# COLOUR REPRODUCTION IN DRY OFFSET PRINTING FOR BEVERAGE CANS: A STUDY OF CONVENTIONAL AND VARIABLE PROCESSES

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DOI: 10.12700/STAR.2026.065

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***Abstract:***

*In this research, we have examined the critical role of colour control in dry offset printing technology for beverage cans, emphasising its contribution to sustainable production. In the presented study, we have compared conventional and variable dry offset printing while maintaining identical manufacturing conditions, with a focus on the stability and precision of colour reproduction. Measurements conducted, ΔE2000, tone and gloss values, were obtained on a defined red colour reference patch. The first phase of the experiment involved printing without any prior colour management inputs. It resulted in inferior colorimetric values, underscoring the essential role of colour management, continuous measurement and process control. Through the second phase of the experiment, we have systematically monitored key colorimetric and surface parameters after the colour management procedure was applied. The results gained indicated that both printing methods are capable of maintaining colour reproduction within acceptable tolerance ranges, confirming their suitability for industrial applications. An interesting finding was that variable printing exhibited slightly greater uniformity in certain printed areas. Ink consumption was also assessed and remained within expected limits for both methods, reinforcing the principles of material efficiency and waste reduction. These findings demonstrate that stringent colour control directly supports sustainable production practices and indicate that variable printing represents a relevant and reliable alternative within the dry offset process. Future investigations should address more complex designs with higher technical demands and incorporate sampling of a broader range of colours, enabling a more precise characterization of the limitations and potential of this specific printing process through increased data quantity.*

***Keywords:*** *dry offset printing, colour control, variable printing, colorimetric parameters*

## 1. INTRODUCTION

In contemporary packaging production, color reproduction control plays a central role as a key factor of quality, consistency and brand identity preservation. Within the aluminum beverage can industry, this function becomes particularly critical, as the dry offset printing process relies on precisely defined spot colors rather than process colors. Maintaining the stability and predictability of color reproduction is therefore essential not only for visual uniformity but also for ensuring the technical sustainability of production [1,2]. In this context, color reproduction control serves as a direct bridge between print quality and process sustainability minimizing waste, setup time and deviations that lead to material losses or repeated printing cycles [3,4].

Modern packaging production must meet the demands of high speed, precision, and consistent quality, all under clearly defined color and process standards [1]. Without stable and predictable color reproduction control, it is impossible to achieve standardization and repeatability, both of which are fundamental requirements of technically sustainable and rational production [2]. Establishing consistent color reproduction control throughout the entire production chain not only that reduces waste and costs but also directly contributes to technical sustainability and overall production efficiency [3]. The consistency and frequency of production parameters contribute to visual coherence as well as to material

efficiency, reducing costs and losses through automated process monitoring and fewer make ready impressions [4].
The production of aluminium cans represents a multi stage process that integrates high speed forming, surface preparation, decoration, and coating. Within this sequence, dry offset printing serves as the core decoration technology, characterized by indirect image transfer from plate to blanket and from blanket to substrate. This method combines the speed of letterpress with the print quality of offset, making it ideal for non-absorbent surfaces such as metal [1,5]. The system operates at high line speeds, frequently exceeding 2000 cans per minute, and typically uses up to eight spot colors. Given these mechanical and chemical constraints, any small deviation in roller pressure, ink viscosity or blanket condition can result in visible color differences, underlining the importance of precise color control.
Dry offset printing is divided into two primary methods: conventional and variable. In the conventional process, all printing units operate with identical blanket configurations, transferring the same image repeatedly throughout the run. In contrast, variable dry offset introduces engraved blankets that enable multiple visuals to be printed within a single run, without replacing plates or halting the machine [6]. According to industry sources, this approach allows for the creation of individualized or regional designs within the same production batch, offering brands greater flexibility while maintaining throughput [7]. In fact, this technology enables printing of 24 different cans within a single production run [8]. However, engraved blankets also change the ink transfer characteristics, demanding stricter technical tolerances and more precise process control to maintain color reproduction accuracy and visual consistency.
Unlike conventional CMYK system, dry offset relies on spot colors, where every ink must match its defined spectral target. This makes spectrophotometric monitoring, calibration and process control critical elements for maintaining color reproduction accuracy. From the sustainability standpoint, color control directly affects the economic and ecological efficiency of can production. A process that maintains consistent color, minimizes ink consumption and ensures stable transfer characteristics over long runs, can be defined as technically sustainable. The introduction of spectral data as a complement to visual color assessment within the overall graphic process provides all participants in the production chain with a reliable tool for precise control of the color appearance on the can [10]. Therefore, the ability of variable dry offset printing to maintain such stability, despite multiple design variations within the same run, represents a critical question for both industrial practice and research.
The aim of this study is to evaluate the impact of color control on the stability and sustainability of variable dry offset printing for aluminium cans. Through a comparative analysis of conventional and variable methods, the study examines color deviations (ΔE2000), gloss levels, and ink consumption, under identical production conditions. The results aim to determine whether variable dry offset can maintain color stability and efficiency within tolerance ranges expected in standard production, thereby supporting both creative flexibility and sustainable manufacturing in the packaging industry.

## 2. MATERIALS AND METHODS

All materials used in this study originate from actual industrial production and therefore reflect realistic process behaviour and performance. The experiment was conducted on a Stolle Rutherford 8cd6-2200 decorator, an industrial scale dry offset press capable of printing up to 2200 aluminium cans per minute [11]. This type of equipment is widely regarded as a production standard in metal packaging and provides the necessary consistency and mechanical stability for reliable testing of both printing methods. Prior to printing, the machine was inspected and calibrated to ensure stable operation throughout the test. The materials that were used are aluminum substrate, a formed can, artwork files prepared for plates and blankets, printing plates, standard and engraved blankets and red spot ink. Artwork files for both the conventional and the variable method were prepared using Esko ArtPro+, following standard production specifications. The same blankets, Day Graphica 3000, were used for both printing methods. For the variable method blankets were engraved with SPG Thorium unit, to include specific variable design elements. Thorium DLE (Direct Laser Engraving), offers high-quality engraving for dry offset printing, using a $CO_2$ laser process without solvents, with a resolution of up to 10,160 dpi and special dot structure and shaping [12]. In this configuration, the blanket becomes part of the printing form itself, transferring variable content directly from its engraved surface. Printing plates of type Toray DH2S83NM were used for both methods. Plates were imaged using the Esko Spark CDI 2530, followed by processing on a Dantex Aquaflex 480L system. This combination provides high imaging resolution and stable reproduction of fine graphic elements throughout the production run. Colour measurements were performed with an X-Rite Ci64 spectrophotometer, a device suitable for curved substrates such as beverage cans. Also, this device offers the ability to measure SPIN/SPEX values, allowing for an accurate assessment of the influence of gloss on color perception [13]. The instrument was calibrated before each session and maintained through monthly NetProfile calibration to ensure alignment with reference standards. Measurement data were recorded and analysed using X-Rite iQC, which supports Lab and LCh colour spaces, ΔE2000 calculations, gloss measurements (SRR Gloss), and the ink film strength parameter %STR-SUM.

### 2.1 Colour measurement parameters

The tested red ink, Figure 1, was defined by the following spectral values: L* = 52.2; a* = 55.41; b* = 28.73; C* = 62.42; h° = 27.4; SRR Gloss = 27.99. These parameters form the basis for comparing color deviations (ΔE2000) against the standard, both in the conventional and variable dry offset printing methods [14].


*Figure 1: Red ink tested on aluminum can substrate, with variable element presented as an example*

Because aluminium cans are highly reflective, gloss can significantly affect the visual appearance of the measured colour [15]. Therefore, all measurements in this study were performed using SPIN mode only, ensuring better comparability across samples. The %STR-SUM parameter from iQC was used to evaluate relative ink-film strength (target = 100%), reflecting tendencies toward oversaturation (>100) or undersaturation (<100) [16]. ΔE2000 tolerances followed industry standards: Upper limit: ΔE2000 = 3; Preferred operational limit: ΔE2000 ≤ 2 [17].

### 2.2 Sample groups

Three sets of printed samples were collected for analysis. The first set was comprised of samples gained using conventional dry offset printing. This set was serving as the baseline and reference for colour stability and ink consumption under optimal process control. The second set was made of samples printed with variable dry offset printing process using engraved blankets. Samples were evaluated against the colour reference and compared directly with the conventional method to assess differences in ΔE2000 behaviour, ink transfer and overall colour stability. The third set of samples was consisting of samples printed using variable printing process without initial colour measurement. This test intentionally excluded early-stage calibration to highlight the practical consequences of omitting colour control in a high-speed production environment. These three groups provide a comprehensive comparison of process stability, the impact of engraved blankets and the critical role of colour monitoring.

### 2.3 Measurement positioning, orientation and angle

Each can was measured at three standardised locations: middle, top and bottom, Figure 2. Although iQC allows averaging across measurement points, each point was treated separately to obtain a more detailed understanding of print uniformity along the vertical curvature of the can.

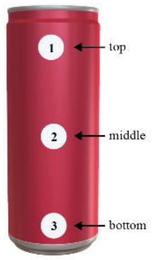


*Figure 2: Measuring points on the printed can*

Because measurements on cylindrical surfaces are sensitive to angular deviation, a fixed angle measurement holder was used to ensure identical positioning for every reading. This setup eliminates variations caused by inconsistent tilt or orientation of the curved surface relative to the spectrophotometer.

### 2.4 Measurement frequency and data collection in iQC

During production, samples were collected every 30 minutes. Each sample set was brought to the laboratory, where spectral values were recorded immediately to minimise the influence of surface contamination, curing variation or handling. The iQC software presented values both numerically and graphically, enabling real time tracking and later analysis of ΔE2000 deviations, L*, a*, b*, C*, h° variations, SRR Gloss, and %STR-SUM ink film strength. This systematic collection approach ensured consistent monitoring of colour stability across all three printing regimes and allowed the identification of short-term and long-term variations within the run.

## 3. RESULTS

### 3.1 Results of conventional (regular) printing measurements

The results of the reference red color measurements obtained through the conventional printing process are presented in Table 1. A set of colorimetric and additional parameters was monitored and compared to the standard red reference. The obtained results show that the color deviation values (ΔE2000) ranged between 0.76 and 2.10, with most samples within the desired industrial tolerance (≤2.0), and all within the general acceptance limit (≤3.0). The highest deviations were recorded for samples 4 (2.10) and 8 (2.05). Changes in lightness (ΔL) ranged from –2.05 to +1.20, while the shifts in the red–green (Δa) and yellow–blue (Δb) axes were more pronounced in several samples. Gloss values (SRR Gloss) varied between 28.45 and 34.57, indicating moderate surface variability. The %STR-SUM parameter ranged from 86.31 to 125.67, where extreme values indicated either excessive or insufficient ink transfer. Analysis of measurement positions (top, middle, bottom) showed that the highest stability was achieved in the middle area of the can, while deviations were more pronounced at the top.

*Table1: Conventional printing – measurement results of red color reference*

| Sample | L | a | b | C | h | ΔL | Δa | Δb | ΔC | Δh | **ΔE2000** | SRR Gloss | **%STR-SUM** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 51.59 | 57.88 | 27.95 | 64.28 | 25.77 | -0.25 | 2.47 | -0.78 | 1.86 | -1.8 | **1.13** | 33.3 | **107.03** |
| 2 | 51.68 | 58.65 | 29.53 | 65.66 | 26.73 | -0.52 | 3.23 | 0.81 | 3.25 | -0.75 | **1.07** | 31.99 | **113.42** |
| 3 | 52.43 | 58.88 | 28.54 | 65.43 | 25.86 | 0.23 | 3.47 | -0.19 | 3.02 | -1.72 | **1.25** | 32.07 | **106** |
| 4 | 50.16 | 56.88 | 29.76 | 64.2 | 27.62 | -2.05 | 1.47 | 1.04 | 1.78 | 0.24 | **2.1** | 31.8 | **122.74** |
| 5 | 50.54 | 57.86 | 30.13 | 65.23 | 27.51 | -1.66 | 2.44 | 1.4 | 2.81 | 0.12 | **1.81** | 30.91 | **121.57** |
| 6 | 52.56 | 56.14 | 27.11 | 62.34 | 25.78 | 0.35 | 0.73 | -1.61 | -0.07 | -1.77 | **1.04** | 31.45 | **95.47** |
| 7 | 50.35 | 57.14 | 29.79 | 64.44 | 27.54 | -1.86 | 1.73 | 1.07 | 2.03 | 0.15 | **1.92** | 31.76 | **121.35** |
| 8 | 50.36 | 58.22 | 30.73 | 65.83 | 27.83 | -1.84 | 2.8 | 2.01 | 3.42 | 0.48 | **2.05** | 30.2 | **125.67** |
| 9 | 52.38 | 56.07 | 27.17 | 62.31 | 25.86 | 0.17 | 0.66 | -1.55 | -0.1 | -1.68 | **0.95** | 33.71 | **97.2** |
| 10 | 50.87 | 57.1 | 28.98 | 64.04 | 26.91 | -1.34 | 1.69 | 0.25 | 1.62 | -0.55 | **1.42** | 30.95 | **115.22** |
| 11 | 52.15 | 56.34 | 27.67 | 62.77 | 26.16 | -0.05 | 0.93 | -1.06 | 0.35 | -1.36 | **0.76** | 34.57 | **100** |
| 12 | 53.4 | 54.84 | 26.22 | 60.79 | 25.56 | 1.2 | -0.58 | -2.5 | -1.63 | -1.98 | **1.67** | 34.25 | **86.31** |
| 13 | 51.2 | 57.27 | 28.91 | 64.15 | 26.78 | -1.01 | 1.86 | 0.18 | 1.73 | -0.69 | **1.16** | 31.41 | **113.08** |
| 14 | 50.6 | 57.35 | 30.1 | 64.77 | 27.69 | -1.6 | 1.94 | 1.37 | 2.36 | 0.32 | **1.71** | 31.47 | **120.38** |
| 15 | 50.86 | 57.36 | 29.81 | 64.65 | 27.46 | -1.35 | 1.95 | 1.08 | 2.23 | 0.06 | **1.46** | 28.45 | **117.5** |
| 16 | 51.66 | 56.53 | 27.42 | 62.83 | 25.87 | -0.55 | 1.12 | -1.31 | 0.41 | -1.67 | **1.08** | 30.69 | **105.27** |
| 17 | 51.38 | 57.32 | 28.89 | 64.19 | 26.75 | -0.82 | 1.91 | 0.16 | 1.77 | -0.73 | **1.02** | 31.37 | **111.62** |
| 18 | 50.85 | 57.24 | 29.74 | 64.5 | 27.46 | -1.36 | 1.82 | 1.01 | 2.08 | 0.06 | **1.45** | 28.51 | **117.13** |

| Measurement positon |
|---|
| middle |
| top |
| bottom |

The ΔE2000 values throughout the regular printing process are illustrated in Figure 3.

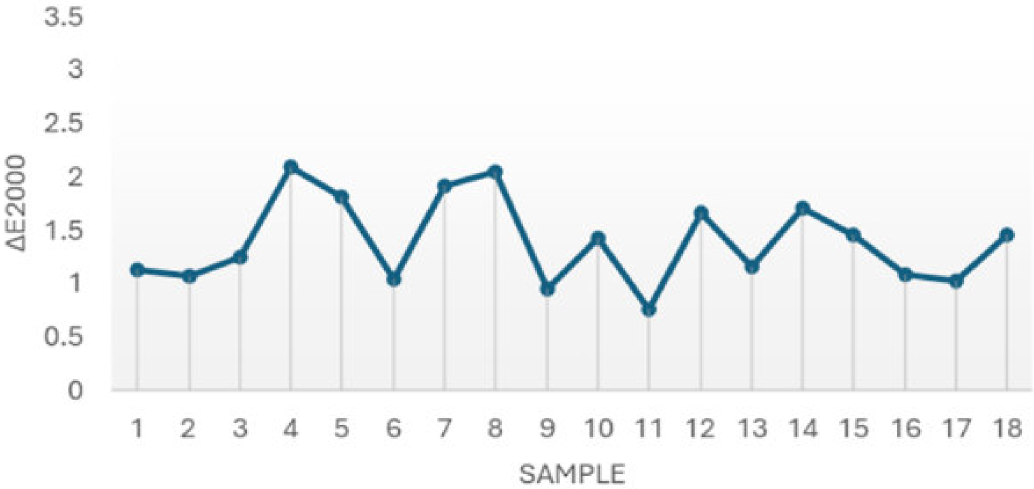


*Figure 3: ΔE2000 values during the regular printing process*

### 3.2 Results of variable controlled printing measurements

The results of reference red color measurements obtained through the variable controlled printing process are presented in Table 2. Compared to the standard reference, the obtained results indicate that the color deviation values (ΔE2000) ranged between 0.87 and 2.06, demonstrating very stable color reproduction within the variable process. The highest deviations were observed for samples 4 and 13, where ΔE2000 values reached 1.7–2.0. Gloss values (SRR Gloss) ranged between 23.7 and 33.9, indicating moderate surface effect variability. The %STR-SUM parameter varied from 95.6 to 121.4. Analysis of measurement positions (top, middle, bottom) confirmed that the middle section exhibited the highest stability, while greater deviations appeared at the top and bottom.

*Table 2: Variable controlled printing – measurement results of red reference*

| Sample | L | a | b | C | h | ΔL | Δa | Δb | ΔC | Δh | **ΔE2000** | SRR Gloss | **%STR-SUM** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 52 | 57.3 | 27.7 | 63.64 | 25.8 | -0.21 | 1.88 | -1.03 | 1.22 | -1.76 | **1.05** | 27.94 | **103.01** |
| 2 | 52.39 | 57.77 | 27.69 | 64.06 | 25.61 | 0.18 | 2.36 | -1.04 | 1.65 | -1.98 | **1.19** | 30.3 | **101.23** |
| 3 | 52.4 | 56.91 | 27.84 | 63.36 | 26.07 | 0.19 | 1.5 | -0.88 | 0.94 | -1.46 | **0.87** | 29.95 | **99.16** |
| 4 | 50.2 | 57.22 | 29.11 | 64.2 | 26.96 | -2 | 1.81 | 0.39 | 1.78 | -0.48 | **2.06** | 23.79 | **121.44** |
| 5 | 52.12 | 57.96 | 27.41 | 64.12 | 25.31 | -0.08 | 2.55 | -1.31 | 1.7 | -2.31 | **1.35** | 26.65 | **103.42** |
| 6 | 51.69 | 57.91 | 27.9 | 64.28 | 25.73 | -0.51 | 2.5 | -0.82 | 1.87 | -1.85 | **1.24** | 33.98 | **106.73** |
| 7 | 51.1 | 56.78 | 27.23 | 62.97 | 25.62 | -1.1 | 1.37 | -1.5 | 0.56 | -1.95 | **1.54** | 26.34 | **108.04** |
| 8 | 51.37 | 57.06 | 27.01 | 63.13 | 25.33 | -0.84 | 1.64 | -1.71 | 0.71 | -2.27 | **1.51** | 31.03 | **104.97** |
| 9 | 50.81 | 57.2 | 27.5 | 63.47 | 25.67 | -1.39 | 1.79 | -1.23 | 1.05 | -1.9 | **1.76** | 29.44 | **109.61** |
| 10 | 50.95 | 57.02 | 27.45 | 63.28 | 25.71 | -1.25 | 1.6 | -1.28 | 0.84 | -1.86 | **1.63** | 24.21 | **109.12** |
| 11 | 51.49 | 57.4 | 27.33 | 63.58 | 25.46 | -0.71 | 1.99 | -1.39 | 1.16 | -2.13 | **1.41** | 27.4 | **104.99** |
| 12 | 51.06 | 56.96 | 27.48 | 63.24 | 25.76 | -1.14 | 1.55 | -1.24 | 0.83 | -1.8 | **1.53** | 26.91 | **107** |
| 13 | 51.72 | 54.88 | 25.35 | 60.45 | 24.8 | -0.49 | -0.53 | -3.37 | -1.96 | -2.79 | **1.71** | 26.31 | **95.63** |
| 14 | 51.81 | 56.59 | 26.54 | 62.51 | 25.13 | -0.39 | 1.18 | -2.18 | 0.09 | -2.48 | **1.43** | 25.03 | **100.58** |
| 15 | 51.55 | 56.29 | 26.75 | 62.32 | 25.42 | -0.66 | 0.87 | -1.98 | -0.1 | -2.16 | **1.36** | 26.23 | **1001.38** |
| 16 | 50.82 | 56.49 | 27.1 | 62.65 | 25.63 | -1.38 | 1.08 | -1.62 | 0.25 | -1.93 | **1.74** | 24.52 | **108.79** |
| 17 | 50.81 | 57.05 | 27.49 | 63.32 | 25.73 | -1.4 | 1.63 | -1.24 | 0.91 | -1.84 | **1.74** | 25.79 | **110.81** |
| 18 | 50.99 | 56.52 | 26.99 | 62.63 | 25.53 | -1.21 | 1.11 | -1.74 | 0.22 | -2.05 | **1.66** | 25.41 | **106.18** |

| Measurement positon |
|---|
| middle |
| top |
| bottom |

The ΔE2000 values across the controlled variable printing process are shown in Figure 4.

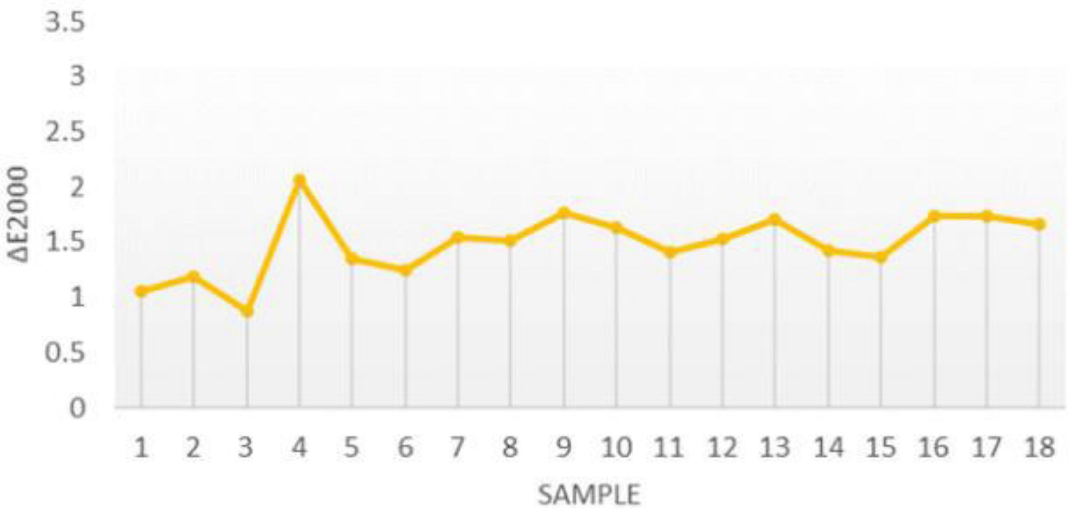


*Figure 4: ΔE2000 values during variable controlled printing*

### 3.3 Results of variable uncontrolled printing measurements

Table 3 presents the measurement results for two reference red samples printed in a variable mode where no measurements were performed during the initial production interval. The absence of in-process measurements led to a notable deterioration in the obtained parameters. The color deviation values (ΔE2000) averaged between 2.0 and 2.7, exceeding the desired tolerance (≤2.0); thus, the color quality was marginal or outside specification. Gloss values (SRR Gloss) ranged from 45 to 49, significantly higher than in controlled runs. The %STR-SUM parameter ranged from 126 to 139, indicating instability and deviations from optimal printing conditions. Analysis of the measurement positions showed that the middle section maintained the most stable results, while greater deviations were observed at the top and bottom.

*Table 3: Uncontrolled variable printing – measurement results of reference red*

| Sample | L | a | b | ΔL | Δa | Δb | ΔC | Δh | **ΔE2000** | SRR Gloss | **%STR-SUM** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 51.11 | 60.39 | 30.4 | -1309 | 4.97 | 1.68 | 5.19 | -0.77 | **1.76** | 49.35 | **126.73** |
| 2 | 49.88 | 59.42 | 32.17 | -2.32 | 4 | 3.44 | 5.15 | 1.16 | **2.74** | 45.24 | **139.14** |
| 3 | 50.54 | 60.08 | 31.32 | -1.66 | 4.66 | 2.59 | 5.33 | 0.15 | **2.14** | 48.72 | **132.56** |
| 4 | 50.75 | 60.69 | 31.46 | -1.45 | 5.27 | 2.74 | 5.94 | 0.01 | **2.09** | 46.44 | **133.64** |
| 5 | 50.3 | 58.98 | 31.12 | -1.91 | 3.56 | 2.39 | 4.27 | 0.47 | **2.21** | 47.7 | **130.43** |
| 6 | 50.61 | 60.02 | 31.24 | -1.59 | 4.61 | 2.52 | 5.25 | 0.11 | **2.7** | 47.21 | **131.42** |

| Measurement positon |
|---|
| middle |
| top |
| bottom |

The ΔE2000 values throughout the uncontrolled variable printing process are illustrated in Figure 5.


*Figure 5: ΔE2000 values during uncontrolled variable printing*

### 3.4 Printing speed and ink consumption in both modes

Ink consumption represents one of the key sustainability factors in production, as it directly influences cost efficiency, process stability and material waste. In the conducted experiment, Table 4, showed ink usage within normal and controlled limits for both printing methods, without deviations that could affect print quality or increase material loss. The standard consumption for conventional printing was slightly higher due to greater red area coverage in the artwork. Printing speed remained consistent at 2200 cans per minute for both methods.

*Table 4: Ink consumption of standard red during conventional and variable printing*

| Red Ink | Standard/reference kg/milion | Live Production kg/milion | Deviation |
|---|---|---|---|
| Conventional Printing | 31 | 30.55 | -0.45 |
| Variable Printing | 31 | 30.45 | -0.55 |

## 4. DISCUSSION

The results obtained for the conventional printing process confirmed a stable workflow and predictable color reproduction. The color deviations, expressed as ΔE2000, ranged from 0.76 to 2.10, with an average of 1.39 and a standard deviation of 0.40. All values were within the generally accepted tolerance of ≤3, confirming reliable and consistent color reproduction.
The %STR-SUM parameter, ideally close to 100, ranged from 86.31 to 125.67, with an average of 110.94. Although certain oscillations were observed, they remained within the acceptable technological limits. The SRR Gloss values ranged from 28.45 to 34.57, with an average of 31.60, slightly above the reference value of 27.99, yet without any visually significant deviation. These data confirm that

conventional dry offset printing provides a stable and predictable process with consistent color and gloss characteristics.

The variable controlled printing method demonstrated even greater uniformity compared to the conventional process. The ΔE2000 values ranged from 0.87 to 2.06, with an average of 1.49 and a standard deviation of 0.29, indicating lower dispersion and more consistent color maintenance during production. The %STR-SUM parameter varied from 95.63 to 121.44, with an average of 105.92, reflecting slightly improved control and efficiency compared to the conventional method. The SRR Gloss values ranged between 23.79 and 33.98, with an average of 27.29, nearly identical to the target reference (27.99). This confirms that the controlled variable printing process achieved both visually and technically optimal results.

In contrast, the uncontrolled variable printing process showed significantly higher deviations. The ΔE2000 values ranged between 1.76 and 2.74, with an average of 2.27, clearly exceeding the deviations recorded in both regular and controlled variable printing. The %STR-SUM parameter remained consistently higher, ranging from 126.73 to 139.14 (average 132.32), indicating excessive ink transfer and lower process efficiency. Likewise, SRR Gloss values were considerably elevated, between 45.24 and 49.35, with an average of 47.44, far from the target reference. These findings clearly demonstrate that the absence of in-process color monitoring in variable printing leads to reduced color reproduction accuracy, increased ink consumption, and compromised production sustainability.

For both printing methods, the standard ink consumption for the reference red was 31.0 kg per million prints. Measured value for conventional was 30.55 kg per million, representing a deviation of –0.45 kg, and for the variable printing process was 30.45 kg per million, corresponding to a deviation of –0.55 kg. These results confirm that both processes operated efficiently, with the variable method showing slightly better alignment with the expected standard due to more uniform ink transfer.

## 5. CONCLUSION

Based on the conducted measurements and analysis, it can be concluded that both conventional and controlled variable dry offset printing methods are capable of delivering results within defined safety and technological limits. The variable printing method under controlled conditions demonstrated even more uniform results compared to the conventional process, particularly in terms of ink laydown, gloss reproduction and material efficiency. Such consistency may be attributed to the inherent complexity of the variable process, which required operators to apply additional precision in machine setup, ink control and plate and blanket adjustments, effectively minimizing the potential for variation. This experiment therefore confirms that variable dry offset printing is a reliable and sustainable industrial process, capable of meeting modern production and color quality standards. Ink consumption in both processes remained within controlled limits, with minimal deviation from the target values. This indicates a high level of process stability and further supports the conclusion that variable printing can be implemented without compromising economic efficiency or sustainability. The uncontrolled variable printing phase, however, underlined the critical importance of integrated process monitoring. Without continuous measurement and color correction, material usage increases, color reproduction accuracy decreases and process sustainability deteriorates. Importantly, the engraved blanket used during the tests did not introduce any additional issues, nor did it negatively affect production speed or consistency, confirming its suitability for industrial applications. Beyond its technical merits, variable printing also provides distinct marketing advantages. The ability to personalize packaging, create limited editions and differentiate visual designs according to market needs adds tangible commercial value.

For future research, it is recommended to explore the performance of variable dry offset printing with more complex and visually demanding designs, where the technological limits of the process can be more rigorously evaluated. In such scenarios, the constraints related to plate and blanket file specifications, ink transfer, roller pressure and potential speed adjustments become more pronounced. This would offer a more comprehensive understanding of the capabilities and boundaries of variable dry offset printing within real world production environments and evolving market requirements.

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