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Investigation on the Effect of Sample Preparation on the Performance of Thermochromic Liquid Crystal

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ABSTRACT

This paper discussed the effect of sample mixture preparation on the performance of Thermochromic Liquid Crystals (TLCs) in terms of maximum intensity, hue sensitivity and aging effect. Three type of TLC mixtures were prepared; (A) solely TLC aqueous slurry solution, (B) TLC aqueous slurry solution and aqueous binder with a ratio of mixing of 3:1, and (C) TLC aqueous slurry solution, an aqueous binder, and tap water with a ratio of 5:1:6. The result obtained shows that sample A gives a higher maximum intensity values compared to the others. Furthermore, sample A with only TLC solution has better hue sensitivity at the red color region. As it goes to the green color region, the sample C, has the highest sensitivity due to the anchoring force present among the molecules. In term of resistance to aging effect, sample B and C that been mixed with other composition are having better resistance towards the effect as it been provided with extra shield resulted from the microencapsulation with aqueous binder. To sum up the result, sample mixing method has significant effect on the performance of the TLCs. The usage of solely of TLC without another additional compound may give higher maximum intensity and sensitivity on certain region but it will have low resistance towards the aging effect.

1. Introduction

Temperature measurements in today's industrial environment comprehend a wide variety of needs and applications. The universal role of temperature in heat mass transport process involving conduction, convection, radiation or a combination of the type of heat transfer modes makes it a variable of fundamental thermodynamic importance [1]. There is a wide variety of temperature measurements technique available depending on what been measured, and the level of accuracy needed, and this paper will be focusing on the Thermochromic Liquid Crystal (TLC). The usage of TLC's in temperature measuring is preferable compared to the infrared camera due to its cost that relatively cheaper or thermocouple sensor which can only measure one point of temperature [2].

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Liquid Crystal (LC) was first been discovered and studied in late of 1800 when a botanist, Friedrich Reinitzer observes that the material knows as cholesteryl benzoate, $C_{34}H_{50}O_2$ has two melting points. Due to the unique molecular structure that liquid crystals possess, it helps to make TLC to become special which has the unique optical properties such as optical activity and selective reflection of visible light as the function of temperature which means that the TLC molecules were able to rotate the plane of polarization of linearly polarized light and reflect color in the visible spectrum from red to blue colour spectrum depending on the temperature [3]. This unique optical property of TLC's been applied to a wide range of usage especially for temperature sensing and measuring. Thermal imaging is also known as Liquid Crystal Thermography.

The application of the liquid crystals covers a wide range of usage from the electronic purpose up to heat transfer mapping. For the application on the electronic part, the most common application is the Liquid Crystal Display (LCD) TV and other liquid crystals display equipment [4]. For the heat measuring or mapping purpose, the usage of liquid crystals covers many application such as for measuring the heat transferred on turbine blades [5], temperature of pipe flow and water [6] [7], medical imaging [8], microelectronic devices temperature monitoring [9] as well lithium-titanite batteries electric vehicle [10]. Liquid crystal has also been applied into fibers to monitor the healing of wound [11] and to investigate the temperature of the membrane distillation channel [12].

Normally, liquid crystal appears to be clear or slightly milky colour when applied to the surface. The TLC will change in color over a range of temperature increment from red to blue and is called as a color-play interval. Typically, the colour play range or bandwidth of about $0.5\ ℃ - 40℃$ as associated with the clearing point temperature of $30℃$ up to $120℃$. The narrowband TLCs offer an accurate resolution of temperature but only a very narrow interval of temperature ($0.5 - 4℃$) while wideband TLC gives rather qualitative information over a bigger temperature interval ($5 - 40℃$), discriminating hot and cold region with lack of accuracy of measured temperature values. These color changes are repeatable and reversible if the TLC's are not physically or chemically damaged. Figure 1 shown the displayed color of red at the low-temperature margin of the colour-play interval and blue at the high end [13].

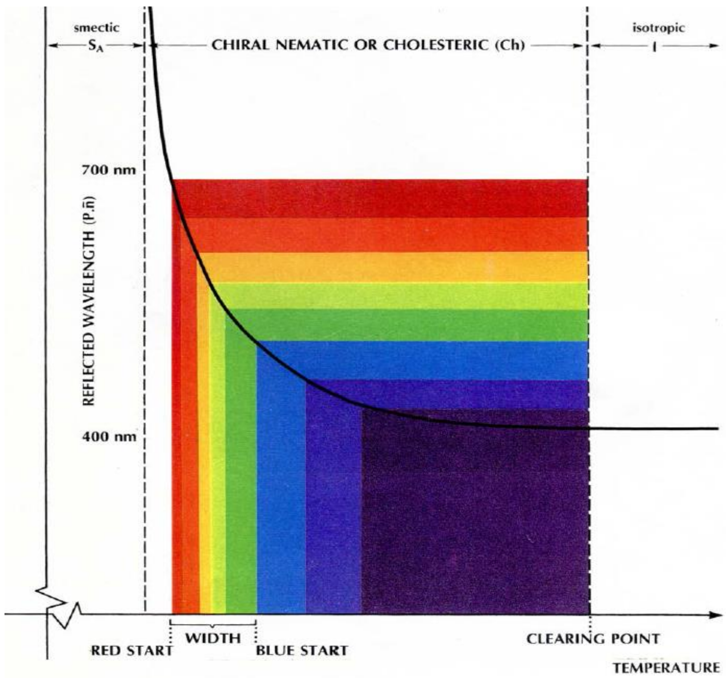

Fig. 1. Typically reflected wavelength (color) temperature response of a TLC (Jan *et al*., [13])

1.1 Factors That Affect the Thermography of the TLCs

There are several factors that affect the thermography of the TLC; Film or Coating Thickness, Hysteresis, Illumination, Imaging System and Colour Space.

1.1.1 Film or coating thickness

According to Kakede *et al*., [2], Abdullah *et al*., [14] and Roth *et al*., [15], for heat transfer experiment application, the thickness of the TLCs film must be thin enough such that the TLCs temperature is uniform as the surface temperature of semi-infinite insulator and subjected to the same heat transfer history. According to Guan *et al*., [16], the colour is not very clear when the size or thickness of the TLC is too small. This is because the typical value of the pitch of the TLC is 300 nm, and the optimum reflection for the TLC requires about 8 twists. Therefore, the optimum size for the prepared TLC is around 3-10 μm. However, too thin film produces poor color play while the too thick film may cause an undesirable change of temperature across the film itself. Besides that, the thickness of the black coating also must be ensured to be appropriate to its use because it may disturb the colour play or the relationship of the hue-temperature calibration [2] [17].

1.1.2 Hysteresis

Hysteresis in TLCs is a phenomenon whereby the cooling curve of the TLCs is different from the heating curve. The effect of the hysteresis has been studied by many previous researchers and most of them stated that the occurrence of hysteresis is notable when the TLCs are heated beyond its clearing point temperature. Some researcher applied preventing approach to avoid the occurrence of hysteresis such as developing a calibration curve by plotting normalized hue against temperature. The calibration range was chosen as it exhibited a monotonic relationship between the temperature and color response which eliminate the hysteresis issue [18]. It is typically assumed that the calibration of TLC is repeatable, reproducible, reversible and ‘hysteresis less’. However, hysteresis can be a significant source of bias in the calibration of TLC since the calibration curve is different when cooled from heat. According to Bakrania and Anderson [19] and Abdullah *et al*., [14], hysteresis is only an issue when the TLCs been heated beyond its clearing point temperature.

1.1.3 Illuminations

The selection of the illuminations source is the first criteria to be taken into count [20]. According to Mustafa *et al*., [21], Illumination variation still a challenging problem in the imaging field especially for appearance-based approaches. For thermography approaches, Kakede *et al*., [2] stated that wideband TLCs are more likely to be affected by the illumination source and angle compared to narrowband TLCs. Owing to these significant advantages, the use of narrowband TLCs seen to be a natural choice for reducing the effect of illumination disturbance. Another reason of hysteresis of TLC also might due to the ultra-violet (UV) induced transformation resulted from the absorption triggered heating from the illuminating source which happened if the TLC been left to cool under the room temperature that drags the period of the cooling process become even longer. As stated by Nastishin, *et al*., [22] which found that the cooling process of the liquid crystal from nematic to isotropic phase sample was found to be slower at ambient temperature to allow hysteresis to occur. The UV light might radiate some heat which affects the cooling process of the LC. Therefore, it is important to choose the right illumination source to illuminate the TLC coated surface. The heating factor from the emitted UV may cause the non-uniform cooling process of the TLC which cause differences between the heating and cooling curve that cause hysteresis.

1.1.4 Imaging system

In general, the issue related to the imaging setting is almost like the illumination issue. This issue has been reported by Farida *et al*., [23], Kakede *et al*., [2] and Cukurel *et al*., [24] which come up with almost the same conclusion such that the angle of the viewing will affect the calibration of the TLCs in terms of temperature shifting and temperature bias. Large viewing angle will cause more significant temperature bias which shifts the calibration curve. Besides the viewing angle effect, the white balance setting of the camera also been studied due to its effect that quite important in the imaging of the color play of the TLCs. According to Cukurel *et al*., [24], wrong white balance setting yield to the unrealistic color cast such that the calibration surface tends to appear reddish, bluish or purplish when it supposed to be appeared black. Therefore, to yield visually favorable results, the definition of the white-point or white balance is matched with the associated ambient light or illumination source during the images capturing [25].

1.1.5 Colorimetry or colour space

In TLC thermography, the colour play is the main interest to be studied. Therefore, the selection of the colour space is very important as it is to determine the correlation between the colour and the temperature calibration curve of the TLCs. Basically, colour is a human perception constructed from the combination of spectral power distribution (SPD) of the illumination source, the spectral reflectance of an object and the trichromatic of human eyes [26]. Due to the fact that colour is the perspective of human eyes, therefore, it is a subjective parameter since different person will have a different perception of what they see. For that reason, a mathematical model was developed to represent and quantify the color and been called colour space. For the TLC thermography, a variety of color space been used to represent the color parameter such as RGB, Hue-Saturation-Intensity (HSI). However, both RGB and HSI color space are device dependent which means that it is depending on the imaging device and brightness information. Therefore, colour space such as CIE XYZ and CIE UVW which are device independent was developed to counter the problem especially for TLC calibration where the hue is more preferred to be defined from the colour space which is independent of the imaging device and brightness information. In CIE color space which been developed by the Commission International de l'Eclairage (international commission on Illumination) in 1931, the hue is represented as a polar coordinated that been normalized with respect to intensity on a two-dimensional chromaticity diagram. In this way, the hue is independent of imaging device an intensity as preferred for TLC calibration process. The development and evolution of the CIE color space was started with CIE XYZ that was developed in 1931 where it been defined from the RGB with normalized intensity which still is widely used nowadays such as in TLCs calibration by Cukurel *et al*., [24] and in colour characterized of coloured stainless steel by Ji *et al*., [27].

Even though there are many research about the calibration of TLC have been reported in different approaches of a factor that affect the performance, there still none or very few studies which focuses on the effect of a mixture of the TLCs on the performance of the TLCs. Hence, the objective of this paper is to investigate the effect of sample mixture on the performance of the TLCs in term of maximum intensity and the response sensitivity of the TLCs.

2. Methodology
2.1 Experimental Set-Up

The design of the experiment facility is basically consisting of several main parts, which include the test surface, temperature sensor, data acquisition system, illumination system, imaging system, heating, and cooling system. The tests surface consists of a test plate and test block that made of pure copper material due to its high thermal conductivity ($398\ W/m.K\ at\ 27$℃), high melting point (1084 ℃) and moderate density ($8.94\ g/cm^3$). The test plate consists of eight square grids onto which the TLCs will be applied. Similarly, the test block also consists of eight square grids with the same dimension with the addition of a groove extending from each grid to fit the thermocouple. The test block is designed so that the thermocouple will be embedded within the test block rather attached to the grid of the test plate. This will prevent damage and disturb the TLC sample during the experiment. The CAD drawing of both test plate and block is shown in figure 2.

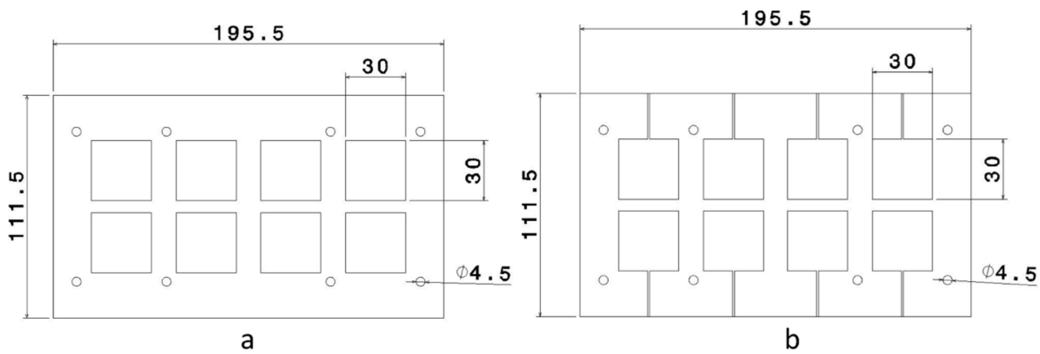

Fig. 2. a) Test Plate b) Test Block

For the temperature sensor, precision grade fine wire type-T thermocouple manufactured by Omega Engineering USA will be used to monitor the temperature of the test surface. The positive and negative leg of the type-T thermocouple is made of copper and constantan (55 % copper and 45 % nickel) and the measuring temperature range is between -250℃ up to 350 ℃. The measuring junction of each thermocouple will be attached to the center of the grid within the test block using OMEGABOND 101 two-part epoxy adhesive.

The data acquisition system consisted of the data logger, data acquisition module, power supply and desktop computer that installed with IO Libraries Suite and Benchlink Datalogger. The data logger will record the signal from the sensor that been placed on the data acquisition module. Data acquisition module which also known as a 20-channel armature multiplexer since it consists of 20 channels that can be used for logging the temperature, voltage, current, resistance, frequency, and period measurement. In this study, only two types of the signal will be measured by the data logger which are the temperature and voltage measurement that gain from the thermocouple and LED.

An illumination system is required to provide white light for calibration of the TLCs. The illumination system employed in this research consist of a pair of the illumination source. The illumination source chosen for this research is a natural daylight linear fluorescent source due to its superior color rendering characteristic compared to the conventional fluorescent source. The fluorescent source has a high colour-rendering index (CRI) of within 96-98 and correlated colour temperature (CCT) of 5500 K and therefore colors will appear more natural when verified under this source.

An imaging system is required to capture and monitor images of the color play of the TLC during the heating and cooling phase of the calibration. The imaging system consisted of a digital video camera which will act as the color play recorder which then will be converted into frames of images for further analysis. The exposure focus and white balance setting are set manually on the camera to achieve best-captured video of TLC color play.

The calibration is carried out in heating and cooling mode. A heating and cooling system is required for this purpose. For this research, a bench-top thermoelectric cold plate cooler has been used as the heating and cooling mechanism. The cold plate cooler has the capability to heat up to 100 °C and is chosen since heating and cooling can be carried out in the same mode of heat transfer with the same heating and cooling rate. This will provide a more controlled condition for the experiment. The temperature of the plate cooler been controlled by bi-directional temperature controller that connected to a computer to monitor and equipped with thermistor for sensing the temperature of the plate cooler. The temperature controller can control the temperature of the cold plate cooler using the Proportional, Integral and Derivative (PID) control and is capable of reversing power of the cold plate cooler automatically to achieve the desired temperature. The schematic diagram on the whole rig of the experiment been shown in figure 3.

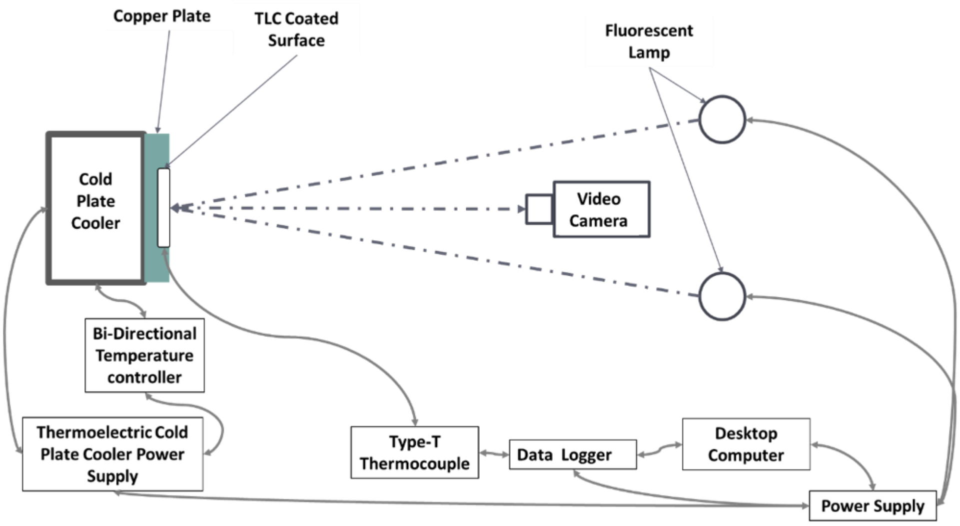

Fig. 3. The schematic diagram on the whole rig of the experiment

2.2 Sample Preparation

The sample consisted of three type of TLC mixtures manufactured by Hallcrest having the identification R35C1W as described in table 1. The laboratory grade magnetic stirrer has been used to ensure that the mixtures are been mixed completely.

Table 1
Type of TLC mixture

Coating	Description
Coating A	Consists solely the TLC aqueous slurry solution
Coating B	Consists of TLC aqueous slurry solution and aqueous binder with a ratio of mixing of 3:1 which been recommended by the manufacturer.
Coating C	Consists of three compositions which are TLC aqueous slurry solution, an aqueous binder, and tap water which will dilute the mixture a little. The ratio of these compositions is 5:1:6 which been suggested by Abu Talib *et al.*, [28]

2.3 Thickness Estimation

The estimation of the TLC thickness is based on the method that been explained by Abdullah *et al.*, [29] which is the dry solid content method. The sample will be weighted using the electronic balance to have a more accurate reading of the weight. The reading of the electronic balance for the sample weight been taken for several times with an interval of five seconds to improve the precision of the reading. The mean of both wet weight and dry weight will be used to calculate the estimation of the dry solid content of the sample using equation 1.

$$DSC_{TLC} = \frac{\overline{W_d}}{\overline{W_w}} \times 100 \tag{1}$$

where DSC_{TLC} represent the percent of the dry solid content of the TLCs sample in, $\overline{W_d}$ represent the mean of the dry sample weight and $\overline{W_w}$ represent the mean of the wet sample weight. The DSC will be used to calculate the volume of the coating using equation 2 so that the desired thickness can be achieved for the next test.

$$V_{TLC} = \frac{t_{dry\,film} \times A_{surface} \times 100}{DSC_{TLC}} \tag{2}$$

where V_{TLC} represent the volume of the TLC coating, $t_{dry\,film}$ represent the desired coating thickness, $A_{surface}$ represent the coating area and DSC_{TLC} represent the Dry Solid Content of the coating. From equation 1, the volume of the coating required to achieve a desired film thickness can be readily estimated provided the desired film thickness, surface area and dry solid content of coating are known. For this experiment the desired thicknesses are 10 μm for sample A, B and C was estimated using equation 1 for a squared grid having length and width of 30 mm, using the dry solid content list in table 2. The result is shown in table 3 and the values were rounded off to two significant digits because in practice, it is possible to measure the estimated volume of coating using syringe having a maximum scale of 1 ml and at least division of 0.01 ml reading.

Table 2
Dry solid content list of samples

R35C1W Sample	W_{empty}, (g)	W_{wet}, (g)	W_{dry}, (g)	W_{solid}, (g)	Ws/Wd, (%)
A	15.70	19.40	16.75	1.05	28.23
B	15.38	19.21	16.35	0.97	25.54
C	16.18	19.80	16.73	0.54	15.05

Table 3
Volume of samples required for the desired thickness

Desired Thickness		The volume of Mixture, V_{TLC} (ml) R35C1W		
μm	cm	A	B	C
10	0.001	0.03	0.04	0.06

The sample will be applied to the surface of the square grids of copper test play by the airbrush method which been suggested by the manufacturer (Hallcrest) using the pressure range of 30 to 35 psi.

2.4 Experimental Procedure

Before starting each of the calibration tests, the lamp or fluorescent source will be left turn on for about 5 to 10 minutes to warm up as been mention by Anderson [30]. Besides that, the digital video camera setting such as the white balance, focus, and shutter speed was manually set as desired. The data logger was then set to record time, temperature and LED histories as one second time interval via Agilent Benchlink Data Logger software. In ensuring that there is no background illumination caused by secondary sources such as sunlight and room light, the rig been covered by thick black cloth which reduces or avoid the incoming light into the rig.

The video camera and the data logger were initiated almost simultaneously to start the video recording and the temperature and LED history of the experiment. After about 10 seconds, the heater and the LED were turned on simultaneously indicating the start of the heating process of the sample. The calibration plate was then being left to be heated to a maximum temperature of 44 °C for maximum intensities test and 50 °C to test the aging effect. When the maximum temperature reaches, the cold plate cooler was set to lower temperature and the LED been turn off simultaneously indicating the start of the cooling process of the sample. The sample has been left to cool down just below the red start temperature. When the temperature reaches about 25 °C, the video camera and data logger were stopped indicating the end of the experiment.

2.5 Images and Data Processing

The captured colour play video of the TLCs was then exported into Adobe Premiere Pro to be extracted into images before been analyzed. The images frames were saved in Bitmap format (.bmp) since Bitmap format contains more image information compared with Joint Photographic Group (JPEG) and Graphic Interchange Format (GIF) image format. JPEG result in reduced image information due to compression losses and GIF is desirable for an image with few colors and therefore more suitable for web logos. The data from the data logger such as the time, temperature and LED histories were saved in excel file before both image frames and the excel data will be imported into MATLAB for analysis.

The image frames and excel file contain the data from data logger were imported into MATLAB and processed using a graphical user interface (GUI) developed by Abdullah *et al*., [29]. The image frames were processed in sequence based on single color intensity which is green color since green color are more dominance as compared with red and blue. The average intensity-time history obtained from processing the sequence of image frames and surface temperature-time histories recorded by data logger were synchronized and interpolated, generating the calibration curve (intensity and hue base calibration curve). The peak intensity and its corresponding temperature were extracted from each calibration curve to examine the behavior of TLC to the difference in direction of temperature change. Besides that, the hue value and its corresponding temperature will also be been extracted from the hue base calibration curve to determine the sensitivity of the TLCs.

3. Result and Discussion

This section discusses the results obtained from the calibration of the TLCs for a different type of the TLCs mixture. The maximum intensity, the effect of repeating cooling and cooling cycles and the sensitivity of the TLCs are discussed in the next subsection.

3.1 Maximum Intensity

Maximum intensity was obtained by extracting the value of the higher peak of each intensity base calibration curve of red, green and blue color as shown in Figure 4-6 respectively. Based on all the curve, it is obvious that sample A which solely consists of the aqueous TLC produce the higher intensity for red, green and blue color followed by sample B and lastly sample C which has lowest intensity level.

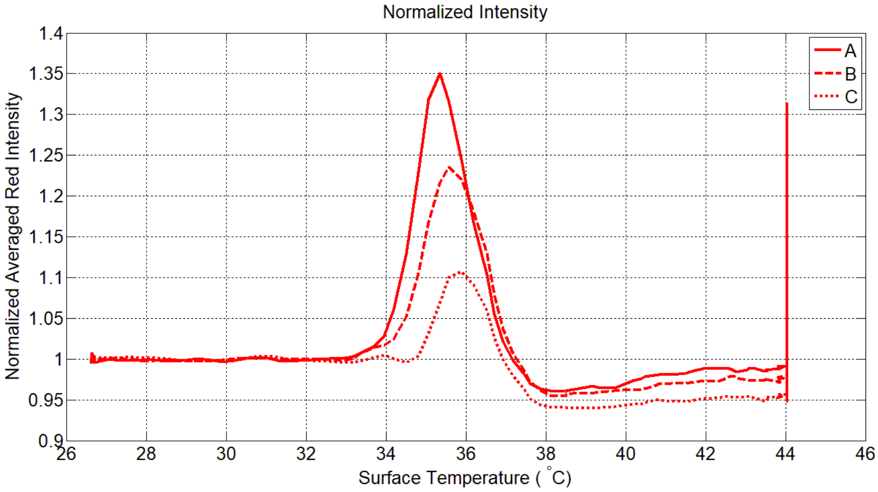

Fig. 4. Red intensity curve

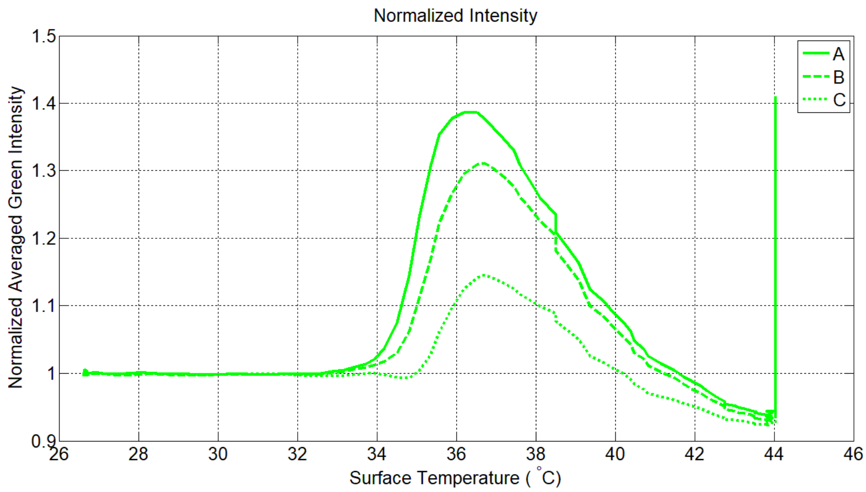

Fig. 5. Green intensity curve

The exact value and the percent difference of the peak intensity (PDI) of each curve relative to sample A were tabulated in table 4. Besides that, the temperature shifting (T_s) and its percentage (PTS) of sample B and C relative to sample A were also included in Table 4.

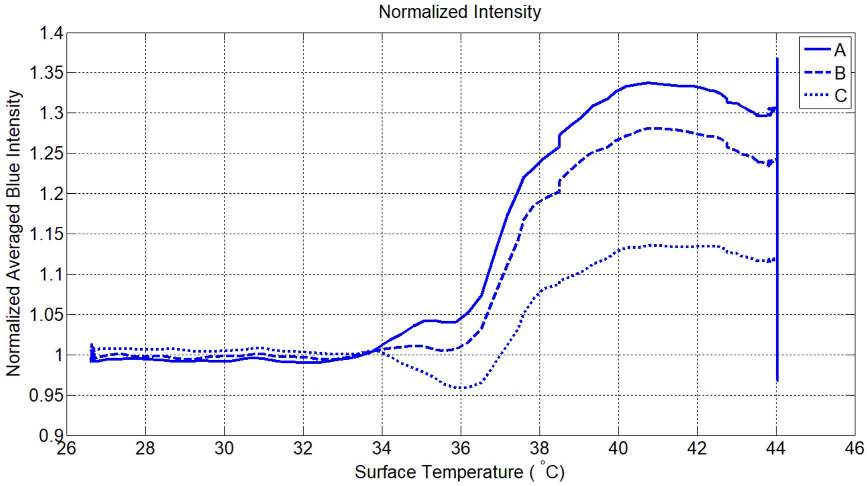

Fig. 6. Blue Intensity Curve

Table 4
Peak Intensity difference and Temperature shifting of sample B and C relative to Sample A

Sample	Red			Green			Blue		
	PDI (%)	T_s (°c)	PTs (%)	PDI (%)	T_s (°c)	PTs (%)	PDI (%)	T_s (°c)	PTs (%)
A	-	-	-	-	-	-	-	-	-
B	8.52	0.22	0.62	5.48	0.52	1.44	4.11	0.11	0.27
C	17.93	0.54	0.90	17.38	0.52	1.44	15.03	0.11	0.27

The reason for sample A has the higher intensity value is because sample A is fully consisting of TLC's crystal particle that been speeded along the surface while sample B and C has other components that been mixed together with the TLCs. This means that the TLCs crystal volume per area of the surface for sample A is higher than sample B and C for the desired thickness of 10 μm. For sample B and C which consist of other composition must share the area with TLCs crystal particle relative to the ratio that has been mentioned. This can be explained by the schematic drawing of the particles arrangement shown in Figure 7 where the size of the particle is assumed to be the same to each other. When the volume of the TLCs particles is larger, the light that been reflected by the TLCs crystal particle is also higher which lead to higher color intensities. Besides that, it also causing small temperature shifting for sample B and C. this is because when the volume of the TLCs particle over the area reducing, the TLCs become less sensitive as the sensor which is the TLCs crystal particle is less to sense the temperature rising. The sensitivity of the TLCs will be discussed in the next sub section.

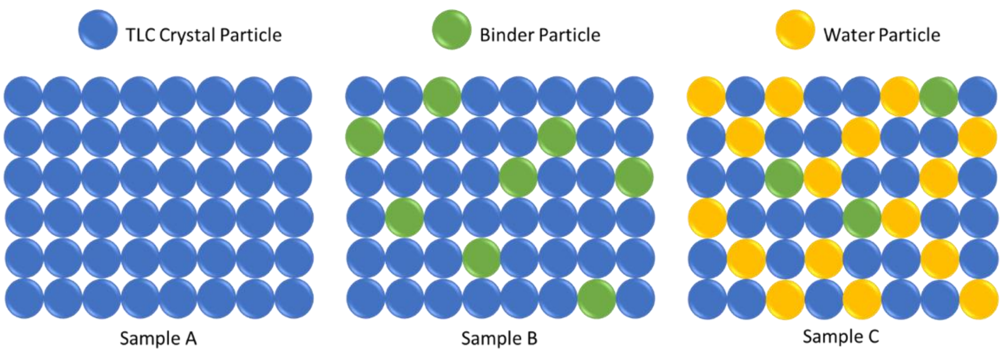

Fig. 7. Schematic Drawing of The Particles Arrangement

3.2 Hue Sensitivity

The sensitivity of the TLC show how fast the TLCs can respond the temperature change and change color from colorless, red, green and blue when been heated. The sensitivity of the curve can be obtained by finding the gradient (equation 3) of the Hue base calibration curve as shown in figure 8. The value of the sensitivity was tabulated in table 5 where there are three part of the curve been examined to find the sensitivity which is assumed to be red, green and blue region of the curve.

$$Sensitivity = \frac{DH}{DT} = \frac{H_{avg_{i+1}} - H_{avg_i}}{T_{i+1} - T_i} \quad (3)$$

where H_{avg} is the average hue, T_s is the surface temperature and i = 1, 2, 3 and 4.

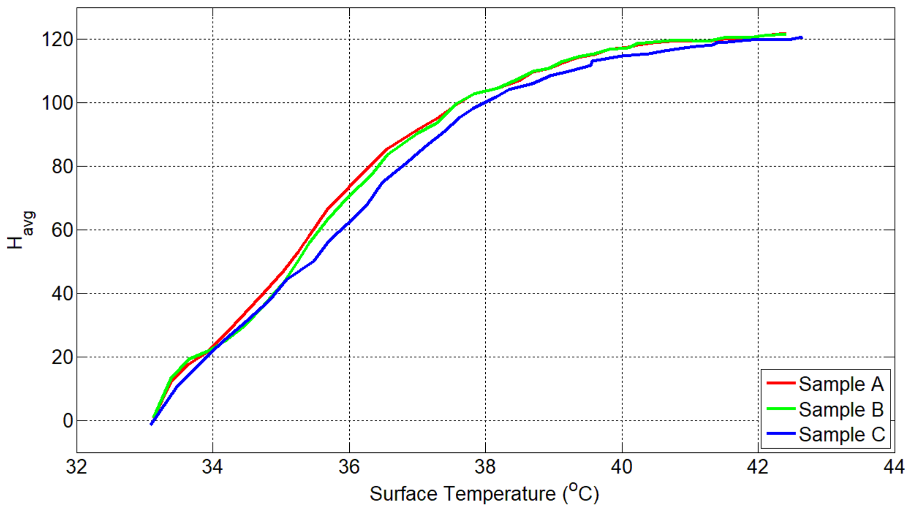

Fig. 8. Hue-Temperature Curve

Table 5
Samples Hue Sensitivity

Region	Sensitivity		
	A	B	C
1 (Red)	23.73	21.81	20.63
2 (Green)	11.11	12.19	15.32
3 (Blue)	5.56	5.73	5.48

As been mentioned in the previous subsection, sample mixture causes the volume of the TLC crystal particle over the area affects the temperature shifting which indicating the sensitivity. Based on the above Figure 8 and Table 5, it can be seen that the sensitivity of the curve can be devised into three regions which assumed where the red, green and blue region are located. At the red region, sample A has the highest sensitivity than sample B and C as indicating it has the faster response to change from colourless to red colour has been heated. As entering the green region, sample C has the upper hand interim of the sensitivity. This is because of the effect of the anchoring force that been explained by Lan *et al.*, [31] and Barberoa *et al.*, [32] which is quite strong due to the contribution of the noncovalent bonding between the particle. In sample C, the water that been mixed in the sample was evaporated when dry up causing the less bonding attraction between the particles as the TLCs as the bonding force contributed by the water particle to become less prominent. This cause the TLCs particle can easily rotate and reflect light in the green region area.

In the Blue region, there is not that much different in term of the sensitivity for all three samples. this might be due to the temperature interval of blue intensities are larger compared to red and green as been mentioned by Abdullah *et al.*, [29]. According to Abdullah *et al.*, [29], the observations correspond to the statement of Elser and Ennulet [34] which also cited in Gandhi *et al.*, [35], which stated that when the TLCs are in the planar texture, the longer wavelength (red occupy a shorter temperature interval compared with shorter wavelength (blue) which occupy a longer temperature interval. This cause the sensitivity on the blue region is not that high as in the red and green region.

3.3 Aging Effect

When the samples are heated and cooled repeatedly, the structure of the sample may undergo some depredation which could affect the performance of the TLCs. It can be seen in term of the reduction of the maximum intensity and shifting of temperature as shown in Figures 9-11. Based on the figures, sample B and C does not shows significant intensities and temperature shifting as compared to sample A, which show some reduction of intensity and temperature shifting after the fifth cycles of heating and cooling.

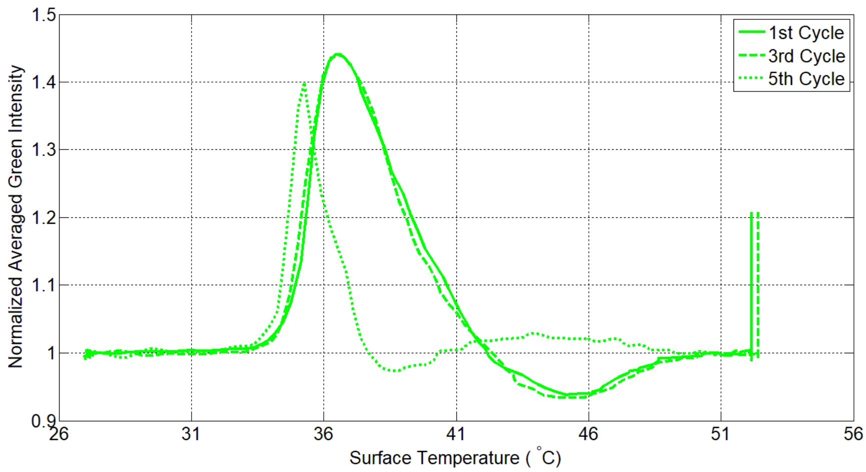

Fig. 9. Sample A

This has been explained by Abdullah *et al.*, [14] which stated that generally, the aging effect of TLC are characterized by decreasing in the magnitude of colour intensities and temperature shifting occurrence. The reason behind the occurrence of aging effect on sample A can be related to the microencapsulating process. Microencapsulation process is the process enveloping the TLCs particle or molecule with a solvent to protect TLC molecules from stress and contaminated by dust and moisture [33]. The binder that been introduced to sample B and C provide an extra microencapsulating shield that keeps the structure of the TLCs sample been damaged by the repeating cycle of heating and cooling.

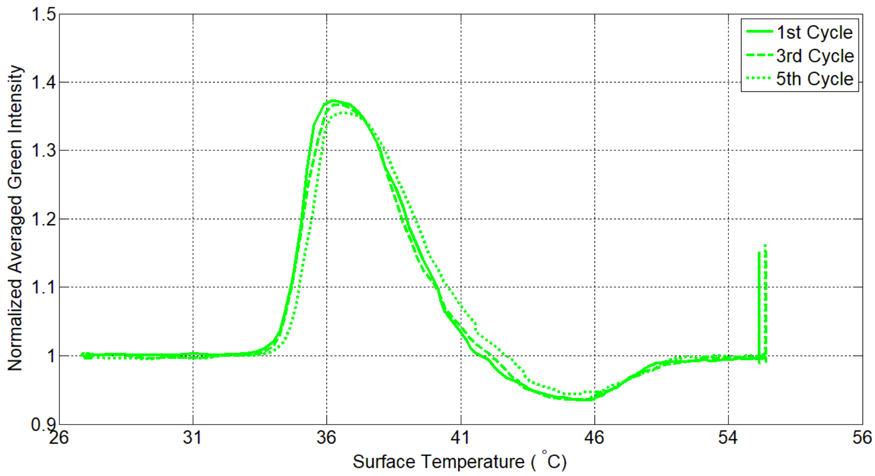

Fig. 10. Sample B

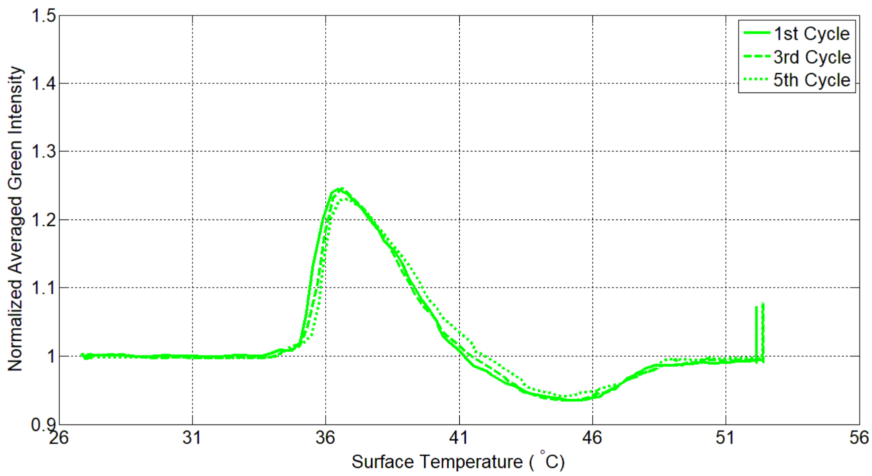

Fig. 11. Sample C

4. Conclusion

The study on the effect of sample mixture of the TLCs on its performance in term of red, green and blue intensity is presented here. In a conclusion, the different composition of the TLCs sample coating mixture will give a different result. The usage of a mixture of the TLC which consists solely the TLC aqueous slurry solution (sample A) will give a higher color intensity as the volume of the TLCs crystal particle which is present to reflect the light over the area is more as compare to the mixture that have other composition (sample B and C). Besides that, it also will give a better hue sensitivity in the especially at the red start region which indicating faster response to change color from colorless to red. However, as entering the green region, due to the bonding force called as anchoring, the sample C which has water composition has the highest sensitivity compared to sample A and B. In term of the resistance to aging effect, sample B has the upper hand due to the additional shield from the microencapsulation process which been done as the TLC's been mixed with the aqueous binder. Based on the observation obtained, it is seen that the mixture of the TLC which consists solely the TLC aqueous slurry solution (sample A) will give a higher color intensity and hue sensitivity but has low resistance to aging effect as it been heated and cooled repeatedly. Therefore, extra microencapsulation could be applied to prolong the resistance of the TLCs sample toward the aging effect. Sample B seems to be the best sample mixing as it gives quite a high color intensity which not too much different from sample A and has higher resistance toward aging effect. However, more study needs to be done in future in term of the mixing effect of the TLCs as it will contribute to a better TLC thermography performance and accuracy.

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