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BOILING POINT DISTRIBUTION OF CRUDE OILS BASED ON TBP AND ASTM D-86 DISTILLATION DATA

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Abstract

The True Boiling Point (TBP) analysis according to ASTM D-2892 standard is the single reliable tool for characterization of crude oil and petroleum mixtures in terms of their boiling point distribution. However, the analytical procedure is expensive and time consuming, which is inappropriate for quick estimation of crude oil distillation characteristics. Thirty three crude oil samples were characterized by means of TBP distillation and ASTM D-86. This paper presents an attempt to test the applicability of the major methods available in the open literature for converting ASTM D-86 to TBP for the whole range of the distillation curve. The whole distillation curve was obtained by using the Riazi's distribution model ($(Ti-To)/To=[A_T/B_T.Ln(\ 1/(1-x_i))]^{1/BT}$), which demonstrated high accuracy with $r^2 \geq 0.99$. All methods demonstrated lower accuracy in converting the ASTM D-86 into TBP than the reproducibility of the ASTM D-2892.

Key words: *crude oil, true boiling point, distillation, ASTM D-2892, ASTM D-86.*

1. Introduction

Having in mind that crude oil cost accounts for more than 80% of refinery expenditure the proper operation of crude distillation unit has great impact on refinery profitability. In order to find the adequate technological regime that provides maximum yields of high value products in a crude distillation unit the process engineer needs to have laboratory analyses data of crude oil that is processed in the unit. The True boiling point distillation (TBP) is the single most important information for any crude oil for modeling of a crude distillation column. The TBP distillation tends to separate the individual mixture components relatively sharply in order of boiling point and is a good approximation of the separation that may be expected in the plant. Unfortunately the TBP analyses are costly and time consuming, a TBP analysis takes about 48 hours. That is why it is impractical to use it as a tool for daily monitoring of the crude distillation unit operation. For refineries, which often switch the crude oils the lack of information about the crude oil quality could negatively impact the optimum operation and in this way the profitability of the crude distillation unit. It was found that boiling point distribution of crude oils and oil fractions obey the Riazi's distribution model [1]:

$$\frac{T_i - T_0}{T_0} = \left[\frac{A_T}{B_T}\ln\left(\frac{1}{1-x_i}\right)\right]^{1/B_T} \qquad (1)$$

Equation 1 can be converted into a linear form :

$$Y = C_1 + C_2.X \qquad (2)$$

where: $Y = \ln\left(\frac{T-T_0}{T_0}\right)$; $X = \ln\ln\left(\frac{1}{1-x_i}\right)$; $B_T = \frac{1}{C_2}$; $A_T = B_T.\exp(C_1.B_T)$

To = initial boiling point in K; Ti = temperature at which i per cent is distilled in K; xi = volume or weight part of distillate.

Equation 2 has been tested on several hundreds samples of different crude oils, gas condensates, bitumen and oil fractions in the Lukoil Neftochim research laboratory and has been proved to be valid for all tested samples. Figure 1 is an illustration of validity of equation 2 applied to different distillation data of crude oil, straight run atmospheric residue, visbreaker residue, and visbreaker diesel. Regardless of the distillation method used (TBP, ASTM D-1160, ASTMD-5236, ASTM D-86, ASTM D-2887 and distillation according to Bogdanov – GOST 10120) the boiling point distribution is perfectly approximated by equations 1 and 2. It could be inferred from these data that one can safely extrapolate distillation curve from a set of data that does not cover the full distillation range of an oil. For example data of TBP distillation of vacuum residue obtained in one of the Lukoil vacuum distillation units is given in Table 1. Due to known limitation of the equipment the distillation was performed for temperature not higher than 540^{0}C. Figure 2 presents graph of equation 2 applied for the data of Table 1. It is evident from these data that eq.2 perfectly describes the boiling point distribution of the vacuum residue (r^2 = 0.9977). Taking into account the proof of validity of equation 2 for the whole distillation range we can build the vacuum residue TBP distillation curve (Figure 3) based on the data for A_T and B_T extracted from Figure 2.

Table 1 Distillation characteristics of Atmospheric Residue from Ural Crude Oil

Properties	Atmospheric Residue	
1. Density @ 20 °C, g /cm 3	0.9489	
2. TBP Distillation	%	∑ %
315-380°C	9.57	9.57
360-400°C		
380-400°C	5.02	14.59
400-430°C	10.77	25.36
430-470°C	11.65	37.01
470-490°C	5.98	42.99
490- 540 °C	13.65	56.64
> 540 °C		**42.34**
Losses		1.02

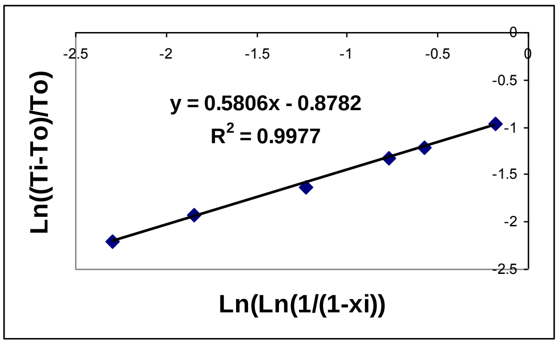

Fig. 2 Application of the Riazi's model (eq.2) for approximation of TBP distillation curve of Atmospheric Residue from Ural Crude Oil

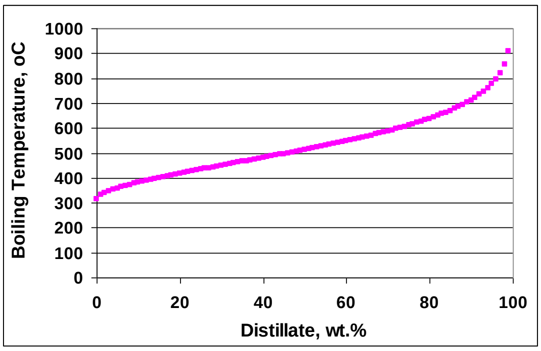

Fig. 3 Full range TBP distillation curve of Atmospheric Residue from Ural Crude Oil obtained by the use of the Riazi's model (eq.2)

Following this way of thinking we decided to test applicability of equations 1 and 2 on ASTM D-86 distillation of 33 crude oil samples with the aim to build the whole range (from 0 to 99%) crude ASTM D-86 distillation curve based on distillation data boiling up to 300^{0}C. The ASTM D-86 distillation is performed within 45 minutes and for that reason it could be used for daily monitoring of the crude distillation unit operation if the whole crude oil curve is available and it could be converted into TBP. Further we tested the ability of the methods available in the open literature for conversion of ASTM D-86 into TBP distillation of the crude oil samples investigated in this study. The aim of this paper is to discuss the obtained results

2. Experimental

TBP distillation of all 33 investigated crude oil samples was carried out in the AUTODEST 800 Fisher column according to ASTM-D 2892 for the atmosphere part of the test and according to ASTM-D 5236 for the vacuum one. The TBP distillation was performed in the AUTODEST 800 Fisher column at pressure drop from 760 to 2 mmHg and in the AUTODEST 860 Fisher column from 1 to 0, 2 mmHg. The results of the TBP distillation of the studied crude oil samples are presented in Table 2.

Distillation of the 33 crude oil samples up to 300^{0}C was performed in accordance with ASTM D-86 and the results of the distillation are given in Table 3. The density at 20^{0}C was analyzed according to ASTM-D 1298.

3. Results and Discussions

Table 4 presents data of TBP distillation of the 33 crude oil samples estimated on the base of the parameters A_T and B_T computed by eq.2 and assuming T_0 =-11.7^{0}C, which is the boiling point of isobutane. The isobutane is assumed to be the lightest compound in a crude oil [1]. The squared correlation coefficient r^2 for all crude oil samples except that of the Light Siberian crude oil is above 0.99. For the Light Siberian crude the r^2 = 0.9898 which is also high enough. This implies that the Riazi's distribution model describes very well the TBP distillation curve of crude oil.

Table 5 presents data of ASTM D-86 distillation of the 33 crude oil samples estimated on the base of the parameters A_T and B_T computed by eq.2. The squared correlation coefficient r^2 for all crude oil samples except that of the Buzachinmski crude oil is above 0.99. For the Buzachinmski crude the r^2 = 0.9751 which is also high. This indicates that the Riazi's distribution model also describes very well the ASTM D-86 distillation curve of crude oil. It may be concluded that by the use of calculated A_T and B_T and the initial boiling point the distillation curve could be safely extrapolated to 99 vol.%. In other words by applying the Riazi's distribution model from ASTM D-86 distillation data of a crude oil boiling up to 300^{0}C it can be estimated the amount of compounds boiling above this temperature and build the full range distillation curve.

In order to examine the capabilities of the available in the open literature correlations for conversion of ASTM D-86 into TBP distillation we had to convert the TBP distillation data from weight % in volume % because all correlations convert ASTM D-86 into TBP vol.%. Table VI presents data of TBP distillation of the 33 crude oil samples in vol.% assuming constant Kw factor for all crude fractions and using the data from Table 5. The squared correlation coefficient r^2 for this data set is above 0.99.

There is number of empirical approaches for converting ASTM D 86 distillations to true boiling point (TBP) distillations. Three of them are the most applicable for engineering purposes.

From chronological point of view the earliest method for conversion of the distillation curves is the method of Edmister [2]. It is a graphical approach, which was developed in the period 1948÷1961. First step in application of the method is definition of the TBP 50% as a function of D 86 50% in Fahrenheit using the graph that is illustrated in Figure 3.

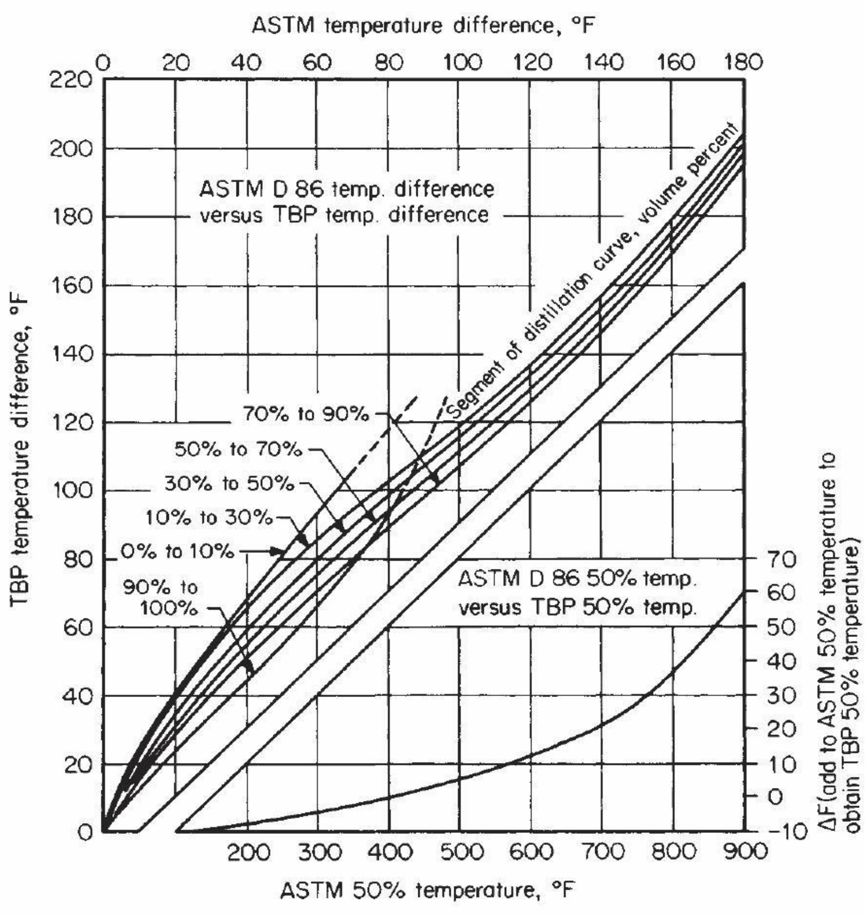

Figure 3 Relationship between ASTM D 86 and TBP distillation curves developed by Edmister and al. [2]

Next step requires making a graphical definition of the temperature differences between the segments of ASTM D 86 distillation curve (0%÷10%; 10%÷30%; 30%÷50%; 50%÷70%; 70%÷90% and 90%÷100%) by means of the same graph. These values are needed in order to define the correspondent temperature differences in TBP. By means of defined temperature differences in TBP and TBP50%, which is available in advance, it is easy to draw the TBP curve. Table VII illustrates the corresponding values from Figure 3, which facilitate conversion procedure.

Riazi-Daubert method for the interconversion of ASTM D 86 distillations to TBP distillations is based on the generalized correlation in the following form [3]:

$$TBP = a(ASTM - D86)^b \tag{3}$$

where both TBP and ASTM temperatures are for the same vol.% distilled and are in Kelvin. Constants *a* and *b* at various points along the distillation curve with the range of application are given in Table 8.

Table 8 Correlation constants in eq. 3

vol%	a	b	range a, °C
0	0.9177	1.0190	20-320
10	0.5564	1.0900	35-305
30	0.7617	1.0425	50-315
50	0.9013	1.0176	55-320
70	0.8821	1.0226	65-330
90	0.9552	1.0110	75-345
95	0.8177	1.0355	75-400

Daubert and his group developed a different set of equations to convert ASTM to TBP, which is also known as a Daubert's method [3]. The following equation is used to convert an ASTM D 86 distillation at 50% point temperature to a TBP distillation 50% point temperature.

$$TBP(50\%) = 255.4 + 0.8851[ASTM - D86(50\%) - 255.4]^{1.0258} \quad (4)$$

where ASTM (50%) and TBP (50%) are temperatures at 50% volume distilled in Kelvin. Equation (4) can also be used in a reverse form to estimate ASTM from TBP. The following equation is used to determine the difference between two cut points:

$$Y_i = AX_i^B \quad (5)$$

Where:
Y_i = difference in TBP temperature between two cut points, K;
X_i = observed difference in ASTM D 86 temperature between two cut points, K;
A, B = constants varying for each cut point and are given in Table IX.

Table 9 Correlation constants in eq. 5

i	Cut point range, %	A	B
1	100-90	0.1403	1.6606
2	90-70	2.6339	0.7550
3	70-50	2.2744	0.8200
4	50-30	2.6956	0.8008
5	10-30	4.1481	0.7164
6	10-0	5.8589	0.6024

To determine the true boiling point temperature at any percent distilled, calculation should begin with 50% TBP temperature and addition or subtraction of the proper temperature difference Y_i.

TBP (0%) = TBP (50%) - Y_4 - Y_5 - Y_6

TBP (10%) = TBP (50%) - Y_4 - Y_5

TBP (30%) = TBP (50%) - Y_4

TBP (70%) = TBP (50%) + Y_3

TBP (90%) = TBP (50%) + Y_3+Y_2

TBP (100%) = TBP (50%) + Y_3 + Y_2 + Y_1

The three approaches for conversion of ASTM D 86 distillations to TBP distillations were applied to the experimental data for 33 crude oil samples. Tables 10-12 present data of absolute deviation calculated as measured value – estimated value. The data in tables X-XII indicate that all three methods of conversion of ASTM D 86 distillation to TBP one used in this work: the Riazi-Daubert Conversion Method, the Daubert Conversion Method and the Edmister Conversion Method do not adequately predict TBP distillation from data of ASTM D-86 distillation data. The maximum deviation in the boiling temperature for each per cent evaporate should not go beyond 10^0C. No one of the conversion method used do not achieve this requirement. Therefore, a new method for conversion of ASTM D 86 distillation to TBP distillation applicable for crude oils should be developed.

4. Conclusions

It was found in this work that distribution of boiling point of the compounds containing in 33 crude oil samples measured by TBP or ASTM D-86 can be approximated by the Riazi's distribution model:

$$\frac{T_i - T_0}{T_0} = \left[\frac{A_T}{B_T} \ln\left(\frac{1}{1 - x_i} \right) \right]^{1/B_T}$$

This distribution model allows from incomplete distillation data the entire distillation curve of a crude oil to be built regardless of the method used for measuring of the distillation characteristics. On this base the entire distillation curve can be constructed by the use of ASTM D-86 method for measuring of the evaporate boiling up to 300ºC. An attempt to apply the Riazi-Daubert Conversion Method, the Daubert Conversion Method and the Edmister Conversion Method for converting ASTM D-86 into TBP of the investigated crude oils was found to be unsuccessful. Therefore a new method for conversion of ASTM D 86 distillation to TBP distillation applicable for crude oils should be developed.

Reference

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[2] Edmister, W.C., Pollock, D.H., "Phase Relations for Petroleum Fractions", *Chem. Eng. Progr.,* vol. 44, 1948, pp. 905-926.

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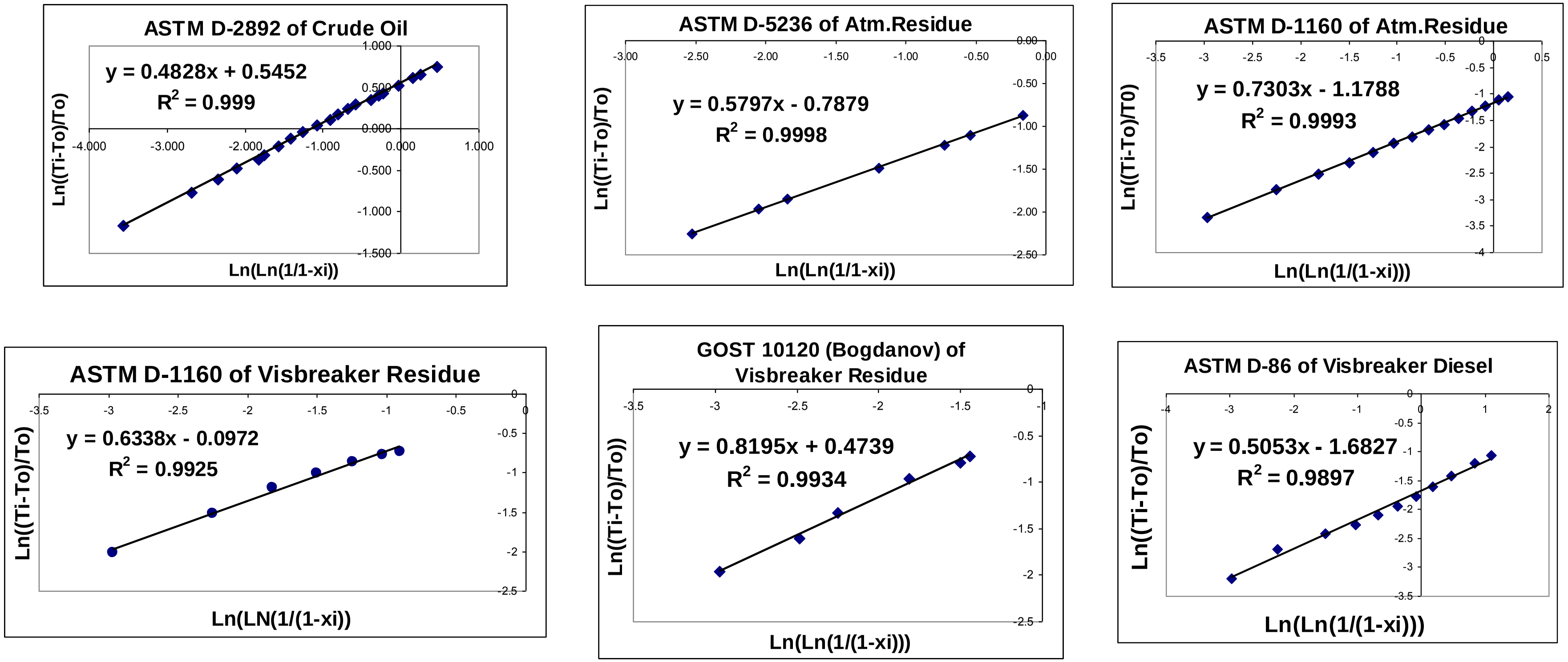

Figure 1 Application of the Riazi's model (eq.2) for approximation of distillation curves of different crude and crude oil fractions by the use of different methods for measuring of distillation characteristics

Table 2 TBP distillation of 33 crude oil samples

Crude Oil Sample	ASTM D 2892 / D 5236, wt.%						
	IBP-70	70-100	100-180	180-240	240-360	360-540	540+
TUN	3.1	3.0	9.9	8.0	23.5	27.8	24.8
TUAP	4.4	4.2	14.1	10.9	23.0	26.2	17.2
BUZ	1.9	2.8	6.1	8.0	23.0	29.5	28.7
LIB1	2.3	2.8	8.1	7.3	22.4	29.6	27.6
LIB2	8.5	6.3	17.9	10.9	22.5	21.7	14.3
GOS	3.5	3.1	11.0	8.6	22.8	31.4	19.6
SYR	4.2	2.4	9.5	6.4	15.8	29.1	32.4
LIR	4.3	4.3	13.8	10.4	21.8	25.0	20.6
LAR	4.0	3.1	13.0	9.9	24.5	25.8	19.8
HIR	6.0	6.8	9.1	9.1	20.0	23.8	26.7
AMCO	4.3	2.7	11.9	9.3	23.4	25.7	22.8
LSYR	4.5	3.6	13.8	11.0	27.7	30.8	9.5
KUW	4.6	3.1	11.8	9.2	20.6	23.7	27.1
IRQ	6.6	5.2	13.9	10.9	21.4	23.3	18.7
LSIB	7.0	5.1	15.0	11.6	22.1	29.0	12.8
ZAIK	11.0	8.1	21.7	12.9	25.7	18.3	5.3
TENG	9.4	7.4	24.0	16.1	24.6	16.2	2.4
HUR	3.9	5.3	4.8	9.0	20.0	32.0	25.0
UOR	2.7	4.8	5.5	9.0	19.0	33.0	26.0
KUM	7.5	7.1	20.7	10.2	22.4	21.6	13.3
URL	3.9	6.9	6.2	11.0	22.0	27.0	23.0
REM	3.0	3.5	11.4	8.1	23.3	28.2	22.5
LAZ	5.5	5.5	14.7	11.2	22.9	23.5	16.7
REBCO1	3.2	3.8	13.5	7.5	17.4	27.9	28.2
REBCO2	3.0	3.8	13.1	7.9	18.2	28.5	26.8
REBCO3	3.0	3.8	14.4	7.8	18.7	29.2	24.6
ABCO1	3.3	3.0	11.5	9.1	22.1	27.1	23.9
ABCO2	3.3	3.2	11.6	9.6	22.2	26.3	23.9
ABCO3	2.9	3.2	10.9	9.2	22.1	28.1	23.7
ABCO4	3.2	3.0	10.9	9.0	22.4	27.7	23.8
ABCO5	3.2	3.1	11.4	8.9	22.0	28.0	23.4
ABCO6	3.3	3.9	11.5	8.9	20.6	28.8	23.1
ABCO7	2.6	2.9	12.2	10.7	20.9	27.2	23.5

Table 3 ASTM D-86 distillation of 33 crude oil samples

Crude Oil Sample	ASTM D 86									
	IBP, ºC	Up to 62ºC, %vol.	Up to 85ºC, %vol.	Up to 120ºC, %vol.	Up to 150ºC, %vol.	Up to 180ºC, %vol.	Up to 200ºC, %vol.	Up to 240ºC, %vol.	Up to 250ºC, %vol.	Up to 300ºC, %vol.
TUN	62.0	-	1.0	4.0	10.0	14.0	17.0	23.0	25.0	39.0
TUAP	40.0	3.0	7.0	13.0	20.0	26.0	29.0	37.0	40.0	50.0
BUZ	60.0	-	2.0	7.0	8.0	15.0	17.0	18.5	26.0	35.0
LIB1	61.0	-	1.5	5.0	10.0	14.0	17.0	18.0	25.0	36.0
LIB2	40.0	3.0	8.5	18.0	27.0	33.0	39.0	46.0	48.0	58.5
GOS	61.0	-	3.0	10.0	15.0	20.0	24.0	30.0	32.0	41.0
SYR	55.0	1.0	5.0	10.0	14.0	19.0	21.0	25.0	26.0	34.0
LIR	33.0	3.5	6.0	12.5	19.0	25.5	30.0	37.0	38.5	48.0
LAR	30.0	2.0	4.0	11.0	17.0	23.0	29.0	36.0	39.0	48.0
HIR	46.0	2.0	6.0	12.0	19.0	25.0	28.0	35.0	37.0	45.0
AMCO	51.0	1.5	5.0	10.0	16.0	21.0	25.5	32.5	34.0	43.0
LSYR	30.0	2.0	5.0	10.0	16.0	23.0	27.0	35.0	37.0	48.0
KUW	30.0	3.0	6.0	12.0	18.0	23.0	26.5	34.0	35.5	45.0
IRQ	44.0	2.0	7.0	14.0	21.0	28.0	32.0	41.0	43.0	54.0
LSIB	28.0	3.0	5.0	13.0	20.0	27.0	31.0	38.0	40.0	50.0
ZAIK	40.0	4.0	9.0	19.0	30.0	40.0	43.0	51.0	53.0	65.0
TENG	35.0	7.0	14.0	25.0	34.0	44.0	49.0	60.0	62.0	74.0
HUR	50.0	1.5	4.0	9.0	13.5	18.0	22.0	27.0	29.0	38.0
UOR	47.0	2.0	5.0	9.0	14.0	18.0	21.0	27.0	29.0	39.0
KUM	50.0	2.0	6.0	11.0	20.0	26.0	29.0	37.0	40.0	50.0
URL	51.0	2.0	5.0	11.0	17.0	22.0	26.0	34.0	36.0	46.0
REM	47.0	1.0	4.0	10.0	15.0	20.0	24.0	30.0	32.0	42.0
LAZ	60.0	1.0	13.0	20.0	28.0	32.0	35.0	40.0	42.0	53.0
REBCO1	53.0	0.5	2.5	9.0	13.0	19.0	23.0	31.0	33.0	44.0
REBCO2	30.0	1.5	3.0	8.0	13.0	18.0	21.5	28.0	30.5	42.0
REBCO3	25.0	2.5	4.5	9.5	14.5	19.5	23.0	29.5	31.0	43.0
ABCO1	62.0	-	2.0	8.0	13.0	18.0	22.0	28.5	30.5	43.5
ABCO2	60.0	-	2.0	7.0	12.0	17.0	21.0	27.5	30.0	41.0
ABCO3	51.0	0.5	4.0	10.0	15.0	20.0	24.0	32.0	34.0	44.0
ABCO4	53.0	1.0	4.0	9.0	14.0	16.0	22.0	30.0	32.0	43.0
ABCO5	47.0	1.5	3.5	8.5	14.0	19.0	22.5	29.0	31.0	42.5
ABCO6	58.0	-	3.0	8.0	13.0	18.0	22.0	30.0	32.0	43.0
ABCO7	62.0	-	2.0	8.0	13.0	17.0	21.0	30.0	31.0	43.0

Table 4 TBP distillation data (wt.%) of the crude oils under study

Crude Oil Sample	5%wt.,	10%wt,	30%wt,	50%wt,	70%wt,	90%wt,	95%wt,	R^2	A_T	B_T	SG
Tunesian	92	138	267	380	507	710	813	0.998	6.255	1.963	0.836
Tuapse	74	112	222	319	428	605	695	0.998	4.345	1.922	0.849
Buzachinmski	115	165	302	416	542	738	836	0.991	8.822	2.137	0.891
Libyan1	105	155	290	406	536	740	843	0.997	7.715	2.046	0.893
Libyan2	45	79	187	293	424	650	773	0.994	2.844	1.550	0.815
Gulf of Suetz	85	131	264	383	521	745	861	0.997	5.700	1.845	0.872
Syrian	83	132	279	416	577	845	987	0.994	5.804	1.724	0.907
Light Iranian	72	113	233	341	466	671	777	0.995	4.513	1.817	0.851
Light Arabian	81	122	237	337	451	633	725	0.999	4.974	1.958	0.856
Heavy Iranian	61	103	235	362	517	782	924	0.993	4.066	1.594	0.863
Arabian AMCO	79	122	249	362	494	708	819	0.999	5.098	1.833	0.871
Light Syrian	75	116	238	347	473	679	786	0.985	4.708	1.830	0.840
Kuwaitian	75	118	245	360	494	715	830	0.999	4.849	1.790	0.868
Iraqi	54	91	207	320	455	688	812	0.997	3.393	1.607	0.840
Light Siberrian	56	95	217	335	479	725	857	0.989	3.617	1.595	0.843
Zaikinski	36	64	157	248	361	557	664	0.980	2.190	1.532	0.792
Tengiz	44	70	150	221	304	440	511	0.997	2.115	1.809	0.793
Heavy Ural	97	146	286	409	550	776	892	0.999	6.889	1.916	0.892
Ural + Oil Residue	102	153	295	419	559	783	898	0.999	7.487	1.956	0.872
Kumkol	50	84	189	290	411	616	725	0.987	2.987	1.639	0.820
Ural	82	126	255	371	503	720	831	0.997	5.394	1.850	0.855
REM	90	135	262	373	499	700	803	0.995	5.977	1.951	0.870
Light Azerski	62	99	207	305	420	610	708	0.997	3.636	1.785	0.842
REBCO 02.12.09	91	136	262	372	497	695	796	0.991	6.065	1.970	0.874
REBCO 30.11.09	93	137	261	368	488	678	774	0.992	6.165	2.013	0.871
REBCO 10.11.09	93	136	255	357	469	647	736	0.990	6.047	2.066	0.869
Average Blend Sept.	88	133	260	371	506	703	807	0.998	5.812	1.927	0.866
Average Blend Oct.	87	131	257	366	491	690	792	0.998	5.724	1.939	0.863
Average Blend Apr.	91	137	265	376	502	703	806	0.997	6.128	1.961	0.865
Average Blend May	89	135	263	376	504	710	816	0.998	5.969	1.931	0.868
Average Blend June	88	133	261	374	503	709	815	0.998	5.858	1.921	0.867
Average Blend July	84	129	258	373	505	719	829	0.995	5.554	1.870	0.867
Average Blend Sept.	95	140	262	366	482	665	757	0.994	6.362	2.062	0.867

Table 5 ASTM D-86 distillation data of the crude oils under study

Crude Oil Sample	IBP, ºC	5%, ºC	10%, ºC	30%, ºC	50%, ºC	70%, ºC	90%, ºC	95%, ºC	R^2	A_T	B_T
Tunesian	62.0	125	159	266	367	488	694	804	0.9947	2.0310	1.6455
Tuapse	40.0	74	101	200	312	462	746	910	0.9986	1.5188	1.2577
Buzachinmski	60.0	113	151	288	436	630	991	1195	0.9751	2.2415	1.3242
Libyan1	61.0	118	156	283	414	579	875	1038	0.9872	2.2370	1.4355
Libyan2	40.0	79	107	205	310	447	698	839	0.9973	1.5987	1.3510
Gulf of Suetz	61.0	96	125	234	361	533	864	1058	0.9975	1.5365	1.2167
Syrian	55.0	88	121	272	470	767	1394	1787	0.9982	1.8817	1.0249
Light Iranian	33.0	74	103	205	313	453	709	854	0.9956	1.7393	1.3613
Light Arabian	30.0	88	118	211	298	402	576	668	0.9962	1.9856	1.6909
Heavy Iranian	46.0	80	107	210	329	489	797	976	0.9994	1.5258	1.2285
Arabian AMCO	51.0	85	113	229	366	557	935	1159	0.9974	1.6233	1.1633
Light Syrian	30.0	86	118	216	309	423	615	718	0.9995	2.0544	1.6252
Kuwaitian	30.0	77	108	218	332	478	741	888	0.9996	2.0048	1.3994
Iraqi	44.0	80	105	194	290	415	645	774	0.9984	1.3819	1.3464
Light Siberrian	28.0	78	107	200	291	401	590	693	0.9927	1.8311	1.5755
Zaikinski	40.0	82	113	222	339	492	775	935	0.9970	1.8076	1.3342
Tengiz	35.0	77	108	226	357	533	864	1055	0.9985	1.9420	1.2711
Heavy Ural	50.0	89	123	260	425	656	1116	1391	0.9955	1.9658	1.1486
Ural + Oil Residue	47.0	85	119	261	435	683	1182	1483	0.9937	2.0027	1.1188
Kumkol	50.0	79	104	202	317	477	791	977	0.9938	1.3566	1.1762
Ural	51.0	81	108	221	358	555	951	1190	0.9909	1.5198	1.1178
REM	47.0	93	124	233	346	492	756	904	0.9985	1.8309	1.3926
Light Azerski	60.0	71	86	165	285	482	947	1259	0.9897	0.8934	0.8740
REBCO 02.12.09	53.0	100	131	234	340	474	712	844	0.9979	1.7322	1.4438
REBCO 30.11.09	30.0	99	135	244	346	467	669	776	0.9970	2.6454	1.7065
REBCO 10.11.09	25.0	86	122	239	354	495	739	871	0.9978	2.6001	1.5489
Average Blend Sept. 2007	62.0	106	136	240	349	490	746	889	0.9969	1.6127	1.3837
Average Blend Oct. 2007	60.0	108	139	248	360	502	758	900	0.9993	1.7620	1.4194
Average Blend Apr. 2006	51.0	98	127	224	321	443	657	775	0.9929	1.6335	1.4850
Average Blend May 2006	53.0	91	123	246	389	585	967	1192	0.9928	1.7925	1.1992
Average Blend June 2006	47.0	91	124	244	376	551	877	1064	0.9924	1.9437	1.2987
Average Blend July 2006	58.0	100	130	240	359	515	805	969	0.9973	1.6822	1.3222
Average Blend Sept. 2006	62.0	106	136	240	350	491	747	890	0.9966	1.6208	1.3864

Table 6 TBP distillation data (vol.%) of the crude oils under study

Crude Oil Sample	5%, ºC	10%, ºC	30%, ºC	50%, ºC	70%, ºC	90%, ºC	95%, ºC	R^2	A_T	B_T
Tunesian	80	123	246	356	482	685	790	1.0000	5.1384	1.8779
Tuapse	64	100	205	298	406	581	671	1.0000	3.6644	1.8525
Buzachinmski	104	152	282	391	513	704	799	0.9996	7.4595	2.0921
Libyan1	92	139	268	381	509	713	817	1.0000	6.2917	1.9608
Libyan2	37	67	167	267	392	612	732	1.0000	2.3729	1.4928
Gulf of Suetz	73	115	241	356	490	712	827	1.0000	4.6798	1.7734
Syrian	70	114	251	380	534	795	933	0.9999	4.7000	1.6628
Light Iranian	62	100	212	316	439	642	748	1.0000	3.7380	1.7434
Light Arabian	71	110	219	316	427	607	699	1.0000	4.1985	1.8936
Heavy Iranian	50	88	209	329	477	735	875	1.0000	3.3067	1.5298
Arabian AMCO	68	108	227	336	464	675	786	1.0000	4.2019	1.7627
Light Syrian	64	103	217	322	446	649	756	1.0000	3.9014	1.7581
Kuwaitian	64	103	222	333	464	683	798	1.0000	3.9778	1.7153
Iraqi	45	78	186	292	422	647	769	1.0000	2.8213	1.5506
Light Siberrian	46	81	194	305	443	682	812	1.0000	2.9786	1.5347
Zaikinski	29	55	141	227	335	525	629	1.0000	1.8672	1.4815
Tengiz	39	64	140	209	290	423	492	0.9999	1.8922	1.7721
Heavy Ural	83	129	262	380	518	741	857	1.0000	5.5911	1.8392
Ural + Oil Residue	89	136	270	390	527	749	863	1.0000	6.0835	1.8801
Kumkol	42	73	171	267	383	583	691	1.0000	2.5227	1.5818
Ural	70	111	233	344	474	688	800	1.0000	4.4260	1.7749
REM	79	121	241	349	472	671	773	1.0000	4.9609	1.8808
Light Azerski	53	87	188	281	392	576	673	0.9991	3.0262	1.7241
REBCO 02.12.09	79	122	242	348	470	667	768	1.0000	5.0154	1.8950
REBCO 30.11.09	82	124	242	346	463	651	748	1.0000	5.1327	1.9410
REBCO 10.11.09	82	123	237	336	447	624	713	1.0000	5.0744	1.9924
Average Blend Sept. 2007	75	117	238	347	472	677	783	1.0000	4.7382	1.8389
Average Blend Oct. 2007	75	117	236	342	465	664	767	1.0000	4.7031	1.8570
Average Blend Apr. 2006	79	122	244	352	475	676	779	1.0000	5.0436	1.8825
Average Blend May 2006	73	115	238	351	482	697	810	0.9991	4.6220	1.7879
Average Blend June 2006	75	116	239	349	477	686	794	0.9999	4.7156	1.8205
Average Blend July 2006	73	114	235	344	472	680	789	0.9999	4.5539	1.8064
Average Blend Sept. 2006	84	126	243	345	459	642	434	1.0000	5.2928	1.9829

Table 7 Edmister conversion data for transforming of ASTM D-86 into TBP

Segment of Destillation Curve, Volume Percent												D-86 50% to TBP 50%	
0 to 10%		10 to 30%		30 - 50%		50 - 70%		70 - 90%		90 to 100%			
D-86 ºF	TBP ºF	D-86 ºF	TBP ºF	D-86 ºF	TBP ºF	D-86 ºF	TBP ºF	D-86 ºF	TBP ºF	D-86 ºF	TBP ºF	D-86 50% ºF	TBP 50% ºF
0.27	0.27	0.27	0.55	0.27	0.27	0.55	1.09	0.28	0.82	0.55	1.09	101.70	-9.87
1.37	4.37	2.74	4.64	1.99	4.89	3.58	8.16	4.13	7.34	6.32	7.61	141.50	-8.75
3.01	8.19	5.21	11.74	5.78	13.05	3.30	7.07	12.10	17.66	14.29	16.30	199.15	-7.62
6.03	13.92	10.14	20.74	10.45	18.21	7.97	12.50	17.87	25.00	22.26	26.08	258.17	-5.66
8.49	19.65	16.71	31.93	13.75	23.92	20.89	31.52	23.09	30.43	30.23	33.41	310.33	-4.26
11.23	25.11	21.10	38.76	18.70	30.44	29.14	42.12	28.31	36.95	36.00	39.66	359.75	-2.32
14.52	30.29	26.03	46.13	22.55	36.69	33.54	46.74	32.98	41.30	41.77	44.82	416.04	-0.10
18.08	36.57	29.59	51.04	27.22	42.94	38.21	52.99	39.03	48.09	46.16	50.25	464.10	2.11
22.19	42.85	33.15	56.50	31.62	48.10	45.35	59.50	43.97	54.07	51.11	54.87	501.18	4.05
27.12	49.95	38.36	62.24	36.02	53.81	53.32	67.65	51.12	61.40	55.23	60.31	553.37	7.35
30.96	55.14	42.74	66.61	40.14	58.70	58.82	73.36	59.36	69.00	59.08	63.84	595.95	10.37
35.07	60.33	46.85	72.07	44.53	63.04	64.86	79.88	64.30	73.08	65.12	70.90	631.67	13.38
39.73	66.61	50.69	75.90	48.93	67.12	71.45	85.31	69.52	78.51	69.52	75.24	685.26	18.31
43.56	71.79	54.52	80.26	55.52	73.91	77.22	90.47	76.12	85.30	73.37	81.50	725.13	22.96
47.12	76.44	58.90	84.09	60.47	78.79	87.11	98.88	83.26	91.27	78.04	88.83	755.39	27.33
50.69	81.35	63.01	88.19	65.14	83.41	92.88	104.59	90.95	98.88	82.99	96.44	787.03	32.51
56.16	87.90	68.49	92.29	69.81	87.49	99.20	110.02	96.45	102.68	85.74	101.88	818.68	38.23
61.10	93.09	72.05	95.84	74.48	91.83	105.79	116.54	98.92	105.94	89.32	108.40	847.60	44.50
66.03	99.65	75.34	98.57	80.25	96.99	113.76	123.60	104.69	111.10	92.34	114.38	869.64	49.67
70.41	105.65	75.34	98.84	85.47	102.42	120.35	129.84	111.01	117.35	94.82	119.82	897.23	58.37
75.62	111.39	90.14	111.68	91.24	106.77	125.30	134.73	118.70	124.68	97.02	125.80		
81.37	117.94	94.25	115.23	95.36	110.84	131.07	140.17	125.57	131.47				
85.21	123.40	97.81	117.42	103.60	118.17	135.46	145.05	130.24	135.81				
89.04	128.04	102.47	122.06	108.54	122.52	140.68	149.40	137.11	143.96				
		106.85	125.62	114.59	127.95	144.81	154.56	142.60	148.85				
		110.41	128.90	120.63	133.38	150.58	161.08	147.00	153.47				
		114.79	132.45	127.23	139.90	157.72	167.33	150.30	156.73				
		119.45	137.09	131.35	143.43	162.39	173.85	153.87	160.80				
		124.93	141.74	137.12	149.68	167.62	182.00	156.34	163.79				

Table 10 ASTM D-86 to TBP volume fraction according to Riazi-Daubert Conversion Method

Crude Oil Sample	**10%, ºC**	**30%, ºC**	**50%, ºC**	**70%, ºC**	**90%, ºC**	**95%, ºC**
	Δ abs	Δ abs	Δ abs	Δ abs	Δ abs	Δ abs
Tunesian	17	11	11	13	27	65
Tuapse	15	14	13	62	185	300
Buzachinmski	20	3	46	130	317	483
Libyan1	2	6	34	81	187	293
Libyan2	24	29	42	61	105	161
Gulf of Suetz	8	16	5	52	177	305
Syrian	10	12	92	252	647	1003
Light Iranian	13	16	4	20	86	162
Light Arabian	9	17	19	21	17	9
Heavy Iranian	3	8	1	19	84	167
Arabian AMCO	12	7	30	103	288	457
Light Syrian	2	10	14	18	19	6
Kuwaitian	11	13	2	21	78	149
Iraqi	11	1	3	2	15	54
Light Siberrian	10	3	15	38	77	77
Zaikinski	41	72	112	164	271	369
Tengiz	28	77	148	252	466	637
Heavy Ural	23	11	46	152	411	641
Ural + Oil Residue	34	18	46	171	471	736
Kumkol	15	22	49	101	230	353
Ural	19	21	14	91	292	477
REM	15	17	3	27	106	191
Light Azerski	16	32	3	97	399	679
REBCO 02.12.09	9	17	8	11	64	131
REBCO 30.11.09	7	7	0	10	35	77
REBCO 10.11.09	18	7	18	55	135	215
Average Blend Sept. 2007	1	7	2	25	89	165
Average Blend Oct. 2007	4	3	18	45	115	193
Average Blend Apr. 2006	13	29	32	27	2	45
Average Blend May 2006	9	1	38	114	299	469
Average Blend June 2006	10	4	27	84	217	345
Average Blend July 2006	2	4	15	51	148	246
Average Blend Sept. 2006	8	12	5	39	125	515
Abs. average deviation, ^0C	13	16	28	73	187	308

Table 11 ASTM D-86 to TBP volume fraction according to Daubert Conversion Method

Crude Oil Sample	**10%, ºC**	**30%, ºC**	**50%, ºC**	**70%, ºC**	**90%, ºC**	**95%, ºC**
	Δ abs	Δ abs	Δ abs	Δ abs	Δ abs	Δ abs
Tunesian	30	25	23	13	43	197
Tuapse	8	2	23	54	66	644
Buzachinmski	12	23	62	110	144	1009
Libyan1	23	27	48	70	59	617
Libyan2	29	40	52	56	6	406
Gulf of Suetz	8	2	17	38	26	795
Syrian	38	52	109	197	277	2992
Light Iranian	6	4	6	14	16	423
Light Arabian	7	9	10	18	69	95
Heavy Iranian	13	6	10	8	51	582
Arabian AMCO	7	13	42	83	105	1115
Light Syrian	3	1	4	17	81	121
Kuwaitian	1	1	9	14	28	414
Iraqi	12	8	6	5	70	257
Light Siberrian	12	5	6	37	138	41
Zaikinski	53	87	123	155	152	690
Tengiz	45	95	160	237	314	1106
Heavy Ural	10	18	61	120	167	1628
Ural + Oil Residue	3	14	61	134	198	1917
Kumkol	22	35	59	89	92	807
Ural	2	2	26	69	96	1233
REM	2	3	8	21	1	461
Light Azerski	14	20	12	74	162	2010
REBCO 02.12.09	1	4	3	7	26	339
REBCO 30.11.09	4	6	11	10	33	199
REBCO 10.11.09	4	8	30	50	40	417
Average Blend Sept. 2007	12	7	13	20	12	415
Average Blend Oct. 2007	17	18	30	39	14	437
Average Blend Apr. 2006	6	18	21	27	77	207
Average Blend May 2006	14	21	52	93	112	1130
Average Blend June 2006	10	15	40	69	68	791
Average Blend July 2006	13	12	27	42	24	584
Average Blend Sept. 2006	4	2	16	34	24	765
Abs. average deviation, ^{0}C	13	18	36	61	85	753

Table 12 ASTM D-86 to TBP volume fraction according to Edmister Conversion Method

Crude Oil Sample	**10%, ºC**	**30%, ºC**	**50%, ºC**	**70%, ºC**	**90%, ºC**	**95%, ºC**
	Δ abs	Δ abs	Δ abs	Δ abs	Δ abs	Δ abs
Tunesian	21	32	38	83	341	557
Tuapse	26	11	32	192	1152	2135
Buzachinmski	123	35	90	488	2646	4682
Libyan1	51	4	72	282	1362	2311
Libyan2	20	37	60	154	726	1279
Gulf of Suetz	36	23	31	273	1852	3554
Syrian	359	220	147	1846	14812	31528
Light Iranian	22	10	15	121	757	1384
Light Arabian	3	2	2	18	141	246
Heavy Iranian	16	10	20	186	1374	2646
Arabian AMCO	67	31	57	427	2925	5677
Light Syrian	1	4	4	33	215	375
Kuwaitian	31	9	20	141	828	1478
Iraqi	14	9	13	64	459	850
Light Siberrian	13	10	1	6	137	275
Zaikinski	21	74	134	307	1241	2130
Tengiz	21	62	173	492	2159	3821
Heavy Ural	184	99	87	808	5584	10944
Ural + Oil Residue	241	138	90	1016	7247	14418
Kumkol	3	22	68	266	1599	3083
Ural	72	47	40	452	3368	6770
REM	28	10	20	149	867	1545
Light Azerski	32	42	18	449	5436	13497
REBCO 02.12.09	11	5	14	101	586	1035
REBCO 30.11.09	11	9	23	77	327	527
REBCO 10.11.09	43	0	43	165	719	1181
Average Blend Sept. 2007	3	4	26	134	767	1364
Average Blend Oct. 2007	5	14	44	158	797	1382
Average Blend Apr. 2006	8	14	12	38	347	638
Average Blend May 2006	83	33	70	474	3058	5848
Average Blend June 2006	58	17	56	322	1831	3343
Average Blend July 2006	20	1	41	207	1207	2171
Average Blend Sept. 2006	12	1	29	148	803	1714
Abs. average deviation, ^{0}C	50	32	48	305	2051	4072