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Formulation of Motor Oil from Blends of Rubber Latex Cup Bottom Oil (RLBO) and Used Frying Oil (UFO)

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Abstract

Most motor oils are made from mineral oils derived from petroleum, the reserves of which are limited and exhaustible. The aim of this study is to produce and characterize motor oil formulations based on mixtures of rubber latex cup bottom oil (RLCBO) and used frying oil (UFO). The results show that these formulations have a density between 0.91 and 0.92. These densities evolve linearly with the proportion of cup bottom oil and temperature. Similarly, the kinematic viscosity of the blends follows an exponential relationship with temperature. By plotting the logarithm of these kinematic viscosities against the inverse of the temperature, we were able to determine the activation energy of the various blends and deduce that the formulations behave Newtonian.

Keywords

Formulation, Oils Blend, Motor Oils, Latex Bottoms Oil

1. Introduction

Motor oils are essential to ensure that an engine runs smoothly. They are composed of 70% to 85% base oils of petroleum or synthetic origin and 15% to 25% additives [1]. These additives give them good properties. In recent years, with the rapid development of the automotive and machinery industries, as well as increasingly stringent environmental protection and energy-saving requirements, the quality requirements for motor oils products have become increasingly stringent. This leads directly to an increase in demand for high-quality lubricating oil [2]. In addition, with the tightening of emissions regulations due to environmental concerns, vehicle fuel efficiency requirements continue to increase. Meeting these requirements has led to a reduction in engine size and the introduction of new equipment to improve vehicle fuel efficiency. However, engine development generally requires significant investment and a long cycle time. A complementary approach to achieving additional energy efficiency is to design lubricants to minimize frictional energy losses in the engine [3]. Lubricants are essential for improving the efficiency and safety of machinery. The lubricants generally used for internal combustion engines are mineral, semi-synthetic or synthetic oils, the vast majority derived from petroleum and enriched with technical additives [4]. Commonly used additives are viscosity and friction modifiers [5]. They have anti-wear, anti-corrosion, antioxidant, detergent, anti-foam and dispersant functions [6]. In this way, the properties obtained from the complex formulation of oils make it possible to satisfy the most stringent requirements imposed by car manufacturers [6]. Global demand for lubricants has reached 37 million tones and the value of the global lubricants market is expected to reach US$182.6 billion by 2025 [7] [8]. Furthermore, the majority of motor oils are made from mineral oils derived from crude oil. Limited and exhaustible oil reserves and the cost of exploiting them are driving up the price of crude-oil derivatives, including motor oils. The relatively high prices of these products are having a negative impact on people's lives, including in Côte d'Ivoire. In addition, one liter of lubricant is enough to pollute one million liters of drinking water [7]. In addition to this direct pollution, used oils have toxic effects on fauna and flora. They are also the cause of malfunctioning or even blockage of collectors and waste water treatment plants [9].

Thus, vegetable oil-based lubricants are becoming important in the industrial lubrication market because of their biodegradability and minimal impact on the environment and humans [9] [10]. Among the cash crops produced and exported by Côte d'Ivoire, rubber occupies an important place. When harvested, the residues are unexploited. It is within this framework that the present study falls, which aims to valorize these residues by the formulation of engine oils from mixtures with used frying oil (UFO). This work is part of the valorization of two types of waste (RLCBO) and (UFO) by the formulation of a product with high added value (lubricants oil).

2. Materials and Methods

2.1. Basic Products

The base products used to produce the various formulations are used frying oil collected from households and oil (residues) from the bottom of rubber latex cups supplied by Bayan Industry Compagny (BIC) (Abidjan, Côte d'Ivoire). Commercially available motor oils were used as a reference (**Table 1**).

2.2. Obtaining the Formulations

The formulations were obtained by making volumetric mixtures of used frying oil

(H) and cup bottom residues. These mixtures were made in different proportions. The different formulations are coded and listed in Table 2. For example, formulation H100 corresponds to 100% used frying oil, R100 corresponds to 100% rubber latex cup bottom oil, HR73 corresponds to 70% used frying oil and 30% latex cup bottom residue.

Table 1. Characteristics of some motor oils.

Motor oil	Density	Kinematic viscosity at 40˚C ($mm^2 \cdot s^{-1}$)	Viscosity index
2-T Semi-synthetic	0.875	62	145
2-T 100% synthetic	0.886	48.7	160
SAE 50	0.892	120	173
4-T	0.865	91.5	160
SAE 10W-40	0.862	98.5	152
SAE 10W-40 diesel (heavy duty)	0.867	89	153
SAE 15W-40	0.873	111	140
SAE 15W-40 for vans	0.883	102	138
SAE 10W-60	0.852	171	170

Table 2. Composition of the different formulations.

Code	H_{100}	R_{100}	HR_{91}	HR_{82}	HR_{73}	HR_{64}	HR_{55}
UFO	100%	0%	90%	80%	70%	60%	50%
RLCBO	0%	100%	10%	20%	30%	40%	50%

2.3. Characterization of Formulations

2.3.1. Water Content

The water content was determined in accordance with international standard ISO 662 [11]. The method involves measuring mass loss by weighing the sample after oven drying at 105˚C ± 1˚C for 24 hours. 10 g of the sample was weighed into a ceramic capsule. The sample was dried in an oven at 105˚C ± 1˚C for 24 hours. After cooling in a desiccator, the sample was weighed again. The water content (T) is given by relationship (1).

$$T = \left(\frac{m_1 - m_2}{m_1 - m_0}\right) * 100 \tag{1}$$

where, m_0, the mass (g) of the empty capsule; m_1 and m_2 the masses (g) of the capsule + sample before and after drying respectively.

2.3.2. Specific Gravity

Specific gravity represents the mass of the unit volume at a given temperature. The density of the formulations was determined according to standard NF EN ISO 6883 [12] over a temperature range from 25˚C to 50˚C.

Volumes of 25 mL of the formulations and distilled water were weighed. The masses obtained were used to determine the specific gravity (d) of the formulations and base products. Relation (2) was used to perform the calculations.

$$d = \frac{\rho_{\text{sample}}}{\rho_{\text{water}}} \tag{2}$$

With, ρ_{water}, the density of water (0.9924 g/cm^3) and ρ_{sample}, the density of the formulation (g/cm^3).

2.3.3. Viscosity

The viscosity of the formulations was determined using a falling ball viscometer (Thermo Scientific) on which a thermostatic bath (Lauda) is mounted [13]. The principle is based on measuring the time required for a volume of liquid to flow by gravity through a viscometer.

The dynamic viscosity was measured over a temperature range from 25˚C to 50˚C. The variable measured is the fall time of the ball for a given fall distance. The cylindrical tube of the viscometer (THERMO SCIENTIFIC HAAKE type C) was filled with oil, then the ball was dropped into the tube. The relationship (3) was used to calculate the dynamic viscosity η of the oil:

$$\eta = k\left[\rho - \rho_h\right]t \tag{3}$$

With

k : the ball constant (mPa·s·cm^3/g·s)

t : the falling time of the ball (s)

ρ and ρ_h the respective densities of the ball and the oil (g·cm^{-3})

The kinematic viscosity of a fluid is the ratio of its dynamic viscosity η to its density ρ (relationship 4). It is expressed in mm^2/s or cSt.

$$\nu = \frac{\eta}{\rho_{\text{sample}}} \tag{4}$$

2.3.4. Viscosity Index

The viscosity index is a widely used and accepted measure of the variation in kinematic viscosity due to changes in the temperature of a petroleum product between 40˚C and 100˚C. The concept of viscosity index (VI) was conceived in 1929 by Dean and Davis. They selected two extreme series of reference oils, some giving the greatest variations in viscosity with temperature (index 0), others the lowest (index 100). The viscosity index of the formulations was determined at 40˚C in accordance with ASTM D2270 [14].

$$VI = 100 \times \frac{L - U}{L - H} \tag{5}$$

where, L, the viscosity at 40˚C of an index 0 oil having the same viscosity at 100˚C as the lubricant; *H*, the viscosity at 40˚C of an index 100 oil having the same viscosity at 100˚C as the lubricant and U, the viscosity at 40˚C of the oil in question.

3. Results and Discussion

3.1. Characteristics of the Formulations

Table 3 shows the characteristics of the formulations used. The values show that the quantity of water and the density increase with the quantity of latex cup bottom residue. The viscosity index and kinematic viscosity of UFO and RLCBO residues could not be determined.

Table 3. Characteristics of the formulations.

Formulations	Water content (%)	Density	Kinematic viscosity at 40˚C (cSt)	Viscosity index
H_{100}	0.089	0.912	38.73	nd
R_{100}	0.846	0.937	nd	nd
HR_{91}	0.640	0.915	102.47	116.21
HR_{82}	0.642	0.916	114.69	111.52
HR_{73}	0.647	0.918	160.2	138.59
HR_{64}	0.712	0.919	256.54	128.24
HR_{55}	0.751	0.921	527.14	116.73

nd: not determined.

RLCBO has a high-water content (0.846%) compared with UFO (0.089%). This moderately high-water content could be due to the high-water content of the latex [15]. However, all the formulations have a water content greater than 0.03%. Therefore, their drying is necessary before their use.

The specific gravities of the formulations produced are close to those of the basic products. These vary slightly with the increase in the proportion of RLCBO. The specific gravity values are in line with those of motor oils (between 0.85 and 0.92) [16]. Although these values comply with the density criterion, the formulations contain a quantity of water well more than 0.2% (limit value), which is a disadvantage for engines [17]. Kinematic viscosity at 40˚C increases as the proportion of rubber latex cup bottom oil increases. With a viscosity of 527.14 $mm^2 \cdot s^{-1}$ and a specific gravity of 0.921, the HR55 formulation is the most viscous and the heaviest. This is due to the high amount of latex cup bottom oil. The kinematic viscosity values of the formulations are comparable to those of the reference motor oils (Table 1), except for the HR64 and HR55 formulations.

The viscosity index is a conventional number that reflects the extent to which viscosity varies with temperature and is used to judge the hot and cold behavior of oils. A viscosity index of 100 indicates very little variation in viscosity and a viscosity index of 0 indicates very high sensitivity to temperature. The viscosity index values range from 111.52 to 138.59. These values are in line with those of synthetic motor oils, which have a maximum value of 240. These oils could be used for easy starting and fast revving at low temperatures. Considering the studied properties, it can be suggested that the formulations can be used as motor oils, except for the HR55 and HR64.

3.2. Evolution of Specific Gravity as a Function of Temperature

The temperature of engine oils increases during engine operation. Figure 1 shows the evolution of the specific gravity of formulations as a function of temperature.

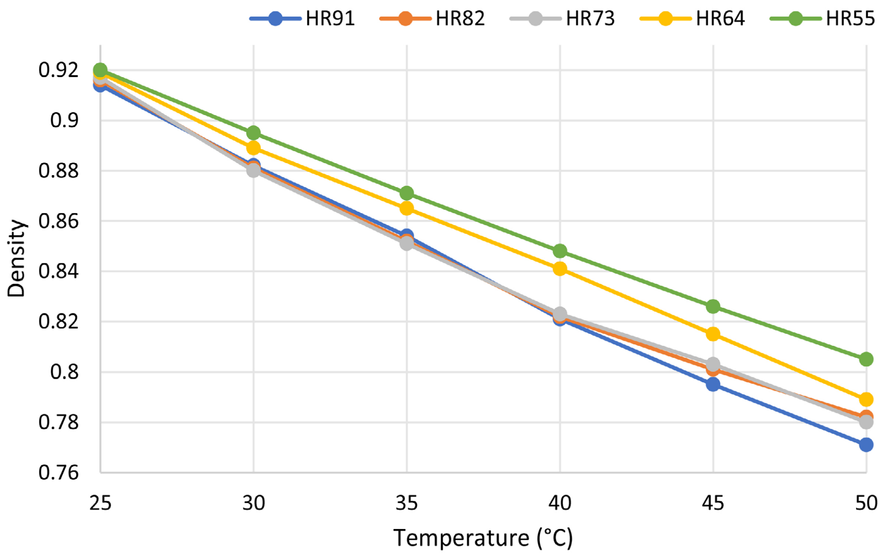

Figure 1. Evolution of the specific gravity as a function of temperature.

The formulations have similar densities at 25˚C, decreasing as the temperature rises. The evolution of specific gravity as a function of temperature follows a linear law. This trend is identical to that for motor oils. Values range from 0.780 to 0.920.

3.3. Kinematic Viscosity as a Function of Temperature

Viscosity is an important criterion for guaranteeing good lubrication. However, it is important to note that viscosity depends on temperature [18]. The ability of oils to lubricate deteriorates if the temperature is too high or too low. For example, paraffinic-based mineral oils have poorer lubricating properties than other oils at low temperatures because the paraffins ("waxes") they contain crystallize and the oil congeals. At temperatures above 90˚C, mineral oils oxidize rapidly. In practice, the service life of a mineral oil can be set at 30 years at 30˚C, falling to 15 years at 40˚C. The life is halved for each 10˚C increase. At 100˚C, it is 3 months. Above 100˚C, it is preferable to use synthetic oils.

To determine and compare the intrinsic parameters of the different formulations, such as activation energy, the influence of temperature on the kinematic viscosity of the formulations was studied (Figure 2).

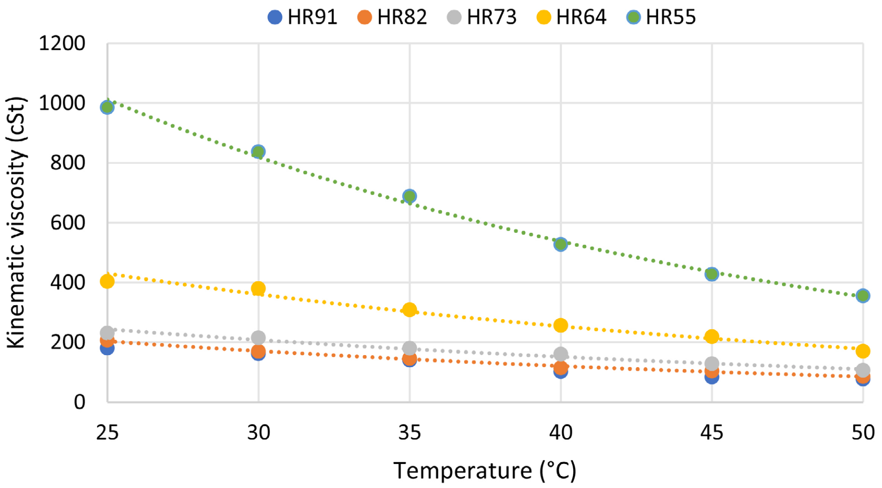

Figure 2. Curves showing the variation in kinematic viscosity as a function of temperature.

The trends in the graphs in Figure 2 confirm that the kinematic viscosity of the HR55 formulation is the highest. The curves obtained are exponential. The kinematic viscosity of the formulations decreases as a function of temperature. This variation is described by Eyring's formula according to Equation (6).

$$\eta = A\mathrm{e}^{\frac{E_a}{RT}} \tag{6}$$

where E_a is the activation energy; R, the perfect gas constant; T, the temperature in kelvin; A, a constant dependent on the nature of the oil and η, the dynamic viscosity coefficient. Since the kinematic viscosity coefficient is the ratio of the dynamic viscosity coefficient to the density of the fluid, we have:

$$\nu = \frac{A}{\rho_{\text{sample}}}\mathrm{e}^{\frac{E_a}{RT}} \tag{7}$$

linearising this equation gives:

$$\ln(\nu) = \ln\frac{A}{\rho_{\text{sample}}} + \frac{E_a}{RT} \tag{8}$$

The graphical representation of $\ln(\nu)$ as a function of $1/T$ for fluids obeying the Eyring model gives a straight line with slope E_a/R, which makes it possible to deduce the activation energy. Figure 3 and Table 4 show the results obtained.

Table 4. Coefficients of determination and activation energy of the formulations.

	HR_{91}	HR_{82}	HR_{73}	HR_{64}	HR_{55}
Coefficient of determination (R^2)	0.971	0.994	0.973	0.976	0.994
Activation energy Ea (kJ/mol)	33.433	31.278	28.375	31.484	37.828

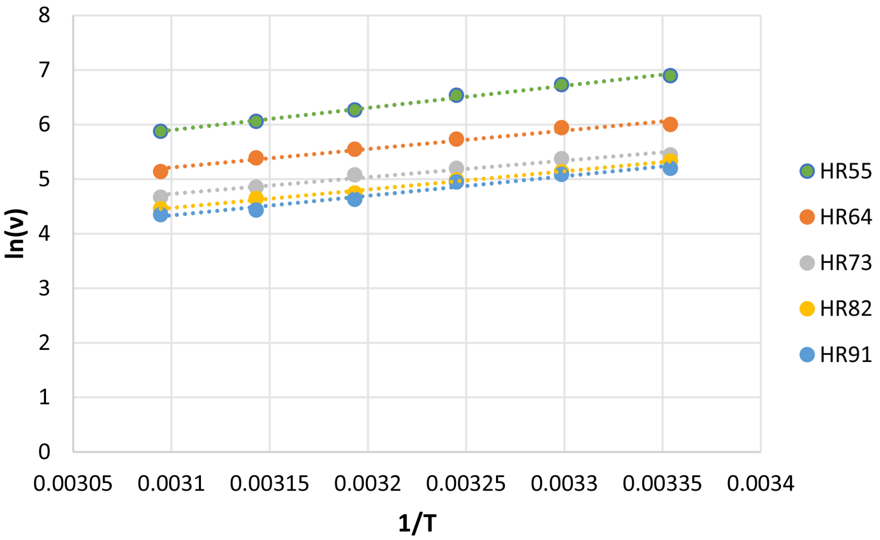

Figure 3. Variation of ln(*ν*) as a function of the inverse of temperature.

As the values of the coefficients of determination are close to 1, the variation of the kinematic viscosity ν as a function of the inverse of the temperature T in the temperature range studied can be described by Eyring's relation. The formulations used are therefore Newtonian [19].

4. Conclusion

This study involved formulating a blend of RLCBO oil and UFO. The properties of the formulations are similar to those of motor oils. The densities of the formulations are between 0.91 and 0.92. These densities develop linearly as a function of temperature, which is consistent with the development of fluid specific gravity. The exponential decrease in kinematic viscosities enabled to determine the activation energy and deduce that the formulations behave Newtonian. It is therefore possible to formulate motor oils by mixing the oil from RLCBO with UFO. These formulations can be used in engines as lubricants. However, their very high-water content is a disadvantage.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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