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INFLUENCE OF PRINTING SUBSTRATE CHARACTERISTICS ON INK TRAPPING BEHAVIOR

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Abstract

In offset printing, image reproduction is achieved using four process colors, black, cyan, magenta, and yellow, which are printed sequentially onto the printing substrate. This widely used printing technique enables high-quality and highly detailed image reproduction, and in order to evaluate print quality, several important qualitative parameters are analyzed.

One of the key parameters is ink trapping, which describes the ability of one ink to be accepted over another during the offset printing process. Ink trapping is expressed as a percentage, where higher values indicate better acceptance and adhesion of a subsequent ink layer over a previously printed one. This parameter depends on several interrelated factors that must be carefully balanced in order to achieve optimal print quality. These include ink tack (stickiness), the order in which colors are printed, the speed of the printing machine, and the physical and chemical properties of the printing substrate. Each of these factors can significantly influence the interaction between ink layers during the printing process.

In this study, three specific substrate characteristics were examined in detail: material absorbency, whiteness, and fluorescence of the printing substrate, and their influence on ink trapping behavior. The relationship between ink trapping and substrate characteristics can significantly contribute to the stability, consistency, and overall quality of the printed result. Four different printing substrates were used in the analysis: uncoated substrate, GC1, GC2, and KD board. The comparative analysis of these substrates and their characteristics provides a more comprehensive insight into how ink is accepted and transferred in multi-color offset printing systems, as well as how substrate properties influence final print quality and visual appearance.

Keywords: *Offset printing, ink trapping, absorbency, whiteness, fluorescence*

Introduction

Multicolor offset printing is considered one of the main printing techniques because it enables the reproduction of high-quality printed materials. (Kipphan, 2001). To achieve high-quality prints, a roller system is used that transfers the four process printing colors – black, cyan, magenta, and yellow – onto the printing substrate (Kipphan, 2001). The printing substrates most commonly used in offset printing are coated and uncoated papers, which differ in terms of their absorbency, composition, and brightness of the printing layer.

To define print quality, several qualitative and quantitative parameters are analyzed. One of the main quality parameters is ink trapping. Ink trapping is the ability of one ink layer to accept another ink layer during the printing process and is expressed as a percentage (Nguyen et al., 2022). The higher the percentage, the better the acceptance of the second ink layer over the first printed layer. Ink trapping can be calculated using the Preucil formula, which requires optical density values for CMY inks. Ink trapping is measured in three color areas—red, green, and blue. Red represents the overprint of yellow on magenta, green represents the overprint of yellow on cyan, while blue represents the overprint of magenta on cyan. Ink trapping depends on several parameters, including ink stickiness, ink sequence in the printing press, printing speed, and the characteristics of the printing substrate (Ragab et al., 2012).

The characteristics of the printing substrate that have a significant impact on ink trapping include absorbency, whiteness, and fluorescence. These optical and physical properties directly affect the interaction between printing ink and substrate, as well as the final quality of color reproduction.

Paper absorbency refers to the ability of a material to absorb printing ink. It depends on several key factors, including surface coating, material composition, smoothness, and porosity of the substrate (Sesli et al., 2023). Higher levels of absorbency lead to greater ink penetration into the structure of the substrate, resulting in reduced print density and weaker visual saturation. Therefore, to achieve optimal print quality, it is necessary to select a printing substrate whose absorbency is compatible with the properties of the printing ink used.

Whiteness is an optical property that significantly affects the visual perception of printed colors. It is quantified using a whiteness index. Higher whiteness values contribute to increased contrast and color saturation, while lower values result in less vivid tones (Jurič et al., 2013). For this reason, whiteness is an important parameter in the analysis of print quality and color reproduction.

Fluorescence of the printing substrate refers to the ability of a material to emit visible light after absorbing ultraviolet (UV) radiation. To increase the whiteness of the material, optical brightening agents (OBA) are often added during production (Pasic et al., 2016). The presence of fluorescence and OBAs can affect color perception in prints, especially under different lighting conditions, may cause colors to appear slightly different than expected.

The aim of this paper is to examine how printing substrate characteristics affect colour reproduction, specifically through their impact on ink trapping. The analysis focuses on key substrate properties such as absorbency, whiteness, and fluorescence, and their role in achieving consistent and high-quality print results

Methodology and equipment

Four different printing substrates were used in the study, with their characteristics are listed in Table 1. The printing substrates differ in the type of pulp that is the primary component of each substrate. All printing substrates were printed on the same Koenig & Bauer 105 printing press at a speed of 8,000 sheets per hour under climatic conditions of T = 20–24 °C and RH = 40–60%. HH plate printing plates and D-L and Huber offset water-based CMY printing inks were used. Table 2 presents the optical ink density values of the process inks.

Table 1. Printing substrates – abbreviations and their characteristics

Paper substrate	abbreviations	Grammage (g/m^2)	Composition
Offset paper	off	250	recycled pulp
KD	kd	250	chemical pulp
GC1 paper	gc1	250	mechanical pulp
GC2 paper	gc2	250	mechanical pulp

Table 2. Optical ink density values of process inks

	cyan	magenta	yellow
Optical ink density value	1,38	1,4	1,4

In the printing industry, multi-color printing relies on photomechanical color reproduction, where color tones are produced by halftone areas of process colors (cyan, magenta, yellow, and black). Halftone areas consist of image elements and non-image elements, and the human eye cannot distinguish the small dots within the image, perceiving only the overall color (Field, 1999).

Technology and control devices in the printing industry are rapidly advancing to achieve the highest quality multi-color prints. One of the main parameters affecting print quality is satisfactory ink acceptance on previously printed ink. Ink trapping is a quality control parameter used to assess ink acceptance behavior on pre-printed ink (Kipphan, 2001). Ink trapping parameters can be calculated by optical measurements using the Preucil method (equation 1), which is based on densitometry.

$$T = \frac{D_{op} - D_1}{D_2} \times 100 \tag{1}$$

Ink trapping parameter (T) is calculated from ink optical density of solid patches: D_1 – ink density of previously printed ink / two inks; D_2 – ink density of last printed ink and D_{op} – ink density of overprint. Whereby, the densities of the ink (D) are observed by using colour filter of the last printed ink.

To compare whether the characteristics of printing substrates affect ink trapping, the following part of the study analyzed the Cobb water absorption parameter and the optical properties of the substrate.

Water absorption parameter refers to measuring the amount of water that paper, board, or corrugated board absorbs over a specific period of time under standardized conditions. The Cobb test, as described in TAPPI T 441, is a simple method for determining the amount of water that paper or board absorbs over a certain period of time. This test defines water absorption as the mass of liquid that one square meter of paper, board, or corrugated board absorbs over a certain period of time under a one centimeter water column (TAPPI, 2009). The calculation of water absorption, or surface area of paper, is performed using equation 2.

$$c(t) = \frac{m_2 - m_1}{\mathrm{P}} \times 10000 \tag{2}$$

where c is Cobb water absorption (g/m^2); m_1 is the mass of the sample before testing (g); m_2 is the mass of the sample after testing (g); t is the exposure time (120 sec); and P is the sample surface area exposed to water ($100\ cm^2$).

To determine the optical properties of printing substrates, several main optical characteristics were analyzed. Opacity (TAPPI 425 om-06), whiteness (ASTM 313), and fluorescence were measured with an X-Rite eXact spectrophotometer, using standard illuminant D65, a 10° observer, without a polarizing filter, and with an M0 (N0) filter (TAPPI, 2011). Optical measurements were repeated 30 times on each sample.

The degree of opacity is a fundamental property of paper, but its measurement is determined by the reflection ratio. The opacity of a paper is affected by its thickness, the amount and type of filler, the degree of bleaching, the coating, and other factors. Opacity is measured in two steps. First, the sample is placed over a white background with a reflectance of 89%, giving a value defined as R0.89. The second measurement is taken with a black background, which provides nearly zero background reflectance (R0) (Hubbe et al., (2008). Opacity is then calculated using equation 3.

$$Opacity\ (\%) = \frac{R_0}{R_{0.89}} \times 100 \qquad (3)$$

Whiteness is a subjectively perceived property based on reflectance data collected across the entire visible spectral range. The CIE Whiteness Index is the global standard for measuring whiteness and is calculated using equation 4.

$$WI = Y + (WI, x)(x_n - x) + (WI, y)(y_n - y) \qquad (4)$$

where Y, x, y are the luminance factor and the chromaticity coordinates of the specimen; x_n and y_n are the chromaticity coordinates for the CIE standard illuminant and source used; and WI, x and WI, y are numerical coefficients (ASTM International, 2025).

The colorimetric method, which measures fluorescence, explains the effect of optical brightening agents in paper. A detailed study of the action of these agents was conducted by Allen (Harrison, 1961), in which the optical brightening agent's effect on improving the appearance of paper is explained as producing both a bluing effect (the shade of the paper goes from yellow to blue) and a lightening effect. Standard fluorescence tests were performed at 365 nm in accordance with ISO 2470-2.

Paper fluorescence is rated by the intensity of the reaction under a UV lamp using the Irwin scale, which ranges from “Dead” (0) to “Hybrid” (12). Where dead paper (0) shows no fluorescence; non-fluorescent (1) shows almost no gloss and absorbs almost all light; dull fluorescent (2–3) shows a subtle bluish or whitish glow; weak fluorescent (3–4) is brightly fluorescent; fluorescent (5–6) shows a light bluish white glow; medium fluorescent (7–8) is very bright and intensely bluish white; highly fluorescent (9–10) is intensely bluish white; hybrid (11–12) shows maximum fluorescence (Brixton Chrome, n.d.).

Presentation of research results (Analysis)

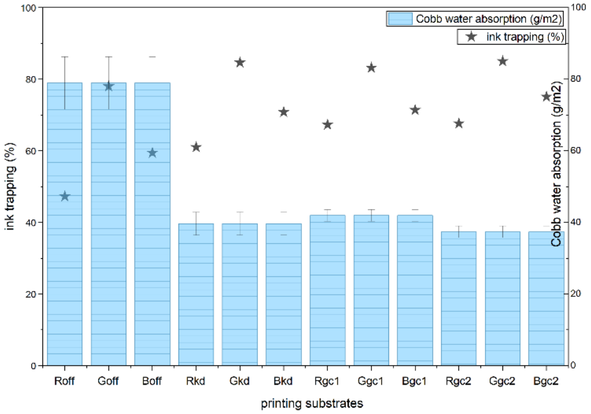

Fig. 1. Correlation between ink trapping and absorption of printing substrates

Figure 1 shows how different printing substrates compare in terms of absorption (bars) and ink trapping efficiency (stars). Uncoated substrate has the highest water absorption values (around 78–80 %), but its ink trapping varies. In contrast, the coated substrates exhibit much lower water absorption (around 37–42%) while generally achieving higher ink trapping percentages, often above 70%. Overall, the results suggest that lower water absorption tends to be associated with better ink trapping performance.

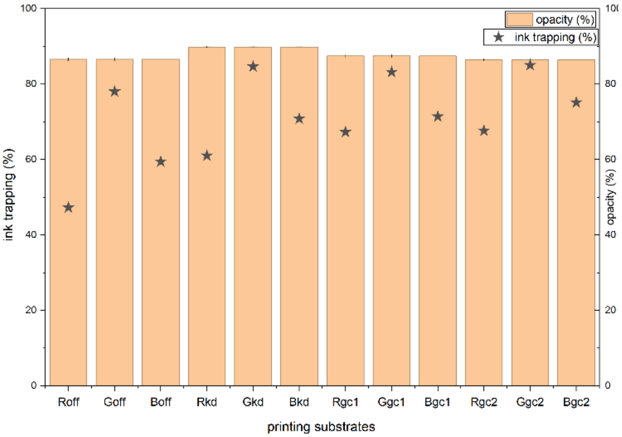

Fig. 2. Correlation between ink trapping and opacity of printing substrates

The results shown in Figure 2 indicate that, although all substrates exhibit high opacity, ink trapping does not change proportionally with opacity. Some substrates with similar opacity values display different ink trapping values, suggesting that opacity alone is not the primary factor influencing ink trapping.

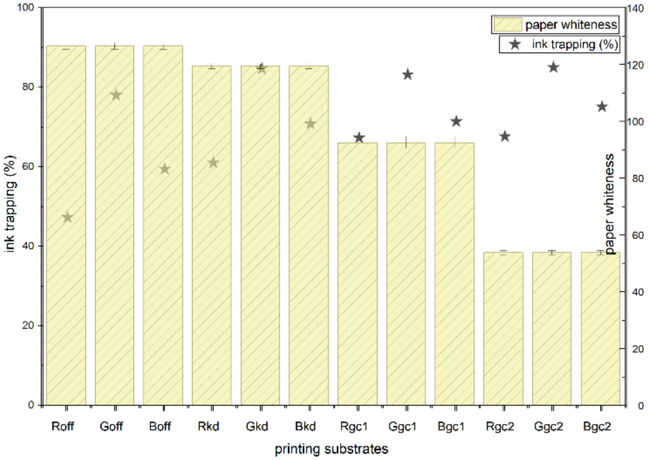

Fig. 3. Correlation between ink trapping and paper whiteness

Results showing the relationship between paper whiteness and ink trapping are presented in Figure 3. A clear trend is observed across the tested substrates: samples with higher whiteness (uncoated substrate, over 90 % whiteness) exhibited lower ink trapping, whereas substrates with moderate whiteness (around 85 %) showed improved trapping performance.

This trend suggests that whiteness itself is not a direct controlling factor for ink trapping. Instead, it is likely correlated with underlying paper properties such as coating composition, surface energy, and ink absorbency, which more directly influence trapping behavior.

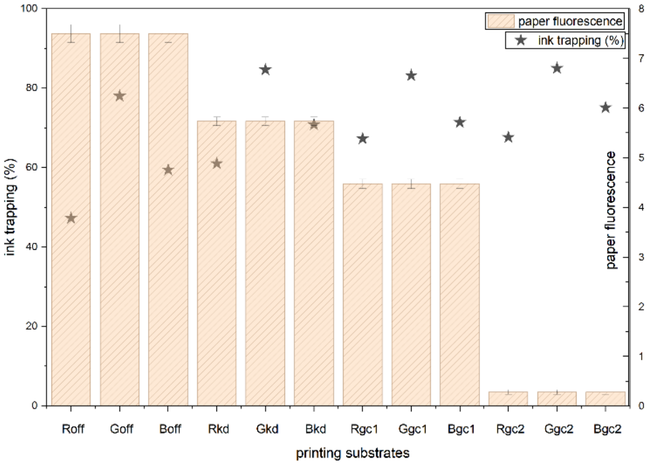

Fig. 4. Correlation between ink trapping and paper fluorescence

Figure 4 compares paper fluorescence with ink trapping across different printing substrates. Uncoated material shows the highest fluorescence (over 90 %), but it ink trapping varies widely, indicating fluorescence alone does not affect trapping performance. Coated materials show moderate fluorescence (around 70 %) with generally consistent ink trapping. The lowest fluorescence appears in the GC2 substrate, but their ink trapping remains relatively high, suggesting that fluorescens does not influence ink trapping performance.

Conclusions

Ink trapping is not determined by a single measurable property but by a combination of surface and structural characteristics of the printing substrate. The results show that optical properties such as opacity do not significantly influence ink trapping, as all tested substrates exhibit similarly high opacity values while showing different trapping performance.

Whiteness and fluorescence also do not directly determine ink trapping behavior. Although variations in these properties are observed between coated and uncoated substrates, the relationship with ink trapping is inconsistent. High whiteness and high fluorescence are associated with both low and variable trapping performance, indicating that these parameters are not controlling factors.

In contrast, water absorption shows a clearer and more consistent relationship with ink trapping. Substrates with lower water absorption generally achieve higher ink trapping values, suggesting that lower porosity contribute to improved interaction between ink layers. Coated substrates, which exhibit lower absorption, consistently demonstrate better trapping performance compared to uncoated materials.

Overall, the results indicate that ink trapping is primarily influenced by surface structure and ink-substrate interaction mechanisms rather than optical characteristics. Key controlling factors are related to porosity, coating presence, and the ability of the substrate to regulate ink penetration and drying behavior.

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