International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 12, December-2014

Thermo-Optical and Order Parameter Studies by Image Analysis

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***Abstract*— Thermo-optical properties of calmatic liquid crystals: 4-Cyano-4'-pentylbipheny and p-ethoxybenzylidene-p-n-butylaniline, have been investigated by applying image analysis technique in conjunction with Polarizing Optical Microscope for image textures. The temperature related textural features will benefit to compute thermo-optical properties. These are analyzed through MATLAB software to investigate thermo-optical parameters such as optical transmittance, absorption coefficient, birefringence, phase retardation and order parameter. This is the most easiest and simple technique than other techniques for studying properties of different optical parameters of liquid crystals in response to temperature.**

***Keywords*— Liquid crystals, Thermo-optical properties, extures, Image analysis.**

1. INTRODUCTION

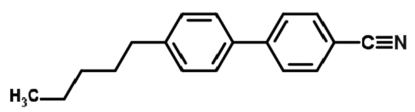
Liquid crystal technology has had a major effect in many areas of science and engineering, as well as device applications. Applications for this special kind of material are still being discovered and continue to provide effective solutions to many different problems. Applications of liquid crystals almost always involve optics. Thermo-optical properties such as optical transmission, degree of polarization, absorption coefficient (AC), refractive index, birefringence and order parameter [1–3] of liquid crystals are important to study relationship between the effect of radiation and matter. These optical properties provide significant information about molecular ordering, molecular dynamics and nature of molecular interactions. There are a number of techniques available for studying the temperature dependence of the optical properties of liquid crystals, including polarizing microscope [4-6], UV-Vis Zeiss Jene Spectrometer [7,8], Correlation Photoacostic Spectroscopy [9], Michelson Interferometer [10], Wedge method [11], Imaging Polariscope [12], abberefracto mater [4], High resolution Optical polarimeter [13], Laser Interferometer [14], FTIR-Spectrometer [15], X-Ray experiment [16], Kossel diagrams technique [17], Polarized Raman Spectroscopy and X-Ray scattering [18,19]. Each method has different separate experimental setups for investigating optical properties of liquid crystals.

In recent years, image analysis for liquid crystals has been applied to microscopic images extract maximum information from image objects [20] The use of image analysis in conjunction with POM in the studies of thermo-optical properties of 5CB and EBBA is reported in this communication.

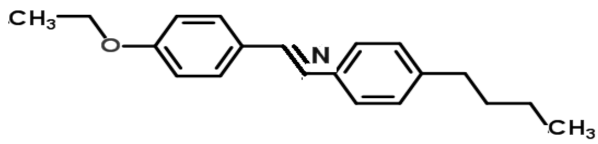
II. EXPERIMENTAL DETAILS

2.1. Materials

The liquid crystal compounds of 4-Cyano-4'-pentylbipheny (5CB) and *p*-ethoxybenzylidene-*p*-*n*-butylaniline (EBBA obtained from Frinton laboratory, USA. The molecular structures of the compounds are shown in Figure.1.



(a)



(b)

Figure 1: Molecular Structures of (a) 5CB (b) EBBA

The indium–tin oxide (ITO) coated homogeneous cell of dimensions 5 mm × 5 mm with 8.7 µm spacing (tolerance ±0.2 µm), was obtained from Instec, USA.

Temperature-dependent textural investigations were carried out using a Meopta POM and its hot stage, as described by Gray [21], and a high resolution colour camera (Canon Digital Rebel XS EOS 1000D). It is a digital single-lens reflex camera having a 10.10 megapixel image sensor and EOS integrated self-cleaning sensor unit to remove dust on the images. The LCD monitor is manufactured for a very high precision at over 99.99% effective pixels. With a 10.10 megapixel output, this camera gives true colour reproduction, low noise, a wide dynamic range and good spatial and spectral resolution. The maximum frame rate is high, at 3 frames per second. Live images are displayed on a monitor. The characteristic colours of microscope samples can be recorded faithfully in true colour reproduction. This enables accurately for colour analysis at high precision. Digital cameras tend to have difficulty in balancing colours accurately, especially red and yellow as a result images often appear unnatural. Hence,

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the camera is designed with a custom white balance, which calibrates the camera to the exact colour temperature of the light illuminating the object [22-25].

2.2. Procedure

Textures of the samples were recorded at a cooling rate of 0.2◦C/min in three monochromatic image planes, red, green and blue, at wavelengths 600 nm, 530 nm and 470 nm, respectively, under crossed and parallel polarizer [25-27]. The texture images detected by the camera have a resolution of 2816 × 1880 pixels and the intensity values of the pixels ranges from 0 to 255. The image dimensions selected are 256 × 256, and the images loaded in the computer for further processing. **MATLAB version 7.7.0 R2008b** software implemented on Intel (R) 1.80 GHz with 4GB RAM computer is used to compute the optical parameters. Measurements of thermo-optical properties are made in three monochromatic image planes, red, green and blue separately.

III. RESULTS AND DISCUSSION

The liquid crystals -5CB and EBBA- have exhibited enantiotropic nematic phase. Texture analysis carried out during cooling of the liquid crystal to avoid paramorphotic defects. Transition temperatures of the two thermo tropic liquid crystals are shown in Table 1.

The temperature dependence of the optical properties of the 5CB and EBBA which are aligned homogeneously in the liquid crystal cell, are defined in terms of image intensity values as follows.

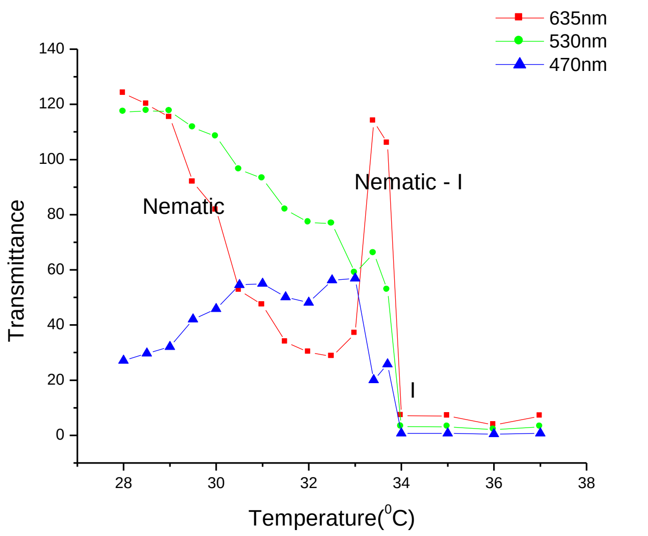
(a) Transmittance:

Optical transmittance of the thermo tropic liquid crystals is measured by computing the average transmitted intensity of the image texture which was recorded from the crossed polarizer condition [28], as in Equation (1):

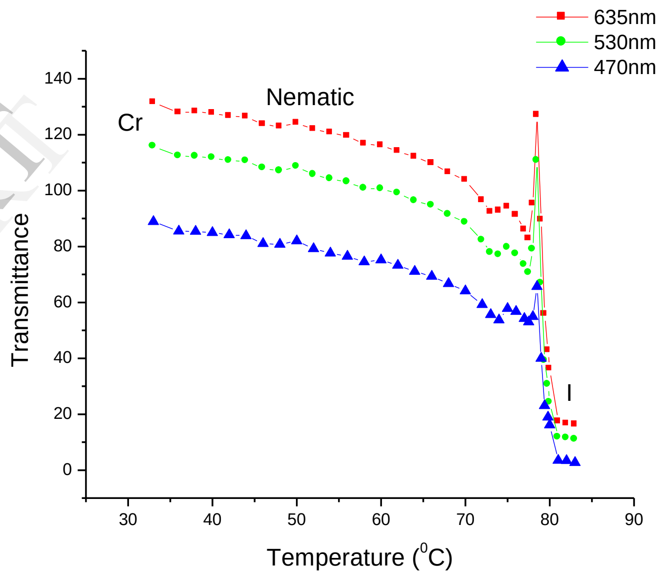
$$\text{Transmittance} = \frac{1}{N}\sum_{i=1}^{m}\sum_{j=1}^{n} I(i,j) \quad (1)$$

where $I(i,j)$ is the image intensity value observed at location (i, j) from the crossed polarization component of the texture image. Between crossed polarizer the value of the optical transmittance is zero in the isotropic liquid phase of the sample. During cooling, the value of optical transmittance has increased close to the isotropic–nematic transition and it is maximum at nematic temperature interval.

Figure 1 shows the variation in the values of optical transmittance at nematic–crystal transitions. The variation in values is due to the fact that in different phases there are changes in the textural features in response to temperature. This can be observed in Figure 2.



(a)



(b)

Figure 2. Temperature dependence of optical transmission of (a) 5CB, (b) *EBBA.*

(b) Absorption coefficient:

Incident and transmitted intensity values and thickness of the liquid crystal layer *d* is related to the absorption coefficient (AC) [29,30]:

$$I = I_0 e^{-ad} \quad (2)$$

where ***a*** denotes the absorption coefficient (AC), I is image intensity value observed with the crossed polarization components, I_0 is the image intensity value observed from the parallel polarization components in the absence of a sample. Using Equation (2), the temperature- dependent optical ACs for 5CB and EBBA have been computed, which are shown Figure 3.

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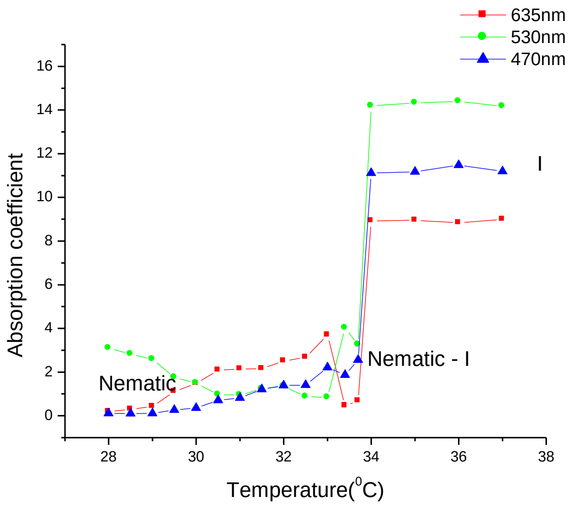
ISSN: 2278-0181
Vol. 3 Issue 12, December-2014



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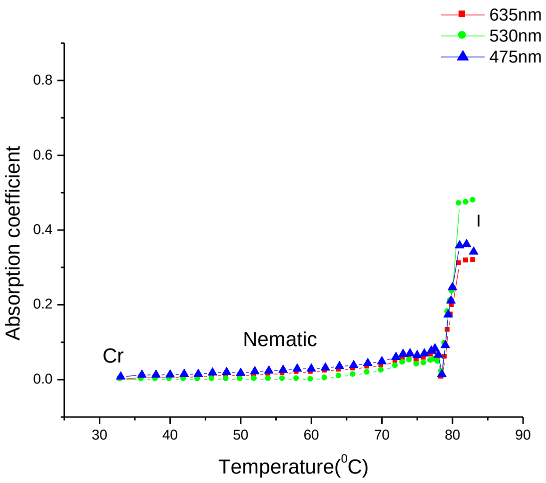


(b)

Figure 3. Temperature dependence of absorption coefficients of (a) 5CB, (b) EBBA

From figure 3 it is seen that the value of AC is a maximum in the isotropic state. In this phase the molecular orientation is random and there is no transmission of light. On cooling, there is a sudden decrease in AC in the biphasic region of the I–Nematic phase temperature interval. This is due to the fact that the transmission of light takes place in the Nematic phase alignment of the molecules. The AC of the sample is inversely proportional to transmittance [31,32].

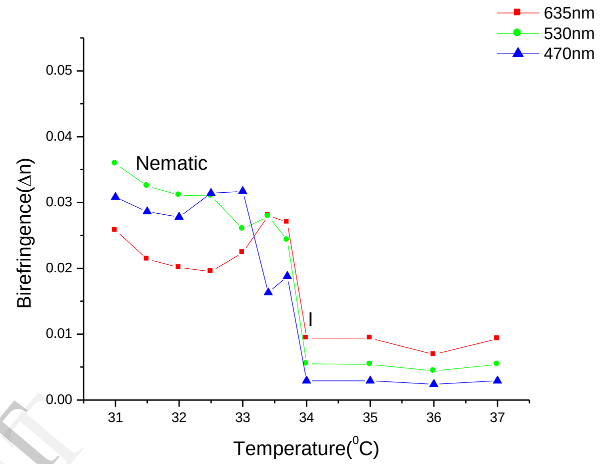
(c) Birefringence:

Birefringence of the liquid crystals is measured as a function of temperature by placing a sample of thickness *d* between crossed polarizer, as in Equation (3) [1,29]:

$$I = I_0 \sin^2 \frac{\pi d \Delta n}{\lambda} \qquad (3)$$

where I is the value of the image intensity observed from the crossed polarization components, I_0, the image intensity value from the parallel polarization components when there is no sample, λ, the wavelength of the colour components (R,G, B). The optical birefringence of 5CB and EBBA is calculated using Equation (3), and it is shown in Figure 4.

For samples in the isotropic state the absence of molecular alignment in their respective phases causes the disappearance of birefringence, resulting in value of zero. On cooling, the value of birefringence has increased abruptly in the biphasic region of the I–nematic temperature interval. The birefringence values of the samples, hence, may be used to predict the temperature-dependent order parameter of the systems.



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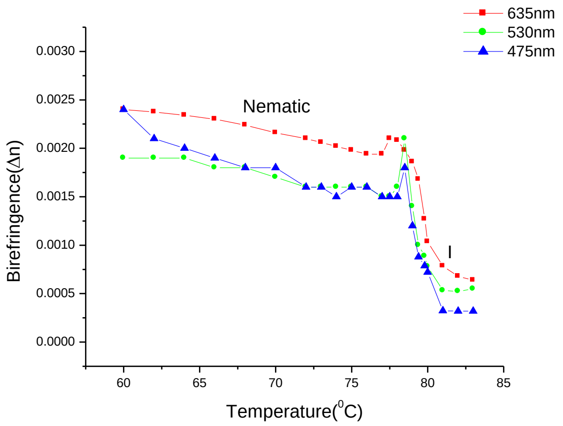

(b)

Figure 4. Temperature dependence of optical birefringence of (a) 5CB, (b) EBBA

(d) Phase retardation

Phase retardation (δ) of the liquid crystal is given by the Birefringence Δn, wavelength of light λ and thickness of the sample *d*: [33-35]. The optical phase retardation of 5CB an EBBA is calculated using equation (4), and it is shown in figure 5.

$$\delta = \frac{2\pi d \Delta n}{\lambda} \qquad (4)$$

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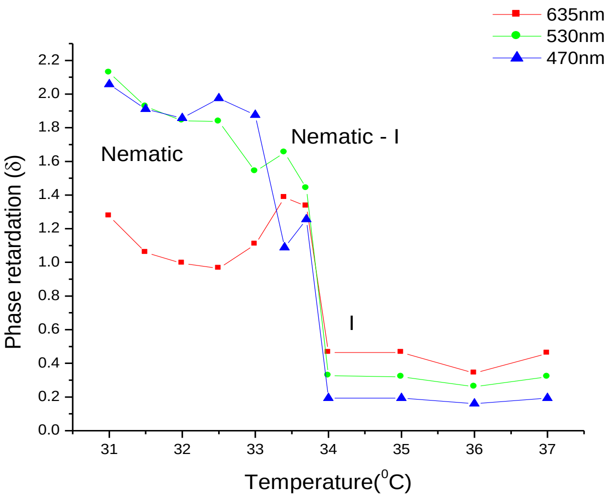

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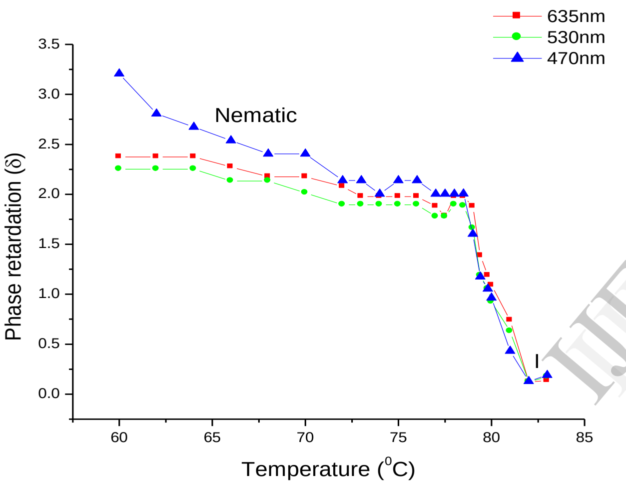


(b)

Figure 5: Temperature dependence of phase retardation of (a) 5CB, (b) EBBA

(e)Order parameter:

Order parameter of the liquid crystals is determined from the Kuczynski equation by using the direct measurement of birefringence values. The birefringence values are computed from Equation (5) [30,31].

$$S = \frac{\Delta n}{(\Delta n_0)} \qquad (5)$$

Where S is order parameter of the system given by Kuczynski.

The well known equation for the determination of temperature dependent birefringence is:

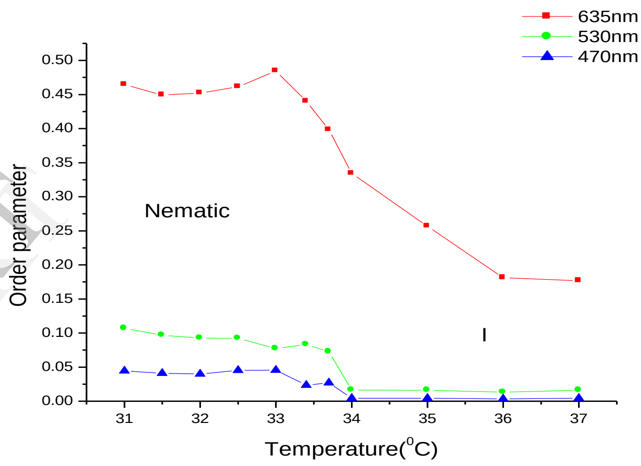
$$\Delta n = (\Delta n)_0 \left(1 - \frac{T}{T_c}\right)^{\beta} \qquad (6)$$

where $(\Delta n)_0$ is the birefringence value liquid crystal at temperature T = 0K, β, material constant and Tc, clearing temperature of the sample. The values of $(\Delta n)_0$, β are obtained from the linear regression method using Equation (6) in the following way.

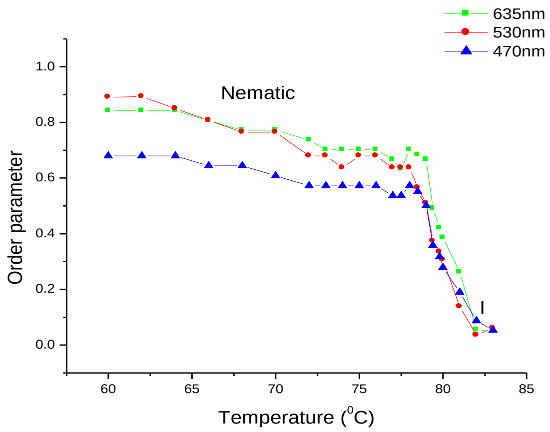
Applied 'log' to the Equation (6):

$$\log(\Delta n) = \log(\Delta n)_0 + \beta \log\left(1 - \frac{T}{T_c}\right) \qquad (7)$$

While applying linear regression method to equation 7, the values of $(\Delta n)_0$ and β are calculated. The order parameter value S is calculated using equation 5 for the obtained values of $(\Delta n)_0$ and (Δn). This procedure is similar to the extrapolation of $(\Delta n)_0$ for the absolute temperature while proceeding with the assumption that the order parameter (S) is 1 at absolute temperature. The temperature dependent order parameter values of the samples obtained from three colour image planes red (600 nm), green (530 nm) and blue (470 nm) are shown in Figure 6.



(a)



(b)

Figure 6 : Temperature dependence order parameter of (s) 5CB, (b) EBBA

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These computations and the plots drawn for the optical parameters as a function of temperature have shown that the values of transmittance and birefringence increased sharply in biphasic region, I–Nematic. For comparison of AC with transmittance and birefringence, there is an abrupt decrease in the value of AC at the transition from isotropic to liquid crystalline phase. The fluctuations in terms of abrupt increases or decreases in optical parameter values of homogeneously aligned samples are due to the fact that, during cooling of sample from its isotropic phase, the realignment of molecules in their respective phases at given temperatures showed the sharp textural transformations of different phases. These textural transformations have brought variations in the transmitted intensities of the images, therefore, became useful for studying the optical properties and phase transitions of the samples in relation to temperature. When compared to other techniques as reported in literature, this method is simple, less complex for time and cost. Like other approaches, there is no need to arrange different setups, just requiring to have the image textures of liquid crystals been recorded under parallel and crossed polarizer from the solid to the isotropic liquid state to compute the defined parameters. Experimentally this method is therefore very easy and is a simple approach for observing the behaviour of the optical parameters of different liquid crystals as a function of temperature.

IV. CONCLUSIONS

It has been concluded that image analysis by POM is a simple and effective method for studying the thermo-optical properties of liquid crystals. Changes in the intensity of the textures as a function of temperature are useful in computing their optical parameters.

V. ACKNOWLEDGEMENTS

The authors gratefully acknowledge University Grants Commission Departmental Research Scheme at Level III program No. F.530/1/DRS/2009 (SAP-1), dated 9 February 2009, and Department of Science and Technology -Fund for Improving Science and Technology program No. DST/FIST/PSI –002/2011 dated 20-12-201, New Delhi, to the department of Physics, Acharya Nagarjuna University for providing financial assistance.

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