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RESEARCH ARTICLE

Print consistency evaluation on uncoated paper using various digital print engines

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Abstract

Print quality is most exclusively aspect which is observed mostly and corelated to different printing attributes. Various attributes like print density, color difference (ΔE value) and overprint trap are some crucial aspects to evaluate print quality. Print density refers thickness of ink film applied on any media, color difference provides significant mismatch between targeted and printed while evaluating print quality and overprint trap is ability to accept subsequent layer of ink on already printed ink. This research emphasizes on study of print quality and evaluation in terms of print consistency on uncoated paper using various digital print engines.

Keywords: Print density, ΔE value, Overprint trap, Uncoated paper, Print engine.

Introduction

Various print engines from different brands are available in market in order to cater the needs of customers on day to day basis. Every digital print engine has its own unique technical characteristics and pigment combinations for imparting color printing on any substrate (Jangra *et al.,* 2023). Print quality is outcome of many technical parameters. So numerous factors including print density, color difference (ΔE Value) and overprint trap are some crucial aspects used to evaluate print quality using different digital print engines (Kumar *et al.,* 2018).

Ink density also termed as SID i.e. solid ink density is the ability of any printed image to absorb or transmit light (Jangra *et al.,* 2014). In the other words darker is the color printed, higher will be ink density and *vice-versa*. Generally, ink film thickness decides the ink density (Jangra, 2016). Reflection type spectrophotometer/densitometer is required for finding ink density on paper (opaque) substrate.

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Color difference is denoted using ΔE value in CIE L*a*b* Color Space developed in 1976 by CIE which is an International Commission on Illumination (Luo & Hunt, 1998). CIE acronym for Commission Internationale de'Eclairage. This color space was developed with an objective to quantify the color using three dimension which includes L (Black-White axis), a* (Green- Red axis) and b* (Blue-Yellow axis) (Robertson, 1990). In CIEL*a*b* color space each axis designates a particular color and accordingly provided precise location of particular color using coordinates in 3D space (Markovic *et al.,* 2013). The value on L axis ranges from 0 (denotes Black) to 1 (denotes White), a* ranges from -100 (denotes Green) to +100 (denotes Red) and b* ranges from -100 (denotes Blue) to +100 (denotes Yellow) for locating particular color in 3D space (Fairman *et al.,* 1997) as shown in Figure 1.

Color difference (Robertson, 1990) is calculated using colorimetric values (Equation 1) i.e. ΔL, Δa* and Δb* which represents difference (Fairman *et al.,* 1997) between standard color and printed color in three dimensional CIEL*a*b* color space. Lower is color difference higher is the accuracy and higher value represents more mismatch (Yang, 2017).

Overprint trap (Nguyen & Van Huy, 2022) is used to define ability for accepting the subsequent (second) ink layer on the top of already printed layer during printing of process color. Ink trapping or apparent trap is found using Preucil equation (Chung & Hsu, 2008) which was derived by Frank Preucil in 1953 and equation is as below:

Precuil equation comprises of three ink densities as shown in Figure 2. Density of first ink laydown (D1) is cyan, subsequent ink laydown (D2) is magenta and overprint trap or apparent trap is C+M denoted by D3. Here D1; D2 and D3

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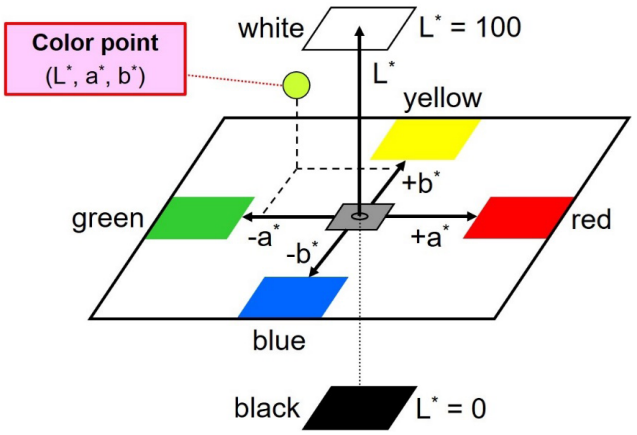

Figure 1: CIE L*a*b* color model (Image courtesy: https://www.ulprospector.com)

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

Equation 1: ΔE equation (courtesy of http://zschuessler.github.io/deltaE/learn/)

$$\%\ Ink\ Trap = \frac{D3 - D1}{D2} \times 100$$

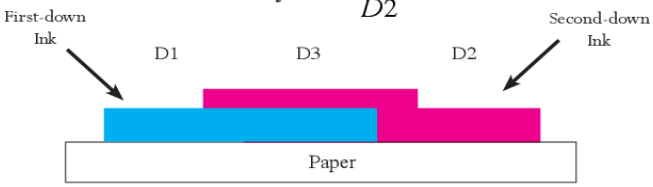

Figure 2: Ink trapping (chung, 2008)

are densities of ink only means paper density is subtracted from all these three densities (Kumar *et al.,* 2018). Apparent trap describes how much interaction of two process inks was occurred during printing (Jangra *et al.,* 2023).

Objectives of study

Digital print engines use own pigment combination for printing. Each print engine exhibits printing differently. This experiment was carried out with an objective to evaluate print quality in terms of print density, color difference and overprint trap on uncoated paper on different digital print engines.

Materials and Methodology

For evaluating print quality using different print quality parameters on uncoated paper using different digital print engines, the experiment was carried out in different phases which are enlisted as below:

Development of test chart: Master test chart by incorporating technical elements for analysis of print quality was prepared.

Selection of digital print engine: Various print engines are available in market. Amongst them five different digital print engines were selected which included HP Indigo, Canon, Xeikon, Konica Minolta and Xerox.

Media/substrate selection: Printing was done on Sunshine Super Print uncoated paper using different digital print engines.

Printing: Finalized master test chart was used on digital print engines. Printing was carried out under standardized optimum conditions on selected paper media after calibrating the digital print engine.

Print quality measurement: Colorimetric measurement were carried out using (standardized photoelectric device) x-Rite i1 Pro Spectrophotometer. The data was collected and analyzed for findings.

Data analysis

During study various printing parameters were taken into consideration in order to evaluate print quality. Description of these parameters in terms of collected data is presented as below:

Print density demonstrated by various digital print engines

Print density (Ink density) of all process color printed using various print engines i.e. HP Indigo, Canon, Xeikon, KM (Konica Minolta) and Xerox on uncoated Sunshine Super Print Media is represented as below:

Cyan Color Print (Ink) Density: The observation of ink density of cyan color on super print paper media using five different digital print engines is depicted in Figure 3. Ink density of cyan color ranges 0.98 to 1.03; 1.12 to 1.20; 0.87 to 0.98; 1.28 to 1.39 and 1.31 to 1.43 while using HP Indigo, Canon, Xeikon, Konica Minolta and Xerox print engines, respectively. The minimum range (0.87–0.98) of cyan color ink density was exhibited by Xeikon print engine, on the other hand Xerox print engine exhibited maximum range (1.31–1.43) of cyan color ink density while printing on super print paper media with many variations. Ink density of cyan color varies linearly in case of HP Indigo methodology as shown in graph and range was found more as compared to Xeikon print engine. In case of Konica Minolta and Xerox digital print engine, both showed same trending with same density ranges.

Magenta Color Print (Ink) Density: Figure 4 depicts the results of magenta color ink density on super print paper media using five different digital print engines. Magenta color ink density ranges 0.92 to 0.97; 1.15 to 1.24; 0.82 to 089; 1.44 to 1.52 and 1.17 to 1.32 while using HP Indigo,

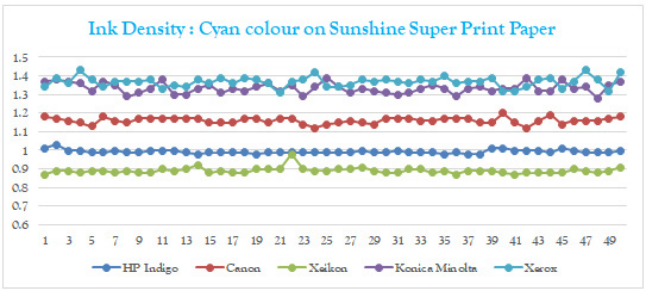

Figure 3: Cyan Color Print (Ink) Density

Canon, Xeikon, Konica Minolta and Xerox digital print engines respectively. Trends in graph have shown that the lowest (0.82 to 0.89) and highest (1.44 to 1.52) ink density range was exhibited in case of Xeikon and Konica Minolta print engine respectively. However, the behaviour of HP Indigo methodology for magenta color ink density was linear means variation during printing is very low. It is also observed from the graph Xerox exhibited near the range of Canon print engine and the density range of magenta color ink density in both cases is nearly identical. Canon print engine exhibited the medium range of ink density for magenta color amongst five digital print engines on super print paper media.

Yellow Color Print (Ink) Density: Five different digital print engines exhibited the results for yellow color ink density are depicted in Figure 5. Ink density range for yellow color ranged 0.66 to 0.68; 0.90 to 0.94; 0.90 to 0.95; 0.87 to 0.92 and 0.95 to 1.02 for HP Indigo, Canon, Xeikon, Konica Minolta and Xerox print engines respectively. The behaviour of yellow ink density by HP Indigo engine indicated lowest ink density range (0.66–0.68) amongst five digital print engines. On the other hand, highest range (0.95–1.02) of ink density of yellow color was exhibited by Xerox print engine. Amongst five digital print engines Konica Minolta exhibited medium range of ink density for yellow color.

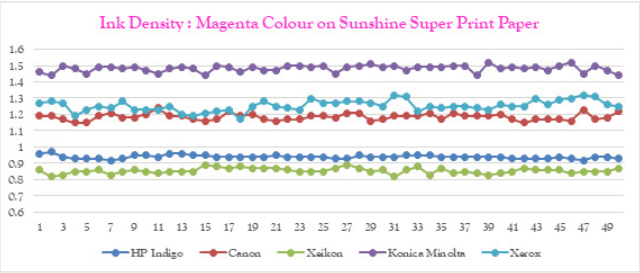

Figure 4: Magenta color print (Ink) density

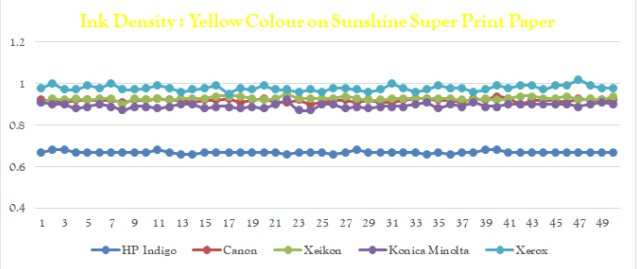

Figure 5: Yellow color print (Ink) density

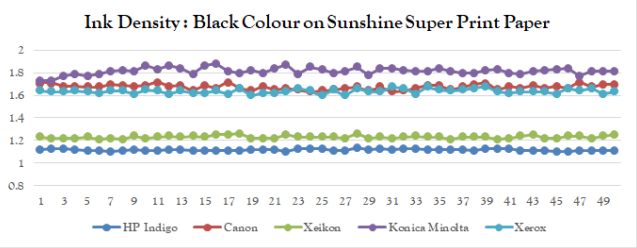

Figure 6: Black color print (Ink) density

Black Color Print (Ink) Density: Observations of black color ink density using five different digital print engines are depicted in Figure 6. Black color ink density range exhibited by different HP Indigo, Canon, Xeikon, Konica Minolta and Xerox print engines were found in the range 1.10 to 1.14; 1.63 to 1.72; 1.21 to 1.26; 1.73 to 1.88 and 1.60 to 1.68 respectively. During observation it was found HP Indigo methodology exhibited lowest ranges (1.10–1.14) and Konica Minolta print engine exhibited highest range (1.73–1.88) for black color ink density on super print paper media. However, for HP Indigo and Xeikon methodology behaviour was found linear with little variations where Xeikon print engine exhibited second lowest range for black color ink density. Both Xerox and Canon have shown haphazard trend for black ink density super print paper media.

Color difference demonstrated by various digital print engines

Various print engine used for printing included HP Indigo, Canon, Xeikon, KM (Konica Minolta) and Xerox on uncoated Sunshine Super Print Media. The essence of data is represented as below:

- Color Difference (ΔE) Value for Cyan Color: Color difference i.e. ΔE values of cyan color using various print engine used for printing included HP Indigo, Canon, Xeikon, KM (Konica Minolta) and Xerox on uncoated Sunshine Super Print Media are depicted in Figure 7 showed that the ranges of HP Indigo, Canon, Xeikon, Konica Minolta and Xerox methodologies were remained in between 5.96 to 7.26; 7.09 to 8.99; 3.35 to 5.23; 10.62 to 12.61 and 11.75 to 13.94, respectively. During study it was noticed that on Xeikon digital print engine demonstrated lowest range of ΔE values i.e. 3.35 to 5.23 while on the other hand Xerox exhibited highest range from 11.75 to 13.94.
- Color Difference (ΔE) Value for Magenta Color: The results of ΔE values for magenta color are depicted in Figure 8 for various digital print engine on Sunshine Super Print media. Reference Figure 8 it was observed that the range of ΔE values were 4.96 to 6.70; 10.42 to 13.11; 5.52 to 8.11; 17.32 to 18.95 and 11.33 to 15.58 for HP Indigo, Canon, Xeikon, KM (Konica Minolta) and Xerox digital print engines respectively. The lowest and highest ΔE values were recorded i.e. 4.96 to 6.7 on HP

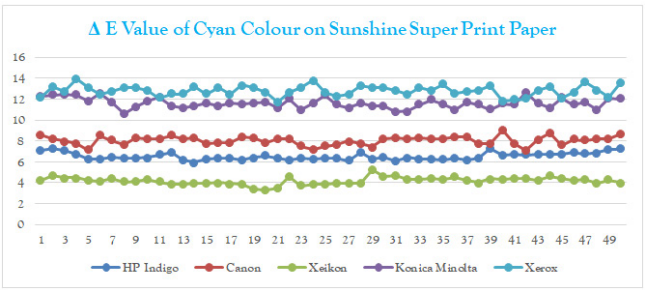

Figure 7: ΔE Value of Cyan Color on Sunshine Super Print Paper

Indigo print engine while Konica Minolta i.e. 17.32 to 18.95 respectively. ΔE values were coincided on many points in case of HP Indigo and Xeikon.

- Color Difference (ΔE) value for yellow color: Observation of ΔE value for yellow color are presented in Figure 9. During observations it was found that the range of ΔE value exhibited by various print engines i.e. HP Indigo, Canon, Xeikon, KM (Konica Minolta) and Xerox on uncoated Sunshine Super Print Media were 4.89 to 7.17; 9.17 to 11.67; 8.25 to 11.12; 10.2 to 13.1 and 9.05 to 12.41 respectively. HP indigo exhibited lowest range (4.89–7.17) of ΔE value while on the other hand Konica Minolta exhibited highest range of ΔE value 10.2 to 13.1. During observations it was found that Canon, Xeikon, KM (Konica Minolta) and Xerox digital print engines exhibited same ΔE value as depicted in Figure 10.
- Color Difference (ΔE) Value for Black Color: The ΔE values of black color on five different print engines i.e. HP Indigo, Canon, Xeikon, KM (Konica Minolta) and Xerox on uncoated Sunshine Super Print Media, is depicted in Figure 10 showed that the ΔE values ranges were remained in between 0.44 to 1.30; 15.60 to 17.66; 4.29 to 5.91; 18.02 to 21.30 and 15.17 to 17.03, respectively. It was also observed that the lowest ranges for ΔE values i.e. 0.44 to 1.30 was exhibited in case of HP Indigo; while Konica Minolta exhibited the highest i.e. 18.02 to 21.30 followed by Canon i.e. 15.60 to 17.66. The behaviour of ΔE values of black color in Konica Minolta methodology was found inconsistent due to deviations while printing on Super Print Paper Media. It was also revealed from graph that ΔE values of Canon and Xerox methodology were coincided on many points.
- Color Difference (ΔE) Value for Red Color: The results of ΔE values of red color on Super Print Paper Media using five different digital print engines is depicted Figure 11 which revealed that the range was found 11.12 to 13.77; 12.89 to 16.11; 2.39 to 5.30; 26.53 to 29.07 and 21.78 to 25.57 while using HP Indigo, Canon, Xeikon, Konica Minolta and Xerox digital print engine respectively. The lowest range of ΔE values of red color was exhibited by Xeikon methodology i.e. 2.39 to 5.30; on the other hand, Konica Minolta methodology exhibited the highest range i.e. 26.53 to 29.07 followed by Xerox which exhibited ΔE values range 21.78 to 25.57 while printing on super print paper substrate.
- Color Difference (ΔE) Value for Green Color: Observations of ΔE value of green color using five different digital print engines are depicted in Figure 12. The range exhibited by green color ΔE value by different HP Indigo, Canon, Xeikon, Konica Minolta and Xerox digital print engines were found in the limit 9.55 to 13.18; 18.74 to 22.04; 3. 81 to 6.84; 19.18 to 22.23 and 18.56 to 22.05 respectively. During observation it was found Xeikon methodology exhibited the lowest ranges (3. 81–6.84) while it was found the highest i.e. 19.18 to 22.23 for Konica Minolta methodology followed by Xerox having range 18.56 to 22.05 for ΔE values of green on super print paper media. It was also revealed from graph that ΔE values of Canon, Konica Minolta and Xerox methodology were coincided on many points.
- Color Difference (ΔE) Value for Blue Color: Five different digital print engines exhibited the results for ΔE value of blue color are depicted in Figure 13. The ΔE values for blue color ranged 10.84 to 14.19; 13.94 to 17.44; 5.09 to 9.48; 20.82 to 23.79 and 17.05 to 20.47 for HP Indigo, Canon, Xeikon, Konica Minolta and Xerox digital print engines, respectively. Xeikon methodology exhibited the lowest range of ΔE values i.e. 5.09 to 9.48 while Konica Minolta methodology exhibited the highest

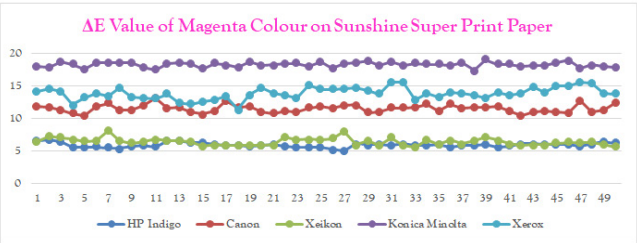

Figure 8: ΔE Value of magenta color on sunshine super print paper

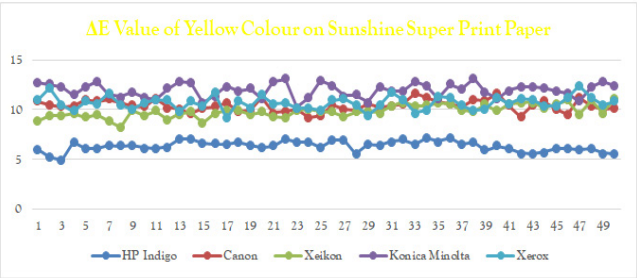

Figure 9: ΔE Value of yellow color on sunshine super print paper

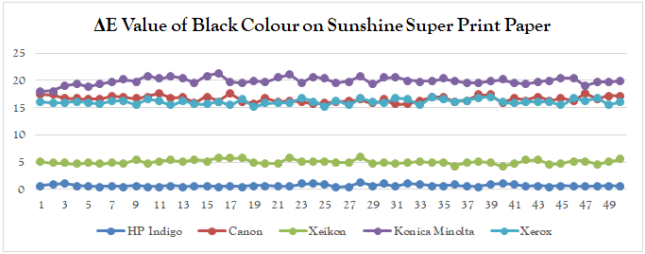

Figure 10: ΔE Value of black color on sunshine super print paper

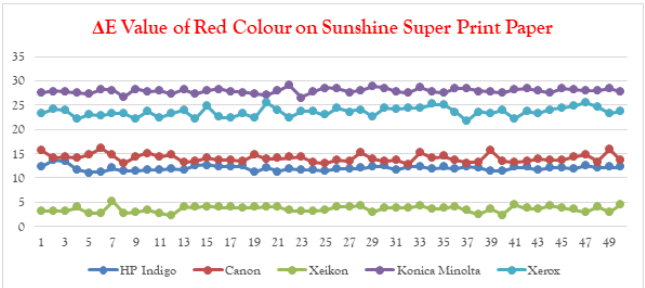

Figure 11: ΔE Value of red color on sunshine super print paper

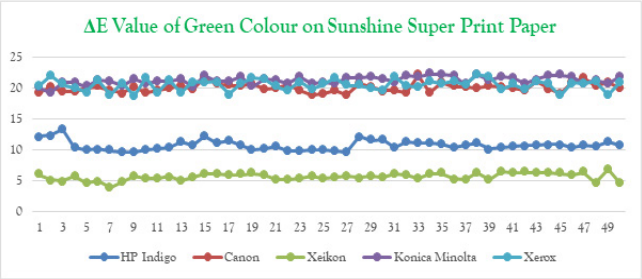

Figure 12: ΔE Value of green color on sunshine super print paper

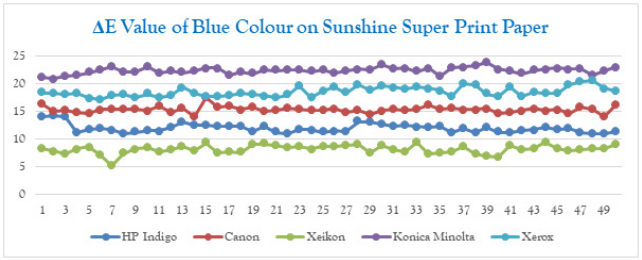

Figure 13: ΔE Value of blue color on sunshine super print paper

range (20.82–23.79) followed by Xerox i.e. 17.05 to 20.47, ΔE values of blue color on Super Print Paper Media.

Overprint Trap demonstrated by various Digital Print Engines

Overprint trap (Ink Trapping) of process color overprinted using various print engines i.e. HP Indigo, Canon, Xeikon, KM (Konica Minolta) and Xerox on uncoated Sunshine Super Print Media is represented as below:

- Red (M+Y) Overprint Trap: The observations of red color overprint on super print paper media using five different digital print engines is depicted in Figure 14. The ranges of red color overprint were observed in between 80% to 84; 74 to 81%; 66 to 73%; 86 to 90% and 84 to 90% on HP Indigo, Canon, Xeikon, Konica Minolta and Xerox print engines, respectively. The lowest red color overprint was exhibited by Xeikon print engine i.e. 66% to 73% while Konica Minolta exhibited the higher overprint in a range of 86 to 90% followed by Xerox methodology with a range of 84 to 90%.
- Green (C+Y) Overprint Trap: The overprint of green color in five different digital print engines are depicted in Figure 15 showed that the ranges of HP Indigo, Canon, Xeikon, Konica Minolta and Xerox digital print engine were remained in between 92 to 94%; 78 to 83%; 76 to 84%; 94 to 97% and 90 to 93% respectively on Super Print Paper Media. It was also observed that Konica Minolta methodology exhibited the highest ranges for green color overprint i.e. 94 to 97% while Canon methodology exhibited the lowest value i.e. 78 to 83%. Almost similar green color overprint was observed in case of Xerox and HP Indigo super print paper media.
- Blue (C+M) Overprint Trap: Figure 16 depicts the results of overprint blue color on Super Print paper media

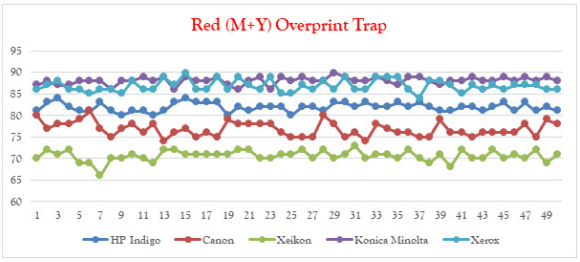

Figure 15: Red overprint trap on sunshine super print paper

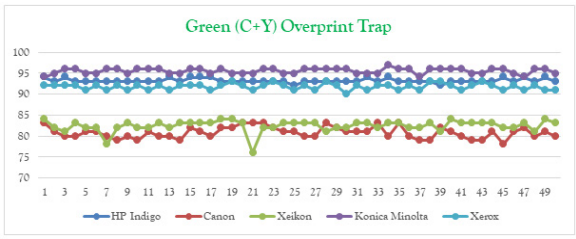

Figure 16: Green overprint trap on sunshine super print paper

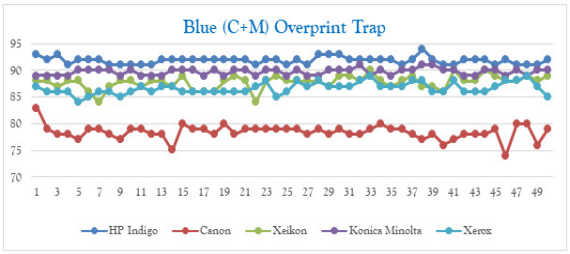

Figure 17: Blue overprint trap on sunshine super print paper

Table 1: Summary of print density using various print engines

Ink Density	*Cyan*		*Magenta*		*Yellow*		*Black*	
	Mini.	*Max.*	*Mini.*	*Max.*	*Mini.*	*Max.*	*Mini.*	*Max.*
HP Indigo	0.98	1.03	0.92	0.97	0.66	0.68	1.1	1.14
Canon	1.12	1.2	1.15	1.24	0.9	0.94	1.63	1.72
Xeikon	0.87	0.98	0.82	0.89	0.9	0.95	1.21	1.26
Konica Minolta	1.28	1.39	1.44	1.52	0.87	0.92	1.73	1.88
Xerox	1.31	1.43	1.17	1.32	0.95	1.02	1.6	1.68

using five different digital print engines. Blue color overprint ranges 91 to 94%, 74 to 83%, 84 to 90%, 89 to 91% and 84 to 89% while using HP Indigo, Canon, Xeikon, Konica Minolta and Xerox digital print engines respectively. During observation it was found Canon print engine exhibited the lowest range i.e. 74 to 83% for blue overprint, while the highest range was found 91 to 94% for HP Indigo print engine followed by Konica Minolta print engine with a range of 89 to 91% on Super Print Paper Media.

Results and Discussion

Data was analyzed so that conclusion can be drawn. During the analysis of data, it was observed that the numeric values

Table 2: Summary of color differences (ΔE Value) using various print engines

ΔE Value		*HP Indigo*	*Canon*	*Xeikon*	*Konica Minolta*	*Xerox*
Cyan	Mini.	5.96	7.09	3.35	10.62	11.75
	Max.	7.26	8.99	5.23	12.61	13.94
Magenta	Mini.	4.96	10.42	5.52	17.32	11.33
	Max.	6.7	13.11	8.11	18.95	15.58
Yellow	Mini.	4.89	9.17	8.25	10.2	9.05
	Max.	7.17	11.67	11.12	13.1	12.41
Black	Mini.	0.44	15.6	4.29	18.02	15.17
	Max.	1.3	17.66	5.91	21.3	17.03
Red	Mini.	11.12	12.89	2.39	26.53	21.78
	Max.	13.77	16.11	5.3	29.07	25.57
Green	Mini.	9.55	18.74	3.81	19.18	18.56
	Max.	13.18	22.04	6.84	22.23	22.05
Blue	Mini.	10.84	13.94	5.09	20.82	17.05
	Max.	14.19	17.44	9.48	23.79	20.47

Table 3: Summary of overprint trap using various print engines

Ink Trapping		*HP Indigo*	*Canon*	*Xeikon*	*Konica Minolta*	*Xerox*
Red (M+Y)	Mini.	80%	74%	66%	86%	84%
	Max.	84%	81%	73%	90%	90%
Green (Y+C)	Mini.	92%	78%	76%	94%	90%
	Max.	94%	83%	84%	97%	93%
Blue (C+M)	Mini.	91%	74%	84%	89%	84%
	Max.	94%	83%	90%	91%	89%

were repeated again and again for various print quality parameters i.e. print density, color difference (ΔE Value) and overprint trap on uncoated media (Sunshine Super Print). The information gathered while carrying out the research for various print quality parameters is tabulated as shown in Tables 1 to 3.

Conclusion

Print quality evaluation in terms of consistency using various print engines i.e. HP Indigo, Canon, Xeikon, KM (Konica Minolta) and Xerox on uncoated Sunshine Super Print Media was done from two different point of view. First approach focused on print quality analysis on basis of various digital print engines. Another approach included assessing print quality in terms of various color in relation to different print engines. These are elucidated as below:

- Print Density: According to first observation it was noticed that black color demonstrated highest value of ink density on uncoated Sunshine Super Print Media using various digital print engines i.e. HP Indigo, Canon, Xeikon, KM (Konica Minolta) and Xerox. On the other hand, Konica Minolta demonstrated highest value for magenta and black color. Also, Xerox demonstrated highest value for cyan and yellow color on uncoated Sunshine Super Print Media.
- Color Difference (ΔE) Value: First approach described that HP indigo, Canon and Xeikon demonstrated lowest ΔE value for black, cyan and red, respectively. Also, Konica Minolta and Xerox demonstrated lowest color difference for yellow color uncoated Sunshine Super Print Media. In contrast, another approach depicted that Xeikon print engine demonstrated minimum ΔE Value for cyan, red, green and blue color. Also, HP Indigo demonstrated minimum value of magenta, yellow and black color on uncoated Sunshine Super Print Media.
- Overprint Trap: While evaluating overprint on uncoated Sunshine Super Print Media, first approach concluded that HP Indigo, Canon, KM (Konica Minolta) and Xerox demonstrated highest overprint value for green color. Also, Xeikon demonstrated maximum value for Blue color. In contrast, second approach revealed that Konica Minolta exhibited highest value for both red and green color. Also, Xerox and HP Indigo exhibited highest value for Red and Blue color respectively.

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