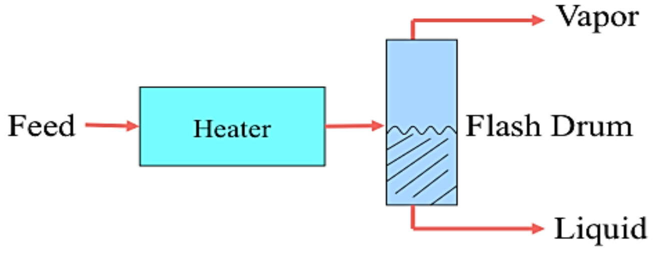
Equilibrium flash vaporization EFV

- EFV involves **heating a flowing feed and the separation of the liquid and vapor in a flash drum** (varying heater outlet temperatures).



- To have a full shape of an EFV curve at least five temperatures at 10, 30, 50, 70, and 90 vol% vaporized are required (**five experiments**) at **constant pressure** (vapour in **equilibrium** with the unvaporized liquid).
- EFV gives the **lowest degree of separation between A and B**, even lower than that given by the ASTM D86 distillation.
- The EFV **initial boiling point** of the fraction is the **bubble point** and the EFV **final boiling** point is the **dew point.**
- EFV distillation curves are **useful in the design and operation of overhead partial condensers and bottom reboilers.** Above atmospheric up to pressures of **15 bar** are useful for design and operation of vaporizing or condensing vessels under pressure.

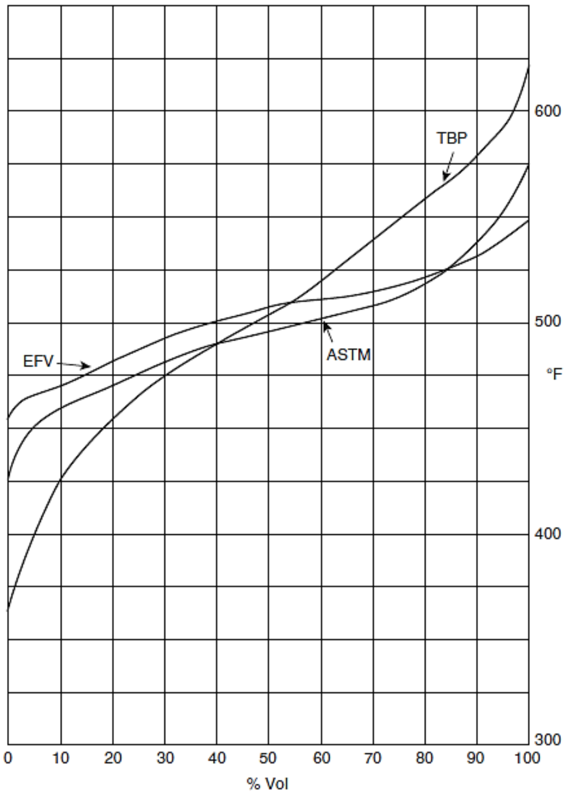


Figure (7): different distillation curves

Comparison between curves

- TBP give actual composition.
- ASTM D86 used by both designers and operators in oil refineries.
- EFV curve is used for determining phase behaviour of liquids and thus is interest of designers.

	TBP	ASTM	EFV
	Batch Type	Batch Type	Batch Type
	Fractionating	Non Fractionating	Non Fractionating
	Crude oil	Petroleum Products	Crude oil
	High Reflux	No Reflux	No Reflux
	atmospheric pressure & Vacuum pressure	atmospheric pressure & Vacuum pressure	Above atmospheric pressure, atmospheric pressure & Vacuum pressure

Conversion from ASTM D86 to TBP Distillation ASTM D2892

***Riazi-Daubert Method* (API method)**

$$T_i(desired) = a(T_i available)^b \ SG^c$$

- ➢ T_i (available) is the distillation temperature at a specific vol% distilled
- ➢ T_i (desired) is the desired distillation data for the same vol% distilled, both are in kelvin
- ➢ A and b, are correlation parameters specific for each conversion type and each vol% point on the distillation curve.

$$TBP = a(ASTM\ K)^b \qquad (15)$$

Factors a and b are given in the following table.

% distilled volume	Coefficient a	Coefficient b
0	0.9177	1.0019
10	0.5564	1.0900
30	0.7617	1.0425
50	0.9013	1.0176
70	0.8821	1.0226
90	0.9552	1.0110
95	0.8177	1.0355

Conversion from TBP to ASTM D86:

$$ASTM\ D86 = [\frac{1}{a} * TBP]^{\frac{1}{b}} \qquad (16)$$

$$EFV = a(ASTM\ D86)^b \ SG^c \qquad (17)$$

Where constants a, b, and c is given in the Table below:

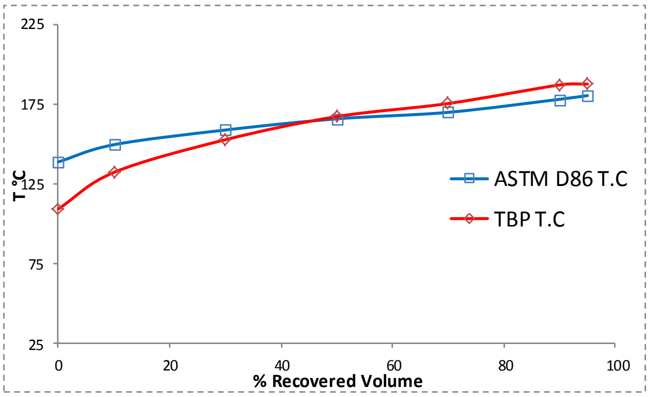
vol %	a	b	c
0	2.9747	0.8466	0.4209
10	1.4459	0.9511	0.1287
30	0.8506	1.0315	0.0817
50	3.268	0.8274	0.6214
70	8.2873	0.6871	0.934
90	10.6266	0.6529	1.1025
100	7.9952	0.6949	1.0737

Exercise: A naphtha fraction has the following ASTM D86 distillation data. Find the TBP curve using the API method.

$$TBP = a(ASTM)^b$$

$$TBP\ at\ 0\% = 0.9177(411.95)^{1.0019} = 382.4\ k = 109.25\ C$$

Vol %	ASTM D86 °C	ASTM D86 k	TBP k	TBP °C
IBP	138.8	411.95	382.4	109.25
10	149.6	422.75	405.36	132.21
30	158.8	431.95	425.86	152.71
50	165.8	438.95	440.38	167.23
70	169.9	443.05	448.59	175.44
90	178.1	451.25	460.25	187.1
95	180.4	453.55	460.8	187.65



$$SL\ (D86) = \frac{178.1-149.6}{90-10} = 0.356℃$$

$$SL\ (TBP) = \frac{187.1-132.21}{90-10} = 0.686℃$$

Note that SL less than 0.8, i.e. MeABP = T50= 167.23 °C

Exercise: For a blend of naphtha-kerosene sample TBP distillation curve are given in the Table below. Use the Riazi-Daubert methods to predict EFV curve from TBP curve**.**

V% distilled	IBP	10	30	50	70	90
TBP °C	10.1	71.10	143.7	204.5	250.2	291.5

Answer

$$ASTM\ D86 = (\frac{1}{a})^{1/b}\ TBP^{1/b}$$

$$ASTM\ at\ 0\% = [\frac{1}{0.9177}\ (10.1 + 273.15)]^{\frac{1}{1.0019}} = 308\ k = 35\ C$$

	vol %	a	b	TBPC	ASTM D86 K	ASTM D86 C
IBP	0	0.9177	1.0019	10.1	308	35
	10	0.5564	1.09	71.1	352.4	79.4
	30	0.7617	1.0425	143.7	418.6	145.6
	50	0.9013	1.0176	204.5	474.7	201.7
	70	0.8821	1.0226	250.2	508.6	235.6
FBP	90	0.9552	1.011	291.5	543.6	270.6

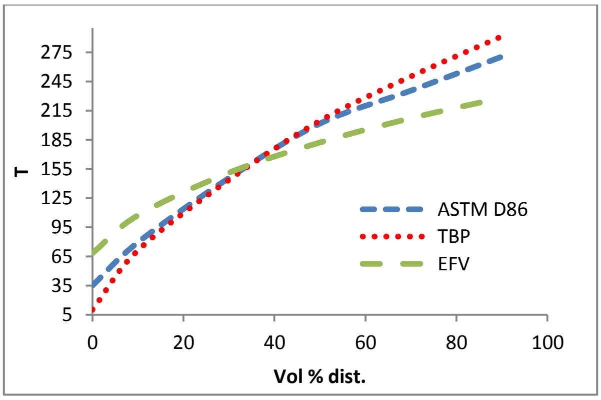
$$EFV = a(ASTM\ D86\ °K)^b\ SG^c$$

$$EFV\ at\ 0\% = 2.9747(308)^{0.8466}\ 0.7860^{0.4209} = 341.5$$

$$EFV\ at\ 50\% = 3.268\ (474.7)^{0.8274}\ 0.7860^{0.6214} = 455.35$$

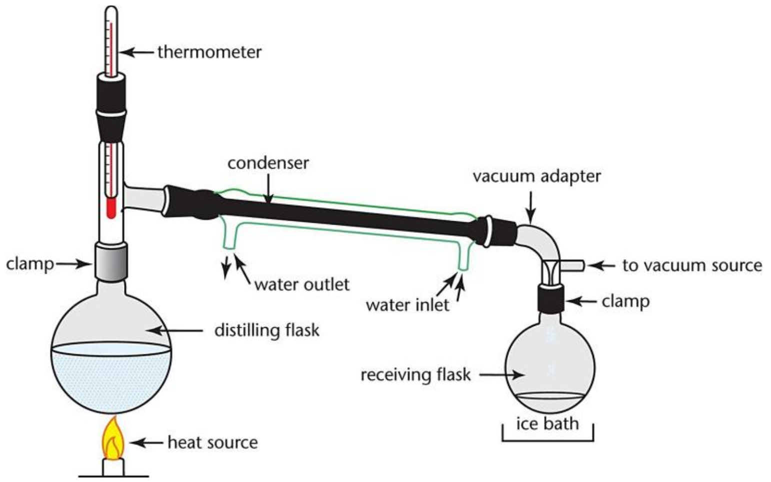
a	b	c	T10	T50	SG
0.10431	0.1255	0.20862	344	477	0.786062

vol %	ASTM D86	EFV K	a	b	c	SG	EFV C
0	308	341.45	2.9747	0.8466	0.4209	0.87606	68.3
10	352.4	380.35	1.4459	0.9511	0.1287	0.87606	107.2
30	418.6	424.25	0.8506	1.0315	0.0817	0.87606	151.1
50	474.7	455.35	3.268	0.8274	0.6214	0.87606	182.2
70	508.6	480.35	8.2873	0.6871	0.934	0.87606	207.2
90	543.6	501.45	10.6266	0.6529	1.1025	0.87606	228.3



ASTM D1160 (for heavy distillate that decompose at temperature higher than 280°C)

- **ASTM D1160** performed at reduced pressures of 1-50 mm Hg.



ASTM D1160 apparatus diagram

Conversion of a boiling point at sub- or super-atmospheric pressures to the normal boiling point.

$$T_b'(760\ mmHg) = \frac{748.1\ QT}{1 + T(0.3861Q - 0.00051606)} \ldots\ldots 18$$

Equation 18 is used to convert boiling point at (P < 760 mm Hg) or (P > 760 mm Hg) to normal boiling point.

$$Q = \frac{6.761560 - 0.987672 \log_{10} P}{3000.538 - 43 \log_{10} P} \qquad (P < 2\ \text{mm Hg})$$

$$Q = \frac{5.994296 - 0.972546 \log_{10} P}{2663.129 - 95.76 \log_{10} P} \qquad (2 \le P \le 760\ \text{mm Hg})$$

$$Q = \frac{6.412631 - 0.989679 \log_{10} P}{2770.085 - 36 \log_{10} P} \qquad (P > 760\ \text{mm Hg})$$

Where P = pressure at which boiling point or distillation data is available, mm Hg.

T = boiling point available at given pressure P, in kelvin.

T_b = normal atmospheric boiling point, in kelvin.

At P = 10 mm Hg, **Q = 0.001956** and as a result **Eq. (18)** reduces to the following simple form:

$$T(10\ mm\ Hg) = \frac{0.683398\ T_b'}{1 - 1.63434\ x10^{-4}\ T_b'} \ldots\ldots 19$$

Conversion ASTM D1160 to TBP, EFV, or ASTM D86 distillation curves

- It should be noted that when ASTM D1160 distillation curve is converted to or reported at atmospheric pressure (760 mm Hg) it is not equivalent to or the same as ASTM D86 distillation data.

To convert ASTM D 1160 to TBP at atmospheric pressure

- **Convert D 1160 at any pressure to D 1160 at 10 mmHg**
- **Convert D 1160 at 10 mmHg to TBP at 10 mmHg using Edmister method**
- **Convert TBP at 10 mmHg to TBP at 760 mmHg using eq. 1**

This means if ASTM D 1160 at 1 mm Hg is available, it must be first converted to D 1160 at 760 mmHg, then to D 1160 at 10 mm Hg followed by conversion to TBP at 10 mmHg and finally to TBP at 760 mmHg.

Edmister-Okamoto method is used to *Convert of ASTM D 1160 at 10 mmHg to TBP Distillation Curve at 10 mm*Hg.

$$TBP(100\%) = ASTM\ D1160\ (100)$$
$$TBP(90\%) = ASTM\ D1160\ (90)$$
$$TBP(70\%) = ASTM\ D1160\ (70)$$
$$TBP(50\%) = ASTM\ D1160\ (50)$$
$$TBP(30\%) = ASTM\ D1160\ (50) - F_1$$
$$TBP(10\%) = ASTM\ D1160\ (30) - F_2$$
$$TBP(0\%) = ASTM\ D1160\ (10) - F_3$$

$$F_1 = 0.3 + 1.2775(\Delta T_1) - 5.539 \times 10^{-3}(\Delta T_1)^2 + 2.7486 \times 10^{-5}(\Delta T_1)^3$$
$$F_2 = 0.3 + 1.2775(\Delta T_2) - 5.539 \times 10^{-3}(\Delta T_2)^2 + 2.7486 \times 10^{-5}(\Delta T_2)^3$$
$$F_3 = 2.2566(\Delta T_3) - 266.2 \times 10^{-4}(\Delta T_3)^2 + 1.4093 \times 10^{-4}(\Delta T_3)^3$$
$$\Delta T_1 = \text{ASTM D 1160(50\%)} - \text{ASTM D 1160(30\%)}$$
$$\Delta T_2 = \text{ASTM D 1160(30\%)} - \text{ASTM D 1160(10\%)}$$
$$\Delta T_3 = \text{ASTM D 1160(10\%)} - \text{ASTM D 1160(0\%)}$$

Where functions F_1, F_2, and F_3 are given in terms of temperature difference in the ASTM D 1160:

In the above relations all temperatures are either in °C or in kelvin.

Example1: for a given petroleum fraction, convert ASTM D1160 at (**1 mm Hg)** to TBP and ASTM D86 both at 760 mmHg.

Vol % distilled	**10**	**30**	**50**	**70**	**90**
ASTM D1160 °C	104	143	174	202	244

Solution

- Convert D1160 at 1 mmHg to D1160 at 760 mmHg using eq.18
- Convert D1160 at 760 mmHg to D1160 at 10 mmHg using eq. 19
- Convert D1160 at 10 mmHg to TBP at 10 mmHg using Edmister-Okamoto method
- Convert TBP at 10 mmHg to TBP at 760 mmHg using eq.18
- Finally, convert TBP at 760 mmHg to ASTM D86

$$T\ 10\%\ (760\ mmHg) = \frac{748.1 * 0.002253 * 377.15}{1 + 377.15 * (0.3861 * 0.002253 - 0.00051606)} \ldots\ldots 18$$

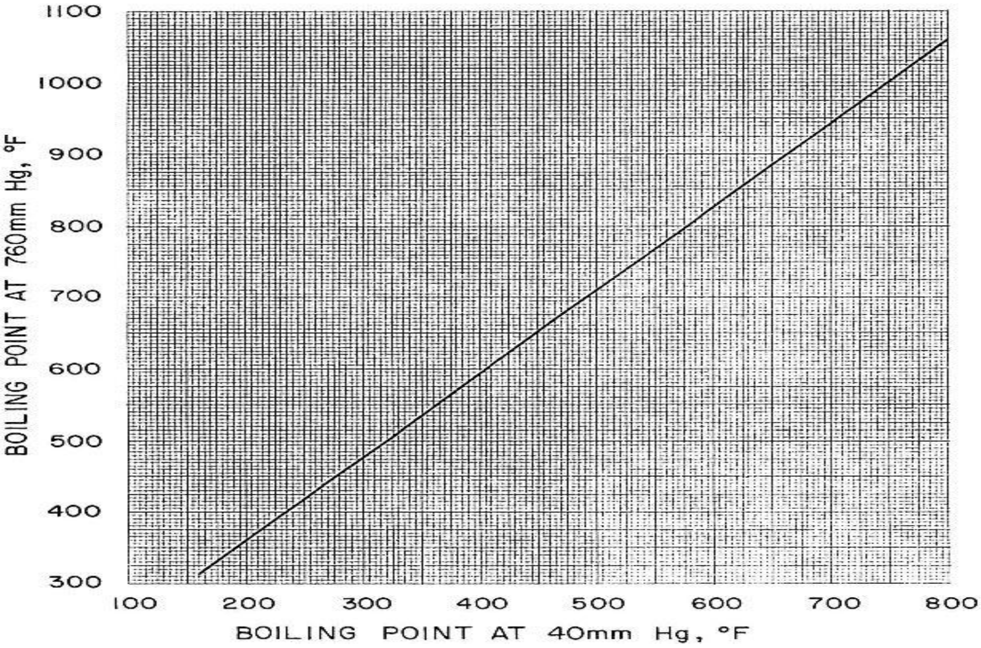
$$T\ 10\%(10mmHg) = \frac{0.683398 * 560.7}{1 - 1.63434\ x10^{-4} * 560.7} \ldots\ldots 19$$

vol %	T at 1 mmHg	Q	Tb at 760 mmHg		Tb at 10 mmHg		TBP at 10 mmHg	TBP at 760 mmHg
10	377	0.002253	560.7084207		421.8443299		417.6348705	555.6236513
30	416	0.002253	611.2676534		464.1039682		459.6904419	606.0328376
50	447	0.002253	650.596001		497.5167125		497.5167125	650.5985795
70	475	0.002253	685.4832894		527.5612713		527.5612713	685.4859649
90	517	0.002253	736.7181342		572.3902252		572.3902252	736.7209445
		ΔT1	ΔT2	ΔT3	F1	F2	F3	
		33.41274	42.25963831		37.82627067	46.4691		

$$ASTM\ D86 = \left(\frac{1}{a}\right)^{1/b}\ TBP^{1/b}$$

a	b	1/a	1/b	ASTMD86
0.9167	1.0019	1.090869	0.998104	
0.5277	1.09	1.895016	0.917431	592.7045
0.7429	1.0425	1.346076	0.959233	620.6816
0.892	1.0176	1.121076	0.982704	650.7765
0.8705	1.0226	1.148765	0.977899	679.5503
0.949	1.011	1.053741	0.98912	722.0916
0.8177	1.0355	1.222942	0.965717	

Any temperature at 40 mm Hg corrected to 760 mm Hg pressure using charts developed by Esso Research and Engineering Company (Figure below).



Figure(8): Boiling point at 760 mmHg versus boiling point at 40 mmHg.

Conversion of Distillation curves by Graphical Method

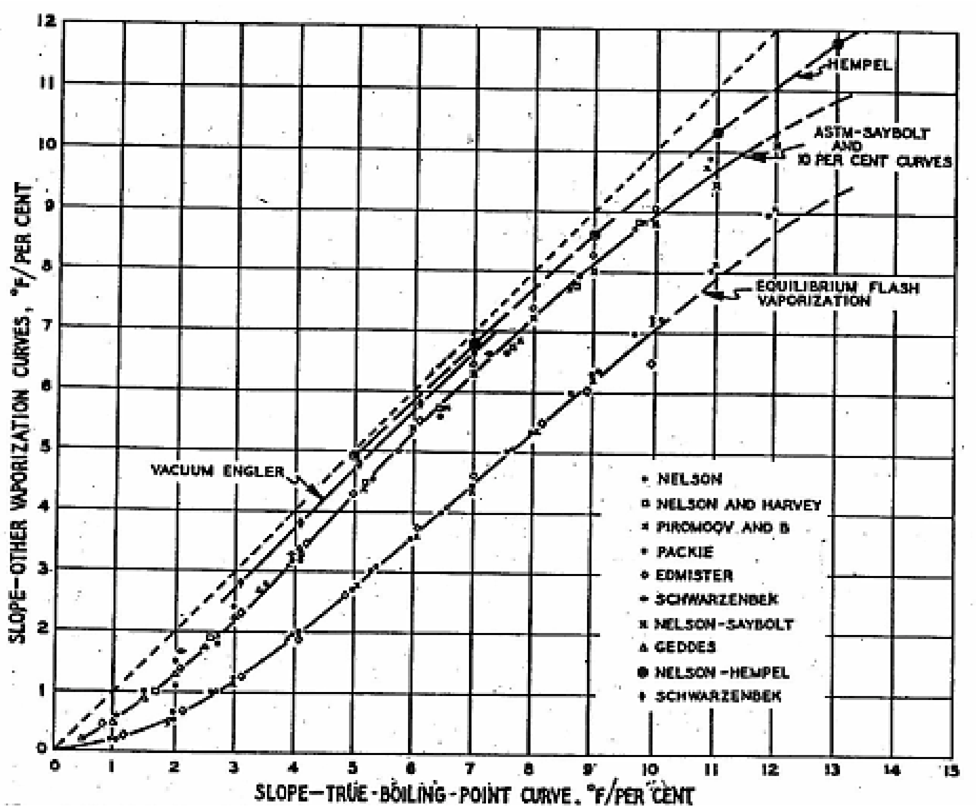


Figure (9): conversion between the slopes of various distillation curves

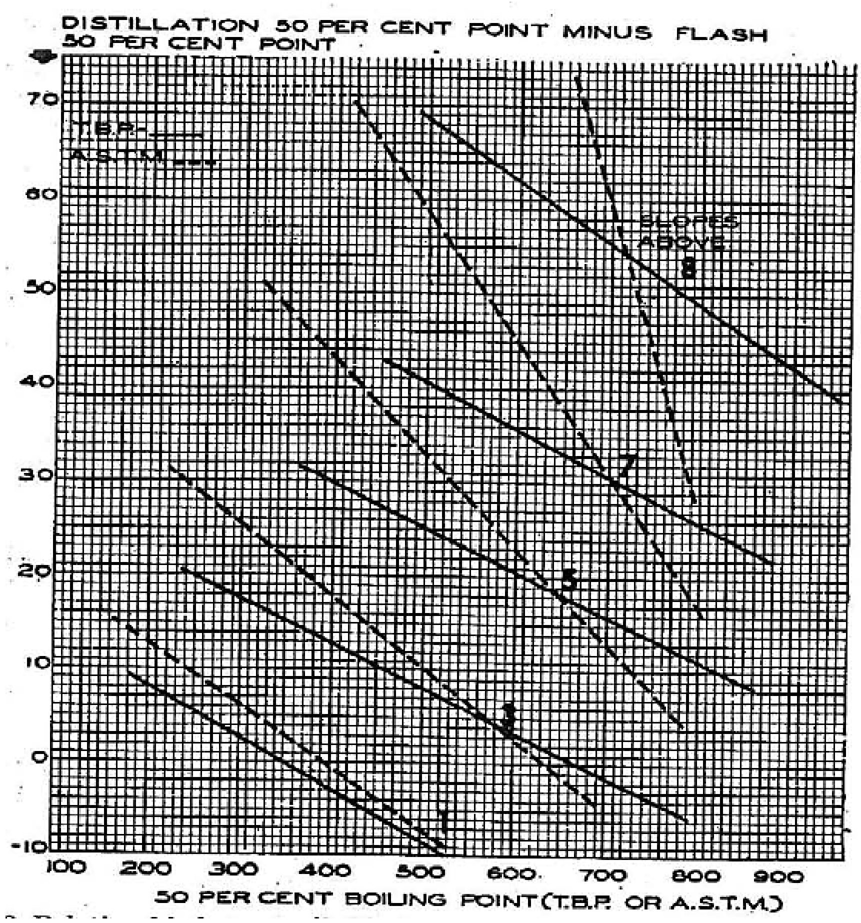


Figure (10) conversion between distillation temperatures at 50% and (E.F.V.) Temp. at 50%

Exercise: **Find $T_{100\%}$ and $T_{0\%}$ for EFV curve knowing that the values of ($T_{50\%}$ = 570 °F) and Slope = 9.4 °F are obtained from TBP curve.**

Solution

Step 1: find the EVF slope from Figure 9.

SL (EFV) = 6.5 °F

Step 2: find $T_{50\%}$ for EFV curve from TBP ($T_{50\%}$ = 570 °F) from Figure 10.

The $T_{50\%}$ of the flash curve will be about 64 °F below the $T_{50\%}$ of the TBP curve

$T_{50\%}$ EFV = 570-64=506 °F

Step 3:

$$6.5 = \frac{T_{100} - 506}{100 - 50} \rightarrow T_{100} = 831\text{°F}$$

$$6.5 = \frac{506 - T_0}{50 - 0} \rightarrow T_0 = 181\text{°F}$$

$$6.5 = \frac{T90 - 506}{90 - 50} = T90 = 766\text{°F}$$

$$6.5 = \frac{506 - T30}{50 - 30} = T30 = 377\text{°F}$$

Problem: A petroleum cut has the following ASTM D86 distillation data

V% distilled	T0	T10	T30	T50	T70	T90	T95
ASTM D86 °C	36.5	54	77	101.5	131	171	186.5

a. Convert ASTM to TBP using API method.

b. Find the slope of EFV and $T_{50\%}$ if $T_{100\%}$ is 850°F.

c. Estimate the MeABP.

d. Find UOP characterization factor if the API of this fraction is 62.

Problem: for the below TBP data, answer the following:

a. From the crude distillation data, plot TBP and gravity- midpercent curves.

b. Select TBP cut-points of products to be used in internal combustion engines.

c. From TBP and gravity curves, determine percentages and gravities of fractions.

Vol % distilled	T5	T10	T20	T30	T40	T50	T60	T70	T80	T85
TBP °F	62	144	255	344	437	531	623	717	819	897