

Transformer oils prepared from the vacuum distillates of Egyptian crude paraffinic petroleum

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Vacuum gas oil and spindle oil obtained from the vacuum distillation of paraffinic crude oil from the Western Desert region of Egypt were utilized for transformer oils production. The vacuum gas oil, spindle oil and blends therefrom containing different percentages of these oils were subjected to aromatic extraction, dewaxing and catalytic hydrogenation processes. The aromatic extraction process used N-methyl-2-pyrrolidone as solvent, for a feed ratio of 0.7 : 1 (wt/wt) at an extraction temperature of 55 °C, while in the dewaxing process the wax is removed by chilling the raffinate at -42 °C using MEK-toluene (60 : 40, vol/vol). The hydrofinishing process was achieved in a pilot plant using NiO-MoO₃/Al₂O₃ catalyst. These refining processes improved the viscosity indices, the pour points of the resulting oils and removed most of the polar impurities. It was found that, the transformer oil formulated from 7:3 b.w. vacuum gas oil : spindle oil respectively meets the IEC 60296-2003 standard specifications requirements. Its sulfur content is very low and non corrosive. The gassing tendency is also low due to its low aromatic content. Further, the electrical properties which are significant for transformer oils fulfill the standard specifications as a result of the low water content and polar contaminants. Moreover, addition of 2,4-dimethyl-6-tertiarybutyl phenol increases the oxidation stability of the produced oil, by acting as a free radical inhibitor.

تم دراسة إمكانية إنتاج زيوت محولات من زيت المغازل والسولار التقريغي والتي تم الحصول عليهما من خلال عملية التقطير التقريغي لخليط من خامات الصحراء الغربية. وقد تم إجراء عمليات استخلاص للمواد العطرية وإزالة المواد الشمعية وكذلك إجراء عملية هدرجة في وجود العوامل الحفازة وذلك لكل من زيت المغازل والسولار التقريغي وكذلك لخلطات بنسب مختلفة لكلا منهما. ولقد تمت عملية استخلاص المواد العطرية باستخدام مذيب ن-ميثيل-2-بيروليدون بنسبة 0,7 : 1 بالوزن (مذيب: تغذية) على الترتيب عند درجة حرارة استخلاص 55 °م، وتمت عملية إزالة الشموع باستخدام خليط حجمي من مذيب ميثيل إيثيل الكيتون والتولوين (3:2) وذلك بتبريد الرافينات إلى -42 °م، وتمت عملية الهدرجة من خلال وحدة هدرجة (Pilot plant) وذلك على سطح العامل الحفاز المكون من أكاسيد النيكل والموليبدنوم المحمولة على طبقات من أكسيد الألومنيوم. وأدت هذه العمليات إلى تحسين معاملات اللزوجة ودرجات الإنسكاب للزيوت الناتجة بالإضافة إلى إزالة الشوائب. وقد أمكن الحصول على زيت محولات مطابق للمواصفات العالمية (IEC 60296-2003) من الخلطة المحتوية على 30% من زيت المغازل مع 70% من السولار التقريغي. ولقد وجد أن نسبة الكبريت لهذا الزيت منخفضة جداً ولا تسبب تآكل وميله لتكوين غازات منخفض أيضاً نظراً لانخفاض نسبة المواد العطرية، كما أن مواصفات هذا الزيت الكهربائية والخاصة بزيوت المحولات مطابقة للمواصفات العالمية نتيجة انخفاض نسبة المياه والشوائب القطبية. وقد أدى إضافة مضاد الأكسدة 2,4-dimethyl-6-tertiary butyl phenol والذي يعمل كمثبط للشق الحر إلى زيادة الثبات ضد الأكسدة لهذا الزيت المنتج.

Keywords: Transformer oils, Vacuum gas oil, Spindle oil, Petroleum refining, Anti-oxidants, 2, 4-dimethyl-6-tertiarybutyl phenol, Specifications of transformer oils

1. Introduction

Transformer oils are an important class of insulating oils. They act as heat transfer medium so that the operating temperature of a transformer does not exceed specific acceptable limits. Transformer oils must have: (1) low viscosity for easy flow and efficient heat transfer, (2) low pour point when using the oil in cold outdoor weather service, (3) low solvency power, (4) high oxidation stability, (5)

reduced gassing tendency, (6) high flash point to reduce fire risk, (7) low vapor pressure at high temperatures, and (8) negligible amounts of contaminants which have adverse effects on the electrical properties [1].

In general, transformer oils are produced from wax-free naphthenic oils. Although these types of crudes permit production of exceptionally low pour point insulating oils without the need for dewaxing or special attention to the degree of fractionation or

distillate cut width, they also contain high percentages of sulfur and nitrogen which must be removed in order to satisfy the stringent stability requirements of insulating oils [2]. It has been found that a highly aromatic, low paraffinic content naphthenic crude oil is a suitable raw material to prepare a good transformer oil. Aromatics have very good stability properties and act as natural oxidation inhibitors. To achieve the right aromatic content, the surplus should either be transformed to naphthenes by using a suitable refining technique, or removed by solvent extraction [3].

However, the aforementioned types of crude oils are not native to many parts of the world and consequently command premium prices and involve high transportation costs. Extremely stable insulating oils produced from paraffinic crudes by conventional dewaxing techniques, are also used in certain applications, where moderate climatic conditions do not demand oils with especially low pour point [2]. Transformer oils with very low pour point are produced through solvent extraction of a narrow cut distillate from paraffinic crude [4-7]. Solvent dearomatization is a process that separates hydrocarbon mixtures into two phases, a raffinate phase which contains substances of relatively high hydrogen to carbon ratio and an aromatic extract phase. Solvent extraction of aromatics serves to improve the quality of lubricating oils in terms of Viscosity Index (VI). The process also removes other undesirable constituents, which may result in rapid darkening, oxidation, and sludge in service. However, intense solvent extraction processes may also remove natural corrosion inhibitors [8]. The process applies any solvent known to have an affinity for aromatic hydrocarbons in preference to non-aromatic hydrocarbons. Examples of such solvents include: sulfolane, furfural, phenol, N-Methyl-2-Pyrrolidone (NMP) [9]. The solvent dearomatization process is followed by solvent dewaxing of the raffinate under liquid-liquid immiscible conditions. Solvent dewaxing is used to lower the pour point of the dewaxed oil (DWO) through wax removal where presence of wax in oil is considered objectionable, as wax crystallizes from the oil at relatively high temperatures and causes loss

of fluidity and prevents the normal circulation of oil in the transformer [7]. Wax can also be removed from oil by chilling the waxy material to a low temperature and filtering. A diluent is required to enable the chilled material to be filtered [9]. In selecting a solvent two requirements are sought: (1) high solubility of the oil in the solvent, (2) high rejection of the wax by the solvent. Although some single solvents do combine these functions, pairs of solvents enable the two effects to be controlled independently. Generally the oil solvent is called the solvent and the wax rejecting solvent is called the anti-solvent. A number of pairs of solvents are used commercially including benzene-acetone, toluene-MEK and methylene chloride-dichloroethane [10-12]. The recovered low pour point oil should be subjected to various finishing operations. In addition, various inhibitors and other additive ingredients such as anti-oxidants, pour point depressants and stabilizers should be added in order to provide final lube oil products [1]. Abou El-Naga et al. [13] found that an Egyptian paraffinic basestock can be used to produce a transformer oil through dewaxing the oil at -30°C using MEK-toluene mixed solvents and reacting the dewaxed oil with either dry SO_3 or fuming sulfuric acid to remove sulfur, nitrogen and the more active aromatic compounds. The produced transformer oil has a breakdown voltage higher than 50 KV and a pour point equal to -12°C .

Due to the high performance requirements of electrical oils, standard specifications were developed to assure their fulfillment. Transformer oils are classified according to the changes in climate and the expected use into three categories [14]: class I for tropical temperature climate; class II for higher cooling requirements; and class III for very cold climates and severe conditions. They differ in viscosity, pour point and flash point. According to these specifications petroleum distillates in the Vacuum Gas Oil (VGO) and spindle oil boiling point ranges are the most suitable fractions for formulating the transformer oils. The VGO and spindle oil are the lowest boiling point fractions obtained from vacuum distillation of atmospheric residue. They boil within the boiling point ranges of $260-330^{\circ}\text{C}$ and $330-410^{\circ}\text{C}$, respectively [9].

In view of these considerations, VGO and spindle oil produced from the Western Desert crude oil and blends there from containing different percentages of these petroleum distillation cuts were evaluated aiming to formulate a transformer oil that fulfills the required specifications from local crude oil. The effect of the addition of an anti-oxidant on the oxidation stability of the produced transformer oil was also investigated.

2. Experimental methods

2.1. Crude oil sample

A sample of oil stream shipped from El-hamra port in Alamein to the oil companies in Alexandria city for refining was used in the present study. It consists of a blend of crude oils from different oil fields located in the Western Desert of Egypt. The general characteristics of this oil are listed in table 1.

2.2. Vacuum distillation process

The VGO and spindle oil have too high boiling ranges to be distilled at atmospheric pressure without decomposition. Thus, the atmospheric residue of Western Desert crude oil was heated up to 330 °C under vacuum of 10 mm Hg to separate the vacuum gas oil fraction using the Claisen distillation apparatus shown in fig. 1. The residue was further heated up continuously to 410 °C under vacuum of 5 mmHg to separate the spindle oil fraction [12].

2.3. Solvent extraction process

The experimental set-up of the extraction operation is shown in fig. 2. The VGO, spindle oil and their blends (7:3, 1:1, and 3:7 b.w. spindle oil : VGO, respectively) were extracted using NMP as solvent. The applied solvent to feed ratio was 0.7:1 (wt/wt) [15]. The operation is conducted at extraction temperature 55°C under nitrogen atmosphere to prevent solvent oxidation, and with continuous stirring for about 30 minutes to ensure complete mass transfer between the two phases. These conditions were chosen

based on a previous work by Aly [15]. The mixture was transferred after cooling to a separating funnel and allowed to settle at room temperature. Two phases were collected: the aromatic extract phase (heavy phase) followed by the raffinate phase containing the lubricating oils [15]. The last traces of NMP were rotary evaporated under vacuum.

2.4. Dewaxing process

The wax was removed by chilling the produced raffinate to -42 °C in a special refrigerator (manufactured in Alexandria petroleum company workshops) using MEK-toluene (60: 40, vol/vol) as a dewaxing solvent. Toluene works as the oil solvent while MEK is the wax anti-solvent. The solvent to feed ratio was 4:1 (wt/wt). The cooled mixture was filtered at -42 °C using appropriate vacuum filters covered with synthetic cloth [9].

2.5. Hydrofinishing process

The produced DWOs were hydrofinished using hydrogen and nickel-molybdenum oxides supported on alumina ($\text{NiO-MoO}_3/\text{Al}_2\text{O}_3$) catalyst (commercial name: HR-348, supplied by Procatalyse France). The percentage weight of NiO and MoO₃ were 2.7 and 16.7, respectively. The MoO₃ and NiO functioned as the catalyst base and catalyst promoter respectively. Alumina is used as support because of its extremely low cracking activity. The catalyst was presulfided prior to the hydrofinishing process in presence of Hydrogen and Dimethyl Disulfide (DMDS). The DMDS is easily decomposed into hydrogen sulfide. When the hydrogen flow was stabilized, the reactor inlet temperature was raised to about 200 °C at a rate of 25 °C per hour. At 200 °C, DMDS was injected with DWO at about 1.5 weight percent of DMDS. After that, the temperature was raised to 275 °C at a rate of 15 °C per hour and it was kept constant until a noticeable quantity of H₂S was formed in the tail gas. The temperature was gradually

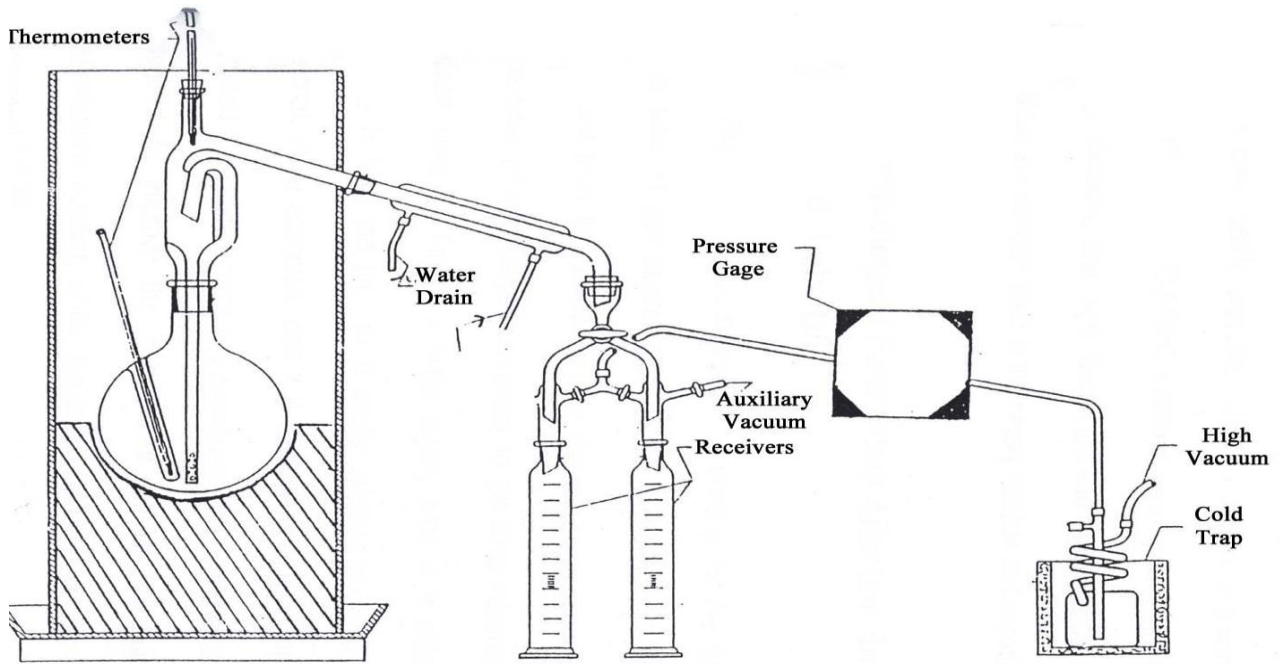


Fig. 1. Vacuum distillation using Claisen distillation apparatus [33].

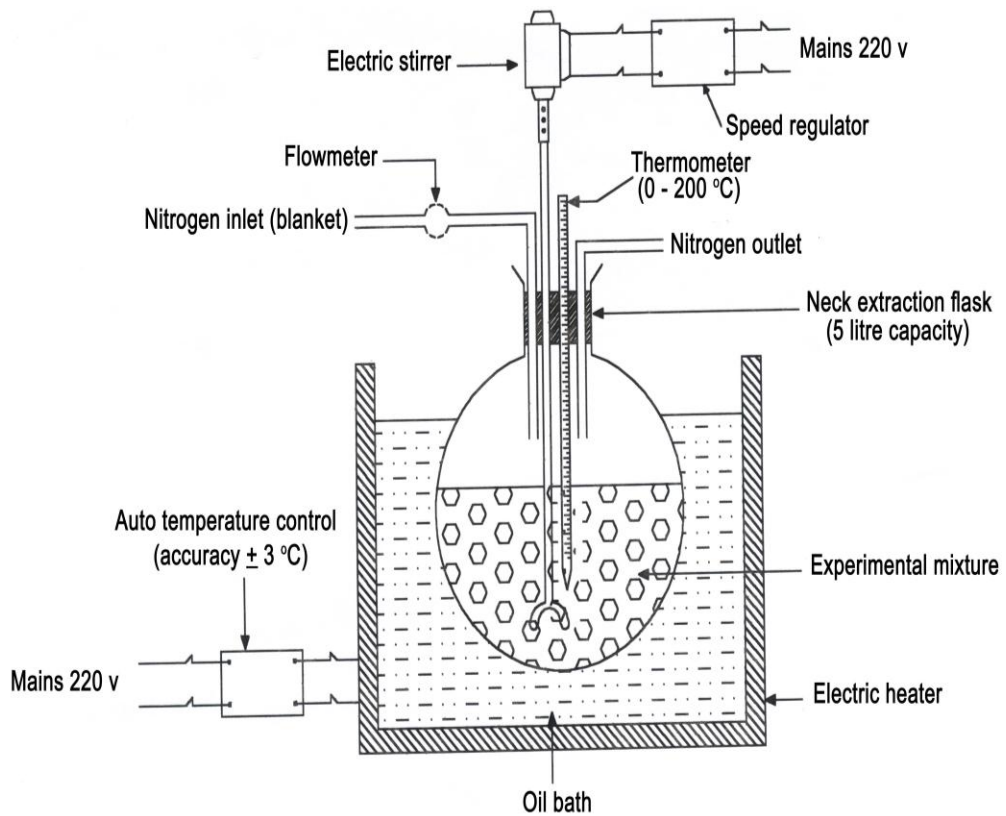
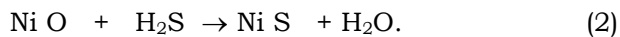
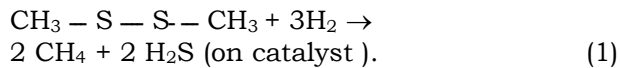


Fig. 2. Experimental set-up of the extraction operation [15].

Table 1
General characteristics of Western Desert crude oil

Properties	Method	
Specific gravity at 60/60 °F, gm/cm ³	ASTM - D1298	0.8272
°API gravity	IP 160	39.97
Kinematic viscosity at 40 °C, cSt	ASTM - D445	4.73
Average molal boiling point, °R		625.5
Viscosity Redwood, No. 1, sec at 25.0 °C	IP 70	44
Pour point, °C	ASTM - D97	-9
Vapor pressure, Reid, kg/cm ²	ASTM - D2503	0.40
Sulfur content, wt. %	ASTM - D4294	0.30
Salt content, wt. %	ASTM - D3230	0.0050
Water content, wt. %	ASTM - D4007	0.155
Carbon residue, Conradson, wt. %	ASTM - D189	2.04
Sediments, wt. %	ASTM - D4007	0.005
Wax content, wt. %	UOP 46	4.54
Asphaltene, wt. %	IP 143	1.23
Ash content, wt. %	ASTM - D482	0.006
Total acidity, mg KOH/g	ASTM - D974	0.06
Hydrogen sulfide, ppm	UOP 163	Nil
Mercaptan sulfur, ppm	UOP 163	6.5
Metals, ppm	IP 285	
Vanadium		3
Nickel		2
Distillation	ASTM - D1160	
Initial boiling point (IBP), °C		43
Recovery to 100 °C, vol. %		15.2
Recovery to 125 °C, vol. %		20.6
Recovery to 150 °C, vol. %		26.7
Recovery to 175 °C, vol. %		31.17
Recovery to 200 °C, vol. %		35.5
Recovery to 225 °C, vol. %		39.8
Recovery to 250 °C, vol. %		44.5
Recovery to 275 °C, vol. %		50
Recovery to 300 °C, vol. %		54.5
Residue after distillation, vol. %		45.5

increased once again to 345 °C at 15 °C per hour and it was kept constant until further H₂S was detected in the tail gas. The reactor inlet temperature was decreased to the required hydrofinishing temperature of the DWOs. Catalytic metal oxides react to give the corresponding sulfides as follows [16]:



The conversion of the metal oxides to their sulfide form brings the catalyst to full activity and prevents its reduction to the metallic form [16].

The hydrofinishing process took place in the pilot plant designed by the Institute Francais Du Petrol, illustrated in fig. 3. Ratio of 800 m³ of hydrogen with 1m³ of DWO were mixed and heated in the furnace to 290 °C [12]. The mixture is passed in down flow over a series of three packed catalyst beds of the adiabatic reactor at Liquid Hourly Space Velocity (LHSV) 0.4 h⁻¹ and pressure 130 kg/cm², where LHSV is the volume of feed per hour divided by the volume of catalyst [9]. Hydrogen quench is used between beds of catalyst to absorb the heat generated by the exothermic reactions. The products are first separated through two stage flash drums, then the light reaction products including H₂S, NH₃, H₂O and small amounts of light hydrocarbons are removed using a steam stripper.

To study the effect of anti-oxidant additive on the oxidation stability of transformer oil, the hydrofinished oil was mixed with 0.4 wt% of Topanol A (produced by Chance & Hunt, Alexander House, Crown Gate, Runcorn, Cheshire). Topanol A is a technical grade of 2, 4 dimethyl-6-tertiary butyl phenol. The added amount is the maximum value permitted for formulating the transformer oils [17].

2.6. Analysis of feed and products

To determine the efficiency of the aforementioned refining processes, both feeds

and products of each process were subjected to complete laboratory analyses. Appropriate tests were carried out to determine the properties of the formulated transformer oils.

Methods used for analyses were American Society for Testing of Materials (ASTM), Institute of Petroleum (IP), Universal Oil Products (UOP) and International Electro-technical Commission (IEC) test methods.

3. Results and discussion

Crude petroleum oils can be classified into three main classes: paraffinic-, intermediate- and naphthenic- base crudes. This classification is deduced from UOP characterization factor (K) which is defined as [18]:

$$K = \frac{1.216(T_B)^{1/3}}{S + 0.0092} \quad (4)$$

where T_B is the average molal boiling point in degree Rankine ($^{\circ}\text{R} = ^{\circ}\text{F} + 460$), and S is the specific gravity of the crude at 15.6 °C. The values of K which ranged from 12.05 to 12.9 corresponded to the paraffinic class, while those ranging from 11.5 to 12.05 corresponded to the intermediate class, and those ranging from 10.5 to 11.5 corresponded to the naphthenic class [19]. Based on the data presented in table 1, the K factor for the Western Desert crude oil is 12.43. Therefore, it can be considered as a paraffinic one.

The physicochemical properties of the VGO and the spindle oil produced from the vacuum distillation of the long residue of Western Desert crude oil are given in table 2. Blends containing different percentages from VGO and spindle oil are prepared in attempt to formulate transformer oils that fulfill the standard specifications. The properties of these blends are also listed in table 2. The results indicated that, as the spindle oil has high boiling point distillation range, its density, viscosity, flash and pour points, sulfur content and average molecular weight are higher than those of VGO. In addition, the color of the spindle oil is darker. The viscosity

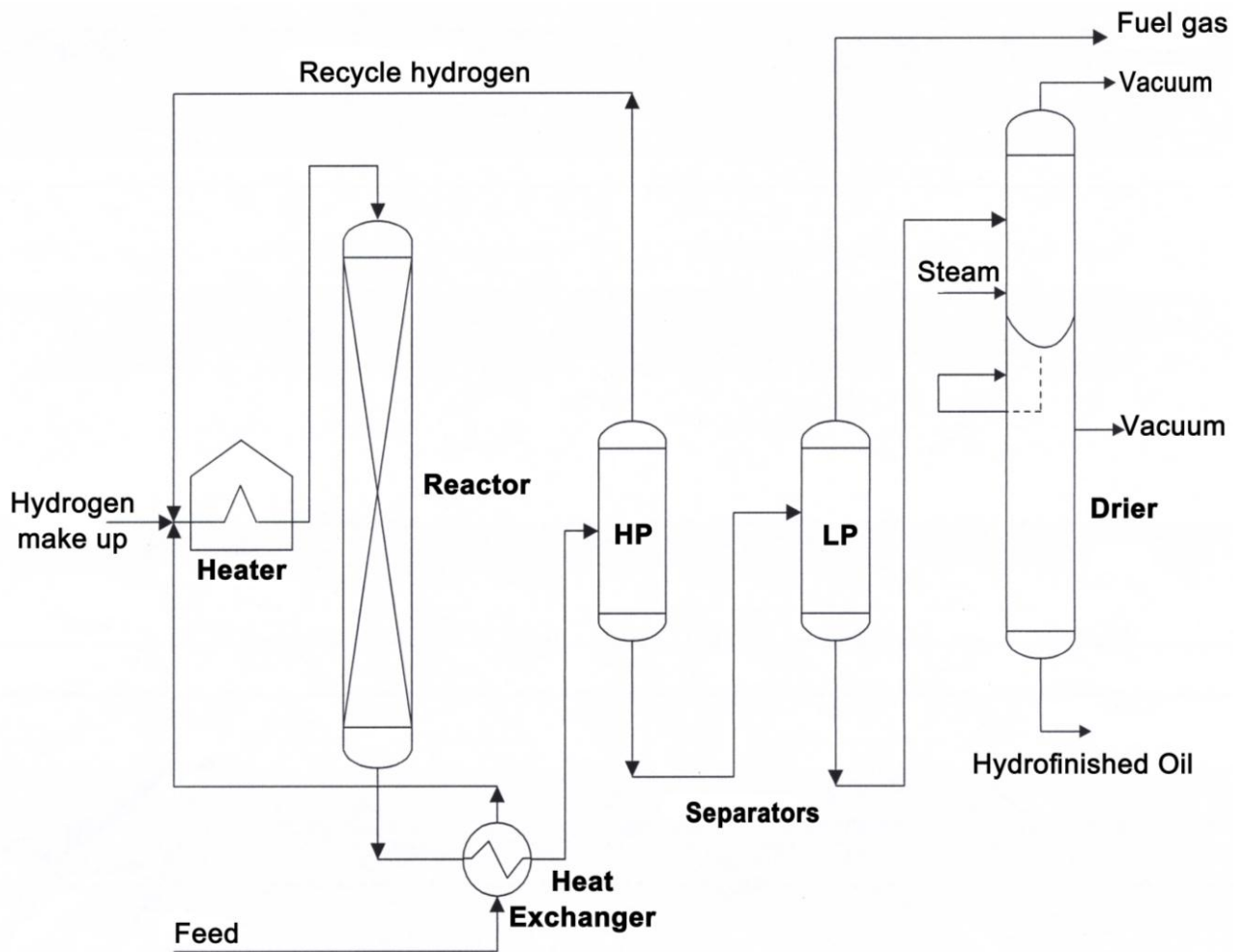


Fig. 3. Process flow for the hydrofinishing plant designed by the Institut Francais Du Petrol [18].

index which reflects the relationship between viscosity and temperature is higher for spindle oil due to the higher saturated contents. It has been reported that the rate of viscosity change with temperature is higher for aromatics than saturated hydrocarbons[9]. On the other hand, blends of VGO and spindle oil have intermediate values for these characteristics, and as the percent of VGO increases in the blend these values decrease.

The VGO, spindle oil and VGO-spindle oil blends were subjected to solvent extraction. This extraction process separates hydrocarbon mixtures into two phases, a raffinate phase that contains substances of relatively high

hydrogen to carbon ratio and an extract phase that contains substances of relatively low hydrogen to carbon ratio. The latter substances are called aromatic materials [20]. Accordingly the process serves to improve the quality of lubricating oils in term of viscosity index. It also removes other undesirable constituents, which may result in rapid darkening, oxidation and sludging in service. The physicochemical properties of the applied feeds for the solvent extraction process together with those of obtained raffinates are given in table 2. The results indicate that in each case there is an increase in the saturated hydrocarbons, viscosity index and pour point

and a decrease in the sulfur contents of the produced raffinates. Moreover, the color becomes brighter. This is due to the removal of aromatics and non-hydrocarbon constituents.

The presence of wax in lubricating oils is generally considered undesirable as wax crystallizes from the oil at relatively high temperatures and causes a decrease in fluidity and prevents the normal oil circulation. As the aromatic extraction process concentrates the wax in the base oil feedstocks, removal of wax from these fractions is necessary to permit the manufacturing of transformer oils with the desired low temperature characteristics [21]. The comparison between the physicochemical properties of the raffinates and the DWOs listed in table 2 clearly shows a sharp drop in the pour points as a result of the wax removal. However, it has also led to a decrease in the viscosity index, where wax possesses a good viscosity-temperature characteristic.

The properties of the transformer oils that are produced from the hydrofinishing of the DWOs are listed in table 3. The standard specifications of class I transformer oils are also included [17]. The comparison between the physicochemical properties of the formulated oils and the standard specification shows that, the transformer oil produced from spindle oil, has kinematic viscosities higher than those values of standard specifications while its flash point is higher. On the other hand, the transformer oil produced from VGO, has lower flash point than that of standard specifications. Consequently, transformer oils produced from either neat spindle oil or neat VGO are considered out of the standard specifications required for transformer oil.

It can be also noticed from the data presented in table 3 that the viscosity and pour points of blends containing 7:3 and 1:1 b.w. spindle oil: VGO respectively, do not fulfill the standard specifications of class I transformer oil.

The transformer oil prepared by blending 3:7 b.w spindle oil and VGO respectively, meets all these specifications. Its kinematic viscosity at -30°C and 40°C are lower than the maximum standard specifications. Low viscosity is recommended for better cooling [1]. For safety requirements, the minimum value for the flash

point is 135°C according to IEC 60296-2003 standard specifications. The flash point for this formulated transformer oil is 150°C well above the specification value.

The sulfur content of the aforementioned blend is very low and non corrosive. As a result, the neutralization number is low and the color is bright. Moreover, it has been reported that a sulfur to nitrogen content ratios ≥ 100 give transformer oils characterized with high oxidation stability[22]. Based on this observation and according to sulfur to nitrogen ratios listed in table 3, the aforementioned blend is expected to possess high oxidation stability.

The water content of the formulated transformer oils are lower than the maximum standard specifications as shown in table 3. It has been stated that the low water content increases the insulation power and the life time of the produced transformer oil [23, 24].

The gassing tendency of oil is a measure of the rate at which hydrogen gas is either evolved or absorbed in an insulating medium when that medium is subjected to electrical stress that is sufficient to cause ionization [25]. The formation of gases in the transformer oil is a result of electrical faults in the transformer, poor compatibility between oil and other materials and the degradation of the oil caused by heat or ageing [26]. It has been stipulated a minimum aromatic content in the oil to ensure adequate gas absorbing properties where aromatic compounds are gas absorbent by nature [27]. They behave in the oil in the same way as in the hydrogenation process, where aromatics absorb hydrogen to form saturated structure [28]. The gassing properties of the transformer oil prepared by blending 3:7 b.w. spindle oil and VGO is expected to be acceptable due to its high saturates table 2 and consequently low aromatic contents.

Measuring the interfacial tension is useful for determining the presence of polar contaminants and oil decay products. New oil generally exhibits high interfacial tension [3]. The interfacial tension of the aforementioned blend of spindle oil and VGO is higher than the value of the minimum standard specification. These results indicate that, the applied

refining processes are reliable where most of the polar contaminants have been removed.

The electrical properties of the transformer oils are important and must be taken into consideration when these oils are processed. The electrical properties include the electrical strength and the dielectric dissipation measurements. Both are sensitive to the presence of impurities and water content [28]. Few amounts of these components multiply the dielectric dissipation and reduce the electrical efficiency as well as the transformer life [29]. It has been reported that dissolved polar compounds change their orientation in an Alternating Current (AC) field. Whenever the voltage polarity changes, the molecular friction associated with dipole movement results in energy dissipation [30]. Within these respects, the electrical strength and the dielectric dissipation known as the power factor of the formulated oils are measured and given in table 3. The data show that, the obtained transformer oil formulated from 3:7 b.w. spindle oil and VGO meets the standard specifications (IEC 60296-2003) [17].

According to the abovementioned results oil produced through mixing 30% of spindle oil with 70% VGO, has physical, chemical and electrical properties complying with the standard and commercial specifications of transformer oils. The results also prove the reliability of the applied treating processes.

3.1 Effect of anti-oxidant

Oxidation of oil is influenced by two main parameters, oxygen and temperature. Oxidation process for paraffinic oils takes place through a free radical chain mechanism. This mechanism produces ketones and alcohols, which are oxidized to organic acids. This reaction is followed by intramolecular rupture reactions causing the release of low molecular weight volatile products (e.g. CO, CO₂, H₂, CH₄, C₂H₂, C₂H₄, CH₃OH) as well as large quantities of water. The oxidation of oil in service forms acids that increase the water solubility in oil and the total acid number. Further reactions could result in sludge, varnish deposits and blockage of oil canals, thus the transformer oil is not cooled well. Also, as a result of acid formation, interfacial

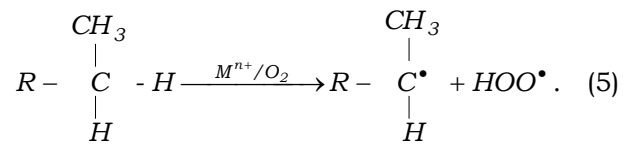
tension decreases as acids have high affinity towards water molecule [2, 27].

Previously, the most widely used transformer oil additives were polychlorinated biphenyls (PCBs). They were very effective in improving the lifetime of transformers and transformer oils. Although PCBs impart ideal characteristics to transformer oils, their use has been reduced due to its environmental hazards [31].

Non PCBs containing transformer oils are dramatically less effective where they demonstrate poorer electrical resistance, greater flammability and a higher tendency to oxidize with the resulting effect of compromising the power factor of the transformers. Therefore, a great need exists for a transformer oil additive that protects transformer oils and transformers from frequent breakdown and enhances the transformers capability. Oxidation inhibitors help to prevent the oxidation of the lubricant base fluid by scavenging the produced free radicals. Hindered phenols are selected type of chemicals used to provide this oxidation resistance feature to the oils [32]. The oxy free radicals formed by hemolytic fission of hindered phenolic O-H bond are relatively stable. This makes the hydrogen atom liable to be attacked by other free radicals in the medium. This in turn will eliminate the free radicals produced from oxygen attack [32].

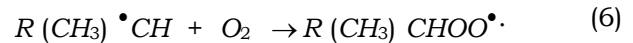
In the present study a technical grade of 2,4-dimethyl-6-tertiary butyl phenol was added to the blend containing 3:7 b.w. spindle oil and VGO to examine its efficiency in increasing the oxidation stability of the hydrofinished transformer oils. Two methods were used to measure the oxidation stability. The first method applies the rotary bomb at a temperature of 150 °C and oxygen pressure of 90 psia. It depends on determining the induction time at which the oil is oxidized [33]. As the oxidation stability increases, the induction time increases. The results show that, the addition of 0.4 wt% of 2,4-dimethyl-6-tertiary butyl phenol significantly increased the induction time from 280 minutes to > 360 minutes. The second method measures the total acidity and total sludge of the oil after oxidation for 164 hour at 120°C as a function of oxidation stability [25]. The data listed in

table 3 show a drop in the total acidity and total sludge after adding the anti-oxidant to the transformer oil. These results can be attributed to the fact that 2, 4-dimethyl-6-tertiary butyl phenol act as radical inhibitor additive where it retards the propagation reaction by producing non-reactive radicals. Stabilization is exercised by transferring the radical onto the aromatic ring [34-35]. The reaction stops according to the mechanism shown in the following scheme [36-37]:

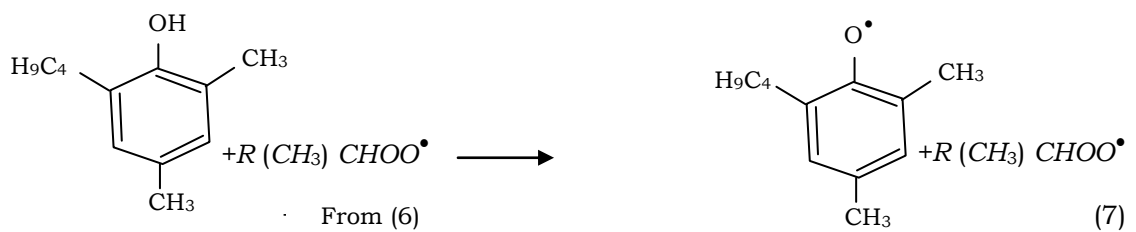


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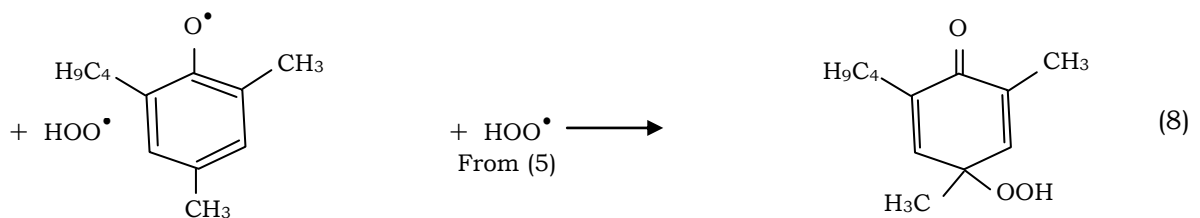
M^{n+} is the transition metal ions such as (Co, Fe, V, Cr, Cu or Mn), and
 R is the alkyl group.



From eq. (5)



Topanol A



2,4-Dimethyl,4-peroxy,6-tertiary butyl
 Cyclohex-2, 5-diene-1-one

The anti-oxidation effect of 2,4-dimethyl-6-tertiary butyl phenol (Topanol A)

4. Conclusions

The process of producing transformer oils from the VGO and spindle oil of paraffinic crude oil from the Western Desert region of Egypt led to the following conclusions:

1. The solvent dearomatization using NMP to a feed ratio of 0.7: 1 (wt/wt) and an extraction temperature of 55 °C significantly improved the quality of lubricating oils in terms of their viscosity index.
2. The solvent dewaxing process applying MEK-toluene (60:40, vol/vol) to a raffinate ratio 4 : 1 and a filtration temperature of -42 °C led to a sharp decrease in the pour point of the produced oils.
3. The hydrofinishing process of the DWOs in presence of NiO-MoO₃/Al₂O₃ decreased the amount of sulfur content, and brightened the color of the hydrofinished VGO and spindle oil.

4. The relevance of the removal of aromatics, polar constituents and water by using the aforementioned refining processes are reflected on improving the gassing tendency and the electrical properties of the produced VGO and spindle oil together by decreasing their interfacial tensions.
5. The transformer oil formulated from 7:3 b.w. VGO and spindle oil fulfills all the IEC 60296-2003 standard specifications requirements.
6. Addition of 2,4-dimethyl-6-tertiary butyl phenol increased the oxidation stability of the transformer oils by scavenging the free radicals produced from oxygen attack.

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List of symbols

<i>AC</i>	is the alternating current,
<i>ASTM</i>	is the American Society for Testing of Materials,
<i>cSt</i>	is the centistocke,
<i>DMDS</i>	is the dimethyl disulfide,
<i>DWO</i>	is the dewaxed oil,
$^{\circ}F$	is the degree Fahrenheit,
<i>HP</i>	is the high pressure,
<i>IEC</i>	is the International Electrochemical Commission,
<i>IP</i>	is the Institute of Petroleum,
<i>K</i>	is the characterization factor,
<i>LHSV</i>	is the Liquid Hourly Space Velocity,
<i>LP</i>	is the Low Pressure,
<i>MEK</i>	is the Methyl Ethyl Ketone,
<i>NMP</i>	is the N-Methyl -2- Pyrrolidone,
<i>PCBs</i>	is the polychlorinated biphenylsm
<i>ppm</i>	is the part per million,
$^{\circ}R$	is the Degree Rankine ($^{\circ}F + 460$),
<i>S</i>	is the specific gravity,
<i>T_B</i>	is the average molal boiling point
<i>UOP</i>	is the Universal Oil Products
<i>VGO</i>	is the Vacuum Gas Oil, and
<i>VI</i>	is the Viscosity Index.

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