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Temperature dependent Refractive indices of Liquid Crystals from image analysis

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***Abstract*—In this paper, temperature effect on the refractive index of liquid crystals: *p-n* alkyl benzoic acids (*n*BA, where *n* = 6,8) are investigated towards the thermometry applications. Here image analysis technique in conjunction with Optical Polarizing Microscope is employed to compute the temperature dependent of refractive index of liquid crystals. It includes the computation of optical transmission, Absorption coefficient and reflectance from the textures of liquid crystals. As a function of temperature in this method parameters are computed from the intensities of the liquid crystal textures. MATLAB software is used for the purpose of parameters computation from the textures of liquid crystals. The obtained results show that, compound with *n* = 8 is more suitable than compound with *n* = 6 for different thermometric applications as it has been associated with good variations in the refractive index values with temperature.**

Keywords—* *Refractive index, textures, Image analysis, Transmission, Reflectance and Absorption coefficient.

I. INTRODUCTION

In recent research a great attention has been paid to the Optical anisotropy: Refractive index of the Liquid Crystals (LCs). This is very important property for various technical and technological applications of LCs [1-8]. In LCs, director of the molecules is easily distorted or reoriented with respect to the external fields like temperature, electric field and magnetic field etc and exhibit the anisotropy in their optical, electrical and magnetic properties. Each external field has its own advantages and applications [9-12]. This is why liquid crystals attain great importance in the technological applications especially in optical and photonic devices besides thermometric devices[13],[14]. Among all anisotropic properties, refractive index of liquid crystal has great importance in the view of device applications. The functioning of the liquid crystal devices utilizes the temperature induced and electric field induced refractive indices. Hence, in this paper temperature dependent refractive index of the liquid crystals : *p-n* alkyl benzoic acids (*n*BA where *n* = 6,8) are investigated. Several theoretical and experimental models have been developed to investigate the temperature dependence refractive indices of liquid crystals. Such as Abbyrefractometer [15],wedge technique [16], hallowprism [17], Fabry Perot interference method [18], Cauchy model and four-parameter model [9],[14],[19] etc.and each technique needs the different experimental setups and analysis. Here, image analysis technique in conjunction with POM is used to investigate the temperature dependent refractive indices of liquid crystals. Textures of liquid crystal samples are captured as function of temperature using POM with camera attachment [20],[21].

Generally, refractive index of the liquid crystal samples depends on the Molecular structure, operating wavelength and temperature. In this technique, the changes in textural features captured from POM as a function of temperature is useful to compute the refractive index of the liquid crystals. As a function of temperature, refractive index of liquid crystal samples makes the changes in the textural features of the samples. The changes in such textural features are color, intensity, roughness, randomness etc. [20]. Analysis of these textural features gives the information to understand the behavior of refractive index in LC with temperature [20-22]. Textures are analyzed using MATLAB software (product by Math Works, Inc., (Natick, MA). This investigation includes the computation of Optical transmission, Absorption coefficient and Reflectance.

II. EXPERIMENTAL

The chemicals *p-n* alkyl benzoic acids (*n*BA where *n* = 6, 8) with 99% purity were procured from Frinton laboratory, New Jersy, USA. Commercially available ITO coated liquid crystal cell with homogeneous (planar) alignment having thickness 5μm are imported from INSTEC company, USA[23]. For measurements, the cell was completely filled with liquid crystal material through capillary action. Once the cell was filled with the sample, it is mounted on the hot stage of the microscope to observe textures of the sample. Here, Meopta Polarizing Microscope (POM) with the accessories of hot stage and camera attachment was used to record the textures of the samples [21],[24]. Canon EOS Digital REBEL XS/ EOS1000D is a digital single lens reflex camera with a 10.10 mega pixel image sensor is used to record the texture images of the samples through the crossed polarizer's of the POM. The color image detected by the camera has a resolution of 3888 x 2592 pixels represents the 24bit true color pixel tone. The pixel intensities of the each image ranges from 0 to 255 in R, G, and B color tones with wavelengths 635nm, 530nm, and 470nm [25],[26], which were useful to investigate the refractive indices of the samples. Computational analysis of liquid crystal textures which are recorded as a function of temperature has been carried out on MATLAB platform [27-29]. Variation of refractive with respect to temperature and material is measured using optical parameters like optical transmission, Absorption coefficient and reflectance [30],[31].

III. THEORY

Optical transmission, Absorption coefficient and Reflectance are the important optical parameters for the computation of refractive index of liquid crystal sample from the image analysis technique. Here, textures or images of the samples are recorded as function of temperature from the solid phase the sample to the isotropic phase via liquid crystal phase on heating and vice versa on cooling.

Recorded image or texture $I(i, j)$ is of size m-by-n a two-dimensional function, and is composed of m pixels in the vertical direction and n pixels in the horizontal direction, and i, j are horizontal and vertical co-ordinates of the image. The total number of pixels in the image is $m * n = N$, $0 \le i \le m$, $0 \le j \le n$. N is total number of pixels of the recorded image. The defined properties are

A. Optical transmission

Optical transmission of the samples are obtained by computing average transmitted intensity of the image texture recorded from the crossed polarizer's condition and given as [32]

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

Where $I(i,j)$ is the image intensity value observed at the location (i, j) from the crossed polarization component of the texture image.

B. Absorption coefficient

Absorption coefficient the samples obtained from Beer-Lambert formula. This formula connected with the incident, transmitted image intensity values and thickness of the liquid crystal layer d and given as [31],[33-35]

$$\text{absorption coefficient} \quad \alpha = \frac{1}{d}\log\left(\frac{I_0}{I}\right) \qquad (2)$$

where α denotes the absorption coefficient, I is optical transmittance of the liquid crystal texture observed from the crossed polarization components, I_0 the optical transmittance image observed from the parallel polarization components when there is no sample.

C. Absorbance and Reflectance

Absorbance is the light that is not transmitted or reflected by a material, but is absorbed. This can be computed from the value of Absorption coefficient [30],[36],[37]. Absorbance and transmittance are known, Reflectance can calculate from the equation

$T + R + A = I_0$

(3)

Here I_0 is the maximum optical transmitted intensity value image (white color image). generally this will be 255 and may vary depending on the experimental conditions. This was observed from the parallel polarization components of POM when there is no sample.

D. Refractive index

The refractive index (n) of the samples are computed from reflectance of liquid crystal textures and given as [30],[37]

$$n = \frac{1 + R + \sqrt{R}}{1 - R} \qquad (4)$$

where R is reflectance of the texture image obtained from (3).

IV. RESULTS AND DISCUSSION

Enantiotropic liquid crystals: *p-n* alkyl benzoic acids (*n*BA, where *n* = 6,8) are exhibit the nematic meso phase and are shown in Figs1,2,3,4. Phase transition scheme of samples on heating is

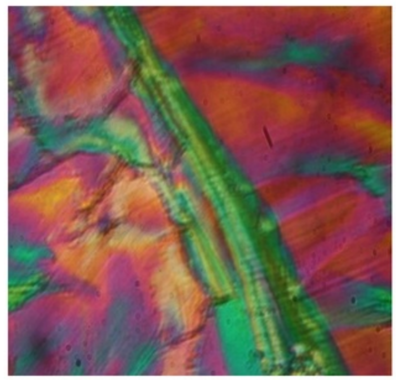
p-n alkyl benzoic acid (6BA),

$$\text{Cr} \xrightarrow{97^{\circ}\text{C}} \text{N} \xrightarrow{115^{\circ}\text{C}} \text{I}\ .$$

p-n alkyl benzoic acid (8BA) ,

$$\text{Cr} \xrightarrow{100^{\circ}\text{C}} \text{N} \xrightarrow{114^{\circ}\text{C}} \text{I}$$

(Cr – Crystal, N-Nematic, I- Isotropic)



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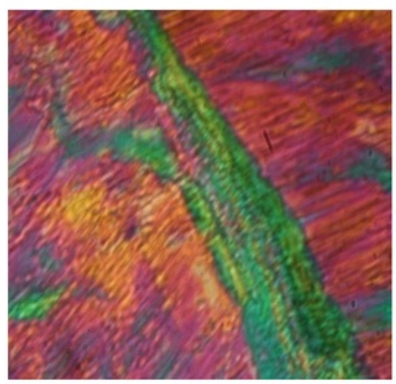

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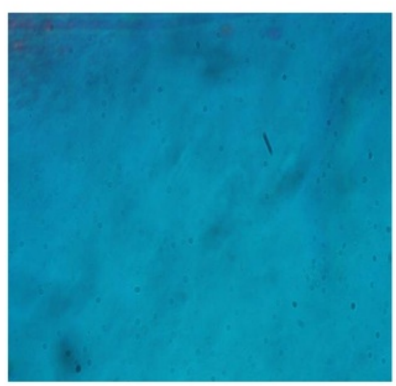

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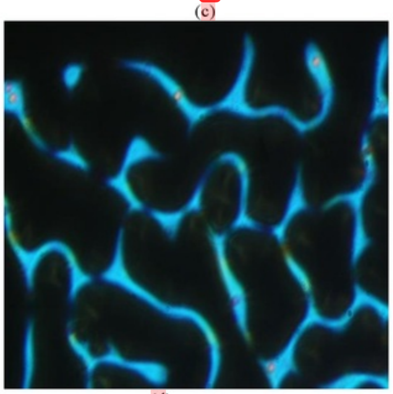
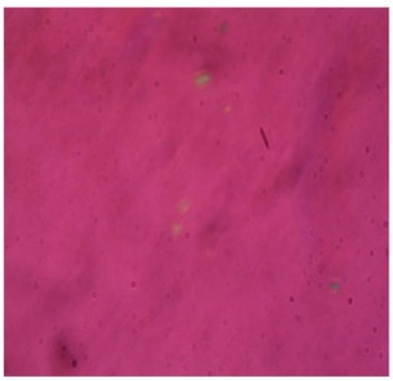


(d)

Fig.1. optical textures of Liquid crystal: : *p-n* alkyl benzoic acids 6BA (a) Cr phase, (b) Cr-Nematic phase (c) Nematic phase, (d) Nematic-Isotropic phase. *(Cr:Crystal; I:Isotropic).*



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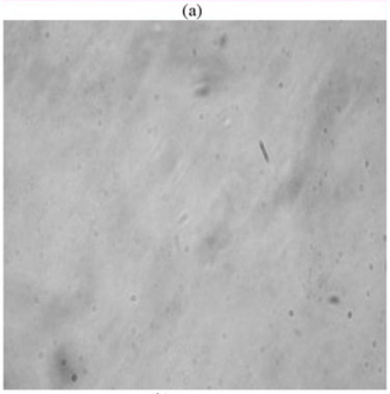

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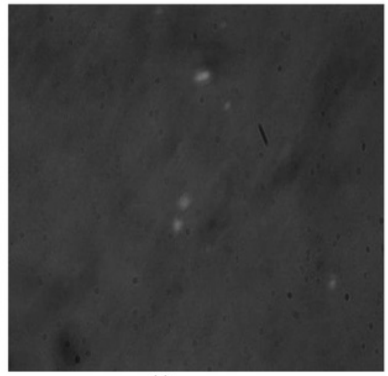

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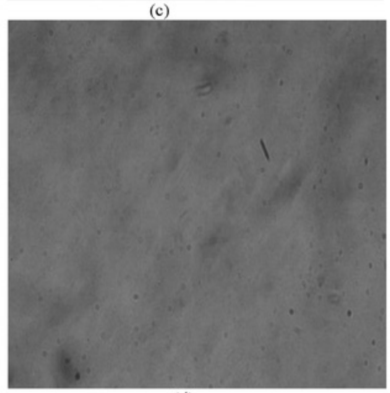
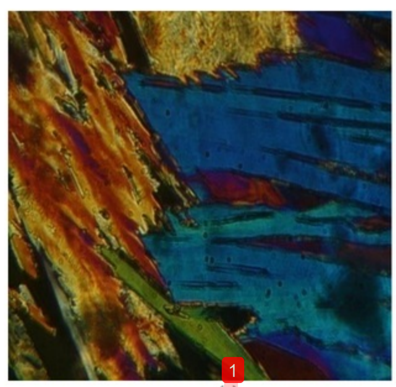
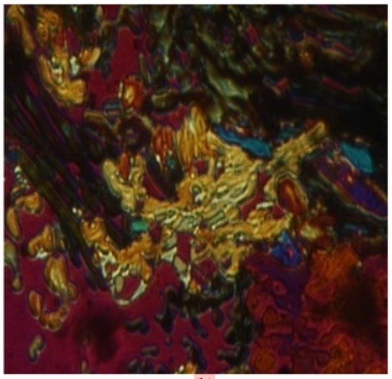


(d)

Fig.2. Nematic texture of Liquid crystal: : *p-n* alkyl benzoic acids 6BA observed between crossed polarizers (a) for RGB colour mode; (b) for red colour image plane; (c) for green colour image plane; (d) for blue colour image plane.



(a)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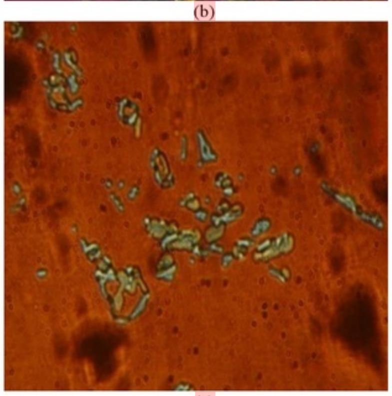
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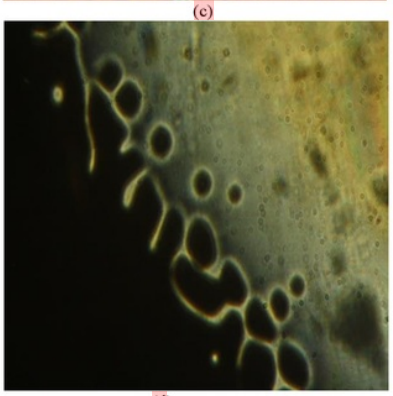
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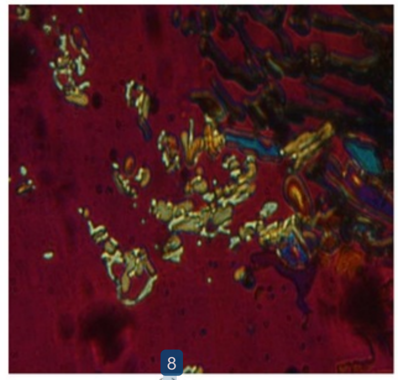
Fig.3: optical textures of Liquid crystal: : *p-n* alkyl benzoic acids 8BA (a) Cr phase, (b) Cr-Nematic phase (c) Nematic phase, (d) Nematic-Isotropic phase.*(Cr:Crystal; I:Isotropic).*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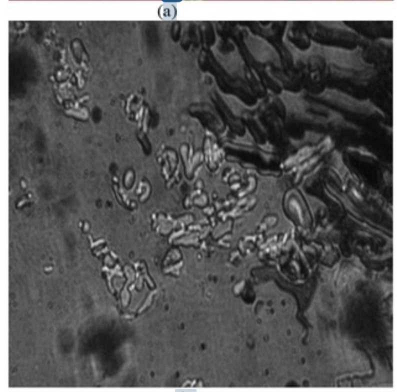
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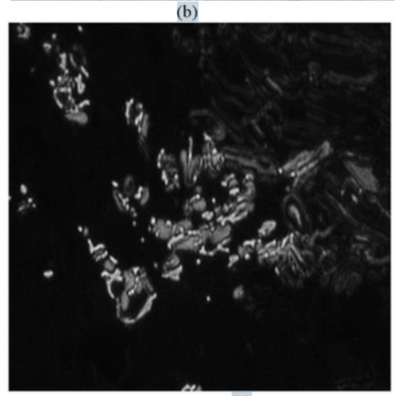
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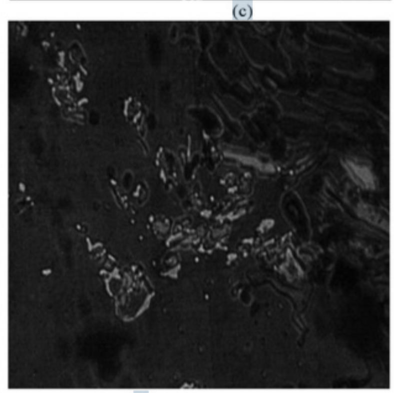
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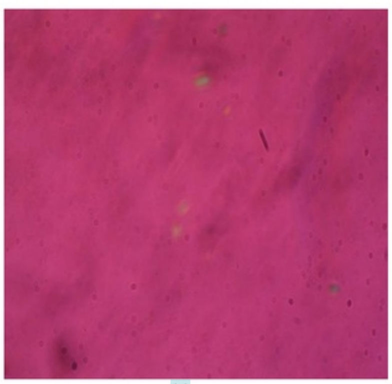
Fig.4. Crystal – Nematic phase texture of Liquid crystal: : *p-n* alkyl benzoic acids 6BA observed between crossed polarizers (a) for RGB

colour mode; (b) for red colour image plane; (c) for green colour image plane; (d) for blue colour image plane.

In solid phase liquid crystal molecule directors remain undisturbed and no phase change occurs. As a function of temperature, phase change occurs due to disturbance in directors of the molecules from the initial phase (solid or Isotropic phase) and called as phase transition [20]. In this region, the optical behaviors of the compounds are varying from the initial phase. This can be observed using the standard optical microscopic technique and transition can be visualized as beautiful textures (shown in Figs 1,3). For small values of temperature, there is no change in the textures and recorded textures remain same. On Phase transition, orientation of the molecules with respect to the temperature affects the refractive indices of the samples. This can be observed and recorded in terms of textural feature changes using POM and can be analyzed using Image analysis technique. Such textural feature changes as a function of temperature are color, intensity, roughness, randomness etc. For given liquid crystals: *p-n* alkyl benzoic acids (*n* = 6,8), the change in the refractive indices with respect to temperature is noticed as parachromatic changes [21], where only the color of the nematic texture is varied but the texture remains the same (excluded solid phase).This was shown in Fig5. Therefore, Liquid crystals: *p-n* alkyl benzoic acids (*n* = 6,8), will be useful for the fabrication thermometric devices like temperature sensors, since the color of the environment gives the temperature at particular wavelength [38].



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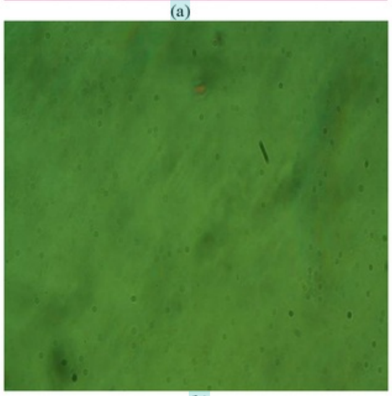

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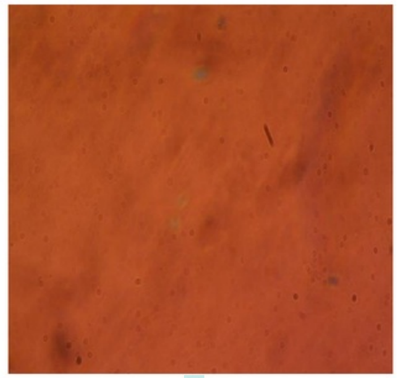

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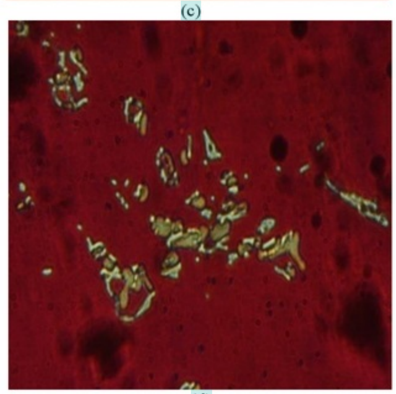

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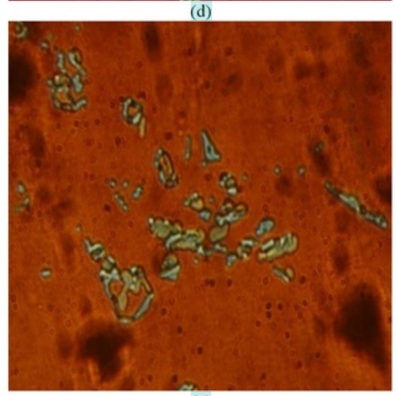

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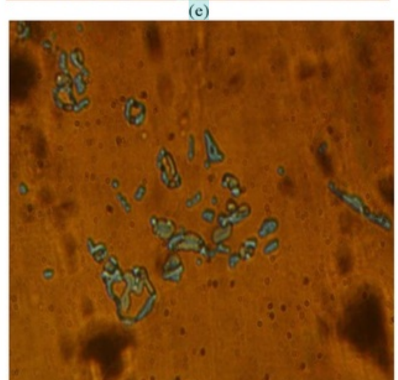
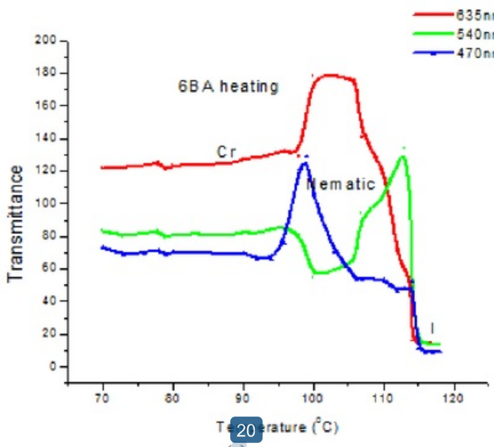


(f)

Fig 5. Parachromatic textures of nematic phase of *p-n* alkyl benzoic acids (a,b,c) for 6BA; (d,e,f) for 8BA.

Analysis of these textural intensities using image analysis technique in conjunction with Optical Polarizing Microscope gives the enormous information to investigate the temperature effect on the refractive index of liquid crystals. The temperature dependence of refractive index of liquid crystals are computed from (1)-(4) and plots are drawn for the parameters as a function temperature. Plots are shown in Figs 6,7.



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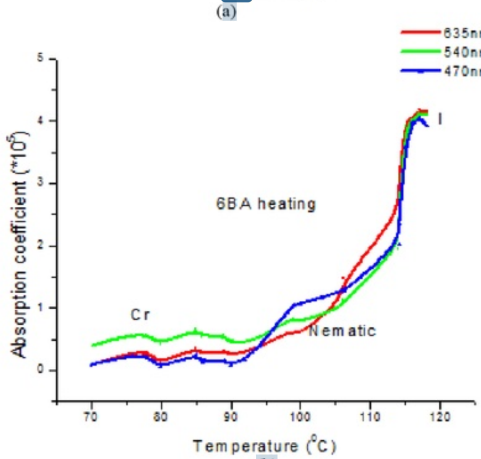

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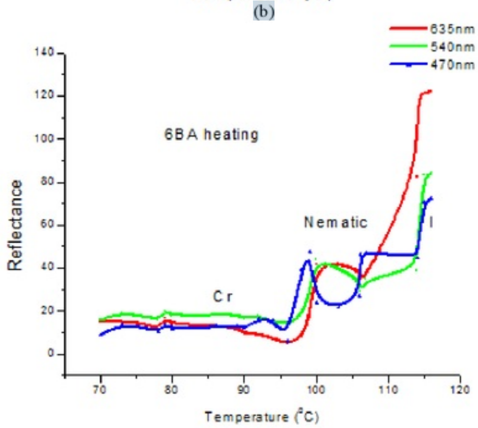

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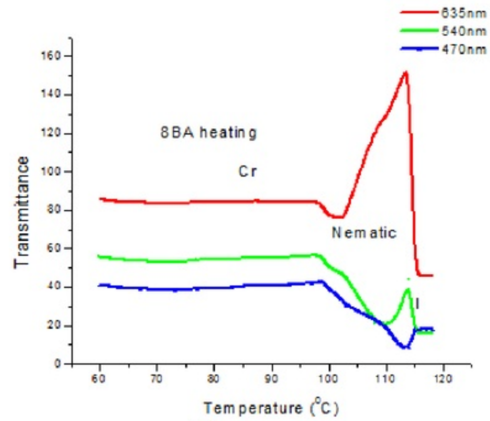
Fig. 6. Parameters of 6BA (a) Optical transmittance; (b) Absorption coefficient; (c) Reflectance. *(Cr:Crystal; I:Isotropic).*



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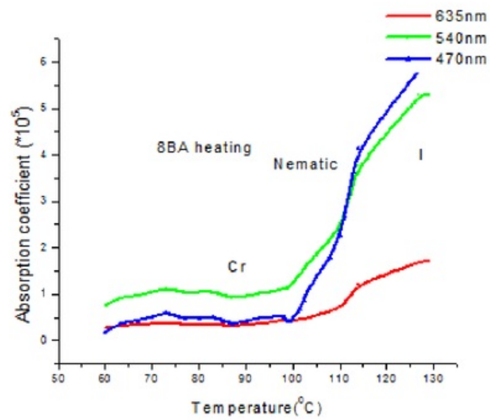

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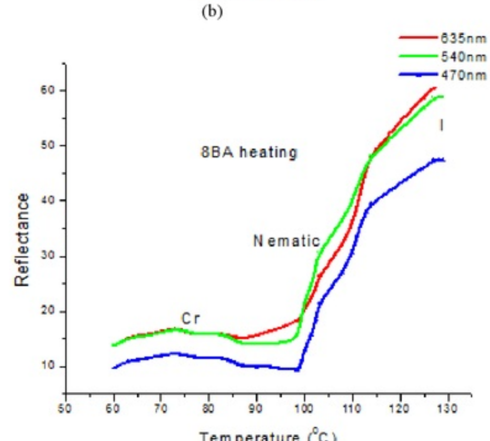
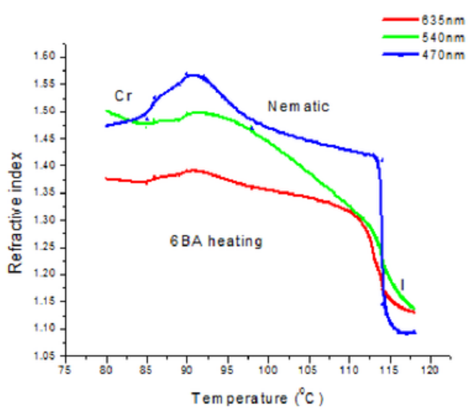
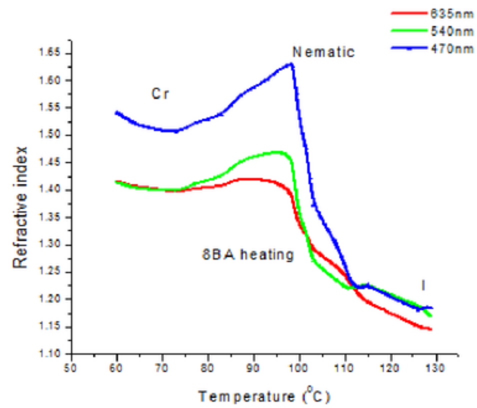


Fig. 7. Parameters of 8BA (a) Optical transmittance; (b) Absorption coefficient; (c) Reflectance. *(Cr:Crystal; I:Isotropic).*

Figs 6, 7 show the analysis results corresponding to optical transmission, Absorption coefficient(AC) and reflectance of the samples at three wavelengths 635nm, 530nm, and 475nm. From Figs 6(a),7(a), it was observed that optical transmittance decreases with increasing temperature of sample. As the sample goes to the isotropic phase, the optical transmittance achieves the value of zero. In this phase, the molecular orientation is random and there is no transmission of light. Therefore, temperature increment of the sample from solid phase to isotropic phase is inversely proportional to the optical transmittance in crossed polarizer condition. But in isotropic phase, the value of AC is maximum. This is due to the fact that, random orientation of molecules absorbs the maximum amount of light intensities and gives high value of AC for the sample. This was clearly shown in Figs 6(b),7(b). Optical transmittance of the sample is inversely proportional to the Absorption coefficient. Therefore, temperature increment of the sample is inversely proportional to the optical transmittance and proportional to the Absorption coefficient (AC) [39],[40]. The abrupt change in the curves at the transitions indicates the phase transition of material. The consequent changes in the textural features with respect to temperature (shown in Fig 1,3) bring the variations computed parameter values which are useful to identify the phase transition of the material. From the values of optical transmission and absorption coefficient [30],[36],[37] reflectance of the liquid crystals are computed using (3). Similar to the optical transmission and AC, abrupt changes in the reflectance curves also gave the transition temperatures of samples and are shown in Fig 6(c),7(c) .This reflectance is used to compute temperature dependent refractive index (n) of the liquid crystal sample. A simple procedure (4) is used for the computation of the refractive index from the reflectance measurements. Temperature dependent refractive indices measurement of liquid crystals: *p-n* alkyl benzoic acids (n = 6,8) at wavelengths 635nm,540nm,470nm were done on heating cycle and are shown in Fig8 .



(a)



(b)

Fig. 8.Temperature dependent refractive indices of (a)6BA; (b)8BA. *(Cr:Crystal; I:Isotropic).*

From Fig 8, it was observed that refractive indices of the samples exhibit the linear behavior with slight fluctuations or abrupt changes at the transitions for three wavelengths. These fluctuations are due to the appearance and disappearance of optical anisotropy of liquid crystal from the solid phase (isotropic) to the isotropic phase (solid) [39-41]. On heating of the samples from the solid to liquid crystalline phase or liquid crystalline phase to the isotropic phase, the changes in the molecular alignment brings the variations in the values of refractive index[20],[21]. For given samples, this can be observed pictorially as textural feature changes as a function of temperature and are shown in Figs 1,2,3,4,5 .In isotropic phase, the destruction of molecular alignment from their respective phases causes the disappearance of optical anisotropy and leads to the decrement of refractive indices value. In liquid crystalline phase the orderedness (long optical path) of the molecules results the appearance of optical anisotropy and gives the high values of refractive index [41] shown in Fig 8 . And also, the refractive indices curves show that there is an inverse proportionality relation between the refractive indices of the samples and wavelengths in LC region and steady state relation in Isotropic phase. In LC phase, the values of refractive indices are high for lower wavelength (470nm) and low for higher wavelength (635nm) [38]. In biphasic region LC - isotropic phase, the value of refractive indices decreases and reaches its steady state value for all three wavelengths. The same can be observed for two samples. But the compound with n = 8 has high value of refractive index in LC region compared to the compound with n = 6. This is due to the fact that, compounds with more number carbon atoms found to have the higher value of refractive indices [42]. These kinds of compounds are excellent components for the fabrication of liquid crystals devices in various applications. Since, Liquid crystals: *p-n* alkyl benzoic acids (n = 6,8) exhibit the parachromatic property. Compound with n = 8 is more suitable for the design of temperature sensors with a wide variety of color responses to the temperature changes.

V. CONCLUSION

In this work, temperature dependent refractive indices of Liquid crystals: *p-n* alkyl benzoic acids (n = 6,8) have been studied successfully using image analysis technique. For all three wavelengths, the values of refractive indices decrease with increasing temperature in biphasic region of Liquid crystal to isotropic phase. Both compounds exhibit the parachromatic property useful for fabrication of thermo metric devices. *p-n* alkyl benzoic acid ($n = 8$) is more suitable component for the design of temperature sensors with high value of refractive indices.

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