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COMPARATIVE STUDY OF SID AND INK TRAPPING IN VIRGIN AND RECYCLED PAPER USING UV INKJET PRINTING

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ABSTRACT
This study investigates how virgin paper and recycled paper affect the quality of prints by comparing the Solid Ink Density (SID) and Ink Trapping values using the cyan, magenta, yellow and black (CMYK) inks in UV inkjet printing. Virgin and recycled paper are used for the study that has same grammage of 80 GSM, but they have different fillers contents in them. Spectrophotometer is used to take measurements at room temperature condition. The results indicate that recycled paper produced higher SID values, this can be due to increased porosity and higher ink absorption which allows more ink to be absorbed in recycled paper, whereas the virgin paper achieved slightly greater Ink Trapping performance because of uniform surface structure and superior ink holdout properties of virgin paper. Overall, the prints on recycled paper are darker and more saturated, while those on virgin paper provided better colour reproduction and better colour strength. The differences between the two substrates were relatively small and fell within acceptable tolerance.
The findings result that recycled paper works well for general printing and doesn't cause major drop in print quality. This study strengthens the case for more sustainable printing methods. sustainable printing practices and aligns with Sustainable Development Goals (SDG 12, SDG 13, and SDG 15) by encouraging greater use of recycled materials and reducing our reliance on virgin wood pulp.
Key words: - Recycled paper, Virgin paper, Sustainability, Solid Ink Density, Ink Trapping, CMYK, Inkjet Printing, Sustainable Development Goals.

Introduction
Paper is one of the most commonly used substrates in the printing and packaging industries due to its flexibility and compatibility with various printing technologies. It is mainly composed of cellulose fibres obtained from different sources such as wood, bamboo, bagasse and recycled materials [1]. In recent years, growing environmental concerns and increasing sustainability requirements have increased the demand for recycled paper as an alternative to conventional virgin paper. Recycled paper is manufactured from recovered fibres that has been processed through multiple recycling cycles, this gradually reduce their mechanical strength. Repeated recycling can affect fibre morphology, resulting in increased porosity, reduced fibre bonding and variations in ink absorption characteristics [2] [3]. These structural modifications can influence key printing attributes, including (SID) Solid Ink Density, Dot Gain, Ink Trapping, Print Contrast and Grey Balance, therefore affecting overall print quality [4] [5].
Print attributes are important parameters used to evaluate print quality, printing system performance and substrate suitability, including paper and plastic materials. These attributes are generally classified into three categories: Visual, Technical and Measurable print elements. Among the measurable print quality parameters SID and Ink Trapping play an important role in analysing print performance [6] [7]. Solid Ink Density (SID) refers to the optical density of a 100% solid ink patch and represents the thickness and strength of the printed ink film. It is considered an essential parameter because it establishes the fundamental printing condition upon which several other print quality characteristics depend. Similarly, Ink Trapping refers to the ability of a subsequently printed ink layer to adhere effectively over a previously printed wet ink film. The evaluation of Ink Trapping

is important because it determines the quality of secondary colour formation, colour strength and overprint efficiency. Ink Trapping is commonly measured using the Preucil formula, which quantifies the effectiveness of ink transfer between successive layers [8].

UV Inkjet printing is a non-contact digital printing technology that operates using drop-on-demand piezoelectric systems, it is widely adopted for industrial printing applications due to its compatibility with UV-curable inks and ability to print on a broad range of substrates. This technology enables the precise deposition of ink droplets onto the substrate surface without direct mechanical contact, thereby improving image formation and print accuracy. In UV Inkjet printing, specially formulated UV-curable inks solidify instantly upon exposure to ultraviolet radiation, resulting in rapid curing, enhanced print durability and improved print quality across different substrate types [9] [10].

This research also contributes to SDG (sustainable development goals), SDGs are a collection of 17 global objectives introduced by the United Nations to promote sustainable development and improve social, economic and environmental well-being worldwide. These goals were developed to address significant environmental challenges, including environmental degradation, climate change, education, health and responsible use of natural resources, this study is primarily associated with resource SDG 12, SDG 13 and SDG 15, SDG 12 stands for "Responsible Consumption and Production", this focuses on efficient resource utilization and minimizing waste generation through sustainable production practices, SDG 13 emphasizes reducing greenhouse gas emissions, improving efficiency, adopting sustainable production methods and strengthening resilience against climate-related challenges, SDG 12 promotes resource efficiency, reduce through reuse and recycling excessive consumption of raw materials, encourage waste reduction and support environmentally responsible industrial practices [10] [5] [4].

Research objective

This research aims to evaluate the differences in SID and Ink Trapping performance between virgin paper and recycled paper printed by UV-Inkjet printer. Since virgin and recycled papers different in terms of surface characteristics, fibre morphology, porosity and ink absorption behaviour, these variations can directly influence print quality and overall printability [1] [12]. Recycled paper is increasingly being considered as a sustainable alternative to virgin paper, research comparing the print performance of both substrates using measurable print quality attributes is rarely available [8]. Therefore, a systematic comparative investigation is needed to understand the influence of substrate properties on print behaviour and to provide technical information for appropriate material selection in printing applications.

The comparative analysis of print attributes also aims to identify the substrate-related limitations that prevent recycled paper from achieving print quality comparable to virgin paper. By examining the specific properties responsible for variations in print performance, the research aims to provide a foundation for future improvements in recycled paper manufacturing. The results of this study may contribute to the development of improved recycled paper grades with better printability than virgin paper [10].

This study also supports SDG 12: Responsible Consumption and Production by promoting the efficient utilization of recycled materials in printing processes. further aligns indirectly with SDG 13: Climate Action, through the encouragement of reduced dependence on resource-intensive virgin paper production and SDG 15: Life on Land, by supporting the sustainable use of fibre-based resources and reducing pressure on forest ecosystems through increased acceptance of recycled paper in printing applications.

The primary objectives of this research are as follows:

- To measure and evaluate, solid ink density (SID) and Ink Trapping, for virgin and recycled paper substrates under identical UV-Inkjet printing conditions.
- To comparatively analyse the variation and performance range of print quality attributes between virgin and recycled paper in order to understand differences in printability, ink transfer behaviour and substrate ink interaction.
- To identify the substrate-related properties of recycled paper that may limit its print quality performance in comparison with virgin paper, thereby providing insights for future material development and process optimization aimed at improving print quality on recycled paper.
- To support Sustainable Development Goals (SDG) 12: Responsible Consumption and Production, SDG 13: Climate Action and SDG 15: Life on Land through efficient resource utilization and reduced dependence on virgin fibre-based materials.

Research methodology

For this research two paper substrates, namely virgin paper and recycled paper, were selected to evaluate their print performance under identical UV-Inkjet printing conditions. To ensure a fair comparison, both substrates were selected with the same grammage (80 GSM). The printing process was carried out using a Konica Minolta AccurioJet 30000, It is a UV-Inkjet based digital printing system that is widely used for industrial and commercial printing applications.

Machine Specifications

The technical specifications of the printing system used during the study are provided below:

- Supported paper size: 585 × 750 mm (B2+)
- Ink type: UV-curable ink
- Ink viscosity: 12–14 cP (centipoise)

UV-curable inks were selected for the experiment due to their rapid curing characteristics and minimal drying requirements on uncoated paper substrates. Unlike conventional inks, UV inks polymerize instantly upon exposure to ultraviolet radiation [13], thereby reducing drying-related variations and ensuring stable print reproduction throughout the experiment.

The measurement of print quality attributes was performed using an X-Rite Spectrophotometer operating under the M0 measurement condition [13], which is commonly used for evaluating prints produced with UV-curable inks. All measurements were conducted under controlled laboratory conditions at room temperature and in accordance with ISO-187 [14] standard environmental conditions, ensuring consistency and reliability in the measurement process.

Sample Preparation and Printing Procedure

To maintain experimental consistency, 50 printed sheets were produced for each substrate type, resulting in a total of 100 printed samples for comparative evaluation. Identical printing parameters were maintained for both virgin and recycled paper throughout the printing process to eliminate variations associated with machine settings and printing conditions. The test chart included all essential print control elements required for print quality evaluation, including SID patches, Ink Trapping overprint areas, pure black and CMY composite black strips and tonal patches ranging from 0% to 100%.

Each printed sheet from both virgin and recycled paper sets was evaluated using the spectrophotometer to obtain measurable print quality data. SID measurements were recorded from the 100% solid ink patches of cyan, magenta, yellow and black process colours. Ink Trapping values were measured using overprint patches formed by process colour combinations, specifically red

(magenta + yellow), green (cyan + yellow) and blue (cyan + magenta), to assess the efficiency of ink transfer and overprint acceptance between successive ink layers.

Standard Reference Values

Since specific standard reference values for SID and Ink Trapping under UV-Inkjet printing on uncoated virgin and recycled paper substrates are not readily available, the reference values provided in ISO 12647-2 for uncoated paper printing were considered for comparative evaluation in the present study. These standard values were used as a benchmark to assess print quality performance and to establish a consistent basis for comparison between virgin and recycled paper under identical printing conditions.

SID standards for uncoated paper according to ISO 12647-2 [15], Tolerance is ± 0.05

Cyan	Magenta	Yellow	Black
0.80	0.80-090	0.70-0.85	1.00-1.15

Ink Trapping standard according to ISO12647-2 [16], Tolerance is ± 5%

Ink colour	Trapping %
Red (Magenta + Yellow)	85
Green (Cyan + Yellow)	90
Blue (Cyan + magenta)	90

All measured data were recorded and organized in digital format using spreadsheets for systematic analysis. The collected data were used to compare the performance of recycled and virgin paper in different printing attributes. Statistical and comparative analysis methods are used to find variations in print quality parameters and to establish relationships between substrate properties and printing performance in virgin and recycled paper.

Data collection and analysis

Solid ink density, Ink Trapping data of 50 samples of each printed sheet of virgin and recycled paper are collected. These data were measured using an X-Rite spectrophotometer in normal room condition in D50 light at spectrophotometer filter of M0.

Solid ink density:

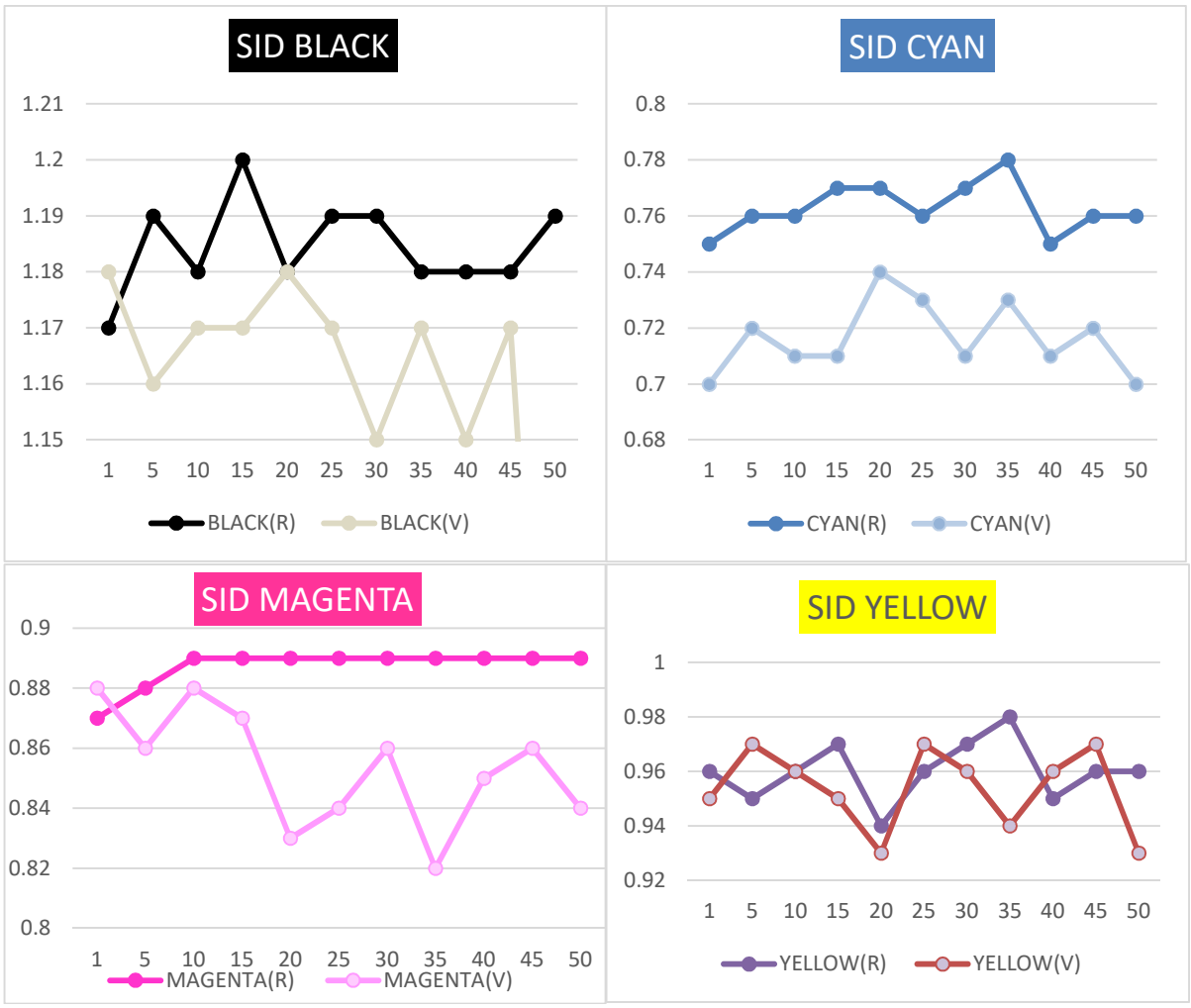

Fig: 5.1 Soid Ink Density (R-recycled paper, V-virgin paper)

The analysis of solid ink density (SID) for the four process colours: cyan, magenta, yellow and black (CMYK): indicates that recycled paper consistently exhibited comparatively higher ink density values than virgin paper across all colours. The average SID values recorded for virgin paper were 0.71 for cyan, 0.84 for magenta, 0.94 for yellow and 1.15 for black, whereas recycled paper demonstrated slightly higher average values of 0.76 for cyan, 0.88 for magenta, 0.96 for yellow and 1.18 for black. A noticeable increase in density was observed for cyan, magenta and black inks on recycled paper.

Ink Trapping:

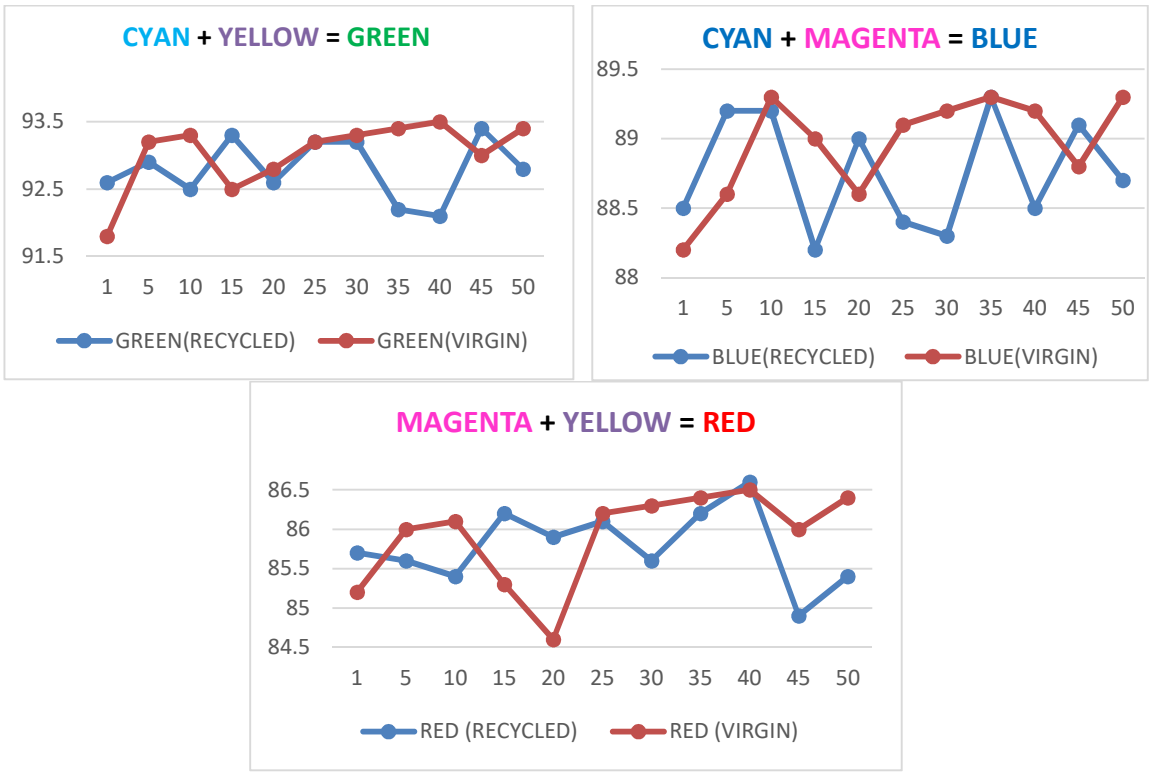

Fig: 5.3 Ink Trapping for Green, Blue, Red (R-recycled paper, V-virgin paper)

The analysis of Ink Trapping values exhibited consistent differences between recycled and virgin paper across the RGB overprint combinations. The average trapping values for recycled paper were: for red (magenta + yellow) 85, for green (cyan + yellow) 92.51, for blue (cyan + magenta) 88.80, whereas for virgin paper they are slightly higher: for red 86.03, for green 92.94 and for blue 88.86. This shows that virgin paper exhibits marginally better Ink Trapping performance for all colour combinations. Among the three, green (cyan + yellow) shows the highest trapping efficiency in both substrates, blue (cyan + magenta) and red (magenta + yellow) showed the lowest values.

Result and discussion

Based on the observations, it can be inferred that recycled paper exhibits comparatively higher ink absorption behaviour due to its fibre structure and surface characteristics, resulting in slightly increased SID values. The higher porosity and altered fibre bonding in recycled paper may facilitate deeper ink penetration into the substrate, thereby increasing optical density and producing a comparatively stronger ink appearance on the printed surface [17]. Virgin paper indicated comparatively better ink holdout properties, tonal stability and print consistency, particularly in solid printing areas. The smoother and less porous surface of virgin paper allows more controlled ink distribution and minimizes excessive penetration this contributes to stable colour reproduction and improved print uniformity [18]. In terms of Ink Trapping performance, the observations indicate that virgin paper provides comparatively better adhesion between successive ink layers due to its uniform surface and improved ink receptivity. Due to higher ink absorption and surface irregularities, recycled paper shows slightly reduced ability to support efficient transfer of next ink layers [19]. However, the measured differences in trapping values between virgin and recycled paper are relatively small, indicating that both substrates maintained acceptable and stable overprinting behaviour [20]. Although virgin paper demonstrated marginally superior print performance, the overall trapping quality of recycled paper may still be considered technically comparable for

practical printing applications [21].

These findings support the potential use of recycled paper as a feasible and environmentally responsible alternative to virgin paper, particularly when minor variations in print quality are acceptable [22]. The study aligns with Sustainable Development Goals, (SDG) 12: Responsible Consumption and Production by encouraging the effective utilization of recycled fibre-based materials in printing applications. Furthermore, the increased adoption of recycled paper may indirectly contribute to SDG 13: Climate Action through reduced reliance on resource-intensive virgin paper production and support SDG 15: Life on Land by reducing pressure on forest-based raw materials and promoting sustainable material utilization in the printing and packaging industry [11] [23].

Conclusion

The overall findings indicate that recycled paper exhibit higher SID, demonstrating good ink film density, colour strength and consistency which results darker and more saturated image in recycled paper than the virgin paper. Virgin paper exhibit slightly higher Ink Trapping values than the recycled paper which indicates accurate colour reproduction and colour strength in virgin paper. Although virgin paper showed slightly improved performance in terms of print quality, particularly for solid printing applications, the difference between the two substrates remained relatively small and within an acceptable tolerance range. The results suggest that the print quality achieved on recycled paper using UV-Inkjet printing is only marginally lower than that of virgin paper, making the variation practically negligible for most printing applications. Therefore, both virgin and recycled paper can be considered suitable for solid printing. However, recycled paper should be preferred because of sustainability considerations, as it supports resource utilization in efficient way and contributes to environmentally responsible printing practices without compromising print quality.

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