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COMPARATIVE ΔE ANALYSIS OF PROCESS INK AND FLUORESCENT INK ON COATED AND UNCOATED MEDIA USING DIGITAL PRINTING

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Abstract
The ΔE of process ink and fluorescent ink on coated and uncoated paper were compared in this study. To execute above analysis of delta E, a test master chart contain all relevant tools was printed on both the substrates (coated and uncoated paper) under the standard printing conditions. The (L*a*b*) values of printed ink and fluorescent ink were measured using a spectrophotometer (X-Rite eXact). The ΔE value of the black color on both substrates was found at lower side whereas, other process ink has shown higher value of delta E on both the substrates but lower than the fluorescent inks.The fluorescent inks has shown higher values of delta E on both the substrates.

Keywords:
Fluorescent ink, Digital Printing, Electrophotography, Coated paper, uncoated paper, ΔE.

I. Introduction
Digital printing is the latest technology in the modern era of the printing industry. The digital printing process is an economical and less time-consuming technique for short run jobs. The electrophotography printing process involves printing in six steps namely: charging, exposure, development, transfer, fusing, and cleaning (AL-Rubaiey, 2009). Electrophotography is a digital printing process in which corona treatments create a positive charge on the photoconductor drum and create a latent image on the cylinder. In the second step, the positive charge is applied to the photoconductor (Ataeefard&Nourmohammadian, 2015). Toner ink has a negative charge. After applying the toner ink, the positive charge of the corona treatment and the negative charge of the toner ink create an image on the cylinder. In the third step, the image is then transferred to the substrate and adheres to the surface by heat and pressure; the image is then solidified on the substrate (Wang et al., 2021). The digital printing uses toner and liquid inks to print the surface of the substrates. The toner ink is widely used commonly in digital printing. Now-a-days, some customised fluorescent ink is also developed. It is used in special printing for wide colour gamut and to enhance brightness of the printed ink. Therefore, there is a thrust area which needs to compare the colour consistency for both the process ink and fluorescent ink on printing paper substrates. This research work explores the comparative analysis of process ink and fluorescent ink in digital press in context to the colour consistency (Delta E) on coated and uncoated paper substrates.
A coloured image is created using four different inks like cyan, magenta, yellow, and black. It is produced by printing each colour in the colour spectrum as a million tiny, overlapping dots. The two primary ingredients of the ink are pigment and vehicles (Spiridonov et al., 2022).A typical dry xerographic toner consists of plastic particles (usually styrene-acrylic copolymers) that are roughly 10–15 μm in size, dyed black with 5–10% sub micrometre carbon black particles, or tinted with cyan, magenta, or yellow colorants (for the colour processes covered later). Following the fusing process, the plastic's purpose is to adhere to the paper physically (Vincett & Sahyun, 2003).
Fluorescent ink has specific pigments; these pigments absorb ultraviolet light and re-emit it into the visible spectrum (Yosuke, 2008). In the visible spectrum, the fluorescent ink gamut expanded as compared to process ink. Fluorescent ink is not fully transparent (Sousa Ribeiro et al., 2020). They have weaker colour strength as compared to process ink. The reflectance angle of fluorescent inks is higher than that of process ink (Song et al., 2018).

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There are two types of paper used; coated and uncoated paper. Coated paper has more smoothness as compared to uncoated paper, so its light reflectance capacity is high as compared to uncoated paper. Printing substrate characteristics include its porosity, surface roughness, and optical properties. The qualities of paper have an impact on how well colour prints reproduce (Yang et al., 2019). Paper's excellent quality is one of its main features; its capacity for absorption is printing. The biggest factor affecting print quality is the paper surface roughness (Morovic et al., 2019). A smooth surface facilitates good ink transfer on paper, and vice versa. Rough surfaces have more irregularities, which makes it harder for the ink to adhere to them (Abdelhameed et al.,2021).

An increase in surface smoothness causes the print density to rise. Whiteness, brightness, and opacity are three crucial aspects of optical paper that also affect print quality. Although pulp bleaching, adding fillers and fluorescent whitening agents (FWA) to the paper, and paper coating are employed to improve optical qualities, it has been established that residual lignin is the primary factor affecting the whiteness of paper (Bhagya et al., n.d,2022). Higher values of whiteness and gloss increase the colour gamut, and higher roughness values harm print reproduction. (Tyagi & NexPress Solutions,2003). Brightness, opacity, basic weight, gloss, roughness, and density had the biggest effects on print quality. It was discovered that a higher opacity value enhanced print quality. Paper properties affect the colour gamut (Sardjeva&Mollov, 2014).

CIELAB, also known as CIE L*a*b*, is a 3D colour space independent of hardware and allows precise measurement and comparison of any colour that can be perceived using three colour values (Promis et al., 2022). In this colour space, the numerical differences between values frequently reflect the range of colour diversity experienced by humans (Tse et al.1995).

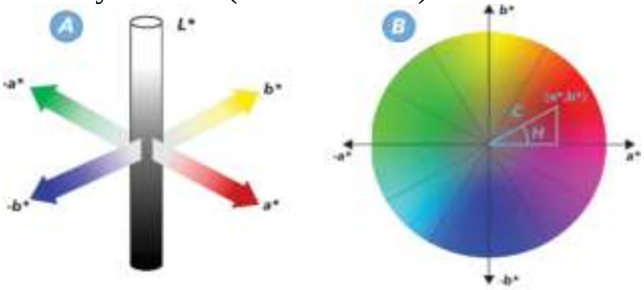

Figure 1: Cross-modal correspondence between vibrations and colours
- Scientific Figure on Research Gate (Delazio et al., 2017).

The L*a*b* colour model was developed in 1976 by the International Commission on Illumination (CIE) as a suitable standard for colour combination (Muthamma et al., 2020). The letters L*, a*, and b* stand for each of the three values that the CIELAB colour space uses to assess objective colour and identify colour discrepancies (Bhagya et al., n.d.2022).While L* indicates brightness on a range from zero to 100 from black to white, a* and b* represent chromaticity with no specific numerical constraints. Negative a* is correlated with green whereas positive a* connects with red; positive b* with yellow, and negative b* with blue (Abouzeid, 2013).

The CIELAB colour space calculates a colour's L*, a*, and b* values in order to represent its position on a chart that has an infinite variety of colours, including colours that are not present in the visible light spectrum (Boora & Baral, 2022).By utilizing the numbers on the L*a*b* chart, and then compute the Delta (Δ), a measurement of the variation in colour(Tanaka, 2020). To calculate L*, for instance, take the sample's L* value and subtract it from the reference colour's L* value (Sardjeva& MOLLOV, 2013).

Delta E values are used to quantify the variation between the colour that is displayed and the original colour standard of the input data. Lower delta E values suggest greater precision, while higher delta E values indicate a significant mismatch. Delta E, or the total colour difference, is computed using the delta L*, delta a*, and delta b* colour values, which collectively provide a thorough numerical descriptor of the colour in a rectangular coordinate system (Singh, 2022).

$$\Delta E_{ab}^{*} = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2} \quad \text{(i)}$$

The equation represents the mathematical formula for the calculation of delta E. (Sardjeva&Mollow,2014).

The brightness variation between the standard colour and the sample is represented by the delta L. Delta a* the symbol delta a* represents the difference in redness or greenness between the sample and standard colours. Variations in blueness and yellowness between the reference and sample colours are represented by delta b*represent (Chen & Yang, 1994,Sonmez et al., 2022).

II. Research Problem

Every colour has a specific colour value. These colour values are measured in L*a*b* measuring system. The deviation in the L*a*b* values to the print standard values is measured by Delta E. It is also representing the consistency of the colour. Paper substrates also have a significant impact on final print quality. There is a need to explore the colour consistency of process ink tonner and fluorescent inks on different types of paper substrates.

III. Objective of the Study

The main aim of this study is
1. To find out the commonly used paper substrates in digital electrophotography printing press.
2. To compare the Delta E values of process ink and fluorescent ink on coated and uncoated paper.

IV. Research Methodology

A test chart was created using desktop publishing software including the measuring elements of L*a*b* as per the print standard. The test chart was printed with digital printing machine. The Xerox® Colour 800/1000 presses were utilized under standard print condition. The target temperature and humidity were set at 23°C (73.4°F) and 50% relative humidity. Ambient dust levels of less than 0.10 mg/m3. The process (C, M, Y, K) and the two types of fluorescent inks (fluorescent pink, fluorescent orange) were used in machine for standard printing on 100 g/m2 coated art paper and 100 g/m2 uncoated art paper. The related paper testing was done in the laboratory and the value of related paper properties has shown in table 1.

Table 1: Properties of coated and uncoated paper

Sr. No.	Parameter	Unit	Coated art paper	Uncoated paper
1	Basis Weight (Gramm age)	g/m^2	100	100
2	Tensile Strength	KN/m	1.5	1.3
3	Bursting strength	Kg/cm^2	2.6	2.4
4	Brightness	%	84	80
5	Gloss	%	72	25

A spectrophotometer (X-Rite eXact) was used to measure L*a*b* values and finally calculated ΔE according to the equation (i) mentioned previously. The collected data was interpreted and represented by various graphs for illustrating differences.

V. Data Collection & Analysis

The required data were collected using a spectrophotometer (X-Rite eXact) on the printed sheets. The measuring conditions shown in Table 2 of the spectrophotometer were: D50, Standard observer 2˚ and M1. After the collection of data, the data is analysed and pictorially presented using a suitable graph.

Table 2: Measuring conditions of Spectrophotometer

Measurement Conditions	
Filter	M1

Standard observer angle	2 °
Illuminate	D50

The L*a*b* values of cyan- (L*62, a*-44, b*-50); magenta- (L*52, a*80, b*-8); yellow- (L*95, a*-7, b*95); black- (L*12, a*2, b*0); fluorescent pink (L*57, a*83, b*-5); fluorescent orange (L*82, a*13, b*81) as shown in table 3.

Table 3: ISO values of L*a*b* for inks for reference

INK	L*	a*	b*
Cyan	62	-44	-50
Magenta	52	80	-8
Yellow	95	-7	95
Black	12	2	0
Fluorescent Pink	57	83	-5
Fluorescent Orange	82	13	81

Table 3: ΔE Average comparison between coated art paper and uncoated paper

ΔE						
	Cyan	**Magenta**	**Yellow**	**Black**	**Fluorescent Pink**	**Fluorescent Orange**
Coated Art paper	13.69	9.17	12.77	7.93	23.29	49.02
Uncoated paper	16.18	10.75	13.81	6.18	25.43	47.22

The ΔE average comparison between coated art paper and uncoated paper, cyan colour of coated art paper was 13.69, magenta colour of coated art paper was 9.17, yellow colour of coated art paper was 12.77, and black colour of uncoated paper was 7.93, fluorescent pink colour of coated art paper was 23.29, fluorescent orange colour of uncoated paper was 49.02. All these colour value show the best results of ΔE average comparison between coated art paper and uncoated paper.

ΔE

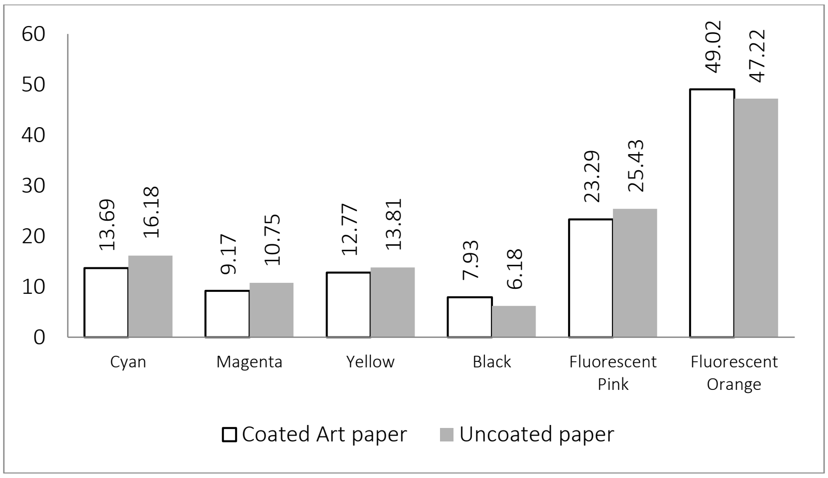

Figure 2: Analysis of ΔE on coated art paper and uncoated paper

The average of ΔE on uncoated paper,cyancolour was 16.19, magenta colour was 10.75, yellow colour was 13.81, and black colour was 6.19, fluorescent pink colour was 25.43, fluorescent orange colour was 47.23, respectively.

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VI. Result & Discussion

In this research work, the ΔE value of process ink and fluorescent ink was compared on coated and uncoated paper printed by an electrophotography digital printing press. According to figure 2, the ΔE value of cyan ink has shown lower value on coated paper, whereas it has shown a higher value on uncoated paper. It means, an improvement in the cyan ink is required. According to figure 2, the ΔE value for magenta and yellow ink has shown lower value on coated paper whereas, higher value on uncoated paper.
The black ink has shown higher value of ΔE on coated paper, whereas, it has shown lower value on uncoated paper. In the process ink, black ink has shown lower value of ΔE compared to cyan, magenta and yellow. The cyan has shown higher value of ΔE amongst the process inks. When compared value of ΔE for fluorescent ink, fluorescent pink has shown lower value of ΔE as compare to uncoated paper whereas, fluorescent orange has shown higher value of ΔE on coated paper and lower value on uncoated paper. Although, the ΔE value for fluorescent ink is high in comparison to process ink, it may be due to the fluorescent effect of the toner. Fluorescent inks shows higher value of ΔE in comparison to the process ink. The optical properties of paper has significant influence of colour consistency of process ink and fluorescent ink. According to table 1, the gloss value of coated paper is 72 % which is higher than the uncoated paper. Therefore, the gloss value of paper significantly impact the fluorescent effect of the fluorescent ink.

VII. Conclusion

This research work compared the ΔE values of process ink and fluorescent ink on coated and uncoated paper using an electrophotography digital printing press. The result has shown that cyan ink has a lower ΔE value on coated paper, resulting the need for improvement. Magenta and yellow inks also show lower ΔE values on coated paper, while black ink has a lowest ΔE value. Cyan ink has a higher ΔE value among process inks. Fluorescent inks, such as pink and orange, have lower ΔE values on coated paper, while orange has a higher ΔE value. Over all the fluorescent ink has high value of ΔE. The high ΔE value of fluorescent ink may be due to the toner's fluorescent effect. The optical properties of paper significantly influence colour consistency, with coated paper having a higher gloss value than uncoated paper. Therefore, the gloss value of paper significantly impacts the fluorescent effect of the fluorescent ink.

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