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Experimental Layout for Investigating Temperature Dependednce of the Vibration Plane Rotation in Some Identified Mineral and Vegetable Oils

[1]Eric Mucunguzi-Rugwebe, [2]E.A. Hammer and [2]Y. Kaahwa,
[1]Kyambogo University, Faculty of Science, P.O. Box, 1, Kyambogo, Uganda
[2]University of Bergen, Norway

Abstract: This study presents results of a recent study done in Norway from Bergen University, to determine temperature dependence of linear birefringence in mineral oil and linear and induced birefringence in vegetable oils. The study was done between the temperature range of 6 and 45ºC in magnetic field up to 140 mT. It found the intrinsic birefringences responsible for optical activity in vegetable oils with impurities and all mineral oils. The results of optical activity in both oils obeyed the equation f = A + a_w (1) where a_w is the angle at which minimum irradiance I_{min} occurs in water and other substances which are optically inactive. Heavy oils like red diesel, Esso diesel and Fina diesel No. 2 rotate more the vibration plane and they possess more intrinsic birefringences than light diesel. The research team found that the temperature effect on rotation in both mineral and vegetable oils with impurities, yielded results that obeyed the equation f_1 = A - bT (3) where b is positive. In vegetable oils for human consumption, application of magnetic field causes induced birefringences responsible for f given byf_2 = VHL + a_w (4) where V is Verdet's constant in rad $T^{-1}m^{-1}$ and H is the magnetic field intensity in Am-1. Also the temperature dependence on rotation in vegetable oils free from impurities obeyed the relationship given by equation = VHL–bT (5). This method can be used to determine the level of refinement of mineral and vegetable oils.

Key words: Birefringences, irradiance, optical activity, vegetable oils, vibration plane

INTRODUCTION

The study was done to determine the temperature dependence of the angle of the vibration plane rotation. This is a method used to detect impurities in mineral and vegetable oils by optical rotation technique. And then use this dependence to get correction for the required angle of rotation due to impurities in both mineral and vegetable oils at any temperature when the sample is tested. It is difficult to get pure oils from processing of vegetable oils or mineral oils. Vegetable oils may contain impurities like (i) variety of particles, (ii) drops of foreign liquids, (iii) soap, (iv) sand, and (v) wax extra. The end product often has oil-fats, oil-moisture or oil-fats-moisture. In the bureau of standards the most used quality indices utilise chemical indices (Kuloba, 1990).

It is desirable to have another alternative method based on physical properties to augment the chemical indices in determining oil quality. In mineral oil industry, various methods listed below have been used to detect impurities in order to improve on oil quality (Thorn *et al.*, 1997): g-ray attenuation; electrical impedance technique; microwave attenuation and phase Shifts; Pulse Neutron Activation (PNA); Nuclear Magnetic Resonance (NMR).There is a need to determine the impurities in mineral oils by optical rotation technique method. The purpose of this work is to utilise the method based on optical activity and Faraday Effect to study the dependence of rotation on impurities and temperature in some of the vegetable and mineral oils. The rotation technique is used as a tool to analyse oil quality and also sort out types of oils.

METHODOLOGY

When a beam of linearly polarised light is directed along the optical axis through optically active medium the vibration plane is rotated through an angle, q, given in (1). Optical activity is caused by asymmetry of molecules that have spiral shape.The relationship between optical activity and molecular structures results from the interaction of plane-polarised light with the electrons in the molecules. Each type of optically active molecules causes different optical rotation. The molecular groups that contribute most directly to optical activity are those that have loosely bound electrons which interact with light. Due to asymmetry of molecules, the binding force on the electrons is not symmetrical. Electrons displaced from their equilibrium positions along one direction have a greater "spring constant'' than when displaced along another direction.

Since the propagation of electromagnetic waves through materials is a process of electrons absorbing and re-radiating this energy, the fact that electrons respond

Corresponding Author: Eric Mucunguzi-Rugwebe, Kyambogo University, Faculty of Science, P.O. Box, 1, Kyambogo, Uganda

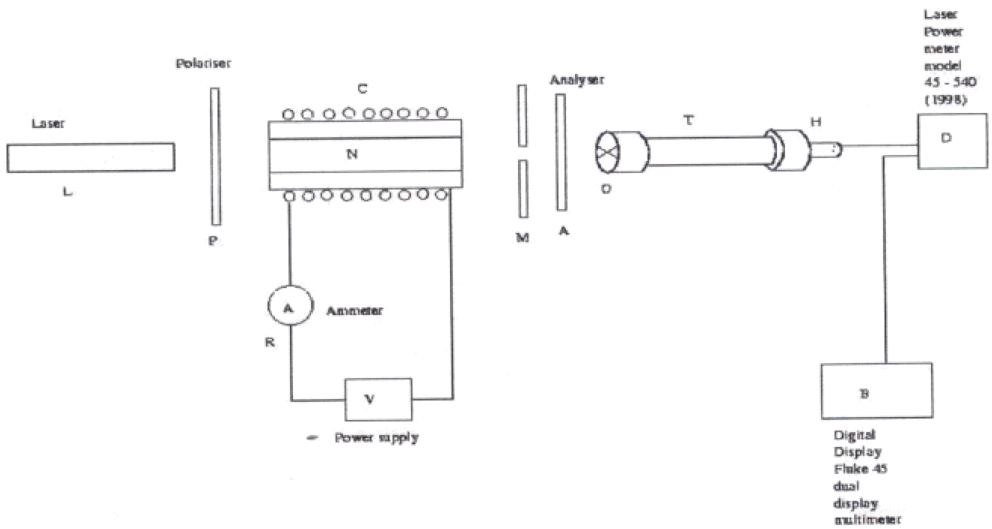

Fig. 1: Experimental setup for detecting small fractions of salt water in oil in salt water

differently along one direction than along another, causes the waves to be transmitted with different speeds in different directions.These eigenwaves, for a given direction of propagation have well-defined phase velocities and directions of polarisation (Yariv, 1985). Linearly polarised light may be considered as the sum of two circular polarisation rotating in opposite directions. The electric field of a wave travelling through a medium polarises the electrical charges of the atoms of the medium in the direction of the wave's oscillations. The electric polarisation of the material is then in the direction of polarisation of the wave.

As a result of different speeds, two circularly polarised waves forming a linearly polarised light traversing optically active specimen must be out of phase and the resultant wave would appear to have rotated. When a certain thickness of optically active material is inserted between the Analyser and a Polariser, the condition of extinction no longer exists, because the E–vector of the light is rotated by the active medium. The optical rotation is found to be linearly dependent on the path length traversed by the light through the sample. The exact angle of rotation can be measured by rotating the Analyser until the extinction occurs again. The rotation measured depends on the (i) the wavelength of light, (ii) the thickness traversed by light (iii) temperature and (iv) the concentration of the optically active substance in the solution and the relationship is given by (Kawamura, 1996):

$$\theta[\deg rees] = L[cm] \times \omega \times d\left[kg/m^3\right] \tag{1}$$

where, w, is the specific rotation and in liquids defined as the rotation due to a 0.1 m column length of the active liquid, q, is the net rotation , L, is the path length through which light traverses in the liquid and d is the concentration expressed as kilograms of active substance per cubic metre. The relation in equation (1) holds for one optically active substance. If N types of optically active substances are involved in the sample under test then:

$$\theta = L \times \left(\omega_1 \times d_1 + \omega_2 \times d_2 + ..., + \omega_N \times d_N\right) \tag{2}$$

Given that the contribution towards the net rotation, q, of each concentration in a mixture can be determined, this is the reason for using this technique to measure purities of transparent liquids.

When a static (dc) magnetic field is applied to a medium in the direction parallel to that of the beam of linearly polarised light passing through the same medium, the vibration plane of the polarised light is rotated through an angle:

$$\alpha = V_x\, B_x\, L_x \tag{3}$$

where, Vx, is the Verdet's constant which depends on the wavelength and temperature, Bx, is the magnetic induction in X direction and, Lx, the length of the material(Moller, 1988):

$$\alpha = \left(\frac{\pi\omega \dfrac{e}{m} \omega_P^2}{\lambda n(\omega_0^2 - \omega^2)^2 - \omega^2 \omega_0^2} \right) BL \tag{4}$$

where, $\omega_p = Ne^2/\epsilon_{o\,m}$ is the plasma frequency and ω_o = k/m is the resonance frequency and, k, is the force constant. The factor in the parentheses in equation (4) is equivalent to Vx- the Verdet constant and it can be seen that Vx depends on the refractive index of the material under test and therefore it can be used as an indicator of oil quality.

Therefore, each grade quality of oil and also every kind of oil has a different natural frequency and consequently a different characteristic magnetic rotation. Contamination of either vegetable or mineral oils changes their quality or grades and this affects their eigen magnetic rotation. Since rotation of the plane of vibration depends on each type of oil grade and its temperature rotation due to either linear or induced birefringences can be used as a tool to analyse oil quality and also to sort out types of oils at a certain temperature. The experimental layout for investigating temperature dependence of rotation in oils is shown in Fig. 1.

Figure 1 shows experimental investigation of temperature dependence of rotation in mineral and vegetable oils.

Likewise, the continuous wave (cw) He-laser, L, model 1676 (1997) provided a randomly polarised light of 543.5 nm and produced light energy of 2.0 mW. A Polariser, P, was for improving the quality of polarisation of the beam; a green laser was preferred because (i) green gives suitable rotation and higher penetration than red laser, (ii) economically cheaper than a blue laser. N is the sample container and C, a coil for producing static magnetic field. M is a mount with an orifice for detecting deviation in the beam's passage caused by misalignment of any item on the optical bench or brought about by refraction particularly when the sample was interposed between the Polariser and the Analyser, A. O is the orifice to assist in directing the beam to the detector head H; T is a tube intended to cut off ambient light (light from the surroundings) and is blackened inside to reduce reflection; D is the detector (laser power meter) model 45-540 (1998) and B is digital display multimeter for displaying the output.

Later on, the analyser was rotated to obtain minimum irradiance, l_{min}, when distilled water was in the container and angle, ax , at which this minimum irradiance occurred was noted. The value of, I_{min}, was regarded as the irradiance reference in determining extinction point for all measurements. Since distilled or pure water is optically inactive, the angle, ax , was also regarded as the reference angle above or below which rotation was considered to have taken place. Before investigating the dependence of the angle of rotation, f on temperature, the following precautions were taken into account:

- Most of the vegetable oils start solidifying just below 20ºC;
- Mineral oils like Super Petrol could be dangerous above 30ºC and would have excessive evaporation causing too much fluctuations in relaxation polarisation;
- Pressure developed at the end of the sample container created by temperature rise, causes photo elasticity effect and this results into intrusive birefringences that upset rotation.

In order to avoid solidification, vegetable oils measurements were taken at temperatures above 20.0ºC. On the other hand, in the mineral oil, the study of rotation dependence on temperature was below 30ºC to avoid explosion and excessive evaporation particularly when Super Petrol was used. Also Esso diesel started solidifying at 5ºC, so the measurements were done at temperatures above 5ºC for this sample. Two holes were bored in the sample container near its one end and a pin with a hole to act as air outlet (safety valve) was screwed into one of the holes, then a junction of a thermocouple BK Precision Type 'K' was inserted in the other hole.

On the other hand, three samples of edible oils were used in the investigation of rotation dependence on temperature and these were:

- Crude oil
- Sunflower oil
- Final grade oil

The safety value was then screwed onto the container to act as an outlet and to minimise sample leakage. The sample under test was then poured into the container and the open end closed. Then sample container was put holder in a warm bath for some time to obtain uniform temperature. While sample container holder was in the bath, a thermocouple junction was inserted in the hole and made to be in contact with the sample to measure temperature. Afterwards, sample container holder was quickly transferred and aligned on the optical bench. The variation of rotation against temperature drop was observed in crude oil without magnetic field. For the case of sunflower and final grade oil, a coil current of 0.7A was used to generate constant magnetic field to induce circular birefringences in the samples. A graph of rotation angle against temperature was plotted for the three samples investigated.

The effect of the temperature on rotation in mineral oils was observed in three samples and these were:

- Super Petrol
- Esso diesel oil
- Fina diesel No.2

The sample holder was put in a freezer for some time and temperature was recorded. Afterwards, sample holder was transferred from the freezer and fixed in its place on the optical bench. The variations in rotation against temperature rise were observed. A graph of rotation against temperature was plotted for each of the three

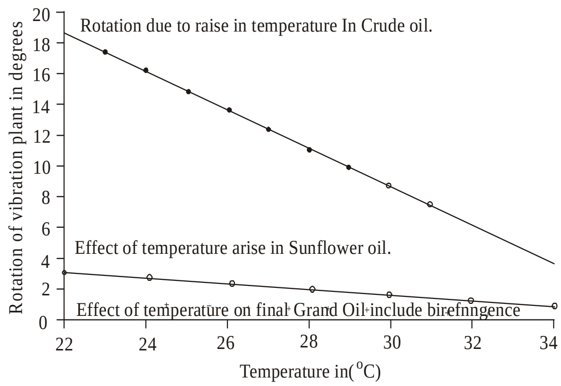

Fig. 2: Comparison of the temperature effect on rotation of the vibration plane in linear birefringences in crude and induced birefringences in sunflower and final grade oil

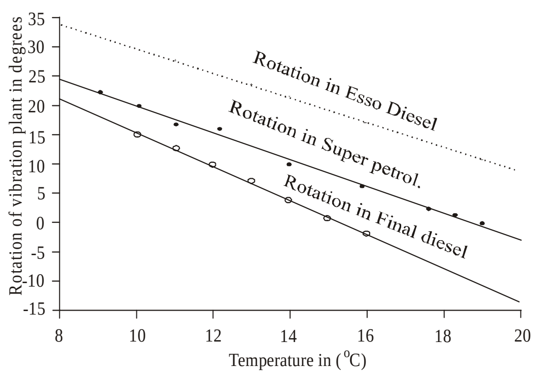

Fig. 3: Comparison of the effect of temperature on rotation of the vibration plane in super petrol, Esso and Fina diesel No.2

samples used; the effect of temperature in three samples was compared graphically.

RESULTS AND DISCUSSION

The key results of the temperature dependence of rotation angle f in various samples of vegetable oils were recorded. The comparison of the impact of temperature on rotation angle of the vibration plane in three vegetable oils, show the greatest reduction in rotation angle was found in crude oil, followed by that in sunflower oil and the least was observed in final grade oil. The results exhibit a ϕ_1 = A-bT temperature-dependence (with b positive) and are in line with what was found by Zaid and Tatan (1994) as shown in Fig. 2.

Figure 2 shows the comparison of the temperature effect on rotation of the vibration plane in linear birefringences in crude and induced birefringences in sunflower and final grade oil.

A summary of temperature effect on rotation angle of the vibration plane in three samples of vegetable oils is given in Table 1.

Table 1: Temperature effect on rotation in vegetable oils

Sample	Constant A at 22.0ºC	Slope (ºC)$^{-1}$
Crude oil	18.8º	-1.50
Sunflower oil	3.2º	-0.19
Final grade oil	1.4º	-0.09

Table 2: Temperature effect on rotation in mineral oils

Sample	Constant A at 22.0ºC	Slope (ºC)$^{-1}$
Esso diesel	33.2º	-1.99
Super petrol	24.3º	-2.28
Fina diesel No.2	21.0º	-2.88

The results presented compared the impact of temperature on rotation in the three samples of mineral oils. The azimuth rotation most affected by temperature was found in Fina diesel, followed by that in Super Petrol and the least affect was observed in Esso diesel. All the results obey f_1 = A–bT relationship with b positive as indicated in Fig. 3. Figure 3 shows a comparison of the effect of temperature on rotation of the vibration plane in super petrol, Esso and Fina diesel No.2

A summary of temperature effect on rotation angle of the vibration plane in three samples of mineral oils is given in Table 2.

Without magnetic field, rotation angle of vibration plane,f, was observed in vegetable oils that contain impurities. The effect of temperature on f obeyed the relationship f = A-bT, where A, is the rotation due to impurity concentration. In vegetable oils suitable for human consumption I_{min} occurs at, a_w, the cut-off angle for distilled water when there is no magnetic field applied to those oils. Application of magnetic field causes induced rotation in such oil with f = VHL. Temperature causes reduction in f obeying the equationf_3 = VHL-bT. In minral oils, the strength of intrinsic birefringences is reduced with increase in temperature. The rotation angle of the vibration plane, f, obeys the relationship f_1 = MKL–bT. Since the eigen azimuth rotation of a type of oil at a certain temperature, is different from that caused by another kind of oil at same temperature, this rotation can be utilised in sorting out different kinds of oils.

CONCLUSION

It can be argued that temperature changes affect the spring constant of the material through which polarised light is propagated. A rise in temperature weakens the spring constant and lowering temperature results in a strong spring constant. Since rotation, q, depends on the constant of propagation, it is necessary to investigate the contribution of temperature on rotation of the vibration plane. Vegetable oils (edible oils) are like mineral oils, which are hydrocarbons with long and complex molecules capable of resonating at a particular frequency. This particular frequency at which resonancy occurs depends upon the nature of the oil.

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REFERENCES

Kawamura, T., 1996. Method and Apparatus for urialysis, method of measuring optical rotation and Polarimeter PCT/JP &/03368.

Kuloba, J.W., 1990. An electronic oil quality control device with interface to microcomputer. M.Sc. Thesis, Makerere University Kampala, Uganda.

Mucunguzi-Rugwebe, E.R.R., 2000. Optical activity and faraday effect in some mineral and vegetable oils. Ph.D. Thesis, Dissertation Makerere University Kampala, Uganda.

Moller, K.D., 1988. Optics University Science Books Mill Valley, California.

Thorn, R., G.A. Johansen and E.A. Hammer, 1997. Review Article: Recent developments in three-phase flow measurement ‘Meas. Sci. Technol, 8: 691-70.

Yariv, A. 1985. Optical Electronics 3rd Edn., Holt, Rinehart and Winston, New York.

Zaid, S.H. and R.P. Tatan, 1994. Farady-effect magnetometry: Compensation for temperature-dependent Verdet Constant. Meas. Sc. Technol. 5: 1471-1479 Cranfield University, Cranfield, Bedford MK43 OAL, UK.