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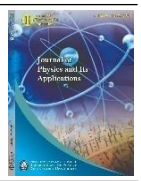

Characterization of The Optical Properties of Motor Vehicle Engine Lubricants Using the Light Polarization Method

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ABSTRACT

This paper has carried out active and non-linear optical characterizations of motor vehicle lubricants. The samples used were three two-wheeled vehicle oil with SAE labels: 10W-40, 20W-50, and 10W-30 without pre-treatment. The active optical property (natural polarization) was measured as a function of the polarizer angle without external field interference. Meanwhile, non-linear optical properties (electro-optical polarization) used changes in the polarization of light as a function of the potential difference imposed on the sample. The light sources used were a green pointer laser (532 nm) and a red pointer laser (632 nm). The results showed that the oil has active and non-linear optical properties. The natural polarization characteristic produces two polarization peaks at 30° and 60° on both wavelengths and holds to all samples. It indicates that the dimensions and shape of the molecules in all samples are identical. It is also shown by electro-optical polarization, where the change in polarization acts as a quadratic function of the potential difference with the concentric curves of the three samples, indicating identical molecules. With electro-optical polarization, the total polarization is enhanced without changing the active optical properties in the sample. It gives an advantage for developing this method as a tracer and evaluator of the molecules of other relevant materials.

1. Introduction

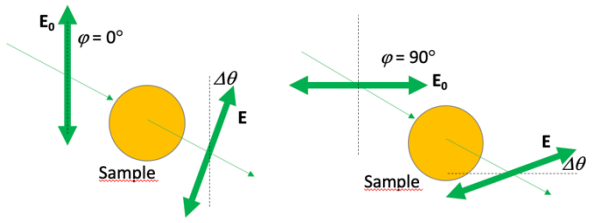
Light polarization is a natural property of light, it was found around the 17 Century by Danish physicist (he was also a mathematician), Erasmus Bartholinus, although he was not aware of the phenomenon of polarization [1]. Starting from it, polarization learn a lot and has many usages in experiments until now. In several previous studies [2-8], by adding electro-optical polarization (non-linear optics), light polarization can also be applied to characterize the optical properties of several other materials, such as cooking oil, whose active optical properties are relatively very small. By setting the observation direction to fluorescent polarization [9-11], light polarization can also be used to identify various cooking oil types and evaluate pork oil contamination. In addition, the combination of natural polarization with electro-optical polarization can become a breakthrough in understanding the study of the interaction of linearly polarized light with materials, providing new insights into the Van der Waals molecular interactions in a matter [12-13]. Other materials, such as colloidal silver solution [14-15], also exhibited optically active and non-linear optical properties. It provides an understanding of the interaction of the direction of the light field with the molecule's orientation.

In this research, we want to investigate the interaction of linearly polarized light using three motorized vehicle engine lubricant samples with different viscosities. The initial study [18] shows that vehicle engine oil also has optically active properties. In that study, typical properties of the oil, such as viscosity or its light spectrum characteristics, were not used. It only used natural light polarization and electro-optical polarization to investigate the optical properties of vehicle engine oil. Based on this result, we broadened the investigation of motor oil's non-linear optical properties based on the viscosities without pre-treatment like before.

2. Methods

In this study, the samples used were three motor vehicle engine oils with different viscosities, with codes 10W-30, 10W-40, and 20W-50. Natural polarization data from the sample was taken by measuring the change in polarization without an external field with a variation of the polarizer angle φ = 0° to 90° with an increase of 10° for each data collection. The angular mode of the polarizer is the variation of linearly polarized light relative to the axis

of the polarizer. The design for measuring the change in polarization as a function of the polarizer angle can be seen in Figure 1. The electro-optical polarization characteristics are obtained by providing an external electric field with a potential difference of 1 to 9 kV with an increase of 1 kV in the sample between two parallel plates, which were about 1.5 cm apart (this distance is the best distance our apparatus arrangement). The light source used was a red and a green pointer laser with wavelengths 632 nm and 532 nm, respectively. In detail, we make a setup experiment as Fig.1 where we took data from 0° -90° with variation every 10^0 in five times repetition each angle.



(a) (b)

Fig.1: Measurement of the change in the polarization of light $\Delta\theta$ as a function of the polarizer angle. The electric field of incident light is $\mathbf{E_0}$, and after hitting the sample, the polarization changes to **E**. Models (a) and (b), respectively, are examples of linearly polarized incident light at φ= 0°φ = 90°.

The target sample in Fig. 1 is a synthetic oil consisting of a collection of hydrocarbon molecules, and their additives are considered identical to each other. An oil *hydrocarbon* molecule is assumed to have three hydrocarbon chains, L1, L2, and L3, as shown in Figure 2 [18]. Molecules are said to be asymmetrical if the length of the hydrocarbon chain is different. It is assumed in this paper is L1 > L2 > L3. In its interaction with the incident light, which is linearly polarized E_0, the point P on the molecule is chosen as the center of symmetry.

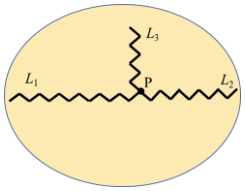


Fig.2: Hydrocarbon molecules model of oil with L_1, L_2, and L_3 are the length of the hydrocarbon chains. A molecule is said to be asymmetric if $L_1 \neq L_2 \neq L_3$.

3. Results and Discussion

Figure 3 is a graph of the change in polarization as a function of the polarizer angle without any additional field disturbance, which acts as a characteristic of the natural polarization of the three samples at wavelengths of 532 nm and 632 nm, respectively. The change in polarization at these wavelengths is in the range of 0,4° to 0,6°. This value is still relatively small than the sugar solution in general, but it is relatively larger than cooking oil [8]. These characteristic results confirm previous studies [18] that the oil also has optically active properties, and asymmetrical molecules are responsible for the natural polarization.

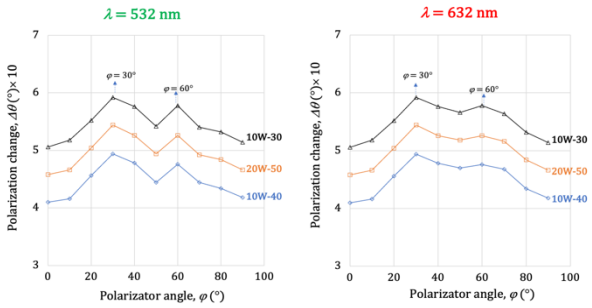


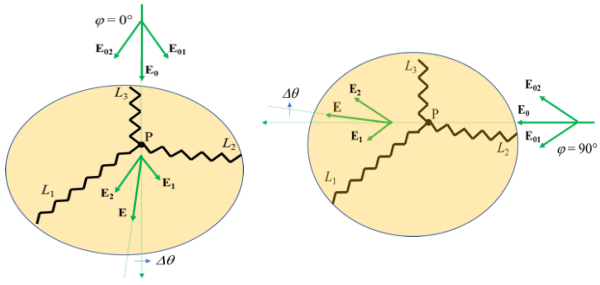
Fig.3: Graph of change in polarization $\Delta\theta$ as a function of polarizer angle φ for wavelengths 532 nm and 632 nm.

The three oils also have two peaks at the polarizer angle φ = 30° and φ = 60° as well as two lowest values at φ = 0°and φ = 90°, indicating identical molecular properties in the three samples. In Table 1, if the average polarization values include polarizer angle φ = 0°and φ = 90°, the increase in polarization value between the closest samples in the amount of 0,05° is obtained. It can indicate the addition of additive molecules. The 10W-30 sample had the highest mean value, which means it obtained the most additives molecules.

Table 1. Polarization change in mode φ = 0°, φ = 30°, φ = 60°, φ = 90° and the average for both wavelengths

Sample	Mode				Average
	φ = 0°	φ = 30°	φ = 60°	φ = 90°	
10W-40	0,41°	0,49°	0,48°	0,42°	0,45°
20W-50	0,46°	0,54°	0,53°	0,47°	0,50°
10W-30	0,51°	0,59°	0,58°	0,51°	0,55°

The first maximum polarization change, φ = 30°, indicates that the orientation of the electric field of light $\mathbf{E_0}$ towards asymmetrical molecules is the most optimum, and the second maximum is at φ = 60°. While the orientation of $\mathbf{E_0}$ relative to the asymmetrical molecule generates the first minimum polarization at φ = 0° and the second minimum at φ = 90°. Because the natural polarization characteristics use linearly polarized incident light that interacts with molecules, the occurrence of peak angles and minimum angles can be explained by using the direction interaction model of light $\mathbf{E_0}$ with an asymmetrical molecular orientation, as shown in Figure 4.



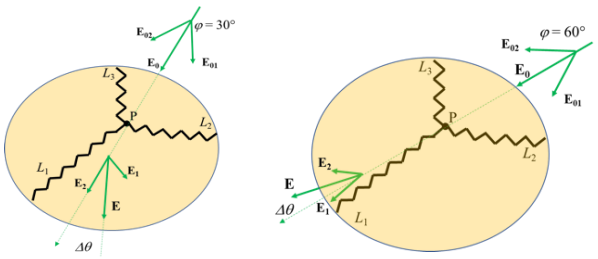


Fig.4: The interaction between $\mathbf{E_0}$ and the asymmetrical molecule results in **E**, whose direction changes from the original $\Delta\theta$.

The electric field of incident light $\mathbf{E_0}$ can be broken down into two vector components, $\mathbf{E_{01}}$ and $\mathbf{E_{02}}$. These two vectors interact with the hydrocarbon chains. If there is an effective difference between the two chains that interact with $\mathbf{E_{01}}$ and $\mathbf{E_{02}}$, the response of the induced electron cloud in each hydrocarbon produces two resultants, $\mathbf{E_1}$ and $\mathbf{E_2}$, that differ in both direction and magnitude from the original. After interacting, the resultant field **E** produces a polarization direction. In this case, the difference in the hydrocarbon chain is greatest at φ = 30°, where the largest polarization change is achieved.

In the graph of Figure 3, the total value $\Delta\theta$ as a function of φ, we assumed that there is an additive mixture in the samples. To determine how the pure asymmetrical molecule contributes, the total value is converted to a polarization ratio by weighting the change in polarization at an angle of φ = 0° as the lowest value, the results are presented in Fig.5. It turns out that the largest polarization ratio is obtained in the 10W-40 sample, and it is strongly suspected the largest asymmetrical molecular composition is in the sample 10W-40. This difference is slightly obvious at each peak φ = 30° and φ = 60°.

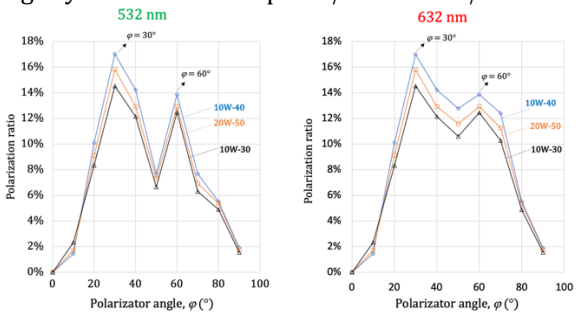


Fig.5: Natural polarization ratios for the three oils at 532 m and 632 nm wavelengths. The 10W-40 sample is suspected strongly show the largest asymmetrical molecules.

Very interesting results can be seen when the polarization ratio for the same sample is compared with two different wavelengths, as shown in Fig. 6.

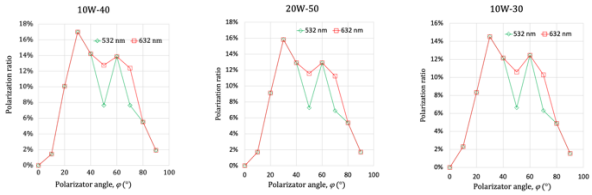


Fig.6: Natural polarization ratio at wavelengths of 532 m and 632 nm for the three samples. There is a birefringent phenomenon at angles φ = 50° and φ = 70° in all samples. The results of a preliminary study using 20W-50 [18] also showed the same phenomenon.

It can be seen that the two wavelengths produce different polarization ratios at angles φ = 50° and φ = 70°, which apply to all oil samples. The phenomenon is most likely birefringent, where there is a change in the optical axis in half on the trajectory of the polarizer angle of 40° to 80°. The refractive index of the 532 nm wavelength is bigger than the 632 nm wavelength. This indicates the green laser to have a shorter optical path at the angle of the polarizer 40° – 50° – 60° and 60° – 70° – 80°, which results in different values of $\Delta\theta$.

For electro-optical polarization, the change in polarization as a function of potential difference can be seen in Figure 7 below.

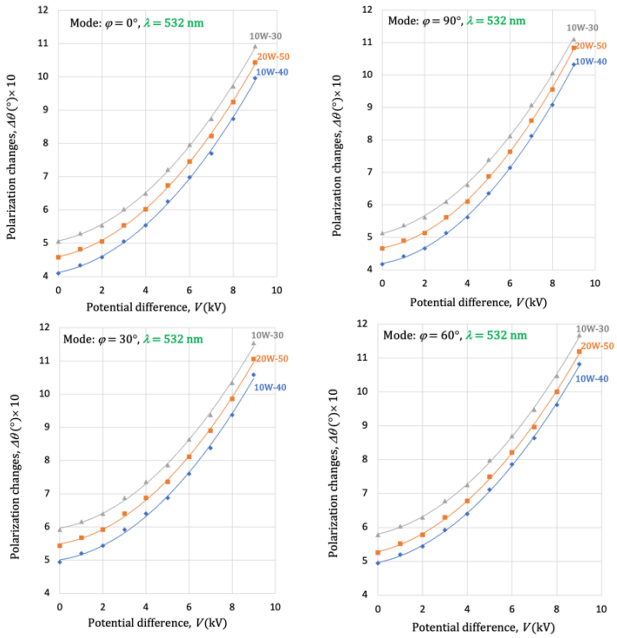


Fig.7: Electro-optical polarization change for three oils at a wavelength of 532 mn.

The electro-optical polarization characterization of the three samples showed that non-linear optical effects (or non-linear polarization) could also occur in oils with a linear external electric field of the order kV. Due to technical constraints in data collection, only non-linear polarization at angle modes φ = 0°, 30°, 60°, and 90° is obtained, with the result being a second-order polynomial,

$$\Delta\theta = \theta_0 + \theta_1 V + \theta_2 V^2 \qquad (1)$$

where V is the potential difference, θ_0 changes in polarization without any external field disturbance, θ_1 linear electro-optic coefficient, and θ_2 quadratic

electro-optic coefficients. The trend is also general for other types of oil and consistent with previous results [18].

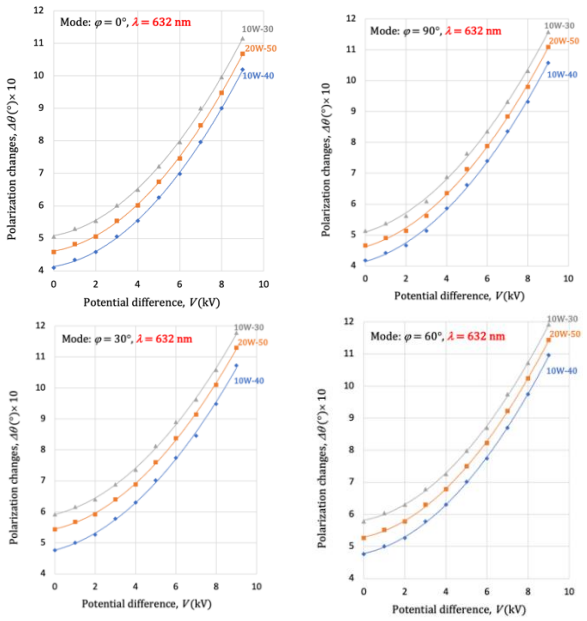


Fig.8: Electro-optical polarization change for three oils at a wavelength of 632 mn.

By looking at the pattern similarity in all samples and both of the wavelengths (Fig.7 and Fig.8), we can say that the molecules seen in all samples are identical in both shape and size. The highest total electro-optical polarization value is at 10W-30 due to the additives, which also contribute to the formation of the average electric dipole.

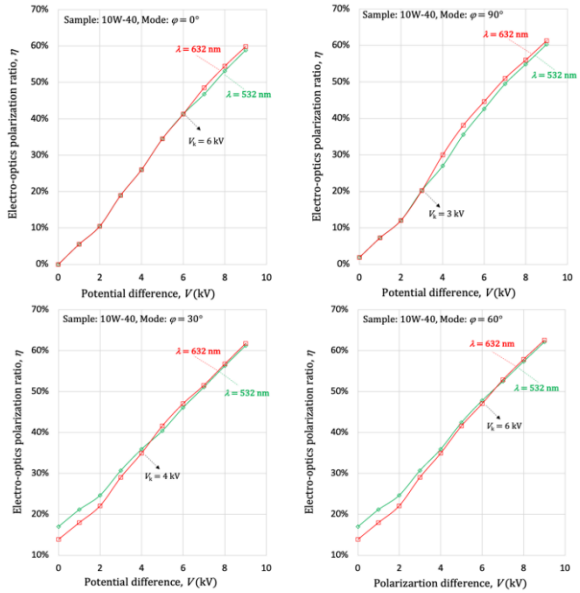


Fig.9: Electro-optical polarization ratio for 10W-40 at 532 nm and 632 nm wavelengths. In the φ = 0°and 90° modes after the critical voltage V_k, the optical axis is split into two, while in the φ = 30°and 60° modes the optical axis is fused.

If the contribution part of the electro-optical polarization is evaluated, then equation (1) is changed to

$$\Delta\theta - \theta_0 = \theta_1 V + \theta_2 V^2 \qquad (2)$$

By defining the ratio of electro-optical polarization as $\eta = (\Delta\theta - \theta_0)/\theta_0$, the ratio of electro-optical polarization for all samples is obtained for both as shown in Figure 9, Figure 10, and Figure 11.

All graphs in Figures 9-11 show the occurrence of optical axis splitting (birefringent) due to electro-optical application to the samples after a critical voltage (V_k), except for samples 10W-40, in φ = 30°and 60° modes, the converging of optical above V_k occurs. Table 2 shows the critical voltage values of all samples in the modes φ = 0°, 30°, 60°, and 90°.

The oil model offered above is an oil with a relatively homogeneous molecular size and shape. The asymmetrical nature of the molecule responsible for the change of natural polarization consisting of two or three chains with different lengths seems quite adequate. Molecules that have three chains of the same length are considered symmetrical and do not contribute to natural polarization. The addition of additives molecules relative to one another seems to increase the polarization but does not change the molecular characteristics of the individual oils. The same pattern in two peaks at φ = 30° and 60° for all samples indicates that the types of hydrocarbon molecules are identic. Similarly, the occurrence of birefringent in the φ = 40° to 80°region is the same in all samples strengthening the argument that the shape and size of the molecule are relatively homogeneous.

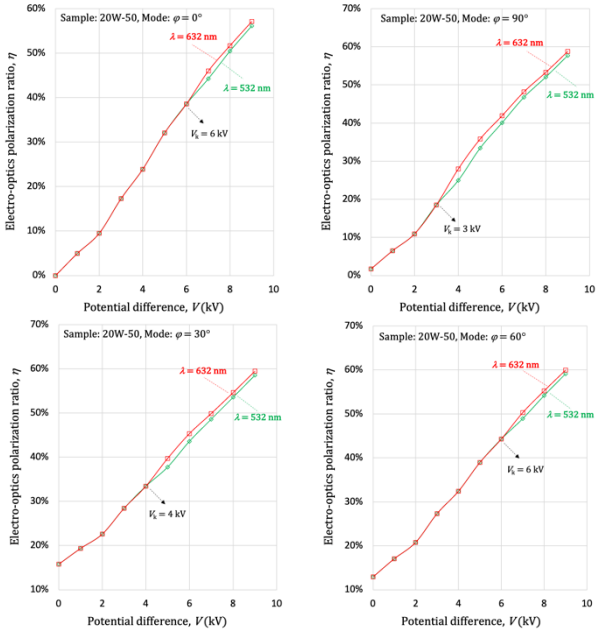


Fig.10: Electro-optical polarization ratio for 20W-50 oil at 532 nm and 632 nm wavelengths. In the φ = 0°, 30°, 60°, and 90° modes after critical V_k, the optical axis is split into two.

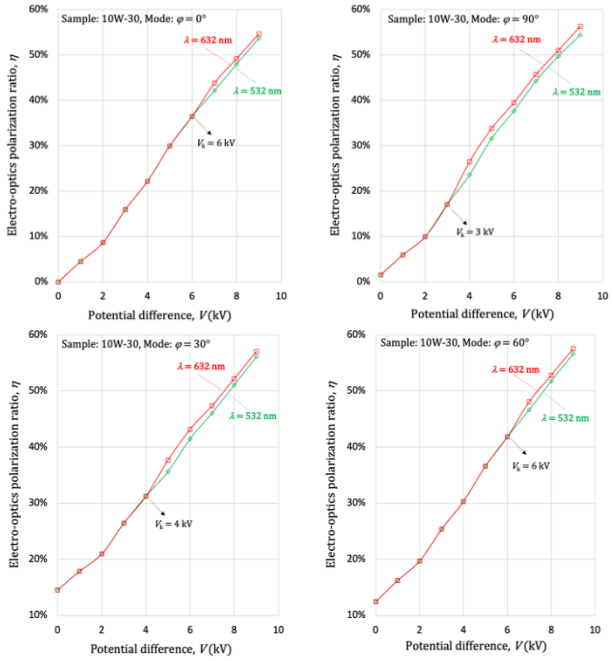


Fig.11: Electro-optical polarization ratio for 10W-30 oil at 532 nm and 632 nm wavelengths. In the mode $\varphi = 0°$, 30°, 60°, and 90° after the critical voltage V_k, the optical axis is split into two.

Table 2. The critical voltage of the optical axis change due to electro-optical polarization.

	Critical voltage, V_k (kV)					
Mode	**Optical axis splitting**			**Optical axis fusion**		
φ	10W-40	20W-50	10W-30	10W-40	20W-50	10W-30
0°	6	6	6	-	-	-
30°	-	4	4	4	-	-
60°	-	6	6	6	-	-
90°	3	3	3	-	-	-

All this time, the active optical properties are largely determined by the chiral or non-chiral properties. In this case, with the new paradigm, the notion of optical properties due to symmetrical or asymmetrical molecules may not be the same as chiral or achiral molecules. It doesn't matter whether the molecule is chiral or non-chiral, as long as the electric field interaction of the light with the molecule produces an effective field with an initial direction change. Molecules are said to be asymmetric if having 2 or 3 different hydrocarbon chains, so all of them contribute to the natural polarization. While the molecule is symmetrical if all the hydrocarbon chains are identical, and it does not contribute to natural polarization. Thus, the practical active optical properties are determined only by the direction of the electric field from the incident light and the orientation of the molecules making up the sample when interacting with each other.

The non-linear optical properties of the oil sample also occur at a potential difference with an order of kV, which we call non-linear or electro-optical polarization. This property also occurs in samples other than oil [8], which is measured by the light polarization method. Unlike the natural optical property or natural polarization, in electro-optical polarization, the change in polarization increases polynomially to the power of the two concerning the voltage due to the formation of electric dipoles of all types of molecules in the oil. The advantage of electro-optics is that the value of the natural polarization (or the characteristic properties of active optics) does not change. It also adds to the total contribution to the change in polarization so that the measurement becomes more accurate. These results strengthen the results obtained in our earlier studies [8]. A concentric pattern was obtained from the pattern of change in polarization as a function of voltage for the three samples. Qualitatively, this indicates that the size of the resulting dipole is equivalent to the shape and size of the oil molecules, which are identic in all samples.

In the phenomenon of electro-optical polarization, there is something that we think is new, namely the interaction of linearly polarized light with dipoles induced by an external field producing an electro-optical gradient associated with Van der Waals interactions between molecules. This term was stated in a previous study [3] when the change in polarization was linear relative to the potential difference. We now emphasize that the electro-optical gradient is the point of the shift in electro-optical polarization, a kind of additional potential energy due to the application of an external field. In several studies [12-13], we also proposed the possibility of a breakthrough regarding the interaction of light with molecules through electro-optical polarization, which is nothing but related to Van der Waals interactions between molecules. In other words, the total change in polarization is related to the Lennard-Jones potential energy. Changes in the distance between molecules are represented relatively with the addition of an electric potential difference across the sample. Considering the relatively uniform size of the oil molecules, it seems that oil molecules are suitable for being used as alternative molecules to explain the intermolecular Van der Waals interactions through electro-optical polarization. This discourse is not limited to oil or cooking oil samples but can also be extended to other non-polar samples.

The optically active and non-linear optical properties of the oil sample using the light polarization method are relatively new, as far as the literature study we have done. Due to technical constraints, the relationship between this optical property and viscosity cannot be described more comprehensively yet. The high and low polarization of one sample with another does not indicate the quality of one with the other is better or worse. Therefore, several things that need to be investigated further are the development of optical properties related to the viscosity quality parameters of the oil, which in our opinion, has a very interesting prospect.

4. Conclusion

In this study, all motor oil samples showed active optical properties (natural polarization) and non-linear optical properties (electro-optical

polarization). In the case of natural polarization, all samples have natural polarization peaks at polarizer angles φ = 30° and 60° and birefringent in the 40°-50°-60° path and 60°-70°-80° path, which indicates that the oil constituent molecules are identical in all samples. In the case of electro-optical polarization, all samples show a trend of change in polarization as a quadratic function of the potential difference. For samples 20W-50 and 10W-30 at critical voltages, there is a slight birefringent splitting of the optical axis at polarizer angles φ = 0°, 30°, 60°, and 90°. As for the 10W-40 sample, the optical axes converge at φ = 30° and 60°, and the optical axes split at φ = 0° and 90°. The lowest average polarization change in the 10W-40 sample is possibly caused by the lowest presence of additives.

The natural polarization characteristic of the oil sample opens up new horizons about the definition of optically active properties, which have been caused by chiral or non-chiral molecules, in this paper, it tends to be caused by the orientation of the electric field direction of the incident light to the orientation of the asymmetrical molecules of the oil when interacting with each other. Likewise, electro-optical polarization, in addition to increasing the total polarization, does not change the optically active properties of the initial molecules but also gives a new perspective on the interaction of linearly polarized light with the induced dipole in the sample, which is correlated with the interaction of Van der Waals forces between non-polar molecules in oil. The combination of natural polarization and electro-optical polarization can be used for the detection of polar molecular traces, oil or oil quality investigation, and so on. The electro-optical gradient associated with the addition of potential energy to the sample is strongly related to the Lennard-Jones potential energy of the oil molecule. This phenomenon opens the opportunity to study polar molecular interactions in other samples through electro-optical polarization.

5. Conflict of Interest

The authors declare that they have no conflict of interest.

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