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An experimentally investigate the effect of physical properties on the production of lubricating materials from crude oils

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Abstract

One of the most important oil derivatives in our time, which all the world seeks to obtain and produce a lot is lubricating oils, which are used for several important purposes and the most important is to keep the thermal engines from damage or collapse due to the phenomenon of friction of the moving parts mechanically at a high temperatures and pressure is relatively high as well as the wear phenomenon This research effort focuses on a comparative study of five types of mix crude Libyan oils (El-Feel Field, Al Wafa Field, Amina Field, Brega Field and Al-Sedra Field) for produced the lubricated oil experimentally . Test carried out on the production the lubrication oil by measuring the physical properties include: normal boiling point, pour point, specific gravity (Sp. gr.), standard density (API), dynamic viscosity (η), kinematics viscosity (ν), Acentric factor and Watson factor (K or K_w).

It's found from the practical results of the production the lubricating oil from crude oil for atmospheric distillation of crude oil practically depends on measurement two physical properties very accurately Watson factor first and then the API. The results from the tests showed that, mix crude oil of Amena, El-Sedra and El-Feel fields suitable than others for production the lubricated oil at atmospheric and then use the vacuum distillation columns. Other results observation, that's two others types are impossible to produce the lubricated oil. Also, the results observed that's the useful mole percentage of lubricated oil cutoff has range very

small from 2 to 17 % for these types of Libyan crude oils, this percentage will be increase when use vacuum distillation with added some additives materials.

In addition, practical results have been found that not all the cutoff produced from atmospheric distillation within the range of temperatures between 370 and 550 °C are lubricating oils, but other compounds are oil derivatives suitable for different fuel depending on the chemical structure of these extracts. The final conclusion of this work is that any crude oil with a light Arabic class (has a relative density API less than 38 and a K_w lower than 12.1) is suitable for the production of lubricated oils from the crude oil.

Keyword: physical properties of crude oil, lubricated oil, Libyan crude oil

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دراسة عملية لتوضيح تأثير الخواص الفيزيائية لإنتاج الزيوت من النفط الخام

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الخلاصة

من اهم المشتقات النفطية في وقتنا الحاضر الذي العالم جميعا يسعى الحصول عليها وانتاجها بكثرة هي زيوت التزيت والتي تستخدم لعدة أغراض مهمة واهمها هي الحفاظ على المحركات الحرارية من التلف او الانهيار بسبب ظاهرة الاحتكاك لاجزائها المتحركة ميكانيكا عند مستوى عالي من الدرجات الحرارية وضغط مرتفع نسبيا وكذلك التقليل بعض الاحيان أو القضاء على ظاهرتي الاحتكاك و البلى للمعادن الذي يحدث نتيجة هذه الحركة الميكانيكية المستمرة للاجزاء الصلبة مع بعضها البعض والتي قد تعمل لمدة 24 ساعة في اليوم .وبناءً على ذلك ، يركز هذا الجهد البحثي على دراسة مقارنة لخمسة أنواع من النفوط الخام اللببية وهي مزيج نفطي لكل من (حقل الفيل ، حقل الوفاء ، حقل أمانة ، حقل البريقة وحقل السدرة) لإنتاج الزيوت التزيت عمليا بالاعتماد على التقطير الجوي للنفط الخام وكذلك قياس الخواص الفيزيائية لهذه القطفات. ثم التقطير الفراغي للقطفات التي يتم الحصول عليها ضمن المدى من درجات الحرارة بين 370 الى 550 مئوي.

نلاحظ من النتائج العملية لانتاج زيوت التزيت وجد ان عند التقطير في برج الجوي والذي يتبعه تقطير تحت الضغط الجوي للنفوط الخام عمليا تعتمد كمية الانتاج لزيوت التزيت على خاصيتين فيزيائيتين يجب حسابهما بدقة وهما معامل واطسون اولا ثم بعد ذلك على الكثافة النسبية العالمية كما موضح في الجدول الثاني وان امكانية أنتاج زيوت التزيت لمزيج النفط الاول و الثالث والخامس ممكنة جدا وينسب معقولة ويزداد لو استخدمنا التقطير الفراغي للنسب المتبقية بعد درجة الحرارة الاكثر من 600 مئوي والتي سوف تزداد من النسبة الوزنية لقطفات زيوت التزيت ولايوجد قطفات معتبرة لزيوت التزيت للنفوط

الخام للمزيج النفطي للحقل الثاني والرابع وقد وجد هناك فرق واضح بين النسب الوزنية للقطفات التي تحتوي الاوزان الجزيئية لزيوت التزيت التي هي ضمن المدى لدرجات الحرارية للدراسات السابقة ضمن برج التقطير الجوي وبين حقيقة الكميات المنتجة من زيوت التزيت ضمن البرج الضغط المتخلخل.

وايضا تم التوصل من النتائج العملية ان ليس كل المركبات المنتجة من التقطير الجوي ضمن المدى لدرجات الحرارة بين 370 و 550 مئوي هي عبارة عن زيوت التزيت وانما هي مركبات أخرى عبارة عن مشتقات نفطية تصلح كوقود مختلف اعتمادا على التركيب الكيميائي لهذه القطفات. والاستنتاج الاخير من هذا البحث ان النفوط الخام ذو الصنف العربي الخفيف والمتوسط (اي لها كثافة نسبية قياسية أقل من 38 ومعامل واطسون أصغر من 12.1) صالحة لانتاج زيوت التزيت من النفط الخام باستخدام برج التقطير الجوي والمتخلخل تواليا.

1. Introduction

It is important to determine the physical and chemical characterizations of crude oil through a crude oil assay, since they are used in different areas in the petroleum refining industry. The most common applications of petroleum assays are:

1. To supply engineering companies with detailed crude oil analyses for their process design of petroleum refining plants.
2. To determine if during refining the crude oil will meet environmental and other standards.
3. To provide extensive detailed experimental data for refiners to establish the compatibility of a crude oil for a particular petroleum refinery.
4. To anticipate if the crude oil will fulfill the required product yield, quality, and production.
5. To help refiners to make decisions about changes in plant operation, development of product schedules, and examination of future processing ventures. The schematic diagram of refinery process is illustrated in the next figure.

Crude Oil Refining

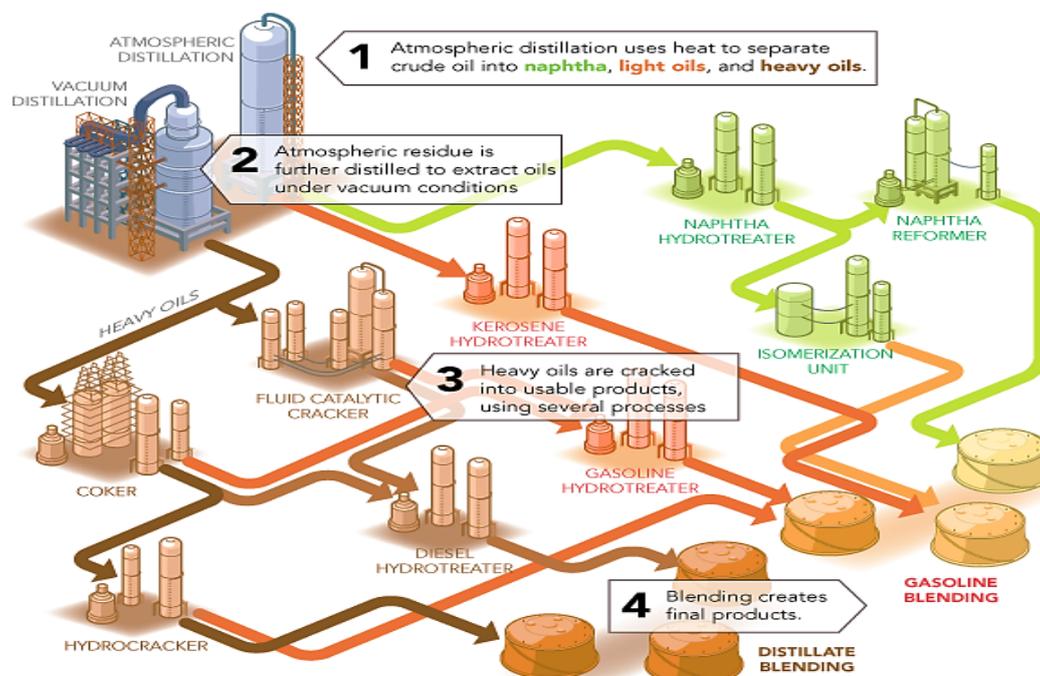


Fig. 1 Production Process Schematic for Crude Oil Refining [10]

A crude oil assay is a compilation of laboratory (physical and chemical properties) and pilot - plant (distillation and product fractionation) data that characterize a specific crude oil. Assay analyses of whole crude oils are carried out by combining atmospheric and vacuum distillation units, which when combined will provide a true boiling - point (TBP) distillation. These batch distillation methods, although taking between 3 and 5 days, allow the collection of a sufficient amount of distillation fractions for use in further testing. The values of the distillation ranges of the distilled fractions are usually defined as summarized in the next table.

Table 1 Typical Distillation Range of Fractions in Petroleum Assays

TBP Distillation Range (° C)	Distillate
TBP – 71	Light straight - run naphtha
71 – 177	Medium straight - run naphtha
177 – 204	Heavy straight - run naphtha
204 – 274	Jet fuel
274 – 316	Kerosene
316 – 343	Straight - run gasoil
343 – 454	Light vacuum gasoil
454 – 538	Heavy vacuum gasoil
370 – 550	Lubricated oil
R538 ° C +	Vacuum residue

On the basis of their refinery product classifications. The most common distillation ranges used in international assays of crude oils are reported in Table 1. There are various types of assays, which vary considerably in the amount of experimental information determined. Some include yields and properties of the streams used as feed for catalytic reforming (naphtha) and catalytic cracking (gas oils). Others give additional details for the potential production of lubricant oil or asphalt. At a minimum, the assay should contain a distillation curve (typically, TBP distillation) for the crude oil and a specific gravity curve. The most complete assay includes experimental characterization of the entire crude oil fraction and various boiling - range fractions. Curves of TBP, specific gravity, and sulfur content are normal data contained in a well – produced assay [13&14].

It is clear that light and heavy crude oils have remarkable differences. Heavy petroleum is characterized by low API gravity, large amounts of impurities, and low distillates yields; light petroleum is of much better quality. In general, the lower the API gravity (i.e., the heavier the crude oil), the higher the impurities content and the lower the distillates yield. Such properties make processing of heavy petroleum different from that used for light crude oil refining. In general, light crude oil is rich in light distillates, and heavy crude oil, in residuum. However, the petroleum composition may vary with its API gravity and origin. Physical properties and exact chemical composition of crude oil also vary from one source to another [Halder & et.al, 1984 and Malone, 1989]. Lubricated oil depend on viscosity. Viscosity is defined as the force acting on a unit area where the velocity gradient is equal at a given density of the fluid. Viscosity is strongly depending on the temperature. With increasing temperature, the viscosity has to be stated for a certain temperature. It is the characteristic of a liquid which relates a shearing stress to the viscosity gradient it produces in the liquid. Lubrication oils are identified by Society of Automotive Engineers (SAE) number. The SAE viscosity numbers are used by most automotive equipment manufacturers to describe the viscosity of the oil they recommend for use in their products. The greater or higher the SAE viscosity numbers, the more viscous or heavier is the lubricating oil (Coyler, (2000)). Viscosity numbers are given in terms of say bolt second universal, SSU. The addition of certain additives is for the improvement of viscosity-temperature characteristics. The important functions of lubricants are as follow (James, 2006).

1. It reduces wear and tear of the surfaces by avoiding direct metal to metal contact between the rubbing surfaces, i.e. by introducing lubricants between the two surfaces.
2. It reduces expansion of metal due to frictional heat and destruction of material.
3. It acts as coolant of metal due to heat transfer media.
4. It avoids unsmooth relative motion.
5. It reduces maintenance cost.
6. It also reduces power loss in internal combustion engines.

A lubricating oil becomes unfit for further use for two main reasons: accumulation of contaminants in the oil and chemical changes in the oil. The main contaminants are water content, soot, carbon and lead. Lubricated oil usually consists of a base fluid, generally of petroleum origin, combined with additive chemicals that enhance the various desirable

properties of the base fluid. Base fluids are essentially obtained from two main sources: the refining of petroleum crude oil and the synthesis of relatively pure compounds with properties that are suitable for lubricants. Oil from the automotive sources will include mono and multi-grade crankcase oils from petrol and diesel engines, together with industrial lubricants that have been inadequately segregated may also be included (Gergel and La Tour, 1977). Lubrication oil is used to provide a film between the moving parts of machine and engines to prevent wear with little or no loss of power. The conventional steps in lubricating oil manufacture are pretreatment of the crude oil charge, followed by distillation of the crude in two steps (an atmospheric tower and vacuum tower), deasphalting (as required by the nature of the crude oil charge), dewaxing, solvent extraction, filtering and blending including mixing various additives with the final lubricating oil (Nadkarni, 1991). The prime objective in the production of lubricating oil is the separation of wax distillate and cylinder stock without any decomposition or cracking of the lubrication oil fractions, thus a vacuum distillation unit is used to separate the wax distillate and the bottom stock at a lower temperature (Concawe 1993). The properties which make the high boiling paraffin hydrocarbon suitable for lubricating manufacture include stability at high temperatures, fluidity at low temperature, only a moderate change in viscosity over a broad temperature range and sufficient adhesiveness to keep it in place under high shear forces. The vacuum tower produces some fuel oil overhead which is sold as a separate product or sent to another area of the refinery for further processing and blending (Concawe 1997). The two main products from the vacuum tower are wax distillate and cylinder stock which is the bottom product. Both streams contain desirable lubricating oil constituents as well as by-products. The wax distillate is charged directly to the dewaxing unit. The vacuum tower bottoms, or cylinder stock are charged to deasphalting unit. These two fractions from the basic stock for lubricating oil manufacture (Hamad, 2005). Refining engineers analyze the True Boiling Points (TBP) curves of the cuts present to determine the behavior of the crude distilled and various saleable products [Liang & et.al, 2010]. Abdolhossein & et.al (2013) study the effect of interfacial tension and miscibility of the CO₂ in Iranian crude oil and at vacuum distillation system. Recently, Al-Jewaree, 2017 investigate a comparative work to measure the physical properties by a modern software with the practically laboratory process results for several types of crude oil. The results were very close and the difference is simple.

2. Experimental method:

The first step in petroleum refining is usually a desalting operation, followed by heating in a furnace where the oil is partially vaporized. The mixture of hot liquid and vapor enters a fractionating column operating at slightly above atmospheric pressure. This device separates groups of hydrocarbons according to their boiling range. A heavy black residuum is drawn from the bottom of the atmospheric tower. Because the residuum tends to decompose at temperatures above 700°F (371°C), higher boiling oils such as lubricating oils must be distilled off in a separate vacuum fractionating tower. The greatly reduced pressure in the tower markedly lowers the boiling points of the desired oil compounds. Bottom materials from the vacuum tower are either used for asphalt or are further processed for other materials such as bright stocks. The fractions separated by crude distillation are referred to as "straight run" products. Petroleum lubricating oils are made from the higher boiling portion of the crude oil that remains after removal of the lighter fractions. They are prepared from crude oils obtained from most parts of the world. These crude oils differ widely in properties. An example of the complexity of the lubricating oil refining problem is the variation that can exist in a single hydrocarbon molecule with a specific number of carbon atoms. A paraffinic molecule with 25 carbon atoms, representing a compound falling well within the normal lubricating oil range, would have 52 hydrogen atoms and could have about 37 million different molecular arrangements. The schematic diagram of two types of distillation tower are shown in figure 2, which are needed for production the real weight percentage of lubricants.

Standard ASTM D-2887 is a simulated distillation standard up to approximately 540°C (1,000°F) atmospheric equivalent boiling point. However, recent efforts have focused on extending the range up to 650°C (1,200°F). This test method is one of a number of tests conducted on a crude oil to determine its value. It provides an estimate of the yields of fractions of various boiling ranges and is therefore valuable in technical discussions of a commercial nature. The fractions produced can be analysed as produced or combined to produce samples

for analytical studies, engineering, and product quality evaluations. The method used in this work to obtain the experimental percentage weight curve was performed under conditions established in ASTM D 482. The properties of most light weight distillate Arab oil are: API grade density and specific gravity at 15.6 °C, Watson factor and other physical properties are measured under standard ASTM D1298.

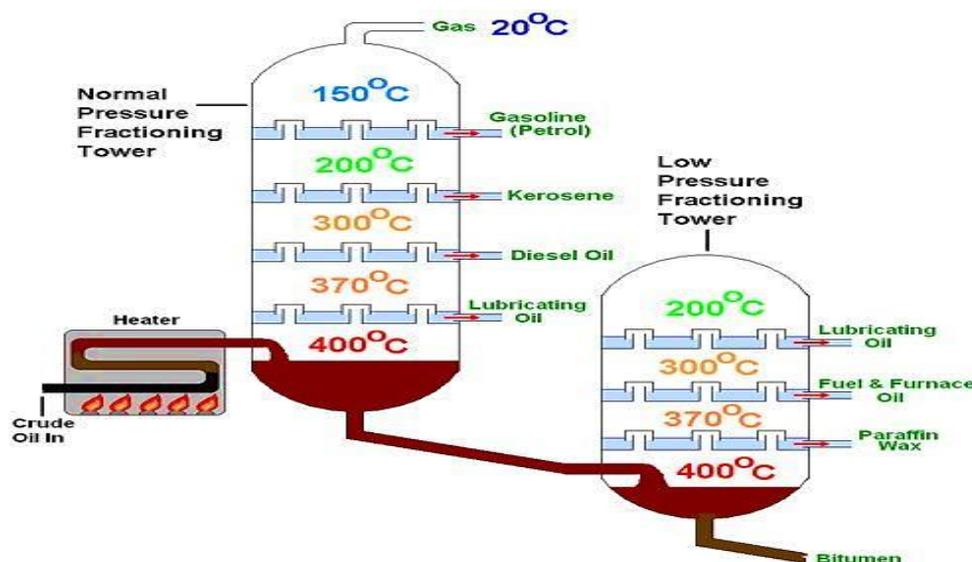


Fig. 2 Schematic diagram of two distillation towers [10]

3. Results and Dissuasions:

Five types of Libyan crude oil are used for our experimental work to examine the possibility of production the lubricated oil. This done by measured the physical properties at laboratories of Libyan petroleum Institute. These types are named as follow: Blend-1 is El-Feel oil field mix, Blend-2 is El-Wafa oil field mix, Blend-3 is Amena oil field mix, Blend-4 is El-Brega oil field mix and Blend-5 is El-Sadra oil field mix. The experimental results for above physical properties to these types of Libyan crude oil are done by automatic atmospheric distillation column as illustrated in next figure.

Cutoff oC	Cumulative Yield wt.% [Blend1]	Cumulative Yield wt.% [Blend2]	Cumulative Yield wt.%% [Blend3]	Cumulative Yield wt.% [Blend4]	Cumulative Yield % [Blend5]
5 - 50	3.9	9.8	2.6	5.78	3.96
50 - 70	5.15	17.61	4.75	6.83	5.66
70 -90	7.2	21.9	7.22	8.95	7.64
90-110	11.43	31	9.74	11.44	10.75
110-130	16.35	37.4	12.78	14.93	14.39
130-150	20.5	43.22	16	19.48	17.43
150-170	28.73	48.65	18.9	23.7	21.1
170-190	31.24	53.2	22.15	31.2	23.57
190-210	35.65	55.3	24.87	36.54	26.85
210-230	40.24	58.73	28.23	40.64	30.33
230-250	44.85	61.86	32.07	44.86	33.57
250-270	48.73	63.67	35.44	48.8	37.65
270-290	52.88	65.1	39.13	52.9	41.12
290-310	56.78	68.83	42.85	55.65	44.86
310-330	61.2	70.22	45.74	59.2	48.73
330-350	64.13	72.57	48.78	62.4	52.44
350-370	67	74.8	50.06	65.74	56.92
370-410	71.8	77.65	51.11	73.36	60.45
410-430	74	79.8	55.83	75.24	64.62
430-450	77.54	82.48	63.42	77.56	68.55
450-470	83.25	84.55	67.65	80.72	70.83
470-490	89.65	86.55	69.87	84.2	73.66
490-510	90.45	90.36	71.68	86.3	80.25
510-530	91.87	93.47	73.47	88.46	82.34
530-550	93.5	95.1	75.56	92.26	83.8
550-570	95.3	97.54	78.93	94.34	86.53
570-590	96.5	99.1	80.22	98.67	88.1
590-610	100	100	83.57	100	90.35
>610			100		100

Table 2 The results of atmospheric distillation for five Libyan crude oils

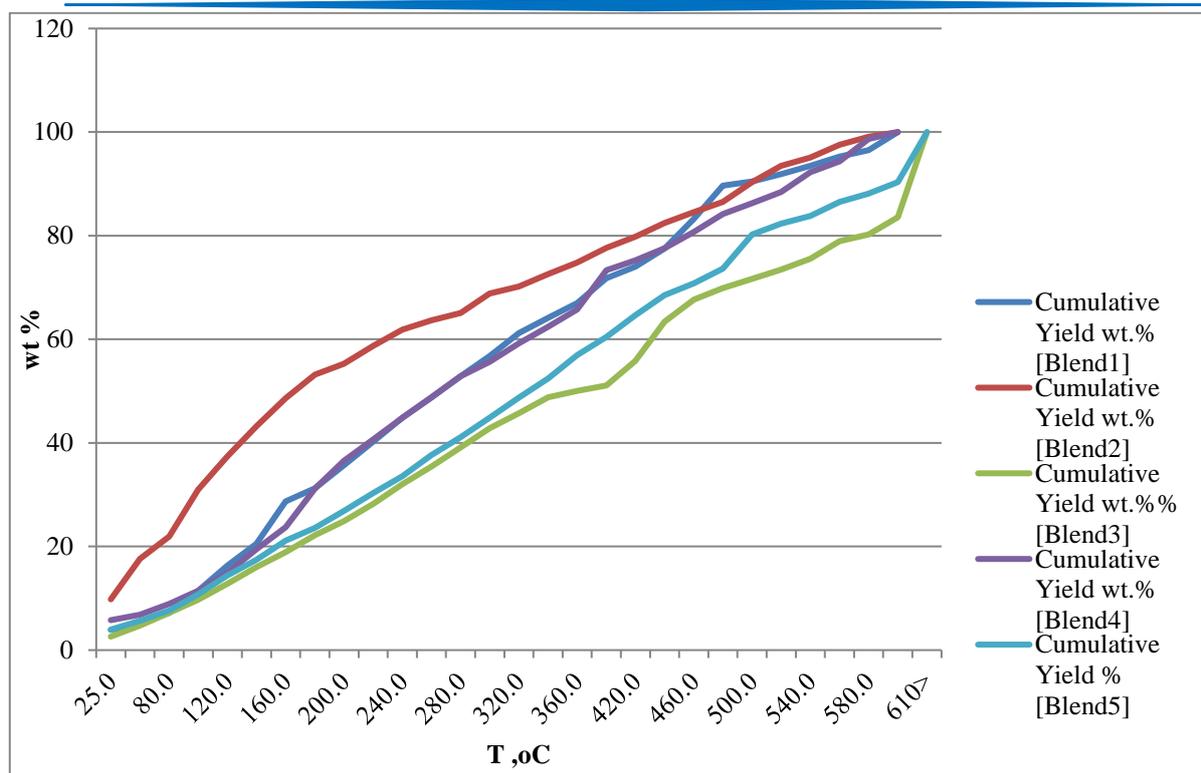


Fig. 3 The cumulative yield of cutoff wt % for the range of distillation temperature to the five Libyan crude oil mix Blends

Table 3 The results of the range of Lubricated oil cutoff to both methods of distillations the suitable range of temperature from 370 to 550 °C

Blend	API	Wt % of Lubricated oil Cutoff by Atmospheric distillation	Actual wt.% of Lubricated oil by Vacuum distillation	Watson Factor
Blend-1	38.4	21.75%	16.75%	11.85
Blend-2	56.3	17.48%	1.78%	12.57
Blend-3	36.7	24.45%	14.15%	12.3
Blend-4	42.6	18.9%	4.9 %	12.1
Blend-5	37.8	23.35%	14.75%	12

The results for five Libyan crude oils are drawn in the next bars figures. It can be deduce from this results, that's very different in physical properties due they comes from different area and each of them has different geology and history. They have different API and Watson factor and these leads to different weight percentage of lubricated oil as summarized in table 3.

In petroleum industry, API gravity is widely used to qualify the petroleum fractions which was introduced by the American Petroleum Institute (API). The API gravity is defined as: [8]

$$\text{API gravity} = [141.5 \setminus \text{S.G (60 } ^\circ\text{F)}] - 131.5$$

Generally, API gravity values are higher for light hydrocarbon fractions and lower for heavy hydrocarbon fractions. Sometimes, it has been used as an input parameter with Watson characterization factor (K_w) to predict the properties such as molecular weights and kinematic viscosities of the fractions. But in our work these two parameters has predict and indicate the lubricated oil cutoff.

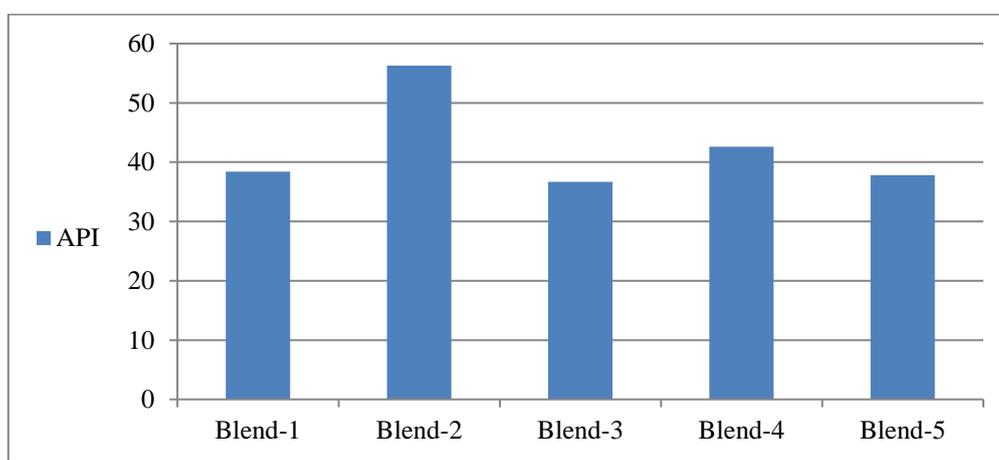


Fig. 4 Bar graph shown the experimentally of API to the five Libyan crude oil mix

The Watson characterization factor (K_w) is one of the oldest characterization factors originally defined by Watson et al. of the Universal Oil Products (UOP) in mid 1930s. This parameter is defined as [7]:

$$K_w = \frac{T_b^{1/3}}{SG} \quad \text{where } T_b = \text{normal boiling point } ^\circ R$$

The naphthenic hydrocarbons have K_w values between paraffinic and aromatic compounds. In general, aromatics have low K_w values while paraffin's have high values. The minimum value is found about 11.8 for El-Feel oil mix field and another's two Blends

(4& 5) has value less than 12.1, that's means these crude oils have a paraffinic – naphthenic compounds. While Blends (2 & 3) have paraffinic compounds only because the K_w more than 12.1.

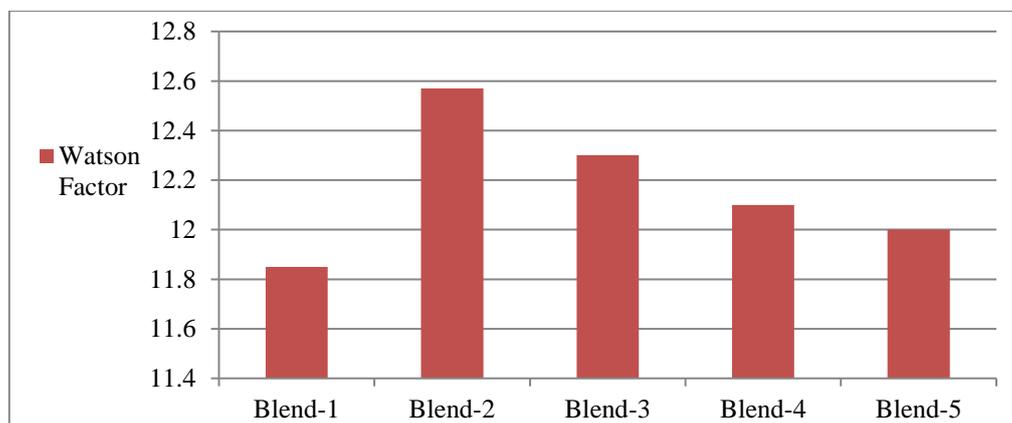


Fig. 5 Bar graph shown the experimentally of Watson factor [K_w] to the five Libyan crude oil mix

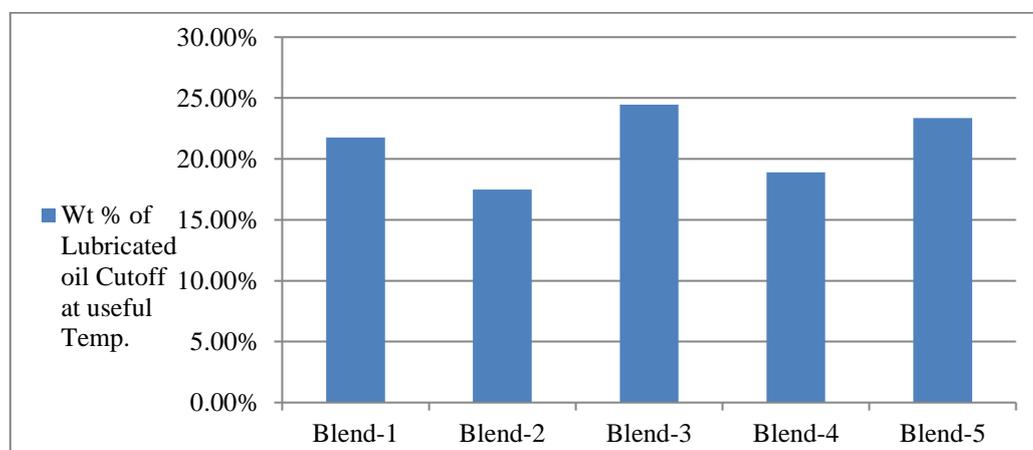


Fig. 6 Bar graph shown of lubricated oil cutoff from the Atmospheric distillation at useful range of temperature

Normally, the heavy hydrocarbons in crude oil undergo a cracking process beyond 370°C; the cracking process where heavy hydrocarbons start to decompose in to small hydrocarbon chains. To avoid this decomposition of hydrocarbons, the further distillation operations after atmospheric (the distillation above 370°C) are conducted under vacuum or at reduced pressure.

The vacuum distillation not only helps to avoid the cracking of hydrocarbons, but also reduces the boiling points of heavy hydrocarbons in order to achieve more and more boiling points for the crude oil without any significant cracking. The vacuum distillation column in the lab work at pressure from 100 to 250 mm consist of (1) the feed input crude oil, (2) vacuum distillation column, (3) the lubricated oil cutoff and (4) control pressure valve as illustrated in figure 7.



Fig. 7 Vacuums distillation for the useful cutoff come from the range of 370 to 550 °C

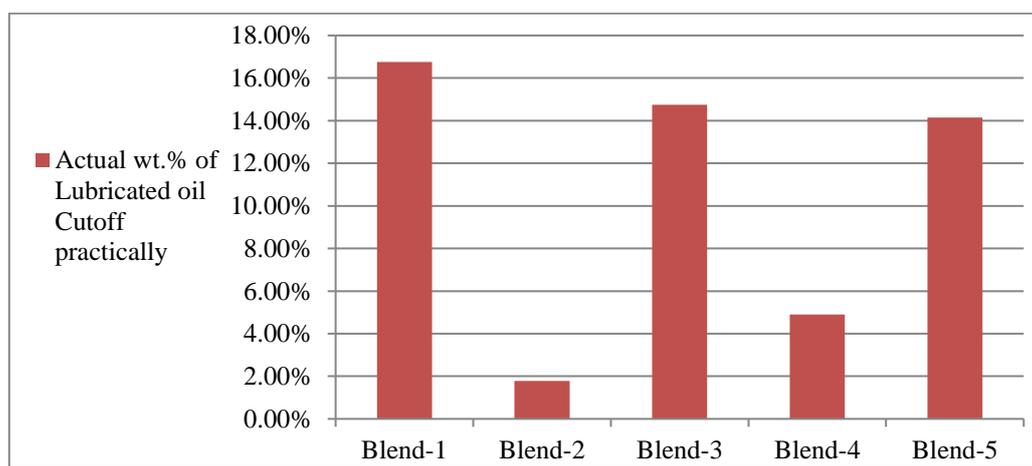


Fig. 8 Bar graph shown actual wt% of lubricated oil gain from vacuum distillation

The results of vacuum distillation are illustrated that's, blends (1,3 and 5) are suitable for production the lubricated oil cutoff due the API no. less than 40 and Watson factor less than 12.1.

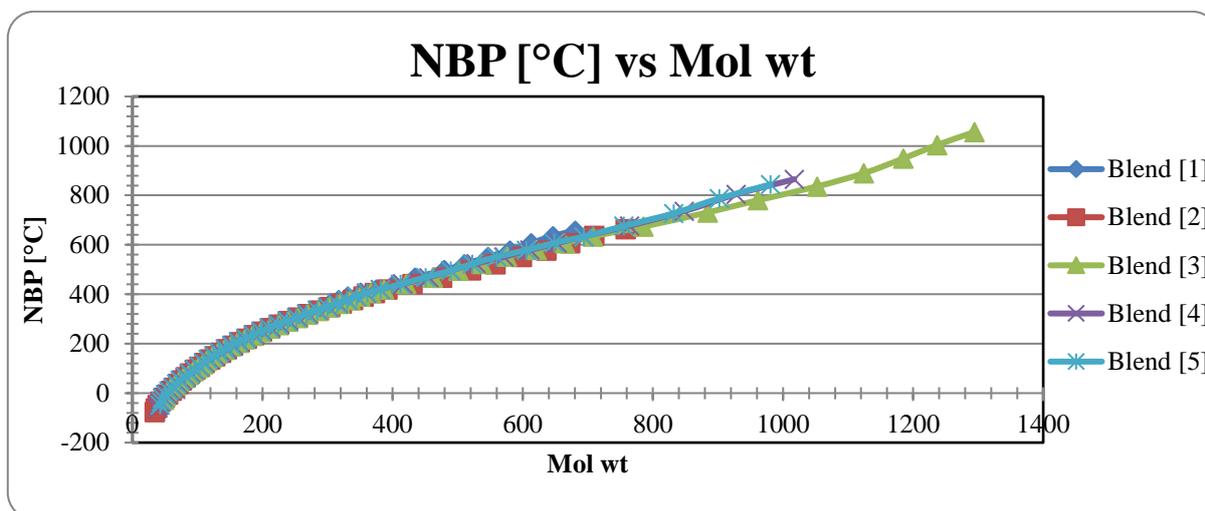


Fig. 9 Normal boiling Point with Molecular weight for different Libyan Blends

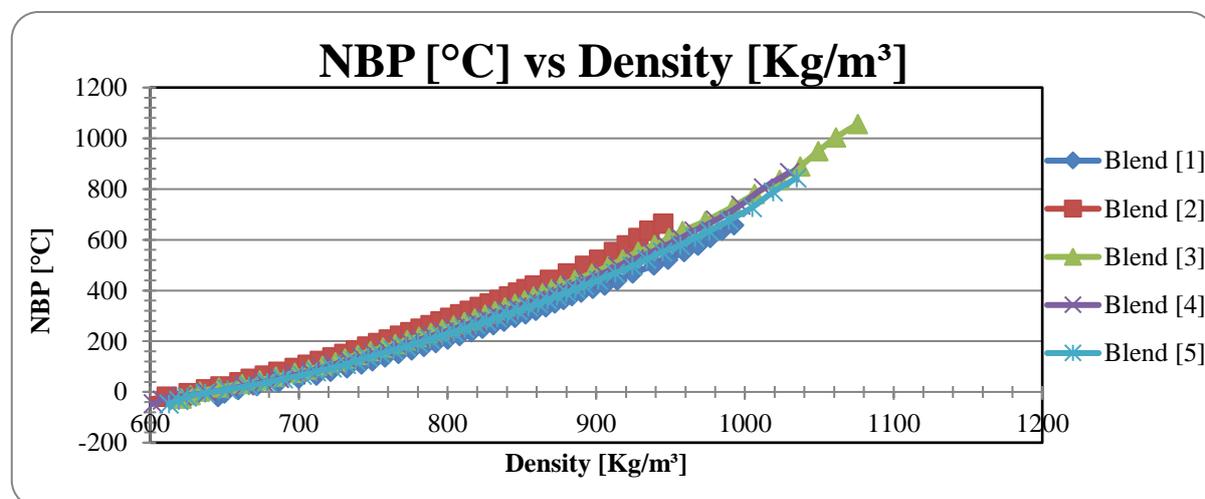


Fig. 10 Normal Boiling Point with density for different Libyan oil Blends

It's clear from the above results at atmospheric distillation of five types of crude oil. Blend-3 has a wide range of molecular weight from 22 to 1295 gm\mole due to the lowering stander specific gravity API=36.7 with small different on Blend 5 at the normal boiling oil temperatures. Blends 2 and 4 has lower molecular weight range for the same range of cutoff

temperatures. Also, as shown in figure 7, the Blend -3 has a high range of cutoff densities from 600 to 1076 kg\m³ and these also indication for suitable lubricated oil cutoff.

The normal boiling point is very important to approach the possibility of production the lubricated oil by examine the molecular weights of distilled crude oil in the range between 370 to 550 C^o, at atmospheric distillation.

4. Conclusions

It can be concludes from this research work, that's the experimental results of the production of lubricating oil from any crude oils found that when the atmospheric distillation of crude oil practically results depends on two physical properties must be calculated accurately Watson factor first and then on the specific relative density API as shown in table 3. Also, the possibility of production lubricating oils from the Blend-1, Blend-3 and Blend-5 are suitable for atmospheric distillation and this increasing, if we use the vacuum distillation. There is a clear difference between the weight percentages of the plate's cutoff, which are containing the molecular weights of the lubricated oils within the range of temperature degrees [370 to 550 °C] in the atmospheric distillation tower with the actual that the quantities produced from the lubricating oils to each crude oil by vacuum distillation tower. The final conclusion of this research is that crude oils classify of medium and low light Arabic crude oil (i.e., API less than 38 and Watson factor less than 12.1) are suitable for the production of lubricating oils.

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