Critical Analysis of Printability of Different Types of Paper Substrates while printed with Piezoelectric and Thermal Inkjet Presses

Sandeep Boora[1] & Anjan Kumar Baral[2]

[1] Research Scholar, Department of Printing Technology,
Guru Jambheshwar University of Science Technology, Hisar City, Haryana, India
[2] Professor, Department of Printing Technology,
Guru Jambheshwar University of Science Technology, Hisar City, Haryana, India
sboora1@cuh.ac.in , anjan_baral2222@yahoo.co.in

Abstract

The main objective of this research study is to evaluate the printability aspect of different inkjet heads (PIJ, TIJ) on various grades of paper by examining different print quality-related factors such as colour cast, colour non-uniformity, graininess, hickeys, and moiré. The study aims to determine the relationship between different inkjet heads and grades of paper in terms of their printability and to identify which combinations yield the best print quality output. Three types of paper, i.e., uncoated (90 gsm), matt coated (90 gsm), and gloss coated (88 gsm), were used for printing under DoD (PIJ, TIJ) inkjet printing. The print quality parameters were assessed by standard observer method to determine the printability of the paper substrate. Standard observers visually observed the print quality for each parameter, and statistical analysis is performed to analyse the data. The experiment is conducted in a controlled environment under standardized lighting conditions and the inkjet presses were calibrated before starting the printing process to ensure consistency in print quality. The results of this study showed that the print quality parameters were affected by the type of paper substrate used, the inkjet technology employed, and the interaction between the two. The uncoated paper substrate showed the negligible colour cast and colour non-uniformity. The gloss-coated paper substrate exhibited the best print quality parameters among all the substrates tested, while the matt-coated paper substrate showed better results compared to the uncoated paper substrate in terms of colour non-uniformity and colour cast. This research study contributes to the understanding of the printability of different types of paper substrates using two widely used inkjet technologies. The study provides valuable insights into the effects of paper substrate properties on print quality parameters, which can be useful for print buyers and printing industry professionals.

Keywords: *Inkjet Printing, Drop-On-Demand, Piezoelectric, Thermal Inkjet, Gloss coated, Matt coated.*

1. Introduction:

In recent years, digitization has transformed all types of industries and same is true with printing industry. The consumer-centric developments of recent years, such as product personalization, innovation, ability to print variable data and communication (through all media, notably digital), are strongly aligned with the expanding possibilities of digital printing. Inkjet is used to add customer specific information to existing print in line with the production (hybrid printing) as there is no need to apply any kind of pressure thus making it as the most suitable technology under the

NIP technologies [1] The advances in the inkjet technologies overcomes the shortcomings in the old inkjet technology such as poor print quality, clogged nozzles, and a high cost per page. Inkjet printing is gaining popularity day by day because of the massive improvement in print quality as well as technology. Due to the improvements in the inkjet printing technology, it is recognized as mainstream digital printing technology [2]. The growth of inkjet printing almost tripled in the last decade [3]. A comprehensive review is done in [4] on classification of inkjet print technologies and their potential applications. The applications of inkjet printing found in different sectors such as thermal inkjet printing technology for medicine [5], electronic device and circuit printing [6] etc. By 2023, it is expected to match the quality of sheetfed offset on standard coated papers and boards [3].

Droplet formation and jetting stability in inkjet depends upon ink viscosity and nozzle diameter as well as jetting principle. Using high viscosity inks in inkjet is a challenging task due to increased risk of nozzle blocking. Several inkjet technologies evolved with time such as piezoelectric inkjet, thermal inkjet etc to suit the high viscosity inks and conductive inks [4][7][8]. Researches study were carried out by Tse et. al. (1998) to develop automated method for print quality analysis in inkjet printing, using commercially available media[9] and Pedersen et. al.(2010) to identify attributes of image quality for colour prints, including sharpness, colour reproduction, and visual appearance, through subjective and objective evaluations. Kumar, S., & Baral, A. K. (2022) critically analysed hue error and print contrast as print quality factors in piezoelectric inkjet press on matt coated and gloss coated cellulosic substrates. The structural and chemical characteristics of the paper surface have a significant impact on print quality, which is one of the most significant factors of customer evaluation [12].

1.1 Inkjet Printing Technology

William Thomson and Abbe Nollet developed the first inkjet print heads in 1858. They also produced an inkjet-like recording instrument with a continuous inkjet head. The inkjet printing technologies are broadly classified into two types i.e. continuous inkjet (CIJ) and Drop-On-Demand (DOD) inkjet. A charging electrode and an applied electric field both have an impact on the stream of droplets that are continually expelled in a CIJ system. A catcher collects the uncharged raindrops. The droplet may be ejected by an output waveform in a DOD printing system. The classification of inkjet technologies is shown in Figure 1.

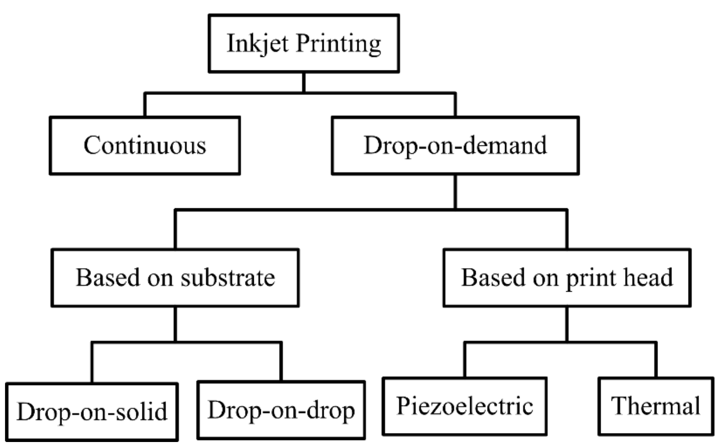


Figure 1 Different types of inkjet printing [13]

In DOD inkjet technology, the drops are generated when required by the creation of a pressure pulse. Depending on the mechanism used to generate a pressure pulse, DOD inkjet can be categorized as piezo, thermal, or electrostatic. The schematic diagram of DOD inkjet is shown in Fig. 2 [14]. In this work, piezoelectric and thermal inkjet technologies are used to print on the paper. The working mechanism of these technologies is explained in the following sections.

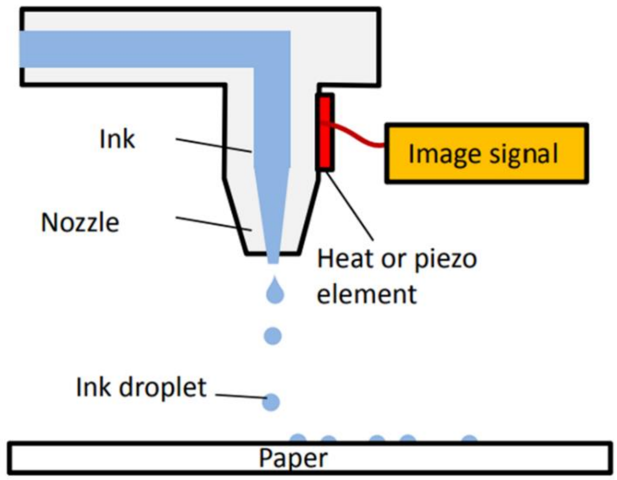


Figure 2 Schematic of Drop-on-Demand inkjet printing technology

1.2 Piezoelectric inkjet

Piezoelectric inkjet is the most reliable and highly available inkjet technologies in the market due to its capability to handle a wide range of inks. In piezoelectric technology, a piezo crystal (Lead zirconium titanate) undergoes mechanical deformation that creates a pressure pulse Applying a voltage waveform to a piezoelectric crystal activates a piezo-driven inkjet printhead. The waveform guarantees the creation of the intended droplet and a steady jet [4,15].

1.3 Thermal inkjet

Thermal inkjet is the most widely used inkjet technology in desktop printers, and now it is being adopted as an industrial inkjet technology. In thermal inkjet, the drops are generated by heating a resistive element inside the ink chamber to the temperature range of 350-400°C. The high temperature causes the ink to vaporize, and a bubble is created that forces the ink from the nozzle to eject out [16]. Inkjet printing essentially involves three primary processes: (1) ink ejection and droplet generation, (2) liquid-solid interaction once droplets are applied to the surface of the substrate, and (3) drying of the ink droplet and subsequent solidification [17].

2. Printability and various print related factors

2.1 Printability

Printability is the result of accurate image reproduction on paper without ink bleed through. Printability is the result of the interplay of various paper-related factors in the printing process, which helps to fully utilize the paper's quality potential in the print process. The primary factors that affect how well a printed product looks are printability parameters. Because other aspects of printing technology also affect print quality, printability is not the same as print quality. The crucial characteristics of paper are brightness, opacity, gloss, smoothness, porosity, and sizing, but the specifications can change depending on the printing method. Coated papers typically look better than uncoated papers because of their improved smoothness, brightness, and gloss [18].

The ink and medium are the two factors that have the biggest impact on image properties, though the printer and print head along with colour management software also play a significant role. The image quality of inkjet printing has started to resemble that of silver-halide photography as a result of advancements like smaller ink drop sizes and the use of up to seven ink colours [19]. The ink layer should stay at the surface after drying for the best print density and colour saturation. The best materials retain the majority of the ink in the top ten-micron range. However, because the colourant is fixed to the surface, it is directly exposed to light and pollution, making it susceptible to dye decomposition. By giving the dyes a polymer layer or surface coating, one can increase their light-fastness [19].

2.2 Colour cast

A colour cast is a tint of a specific colour, typically undesired, that uniformly affects an entire or a portion of a photographic image. A colour change that isn't desired throughout the entire image may be brought on by neighbouring objects' reflected light. For instance, photos taken under fluorescent illumination frequently have a greenish tint. A colour cast is a discernible colour tint to an image, typically one that is undesirable. They happen when the white balance is off or when light is tainted with colour, such as when it bounces off of a coloured surface.

Anything neutral, e.g., white, is very helpful to spot colour. Colour is detected easily in the highlight portion of the image as compared to shadows [20] There are three categories of colour casting in the images: intrinsic, actual, and no casting. There is an intrinsic colour cast in the image since a large portion of it is made up of the same or closely related colours. The white balance algorithm must be used on the test image if it is determined to have actual cast. Cast detection is typically not included in white balance algorithms [21].

Printed sheets may exhibit a colour cast when exposed to certain types of light. Using diverse colour temperature light sources to illuminate a subject will typically result in colour cast issues in the shadows. Because our eyes and brains can accommodate different types of light in ways that cameras cannot, the human eye typically does not detect odd colour. Old images may also have colour casts from dye fading, especially when exposed to ultraviolet radiation. These might be fixable using image editing methods on a scanned copy of the picture [22].

Colour cast in colour printing refers to an undesirable tint of any colour. Colour cast can be subjectively perceived. Human perception and eyesight are key factors. While the human eye is capable of detecting some colours, it is less adept at doing so with others [23].

2.3 Colour Non-Uniformity

The term "colour non-uniformity" describes variances in the print's colour or density. Colour irregularity is sometimes referred to as "visual banding." The amount of light reflected by the ink is used to determine its density. If the ink layer thickness is not uniform for some reason, the amount of reflected light that reaches the sensor fluctuates, which affects the density values [23,24,25] To ensure that the printed output will conform as shown by the colour bar for each press, print consistency has a fundamental impact on both the optimization of process goals and the value of these proxy measurements [26] The variability of the ink density should, in theory, affect how much a printing job costs. Jobs printed with little variation, which translates to more accurate colour, should cost more than jobs printed with a lot of variation or with less accurate colour. Print customers prefer the most consistent and precise colour. Tolerances that allow for the comfortable positioning of the innate process variations are what printers want. The issue is that, frequently, neither printers nor customers are aware of the press's inherent variability throughout the printing plane and across prints; instead, they only pay attention to the variety of the colour bars [26].

2.4 Graininess

Graininess in inkjet printing refers to the visual appearance of dots. Graininess or noise is a very common defect in inkjet printing. Both macroscopic and microscopic levels of graininess are possible. The halftone regions of a print are where graininess is most noticeable. It happens as a result of the non-randomization of dots. If 200% solid colours in a range of tones are used in the test chart, graininess may be determined accurately [23, 24, 27] Vision in humans in the printing industry places a high value on perceptible image noise. Two types of image noise that are particularly important are mottling (low frequency noise) and graininess (high frequency noise). The ink-jet printing sector has placed a lot of emphasis on reducing image noise (graininess and mottle) in single colours. Image noise, however, may be significantly worse for multicolour images. One explanation is that, for patches of single colours, ink-paper interactions dominate the image noise [10,27].

However, when printing in multiple colours, ink drops of a different colour may overlap with ink layers of a prior colour. Ink-ink interaction that results from this can produce intricate, high-frequency ink flow patterns that can appear as perceptible image noise [10,27].

The physical process of ink-jet printing is complicated. In a printer, noise can come from a variety of places, including variations in drop size, drop velocity, drop direction, and noise related to the paper.

2.5 Hickey

Small deformities, specks, or other defects that appear on a page, cover, or spine as a result of the printing or reproduction process are known as hickies and spots [28]. They typically look like dots with rings around them. Sometimes they are only a spot of colour that is absent. In any case, an image is missing. Whether the lack of image is in the area surrounding the dot or on the dot itself [29]. The majority of the time, hickies are caused by dust, ink, or paper in the environment [29]. Ink Hickeys are brought on by substances that are conveyed by the ink and not by paper-derived particles. Hickeys may be caused by ink skin fragments, uncooked ink resin, or rubber roller parts from a dried-out or decaying roller rubber ink roller [30]. Hickeys can be of two different types: In a printed area, void hickeys are empty, unprinted spaces. Doughnut hickeys are circular unprinted areas encircled by solid printed portions [31].

2.6 Moiré

When halftone screens are printed on top of one another at the wrong screen angles, undesirable patterns known as moiré are produced. When rescreening a single-colour halftone or screening an original halftone that has patterned items, moiré may also occur (e.g., fabrics). Avoidable moiré is moiré that results from subpar manufacturing practices as opposed to the process's inalienable constraints (e.g., 15-degree yellow screen angle, rescreened halftones) [28]. Halftone printing is required for colour images. The three primary colour halftones plus a grey halftone are typically used to print a colour image in practice. A colour graphics grey scale (or brightness) can be produced by a grey halftone more effectively than by mixing the three basic colours [31].

In all devices that are not capable of actually rendering the continuous data directly onto paper, an intermediate halftoning step has to be performed. The best-known halftoning process is the conventional rotated dot halftoning as it is found in every magazine or newspaper photo. Other halftoning methods include stochastic halftoning, adaptive halftoning, or even iterative halftoning schemes. The angles between the different colour separations have to be precisely controlled, or moiré will occur [31].

The two most common types of colour moiré that affect print quality are. The first is a colourant moiré, which is frequently seen between the colours yellow and cyan or yellow and magenta. The superposition of the colours cyan, magenta, and black results in the second moiré, which is typically more unsettling. It should be noted that the printing materials' unwanted absorption is what causes moiré. Only the black separation would interact with the other separations in "perfect" inks, preventing any of the described two- or three-colour moiré from happening [31].

3. Research Objective

Printability is one of the fundamental requirements to enhance the production capabilities in any printing process. Different types of papers are available in the market to suit various end requirements. Printability is largely affected by the type and structure of the paper to be used as well as the different print quality parameters of the image to be printed. Different papers yield different print results when printed with inkjet printing thus yield varying print quality output.

In this research study focus is laid upon different print quality related factors (colour cast, colour non-uniformity, graininess, hickeys and moiré) in relation to determine the printability aspect of different inkjet heads (PIJ, TIJ) on various grades of paper. The print quality factors considered in the present study are measured by standard observer method. The colour non-uniformity can be measured by two methods; visually and measuring devices. In the present study standard observer method has been adopted for the assessment of all print quality factors. The objective of this research is to study and evaluate various print related factors on uncoated, gloss coated and matt coated papers which are frequently used in inkjet printing.

4. Research Methodology

Three types of papers under uncoated and coated category; Uncoated (90 gsm), Matt coated (90 gsm) and Gloss coated (88 gsm) were selected to print in piezo and thermal inkjet print heads. Collected papers were tested in a standard paper testing lab. A standard test master including various elements to measure print quality was prepared. Various elements like colour control bar, gray scale, lines, solids, tints were incorporated in the test master. The printing of the test master on the selected papers (uncoated, matt coated and gloss coated) was carried out on DOD presses based on piezo DOD inkjet (Oce Canon (Kyocera KJ4B), and thermal DOD Hewlett Packard (A53 HDNA). The methodology adopted for the study consists of the following stages;

Paper Selection and Testing: Four samples of paper in each category (Uncoated, matt coated, Gloss coated) were collected and tested for their surface properties in a standardized testing laboratory. Out of four samples in each category the papers with nearest values to ISO 12647-2 were finally selected and used for printing work under piezo and thermal inkjet print heads. The characteristics of papers are shown in table.1 measured in calibrated paper testing laboratory.

Sr. No.	Property	Standard Procedure	Unit	Direction	Sample 1 (matt coated)	Sample 2 (Gloss coated)	Sample 3 (Uncoated)
1	GSM	Tappi Test Method T 410	g/m^2	-	90.8	88.0	90.9
2	Thickness	IS: 1060:1	um	-	64	56	99
3	Burst Factor	IS: 1060:1	-	-	15.8	14.8	14.3
4	Cobb value	IS: 1060:1	g/m^2	Top	35.7	30.0	45.7
				Bottom	33.5	27.4	44.1
5	L*	T 524	-	-	86.6	85.5	79.3
6	a*	T 524	-	-	1.1	0.8	1.2
7	b*	T 524	-	-	-13.5	-11.0	-13.9
8	Porosity	T 547	ml/min	-	127.8	108	140
9	Roughness	ISO 8894	ml/min	Top	11.9	10.0	14.9
				Bottom	11.3	9.5	17.5

Table 1 Characteristics of Paper Samples

Test Chart Preparation and Selection of Standard Observers: - A test chart was prepared in Corel Draw Graphics Suite 2020 with the help of various elements i.e., line, text, solids, fine lines, gray scale and ISO images. The colour control having C, M, Y, K solids,40 %- 80% tint areas, slur patches and RGB were selected for the preparation of master test chart. The test master used in this study is shown in Figure 3.

Figure 3 Test Master used for Printing

Twenty observers participated in the experiment, all had normal vision without any visual deficiency based on the FM100 hue test. Subjective approach was adopted to measure the print related factors. The print quality was evaluated on the Likert Scale in the 1-5 reading, where "1" denoting the minimum and "5" as the maximum value of that particular print quality factor. Any reading in between these values denotes the medium range. For example; the colour cast was assessed on a Likert scale of 1 to 5 as "1" for no colour cast observed, "2" for low colour cast observed, "3" for moderate colour cast observed, "4" for significant colour cast observed and "5" for high colour cast observed. All other print quality factors were also observed on the same scale.

Based on responses from the observers the results are represented in tabular format with the standard deviation and the same is represented in graphical format to evaluated different print related factors in the piezo and thermal inkjet.

The samples were tested under standard D-50 lighting conditions and with a magnifying glass (Techkon Dens).

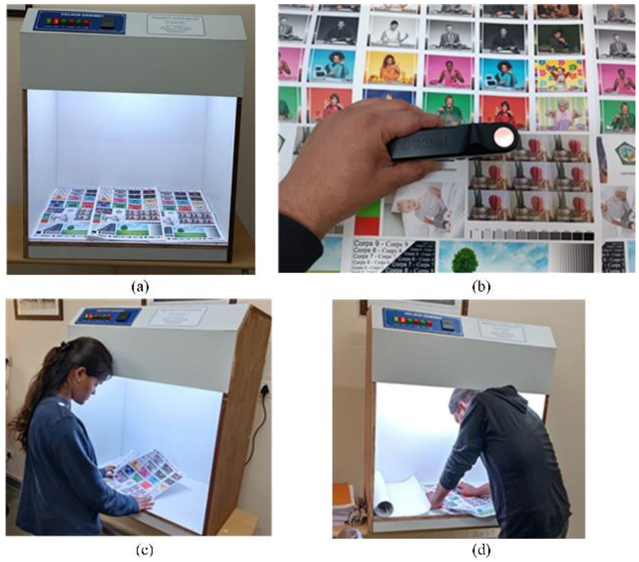


Figure 4 Image testing a) Colour matching booth b) Magnifying glass c) and d) Observers looking at the prints

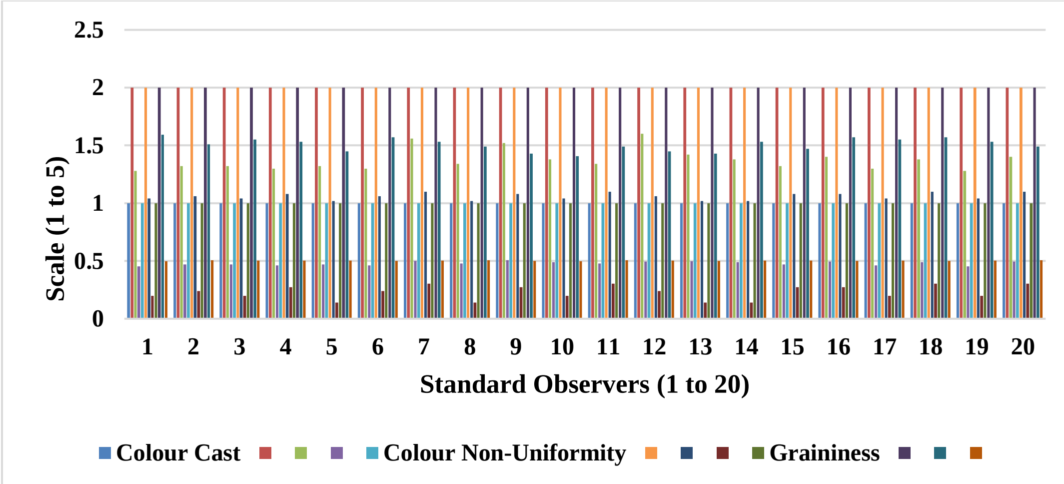
Printing Work: - The printing of the test master on the selected papers (uncoated, matt coated and gloss coated) was carried out on DOD presses based on piezo DOD inkjet (Oce Canon (Kyocera KJ4B), and thermal DOD Hewlett Packard (A53 HDNA) under the standard pressroom conditions on calibrated machines by highly professional operators.

5. Printability testing and data collection

For testing the printability of the inkjet heads on different varieties of paper substrates the printed sheets were presented to the selected standard observers for visual evaluation. The observers were asked to test and give ratings for different prints i.e. print technology and paper type as well. The sheets were printed using piezoelectric and thermal inkjet using three different types of papers i.e. uncoated, matt coated and gloss coated. Each observer has to test total of 6 sets of test prints to judge different factors. Each set is comprised of 50 sheets printed with different inkjet technologies on various types of papers.

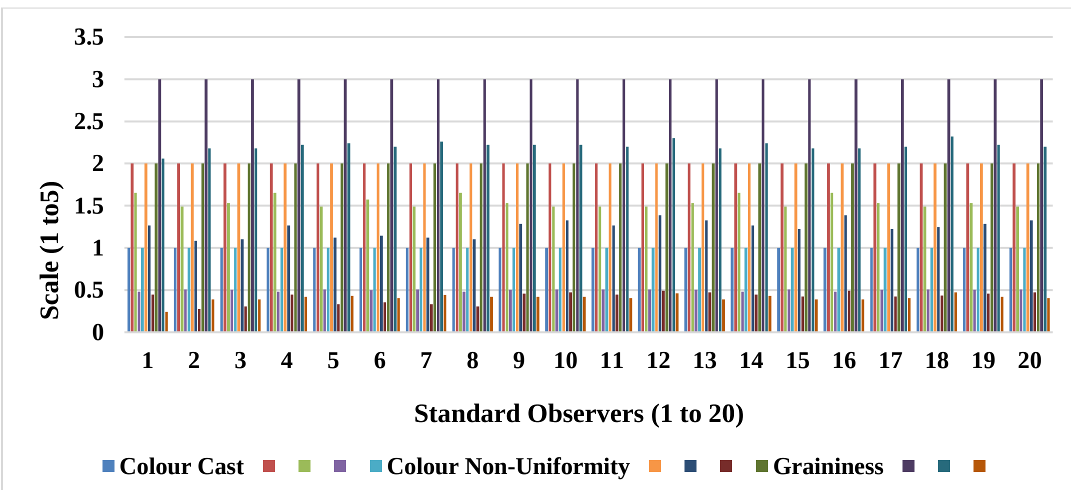
The standard observer values, comprising minimum, maximum, average, and standard deviation for 50 printed sheets of various types of papers, are presented in a suitable graphical format. The print quality factors i.e., colour cast, colour non uniformity, graininess and hickeys and moire were observed visually in order to evaluate the printability of DOD inkjet heads on various grades of paper. Because hickeys and moiré were not observed in digital presses, particularly inkjet, they are not represented in the graphs below.

The observer's responses were collected on different factors (as discussed in previous sections). The average response for each printed sheet from each observer is taken for further analysis. The average response is plotted as bar charts for easy understanding. The Graph 1, Graph 2, Graph 3, Graph 4, Graph 5 and Graph 6 are showing the observers average responses on each type of papers with different print heads.



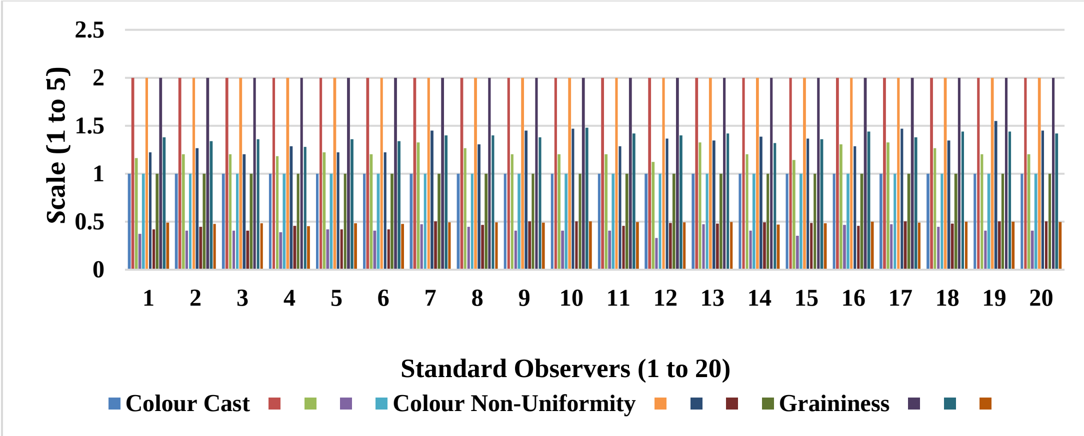
Graph 1. (Piezoelectric Inkjet, Uncoated Paper)

From the responses recorded on a Likert scale of 1 to 5, the average values of colour cast, colour non-uniformity, and graininess on uncoated paper printed with the piezoelectric inkjet print head are 1.37, 1.05, and 1.50, respectively. On uncoated paper, the value ranges from 1.28 to 1.56 for colour cast, 1.02 to 1.1 for colour non-uniformity, and 1.41 to 1.59 for graininess with a standard deviation of 0.48, 0.22 and 0.50 respectively.



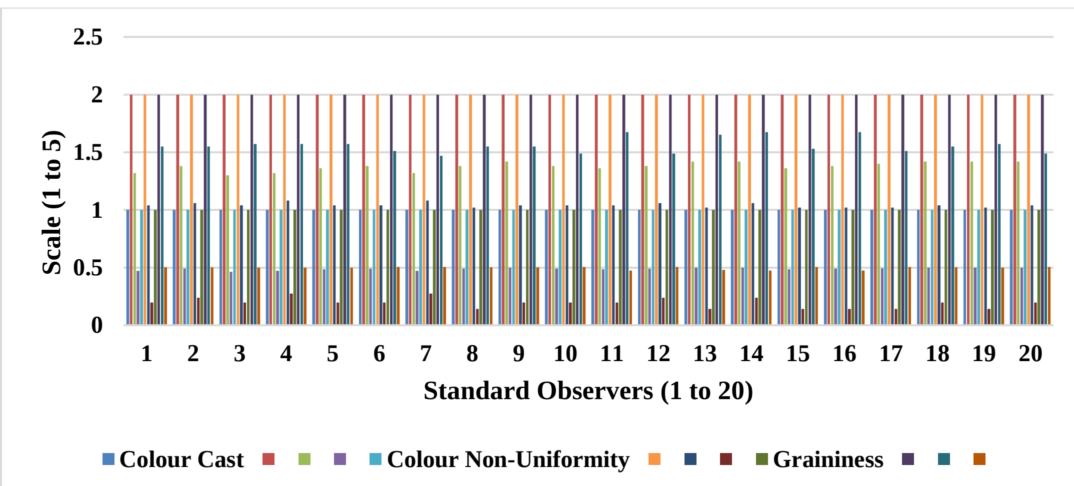
Graph 2. (Piezoelectric Inkjet, Matt Coated Paper)

Graph 2, shows the average values of colour cast, colour non-uniformity, and graininess on matt-coated paper printed with the piezoelectric inkjet print head. The values for colour cast, colour non-uniformity, and graininess are 1.54, 1.24, and 2.21 respectively on a Likert Scale of 1 to 5. On matt-coated paper, the value ranges from 1.00 to 2.00 for colour cast and colour non-uniformity and 2.00 to 3.00 for graininess with an average standard deviation of 0.50, 0.41 and 0.41 respectively.



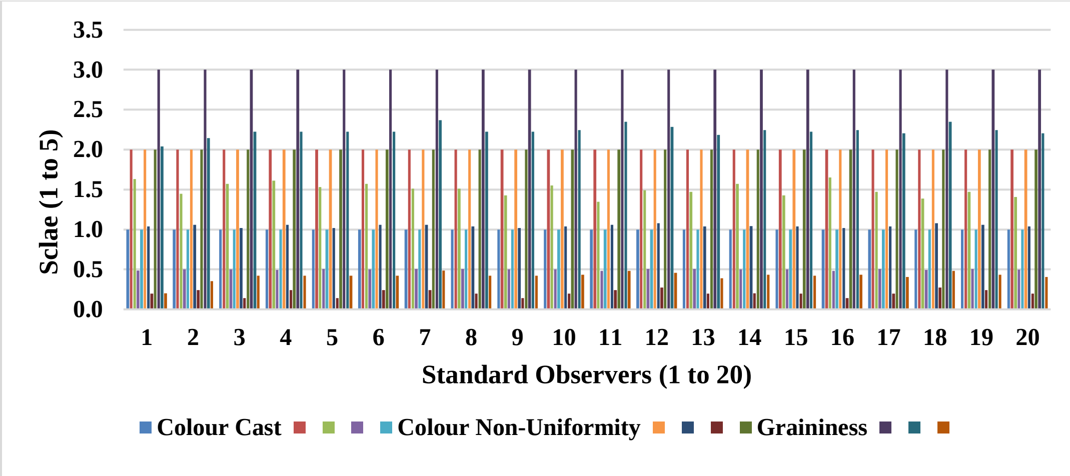
Graph 3. (Piezoelectric Inkjet, Gloss Coated Paper)

Graph 3 shows that the average values of colour cast, colour non-uniformity, and graininess on gloss coated paper printed with a piezoelectric inkjet print head are 1.22, 1.35, and 1.39 respectively. On gloss coated paper, the standard deviation values for colour cast, colour non-uniformity, and graininess are 0.42, 0.47, and 0.49, respectively.



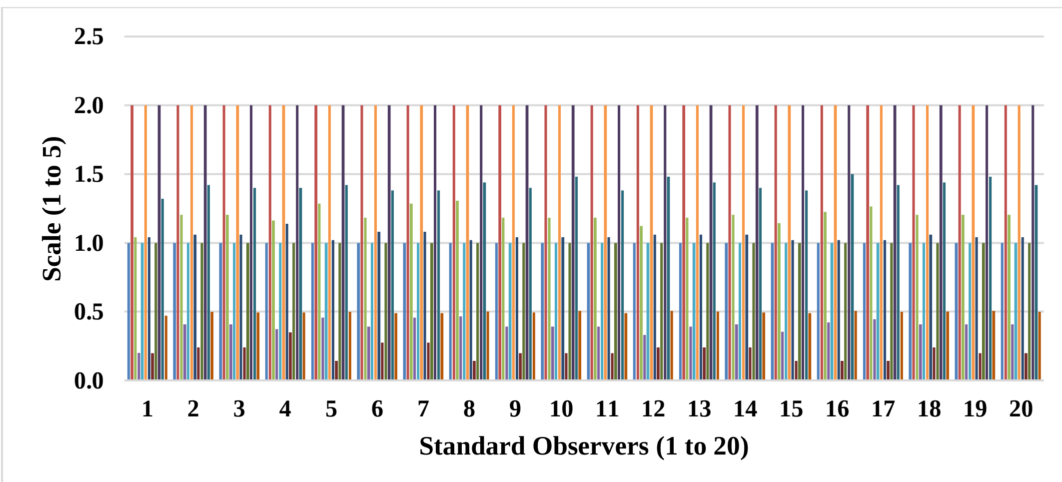
Graph 4. (Thermal Inkjet, Uncoated Paper)

Graph 4, shows the average values of colour cast, colour non-uniformity, graininess on uncoated paper printed under thermal inkjet print head are 1.38, 1.04 and 1.56 respectively on a Likert Scale of 1 to 5. On uncoated paper, the value ranges from 1.0 to 2.0 each for colour cast, colour non-uniformity and graininess with standard deviation of 0.49, 0.19 and 0.50 respectively.



Graph 5. (Thermal Inkjet, Matt Coated Paper)

On a 5-point Likert scale, Graph 5's average values for colour cast, colour non-uniformity, and graininess on matt coated paper printed with a thermal inkjet print head are 1.50, 1.05, and 2.23, respectively. On matt-coated paper, the values of colour cast, colour non-uniformity from 1.00 to 2.00 while the values of graininess ranges from 2.00 to 3.00, with standard deviations of 0.50, 0.21, and 0.42 respectively.



Graph 6. (Thermal Inkjet, Gloss Coated Paper)

Graph 6, shows that the average values of colour cast, colour non-uniformity, graininess on gloss coated paper printed with the thermal inkjet print head are 1.20, 1.05 and 1.42 respectively on a Likert Scale of 1 to 5. On gloss coated paper, the value ranges from a minimum value of 1.00 to a maximum value of 2.00 for colour cast, colour non-uniformity and graininess with standard deviation of 0.40, 0.21 and 0.50 respectively.

6. Results and Discussions

The standard observer data is processed for the purpose of comparison. The processed data consist of minimum, maximum, average, and standard deviation. The mean value of minimum, maximum, average, and standard deviation are presented from table 2 to 7 for all test prints. The print quality factors i.e., colour cast, colour non uniformity, graininess and hickeys and moire were observed visually in order to evaluate the printability of DOD inkjet heads on various grades of paper. The hickeys and moiré were not observed in digital presses, particularly inkjet, hence, they are not represented in the tables below. The subcategories are combined and represented as single category for colour non-uniformity and graininess.

	Print Quality Factors		
	Colour Cast	**Colour Non-Uniformity**	**Graininess**
Min	1.00	1.00	1.00
Max	2.00	2.00	2.00
Average	1.37	1.06	1.51
SD	0.48	0.23	0.50

Table 2 Minimum, maximum, average and SD values on Uncoated, 90 GSM paper, Piezoelectric Inkjet(PIJ)

From the Table 2, it is observed that on a Likert scale of 1 to 5, the average values of colour cast, colour non-uniformity, and graininess on uncoated paper printed with the piezoelectric inkjet print head are 1.37, 1.06, and 1.51 respectively. On uncoated paper, the value ranges from 1.0 to 2.0 for colour cast, colour non-uniformity, and graininess with a standard deviation of 0.48, 0.23 and 0.50 respectively. As the average values lies between "no colour cast" and "low colour cast" and also the values are very close to the minimum values on the selected Likert's scale thus the results clearly show that colour cast and colour non-uniformity are very low in the case of uncoated paper, while graininess value of 1.51 lies in middle of the "no graininess" and "low graininess".

The average values of colour cast, colour non-uniformity, and graininess on matt-coated paper printed under piezo DOD inkjet are given in the Table 3. The data shows that the matt-coated paper exhibits the perceived values towards the lower middle ranges.

	Print Quality Factors		
	Colour Cast	**Colour Non-Uniformity**	**Graininess**
Min	1.00	1.00	2.00
Max	2.00	2.00	3.00
Average	1.54	1.24	2.21
SD	0.50	0.41	0.41

Table 3 Minimum, maximum, average and SD values on Matt Coated, 90 GSM paper, Piezoelectric Inkjet(PIJ)

The observations from the Table 3 shows that the average values of colour cast, colour non-uniformity, and graininess on matt-coated paper printed with the piezoelectric inkjet print head are 1.54, 1.24, and 2.21 respectively on a Likert Scale of 1 to 5. On matt-coated paper, the value ranges from 1.00 to 2.00 for colour cast and colour non-uniformity, and 2.00 to 3.00 for graininess with a standard deviation of 0.50, 0.41 and 0.41 respectively. The results demonstrate that negligible colour cast and colour non-uniformity was observed on matt-coated paper while graininess is towards the lower mid-range. Hence matt coated papers have good colour uniformity and colour cast is not prominently visible. The print quality is smooth and the graininess is slightly visible due to the matt coated surface of the paper.

Table 4 presents the mean values observed of the various print quality factors on gloss coated paper. The data shows that the graininess observed is very low thus yielding smooth and vivid print quality.

	Print Quality Factor-		
	Colour Cast	**Colour Non-Uniformity**	**Graininess**
Min	1.00	1.00	1.00
Max	2.00	2.00	2.00
Average	1.22	1.35	1.39
SD	0.42	0.47	0.49

Table 4 Minimum, maximum, average and SD values on Gloss Coated, 88 GSM paper, Piezoelectric Inkjet(PIJ)

On a Likert scale of 1 to 5, the average values of colour cast, colour non-uniformity, and graininess on gloss coated paper printed with a piezoelectric inkjet print head are 1.22, 1.35, and 1.39 respectively. On gloss coated paper, the values for colour cast, colour non-uniformity, and graininess have standard deviations of 0.42, 0.47, and 0.49 respectively, and the minimum to maximum range from 1.00 to 2.00. According to the findings, colour cast, colour non-uniformity and graininess are on the lower end of the scale on gloss-coated paper. The print is of excellent quality. The values of assessed print quality factors on uncoated stock printed with thermal DOD inkjet head are given in Table 5. The data shows that there is no colour cast and no colour non-uniformity was observed on the uncoated stock printed with thermal DOD. Although uncoated paper showed slight presence of graininess due to its surface characteristics.

	Print Quality Factor-		
	Colour Cast	**Colour Non-Uniformity**	**Graininess**
Min	1.00	1.00	1.00
Max	2.00	2.00	2.00
Average	1.38	1.04	1.56
SD	0.49	0.19	0.50

Table 5 Minimum, maximum, average and SD values on Uncoated, 90 GSM paper, Thermal Inkjet (TIJ)

From the Table 5, it is observed that the average values of colour cast, colour non-uniformity, graininess on uncoated paper printed by thermal inkjet print head are 1.38, 1.04 and 1.56 respectively on a Likert Scale of 1 to 5. On uncoated paper, the value ranges from 1.0 to 2.00 for colour cast, colour non-uniformity and graininess with standard deviation of 0.49, 0.19 and 0.50 respectively. The results clearly show that colour cast and colour non-uniformity is very low in case of uncoated paper yielding consistent colour and negligible cast with slight graininess.

Table 6 shows the values of print quality factors on matt coated stock printed under thermal DOD inkjet head. The data shows that the colour uniformity is excellent on matt coated stock with minimal standard deviation of 0.21.

	Print Quality Factor-		
	Colour Cast	**Colour Non-Uniformity**	**Graininess**
Min	1.00	1.00	2.00
Max	2.00	2.00	3.00
Average	1.50	1.05	2.23
SD	0.50	0.21	0.42

Table 6 Minimum, maximum, average and SD values on Matt Coated, 90 GSM paper, Thermal Inkjet (TIJ)

The results from Table 6 clearly indicate that the no colour cast and colour variation was observed except on a few sheets where slight presence was observed. The average values of colour cast, colour non-uniformity, and graininess on matt coated paper printed with a thermal inkjet print head are 1.50, 1.05, and 2.23 respectively on a Likert scale. The values of colour cast, colour non-uniformity from 1.00 to 2.00 while the values of graininess ranges from 2.00 to 3.00, with standard deviations of 0.50, 0.21, and 0.42 respectively.

Table 7 presents the observed values of print quality factors on gloss coated stock printed under thermal DOD inkjet head. The data shows that the colour cast, colour uniformity and graininess values are very low on gloss coated stock with minimal standard deviation of 0.21 for colour non-uniformity.

	Print Quality Factor-		
	Colour Cast	**Colour Non-Uniformity**	**Graininess**
Min	1.00	1.00	1.00
Max	2.00	2.00	2.00
Average	1.20	1.05	1.42
SD	0.40	0.21	0.50

Table 7 Minimum, maximum, average and SD on Gloss Coated, 88 GSM paper, Thermal Inkjet (TIJ)

The average values of colour cast, colour non-uniformity, graininess on gloss coated paper printed with the thermal inkjet print head are 1.20, 1.05 and 1.42 respectively on a Likert Scale. On gloss coated paper, the value ranges from 1.00 to 2.00 for colour cast, colour non-uniformity and graininess with standard deviation of 0.40, 0.21 and 0.50 respectively. The results demonstrate that colour non-uniformity, colour cast and graininess is towards the lower range on gloss coated paper. Hence gloss coated papers shows excellent colour uniformity. The print quality is very smooth and the graininess is negligible with no colour cast observed.

The print quality factors considered in this research study are very detrimental for establishing a relationship with the printability of various substrates. The study analysed the print quality factors of inkjet prints on various grades of paper using Piezoelectric and Thermal DOD inkjet heads. The results show that uncoated paper printed with Piezoelectric DOD inkjet head has very low colour cast and colour non-uniformity, with slight graininess because inkjet inks are very thin and volatile and hence the porous nature of the substrate has a direct impact on the smoothness of the print. Ink particles get quickly absorbed in the pores of the paper, which affects the smoothness of the print and makes some grainy structure visible under both print heads. Matt-coated paper exhibited good colour uniformity with negligible colour cast and colour non-uniformity, and slightly visible graininess. Under the thermal inkjet print head, the colour consistency is excellent, but there is the presence of graininess in some printed sheets. That can be attributed to the matt nature of the coating, which is matt. Gloss-coated paper yielded excellent print quality with very low colour cast, colour non-uniformity, and graininess.

7. Conclusions

A key element in enhancing the production potential or making the best use of the printing process is its printability. To ensure good printability; the ink, and substrate to be printed must have good compatibility with each other. For optimum printability, the substrate's surface energy must be greater than the ink's surface tension. The substrate's characteristics, specifically its porosity and surface conditions, have direct impact on printability. Printability is a result of permeability, which is induced by porosity of the printing substrate. It essentially establishes how well the substrate can absorb inks and varnishes. Based on the results presented in Tables 2 to 7, it can be concluded that the print quality factors, namely colour cast, colour non-uniformity, and graininess, vary depending on the type of paper and the type of inkjet head used. Uncoated paper printed with piezoelectric inkjet heads exhibited very low levels of colour cast and colour non-uniformity, while the graininess was slightly visible. On the other hand, matt-coated paper exhibited negligible colour cast and colour non-uniformity, but the graininess was towards the lower mid-range. Gloss coated paper yielded excellent print quality with very low levels of colour cast, colour non-uniformity, and graininess. Moreover, it was observed that thermal DOD inkjet heads produced prints with no colour cast and colour non-uniformity on uncoated paper, but slight graininess was present. It is also important to note that hickeys and moire were not observed across the printed sheets.

References:

1. Niga, P., Örtegren, J., Alecrim, V., Klaman, M., Blohm, E., & Lofthus, J. (2012). Hybrid printing: paper media for combined flexographic and inkjet printing. In *2012 International Paper Physics Conference, Stockholm, June 10-14, 2012* (pp. 79-81). Innventia.
2. Mills, R. N. (1994). Ink Jet Printing-Past, Present and Future (Focal). In International Congress on Advances in Nonimpact Printing Technologies (pp. 410-413).
3. Future of Inkjet Printing (Tech.). (n.d.). Available at: https://www8.hp.com/h20195/v2/GetPDF.aspx/4AA7-4499EEE.pdf
4. M. A. Shah, D. -G. Lee, B. -Y. Lee and S. Hur, "Classifications and Applications of Inkjet Printing Technology: A Review," *IEEE Access*, vol. 9, pp. 140079-140102, 2021.
5. Uddin MJ, Hassan J, Douroumis D. "Thermal Inkjet Printing: Prospects and Applications in the Development of Medicine," *Technologies*. vol. 10, no. 5, pp. 108, 2022.
6. Singh, M., Haverinen, H.M., Dhagat, P. and Jabbour, G.E. "Inkjet Printing—Process and Its Applications," *Advanced. Materials*, vol. 22, pp. 673-685, 2010.
7. Bernasconi, R., Brovelli, S., Viviani, P., Soldo, M., Giusti, D. and Magagnin, L. (2022), Piezoelectric Drop-On-Demand Inkjet Printing of High-Viscosity Inks. Advanced Engineering Materials, 24: 2100733.
8. T.C. Gomes, C.J.L. Constantino, E.M. Lopes, A.E. Job, N. Alves, Thermal inkjet printing of polyaniline on paper, Thin Solid Films, Volume 520, Issue 24, 2012,

9. Tse, M. K., Klein, A. H., & Briggs, J. C. (1998). Automated print quality analysis in inkjet printing: Case study using commercially available media. Proc IS&T's NIP14, 167-171.
10. Pedersen, M., Bonnier, N., Hardeberg, J. Y., & Albregtsen, F. (2010). Attributes of image quality for colour prints. Journal of Electronic Imaging, 19(1), 011016-011016.
11. S. Kumar and A. K. Baral, "Critical Analysis of Print Quality Factors (Hue Error and Print Contrast) in Piezoelectric Inkjet Press on Matt Coated and Gloss Coated Cellulosic Substrates," 2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), Greater Noida, India, 2022, pp. 1948-1952, doi: 10.1109/ICACITE53722.2022.9823474.
12. Gigac, J., Stankovská, M., Letko, M., & Opálená, E. (2014). The effect of base paper properties on inkjet print quality. *Wood Research*, *59*(5), 717-730.
13. Hudd, A. (2010). Inkjet Printing Technologies (pp. 3-18). World Scientific Publishing, Hackensack, NJ, USA.
14. Lau, G. K., & Shrestha, M. (2017). Ink-Jet Printing of Micro-Electro-Mechanical Systems (MEMS). Micromachines, 8(6), 194.
15. Askeland, R. A. (2015). Inkjet Print Engines. Handbook of Digital Imaging, 1-31.
16. Hudd, A. (2010). Inkjet Printing Technologies (pp. 3-18). World Scientific Publishing, Hackensack, NJ, USA.
17. Uddin, M. J., Hassan, J., & Douroumis, D. (2022). Thermal Inkjet Printing: Prospects and Applications in the Development of Medicine. Technologies, 10(5), 108.
18. Kumaraguru, K., Rengasamy, M., Kumar, E. T. P., & Venkadesh, D. (2014). Factors Affecting Printing Quality of Paper from Bagasse Pulp. International Journal of Chemtech Research, 6(5), 2763-2767.
19. des Stabilitätsverhaltens, T. Z. U. (2001). Stability Issues and Test Methods for Ink Jet Materials (Doctoral dissertation, Fachhochschule Köln).
20. Mireles, A. (2022, January 21). What are Colour Casts and How to Avoid & Fix Them. Shotkit. Retrieved September 6, 2022, from https://shotkit.com/colour-casts.
21. Lin, S. F., Chen, H. T., & Lin, T. H. (2011). Colour Casts Detection and Adjustment. International Journal of Computer Science Issues (IJCSI), 8(4), 13.
22. Colour cast - Wikipedia. (2020, July 1). Colour Cast - Wikipedia. Retrieved October 6, 2022, from https://en.wikipedia.org/wiki/Colour_cast
23. Gast, G.; Tse, M. K.; A Report on a Subjective Print Quality Survey Conducted at NIP16. in NIP & Digital Fabrication Conference (Vol. 2001, No. 2, Pp. 723-727). Society for Imaging Science and Technology (2001, January).
24. Pedersen, M., Bonnier, N., Hardeberg, J. Y., & Albregtsen, F. (2011, January). Image Quality Metrics for the Evaluation of Print Quality. In Image Quality and System Performance Viii (Vol. 7867, Pp. 11-29). SPIE.
25. Lundberg, A.; Örtegren, J. Ö.; Alfthan, E.; Ström, G.; Ink Interactions: Microscale Droplet Absorption into Paper for Inkjet Printing. Nordic Pulp & Paper Research Journal, 26(1), 142-150 (2011).
26. Abdel Motaal, S. A. (2014). Spatiotemporal Variability: Process-Independent Analysis of Printing Uniformity.

27. Chen, Q.; Ramesh P.; Liu, C. H.; Allebach, J. P.; (2020, October) Ink Flow Patterns in Multi Colour Inkjet Images and their Impact on Graininess Noise. In 2020 IEEE International Conference on Image Processing (ICIP) (PP. 2561-2565). IEEE.
28. GPO Contract Terms. (2001, March 1). In Quality Assurance through Attributes Program for Printing and Binding, 1996, April. https://doi.org/10.1604/9780160616976
29. Profile, V. (n.d.). How to Troubleshoot Hickeys on Your Press. Retrieved March 6, 2021, from http://www.offsetprinting.info/2011/04/how-to-troubleshooting-hickeys-on-your.html
30. Liu, X. (1996). Analysis and Reduction of Moire Patterns in Scanned Halftone Pictures (Doctoral Dissertation, Virginia Polytechnic Institute and State University)
31. Balasubramanian, R., & Eschbach, R. (2001). Reducing Multi-Separation Colour Moiré by A Variable Undercolour Removal and Gray Component Replacement Strategy. Journal of Imaging Science and Technology, 45(2), 152-160.