Section: Research Paper

Evaluation of Print Consistency contemplating Colour differences (ΔE Value) and Ink Trapping on Matt Paper using different Digital Printing Methodologies

Vikas Jangra[1], Prof. Ambrish Pandey[2], Prof. Rajendrakumar Anayath[3]

[1] PhD Scholar, Assistant Professor, Department of Printing Technology, Guru Jambheshwar University of Science & Technology, Hissar - 125001 (Haryana) INDIA

[2] Supervisor, Professor, Department of Printing Technology, Guru Jambheshwar University of Science & Technology Hissar - 125001 (Haryana) INDIA

[3] Co-Supervisor, Vice-Chancellor, DCRUST, Murthal (Haryana) INDIA

[1] vjangragju@gmail.com, [2] ambrishpandey12@yahoo.co.in, [3] profanayath@gmail.com

Corresponding Author: Vikas Jangra

ABSTRACT: Numerous factors are considered while evaluating the print consistency. Colour differences (ΔE Value) and Ink Trapping are crucial parameters amongst them. Evaluating these parameters is of prime significance. Colour differences i.e. ΔE Value describes the levels of mismatch between two hues. On the other hand, ink trapping provides the indication of grade of ability of printed ink to accept the next subsequent ink compared to how well paper accepts that ink. It becomes mandatory to comprehend behaviour of both these technical aspects for print consistency. The main objective of this research paper is to evaluate print consistency in terms of colour differences (ΔE Value) and ink trapping using different digital printing methodologies on matt paper.

Keywords: Digital Printing, Colour Difference, ΔE Value, Ink Trapping, Matt Paper

Introduction

Digital methodologies for printing are known for their versatility and flexibility offering various advantages over the conventional printing methodologies. These methodologies offer direct printing of image, text, illustration and their combinations on large variety of substrates by eliminating numerous intermediate steps used in conventional methodologies. No master preparation is required for digital printing methodologies. Digitized information is directly printed on the substrate by application of imaging unit. Digital printing methodologies consists of complete cycle for one impression (printing) with imaging process, inking process, toner transferring (printing), toner fixing process and cleaning process as numerous sequential steps as shown in functional components.

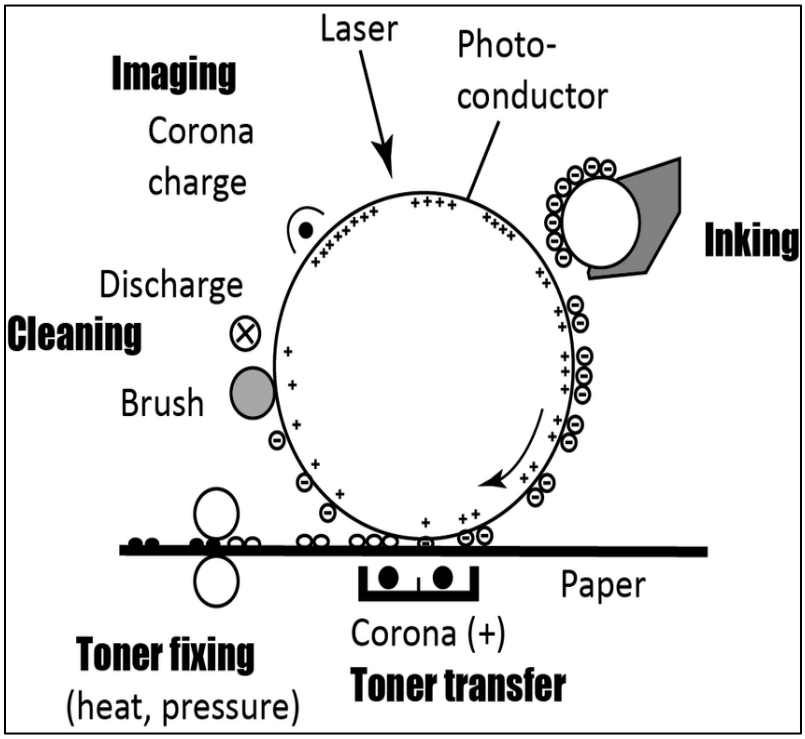

*Figure 1: Digital Printing Methodology Process Functional Components (*Nguyen et al., 2021)

Colour differences exhibited by any printing methodology are represented in terms of ΔE Value. Delta E (ΔE) measurement plays a crucial role while evaluating the colour accuracy during printing. Delta E is a standard measurement process which is used to quantify the difference between two colour appear on printed or digital screen. This approach of finding colour differences was developed by CIE i.e. Commission Internationale de I'Eclairage which is an International Commission on Illumination using CIE Lab Colour Model.

CIE L*a*b* Colour Space: It (also known as CIELAB Colour model) was developed in 1976 by CIE, which is a uniform colour space used for the applications based on subtractive mixing of colour in printing industry. In this colour space, three dimensions are represented by 'L', 'a' and 'b'- axis with the following descriptions:

- **L-axis**: L ranges from 0 to 100. (L=0 represents Black; L=100 represents White)
- **a-axis (Red-Green axis):** It ranges from -100 to +100. Red (+a)-Green (-a) axis.
- **b-axis (Yellow-Blue axis)**: It ranges from -100 to +100. Yellow (+b)-Blue (-b) axis.

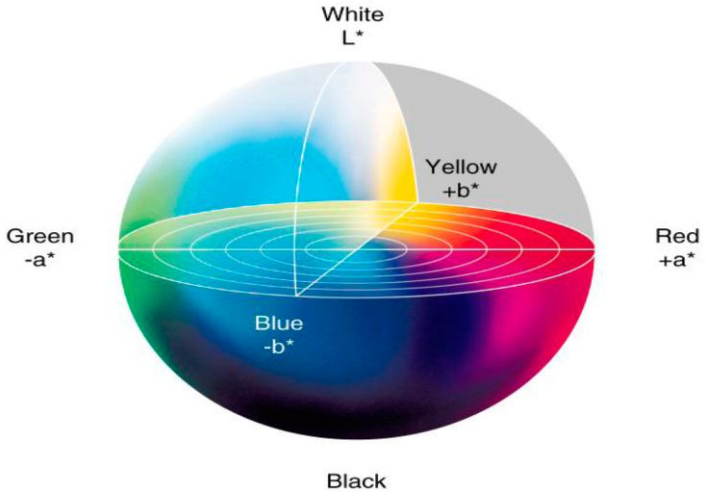

*Figure 2: CIE L*a*b* Colour Model (Image courtesy:www.mdpi.com)*

Delta E: Delta E (ΔE: Colour difference) is based on ΔL, Δa and Δb colour values where:

- ΔL represents Lightness difference between printed sample and standard colour.
- Δa represents redness to greenness (Red-Green axis) difference between printed sample and standard colour.
- Δb represents yellowness to blueness (Yellow-Blue axis) difference between printed sample and standard colour.

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

ΔE Equation (Courtesy of http://zschuessler.github.io/DeltaE/learn/)

Value of delta E ranges from 0 (less colour difference) to 100 (complete distortion). Lower value of ΔE indicates greater accuracy while on the other hand higher ΔE indicates significant mismatch.

Ink Trapping: Ink trapping describes the ability or inability to accept the second ink transferred on the top of already printed first ink while printing process colour. The credit of devising ink trapping formula was crowned to Frank Preucil in 1953. Ink trapping or apparent trap is determined by using Preucil equation expressed as:

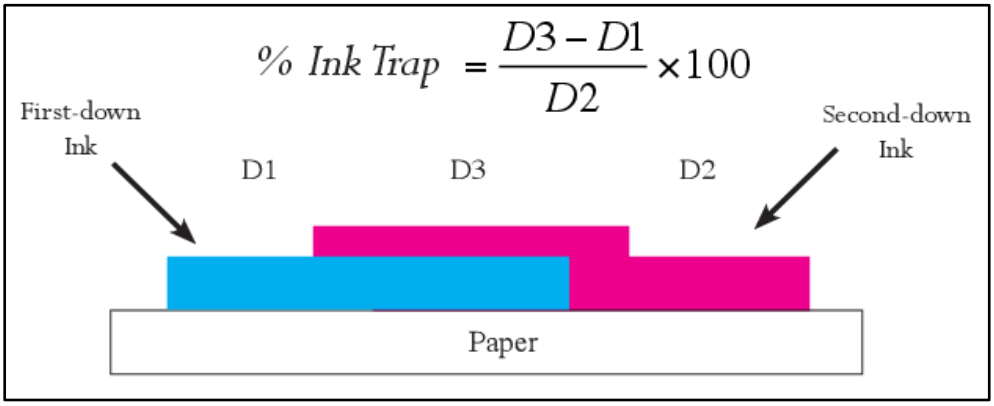

Figure 3: Ink Trapping (Chung, 2008)

Here C+M is overprinted where first ink laydown is cyan and subsequent ink laydown is magenta colour as depicted in figure 3. The meaning is D1, D2 and D3 are enlisted as below:

a. D1: First ink laydown (Cyan colour printing) minus paper density
b. D2: Second/subsequent ink laydown (magenta colour printing) minus paper density
c. D3: C+M overprint minus paper density

Apparent trap or ink trapping provides quantitatively the interaction of two process colour during printing. In the other words value of ink trapping varies, the hue of the overprint is also likely to change.

Research Objective of Study

Main objective of research work is to evaluate print consistency in terms of colour differences i.e. ΔE value and ink trapping exhibited by different digital printing methodologies on matt paper media.

Material and Methodology

For carrying out the study of Colour differences (ΔE Value) and Ink Trapping using various Digital Printing Methodologies, first and foremost a Test (Master) Chart was developed consisting of technical parameter as per printing standard. The flowchart for executing the research process is as below:

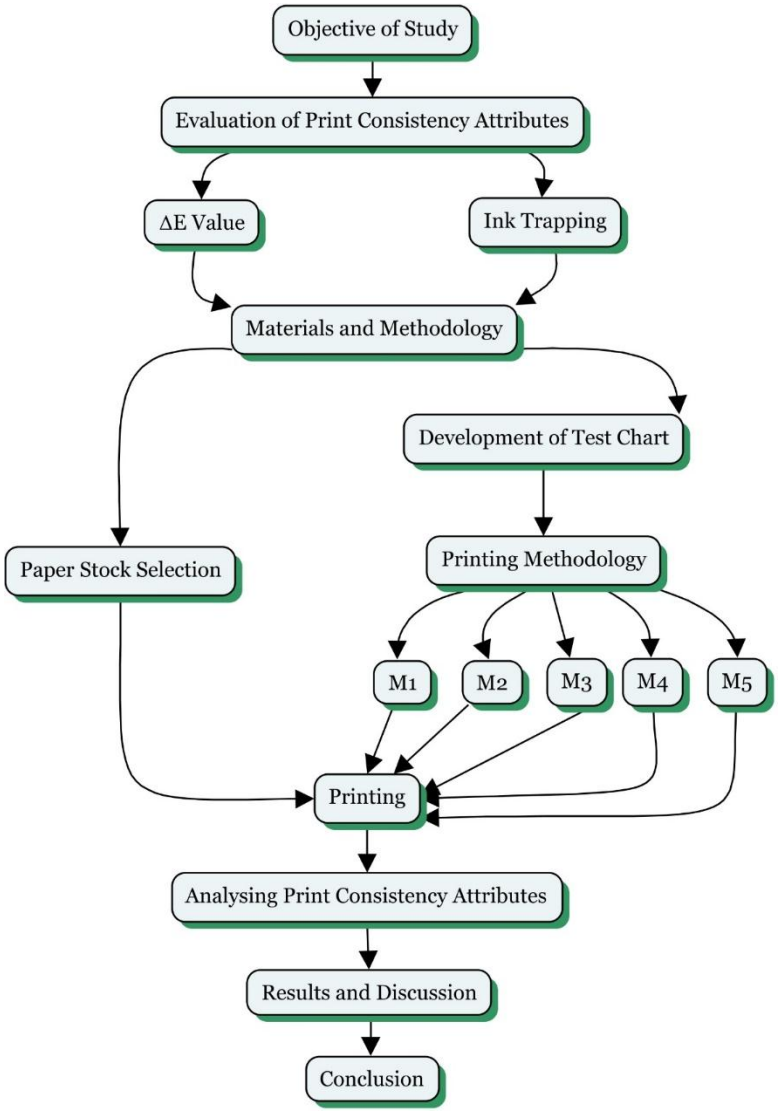

Figure 4: Research Methodology flow chart

During study, numerous digital printing methodologies were used which included M1: HP Indigo, M2: Canon, M3: Xeikon, M4: Konica Minolta and M5: Xerox for printing on Matt Paper under standard printing conditions. Each and every digital printing methodology was calibrated before printing on matt paper substrate. In order to measure Colour differences (ΔE Value) and Ink Trapping x-Rite i1 Pro Spectro-densitometer was used. After proper calibration of Spectro-densitometer, the colour differences (ΔE Values for Cyan, Magenta, Yellow, Black, Red, Green and Blue) and ink trapping (Red, Green and Blue colour) were recorded under standard viewing conditions and analyzed.

Data Analysis

The data was collected for analyzing the colour differences (ΔE Values) and Ink Trapping for various colour whose finding are presented as:

1. **ΔE Value i.e. Colour differences:** To study colour difference using numerous digital printing methodology on Matt paper substrate, namely KM (Konica Minolta), Xerox, HP (Indigo), Canon and Xeikon digital printing methodologies were taken into consideration whose results are presented as below:

   i. **Cyan (ΔE Value) Colour difference:** The observations of ΔE Value of cyan colour on Matt paper substrate using five different methodologies are depicted in figure 5. The ranges of ΔE values of Cyan colour were observed in between 2.67 to 4.02; 5.21 to 6.60; 13.71 to 18.71; 12.64 to 14.15 and 6.64 to 8.23 in HP Indigo, Canon, Xeikon, Konica Minolta and Xerox methodologies respectively. HP Indigo methodology exhibited the minimum range (2.67 to 4.02) while Xeikon methodology exhibited maximum range (13.71 to 18.71) followed by Konica Minolta i.e. 12.64 to 14.15, ΔE values of cyan colour on matt paper substrate. The minimum variations were observed in the ΔE values of cyan colour in case of Canon methodology, while maximum deviations were observed in case of Xeicon methodology.

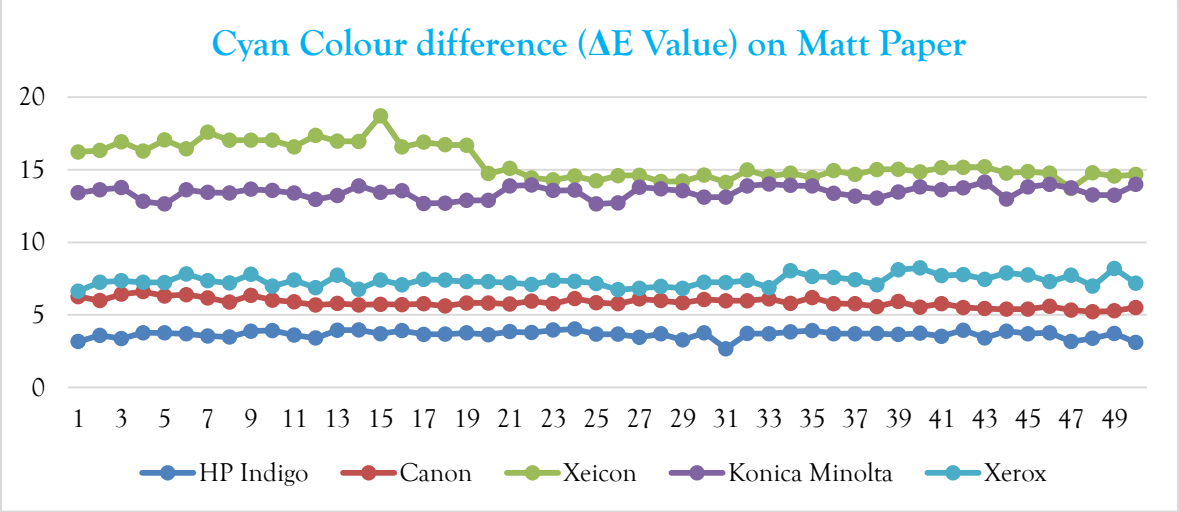

Figure 5: Cyan (ΔE Value) Colour difference

   ii. **Magenta (ΔE Value) Colour difference:** Figure 6 depicts the results of magenta colour ΔE values on Matt paper substrate using five different methodologies. Magenta colour ΔE values ranged 6.83 to 7.96; 3.50 to 4.88; 22.02 to 25.73; 6.35 to 8.78 and 7.82 to 11.56 while using HP Indigo, Canon, Xeikon, Konica Minolta and Xerox methodology respectively. The ΔE values vary linearly in case of

Canon methodology means variation during printing was very low. Minimum range i.e. 3.50 to 4.88 of magenta colour ΔE values were exhibited by Canon methodology and on the other hand Xeikon exhibited maximum range i.e. 22.02 to 25.73 of ΔE values of magenta colour on matt paper substrate. It was also observed from the graph that ΔE values of Konica Minolta and Xerox methodology were coincided on many points as shown in figure 6.

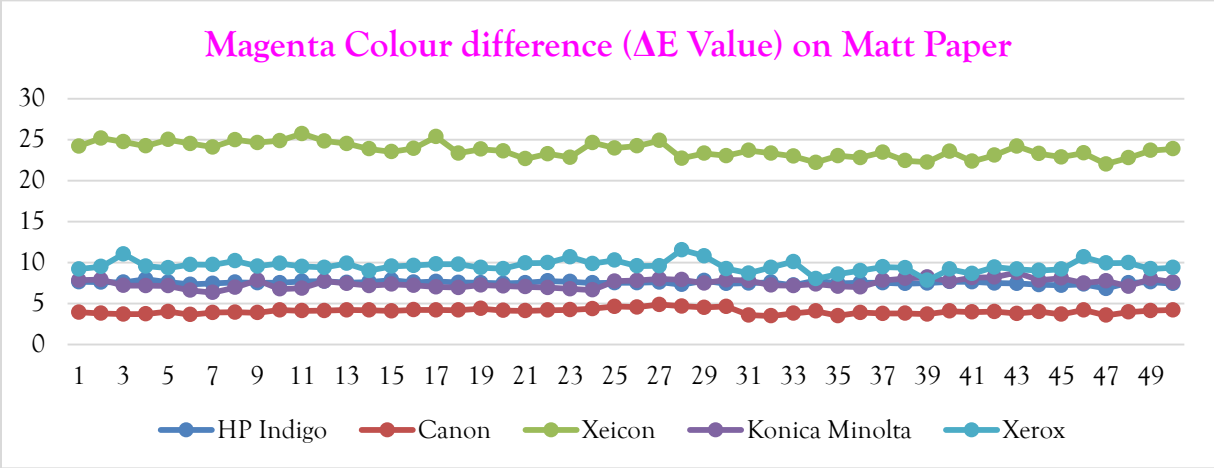

Figure 6: Magenta (ΔE Value) Colour difference

iii. **Yellow (ΔE Value) Colour difference:** Five different methodologies exhibited the results for ΔE values of yellow colour are depicted in figure 7. The ΔE values for yellow colour ranged 13.81 to 15.21; 3.58 to 5.10; 16.53 to 19.93; 5.92 to 10.51 and 4.75 to 6.53 for HP Indigo, Canon, Xeikon, Konica Minolta and Xerox methodology respectively. Canon methodology exhibited the lowest range of ΔE values i.e. 3.58 to 5.10 while Xeikon methodology exhibited the highest range (16.53 to 19.93) followed by HP Indigo i.e. 13.81 to 15.21, ΔE values of yellow colour on matt paper substrate. The behaviour of ΔE values of yellow colour by Konica Minolta methodology was haphazard in nature and in contrast, HP Indigo and Canon methodology trend was linear as shown in figure 7.

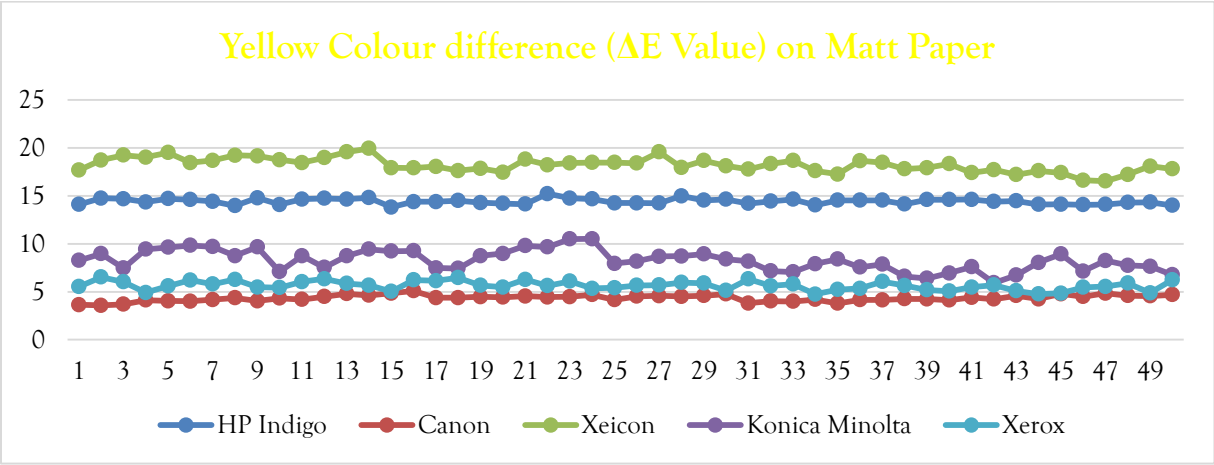

Figure 7: Yellow (ΔE Value) Colour difference

iv. **Black (ΔE Value) Colour difference:** The ΔE values of black colour using five different methodologies are depicted in figure 8 which revealed that the ranges of HP Indigo, Canon, Xeikon, Konica Minolta and Xerox methodologies were remained in between 2.03 to 3.75; 5.38 to 8.81; 12.21 to 16.27; 0.55 to 3.78 and 2.78 to 4.56 respectively. It was also observed that Konica Minolta methodology exhibited the lowest ranges for ΔE values i.e. 0.55 to 3.78; while Xeikon methodology exhibited the highest i.e. 12.21 to 16.27 followed by Canon i.e. 5.38 to 8.81. The behaviour of ΔE values of black colour in Xeikon methodology was found inconsistent due to deviations while printing on matt paper substrate (figure 8).

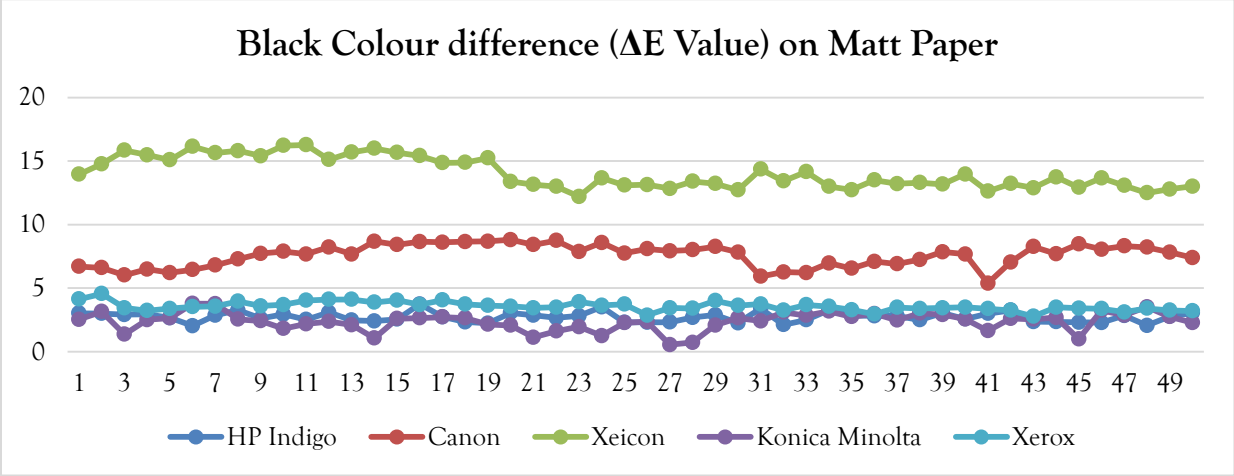

Figure 8: Black (ΔE Value) Colour difference

v. **Red (ΔE Value) Colour difference:** The results of ΔE values of red colour on Matt paper substrate using five different methodologies are depicted in figure 9 which revealed that the range was found 4.06 to 5.7; 2.91 to 5.73; 21.14 to 25.77; 2.59 to 4.30 and 4.16 to 6.27 while using HP Indigo, Canon, Xeikon, Konica Minolta and Xerox methodology respectively. The lowest range of ΔE values of red colour was exhibited by Konica Minolta methodology i.e. 2.59 to 4.30; on the other hand, Xeikon methodology exhibited the highest range i.e. 21.14 to 25.77 followed by Xerox which exhibited ΔE values range 4.16 to 6.27 while printing on matt paper substrate. It was also observed from the graph that ΔE values of HP Indigo and Xerox methodology were coincided on many points (figure 9).

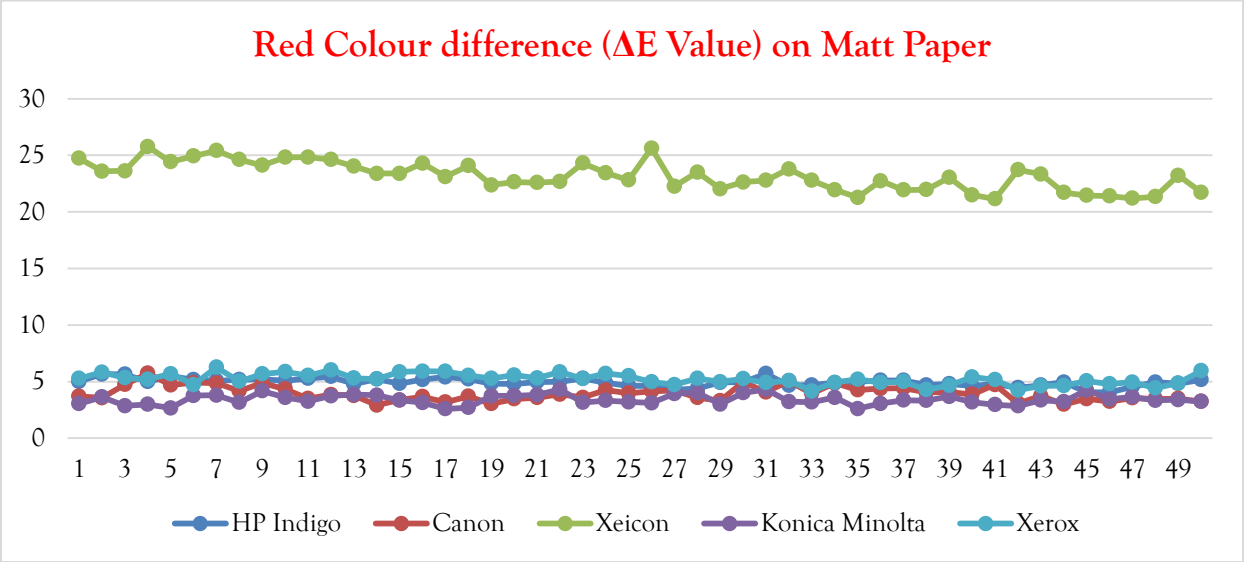

Figure 9: Red (ΔE Value) Colour difference

vi. **Green (ΔE Value) Colour difference:** Observations of ΔE value of green colour using five different methodologies are depicted in figure 10. The range exhibited by green colour ΔE value by different HP Indigo, Canon, Xeikon, Konica Minolta and Xerox methodology were found in the limit 6.57 to 8.62; 11.1 to 14.18; 18.36 to 22.43; 11.02 to 13.43 and 6.11 to 8.59 respectively. During observation it was found that Xerox methodology exhibited the lowest ranges (6.11 to 8.59) while it was found the highest i.e. 18.36 to 22.43 for Xeikon methodology followed by Canon having range 11.1 to 14.18 for ΔE values of green on Matt paper substrate.

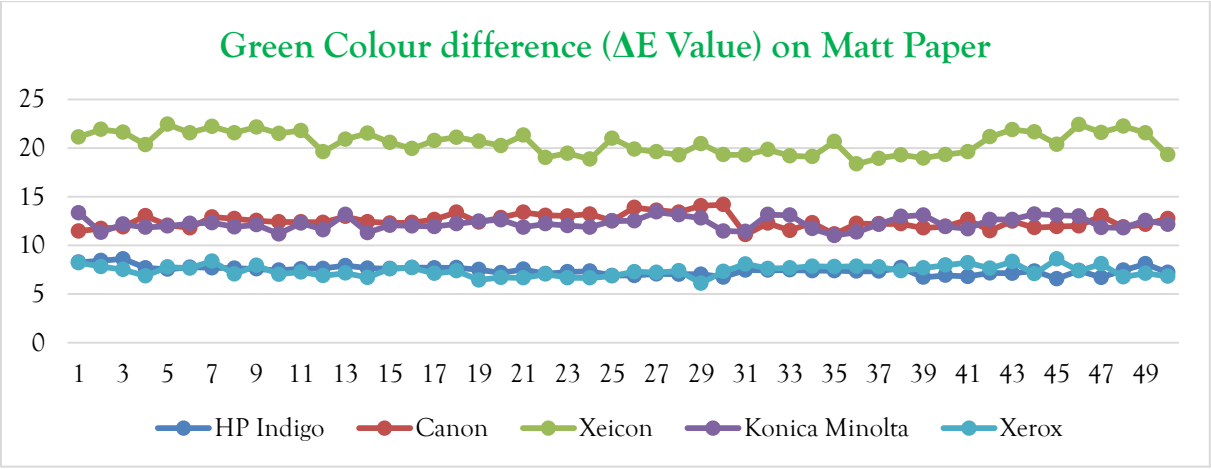

Figure 10: Green (ΔE Value) Colour difference

vii. **Blue (ΔE Value) Colour difference:** Five different methodologies exhibited the results for ΔE values of blue colour are depicted in figure 11. The ΔE values for blue colour ranged 3.55 to 5.92; 5.6 to 8.66; 15.07 to 18.35; 4.43 to 6.03 and 6.04

to 8.42 for HP Indigo, Canon, Xeikon, Konica Minolta and Xerox methodology respectively. HP Indigo methodology exhibited the lowest range of ΔE values i.e. 3.55 to 5.92 while Xeikon methodology exhibited the highest range (15.07 to 18.35) followed by Xerox i.e. 6.04 to 8.42, ΔE values of blue colour on matt paper substrate.

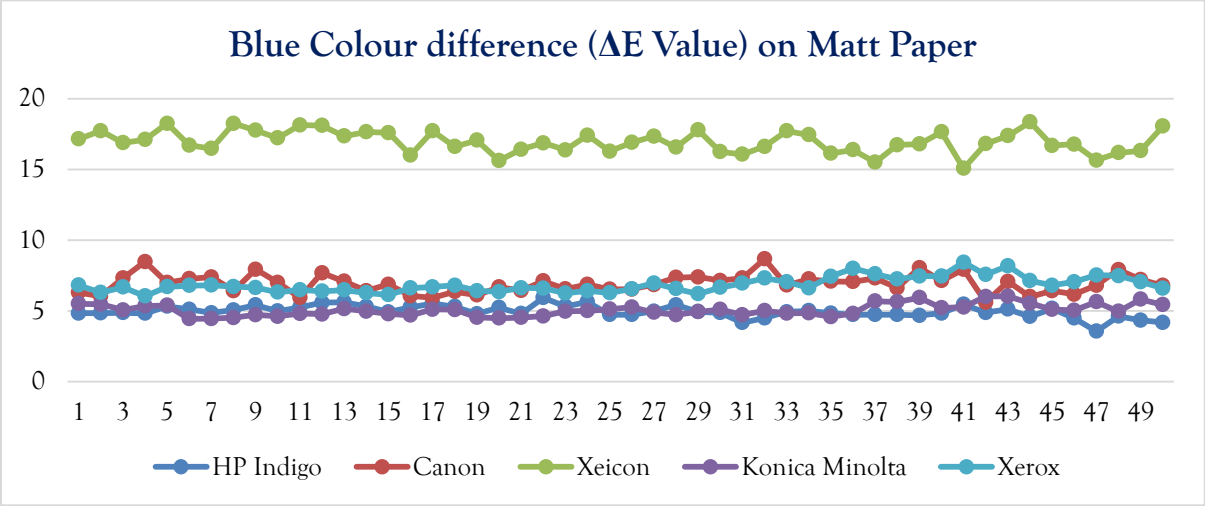

Figure 11: Blue (ΔE Value) Colour difference

2. **Ink Trapping:** Ink trapping value for red, green and blue colour on matt paper using M1: HP Indigo, M2: Canon, M3: Xeikon, M4: Konica Minolta and M5: Xerox printing methodologies are presented as:
   i. **Ink Trapping for Red Colour:** The results of red colour overprint on matt paper substrate using five different methodologies are depicted in figure 12. Overprint of red colour ranges 87% to 90%, 84% to 87%, 75% to 80%, 86% to 91% and 87% to 91% while using HP Indigo, Canon, Xeikon, Konica Minolta and Xerox methodology respectively. The minimum range (75% to 80%) of red colour overprint was exhibited by Xiecon methodology, on the other hand Konica Minolta and Xerox methodology exhibited maximum range (86% to 91%) while printing on matt paper substrate.

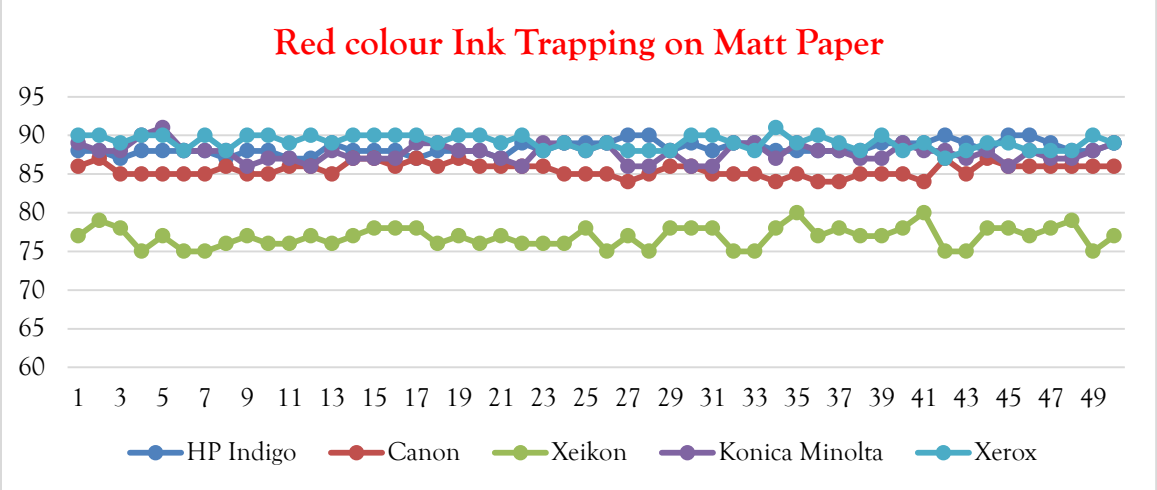

Figure 12: Ink Trapping (Red Colour)

ii. **Ink Trapping for Green Colour:** Figure 13 depicts the results of overprint green colour on matt paper substrate using five different methodologies. Ink trapping for green colour ranges 93% to 96%, 87% to 89%, 85% to 88%, 95% to98% and 92% to 94% while using HP Indigo, Canon, Xeikon, Konica Minolta and Xerox methodology respectively. Minimum range of green colour overprint was exhibited by Xeikon methodology and on the other hand Konica Minolta exhibited maximum range of green colour overprint on matt paper substrate.

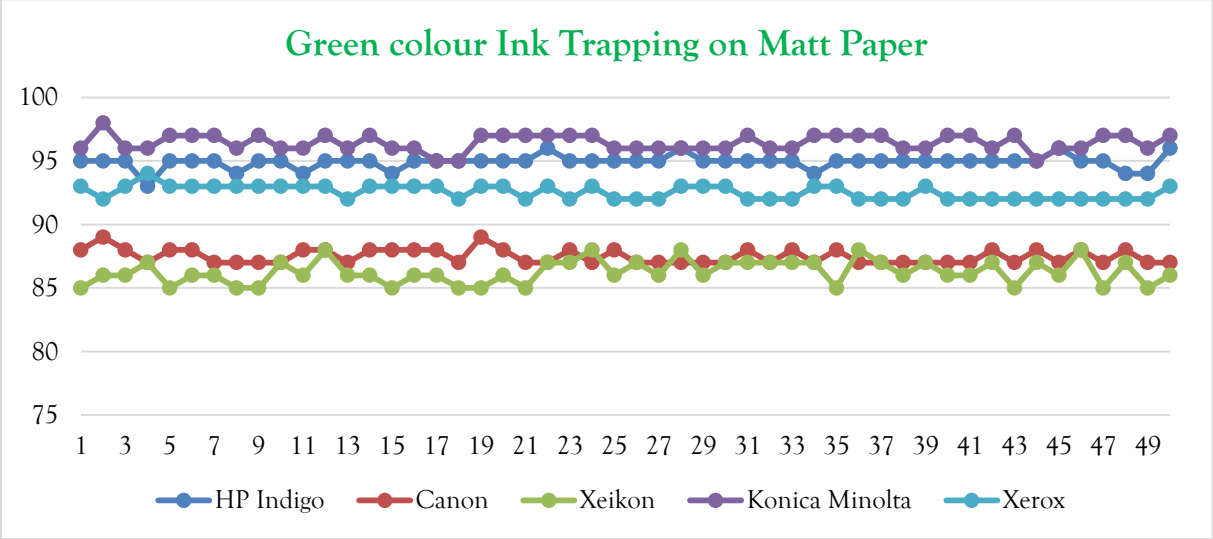

Figure 13: Green colour Ink Trapping on Matt Paper

iii. **Ink Trapping for Blue Colour:** Observations of blue colour overprint using five different methodologies are depicted in figure 14. Blue colour overprint range exhibited by different HP Indigo, Canon, Xeikon, Konica Minolta and Xerox methodology were found in the range 95% to 96%, 85% to 88%, 89% to 93%,

89% to 91% and 88% to 91% respectively. During observation it was found Canon methodology exhibited lowest ranges (85% to 88%) for blue overprint. Moreover, the value of blue overprint range was found maximum (95% to 96%) for HP Indigo methodology on matt paper substrate.

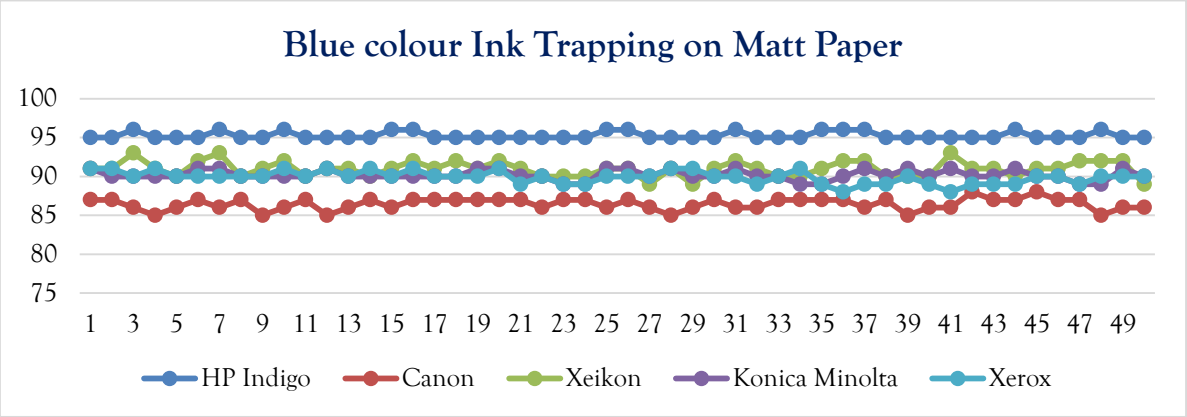

Figure 14: Blue colour Ink Trapping on Matt Paper

Results and Discussion

Information collected during the research was evaluated in order to conclude. During study it was observed that the values of Colour differences (ΔE Value) and Ink Trapping exhibited by various digital printing methodology (M1: HP Indigo, M2: Canon, M3: Xeikon, M4: Konica Minolta and M5: Xerox) on matt paper substrate were not only reiterated many times, but also as per the acceptable range in context to print quality. An outline of the value of Colour differences (ΔE Value) and Ink Trapping is tabulated in table 1 and 2 respectively.

ΔE Value		HP Indigo	Canon	Xeikon	Konica Minolta	Xerox
Cyan	*Mini.*	2.67	5.21	13.71	12.64	6.64
	Max.	4.02	6.60	18.71	14.15	8.23
Magenta	*Mini.*	6.83	3.50	22.02	6.35	7.82
	Max.	7.96	4.88	25.73	8.78	11.56
Yellow	*Mini.*	13.81	3.58	16.53	5.92	4.75
	Max.	15.21	5.10	19.93	10.51	6.53
Black	*Mini.*	2.03	5.38	12.21	0.55	2.78
	Max.	3.75	8.81	16.27	3.78	4.56
Red	*Mini.*	4.06	2.91	21.14	2.59	4.16
	Max.	5.7	5.73	25.77	4.30	6.27
Green	*Mini.*	6.57	11.1	18.36	11.02	6.11

	Max.	8.62	14.18	22.43	13.43	8.59
Blue	*Mini.*	3.55	5.6	15.07	4.43	6.04
	Max.	5.92	8.66	18.35	6.03	8.42

Table 1: ΔE Value on Matt Paper using different methodologies

Ink Trapping		**HP Indigo**	**Canon**	**Xeikon**	**Konica Minolta**	**Xerox**
Red	*Mini.*	87%	84%	75%	86%	87%
	Max.	90%	87%	80%	91%	91%
Green	*Mini.*	93%	87%	85%	95%	92%
	Max.	96%	89%	88%	98%	94%
Blue	*Mini.*	95%	85%	89%	89%	88%
	Max.	96%	88%	93%	91%	91%

Table 2: Ink Trapping on Matt Paper using different methodologies

Conclusion

This research work has depicted the outline of the print consistency evaluation in terms of Colour differences (ΔE Value) and Ink Trapping exhibited by various digital printing methodology (M1: HP Indigo, M2: Canon, M3: Xeikon, M4: Konica Minolta and M5: Xerox) on matt paper substrate. As per the results of aforesaid research study, it was noticed that the values of Colour differences (ΔE Value) and Ink Trapping were in relation to the printing standards. The collected information may be explained from two distinct perspectives. The first approach is to assess colour variation produced by various digital print methodologies. Another method is to compare different digital printing methodologies for individual colour.

i. **Colour differences (ΔE Value):** First approach outlined that Canon exhibited lowest ΔE Value for red colour while other remaining (HP indigo, Xeikon, Konica Minolta and Xerox) digital methodologies exhibited lowest ΔE Value for black colour. On the other hand, while using another approach i.e. to compare different digital printing methodologies for individual colour, the lowest exhibited ΔE Value was found in case of HP indigo for Cyan and Blue, Canon for Magenta and Yellow, Xerox for Green and Konica Minolta for Black and Red colour.

ii. **Ink Trapping:** While assessing ink trapping exhibited by various methodologies it was observed that HP indigo exhibited highest Ink trapping for Green and Blue while Canon, Konica Minolta and Xerox for Green and Xeikon for Blue colour. In

contrast to this using another approach revealed that Konica Minolta exhibited highest ink trapping for Red and Green while HP Indigo for Blue colour.

References

1. Jangra, V., Pandey, A., & Anayath, R. Analysing Ink Density behaviour on Matt Paper using different Digital Printing Methodologies.
2. Wu, Y. J., Fleming, P. D., & Pekarovicova, A. (2007, January). Color matching capability of digital printers. In NIP & Digital Fabrication Conference (Vol. 2007, No. 1, pp. 414-418). Society for Imaging Science and Technology.
3. Sharma, A., & Rong, X. (2014). Establishing standards for color and print quality in large format inkjet printing. Journal of Imaging Science and Technology, 58(3), 30504-1.
4. Jangra, V., Saini, A., & Kundu, A. (2014). Relationship of Solid Ink Density and Dot Gain in Digital Printing. International Journal of Engineering and Technical Research (IJETR), 2321-0869.
5. Livens, S., Mahy, M. F., & Vansteenkiste, D. (2001, December). How to ensure consistent color quality in inkjet proofing. In Color Imaging: Device-Independent Color, Color Hardcopy, and Applications VII (Vol. 4663, pp. 130-136). SPIE.
6. Tse, M. K., Forrest, D. J., & Briggs, J. C. (1998). Automated print quality analysis for digital printing technologies. PPIC/JH, 98, 15-17.
7. Dharavath, H. N. (2021). Statistical evaluation of a Color Managed Digital Printing Workflow (CMDPW) consistency [4th C of CMW]. Journal of Graphic Engineering and Design, 12(4), 17-31.
8. Kuo, Y. F., Yang, C. L., Chiu, G. T. C., Yih, Y., Allebach, J. P., & Abramsohn, D. A. (2011). Model-based calibration approach to improve tone consistency for color Electrophotography. Journal of Imaging Science and Technology, 55(6), 60505-1.
9. Li, Y., Zhang, X., Yang, L., Zhang, R., & Li, R. (2023). Study of color reproduction in pigment digital printing. Textile Research Journal, 00405175221147725.
10. Mr. Sanjeev Kumar*1, Ms. Monika2 & Mr. Amit Kumar3. (2019). Study of Ink Trapping in Different Dot Shapes of Halftone on Digital Press (Dry Toner Electrophotography). Global Journal of Engineering Science and Researches, 6(4), 255–257. https://doi.org/10.5281/zenodo.2650955
11. Dharavath, H. N., & Kokil, U. (2014). Effect of pre-defined Color Rendering Intents (CRI) on the Hue attributes in a Color Managed Workflow (CMW). The Journal of Technology Studies, 12-25.
12. Maohai, L. I. N., Shisheng, Z. H. O. U., & Fuqiang, C. H. U. (2009). Quality analysis in digital printing based on color management system. International Journal of Engineering and Technology, 1(2), 135.

13. Norberg, O. (2004). Achieving consistent colours in digital printing (Doctoral dissertation, Linköpings universitet).
14. Zhang, N., Ma, B., & Lan, W. (2006, August). Next generation color management process modeling for digital printing. In 2006 4th IEEE International Conference on Industrial Informatics (pp. 932-937). IEEE.
15. Elliot, M. W., & Cockburn, J. C. (2010, November). Print engine color management using customer image content. In 2010 Western New York Image Processing Workshop (pp. 38-41). IEEE.
16. Sardjeva, R., & MOLLOV, T. Digital Electrophotography with Improved Printed Color Quality. International Journal of Electronics and Communication Engineering, 2, 167-74.
17. Sardjeva, R., & Mollov, T. (2014). Study of Color Quality Uniformity in Digital Dry Toner Electro-Photographic Printing. International Journal of Modern Communication Technologies and Research, 2(9), 265765.
18. Safi, M., & Mola, F. (2017). Color Management: A Necessity for Reproduction of Digital Color Images. Journal of Studies in Color World, 7(1), 67-81.