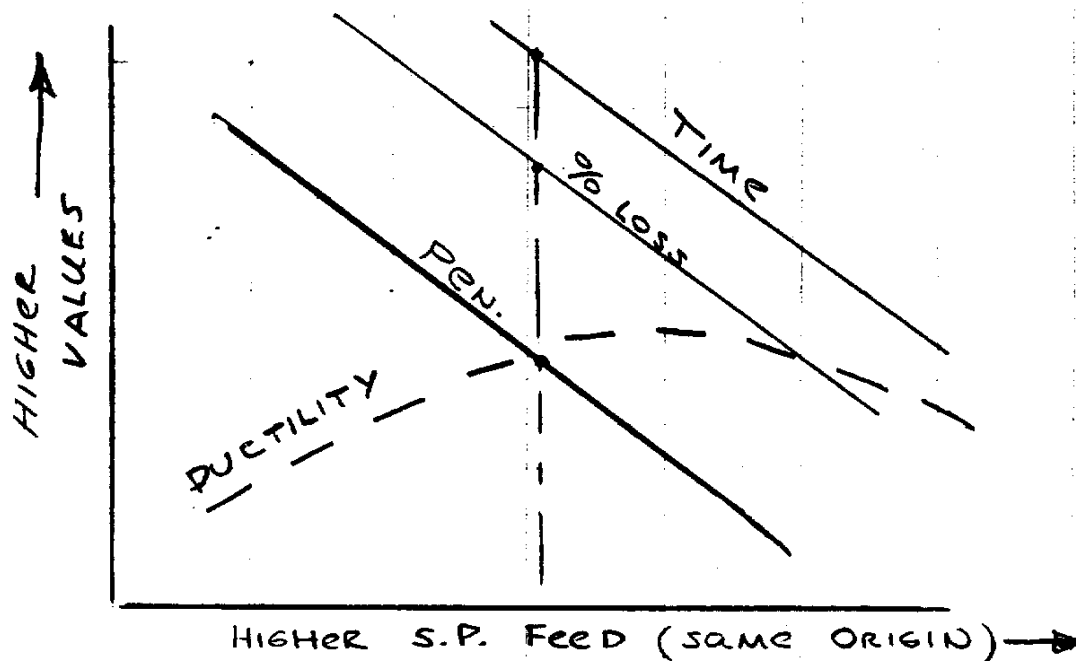
PRESSURE IN OXIDIZER



BLOWING TO THE SAME SOFT. PT.
PRODUCT FROM THE SAME FEED
AT A HIGHER PRESSURE.

- TIME WILL BE SHORTER
- PEN. WILL BE HIGHER
- % LOSS WILL BE LOWER

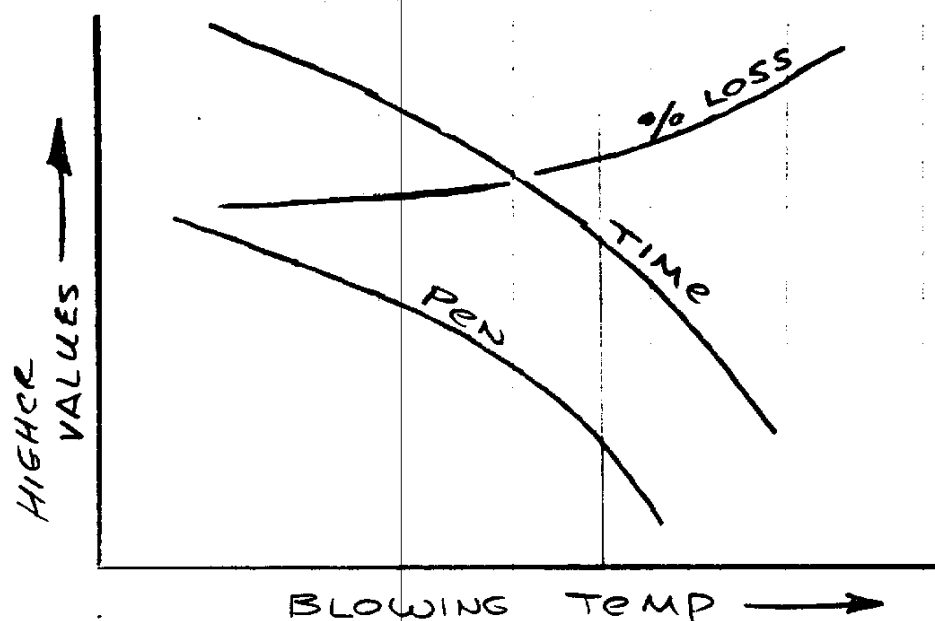
FEED PROPERTIES



HIGHER SOFT. POINT FEED
BLOWING TO THE SAME SOFT. PT.

- PRODUCT PEN. WILL BE LOWER
- % LOSS OF PRODUCT WILL BE LESS
- SHORTER BLOWING TIME
- DUCTILITY MORE THAN LIKELY WILL BE HIGHER

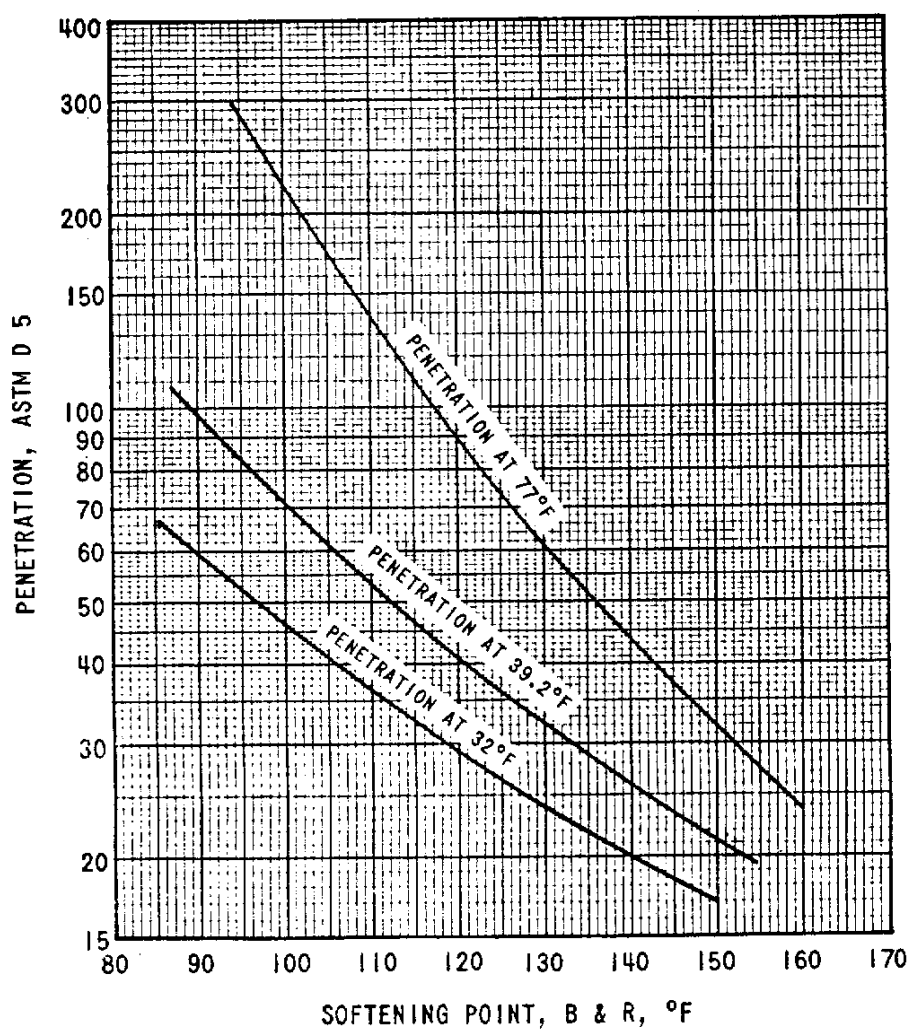
BLOWING TEMPERATURE



BLOWING TO THE SAME
SOFT. PT. PRODUCT FROM THE
SAME FEED AT HIGHER BLOWING TEMP.

- TIME WILL BE SHORTER
- PEN. WILL BE LOWER
- % LOSS WILL BE GREATER

CHART H-6
ARABIAN CRUDE OIL
PROPERTIES OF LABORATORY PRODUCED ASPHALTS
AIR BLOWN FROM 450 SSF AT 210°F VISCOSITY RESIDUUM
PENETRATION VS. SOFTENING POINT



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process variables

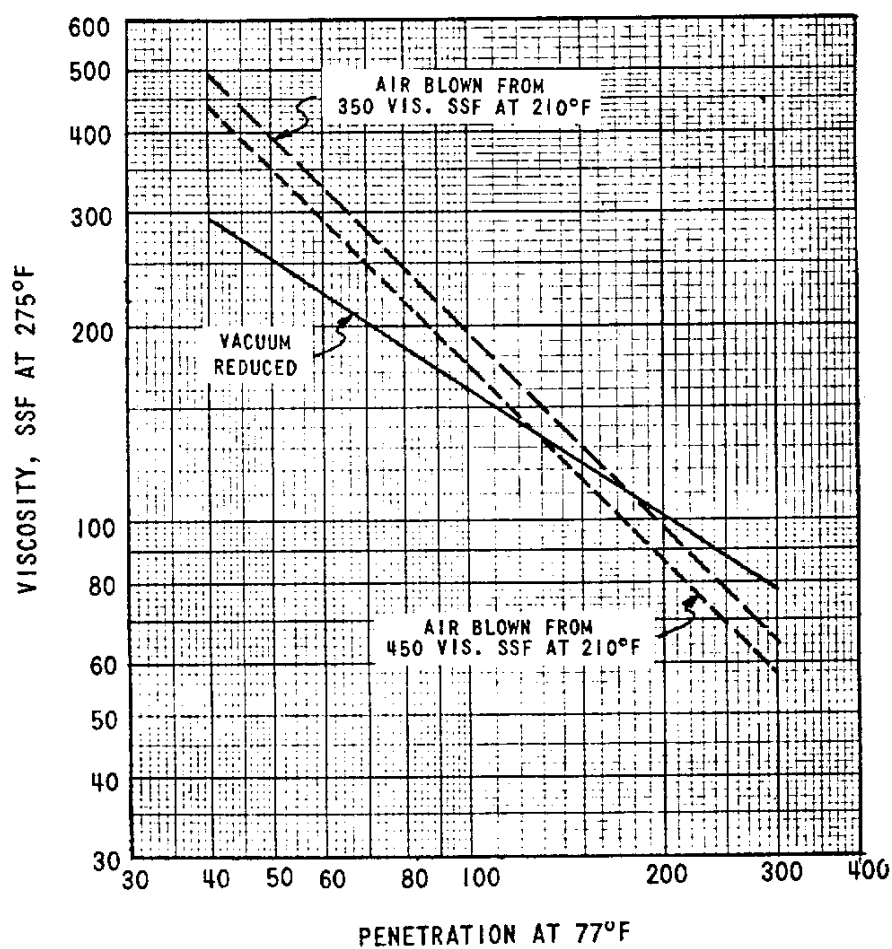
two principle variables

- feedstock properties
- degree of blowing

other variables

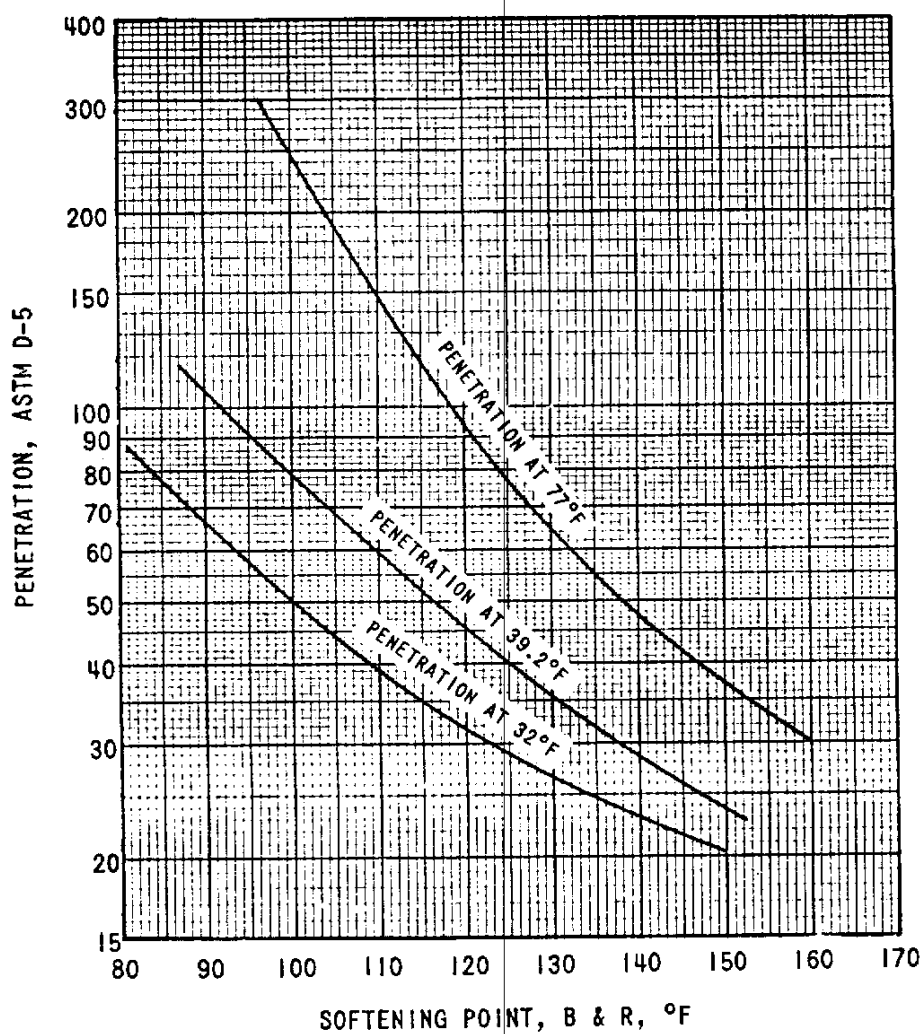
- blowing temperature
- air rate
- pressure

CHART H-4
ARABIAN CRUDE OIL
PROPERTIES OF LABORATORY PRODUCED ASPHALTS
VISCOSITY VS. PENETRATION AT 77°F



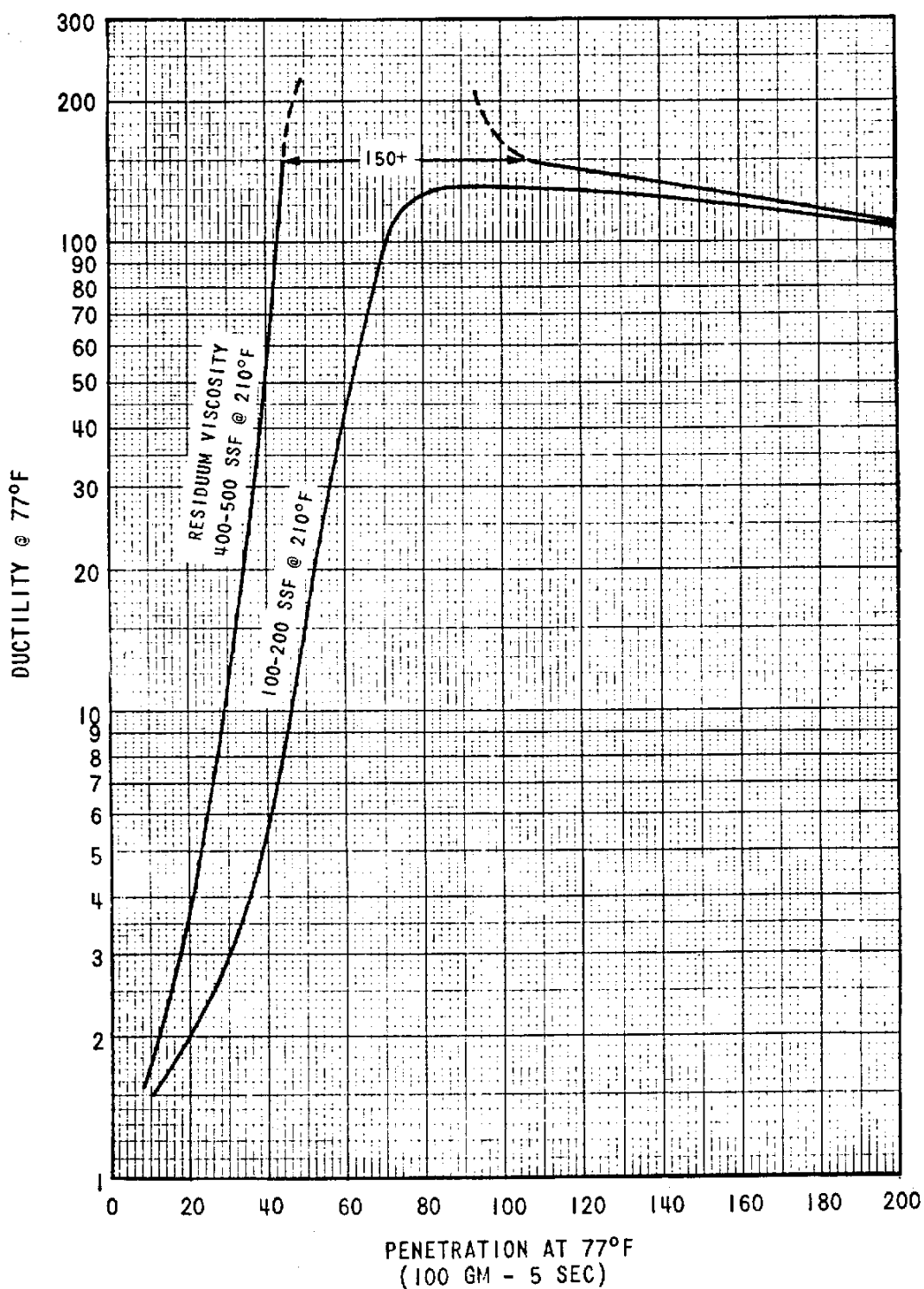
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CHART H-5
ARABIAN CRUDE OIL
PROPERTIES OF LABORATORY PRODUCED ASPHALTS
AIR BLOWN FROM 350 SSF AT 210°F VISCOSITY RESIDUUM
PENETRATION VS. SOFTENING POINT



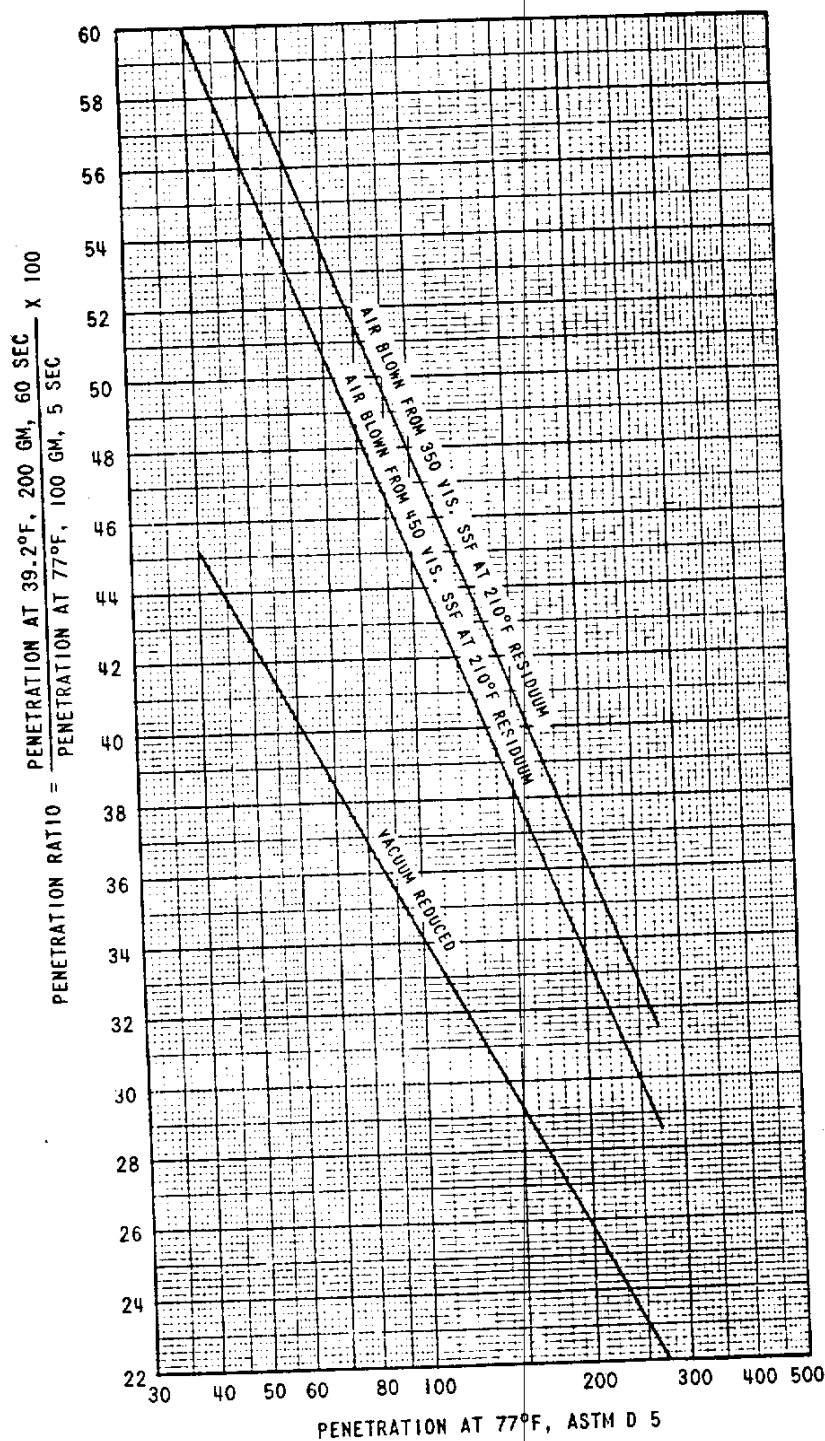
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CHART H-2
ARABIAN CRUDE OIL
PROPERTIES OF COMMERCIALY PRODUCED ASPHALTS
BY AIR BLOWING HEAVY RESIDUUM
DUCTILITY VS. PENETRATION



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CHART M-3
 ARABIAN CRUDE OIL
 PROPERTIES OF LABORATORY PRODUCED ASPHALTS
 PENETRATION RATIO VS. PENETRATION AT 77°F



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 RE 574681

TYPICAL REFINERY SPECIFICATIONS

penetration grades

pen. @77°F	soft. pt., °F
100±20	104-120 (40-49°C)
50±10	117-132 (47-56°C)
25±5	131-152 (55-67°C)

hard grades

pen. @ 77°F	soft. pt., °F
6-12	176-194 (80-90°C)
2-7	230-248 (110-120°C)

blown grades

pen. @ 77°F	soft. pt., °F
25-35	158-176 (70-80°C)
20-30	194-212 (90-100°C)
10-20	230-248 (110-120°C)
5-10	302-320 (150-160°C)

SPECIFICATIONS

Asphalt for Constructing Built-Up Roof Coverings

soft. pt., °F	pen., @77°F
135-150 (57-66°C)	18-60
160-175 (71-79°C)	18-40
180-200 (82-93°C)	15-35
205-225 (96-107°C)	12-25

Specifications for Asphalt Materials CEMENTS

Characteristics	A.S.T.M. Method	Paving Cements		
General Requirements.....		The asphalt shall be prepared by the refining of petroleum. It shall be uniform in character and shall not foam when heated at 350° F.		
Flash Point (Cleveland Open Cup), °F.....	D92	450+	425+	350+
		Penetration Grades		
Penetration, 77° F., 100 g., 5 sec.....	D5	40-50 50-60 60-70 70-85 85-100	100-120 120-150 150-200	200-300
Loss on Heating 325° F., 5 hrs., %.....	D6	1-	2-	2-
Penetration After Loss on Heating 77° F., 100 g., 5 sec., % of Original.....	D5	70+	70+	60+
Ductility:				
At 77° F., cms.....	D113	100+	60+	.....
At 60° F., cms.....	D113	.....	.....	60+
Solubility in Carbon Tetrachloride, %.....	D4*	99.5+	99.5+	99.5+

*Except that carbon tetrachloride is used instead of carbon disulphide as solvent, Method No. 1.

RAPID-CURING LIQUID ASPHALTIC MATERIALS

Specification Designation	RC-0	RC-1	RC-2	RC-3	RC-4	RC-5
General Requirements	A.S.T.M. Method—The material shall be free from water—					
Flash Point (Open Tag.), °F..... *	.....	.....	80+	80+	80+	80+
Furol Viscosity at 70° F., sec.....	75-100	.....	.....	.....	.....	.....
Furol Viscosity at 122° F., sec..... D88	.....	75-150	.....	.....	.....	.....
Furol Viscosity at 140° F., sec.....	.....	.....	100-200	250-500	.....	.....
Furol Viscosity at 180° F., sec.....	.....	.....	.....	.....	125-250	300-600
Distillation:						
Distillate (per cent of total distillate to 680° F.)						
To 374° F.....	15+	10+	.....	.....	.....	.....
To 437° F..... D402	55+	50+	40+	25+	8+	.....
To 500° F.....	75+	70+	65+	55+	40+	25+
To 600° F.....	90+	88+	87+	83+	80+	70+
Residue from distillation to 680° F. *						
Volume per cent by difference..	50+	60+	67+	73+	78+	82+
Tests on Residue from Distillation						
Penetration 77° F., 100 g., 5 sec.. D5	80-120	80-120	80-120	80-120	80-120	80-120
Ductility 77° F..... D113	100+	100+	100+	100+	100+	100+
Solubility in Carbon Tetrachloride, %..... D4**	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+

*A.A.S.H.O. Method T79-42.

**Except that carbon tetrachloride is used instead of carbon disulphide as solvent, Method No. 1.

Specifications for Asphalt Materials (continued)

MEDIUM-CURING LIQUID ASPHALTIC MATERIALS

Specification Designation	MC-0	MC-1	MC-2	MC-3	MC-4	MC-5
General Requirements	The material shall be free from water.					
Flash Point (Open Tag.), ° F.	100+	100+	150+	150+	150+	150+
Furol Viscosity at 77° F., sec.	75-150					
Furol Viscosity at 123° F., sec.	D88 {	75-150				
Furol Viscosity at 140° F., sec.			100-200	250-500		
Furol Viscosity at 180° F., sec.					125-250	300-600
Distillation:						
Distillate (per cent of total distillate to 680° F.)						
To 437° F.	25—	20—	10—	5—	0	0
To 500° F.	40-70	25-65	15-55	5-40	30—	20—
To 600° F.	D402 {	75-93	70-90	60-87	55-85	40-80
Residue from distillation to 680° F. Volume per cent, by difference.						
		50+	60+	67+	73+	82+
Tests on Residue from Distillation						
Penetration 77° F., 100 g., 5 sec.	D5	120-300	120-300	120-300	120-300	120-300
Ductility 77° F.**	D113	100+	100+	100+	100+	100+
Solubility in Carbon Tetrachloride, %	D4***	99.5+	99.5+	99.5+	99.5+	99.5+

*A.A.S.H.O. Method T79-42.

**If penetration of residue is more than 200 and its ductility at 77° F. is less than 100, the material will be acceptable if its ductility at 60° F. is 100+.

***Except that carbon tetrachloride is used instead of carbon disulphide as solvent, Method No. 1.

SLOW CURING LIQUID ASPHALTIC MATERIALS

Specification Designation	SC-0	SC-1	SC-2	SC-3	SC-4	SC-5
General Requirements	The material shall be free from water					
Flash Point (Cleveland Open Cup), ° F.	D92	150+	150+	175+	200+	225+
Furol Viscosity at 77° F., sec.		75-150				
Furol Viscosity at 122° F., sec.	D88 {		75-150			
Furol Viscosity at 140° F., sec.				100-200	250-500	
Furol Viscosity at 180° F., sec.						125-250
Water, %	D95	0.5—	0.5—			
Distillation:						
Total Distillate at 680° F.	D402	15-40	10-30	5-25	2-15	10—
Float Test on Residue at 122° F., sec.	D139	15-100	20-100	25-100	50-125	60-150
Asphalt Residue of 100 Penetration, %	D243	40+	50+	60+	70+	75+
Ductility Asphalt Residue at 77° F.	D113	100+	100+	100+	100+	100+
Solubility in Carbon Tetrachloride, %	D4*	99.5+	9.5+	99.5+	99.5+	99.5+

*Except that carbon tetrachloride is used of carbon disulphide as solvent. Method No. 1. If the material fails to meet the requirement for solubility it will be acceptable if its solubility in carbon disulphide is 99%+, and proportion of bitumen soluble in carbon tetrachloride is 99.65%+.

EMULSIFIED ASPHALTS

Specification Designation	A.S.T.M. Method	Rapid Setting RS-1	Rapid Setting RS-2	Medium Setting MS-2	Slow Setting SS-1
Tests on Emulsion:					
Viscosity, Saybolt Furol at 77° F., sec.		20-100		100+	20-100
at 122° F., sec.			75-400		
Residue by distillation, %		57-62	62-69	62-69	57-62
Settlement, 5 days, %	D224	3—	3—	3—	3—
Demulsibility:					
35 ml. of 0.02 N CaCl ₂ , %		60+	50+		
50 ml. of 0.10 N CaCl ₂ , %				30—	
Sieve Test (Ret. on #20), %		0.10—	0.10—	0.10—	0.10—
Cement Mixing Test, %					2.0—
Tests on Residue:					
Penetration at 77° F., 100 g., 5 sec.	D5	100-200	100-200	100-200	100-200
Soluble in CS ₂ , %	D4	97.5+	97.5+	97.5+	97.5+
Ductility at 77° F., cm.	D113	40+	40+	40+	40+

PART 1 (CONT'D)

— AREA REQ'D FOR TOWER

$$\frac{\text{MAX CFS FLUE GAS} \times \text{M}^2}{\text{M}^2/\text{SEC}} = 59 \text{ FT}^2$$

$$\frac{\text{VAPOR VELOCITY FT/SEC}}{0.229} = 0.75$$

CROSS SECTIONAL AREA

$$\frac{\text{COLD M}^3/\text{HR}}{\text{BPSD OF CHARGE}} = \text{HOT M}^3/\text{HR}$$

$$\text{LQ EXP. FACTOR} = \text{HOT BPSD}$$

$$\frac{\text{HOT BPSD}}{24} \times 5 = \text{HOT Bbls}$$

$$\frac{\text{HOT Bbls} \times 5.614}{\text{Area}} = \text{HT OF OIL IN TOWER}$$

$$\frac{\text{HOT M}^3/\text{HR}}{\text{Area of TOWER}} = \text{HT OF OIL}$$

$$0.875$$



FIGURE 2

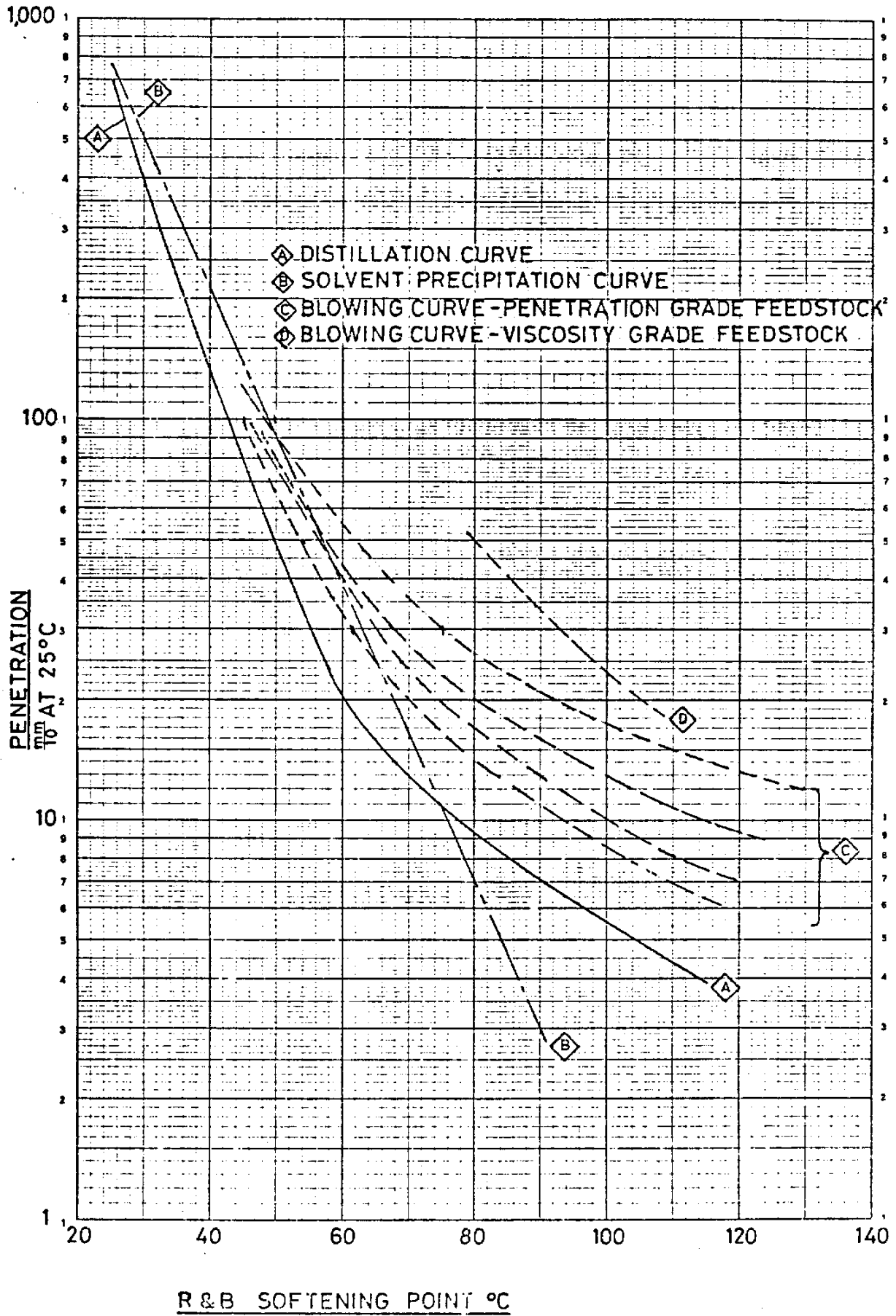


FIGURE 3

BLOWN BITUMEN: TYPICAL MARKETING SPECIFICATIONS & BLOWING FEEDSTOCKS

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