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TRANSITION TEMPERATURE IN THERMOCHROMIC LIQUID CRYSTALS USING SECOND-ORDER FEATURES EXTRACTION

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ABSTRACT

Liquid crystals are a type of substance that has solid and liquid properties. One of the types of it is cholesteric. Cholesteric liquid crystals have a characteristic which is called pitch. Pitch is very sensitive to changes in temperature. The pitch will reflect different colors depending on the wavelength at a particular temperature. Thermochromic Liquid Crystals (TLC) is the cholesteric liquid crystal material sold commercially. At the transitional temperature, the texture of TLC changes, so the reflected color will also change. Second-order feature extraction was chosen to determine the change in texture with the transition temperature. A thickness made the TLC layer of 100 µm. This layer was heated and observed using a polarizing microscope with an angle between the polarizer and analyzer of 90°. The obtained result is cross patterns emerged at anisotropic transition temperature and higher temperature on TLC will lead to an isotropic phase.

Keywords: Second-order feature extraction; liquid crystals; transition temperature; thermochromic liquid crystals

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INTRODUCTION

Liquid crystals are a type of substance that has the properties of a regular crystalline solid and changes to a liquid state when heated at a certain temperature. Liquid crystals were first discovered in 1888 by Friedrich Reinitzer through experiments on cholesteryl benzoate samples. The sample is known to be in solid form and melts at 145°C through the mesophase stage [1].

Based on the motion of the molecular arrangement, liquid crystals are divided into three types of phases, namely, smectic, nematic, and cholesteric [2]. The first liquid crystals phase is smectic, which has a two-way motion that rotates by an axis. The nematic phase has three molecular motions that rotate by an axis and the cholesteric phase has a twisted structure [3]. Cholesteric liquid crystals have layers of molecules lined up in each plane and the direction of the molecules in these planes differs from the other planes. The direction of the molecule will repeat after several layers which will form a 360° angle. The length of one twisted cholesteric liquid crystal is called the pitch [4-5].

The specialty of this pitch shows at different temperature. At low temperature, the pitch will elongate and reflect longer wavelengths (red color). In contrast, when it is given a high temperature, the pitch will shorten and reflect short wavelengths (blue color) [6]. One of the materials that are commercially produced is Thermochromic Liquid Crystals (TLC) [7-8]. TLC will change color at a certain temperature, which is called *Color Play* [9-10]. If it exceeds this temperature range, TLC will no longer change color [11].

Cholesteric liquid crystals have two types of textures, namely focal conic and planar [10,12]. The optical property of the planar-type cholesteric liquid crystals is double refraction of incident light. Cholesteric liquid crystals also have dichroic properties which can absorb several directions of refracted light, causing light to become linearly polarized. When light is refracted and linearly polarized and enters the helical structure of the cholesteric liquid crystals, the light will experience circular polarization [13-14].

TLC will experience pattern and color changes at the transition temperature. The transition temperature at TLC is divided into two phases, namely the anisotropic and isotropic phases. Anisotropic materials have optical properties of multiple refractions, which can cause polarization effects. The effect of polarization on TLC is indicated by observing the intensity of reflected light. It changes by putting different polarization angle. When the polarizer is perpendicular to the TLC molecule, it will give a high intensity and the part other than the TLC molecule will give a darker intensity.

Currently, research on thermochromic liquid crystals is developing, such as applying temperature sensors, smart materials, and observing related physical phenomena. Research on thermochromic liquid crystals is often constrained by temperature stability. Some types of thermochromic liquid crystal materials may have a narrow temperature range over for a change in color or pattern to occur. Another problem arises when the temperatures is out of this range which causes the liquid crystal to lose its thermochromic properties.

This research aims to determine the relationship of changes in TLC pattern to temperature variations to determine the transition temperature. Pattern changes in TLC were observed by second-order feature extraction using the Gray Level Co-occurrence Matrix (GLCM) method using contrast and homogeneity components [15]. The contrast shows the range of intensity values and homogeneity shows the variance similarity in the degree of gray.

METHOD

Thin TLC Film Preparation

Thin TLC films were prepared at a thickness of 100 μm using two slides, mylar spacers, and TLC liquid. The layer is closed using adhesive to make it airtight.

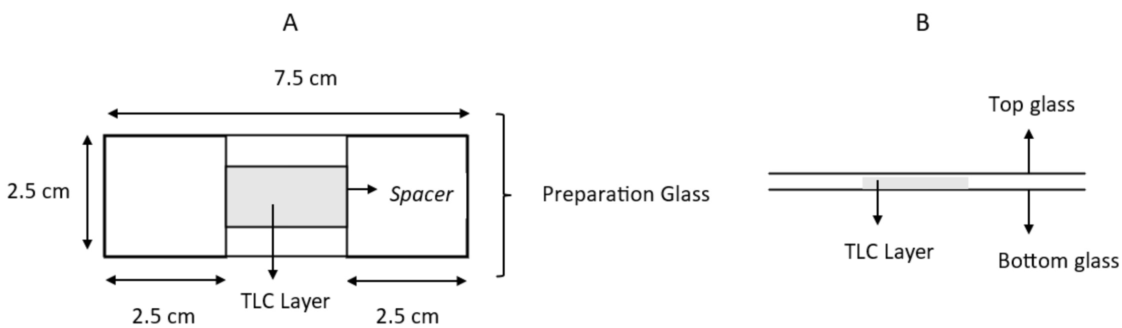


Figure 1. Thin TLC film (a) top view and (b) front view

Preparation of Thermoelectric Circuits

The thermoelectric circuit is used as a heat source on the TLC layer. The thermoelectric circuit consists of two TEC1-12706 thermoelectrics, aluminum foil, and thermal paste. The two thermoelectric pieces are wrapped in aluminum foil and coated with thermal paste for even heat distribution.

Preparation of a Polarizing Microscope Set

A BEM126 microscope was used in this research. The polarizer is placed under the light source and the analyzer is placed under the objective lens. The polarizer angle was set to 90°C. A thin layer of TLC is placed on the microscope preparation table and then a thermoelectric circuit is placed on the left and right sides of the thin layer. The voltage used in this study is 10 V with a current of 2A. Next, the microscope circuit connected to the computer for observation. When heated, the temperature change is measured using an infrared thermometer. The temperature range used is between 30°C to 48°C. Changes in the pattern and color of TLC are captured as image data and to be analyzed.

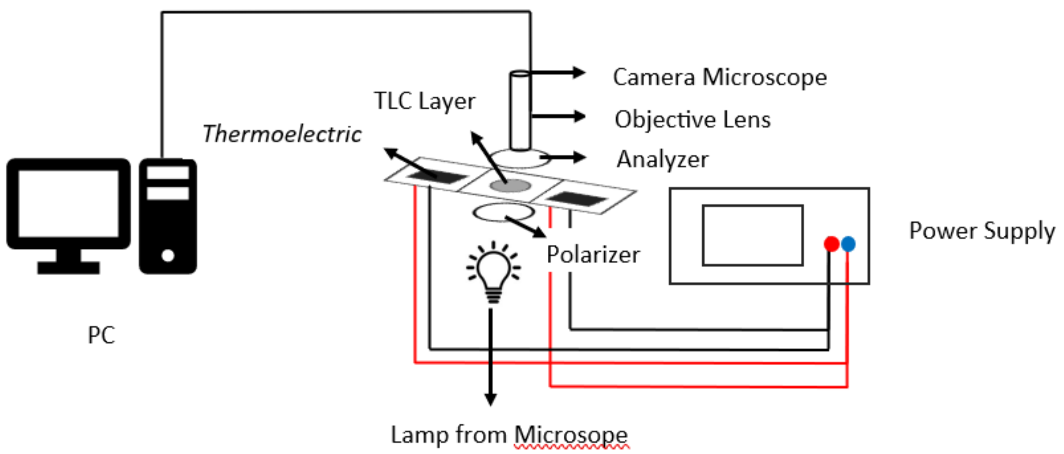


Figure 2. The entire series of TLC image capture

Image processing

Image processing is done with the help of MATLAB 2016a *software*. Image data is cropped in order to get the same pixel size and remove unnecessary components. Next, conversion from RGB image to HSV is done to archive the value (V) component. This is done because the value component is proportional to the intensity value. The converted image is thresholded to distinguish pixels based on the degree of gray. The threshold value used is 0.75 because at this value it is already able to distinguish the components of TLC molecules and nonmolecules of TLC. TLC molecules will give a white color and other than TLC molecules will give a black color.

Next, process the image using the GLCM method using the MATLAB GUI. GLCM is a technique that calculates the probability of a neighboring relationship between two pixels at a certain distance and orientation angle [16]. Orientation angles used are 0°, 45°, 90°, and 135° and the distance between pixels is 1 [17-18]. In second-order feature extraction, there are many features such as energy, correlation, contrast, and homogeneity. However, this article only uses two components, namely contrast and homogeneity because wants to know the relationship with intensity.

The contrast was chosen so it can provide indications about the texture of the image. Contrast shows the difference in intensity among pairs of pixels. The higher the contrast value, the greater the difference in intensity among pairs of pixels, which indicates a strong change in texture. When the contrast value is low, the difference in intensity among pixel pairs is smaller, which means that texture changes are insignificant [6].

Homogeneity was chosen so it can provide information about the level of intensity uniformity of the image texture. A high homogeneity value indicates a uniform intensity among pairs of pixels, while a low homogeneity value indicates a significant intensity difference among pairs of pixels [6].

These two components can be calculated using the equation below. The contrast shows the variation in pixel intensity concerning the main diagonal [19].

$$\text{Contrast} = \sum_i \sum_j (i-j)^2 P(i,j) \quad (1)$$

Where i denotes the row, j denotes the column, and P(i,j) denotes the value in the i-th row, j-th column of the co-occurrence matrix.

Homogeneity expresses the close relationship of the distribution of elements in the GLCM to the main diagonal of the GLCM [19].

$$\text{Homogeneity} = \sum_i \sum_j \frac{1}{1+(i-j)^2} P(i,j) \quad (2)$$

RESULTS AND DISCUSSION

Based on the research results, Figure 3 shows a cross pattern emerges between 32^{o}C to 36^{o}C. This is due to the TLC molecule undergoing circular polarization. The pitch will shorten and reflect blue light. The color and texture of TLC will slowly disappear when the color play is exceeded.

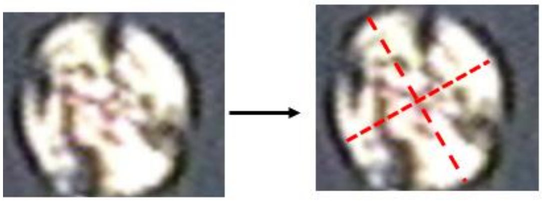


Figure 3. Cross pattern on temperature 36^{o}C

Figure 4 shows the thresholded value component of the TLC image, which highlights the brighter part of the TLC molecule and any other parts will be set to black. This is because the TLC is no longer circularly polarized and the pitch is no longer twisted. So TLC goes to an isotropic phase where in that phase TLC behaves like an ordinary liquid.

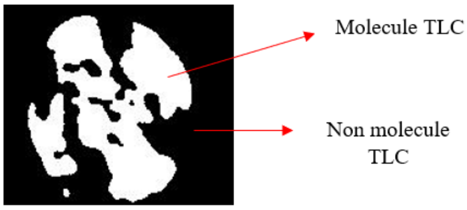
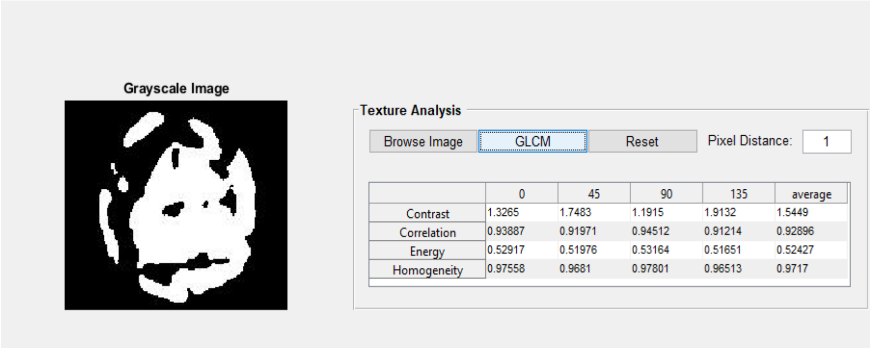


Figure 4. Part molecule and non-molecule of TLC

To determine the transition temperature for changes in texture, Figure 5 shows how the obtained data is processed using MATLAB GUI. The data is presented in the form of a graph of the value of each second-order feature extraction component in various degrees of neighborliness.



	0	45	90	135	average
Contrast	1.3265	1.7483	1.1915	1.9132	1.5449
Correlation	0.93887	0.91971	0.94512	0.91214	0.92896
Energy	0.52917	0.51976	0.53164	0.51651	0.52427
Homogeneity	0.97558	0.9681	0.97801	0.96513	0.9717

Figure 5. Display of the second-order feature extraction process in MATLAB

Figure 6 shows a graph of temperature against contrast values. A temperature of 33°C to 36°C is the anisotropic phase transition temperature. Based on the contrast value, a temperature of 35°C is a critical temperature at which point the TLC begins to show a cross pattern. A temperature of 45°C to 48°C is the isotropic phase transition temperature. The contrast value at this temperature is lower, which means that TLC is like an ordinary liquid. The second critical temperature occurs at 45°C where the transition of TLC towards the isotropic phase.

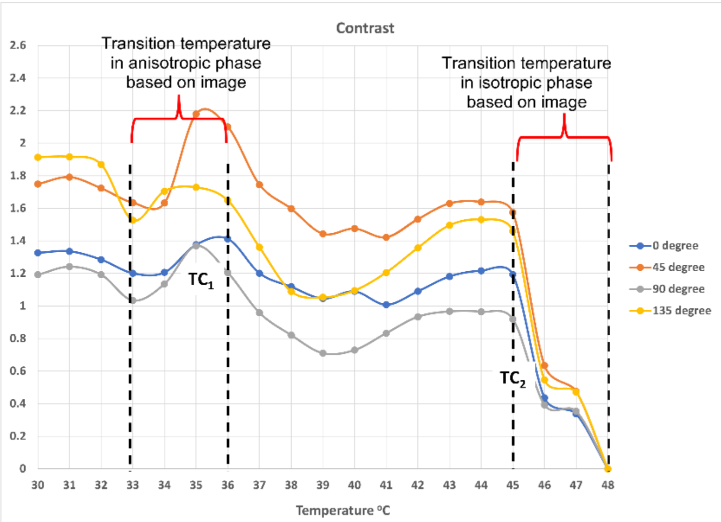


Figure 6. Graph of temperature relationship with contrast values

Figure 7 shows a graph of temperature against homogeneity values. The anisotropic phase transition temperature occurs in the temperature range of 33°C to 36°C with a first critical temperature at 35°C. Based on the homogeneity value, this temperature has the lowest value which indicates changes toward regularity. The isotropic phase transition temperatures occur in the range of 45°C to 48°C with a critical temperature of two occurring at 45°C. The higher the temperature, the higher the homogeneity value obtained, which means the image is learning regularity. This means that TLC is no longer experiencing circular polarization because the molecule is already in an isotropic phase.

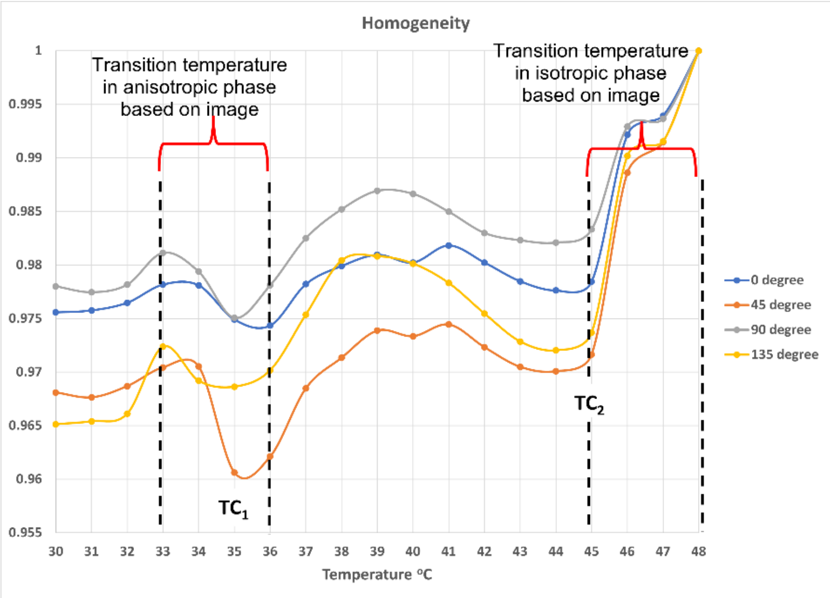


Figure 7. Graph of temperature relationship with homogeneity values

Figure 8 and 9 compares TLC images before and after the thresholded at the transition temperature in each phase. At 48°C the TLC image is dark which shows low intensity because no more circular polarization and the molecule has already turn into an ordinary liquid.

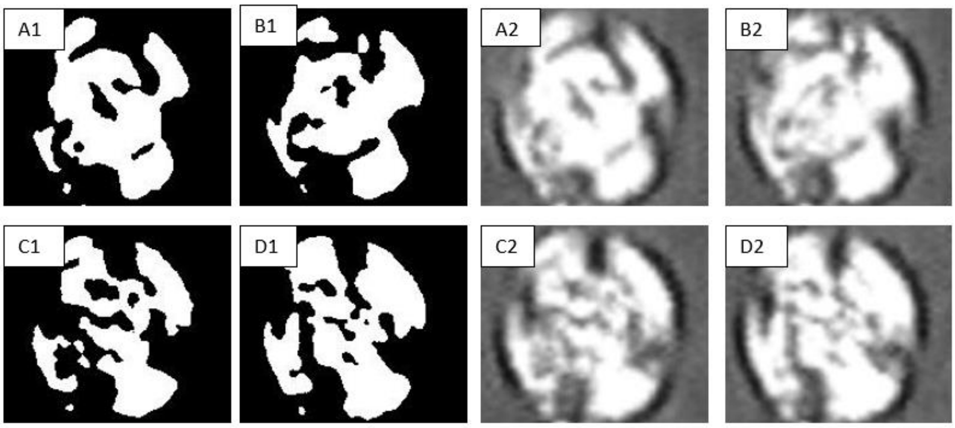


Figure 8. TLC image for each threshold component and V for each temperature at anisotropic condition (A) 33°C, (B) 34°C, (C) 35°C, and (D) 36°C

Figure 8 shows the threshold and value components of the TLC image in anisotropic phase for each temperature. At the temperature of 33°C-34°C the obtained images show no significant change in pattern (Figure 8. A1, B1, A2, and B2). At temperatures 35°C and higher (Figure 8. C1 and C2) a pattern change begins to occur in the shape of a cross as shown in Figure 3. This pattern stays stable up to 36°C (Figure 8. D1 and D2). Therefore, at 35°C is referred to as the first critical temperature in the anisotropic phase. In the threshold component, the white image shows TLC molecules and the black part shows molecules other than TLC.

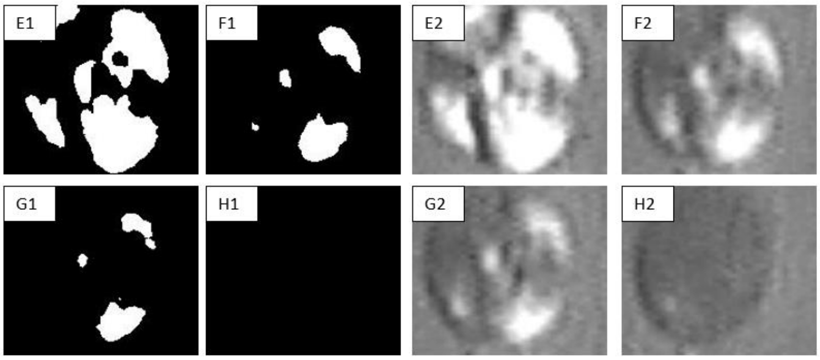


Figure 9. TLC image for each threshold component and V for each temperature at isotropic condition (E) 45^{o}C, (F) 46^{o}C, (G) 47^{o}C, and (H) 48^{o}C

Figure 9 shows the threshold and value components of the TLC image in the isotropic phase for each temperature. At 45°C, the cross pattern slowly fading until 47°C (Figure 9. E1, F1, G1, E2, F2, and G2). Therefore, the temperature of 45°C indicates the second critical point in the isotropic phase. At 48°C, the cross pattern is completely invisible. This can be seen in Figure 9. H1 and H2. In figure H2, the TLC molecule has no circular polarization which indicates that it turns into an ordinary liquid; therefore the threshold component (Figure 9. H1) shows a black color.

Based on the literature, heating the thermochromic liquid crystals leads change of phase and color. The smectic-nematic type liquid crystal transitions at temperature of 32.8^{o}C, the pure nematic type liquid crystal at 35.9^{o}C, and the pure cholesteric type liquid crystal at 37.1^{o}C. On average, changes in color and texture occurred at the temperature range of 23.4^{o}C to 35.7^{o}C [21,22]. This phenomenon is in line with the other research where change in pattern first appeared at 35^{o}C.CONCLUSION

TLC has a change in texture and color when given temperature variations. The change in texture is indicated by the appearance of a cross-temperature transition pattern on TLC. The TLC transition temperature is divided into two, namely when the anisotropic phase and the isotropic phase. When the phase transition temperature is anisotropic, TLC changes to a cross pattern from its irregular pattern. At the isotropic phase transition temperature, the cross pattern on TLC begins to disappear and TLC changes to its properties as an ordinary liquid.

The results of this study indicate that the anisotropic phase transition temperature occurs in the range of 33^{o}C to 36^{o}C and the isotropic phase transition temperature occurs in the range of 45^{o}C to 48^{o}C. So, it can be concluded that at higher temperatures the TLC will turn into an ordinary liquid because of the absence circular polarization.

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