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Study of Light Induced Fading of Electrophotographic Prints

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Abstract*— In various practical contexts, printed images or textual content are subjected to light exposure, rendering their lightfastness a critical parameter. Adequate lightfastness ensures consistent color stability even with extended usage. This work aims to characterize the color-fading behavior in electrophotographic prints under the influence of light source exposure The application of electrophotography prints has witnessed a notable surge in recent times, expanding its scope beyond conventional document printing to art and photography. There is an increasing concern about the longevity and color stability of electrophotographic print. In this study, the Altona test color chart has been printed using the electrophotographic method on the paper substrate and has been exposed to an accelerated aging procedure utilizing a xenon arc lamp to examine the deterioration of color. The test chart that has been printed consisted of six solid color patches (red, green, blue, cyan, magenta, and yellow). The spectrophotometric measurements of the prints have been performed using a Spectroradiometer, and the data has been analyzed using Principles Component Analysis (PCA). The color fading observed in all the color prints adheres to the characteristics of type II fading. This fading pattern is characterized by an exponential and rapid color shift within the initial 10 hours of exposure, followed by a gradual and linear decline. To analyze the rate at which color fading occurs, a curve fitting method was employed, utilizing a first-order kinetic model. The level of fit quality, represented by R2, is approximately 0.95 across all color patches. The fading behavior of the colors results from a combination of distinct kinetics, yet the fading rate itself exhibits a singular nature. The study has shown that each color patch has exhibited a unique level of light sensitivity, influenced by factors such as toner composition, substrate material, fusion temperature, and the light source employed.

***Index Terms*— Color fading, Electrophotography printing, Paper, CIE Lab, Principal Component Analysis (PCA).**

I. INTRODUCTION

Over the past few decades, digital printing has undergone remarkable advancements, cementing its pivotal role and exponential growth in various industries. It has changed the way of printed materials production. The high-quality output, cost-effective small run, variability, flexibility and customization, on-demand printing, and prototyping and proofing make it unique concerning the conventional printing process[1]–[3]. In the realm of printing technology, digital printers offer enhanced options, features, and flexibility for tasks with limited production runs, including desktop publishing, variable data printing, print-on-demand, and photo printing. Digital printers excel in producing digital photographs, artwork, books, journals, posters, and more. The longevity of digital prints stands as a critical factor. To gauge the projected lifespan of a digitally printed piece, evaluating its lightfastness properties becomes pivotal. Lightfastness refers to a print's ability to retain its color intensity when exposed to light. Various factors like light exposure, water, heat, and chemicals influence the stability of the printed image. Assessing the lightfastness of prints from different printers provides valuable guidance to consumers seeking enduring prints that suit their requirements. Electrophotography, a cornerstone of digital printing processes, has emerged as a pivotal technology driving innovation across numerous printing industries. Its widespread application and substantial growth across diverse fields have been truly remarkable, from office document print to photobooks and photo printing. As the demand in the market continues to rise, so too does the heightened concern surrounding print stability and longevity. The color stability and characteristics of electrophotography photo print are the main concern. Color change of a print mainly occurs due to various reasons like light exposure, heat, water, and other chemical agents. This study meticulously examines the impact of light on electrophotographic prints, delving into its comprehensive effects. H. Wilhelm and M. McCormick-Goodhart have discussed extensively the examination of image permanence studies related to prints [4]-[5]. Their exploration has encompassed a thorough analysis of the impact of temperature, humidity, illumination, and air pollutants on light stability. Furthermore, their investigation has considered the phenomenon of reciprocity failure within high-intensity accelerated light stability tests, which played a pivotal role in formulating predictions regarding display longevity.

Significant research efforts have focused on the color degradation of images by applying different mathematical models [6-9]. Extensive research has been conducted to examine the impacts of light on paper substrates, dyes, pigments, and photographs [10]-[17]. Several previous research in electrophotography has been has been focused on improving the underlying process, as well as refining toner adhesion across various machines and substrates. The primary focus of color fading research often centers around textile materials, particularly emphasizing the dyes employed within the textile industry. Limited research has been conducted on the fading characteristics of liquid toners using

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the electrophotographic process. The stability of light faded color image of electrophotographic print depends on the light source, substrate, and toner as discussed by Etsuo Fujii et al [18]. Konig et al. present a new approach to studying color fading based on chrominance histogram quantification and shows its application in image analysis [19]. It is found that the new image processing method based on chrominance histogram quantification is more promising than the conventional spectrophotometric approach. The utilization of CIE Lab and spectral reflectance in assessing image stability has been demonstrated [20]-[23]. In 1968, Giles et al. [24] give the first light on the kinetic nature of color fading. As per Giles, light-induced fading can be categorized into five primary groups along with their respective subgroups. The primary factor influencing the shape of the fading curve is investigated to be the physical state of the colorant and the surrounding environment of the coloring material. In this work, Giles et al. have tried to connect a link between the physical state of the color matter to the nature of color fading. Crews [25] has studied the fading rate curves of a few natural dyes using the colorimetric tristimulus value. The study has shown that most natural dyes decay rapidly initially followed by a slow rate of decay. The study has defined the fading class based on the CIE Lab color difference value which plays a significant role in later investigation. The result of the examination has exhibited that most of the dyes faded in a type II way. The second tendency of the dyes demonstrates a Type III behavior characterized by a consistent rate of decay. This provides a comprehensive understanding of color fading that occurs on our clothing.

In the previous work, the kinetic model was suggested to determine the fading behavior of prints on the foil with time [20]. In the current study, the fading nature of electrophotography prints has been investigated by applying Principal Component Analysis (PCA). Six distinct primary colors, namely red, green, blue, cyan, magenta, and yellow, have been printed utilizing a liquid toner and subsequently exposed to a light source. The experimental spectral reflectance and CIE Lab data have been studied.

II. OBJECTIVE

The process of electrophotography has a profound influence on both the photo book and photo printing industry. This study aims to investigate how a light source influences the color image produced through an electrophotographic process. The ink material used here is liquid toner which is widely used in color photo printing. Furthermore, an exploration into the kinetic nature of the fading rate has been undertaken to gain a comprehensive understanding of its inherent characteristics. This study's findings will offer valuable insights for safeguarding framed images and will also encourage subsequent investigations involving diverse combinations of substrates, toners, and light sources.

III. EXPERIMENTAL MATERIAL AND METHODS

The experiment has utilized an Altona-printed test chart in conjunction with the Pro C5310s electrophotographic printer. A printed sample of the Altona test chart has vividly showcased an array of six distinct standard color toners, red, green, blue, cyan, magenta, and yellow. A4 size paper with a weight of 170 gsm matte coated has been taken as the substrate material. Color PxP-EQ Liquid toner-based printing inks have been used to print the solid patches of six process colors. The output speed of the machine is at 80 ppm. The speed and the pressure of the printing machine have been kept constant during all of the sample printing. The experiments have been performed on a 100% solid patch of Red, Green, Blue, Cyan, Magenta, and Yellow inks of 1,200 x 4,800 dpi resolution. To ensure both liability and repeatability of each run, a set of five samples is collected, from which final measurements are obtained. The workflow of the color fading characteristics is depicted in Figure 1.

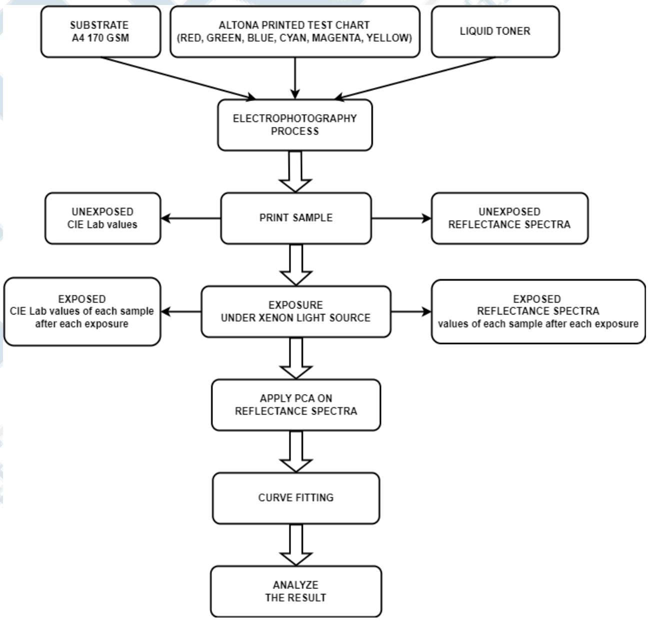

Figure 1: Workflow diagram of the study

A. Lightfastness

The artificial aging process is conducted to perform the experiment in a much shorter time than natural aging under controlled conditions and to map the time-dependent changes of the print samples. The drawback behind natural aging is that it is a very slow, irreversible, and unstoppable process. It is affected by external and internal factors. In contrast, artificial aging is a more effective and controllable process. It has been used to generate controlled time-dependent changes in a much shorter time than the natural aging process. ASTM DC3424-01 standard is carried out to perform the test, test method 3 for evaluating the reflectance of print. BGD 865/A Bench Xenon Test Chamber(B-SUN) is used to measure the reflectance of foil prints. The irradiance level of the experiment is set at 0.35 W/ m2.nm (±0.02 W/m2 nm) at 340 nm wavelength. The temperature and humidity of the experiment inside the chamber have been monitored by an embedded black panel thermometer that consists of a PT100 sensor and a metal panel painted with a black coating. The uninsulated black panel temperature is set to 55 ± 3°C, and the relative humidity is set to 40 ± 5%. The sample substrate size of the experiment is taken by 150 mm × 70 mm and placed in the sample holders for the test. A Xenon light source of 1.8 KW power is used to expose the sample prints continuously. ASTM G155 procedure is followed to expose the print samples under the artificial light source. The print sample is exposed at different time intervals and data is collected accordingly. The samples are continuously exposed to a xenon light tester for a total of 180 hours under a controlled environment to support the repeatability and reliability of the experiment.

B. Measurement

The experimental measurement has been taken using a spectroradiometer, following the guidelines outlined in the ASTM D3424-01 standard. For instrumental evaluation, the experiment has employed an Ocean Optic Spectroradiometer (DH2000BAL) with Tungsten Halogen and Deuterium light sources. After printing, spectrophotometric curves and color values (L*, a*, b*) have been acquired using the Ocean Optic Spectroradiometer. After each exposure to artificial light, spectrophotometric curves have been captured at various time intervals using a 2° standard observer. For every sample, five readings are taken and averaged to enhance accuracy. Data collection occurs within a temperature range of 17°C to 23°C. The experimental procedure initially involved collecting spectral and color data at 15-minute intervals for the first hour. Subsequently, data collection has been shifted to an hourly basis until 24 hours, followed by measurements at 5-hour intervals and later at 10-hour intervals up to 180 hours. This process has been repeated five times, generating five distinct datasets for the proposed model to assess its accuracy.

The CIELab values have been measured to determine the color changes of the unexposed and exposed prints. The CIELab color space encapsulates essential attributes: L*, denoting the lightness of prints; a*, quantifying the extent of redness to greenness; and b*, gauging the degree of yellowness to blueness. Subsequently, these color coordinate values were employed to compute color differences (ΔE_{00}) for red, green, blue, cyan, magenta, yellow, and black prints. This computation involved comparing data from unexposed and exposed samples at distinct time intervals [23,24].

IV. THEORY

A. Principal Component Analysis (PCA)

In the realm of research, Principal Component Analysis (PCA) emerges as a pivotal and widely embraced statistical methodology, finding extensive utilization in diverse domains like data analysis and compression. Rooted in its fundamental premise, PCA operates by transforming intricate high-dimensional data into a more comprehensible visual representation spanning two or three dimensions [29]. PCA is an excellent tool for revealing the hidden feature of data. It helps to identify the important variables that need to be considered and studied. The application of PCA in color science has been studied by Tzeng, and Berns [28]. It assumes a pivotal role in comprehending and mathematically formulating color theory and color estimation. Tzeng and Berns have shown two major applications of PCA. The first is for data reduction, a set of spectra colorants can be derived from a large spectral space in which their admixture represents the properties of the large set of spectra. The second purpose is to define the principal direction that a set of data orient, for example, the major and minor axes of a color tolerance ellipsoid. This research study signifies a pioneering application of PCA [28,29], where the profound impact of significant principal components is rigorously investigated to unearth latent trends residing within the dataset. The execution of this analytical endeavor is seamlessly integrated within the MATLAB programming environment [31].

V. RESULT AND DISCUSSION

The investigation encompasses two distinct yet interconnected segments, spectral reflectance analysis, and colorimetric analysis. These two methodologies have been employed to meticulously examine and elucidate the shared characteristics within the realm of discoloration phenomena.

A. Spectral Reflectance

Principal Component Analysis (PCA) has been methodically employed to examine the spectral reflectance data obtained from six distinct color patches, red, green, blue, cyan, magenta, and yellow. This analytical approach involves treating wavelength as the variable while considering observations at various exposure times. This deliberate arrangement has been chosen with the specific intention of extracting and identifying significant trends residing within a reduced-dimensional space. The most significant principal components and their percentage variance is shown in Figure 2. The first principal component holds the most variance of the data, around 75% to 80%, followed by the second principal component. This analysis strongly indicates that the primary manifestation of color-fading tendencies has been encapsulated within the first principal component.

The spectral reflectance data from all the color prints have been effectively transformed into the realm of the first principal component. The alterations over time in these transformed values are visually depicted in Figure 3. The plotted data indicates a shared pattern among all color patches, characterized by an exponential shift in reflectance during the initial hours of exposure, succeeded by a predominantly linear trajectory with intermittent peaks and troughs. It is noticeable that the span of the exponential decay and slant of the linear decay is almost the same for all the color prints i.e. the curve structure for all patches

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demonstrates a notable similarity. The depicted plot strongly implies that, despite variations in the chemical composition of the toners, the nature of color fading remains consistent and independent of their distinct formulations.

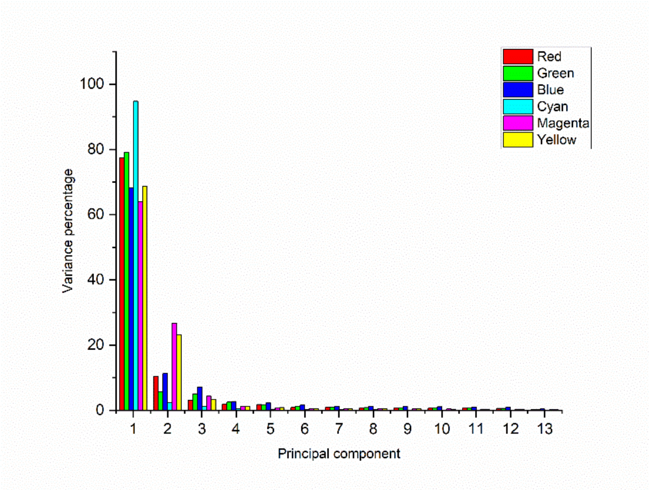

Figure 2: Variance percentage of principal component

Giles's research on the kinetics of dye fading establishes a classification framework encompassing five distinct categories that characterize the nature of dye fading [25]. Type I is a fading rate that decreases steadily with time, but rarely occurs in practice; Type II fading initially occurs at a rapid rate followed by slower fading at a constant rate; Type III is a fading rate curve characterized by a linear or constant rate of fading. This type of fading occurs most often with pigments and fast dyes that form larger aggregates inside the fibers. Type IV is a fading rate of initially darkening, followed by a slow fading rate. This type of fading occurs in a few fast dyes. Type V is a fading rate that steadily increases with time and is observed occasionally with azo dyes on cellulose. In this study, all the color prints adhere to the Type II fading type.

Figure 4 illustrates the temporal evolution of the reflectance change rate. The nature of the curve remains consistent across all patches. The curve exhibits an initial steep incline, transitioning into a subsequent phase of a straight, flat line. But, the physical character of the rate of reflectance change is not like this. The plot is constructed by calculating the first-order derivative of the data presented in Figure 3. This involves using the transformed data on pc1 about the exposure time. Upon visual examination, it becomes evident that the initial few hours has shown a negative exponential curve. The scenario can be assumed like equation 1. Equation 2 presents the outcome of deriving the first-order derivative of Equation 1. The negative sign in the right hand of equation 2 expresses an upside-down reversion of the curve. Thus, the plot can be interpreted physically as depicting a rapid fading rate during the initial few hours of exposure, gradually transitioning into an exponential decrease, and eventually settling into a consistent linear rate.

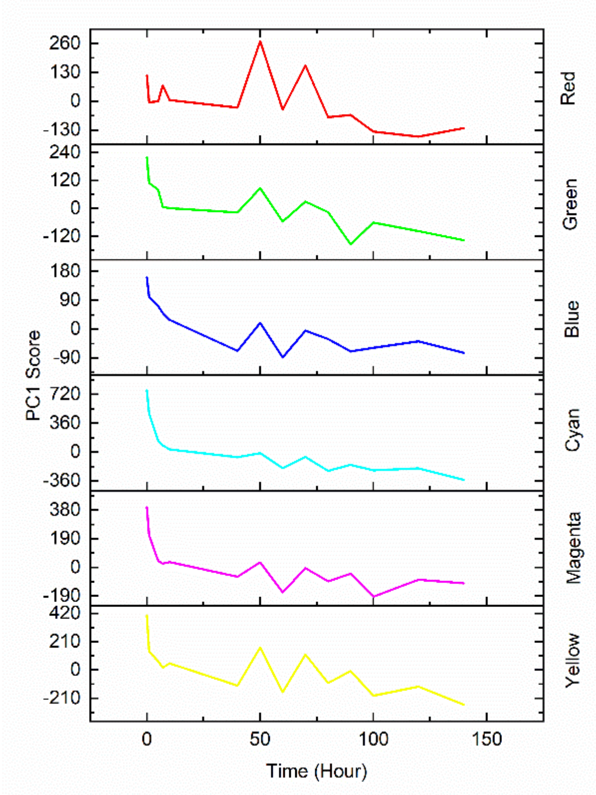

Figure 3: PC1 score respective to the exposure time

$$y = ae^{-bx} \quad (1)$$

$$y_1 = -(ab)e^{-bx} \quad (2)$$

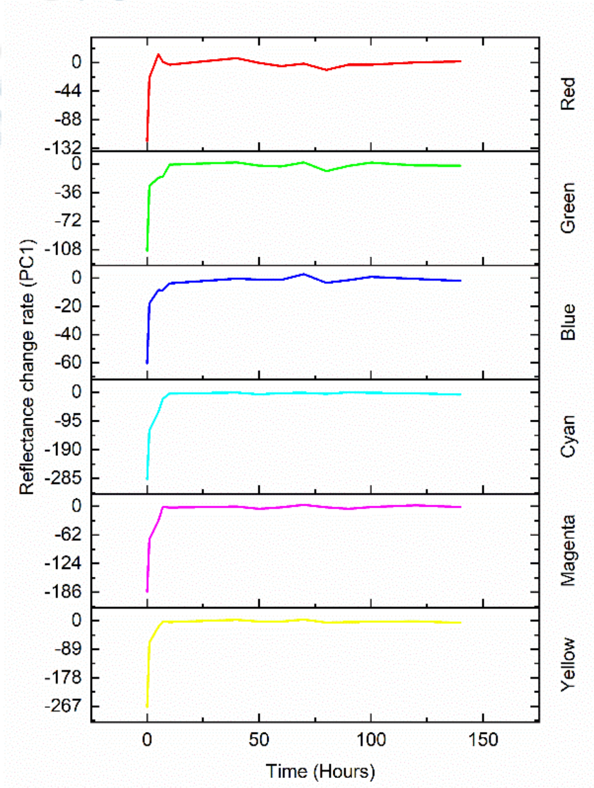

Figure 4: Reflectance change rate

Figure 4 has implied a correlation between the rate of reflectance change and the passage of time. Regression analysis has been conducted on the rate of reflectance change using the curve fitting technique. Various mathematical functions have been analysed, and ultimately, an exponential function yielded the most optimal outcome. The resulting plot has been depicted in Figure 5. The goodness of fit, R-Square, and the co-efficient value are shown in table-I. The R-Square value is approximately 0.95 across all color patches. The curve fitting function is shown in Equation 3.

B. Kinetic of Fading Rate

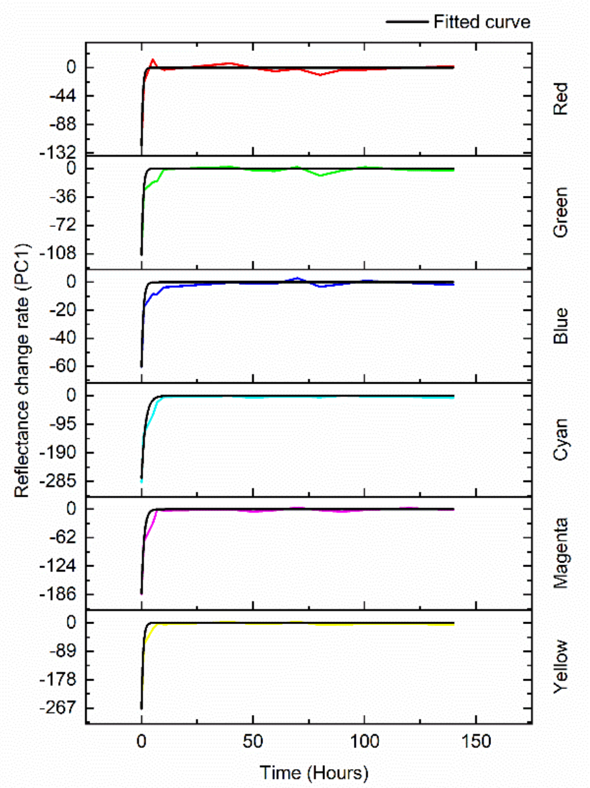

Figure 5: Curve fitting of reflectance change rate

$$r = ae^{bt} \quad (3)$$

Here, r represents the reflectance change rate at a specific exposure time, t is exposure time, and a and b as co-efficient (with 95% confidence bounds). From the table, it is obvious that the coefficients a and b are negative in nature. Upon comparing Equation 3 with Equation 2 and considering the physical significance of the rate, by negating the sign of parameter 'a,' the equation can be expressed as Equation 4.

$$r = r_0 e^{-kt} \quad (4)$$

Here, r is the rate of reflectance change at any time t, t is the exposure time, and r_0 is the coefficient a value. The negative exponential nature is expressed by taking the absolute b value as k and taking the negative sign out. Considering both the first-order chemical kinetics and Equation 4, their congruence indicates that the fading rate conforms to a first-order kinetic pathway.

Table I: Curve fitting statistics of reflectance change rate

	A	B	R-Square
Red	-121.38	-1.65	0.97
Green	-109.78	-1.36	0.94
Blue	-60.30	-1.19	0.95
Cyan	-276.00	-0.57	0.95
Magenta	-184.17	-0.89	0.97
Yellow	-269.15	-1.36	0.99

C. Point of Inflection

The point at which the nature of the fading class change is called the point of inflection. At this point the kinetic of the reflectance change from first-order kinetic (n=1) to zero-order kinetic (n=0). The analysis has been performed by taking the second-order derivative of the reflectance value projected on the pc1. The concept behind this is that Figure 3 and Figure 4 curve shows a bit of turbulence at its later linear part. The gradient of the Figure 4 curve can properly represent the inflection change. The plotting is shown in Figure 6. It is observable that the curve is reversed in Figure 4. The reason is the same as the previous Figure 3. Here, the sharp turn of the curve is the main interest. The steep curve become flat after 10 hours of exposure and the curve feature is almost identical in all the color patches. The change in the fading kinetic is shown by the dashed line. This suggests that the fading follows a negative exponential pattern for the initial 10 hours of exposure, after which the kinetics shift to a linear and gradual decay.

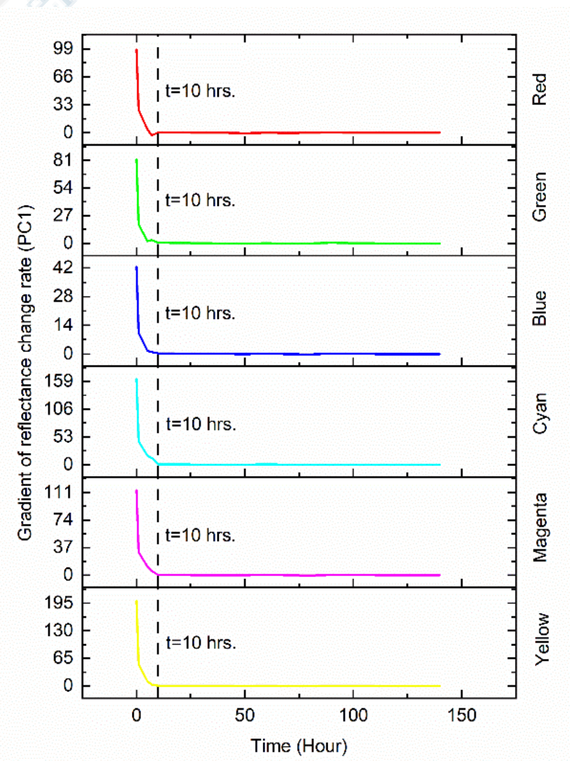

Figure 6: Reflectance changes Inflection point

D. Colorimetric Analysis

The investigation of color fading has been conducted through mathematical analysis using the CIE Lab tristimulus colorimetric values. The lightness and color difference, ΔE_{00} parameter are taken into consideration. Lightness refers to the metric that quantifies the darkness or brightness of color present in an object. The study of the lightness change at different exposure times is shown in Figure 7. The plot indicates an initial steep darkening trend across all color patches, followed by relatively stable lightness values except for the blue color toner. Unlike the others, the blue toner displays minimal lightness alteration throughout its exposure duration. Instead, it demonstrates a fluctuating linear progression in lightness change. The nature of the lightness curve is compared with the Giles color fading class [25] and it is found that all the color toner follows the type-II fading class. Blue shows a type-III similar fading nature. It is also observable that the brightness of all the color prints is equal. Among the color toners, yellow exhibits a higher level of brightness, while blue appears as the darkest. The remaining color prints have shown similar brightness characteristics, falling between the spectrum of yellow and blue.

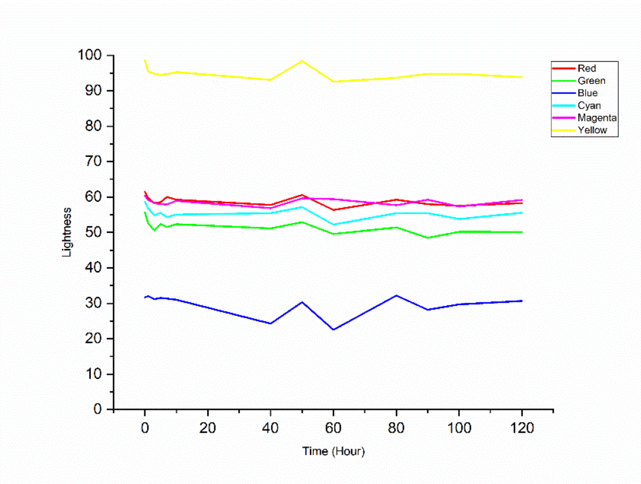

Figure 7: Lightness change at different exposure times

The rate of change in lightness is analyzed and the outcomes are presented in Figure 7 through color-coded lines. The curve demonstrates a steep nature during the initial few hours, transitioning into a linear trend thereafter. The actual physical interpretation differs from this observation. It shows a reversion according to the Figure 3 discussion. Physically, it indicates a negative steepness, implying a diminishing rate of fading. This implies that the initial exposure period experiences a rapid rate of lightness change, which then exponentially diminishes over a few hours. Subsequently, a constant and consistent rate of change is maintained. This trend is followed in all color prints but blue. It shows different features. The rate of blue prints is initially high and later decreases and follows a turbulent change. The kinetic of rate change is studied by the curve fitting method which is shown in Figure 7 with a solid black line. The result follows Equation 4 except for the blue prints. The goodness of fit, R-Square, and the co-efficient are shown in table-II. The result suggests that the lightness change rate also follows the first-order kinetic model. The blue color toner is an exception here. Visual observation indicates that its rate remains nearly constant throughout the exposure period and undergoes minimal change.

Table II: Curve fitting statistics of lightness change rate

	A	B	R-Square
Red	-1.89	-0.68	0.93
Green	-3.14	-0.77	0.98
Blue	-0.02	-0.02	0.01
Cyan	-1.90	-0.51	0.98
Magenta	-1.17	-0.52	0.95
Yellow	-3.21	-0.92	0.99

The inflection point, which signifies the exposure time when kinetic fading occurs, is examined about changes in lightness and illustrated in Figure 8. The analysis is conducted on the second-order derivative of the Figure 7 plot, with the rationale being consistent with what was explained earlier in the case of reflectance.

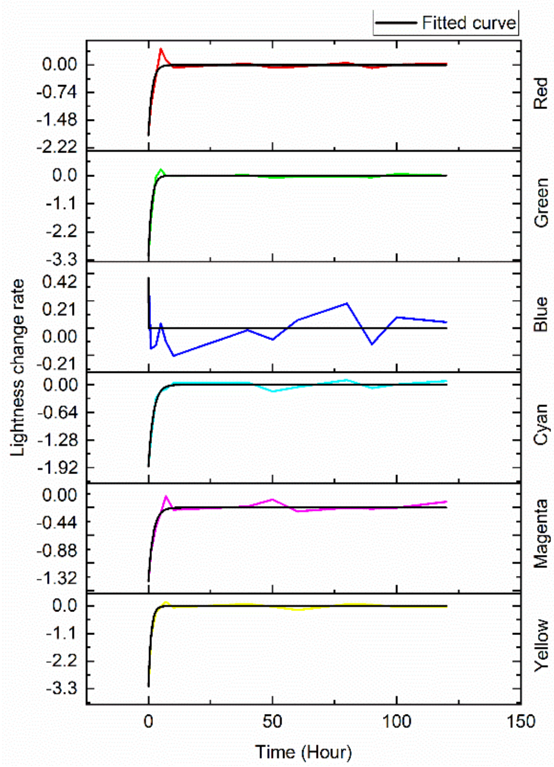

Figure 7: Lightness change rate

The point is marked with a vertical dashed line which represents a 10 hours exposure time. Here it is noticeable that the blue plot is opposite in nature because it gets slightly brighter compared to the other which gets darker with exposure.

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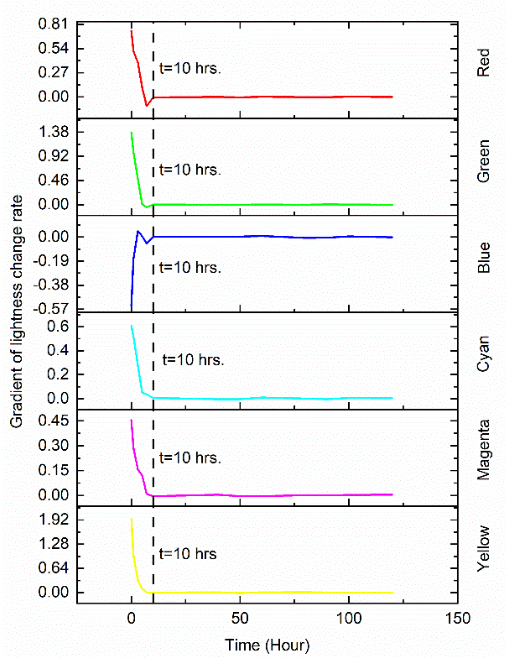

Figure 8: Lightness change inflection point

Color difference serves as a direct measure of fading, providing a mathematical comprehension of its characteristics. The chromatic change in color is scrutinized by analyzing the color difference, ΔE value according to the CIE Lab 2000. The result is shown in Figure 8. The nature of the curves in all the patches is almost similar. The color change follows an initially steep curve that shifts its trajectory to a gentler slope after a few hours. This indicates that color fading is notably rapid during the initial hours, followed by a gradual slowdown and a transition to a more linear progression. The nature of the curve is studied with Cristea's fading curve [17] and it implies that all the color changes take place according to the type-II fading class. The range of color change is not even the same for all the color prints. Magena shows a greater change in chromatic appearance while blue shows high resistivity in light fading. The rest of the color prints falls between magenta and blue with a moderate chromatic change.

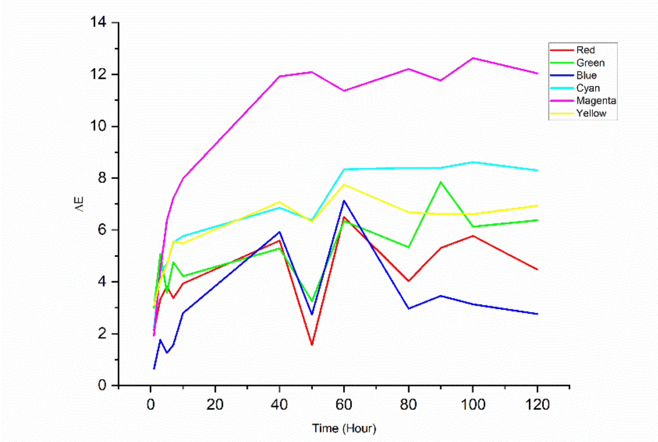

Figure 8: Change of color difference

The speed of the color fading process is investigated by the rate of the color difference. The result is shown in Figure 9 with the colored curve. The fading process exhibits rapid acceleration during the initial hours of light exposure. Subsequently, the fading rate decelerates, displaying a steep decline before stabilizing. Eventually, it settles into a consistent pattern. These characteristics are consistent across all color prints. The analysis of the rate nature is done by applying the curve fitting method. The fitted curve is shown in Figure 9 with the solid curve upon the colored experimental plot. The negative exponential equation 4 fitted well with all the curves and the result of the goodness of fit and R-Square value is shown in table-III. The fit result in red and blue is slightly less since it has high turbulence at the linear part. The fitting of the curve suggests that the nature of the rate of fading follows the first-order kinetic method with a high at the begging and a constant change at the end.

Table III: Curve fitting statistics of color difference change rate

	A	B	R-Square
Red	0.94	-0.39	0.86
Green	2.93	-1.04	0.96
Blue	0.93	-0.53	0.66
Cyan	1.50	-0.31	0.99
Magenta	1.67	-0.19	0.97
Yellow	0.61	-0.16	0.94

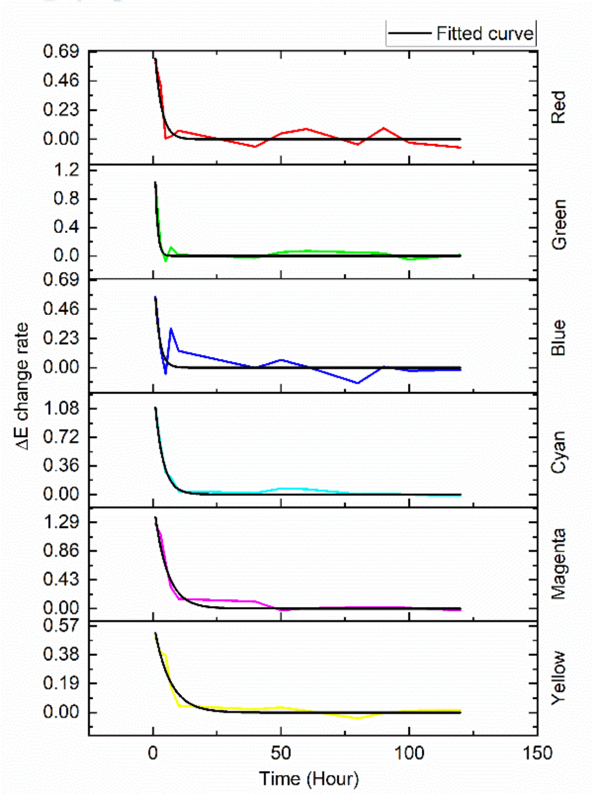

Figure 9: Rate of color difference change

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The alteration in color difference showcases dual characteristics, and the juncture where this shift occurs is referred to as the point of inflection in Giles's study [25]. The change point has been analyzed with the second-order derivative of Figure 8 and the concept behind this is the same as stated before. The result is shown in Figure 10. From the plot, it is observable that all the color tonner shows identical fading characteristics. The inflection point situated between the steep curve and the straight parallel line showed a vertical dashed line. The exposure time at this point is found to be 10 hours which resembles other analyses.

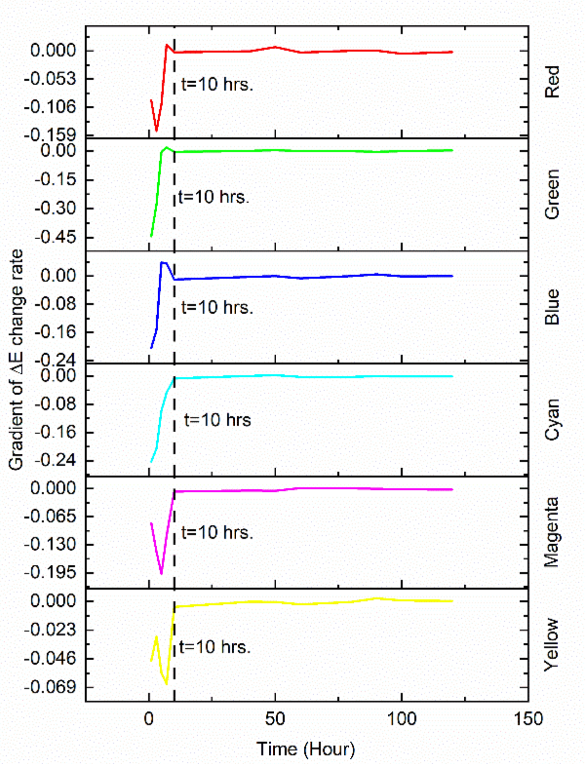

Figure 10: Color difference inflection point

Chromatic color distribution analysis has been conducted utilizing the CIELab color coordinates a* and b* distributions. The objective of this study is to examine how fading occurs within the chromatic color disk. The outcome of this investigation has been presented in Figure 11. The plot represents the range of the chromatic change of color prints during the whole exposure. The visual observation has suggested that cyan and magenta show a very high elongation change followed by blue, red and green, and yellow with almost a circular distribution. Elongation distribution shows a greater change in color appearance while small centric distribution represents local-centric color change. Thus, the chromatic change in magenta and cyan is greater than the other prints. The light sensitivity is high in magenta and cyan.

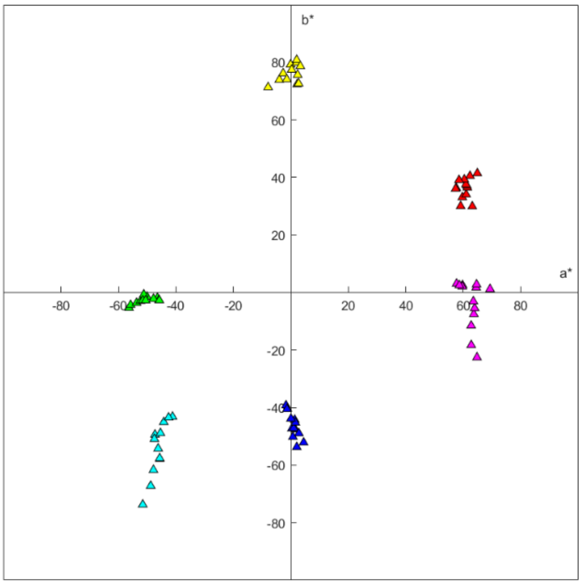

Figure 11: CIELab chromatic distribution

E. Discussion

The color of an object is a visual perception created by the colorant present on the surface of the object. The print material achieves this visual appearance using a thin layered ink material applied on the substrate. The nature of the ink material is a combination of many individual ingredients such as colorant, resin, solvent, modifiers, etc. The overall effect of those ingredients gives the print a proper color and texture. Any slight alternation or chemical change in the ink configuration can alter the color perception in the prints. Light is one of the major disturbances of those harmonies in the ink formulation. It acts as a catalyst for the chemical reaction which changes the ink configuration on the surface of the object and as a result color alteration takes place. The study of reflectance change and CIELab gives a glimpse of the fading process that takes place due to light exposure. The analysis has suggested that the kinetic characteristics of color change are dual in nature. At the initial exposure, the process of fading follows the first-order kinetic (n=1) with a very high fading rate. The fading rate later keeps decreasing with exposure time. Later, the fading characteristics take a sharp turn and follow a slow linear zero order (n=0) kinetic change with a constant fading rate. Giles has suggested that this kind of fading is a type-II class [25]. The kinetic of fading rate is tested with the curve fitting that suggests a first-order kinetic change. It means although the color fading characteristics are dual in nature the rate of fading is singular and unique. The dual nature of the fading phenomenon can be attributed to variations in the thickness of the printing ink layer and its penetration into the substrate. Giles has illustrated how the physical properties of colorant can impact the fading characteristics [25]. The top layer of the printing ink on the substrate exhibits the initial fading characteristics which are in first order kinetic. The colorant particles at this part are well dispersed and easily accessible by the incident light to get excited. The particle size for this decay lies in a small aggregate whose surface area is more to get the incident light. For this reason, the environment at his level become suitable to go for the first order decay. The later linear fading is in zero order kinetic which takes place due to the large aggregate colorant particle inside the fiber of the substrate. Due to its position below the top layer of the ink and small surface area, it does not get much exposure to light, oxygen, or moisture which makes it suitable to go for zero order color change. The exposure time of 10 hours in this study is the crucial point where this dual kinetic takes place. The inflection point is dependent on the colorant-substrate combination and printing process. The fusion temperature plays a crucial role in this regard of the electrophotography process. The temperature effect the toner adhesion and penetration into the substrate surface and affect the kinetic change point. The chromatic investigation gives an inner view of the prints. The lightness change analysis suggests that the prints get darker with time. The value of lightness is not the same in all the prints and the change of it does not vary much. The kinetics study of lightness is similar to reflectance. The lightness curve and reflectance curve shows similar trends which is an indication that the reflectance of an object is directly related to the lightness of the object. The same study is carried out in color difference which suggests the same fading nature as well. But the range of their fading is not the same. The chromatic distribution of CIE Lab a* and b* allow us to visualize the chromatic range of their fading. Larger the range more the fading takes place and the higher the light sensitivity of the print. It suggests that the magenta and cyan are highly sensitive to light. The light sensitivity of the toner varies with its chemical composition and light source.

VI. CONCLUSION

The outcomes of this study indicate that all color toners experience fading in the presence of a light source. The characteristics of the fading are the same in all the color toners irrespective of their ink composition. The fading takes place according to the type-II fading class. It implies a common light-sensitive phenomenon in all the prints. The curve fitting and the rate analysis allow us to understand the nature of the discoloration. The fading at the initial 10 hours is very high. Later, the fading rate decrease exponentially, and after a point fading takes place with a constate rate. It has been found that most of the dye, pigments, and toner follow the type-II fading class which is a combination of two kinetic, first phase takes place as first-order kinetic and after an inflection point, it follows the straight zero-order kinetic. Even though the fading rate is consistent and adheres to a singular pattern, it follows the first-order kinetic model. The point at which the fading nature takes its turn implies the ink layer thickness, colorant particle size, ink penetration into the substrate, and the printing process. Suitable ink formulation can be used to vary the inflection point. When the point is situated near the initial exposure time, signifying a steep curve, the first phase of fading concludes rapidly, followed by a swift deceleration in the fading process.

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