Physicochemical Characteristics and Thermal Stability of Jordanian Jojoba Oil

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ABSTRACT: Viscosity, flash point, refractive index, viscosity index, specific gravity, aniline point, foam testing, color stability, ash content, water content, saponification value, iodine value, and other properties were investigated for Jordanian jojoba oil. Results showed that jojoba oil has low ash and water contents and high flash point and viscosity index . Viscosity and specific gravity changed only slightly with temperatures. As an additive, jojoba oil improved the viscosity index of lubricants from 100 to 130. When subjected to heating and cooling from 40 to 200°C, the chemical structure, kinematic viscosity, and refractive index remained almost constant. Thus, jojoba oil was highly stable in this temperature range.

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KEY WORDS: Lubricant oil additive, oil physicochemical characteristics, thermal stability, viscosity, viscosity index.

Jojoba is a desert shrub that grows wild in southern Arizona, northwestern Mexico, and neighboring areas (1). Jojoba seeds contain a unique oil that seems to have exceptional commercial promise (2). Jojoba is fairly new to Jordan, where the first jojoba plantations were established in 1986 at the Jordan University of Science and Technology (JUST).

Yermanos (3) showed that temperature and soil type limit jojoba productivity. Natural jojoba populations occur on coarse, light- or medium-textured soils with good drainage and water penetration. Other environments delay blooming and growth rate.

The potential importance of jojoba oil for industrial uses has stimulated research on recovery, usage as a component or additive, and reaction with other materials. Sivasankaran *et al.* (4) showed the suitability of jojoba oil as a component in lubricating oil formulations for two-cycle gasoline engines. Investigation of physicochemical, wear, and scuffing characteristics along with deposit-forming tendencies demonstrated that jojoba oil has good potential as an additive in oil formulations for this type of engines. Bisht *et al.* (5) studied the utilization of jojoba oil as a compound and as an additive in lubricating oil base stocks; properties such as viscosity index (VI), rust protection, foaming, friction, and wear characteristics were evaluated. Their results showed that jojoba oil can enhance or impart certain desirable characteristics, such as VI improvement, antirust, antifoam, antiwear, and friction reduction properties to the blend. They also concluded that jojoba oil can help reduce use of conventional petroleum-based additives. Their tests did not cover viscosity, refractive index, specific gravity, color, and chemical structure variations due to heating. Viscosity was only measured at 40 and 100°C. The refractive index and specific gravity were measured at ambient temperature. These properties are indicators of substance stability.

The potential importance of jojoba oil led Aracil *et al*. (6) to look for a synthetic analog through esterification of oleic acid with oleic alcohol and ultrastable Y-Zeolites as catalysts. Many parameters in this reaction were studied, such as the influence of the quantity and type of acid sites, pore accessibility, and crystal size on conversion and product distribution. Sanchez *et al*. (7) studied the kinetics of synthesis in a homogeneous liquid phase of a jojoba oil analog in a stirred tank reactor with cobalt chloride as a catalyst at different temperatures, concentrations of catalyst, and acid/alcohol molar ratios.

Because jojoba is a new crop to Jordan, we wanted to evaluate the oil characteristics from plants grown under our environmental conditions. The objectives of this research were: (i) to measure the physicochemical properties of Jordanian jojoba oil obtained by pressing; (ii) to compare those properties with published data to evaluate the effects of environmental conditions on oil properties; and (iii) to evaluate the thermal stability of jojoba oil under operating conditions similar to what might be experienced in gasoline engines.

EXPERIMENTAL PROCEDURES

The jojoba seeds used in this study, originally supplied to Jordan *via* the Food and Agriculture Organization (FAO) from Australia, were harvested in 1995 from 9-yr-old plantations at the JUST. Plants were spaced 1 m apart with 4 m between adjacent rows. The soil at the site has a clay texture. Annual rainfall in this part of Jordan is around 200 mm. The average seasonal [temperature (°C), relative humidity (%)] values during 1995 were (10, 75), (16, 52), (25, 52) and (19, 55) for winter, spring, summer, and autumn, respectively.

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The oil used in this study was obtained by pressing. Whole jojoba seeds were placed in a cylindrical container, then subjected to a 12-ton load *via* a manually operated hydraulic press. The oil collected from the bottom of the container was then filtered to remove any solid impurities.

The testing methods used to measure physicochemical properties of the oil are listed and referenced in Table 1. Also, the following experiments were carried out.

Lube oil additive. The use of jojoba oil as an additive in a Jordanian lubricating (Jopetrol) oil for gasoline engines was examined. Blends containing 5, 10, 15, or 20% by weight jojoba oil in Jopetrol oil were prepared and evaluated for pertinent properties, such as viscosity at different temperatures and VI. The Jopetrol oil for gasoline engines, which is produced by the Jordanian Petroleum Refinery in Zarka and used in this study, was classified as SAE 40 .

Thermal stability test. The specific gravity and kinematic viscosity of jojoba oil were measured according to American Society for Testing and Materials (ASTM) methods D287-82 and D446-79 (8), respectively, at different temperatures. The range was from ambient temperature up to 100°C for the specific gravity test and up to 140°C for the kinematic viscosity test. Also, the thermal stability of jojoba oil was determined by filling a 40-mL stainless-steel pipe with jojoba oil and heating it at 40 to 200°C for 4 h before cooling to ambient temperature. For each sample, the kinematic viscosity, color, and refractive index were measured according to ASTM methods D1218-82, D1500-77, and D446-79 (8), respectively, to determine any changes in the properties of the jojoba oil. Also, the chemical structure of an unheated oil sample and oil samples heated to 100 or 200°C were analyzed by infrared (IR) spectroscopy to determine whether heating had any effect on the oil properties.

All of the foregoing tests were repeated at least three times. Variations among the runs were negligible, and the averages of the values for each test are reported.

TABLE 1
Physicochemical Characteristics of Jordanian Jojoba Oil Compared with Other Jojoba Oils

Characteristics	Method[a]	This work	Literature values (reference)
Specific gravity (25°C)	D287-82	0.861	0.863(1), 0.866(5[b])
Flash point–open cup (°C)	D92-85	275.0	295 (1)
Flash point–closed cup (°C)	D93-85	224.0	NA[c]
Fire point (°C)	D287-82	322.0	338(1)
Pour point (°C)	D97-85	8.0	9.0 (5)
Aniline point (°C)	D611-77	52.9	NA
Carbon residue (wt%)	D189-81	.012	0.1 (4)
Extraction method (% water)	D473-81	nil	NA
Moisture content by infrared (% water)	As in Ref. 9	0.64	NA
Iodine value (mg per 100 g)	—	81.0	82 (1), 82.98(5)
Saponification value	D94-80	88.0	92 (1), 94.69(5)
pH	—	6.95–7.34	NA
Calorific value (cal. per g)	D240-80	10086.0	NA
Foaming (mL)			
at 24°C	D3519-76	3–5	NA
at 94°C		3–5	
TAN[c] (mg KOH/g)	D974-80	0.36	NA
TBN[c] (mg KOH/g)	D2896-80	1.0	NA
Refractive index (at 25°C)	D1218-82	1.4593	1.465 (1), 1.464(5)
Color value	D1500-77	1.0	1.5(2),0.5(2[b])
Ash content (wt%)	D482-80	nil	nil (5)
Kinematic viscosity (cSt)			
at 40°C	D446-79	24.75	24.95 (5)
at 100°C		6.43	6.43 (5)
Viscosity index	D2270-79	233	233 (5)
Cu–corrosion	D130-83	<1a[c]	<1a (5)

[a]All these methods are listed in Reference 8, unless otherwise indicated.
[b]Properties of hexane-extracted jojoba oil.
[c]NA, not available; TAN, total acid number; TBN, total base number; 1a, a negligible degree of corrosion.

RESULTS AND DISCUSSION

Physicochemical characteristics of Jordanian jojoba oil. The physicochemical properties of the Jordanian jojoba oil used in this study are presented in Table 1. Clearly, jojoba oil has many promising physicochemical properties, such as high flash and fire points, low viscosity, high VI, and low carbon residue. Most of the oil properties are similar to those already published (1,2,4,5), except that Jordanian jojoba oil has a lower flash point (open cup), fire point, pour point, carbon residue, and saponification value. These differences could be due to the low rainfall and the type of soil where the jojoba plants were grown. The climatic conditions, temperature, and relative humidity at the site where the jojoba plants were grown are suitable, but annual rainfall is low in the recommended range for jojoba populations (3).

The saponification value indicates the polar nature of jojoba oil, which can impart rust protection, antifoaming, and oily characteristics. On the other hand, the saponification and iodine values of jojoba oil are relatively low compared with other vegetable oils, such as castor, soybean and rapeseed, suggesting better stability (4,5).

As shown in Table 1, jojoba oil has a low and constant foam tendency. This means that jojoba oil is stable in mechanical systems, such as high-speed gearing, high-volume pumping, and splash lubrication. The nearly zero ash content in jojoba oil indicates that it does not contain any metallic, dirt, or rust materials. Also, jojoba oil is not a corrosive material because it does not contain sulfur compounds. The pH is about 7.

The pour point of the oil is slightly high. This might be a problem in cold weather or in any refrigerated applications. On the other hand, the value of the aniline point indicates that this oil is less aromatic. The moisture content was determined by two methods: water extraction and IR. Both methods indicate that jojoba oil has a low (nil) moisture content. Therefore, jojoba oil will not have any corrosive effects and also will not produce any hydrous compounds.

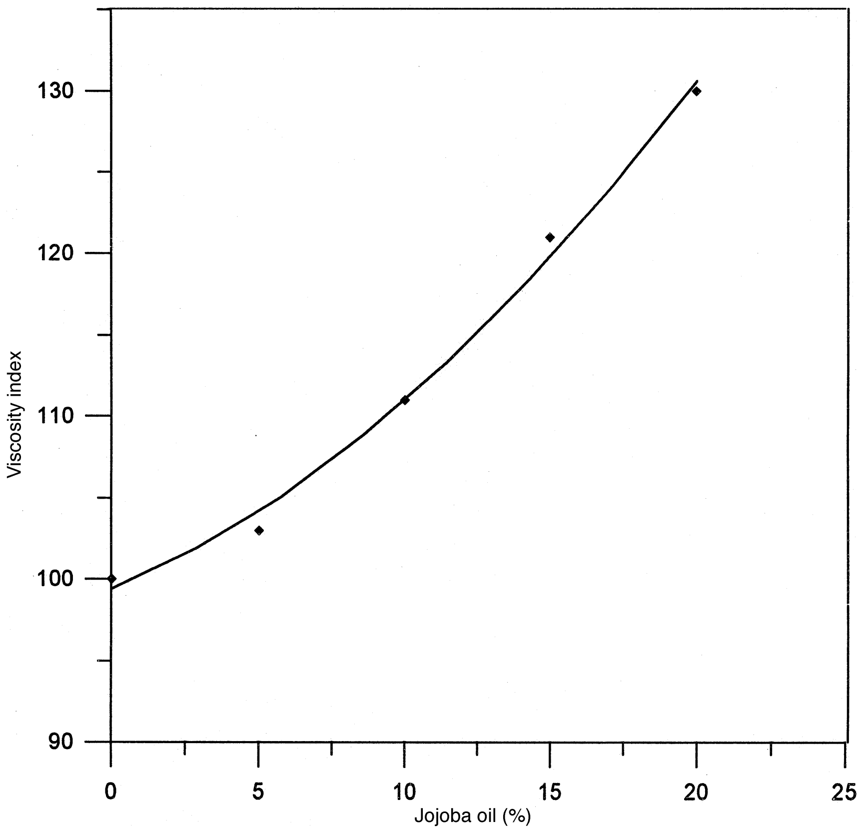

FIG. 1. Effect on the viscosity index of adding jojoba oil to Jordanian Jopetrol engine oil (SAE 40).

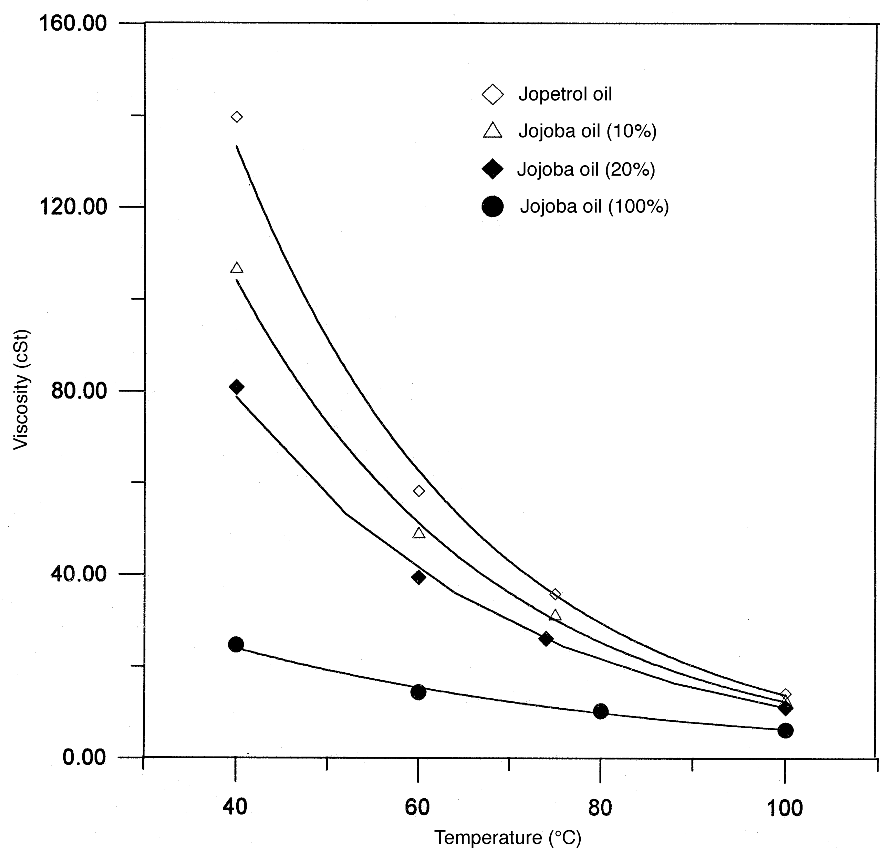

FIG. 2. Viscosity of Jopetrol oil (SAE 40), Jopetrol oil plus jojoba oil, and jojoba oil at different temperatures.

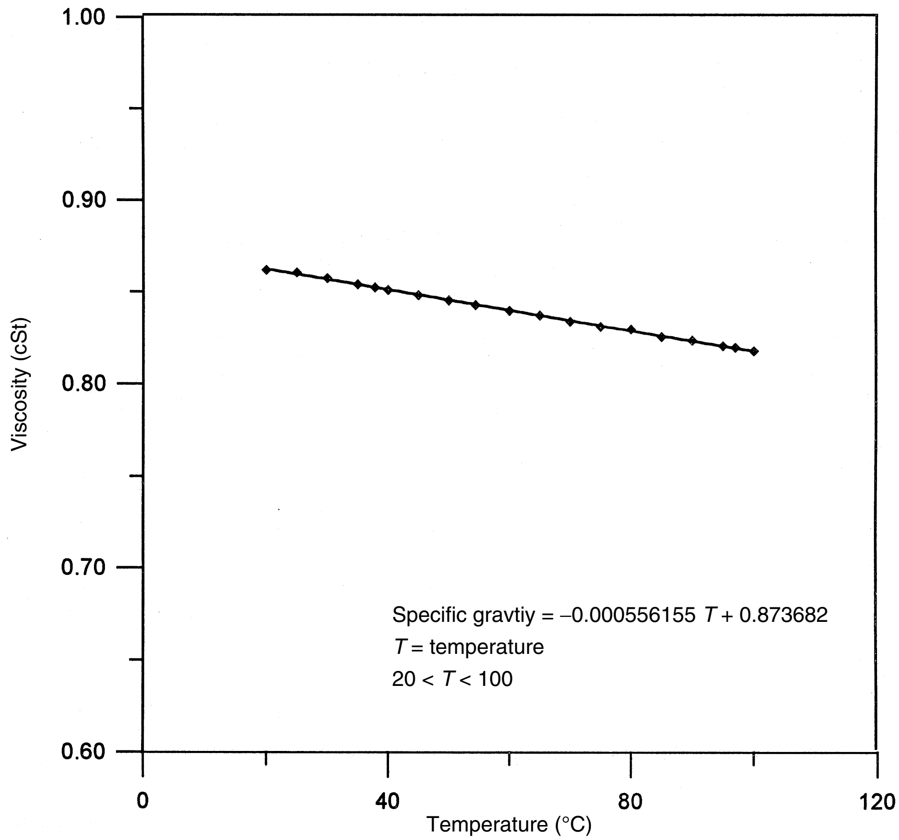

FIG. 3. Specific gravity of jojoba oil at different temperatures.

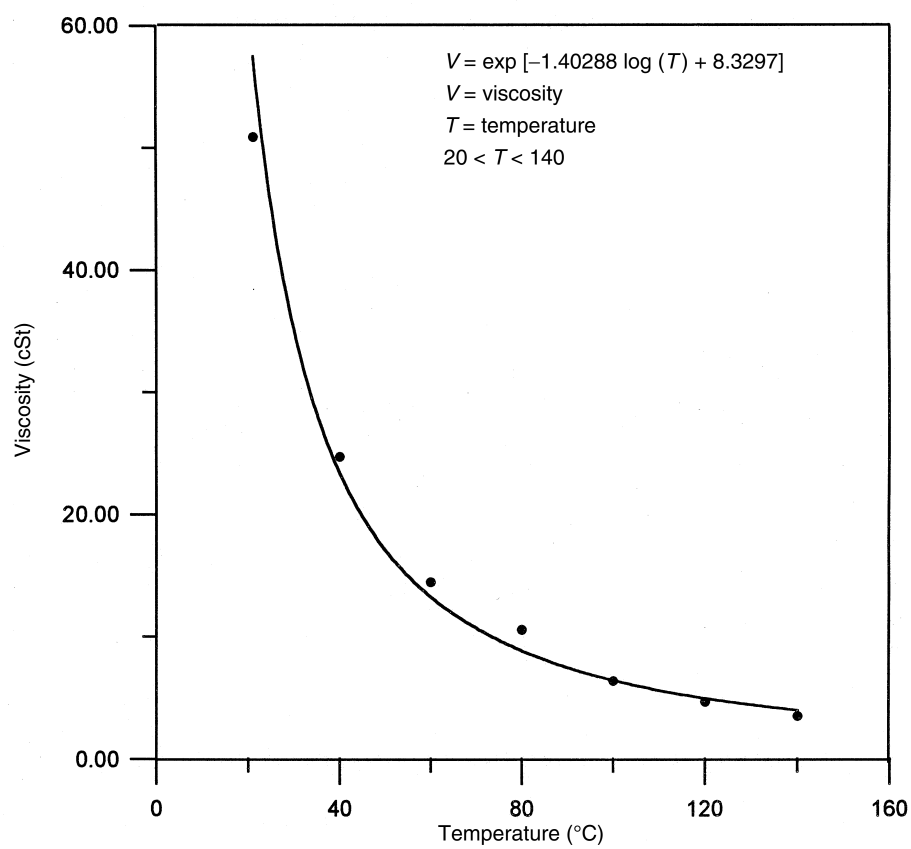

FIG. 4. Viscosity of jojoba oil as a function of temperature.

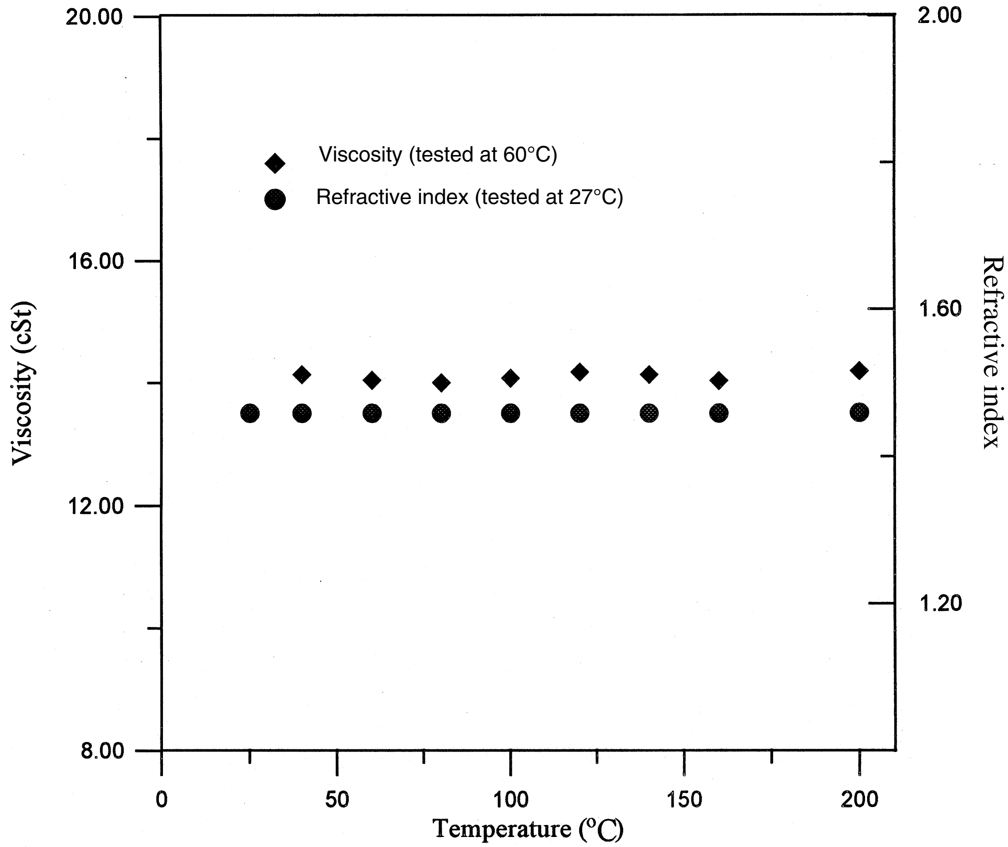

FIG. 5. Viscosity and refractive index of jojoba oil heated for 4 h and then cooled to ambient temperature.

Jojoba oil additive. Jordanian Jopetrol oil for gasoline engines has a low VI. To improve the VI, high-molecular-weight polymers are generally used. Some of the VI additives have poor shear stability and make selection difficult (5). The ability of jojoba oil to improve the VI is shown in Figure 1. Jopetrol engine oil (SAE 40) was selected because it has a low VI of around 100. Blends were prepared with different dosages of jojoba oil, and then their VI were measured according to ASTM method D2270-79 (8). Jojoba oil (20%) as an additive increased the VI value up to 130. Thus, the lubricating oil was more stable. This is in accordance with the findings of Bisht *et al.* (5).

Figure 2 shows the viscosity behavior at different temperatures of Jopetrol oil, Jopetrol oil with added jojoba oil, and jojoba oil. Lubricating oil, in general, should maintain its viscosity at high temperatures, while at low temperatures its viscosity should not be high and it should maintain its performance in engines. Certain ingredients are added to lube oil to achieve these characteristics. Figure 2 shows that pure jojoba oil's viscosity changed only slightly with temperature, whereas Jopetrol oil's viscosity dropped from 140 cSt at 40°C to 14 cSt at 100°C. The addition of jojoba oil reduced the viscosity of Jopetrol lubricating oil at low temperatures. Additionally, at engine-operating temperatures (around 100°C), the viscosity of mixtures of jojoba oil and Jopetrol oil did not change much, indicating that jojoba oil can improve the lubricating oil's performance at high temperatures.

Thermal stability of jojoba oil. Specific gravity and kinematic viscosity are affected by temperature. As shown in Figure 3, the specific gravity changed only slightly with temperature. Figure 4 shows that the viscosity dropped significantly at low temperatures but changed only slightly in the temperature range 100–140°C.

The effect of heating on jojoba oil color was determined by measuring the color value according to ASTM method D1500-77 (8). Jojoba oil has a yellowish color that changes slightly with heating. The color values were 1.0 when heated up to 100°C, L1.0 when heated from 120 to 140°C, and 0.5 to L0.5 when heated from 160 to 200°C, which indicates that slight changes in the structure of the oil had occurred that affected its color, but apparently not its other physical characteristics. These could be due to the presence of traces of low-boiling compounds, which upon heating evaporate, leading to changes in color.

The IR spectrum of the unheated jojoba oil indicated that Jordanian jojoba oil contains the following functional groups (10): ester (C=O with frequency 1820–1660 cm^{-1} and C–O with frequency 1300–1000 cm^{-1}), alkanes (CH aliphatic with frequency 1300–1000 cm^{-1}), CH_2 and CH_3 with frequency 1465–1375 cm^{-1}. The IR structure of jojoba oil did not change due to heating at 100 and 200°C, indicating no degradation of the oil. Therefore, jojoba oil remains stable over a wide range of temperatures.

Other physical tests were conducted on the heated jojoba oil, including viscosity and refractive index. Figure 5 shows that the viscosity of Jordanian jojoba oil, cooled to ambient temperature after heating to various temperatures, is almost constant, which means that there is no degradation or structural changes in the oil upon heating. Additionally, Figure 5 shows that the heating process does not have any effect on the refractive index, so there are no cracking effects.

This work reveals that annual rainfall and soil type may have affected some of the physicochemical properties of jojoba oil, such as flash point, fire point, pour point, carbon residue, and saponification value. Adding jojoba oil to gasoline engine lubricating oil improved its VI, a positive indicator for considering jojoba oil as a lubricating oil additive. Heating jojoba oil samples to various temperatures, ranging from 40 to 200°C, then cooling each time to ambient temperature, did not affect the chemical structure, kinematic viscosity, and refractive index of the oil. Thus, jojoba oil can be considered as a highly stable oil in these temperature ranges.

REFERENCES

1. National Research Council, *Jojoba: New Crop for Arid Lands, New Material for Industry,* National Academy Press, Washington, D.C., 1985.
2. Wisniak, J., Jojoba Oil and Derivatives, *Prog. Chem. Fats Other Lipids, 15*:167–183 (1977).
3. Yermanos, D.M., Jojoba. I. Establishment of Commercial Plantations, *J. Am. Oil Chem. Soc. 55*:888A–891A (1978).
4. Sivasankaran, G.A., R.P.S. Bisht, V.K. Jain, M. Gupta, A. Sethuramiah, and V.K. Bhatia, Jojoba-Oil-Based Two-Stroke Gasoline Engine Lubricant, *Tribology Int. 21*:327–333 (1988).
5. Bisht, R.P.S., G.A. Sivasankaran, and V.K . Bhatia, Additive Properties of Jojoba Oil for Lubricating Oil Formulations, *Wear 161*:193–197 (1993).
6. Arcil, J. , M. Martinez, N. Sanchez, and A. Corma, Formation of a Jojoba Oil Analog by Esterification of Oleic Acid Using Zeolites as Catalyst, *Zeolites 12*:233–236 (1992).
7. Sanchez, N., A. Coteron, M. Mortinez, and J. Aracil, Kinetic Analysis and Modeling of the Esterification of Oleic Acid and Oleyl Alcohol Using Cobalt Chloride as Catalyst, *Ind. Eng. Chem. Res. 31*:1985–1988 (1992).
8. ASTM, *Book of Standards*, American Society for Testing and Materials, Philadelphia, 1985.
9. *Standard Methods for the Examination of Water and Wastewater,* part 1, 16th edn., American Public Health Association, American Waterworks Association, Water Pollution Control Federation, Washington, D.C., 1985.
10. Pavia, D.L., G.M. Lampman, and G.S. Kriz, *Introduction to Spectroscopy,* Saunders College Publishing, Philadelphia, 1979.

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