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Correlations of Some Saudi Arabian Crude Cuts Physical Properties

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ABSTRACT. The physical properties, such as molecular weight, specific gravity and cumulative volume of both light Arabian and heavy Arabian crude oil cuts, can be correlated with their boiling points if the incremental volumes (TBP distillation) are known. The data obtained experimentally were fitted by using multiple regression analysis technique to predict the various cuts properties.

In general, the obtained correlations predicted the various properties within acceptable accuracy limits. The correlations predictions also agreed well with other relevant data reported in the literature.

1. Introduction

Crude oil is a mixture of a large number of hydrocarbon compounds with each compound having its own boiling point. Therefore, there are ranges of boiling points when a sample of crude oil is heated to successively higher temperatures. As the crude oil temperature is raised, a point is reached where boiling starts which is known as the initial boiling point (I.B.P.). As temperature increases, butane and lighter components will vaporize first from, the I.B.P. to just below 38°C. The next higher fractions are called straight-run gasoline, naphtha, kerosene and gas oil which will

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vaporize at different temperatures ranging from about 40°C to 350°C. All those cuts are obtained when distillation is carried out at atmospheric pressure. The rest of the crude is defined as the residue cut which is then vacuum distilled[1].

Molecular weights of petroleum cuts are important in the petroleum industry for the purpose of design as well as for process operations. Several indirect methods have been proposed for correlating the molecular weight with other more readily measured physical properties such as specific gravity and temperature[2].

Maxwell[3] proposed a correlation in a graphical form for determination of molecular weights of petroleum fractions as a function of mean average boiling point temperature (T_m) and specific gravity.

The API Technical Data Book[4] gives the following relationship for the molecular weight of a virgin (unfinished) petroleum fraction

$$MWT = A \times e^{T_m} \times e^{b(SP\ GR)} \times (T_m)^c \times (SP\ GR)^d \tag{1}$$

where T_m is the mean average boiling point and $SP\ GR$ is specific gravity at 60/60°F for the cut. A, b, c and d are constants.

Adler and Hall[5] and Huggins[6] have applied equation (1) on a wide range of temperatures and specific gravities to predict molecular weight.

Riazi and Daubert[7,8] have developed the following correlation for the molecular weight prediction of pure hydrocarbons

$$MWT = A \times (T_b)^c \times (SP\ GR)^d \tag{2}$$

where T_b is the absolute boiling point and A, c and d are constants to be empirically determined.

When applying Eq. (2) to petroleum fractions, Riazi and Daubert[8] recommended the use of ASTM 10% temperature instead of the mean average boiling point (T_m) of the cut.

Regarding the cumulative volumes of crude cuts, some graphical prediction methods are recommended by API. However, no empirical or analytical correlation was found in the literature to describe the behaviour of cumulative volumes as a function of temperature.

2. Experimental

The light (36° API) and heavy (27° API) Arabian crude oil samples, provided by Jeddah Oil Refinery Company (JORC), were distilled using a true boiling point (TBP) distillation apparatus according to procedures prescribed in ASTM standards. Each time a sample in the amount of four liters was loaded and atmospherically distilled producing about 40% of the feed as overhead products. Also the obtained cuts were further analyzed in JORC laboratory facilities to determine their specific gravities and estimate their molecular weights.

The specific gravity of each cut was determined using a hydrometer. The molecular weight value for each cut was estimated from its specific gravity and mean average boiling point temperature, by using standard molecular weight charts[9]. The obtained data are presented in Table 1 and 2.

TABLE 1. TBP distillation data of light Saudi Arabian crude oil.

Cut range °C	% Cumulative volume	Specific gravity at 15°C	Molecular weight
20 - 60	2.49	–	76
60 - 80	5.02	0.6755	–
80 - 100	8.09	0.7052	93
100 - 120	11.14	0.7242	103
120 - 140	14.93	0.7421	113
140 - 160	18.92	0.7571	124
160 - 180	23.07	0.7745	134
180 - 200	26.97	0.7838	149
200 - 220	30.59	0.7931	160
220 - 240	34.48	0.8020	177
240 - 260	38.53	0.8178	189

TABLE 2. TBP distillation data of heavy Saudi Arabian crude oil.

Cut range °C	% Cumulative volume	Specific gravity at 15°C	Molecular weight
20 - 60	1.62	–	78
60 - 80	3.73	0.6752	85
80 - 100	6.35	0.7010	97
100 - 120	8.55	0.7406	106
120 - 140	11.40	0.7565	112
140 - 160	14.28	0.7714	124
160 - 180	17.34	0.7848	135
180 - 200	20.33	0.7928	150
200 - 220	23.15	0.8017	161
220 - 240	26.36	0.8185	178

Each cut was further distilled to obtained percentage cumulative volume data. Sample data are given in Table 3 for the cut with boiling temperature range of 100-120°C.

The percentage cumulative volumes were correlated as a function of the mid-cut temperature (T_{mid}) for the two crude oil cuts.

The best fit was obtained in the following form

$$V = A + B \times (T_{mid})^{C} + D \times (T_{mid})^{2} + E \times \ln T_{mid} \qquad (3)$$

where V is the percentage cumulative volume, T_{mid} in °C, and A, B, C, D and E are constants.

TABLE 3. Distillation data of the 100-120°C cut for the light and heavy Saudi Arabian crude oils.

Percentage cumulative volume	Light	Heavy crude
	Temp. °C	Temp. °C
I.B.P.	98.0	99.0
5	100.0	101.0
10	102.0	102.0
15	102.0	102.9
20	103.0	103.5
25	103.0	104.0
30	103.5	104.5
35	104.0	105.0
40	105.0	105.3
45	105.2	106.0
50	106.0	106.2
55	106.3	107.0
60	107.0	107.5
65	107.5	108.1
70	108.2	109.0
75	109.0	109.8
80	110.1	110.8
85	111.3	112.0
90	113.0	114.0
95	116.0	116.5
100	119.8	120.0
F.B.P.	124.0	133.8

No single correlation was found which would fit both the data of light and heavy Saudi Arabian crude oil cuts, therefore two sets of constants are recommended for equation (3) which are presented in Table 4.

When the mid-cut temperature (T_{mid}) is not available for a certain petroleum cut, the following equation is recommended for estimating T_{mid} in K as a function of the cut's API

$$T_{mid} = 0.0717\,(\mathrm{API})^2 - 13.643\,(\mathrm{API}) + 964.498 \qquad (4)$$

Regarding the molecular weight, equation (2) which was recommended by Riazi and Daubert[8] was used to fit the experimental data of this work. The best fit of the equation for both light and heavy Saudi Arabian crude oil cuts is as follows

$$MWT = 4.575 \times 10^{-5}\,(T_m)^{2.405}\,(SP\ GR)^{-1.070} \qquad (5)$$

where T_m is the mean average boiling point temperature of the cut in K, and *SP GR* is the specific gravity of the cut at 150°C.

Here again, when the mean average boiling point temperature (T_m) for a certain cut is not available, the following equation is recommended for estimating T_m in K as a function of the cut's API

$$TM = 0.0772(\mathrm{API})^2 - 14.117(\mathrm{API}) + 966.962 \qquad (6)$$

Equations (3) through (6) were developed by applying regression analysis technique to the experimental data of this work.

TABLE 4. Values of constants for equation (3).

Parameter	Light crude cuts	Heavy crude cuts
A	21.007	27.294
B	2.500	8.080
C	1.530	0.450
D	1.000×10^{-3}	1.266×10^{-4}
E	6.474	18.535

3. Discussion

Equation (3) predicted the percentage cumulative volumes of various cuts obtained in this study for both light and heavy Saudi Arabian crude oil cuts with average absolute deviation (AAD) values of 0.57% and 1.12% respectively. The results are presented graphically in Fig. 1. Further testing of the equation to check its applicability was performed on data provided by JORC and Saudi Arabian Oil Company (Saudi ARAMCO). The equation predicted the experimental data of JORC with AAD values of 5.73% and 4.17% for light and heavy Saudi Arabian crude oils cuts respectively. The Saudi ARAMCO data on the other hand were predicted by the same equation with AAD values of 5.38% and 2.09% for light and heavy Saudi Arabian crude oil cuts respectively.

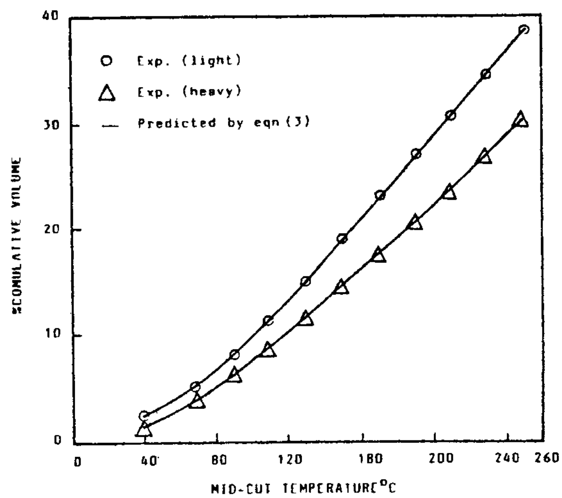

FIG. 1. Comparison of experimental and predicted percentage cumulative volumes.

These results prove the general applicability of equation (3) for the prediction of the percentage cumulative volumes of light and heavy Saudi Arabian crude oil cuts within acceptable limits.

Equation (4) predicted the mid-cut temperature (T_{mid}) for light and heavy Saudi Arabian crude oil cuts with AAD value of 1.17%. Equation (3) and equation (4) could be coupled to predict the percentage cumulative volume provided that the cut's specific gravity or the mid-cut temperature is known.

Equation (5) predicted the molecular weight values of the various light and heavy Saudi Arabian crude oil cuts obtained in this study with an AAD value of 1.53%.

Equation (1) which is recommended by the API was applied for molecular weight prediction of both light and heavy Saudi Arabian crude oil cuts. The predicted values were within an AAD value of 8.20%. The predictions by both equations (1) and (5) are graphically presented in Fig. 2. As seen from the figure and from the average absolute deviation results, equation (5) which is recommended by this work gives better predictions for the tested Saudi crudes than the API equation.

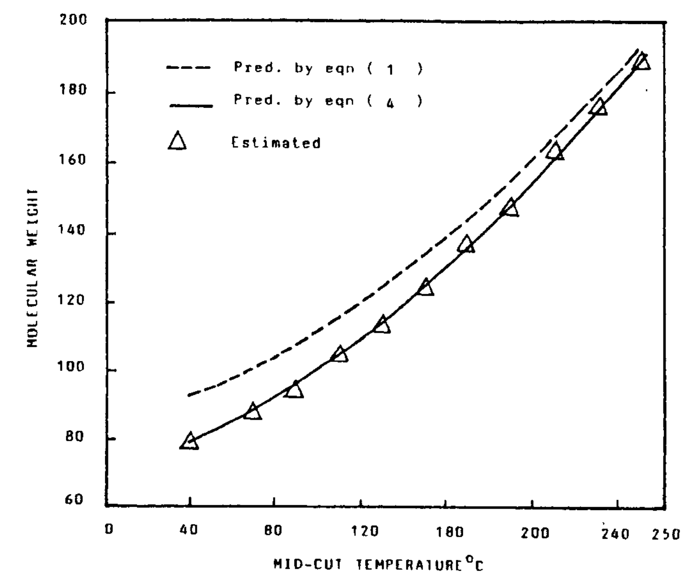

FIG. 2. Comparison of estimated and predicted molecular weight for Saudi Arabian crude cuts.

Further testing of equation (5), which was performed on the data reported by Amin *et al.*[10,11,12], confirmed its general applicability. The AAD value of predicting those reported data is 3.86%.

Equation (5) can also be easily applied to predict various Saudi Arabian crude oil cuts specific gravity values if the molecular weight and T_m of the cut are known.

When equation (5) was applied for the prediction of the experimentally determined specific gravity values for both light and heavy Saudi Arabian crude oil cuts, an AAD value of 0.53% was obtained.

Equation (6) predicted the mean average boiling point temperature for light and heavy Saudi Arabian crude oil cuts with an AAD value of 1.05%. This equation coupled with equation (5) is helpful for the estimation of molecular weight of light and heavy Saudi Crude Oil cuts when only the specific gravity of the cut is known.

4. Conclusion

The percentage cumulative volume, the molecular weight, the specific gravity, the mid-cut temperature and the mean average boiling point temperature of light and heavy Saudi Arabian crude oil cuts can be easily and accurately predicted by the correlations developed in this study. The resulting accuracies of predictions were generally within acceptable limits and can be safely recommended for use.

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العلاقـة بـين الخواص الفـيزيائيـة لقطـفات بعض أنواع الزيت الخام السعودي

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المستخلص . من الممكن ايجاد علاقة بين الخواص الفيزيائية مثل الوزن الجزيئي والكثافة النوعية والحجم التراكمي لقطفات الزيت الخام السعودي الخفيف والثقيل ودرجات غليان تلك القـطفـات ، إذا عُرفت أحجامها التزايدية من خلال عملية التقطير ذات درجات الغليان الحقيقية . وقد تم توليف البيانات الناتجة من التجارب المعملية باستخدام طريقة تحليل الارتداد لتقدير الخواص الفيزيائية المختلفة للقطفات .

وبشكـل عام فإن العـلاقـات التي أُوجِدت قد أعطت تقديرات للخواص الفيزيائية المختلفة ضمن حدود الدقة المقبولة . كما توافقت التقديرات التي أعطيتها هذه العلاقات بشكل جيد مع البيانات المتوافرة في الأبحاث المنشورة عن الزيت الخام السعودي .

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