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Temperature Dependent Refractive Indices of Liquid Crystals from Image Analysis

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Abstract:- In this article, temperature dependent refractive index of liquid crystals: 4-n alkyl benzoic acids (nBA, where n = 6,8) are investigated towards the thermometry applications. Here the technique of image analysis in conjunction with Optical Polarizing Microscope is used to compute the refractive index of liquid crystals. This technique involves the computation of optical transmission, Absorption coefficient and reflectance from the liquid crystal textures. These parameters are determined from the intensities of the liquid crystal textures as a function of temperature. 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 for various thermometric applications than compound with n = 6 because it has been associated with strong variations in the refractive index values temperature.

Keywords:- *Refractive Index, Textures, Image Analysis, Transmission, Reflectance and Absorption Coefficient.*

I. INTRODUCTION

Recent research has focused on optical anisotropy: Liquid Crystals (LCs) refractive index due to their applications in various branches of science and technology. This is very important physical property for various technical and technological applications of LCs [1-8]. In LCs, the molecules director is easily skewed or reoriented in relation to external fields such as temperature, electrical field and magnetic field, etc. and exhibits anisotropy in its 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. Here, in this paper temperature dependent refractive index of the liquid crystals : 4-n alkyl benzoic acids (nBA where n = 6,8) are investigated. To investigate the temperature dependence refractive indices of liquid crystals, several theoretical and experimental models have been developed by so many authors. 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. Using POM with camera attachment [20],[21], liquid crystal sample textures are recorded as a function of temperature. Generally, refractive index of the liquid crystal samples depends on the Molecular structure, operating wavelength and temperature. In this method, refractive indices of the liquid crystals are computed from the changes in liquid crystal textural features as a function of temperature. Such textural features changes 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 4-n alkyl benzoic acids (nBA where n = 6, 8) were procured from Frinton laboratory, New Jersy, USA. Commercially available Indium Tin Oxide coated liquid crystal cell with homogeneous (planar) alignment having thickness 5µm are imported from INSTEC company, USA[23]. For measurements, the liquid crystal sample is filled in cell 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 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 is used to record the texture images of the samples through the crossed polarizer's of the POM. The recorded color image has a resolution of 3888 x 2592 pixels with 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. On the MATLAB platform [27 29], computational analysis of liquid crystal textures which are recorded as function of temperature was performed. Variation of refractive with respect to temperature and wavelength is computed using optical parameters like transmission, Absorption coefficient and reflectance [30],[31].

III. THEORY

Optical transmission, Absoprtion 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 crystalline phase of the sample to the isotropic phase via liquid crystal phase on heating and vice versa on cooling. Liquid crystal texture *I(i, j)* is of size *m*-by-*n*, composed of *m* pixels in the vertical direction and *n* pixels in the horizontal direction. Here, *i, j* are horizontal and vertical co-ordinates of the texture image. The total number of pixels in the image is $m * n = N$, $0 \leq i \leq m$, $0 \leq j \leq n$. *N* is total number of pixels of the recorded texture image. The defined properties are

A. Optical Transmission

The sample optical transmission is obtained by compu t-ing
the average transmitted intensity of the image texture re corded from the condition of the crossed polarizers and given as [32]

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

Where *I* *(i,j)* is the value of image intensity 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]

Absorption coefficient $\alpha = \frac{1}{d}\log\left(\frac{I_0}{I}\right)$ (2)

Where denotes the coefficient of absorption, I is optical transmission of the liquid crystal texture from the crossed polarization components, I0 an optical transmission of image from the parallel polarization components when there is no sample.

C. Absorbance and Reflectance

Absorbance is the light that a substance does not emit or reflect, 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 recorded from the parallel component polarizer's 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]

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

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

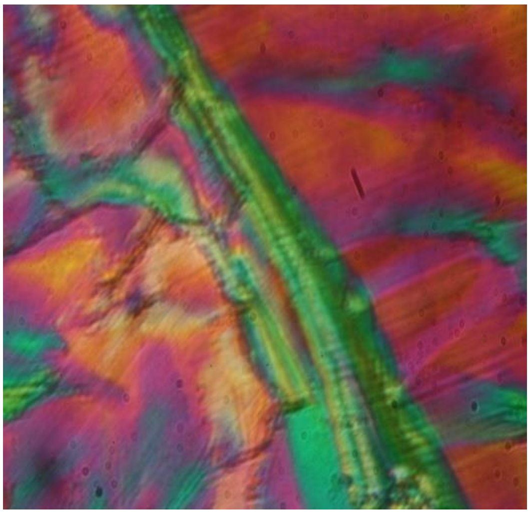
IV. RESULTS AND DISCUSSION

Enantiotropic mesomorphic compounds: *4-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

Hexyl benzoic acid (6BA), $\text{Crs} \xrightarrow{97^0\,\text{C}} \text{N} \xrightarrow{115^0\text{C}} \text{Iso}.$

Octyl benzoic acid (8BA) , $\text{Crs} \xrightarrow{100^0\,\text{C}} \text{N} \xrightarrow{114^0\text{C}} \text{Iso}$

(Crs – Crystal, N-Nematic, Iso- Isotropic)



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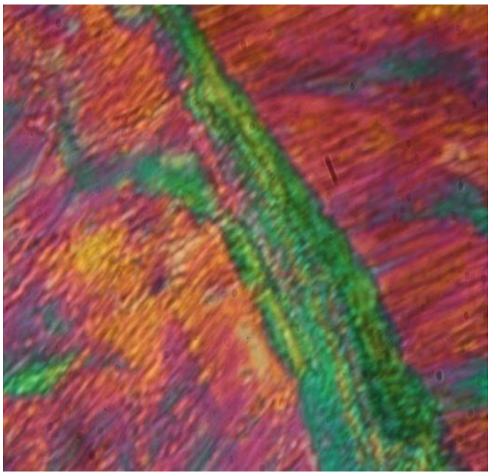
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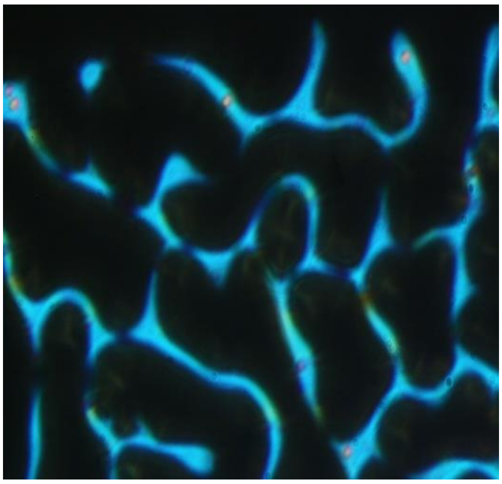
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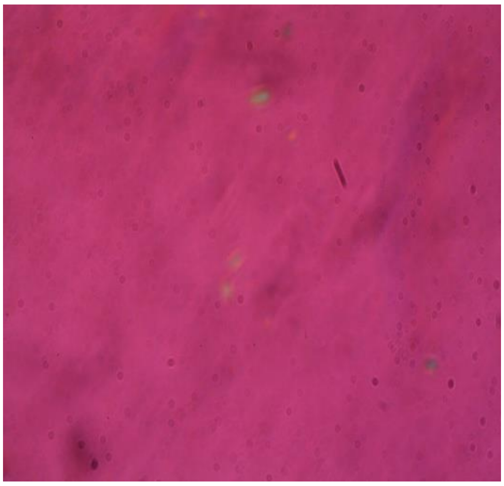
Fig 1:- Optical Microscopic Textures of Liquid Crystal: : Hexyl Benzoic Acids 6BA (a) Crs Phase, (b) Crs-Nematic Phase (c) Nematic Phase, (d) Nematic-Isotropic Phase. *(Csr:Crystal; Iso:Isotropic).*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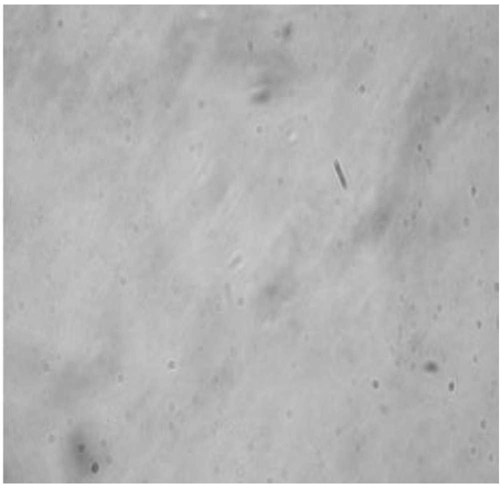
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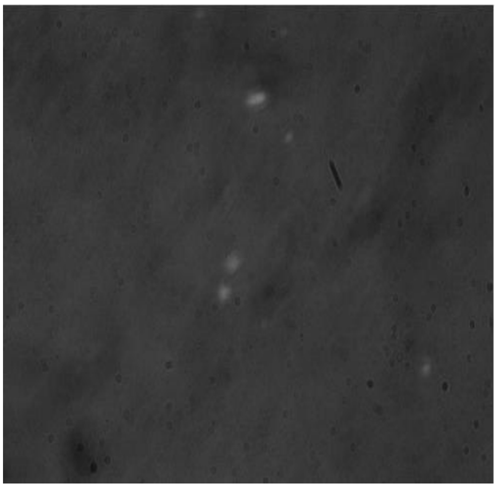
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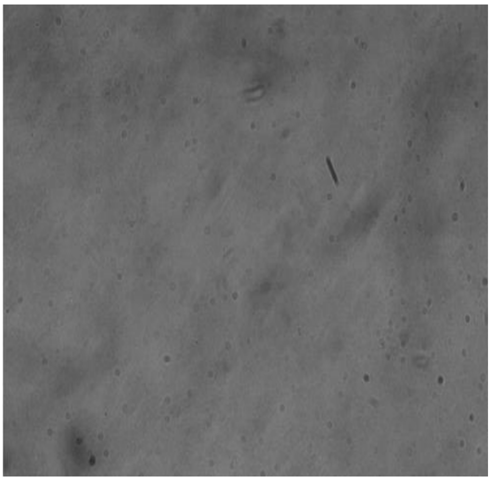
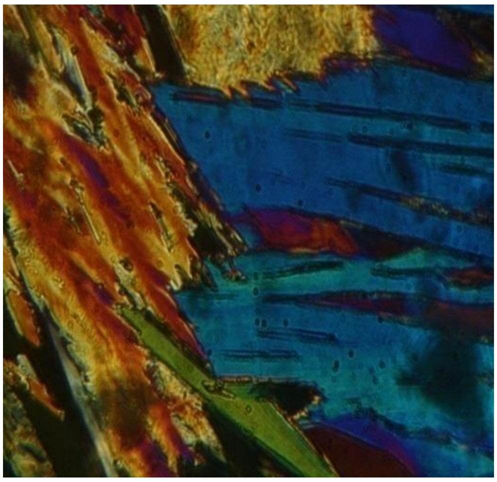


(d)

Fig 2:- Nematic Mesophase of Liquid Crystal: Hexyl Benzoic Acid 6BA Recorded from the Crossed Polarizers of POM (a) in RGB Colour Mode; (b) in Red Colour Mode; (c) in Green Colour Mode; (d) in Blue Colour Mode.



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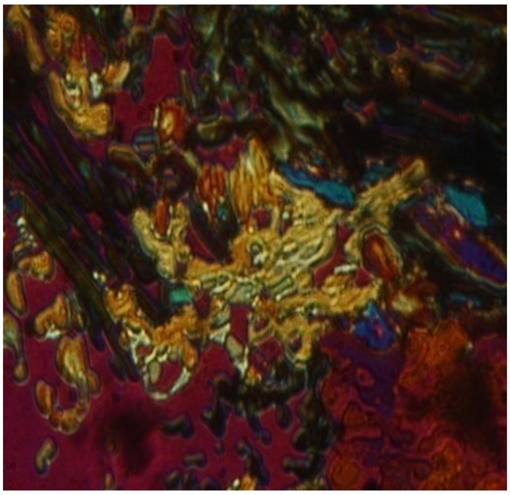

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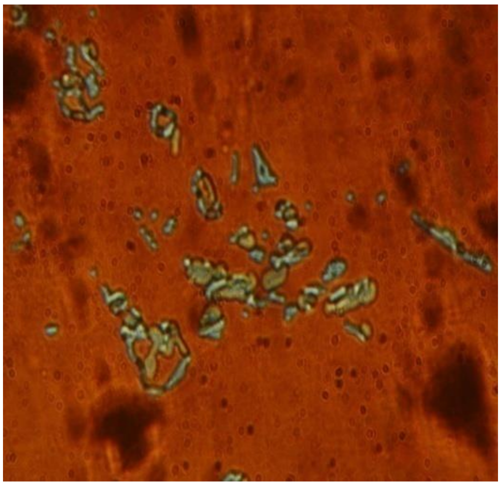

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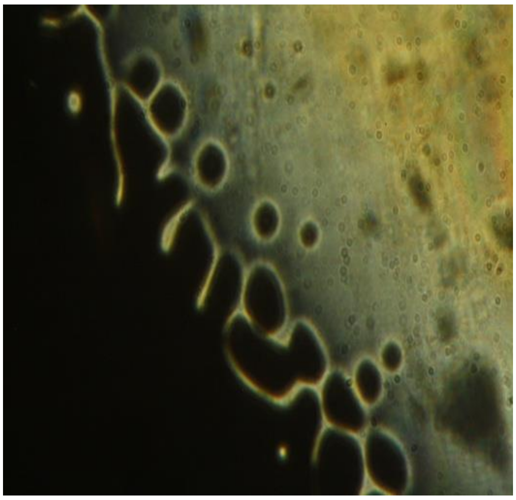
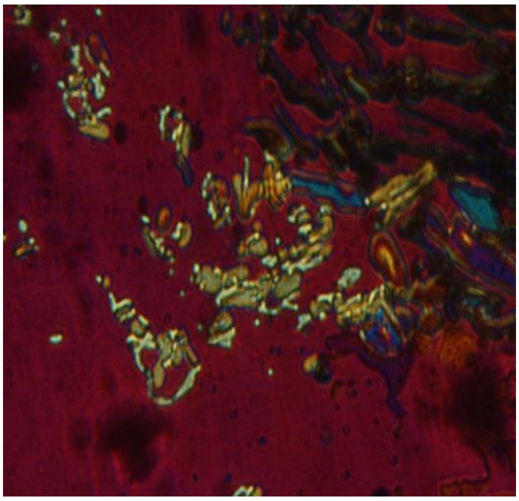


(d)

Fig 3:- Optical Microscopic Textures of Liquid Crystal: Octyl Benzoic Acids 8BA (a) Crs Phase, (b) Crs-Nematic Phase (c) Nematic Phase, (d) Nematic-Isotropic Phase.*(Crs:Crystal; Iso:Isotropic).*



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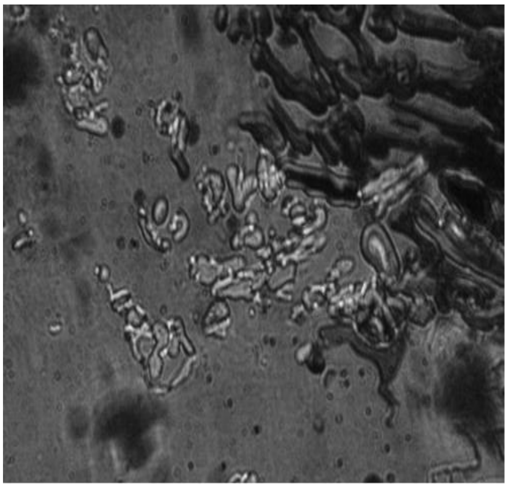
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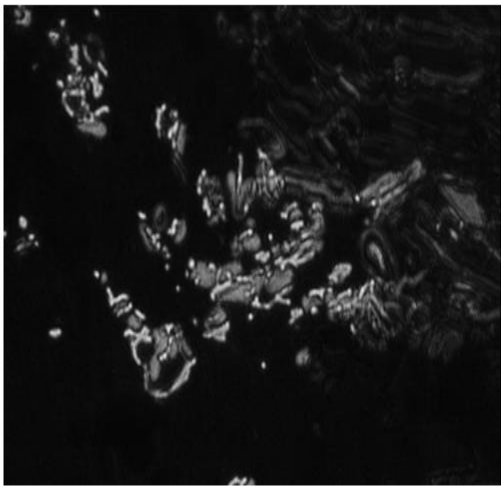
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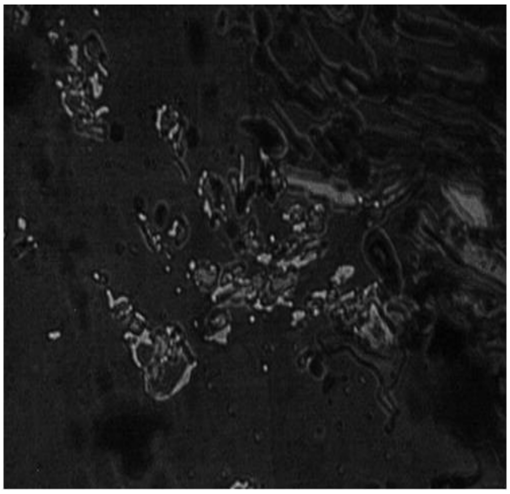
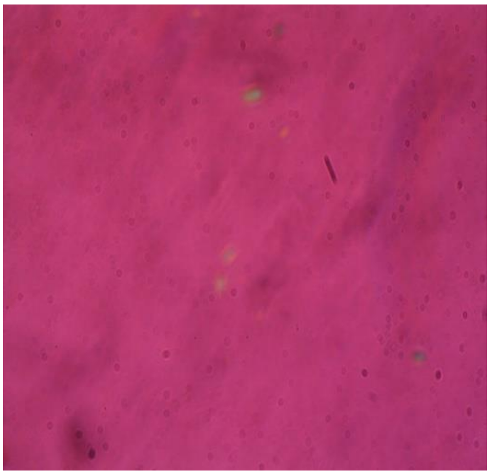

(d)

Fig 4:- Crystal – Nematic phase texture of Liquid crystal: : *hexyl* benzoic acids 6BA recorded from the crossed polarizers of POM (a) in RGB colour mode; (b) in red colour mode; (c) in green colour mode; (d) in blue colour mode.

In crystalline phase, Directors of liquid crystal compound remain undisturbed and there is no change in phase.As a function of temperature, changes in phase occur as a result of disruption in molecular directors from the initial phase (solid or isotropic phase) and named 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 transitions can be visualized as beautiful textures (shown in Figs 1,3). There is no change in the textures of samples at small temperatures, and the recorded textures remain the same. On the transition, temperature of sample causes the orientation of the molecules which influence the refractive indices of the liquid crystals. 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 mesomorphic compounds: 4-n alkyl benzoic acids (nBA, 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: mesomorphic compounds: 4-n alkyl benzoic acids (nBA, 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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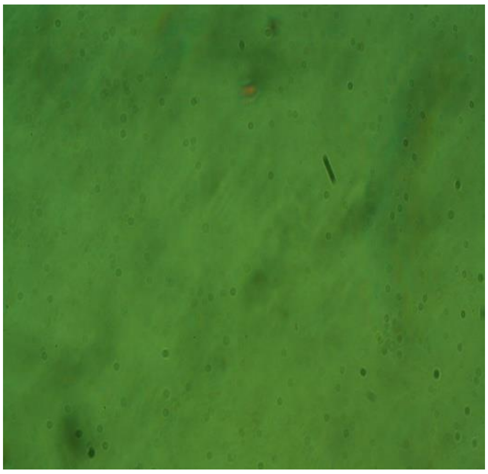
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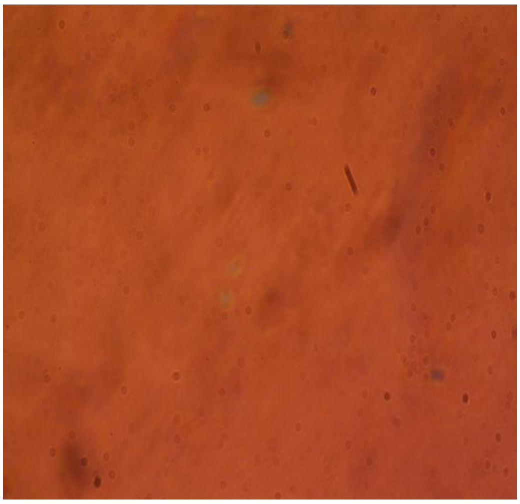
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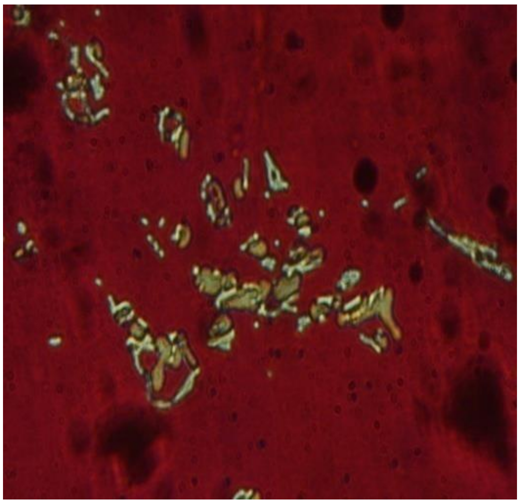
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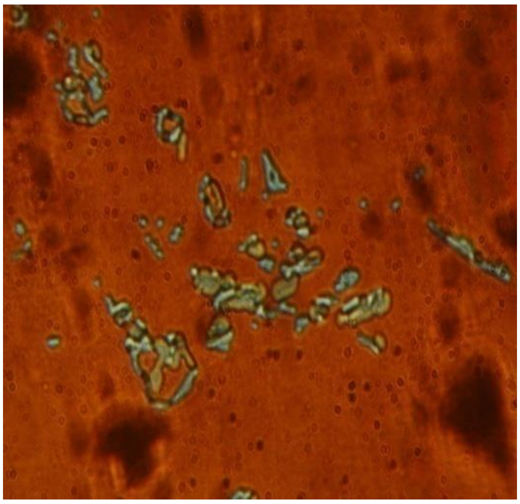
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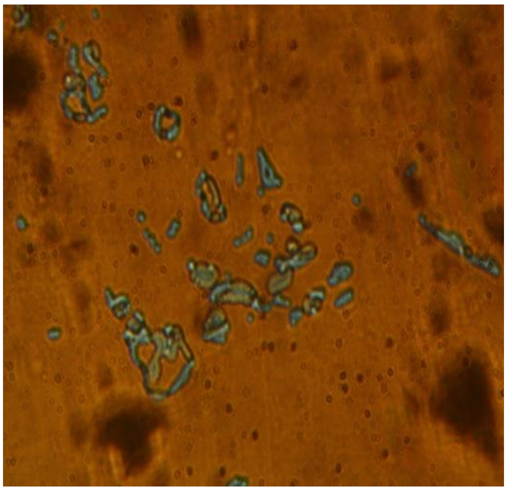
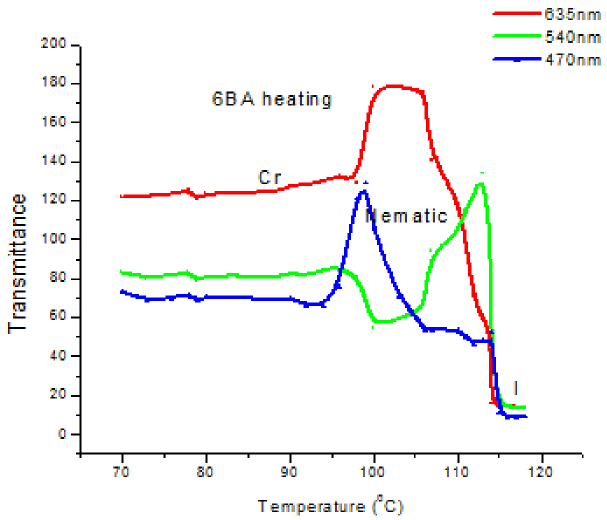

(f)

Fig 5:- Parachromatic Textures of Nematic Meso Phase of Alkyl Benzoic Acids (a,b,c) for 6BA; (d,e,f) for 8BA.

Analysis of these textural intensities using present technique gives the enormous information to investigate the influence of temperature on the liquid crysta l refractive index. The temperature dependence of refractive index of liquid crystals are computed from (1)-(4).

Plots are drawn as a function temperature for the para meters and are shown in Figs 6,7.



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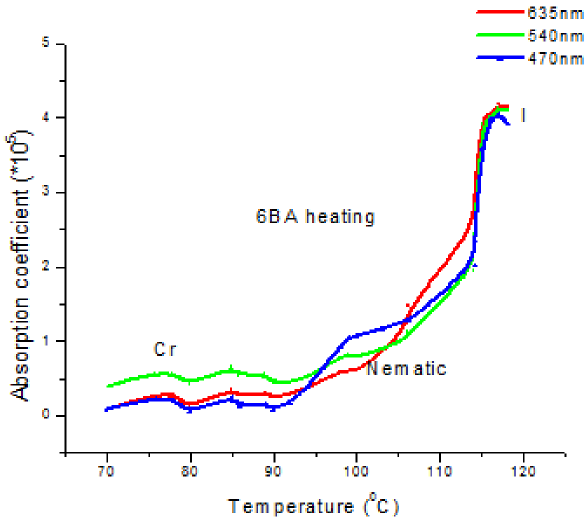

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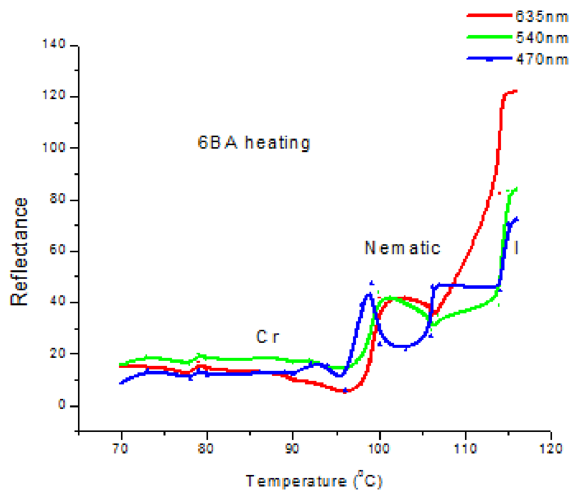

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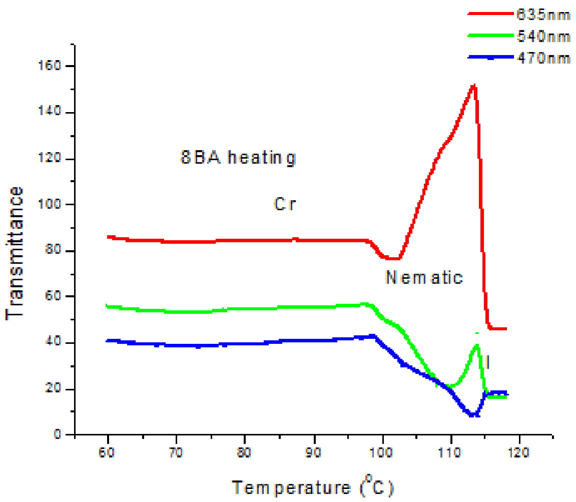
Fig 6:- Computed Parameters of 6BA (a) transmittance; (b) coefficient of absorption (c) Reflectance. *(Cr:Crystal; I:Isotropic).*



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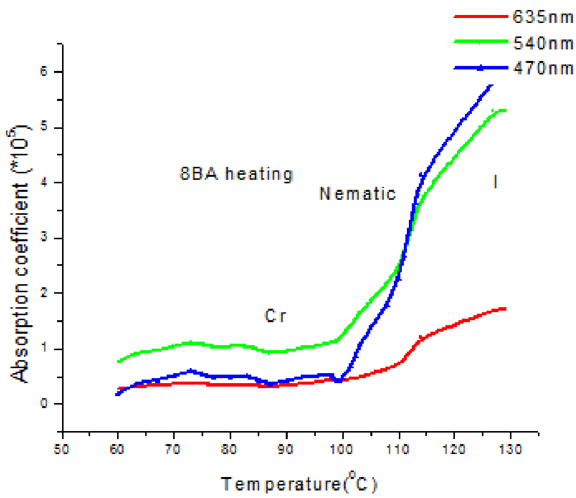

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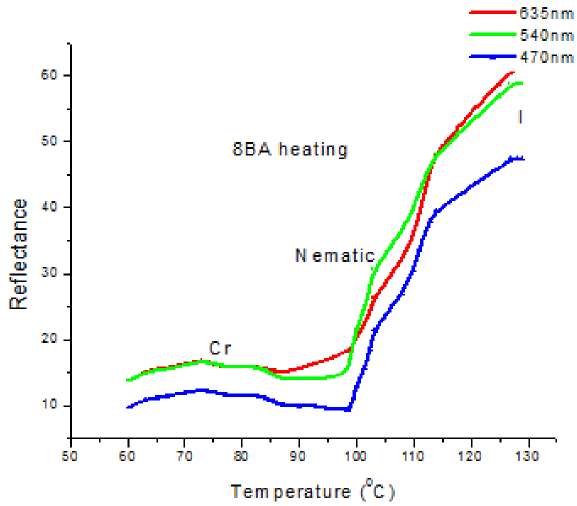
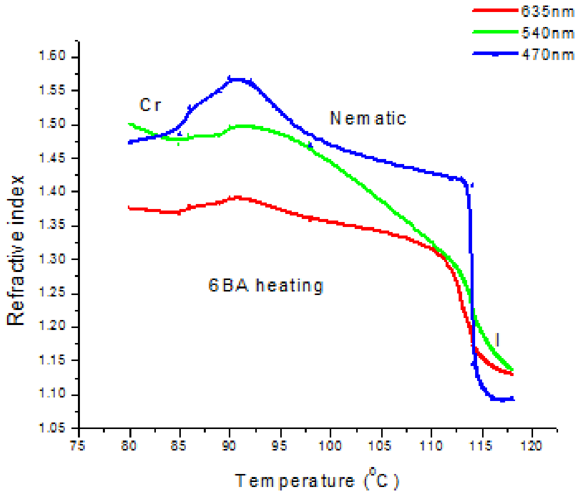


(c)

Fig 7:- Parameters of 8BA (a) transmittance; (b) coefficient of absorption (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. In isotropic phase, liquid crystal samples achieve the zero value transmittance. The molecular orientation is random in this phase and there is no light transmission. 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). The sample's optical transmittance is inversely proportional to the coefficient of absorption. Therefore, the increment of sample temperature is inversely proportional to the optical transmission 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 temperature characteristics (shown in Figs 1,3) results the variations in the measured parameter values that are useful in defining the material's phase transition. 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 phase transition temperatures of samples shown in Fig 6(c),7(c). This reflection is used to compute the liquid crystal refractive index (n). For computing the refractive index from the reflectance measurements, a simple procrdure (4) is used. Temperature dependent refractive indices measurement of liquid crystals: 4-n alkyl benzoic acids (nBA, n = 6,8) at wavelengths 635nm,540nm,470nm were done on heating cycle and are shown in Fig8 .



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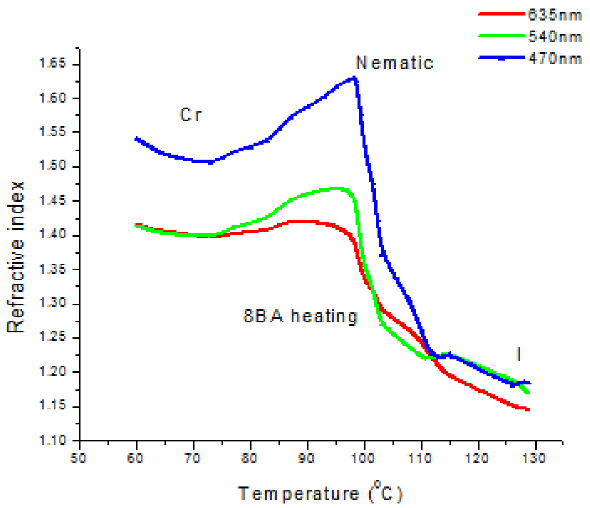

(b)

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 crystalline phase (isotropic) to the isotropic phase (crystalline) [39-41]. When samples are heated from the solid to liquid crystalline or liquid crystalline phase to the isotropic phase, changes in molecular alignment result in variations in refractive index values [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. The destruction of molecular alignment from their respective phases in the isotropic process 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. This can be observed for two liquid crystal 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: 4-n alkyl benzoic acids (nBA, n = 6,8) exhibit the parachromatic property, compound n = 8 is more suited for developing temperature sensors with a wide range of color responses to changes in temperature.

V. CONCLUSION

In this work, temperature dependent refractive indices of Liquid crystals: 4-n alkyl benzoic acids (nBA, n = 6,8) have been studied successfully using image analysis technique. With increasing temperature in the biphasic region of liquid crystal to isotropic phase, the values of refractive indices decrease for all three wavelengths. Both compounds exhibit the parachromatic property useful for fabrication of thermo metric devices. 4-n alkyl benzoic acid (nBA, n = 8) is more suitable component for the design of temperature sensors with high value of refractive indices.

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