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Original article

Prediction of the Kinematic Viscosity of Libyan Crude Oil as a Function of its Specific Gravity as One Input Data

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ABSTRACT

The prediction of the kinematic viscosity of some Libyan crude oils based on its specific gravity as one input parameter has been investigated. The correlation was developed in order to improve on the accuracy of existing correlations and to assist oil kinematic viscosity where the knowledge of viscosity of uncharacterized crude oils is required. The data used to build the correlation consist of measurements from 4 crude oils from various locations around Libya, the range from 0.81 to 0.84 g/cm3, resulting in kinematic viscosity values ranging from 5 – 11 mm2/s. The correlation can be used as far as the specific gravities' values are available. When a single specific gravity measurement is available at 15oC, it can predict the viscosity at 40 oC with an average absolute deviation (AAD) of 6.58%, which is an improvement in accuracy compared to previously published correlations (Puttagunta) with the kinematic viscosity at 37.8 as one input for kinematic viscosity prediction was 7.17%. Finally, when a t-test which is an inferential statistic used to determine if there is a significant difference between the means of experimental and theoretical data of kinematic viscosity, the difference was considered to be not statistically significant. It is worth noting that the required input for this equation is only the specific gravity.

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INTRODUCTION

The characteristic of crude oil that characterizes its resistance to movement, mostly as a result of collisions, electrostatic forces, and hydrogen bonding between its molecules traveling in various directions and at varying speeds, is called viscosity. This feature is crucial for modeling reservoirs, designing production and transportation machinery, and designing processing facilities in crude oil refineries [1]. Since the fluid's composition and physical characteristics, including viscosity, are always changing, estimating viscosity becomes necessary because initial estimates are no longer reliable [2].

For the purpose of estimating the kinematic viscosity of crude oils and hydrocarbon blends, many of published papers predictive models and relationships exist. Theoretical models and empirical correlations are the two general categories into which they fall [3].

Table 1. List of the most common correlations and their corresponding accuracy in kinematic viscosity prediction of crude oil.

Equation type	Input data	% AAD	References
Eyring's Equation	T_b, SG	37.22	[4]
Beg's Equation	T_b, SG	7.40	[5]
Dutt's Equation	T_b	6.31	[6]
Mehrotra's Equation	T_b	5.00	[7]
Aboul-Seoud's Equation	T_b, SG	3.05	[8]
Puttagunta's Equation	V	1.59	[9]

Where Tb = 50% mass boiling point, which is the temperature where 50% of the mass of a sample has been distilled; SG = specific gravity; ν = kinematic viscosity@ 37.8 oC; AAD = average absolute deviation.

Theoretical models usually more complicated and requiring a better characterization of the oil, including factors like critical qualities, chemical composition, acentric factor, or other properties that are unavailable. In the other hand theoretical models are typically more accurate. In order to extrapolate the viscosity to a different temperature and usually simpler and just require a few fundamental data, such as the oil's specific gravity and mid-boiling point temperature, or alternatively, a single viscosity test.One of the three equations created by Vogel (1921), Walther (1931), or Andrade (1934), respectively, serves as the basis for the majority of empirical correlations [10].

The objective of this study was to create or improve the existing correlations, without increasing the input parameters, so that a better predictive tool is available, especially for whole crude oils. To verify the results obtained from this work, The Puttagunta equation [9] was used for a comparison, which proposed a relatively more accurate correlation which requires a single viscosity measurement at 37.78°C and atmospheric pressure to make the prediction (Table 1). Briefly, the viscosity at a different temperature can be estimated by this equation:

$$\ln[ln(v + 0.8)] = ln[ln(v_0 + 0.8)] + a_2 \ln\left({}^{T}/_{T_0}\right)$$

where ν = predicted kinematic viscosity (cSt), T = temperature of prediction (K), νo = measured kinematic viscosity (cSt) and to = temperature of the viscosity measurement (K). Estimated the value of a_2 to be equal to -3.7 this value was confirmed recently by Kotzakoulakis and George (2017) [2].

METHODS

Specific gravity measurements

Every sample was measured precisely in accordance with ASTM D1298-12b(2017) [11]. This test method covers the determination of the specific gravity of crude oils that are typically handled as liquids and have a Reid vapor pressure of 101.325 kPa or less. In a laboratory setting using a glass hydrometer in conjunction with a series of calculations. Values are calculated using a number of formulas and international standard tables, and they are then adjusted to 15 °C at the current temperature.

Kinematic viscosity at 40 oC measurements

Kinematic viscosity was measured in accordance with ASTM D445-24 [12]. This test technique describes how to measure the time takes for a liquid to flow under gravity via a calibrated glass capillary viscometer in order to determine the kinematic viscosity, or ν, of liquid petroleum products, both clear and opaque. Multiplying the kinematic viscosity (ν) by the liquid's density (ρ) yields the dynamic viscosity (η).

RESULTS

This study aimed to investigate the relationship between the kinematic viscosity and the specific gravity of crude oil to enable the prediction of kinematic viscosity based on specific gravity. Samples were obtained from four Libyan oil fields: Al-Bayda, Hamada, Majid, and Sarir. The specific gravity and kinematic viscosity of crude oil samples from these fields were measured at a temperature of 40°C. The results for the pure samples are summarized in Table 2.

Table 2. Specific gravities value and kinematic viscosities at 40 ºCfor four Libyan oil fields used in this study.

Oil Field	Specific gravity (gcm^{-1})	Kinematic Viscosity (mm^2/s)
Albeda Crude	0.8370	10.52
Hamada Crude	0.8177	5.66
Majed Crude	0.8140	5.78
Sarir Crude	0.8205	7.69

Experimental Findings for Pure Samples

The results show variations in the specific gravity and kinematic viscosity among the crude oil samples from the four fields. These variations reflect the diverse chemical and physical properties of crude oil across different locations. Specific gravity values ranged from 0.8140 g/cm³ to 0.8370 g/cm³, while kinematic viscosity ranged from 5.66 mm²/s to 10.52 mm²/s.

Effect of Mixing on Specific Gravity and Kinematic Viscosity

To study the effect of mixing on these properties, the samples were blended with light naphtha (L.N) and heavy fuel oil (H.F.O) at mixing ratios of 10% and 20%. The purpose of mixing was to alter the specific gravity of the samples, reducing it with light naphtha and increasing it with heavy fuel oil. These additives were chosen due to their contrasting specific gravities, with light naphtha representing the lightest fraction and heavy fuel oil representing the heaviest fraction derived from the refining process. The mixing process yielded five samples for each field, including the pure sample and four mixed samples. The specific gravity and kinematic viscosity values for all samples are presented in table 3.

Table 3. Specific gravity at 15ºC value and kinematic viscosity at 40ºC For All samples.

Oil Field	Mix. Ratio	Specific Gravity (g/cm^3)	Kinematic Viscosity (mm^2/s)
Al-Bayda Oil Field	20:80 (L.N:Oil)	0.8051	4.30
	10:90 (L.N:Oil)	0.8268	7.01
	Pure	0.837	10.52
	10:90 (H.F.O:Oil)	0.839	11.57
	20:80 (H.F.O:Oil)	0.8411	11.90
Hamada Oil Field	20:80 (L.N:Oil)	0.7998	3.11
	10:90 (L.N:Oil)	0.8048	4.30
	Pure	0.8177	5.66
	10:90 (H.F.O:Oil)	0.8182	5.97
	20:80 (H.F.O:Oil)	0.8196	6.96
Majed Oil Field	20:80 (L.N:Oil)	0.7921	4.00
	10:90 (L.N:Oil)	0.8039	4.75
	Pure	0.814	5.78
	10:90 (H.F.O:Oil)	0.8143	6.10
	20:80 (H.F.O:Oil)	0.8155	6.23
Sarir Oil Field	20:80 (L.N:Oil)	0.8064	5.13
	10:90 (L.N:Oil)	0.8135	6.70
	Pure	0.8205	7.69
	10:90 (H.F.O:Oil)	0.8222	8.73
	20:80 (H.F.O:Oil)	0.8256	8.85

It was observed that as the specific gravity increased with the addition of heavy fuel oil, the kinematic viscosity also increased. Conversely, reductions in specific gravity through the addition of light naphtha resulted in lower kinematic viscosities.

Correlation Analysis

The relationship between the specific gravity and kinematic viscosity was evaluated for all samples. A strong linear correlation was identified, with a correlation coefficient of 0.8971, as illustrated in Figure 1. This finding suggests that specific gravity can serve as a reliable predictor of kinematic viscosity for crude oil samples within the studied range..

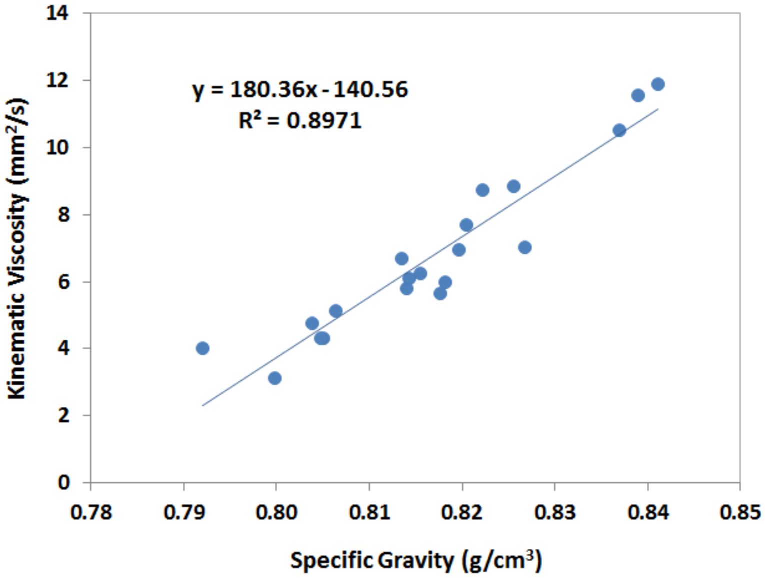

Figure 1. The relationship between the specific gravities and kinematic viscosities.

From the correlation analysis, a mathematical equation was derived to represent the relationship between the two properties at 40°C. The equation is as follows:

A = (180.36 × B) – 140.56 @ 40°C

Where:

A = Theoretical kinematic viscosity (mm²/s).

B = Specific gravity (g/cm³).

This equation was applied to the specific gravity values of the samples to calculate theoretical kinematic viscosities, which were then compared to the experimental values.

Comparison with Existing Models

To validate the derived equation, its predictions were compared with those obtained using Puttagunta's equation [9]. The predicted and experimental kinematic viscosity values for all samples are presented in Table 4.

Table 4. Comparison of the kinematic viscosity predicted (mm²/s) @ 40 °C by Puttagunta and this work.

Oil Field	Experimental Kinematic Viscosity (mm²/s)	Predicted Kinematic Viscosity (mm²/s) This work	Predicted Kinematic Viscosity (mm²/s) Puttagunta's Equation
Al-Bayda Oil Field	4.30	4.65	5.79
	7.01	8.56	6.30
	10.52	10.40	6.78
	11.57	10.76	6.90
	11.90	11.14	6.93
Hamada Oil Field	3.11	3.69	5.48
	4.30	4.59	5.79
	5.66	6.92	6.07
	5.97	7.01	6.13
	6.96	7.26	6.30
Majed Oil Field	4.00	2.30	5.72
	4.74	4.43	5.89
	5.78	6.25	6.09
	6.10	6.31	6.15
	6.23	6.52	6.17
Sarir Oil Field	5.13	4.88	5.97
	6.70	6.16	6.25

	7.69	7.43	6.41
	8.73	7.73	6.56
	8.85	8.35	6.57
AAD		6.58	7.17

DISCUSSION

The results indicate that the derived equation provides a robust and practical method for predicting kinematic viscosity from specific gravity. The strong correlation coefficient of 0.8971 demonstrates the reliability of the relationship across a range of crude oil samples.

The observed changes in kinematic viscosity with variations in specific gravity align with theoretical expectations. The addition of light naphtha, which reduced specific gravity, consistently decreased kinematic viscosity, while heavy fuel oil, which increased specific gravity, had the opposite effect. These results highlight the utility of blending for tailoring crude oil properties to specific processing requirements.

The comparison between the derived equation and Puttagunta's equation showed that the new equation provided superior predictions of kinematic viscosity, particularly for samples with higher specific gravity. The average absolute deviation (AAD) for the derived equation was 6.58, compared to 7.17 for Puttagunta's equation, as detailed in Table 4. This indicates that the derived equation is more accurate for the range of samples studied.

A t-test which is an inferential statistic used to determine if there is a significant difference between the means of experimental and theoretical values of kinematic viscosity of this work, and how they are related. The results of t-test of this study showed that the two-tailed P value equals (0.9446) and the mean of experimental results minus theoretical results equals (-0.0540) and (95%) confidence interval of this difference: From (-1.6181 to 1.5101) and by conventional criteria, this difference is considered to be not statistically significant.

The simplicity of the derived equation, which requires only specific gravity as an input, makes it particularly valuable for rapid and cost-effective analysis of crude oil properties. Since specific gravity is an easy and quick parameter to measure, this method offers a practical solution for field and laboratory applications.

While the derived equation performed well for the samples studied at 40°C, its applicability to other temperatures has yet to be tested. Future research should focus on extending the study to include measurements at different temperatures. This would allow for the development of temperature-specific equations, enhancing the versatility of the method and broadening its applicability to a wider range of operational conditions. Additionally, while the derived equation outperformed Puttagunta's equation, further comparisons with other existing models would provide a more comprehensive evaluation of its accuracy and robustness.

CONCLUSION

A new simple correlation for the prediction of crude oil viscosity has been successfully developed. The new correlation is applicable can be used when available data specific gravities in the range from 0.81 to 0.84 g/cm^3, and the predicted kinematic viscosity values ranging from 5 – 11 mm^2/s. When a single specific gravity at 15^{o}C, the equation from this work can be used to predict the viscosity at 40 ^{o}C with an average absolute deviation (AAD) of 6.58%, which is an improvement in accuracy compared to previously published correlations (Puttagunta) with the kinematic viscosity at 37.8 as one input for kinematic viscosity prediction was 7.17%. The statistical information (t-test) showed that the difference of the mean of experimental results and theoretical results is considered to be not statistically significant. The new correlation has eliminated the need to measure other parameters apart from the specific gravity of the crude oil at 15 ^{o}Cfor viscosity prediction which is usually already available. Finally, the present study describes an easy and effective method to estimate kinematic viscosity of the crude oils at 40 ^{o}C and maybe same work should be done to estimate the kinematic viscosity for the wide range of temperature.

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Conflicts of Interest

The authors declare no conflicts of interest.

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التنبؤ باللزوجة الحركية لبعض خامات النفط الليبية بناءً على معرفة نوع واحد من المتغيرات (الكثافة النوعية للنفط)

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المستخلص

تم التحقيق في معرفة قيمة اللزوجة الحركية لبعض خامات النفط الليبية باستخدام الكثافة النوعية كمعامل وحيد يتم ادخاله في علاقة رياضية للتنبؤ بقيمتها. حيث تم تطوير العلاقة بهدف تحسين دقة العلاقات السابقة المستخدمة لهذا الغرض والمساهمة في تقدير اللزوجة الحركية عند غياب بيانات دقيقة عن خامات النفط. استُخدمت بيانات مأخوذة من قياسات أربع خامات نفطية من مواقع مختلفة في ليبيا وهي خام ماجد والحمادة والسرير والبيضاء البيضاء ، حيث تراوحت قيم الجاذبية النوعية بين 0.8140 و0.8370 جم/سم^3، وأسفرت عن لزوجة حركية تتراوح بين 5 و11 مم^2/ثانية على التوالي. حيث نتج من معادلة الخط المستقيم علاقة يمكن استنتاج منها معادلة رياضية تكون ذات قيمة عند توفر الكثافة النوعية للنفط المراد تعيين لزوجته الحركية، فيمكن للعلاقة التنبؤ بلزوجة النفط عند درجة حرارة 40 مئوية بمتوسط انحراف مطلق (AAD) يبلغ 6.58%، مما يمثل تحسنًا في الدقة مقارنة بالعلاقات المنشورة سابقًا مثل علاقة (Puttagunta) التي مقدار الدقة لها 7.17%. أظهرت نتائج اختبار **t** في هذه الدراسة أن قيمة **P** ثنائية الطرف تساوي (0.9446)، وأن متوسط الفرق بين النتائج التجريبية والنتائج النظرية يساوي (-0.0540)، معدل ثقة بنسبة (95%) لهذا الفرق تتراوح بين (-1.6181 إلى 1.5101). ووفقًا للمعايير التقليدية، يعتبر هذا الفرق غير معنوي من الناحية الإحصائية مما يؤكد صلاحية هذه العلاقة لاستخدامها لمعرفة قيمة اللزوجة الحركية لخام النفط عند معرفة الكثافة النوعية فقط له.

الكلمات الدالة. ارتباط اللزوجة، النفط الخام، الوزن النوعي، معادلة بوتاجونتا، خصائص البترول.