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Research Article

Critical Analysis of Ink-Trapping on Paper Substrate using Piezoelectric Inkjet

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ABSTRACT

The ability of the ink to trap or not trap on top of another layer of ink, affecting the degree of colour reproduction, contrast, and the overall quality of the print, is a critical issue in colour reproduction and contrast. This research paper critically explores the behaviour of the ink trapping on various types of paper substrates when using piezoelectric inkjet printing technology. Three types of paper, i.e., gloss-coated, matt-coated, and plain were examined with respect to surface properties, i.e. porosity, Cobb value and roughness. A test chart was printed with cyan, magenta, and yellow inks and trapping efficiency assessed by spectrophotometric analysis. The results suggest that uncoated paper trapped the most ink with blue (cyan + magenta) and that the matt-coated paper trapped the most ink with green (cyan + yellow) and red (magenta + yellow). Gloss coated paper has had the lowest values of trapping always. The statistical analysis led to the conclusion that Cobb value and porosity have a strong effect on ink trapping, and high Cobb and porosity values relate to the high rate of ink penetration and mixing. The findings highlight the vital importance of substrate properties in the quality of inkjet prints and that paper is not a passive component in the structure of the image but rather an active component. It was hoped that these discoveries would guide printers, manufacturers and designers to make informed choices of substrates to maximise colour fidelity and visual effect in inkjet printing.

Keywords: Digital image, Ink trapping, inkjet, paper substrate, piezoelectric

I. INTRODUCTION:

Inkjet printing is one of the most advanced and diverse processes in modern printing methodology combining artistic sense and engineering principles to the greatest extent. The ability to closely recreate vivid colours, subtle tints, and very delicate elements on a variety of surfaces is an example of the symbiotic relationship between scientific rigour and creative art. In comparison to conventional printing techniques, the inkjet technology uses the carefully controlled mini droplets of ink to create an image; hence, paper or substrate is the primary factor that determines the sharpness of the final print, colour accuracy and the overall effect of the print. Figure 1 depicts the range of variants of inkjet technologies in the printing sector [1].

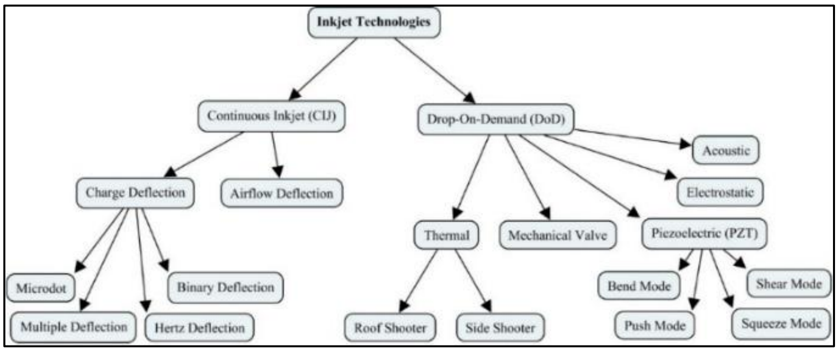

Figure 1. Various inkjet Technologies [1]

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One of the many factors that dictate the quality of prints is the type of paper that is used. The topography on its surface, its porosity, absorbency, and coating all combined in response to the ink thus affecting a range of properties among which are: the drying time, the formation of dots, the density of coloration, and the smoothness of tones [2]. An example of this is the use of coated papers in high quality inkjet printing, which is enabled by the ability to control the dispersion of ink, hence resulting into images with enhanced sharpness and colour exactness [3]. On the contrary, there is a likelihood of the creation of artefacts because of the use of uncoated or highly absorbent paper substrates, including feathering, reduced saturation, or uneven tone distribution; thus, potentially undermining the desired visual result [4].

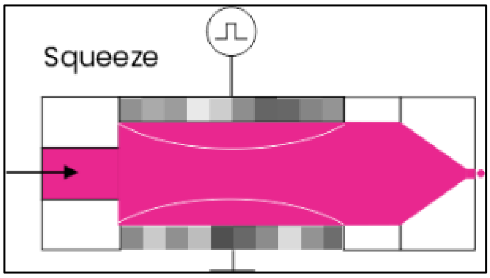

Figure 2. Piezoelectric inkjet method [1]

The given research work is devoted to one of the highly significant and, at the same time, often overlooked aspects of inkjet printing, i.e. ink trapping. The level of ink adherence to be used when the ink is printed over another ink layer is known as ink trapping, this directly affects colour blending, contrast and stability of the image [5]. The lack of proper trapping of ink may cause blurriness in an overlapping colour area, loss of sharpness and a decrease in depth perception; however, if trapping is done well, it will give the print richness and guarantee that the print can be repeated across the entire print run [1]. The inkjet printing phenomena analysed in this paper clarify the active role as played by the substrate in the image formation rather than being a passive surface.

This study aims to define the decisive position of substrates by specifying the aesthetic and technical excellence of the prints by examining the relationships among paper characteristics, ink behaviour, and the efficiency of trapping [6]. The findings are expected to be of great value to practitioners in the arts, design and industries that depend on inkjet printing to provide precision and impact, besides printers and manufacturers [7]. In this respect therefore, this section highlights the fact that the canvas of inkjet printing is much more than just a canvas; it is a very important component in the exploitation of the technology [8].

The research will investigate the appearance of ink trapping in real world printing conditions and the resultant implications on the quality of the image. This work aims at providing detailed knowledge on ink trapping against the paper choice in inkjet printing that will help professionals and consumers [9]. Finally, the study will contribute to the understanding of colour reproduction in the sphere of ink trapping and contribute to making informed choices in the developing area of inkjet printing by shedding light on the complex interaction between paper types and ink trapping.

II. REVIEW OF LITERATURE

It is obligatory to form a background knowledge of the fundamentals behind the colour reproduction and grey balance before getting down to the numerous effects of paper types on inkjet printing. Colour perception depends on many factors such as the properties of ink, the technology of the printer and the properties of paper. The accuracy of colour and grey balance are most important in the aspect of fidelity in the printed images. The interaction of the ink formulations and printer calibration has been studied by [10] and [11], and they have shown that they play crucial roles in obtaining the accurate colours and neutral grey shades [6]. Surface properties of paper such as texture, porosity and coating are known to affect ink interaction with substrate. As observed in the studies carried out by Brown (2016), matte papers, which normally exhibit a more porous finish, will exhibit increased absorption of the ink, accompanied by reduced colour vibrancy. Glossy papers, on the other hand, because they exhibit smooth, shiny finishes, will result in enhanced colour saturation, as well as gloss [12].

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The properties of a surface also influence the colour gamut noticeably and could be responsible for hue error variation. Examinations conducted by [13], [14], and Rodriguez (2018) support the idea that paper absorbency may cause changes to hue error [6]. Very absorbent paper is more likely to spread inks on contact resulting in colours that are less saturated or shifted in colour. The knowledge of the absorbency of various types of paper is important to the prediction of the level of hue error that each type produces. Surface texture which is a property of all types of papers also determines grey balance [15]. It has been shown in studies by [16] and [17] that textured papers have the potential to influence the uniformity of grey tones because the differences in surface height may distribute light differently across the paper, resulting in noticeable differences of grey tones [6].

Specialty papers like fine art papers add one more level of complexity to the paper type equation [18]. To serve artistic and archival printing, these papers are made with certain characteristics. Studies by Turner (2019) and Patel (2021) have highlighted the extensive effect that the inherent properties of fine art papers can have on hue error and grey balance and make them a key factor to consider in the decision-making in the reproduction of art with the use of substrates [19]. Surfaces of paper have been getting interest in recent studies due to coating on them [20]. Green (2018) and Blue et al. (2022) have studied the impact of coatings on inkjet printing and both studies have found them to affect both the quality and grey balance of colour by changing how well the ink adheres and absorbs [2].

III. HYPOTHESIS

The hypothesis is that various paper types has a great effect on ink trapping in inkjet imaging. Various paper types will lead to the different ink trapping in the printed images. It is these interactions between the ink droplets, paper surface properties and the perceptual responses of the human observers which will be observable. In addition, it is expected that some paper types will show a stronger influence on ink trapping including the fine art papers, whereas more standard types of papers including the glossy or matte papers might show smaller effects.

IV. RESEARCH OBJECTIVES:

The main objective of this research project is to find out

1. To analyse the ink trapping on different papers using inkjet printing methodology.
2. To relate ink trapping with the paper properties like Porosity and Cob Value.

V. METHODOLOGY

The Methodology followed to achieve the above-mentioned objectives was:

1. Identification of commonly used inkjet papers of different grade and basis weight.
2. Preparation of the master test chart according to the required tools.
3. Identification of inkjet printing methodology to print the master test chart.
4. Measurement of ink trapping values using the relevant tools and device.

The printing business primarily uses two kinds of paper: coated papers and uncoated papers, which are classified according to their use. Uncoated papers are made of base paper that has a rough and uneven surface and is not coated. A coating solution is used to smooth out the rough and uneven surfaces of uncoated sheets, turning them into coated papers. The surface of coated paper is smoother and more uniform than that of uncoated paper because it is made by treating uncoated paper with the right coating solution. Coatings are applied to base papers throughout the papermaking process; the finished product may be either glossy or matte coated, depending on the coating type. The surface qualities of coated papers are superior to those of uncoated ones, leading to better print quality in general.

To create coated paper, an uncoated sheet of paper is first dipped into a coating solution, which uniformizes and smooths out the surface. Compared to uncoated papers, coated ones have better surface qualities and overall print quality. The coating's sheen determines whether the coated paper is gloss coated, or matt coated; this is one way in which coated papers are categorised. A certified paper testing laboratory assessed four samples from each category: Type 1, Type 2, Type 3, and Type 4. Table 1 shows the results of the examination of several paper properties.

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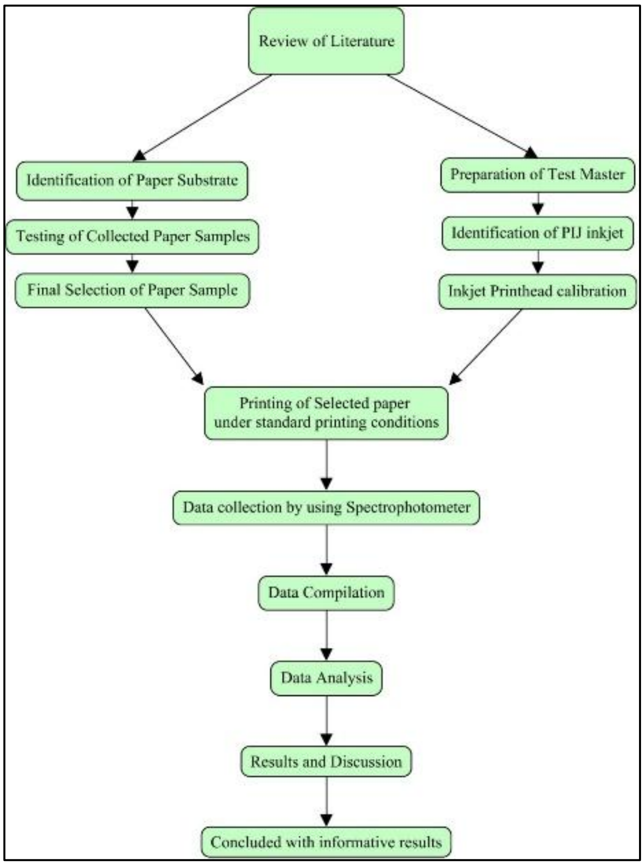

Figure 3. Research Methodology for ink trapping

5.1 Paper Specifications

TABLE 1. PAPER SPECIFICATIONS AND PROPERTIES

Sr. No.	Descriptions	Equipment/Method	Unit	Side	Gloss Coated	Matt Coated	Uncoated
1	Basis Weight (grammage)	Digital GSM Tester	g/m²		90.3	90.5	90.9
2	Cobb Value	Cobb Sizing Tester (Tilting Type)	g/m²	Side-1	29.4	34.7	38
				Side-2	26.5	27.7	33.5
3	L*	Digital Brightness Tester (technibrite/elrepho Type)			82.0	87.6	84.6
4	a*				1.7	1.0	1.4
5	b*				-13.5	-13.1	-11.4
6	Porosity	S-P-S Testers (Gurley Method)	ml/min.		118.0	137.5	153.1
7	Roughness	Roughness Tester (Bendtsen)	ml/min.	Side-1	9.8	11.5	15.5
				Side-2	10.0	10.6	14.3
8	Tear Factor	Tear Tester (Elmendorf Type)	N/A	MD	27.35	29.63	30.5
				CD	29.13	32.78	34.5

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5.2 Test Chart

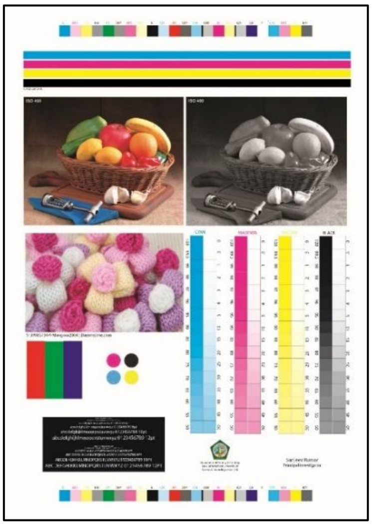

Figure 4. Test Chart

Figure 4 is the flow chart of research methodology used to execute the research work.

5.3 Inkjet Specifications

TABLE 2. INKJET SPECIFICATIONS

PIJ INKJET SPECIFICATIONS

Sr. No.	Parameters	Piezoelectric Inkjet
1	Printhead Type	DOD
2	Printhead Model	Kyocera KJ4B
3	Dimensions (WxDxH) (mm)	200 x 30 x 68.6
4	Resolution (dpi)	600 x 600
5	Print width (mm)	108.25
6	Droplet Size (pL)	2 -12 pL
7	Number of Nozzles	2656 per colour
8	Frequency (kHz)	30
9	Printing Machine Make	Océ Canon
10	Press Model	VarioPrint i300
11	Type of Paper feeding	Sheet Fed
12	Media Range (g/m2)	58 -300
13	Size of Media	13.8"x 19.7"
14	Type of ink used	Water based ink

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15	Ink Viscosity (mPa*s) (1-20)	5.0-6.0
16	Standard drying time	2.2 second at 300 in/min
17	Ripping	APPE

5.4 Spectrophotometer Measuring conditions

TABLE 3. MEASURING CONDITIONS

Sr. No.	Description	Specifications
1	Colorimetric Functions	M1 (D50)
2	Densitometric Functions	M1 (D50)
3	Illuminant / Observer	D50/ 2°
4	ΔE Method	CIE ΔE* (2000) (kL- 1.00, kC- 1.00, kH – 1.00)
5	Density Status	ISO Status T
6	Density White Base	Absolute
7	Ink Order	KCMY

VI. DATA COLLECTION & ANALYSIS

A spectrophotometer (x-rite) was used to get the data, and the Preucil method of ink trapping was used. The date that the ink trapping statistics for cyan and magenta were measured is displayed in table 4. Blue is the result of combining magenta and cyan. The blue colour data on gloss-coated, matt-coated, and untreated paper are displayed in the table below.

TABLE 4. VALUE OF INK TRAPPING FOR CYAN AND MAGENTA

	C+M=Blue		
Sr. No.	GC (%)	MC (%)	UC (%)
1	90.70%	93.20%	94.20%
2	91.20%	93.60%	93.90%
3	86.10%	93.60%	94.10%
4	91.00%	93.70%	94.30%
5	90.70%	92.60%	94.20%
6	90.80%	93.10%	94.10%

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7	90.80%	93.10%	94.20%
8	91.00%	93.40%	94.50%
9	91.00%	93.00%	94.00%
10	90.90%	93.00%	93.90%
11	91.30%	92.50%	94.00%
12	91.20%	92.90%	94.30%
13	90.60%	92.90%	94.30%
14	90.90%	92.80%	94.20%
15	90.80%	93.00%	94.10%
16	90.80%	93.10%	93.80%
17	91.00%	92.90%	94.60%
18	89.90%	92.90%	94.40%
19	90.90%	92.70%	94.40%
20	90.80%	92.90%	94.60%
Min.	86.10%	92.50%	93.80%
Max.	91.30%	93.70%	94.60%
Mean	90.62%	93.05%	94.21%
S.D.	0.011	0.003	0.002

Table 4 displays the average percentage of ink trapped on UC paper (94.205 percent), matt coated paper (93.045 percent), and gloss coated paper (90.620 percent). It demonstrates that the UC paper has the highest ink trapping value while the GC paper has the lowest. All inks do, however, have ink trapping values greater than 80%.

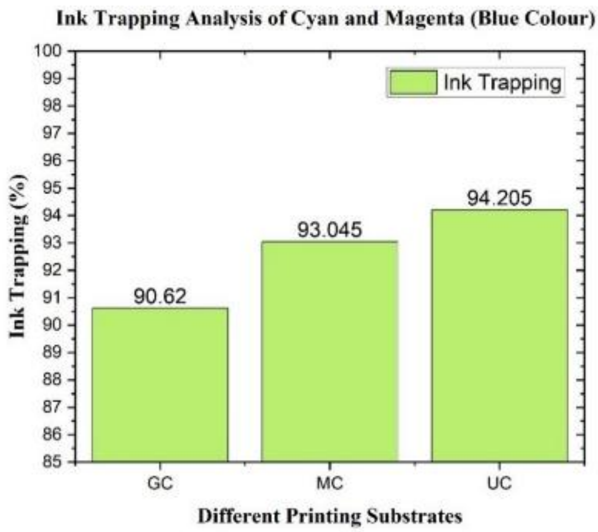

Figure 5. Ink Trapping of Cyan and Magenta (Blue)

Using PIJ inkjet printing technology, figure 5 compares the ink trapping of cyan and magenta on gloss coated, matt coated, and uncoated paper substrates. The comparative value of ink trapping for UC paper was determined to be

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high, whereas the lowest value was observed for GC paper out of the three. Out of the three, MC paper has a considerable amount of ink trapping.

Table 5 presents the measured ink trapping values for both yellow and cyan. Green is the result of cyan and yellow combined. Data in green on gloss-coated, matt-coated, and uncoated paper are displayed in the table below. Table 5 displays the average percentage of ink trapped on GC paper (89.75 percent), matt coated paper (94.72 percent), and uncoated paper (90.79 percent). It demonstrates that the GC paper has the lowest ink trapping value, and the MC paper has the highest. All inks do, however, have ink trapping values greater than 80%.

TABLE 5. VALUE OF INK TRAPPING FOR CYAN AND YELLOW

	C+Y=Green		
Sr. No.	**GC (%)**	**MC (%)**	**UC (%)**
1	89.20%	94.70%	91.00%
2	90.00%	94.30%	90.70%
3	90.10%	95.00%	91.10%
4	90.20%	94.60%	91.00%
5	89.40%	94.40%	91.00%
6	89.50%	95.40%	90.80%
7	89.80%	94.90%	90.50%
8	89.80%	94.30%	90.80%
9	89.30%	94.70%	90.80%
10	89.60%	94.80%	90.70%
11	90.00%	94.50%	90.90%
12	89.60%	95.20%	91.10%
13	89.60%	94.20%	90.70%
14	90.10%	95.30%	91.00%
15	89.70%	94.60%	90.60%
16	89.90%	94.90%	90.80%
17	89.70%	94.80%	91.00%
18	89.90%	94.40%	90.30%
19	90.00%	94.20%	90.50%
20	89.60%	95.20%	90.60%
Min.	89.20%	94.20%	90.30%
Max.	90.20%	95.40%	91.10%
Mean	89.75%	94.72%	90.80%
S.D.	0.003	0.004	0.002

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TABLE 6. VALUE OF INK TRAPPING FOR MAGENTA AND YELLOW

M+Y=Red			
Sr. No.	**GC**	**MC**	**UC**
1	88.50%	93.70%	92.30%
2	82.80%	93.70%	92.50%
3	88.00%	93.70%	92.40%
4	88.00%	93.60%	91.70%
5	88.00%	94.00%	92.60%
6	88.20%	94.40%	92.70%
7	87.80%	93.80%	92.60%
8	87.80%	93.90%	92.60%
9	87.80%	94.30%	92.40%
10	88.00%	93.90%	92.70%
11	87.70%	93.80%	92.30%
12	88.10%	93.90%	92.30%
13	87.80%	93.70%	92.20%
14	87.90%	94.20%	92.40%
15	88.10%	93.80%	92.20%
16	88.00%	93.80%	92.50%
17	88.10%	93.70%	92.40%
18	87.60%	94.10%	92.40%
19	87.90%	93.50%	92.50%
20	88.00%	93.90%	92.50%
Min.	82.80%	93.50%	91.70%
Max.	88.50%	94.40%	92.70%
Mean	87.71%	93.87%	92.41%
S.D.	0.012	0.002	0.002

Figure 6 compares the ink trapping of yellow and cyan on gloss, matt, and uncoated paper substrates printed using the PIJ inkjet printing technique. Among the three, the comparative value of ink trapping for MC paper was determined to be the highest, while for GC paper it was the lowest, followed by UC.

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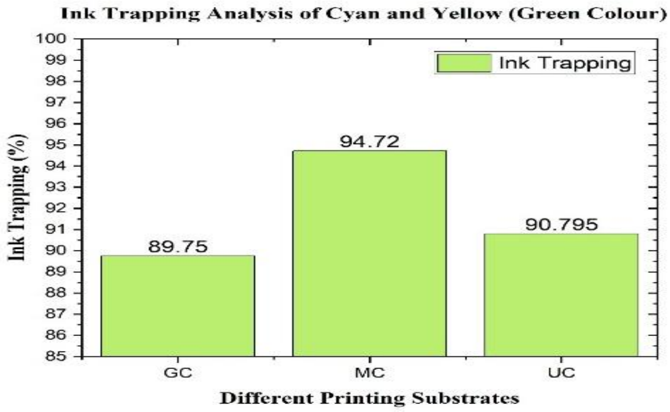

Figure 6. Ink Trapping of Cyan and Yellow (Green)

The measured ink trapping data for magenta and yellow are displayed in Table 6. The colour red is created by combining magenta and yellow. The data in the table below pertains to red-coloured paper that is coated, uncoated, and matte-coated. According to Table 6, the average ink trapping values for GC paper were 87.705 percent, matt coated paper was 93.870 percent, and uncoated paper was 92.410 percent. The results indicate that the MC paper has the highest ink trapping value while the GC paper has the lowest. Every ink, nevertheless, has an ink trapping value more than 80%.

The comparative study of cyan and yellow ink trapping on gloss-coated, matt-coated, and uncoated paper substrates printed using the PIJ inkjet printing technique is displayed in figure 7. Of the three, the comparative value of ink trapping for MC paper was found to be the highest, while for GC paper it was determined to be the lowest, followed by UC.

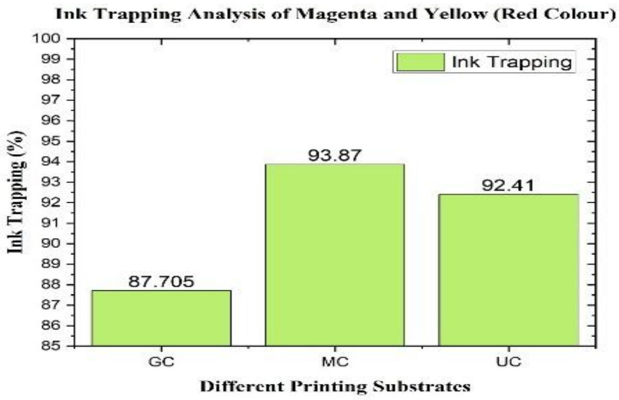

Figure 7. Ink Trapping of Magenta and Yellow (Red)

Table 7 presents the measured ink trapping dates for the colours blue, green, and red on gloss-coated paper that was printed using the PIJ inkjet printing process. Table 6 indicates that the average percentage of ink trapped for blue, green, and red was 90.62 percent, 89.75 percent, and 87.71 percent, respectively. The data indicates that blue has the highest ink trapping value whereas red has the lowest. Every ink, nevertheless, has an ink trapping value more than 80%.

TABLE 7. INK TRAPPING ON GLOSS COATED PAPER

Colour	Blue	Green	Red
Ink Trapping (%)	90.62%	89.75%	87.71%

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The comparative study of ink trapping on gloss coated surfaces for the colours red, green, and blue produced by PIJ inkjet printing technique is displayed in figure 8. The comparative value of ink trapping for blue was determined to be the highest, while the value for red was found to be the lowest of the three, followed by green.

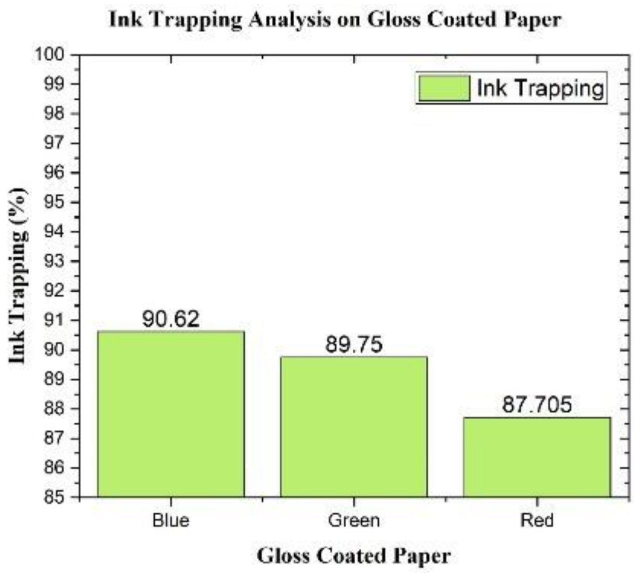

Figure 8. Ink Trapping on Gloss Coated Paper

Table 8 displays the date-measured ink trapping statistics for red, green, and blue printouts using the PIJ inkjet printing method on matt-coated paper. According to Table 8, the average ink trapping percentage for the colours blue, green, and red was 93.05 percent, 94.72 percent, and 93.87 percent, respectively. The data indicates that green has the highest ink trapping value, with red and green having about identical values. All inks do, however, have ink trapping values greater than 80%.

TABLE 8. INK TRAPPING ON MATT COATED PAPER

Colour	Blue	Green	Red
Ink Trapping (%)	93.05%	94.72%	93.87%

The comparative study of ink trapping on matt coated surfaces for the colours red, green, and blue produced by PIJ inkjet printing technique is displayed in figure 9. Green had the highest comparative value of ink trapping, whereas the values for red and green were nearly equal.

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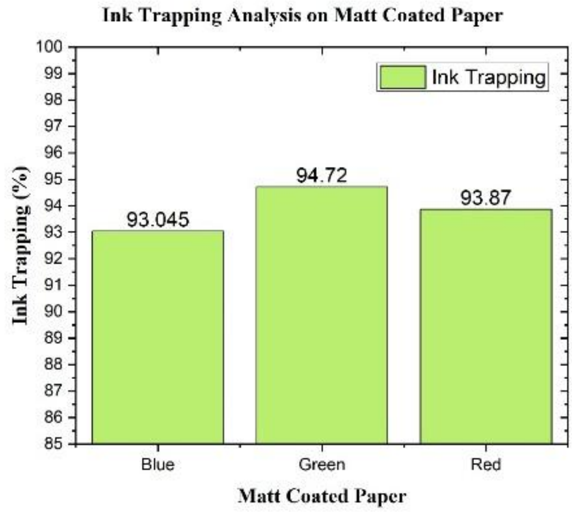

Figure 9. Ink Trapping on Matt Coated Paper

The table 9 is showing the date measured the ink trapping data for blue, green and red on uncoated paper printed by PIJ inkjet printing method. The table 9 has shown that the average ink trapping value was 94.21 percent for blue, 90.80 percent for green and 92.41 percent for red colour. It shows the blue colour has highest ink trapping value and green has lowest value of ink trapping. Red colour has moderate value of ink trapping. However, all inks have ink trapping value above the 80 percent.

TABLE 9. INK TRAPPING ON UNCOATED PAPER

Colour	Blue	Green	Red
Ink Trapping (%)	94.21%	90.80%	92.41%

The figure 10 has shown the comparative analysis of ink trapping on uncoated for blue, green and red colour achieved by PIJ inkjet printing methodology. The comparative value of ink trapping for blue colour was found highest whereas for green, it was found lowest amongst all three followed by red colour.

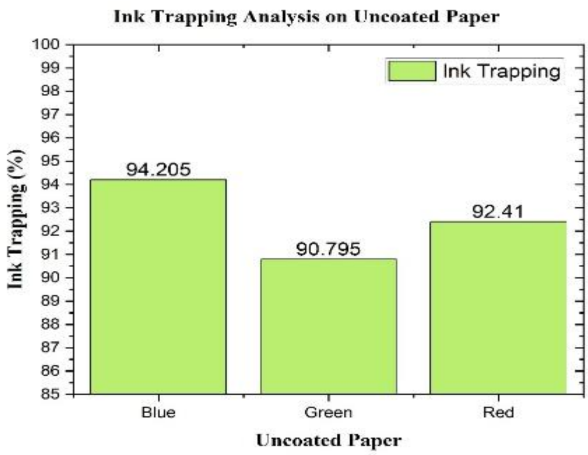

Figure 10. Ink Trapping Uncoated Paper

VII. RESULT AND DISCUSSION

The comparative value of ink trapping for cyan and magenta (blue) on UC paper was determined to be high, whereas the lowest value was observed for GC paper out of the three. Out of the three, MC paper has a considerable amount of ink trapping. Among the three, the comparative value of ink trapping for cyan and yellow (green) on MC paper was determined to be the highest, while for GC paper it was the lowest, followed by UC. Of the three, the comparative value of ink trapping for magenta and yellow (red) on MC paper was found to be the highest, while for GC paper it was determined to be the lowest, followed by UC.

The comparative study of ink trapping on gloss coated surfaces for the colours red, green, and blue produced by PIJ inkjet printing technique as displayed in figure 8. The comparative value of ink trapping for blue was determined to be the highest, while the value for red was found to be the lowest of the three, followed by green. The comparative study of ink trapping on matt coated surfaces for the colours red, green, and blue produced by PIJ inkjet printing technique as displayed in figure 9. Green had the highest comparative value of ink trapping, whereas the values for red and green were nearly equal. The figure 10 has shown the comparative analysis of ink trapping on uncoated for blue, green and red colour achieved by PIJ inkjet printing methodology. The comparative value of ink trapping for blue colour was found highest whereas for green, it was found lowest amongst all three followed by red colour.

Cobb value and ink trapping: it is observed that the value of cobb has significant influence on ink trapping in inkjet print quality. High cobb value (table 1) gives more penetration of ink in the paper substrate and more blending of liquid ink on paper surface as ink particles also get penetrates. In case of GC paper, coating blocks in ink penetration which gives less amount of ink penetration and finally effect the ink trapping. In case of UC paper, the ink gets penetrates, due to which blending of inks gives more interaction and ink trapping values.

Porosity and ink trapping: porosity also has affected on ink trapping. GC paper has low porosity which gives low ink trapping value whereas, MC and UC paper has more porosity ultimately leads to more ink trapping value.

VIII. CONCLUSION

The study analysed the ink trapping of cyan and magenta (blue) on UC paper, GC paper, and MC paper. The highest ink trapping was observed for cyan and yellow (green) on MC paper, followed by GC paper. The highest ink trapping was found for magenta and yellow (red) on MC paper.

The study also examined ink trapping on gloss coated surfaces for red, green, and blue produced by the PIJ inkjet printing technique. The highest ink trapping was found for blue, followed by red and green. Green had the highest comparative value of ink trapping, while the values for red and green were nearly equal.

The study also found that the cobb value significantly influences ink trapping in inkjet print quality. High cobb values lead to more penetration of ink in the paper substrate and more blending of liquid ink on the paper surface. Ink penetration is less in GC paper, resulting in less ink trapping. Ink penetration in UC paper leads to more interaction and ink trapping values.

Porosity also affects ink trapping. GC paper has low porosity, resulting in low ink trapping values, while MC and UC paper have more porosity, leading to more ink trapping values.

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