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Minimize Print Mottle by Optimizing Process Parameters in Offset Print

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Abstract

The offset printing technology is extensively utilized in packaging and commercial printing for both short and large production runs. The offset printing process is a multifaceted technique that encompasses the printing machine, substrate, ink, and their interaction. The offset printing process involves the greatest number of variables compared to all other printing methods. The minor fluctuation in process parameters causes in variations in ink transfer, leading to unequal outcomes. This results in variations in color and gloss on the printed surface, referred to as print mottle. Therefore, it is essential to comprehend and regulate the process parameters to achieve high-quality printing while minimizing mottle. The study aims to investigate the impact of key elements, including ink tack, alcohol percentage, press speed, and impression pressure, on print mottle. The color variance is assessed by differences in ink transfer, which is influenced by print mottle. The IA Print Target Software has been utilized to assess print mottle. Production runs have been executed on the press to establish a baseline for print defects, and a target has been established to minimize them. A comprehensive full factorial design of experiments has been established for the aforementioned process parameters at two levels. The experimental data has been evaluated using ANOVA and Main and Interaction plots to identify the ideal combination that produces high-quality prints with reduced print mottle. The optimized configuration demonstrated a 65% decrease in solid mottle.

I. INTRODUCTION

The objective of a printer is to complete the task punctually and with high quality, hence ensuring customer retention. The uniformity of print qualities both within individual tasks and across many works is crucial for both printers and clients. Paper and board serve as the primary substrates for commercial printing and packaging, predominantly utilizing the offset printing method. One of the primary issues encountered by the printer is to regulate print mottle both spatially and temporally for a specific project. The irregular ink application leads to color variation in the print, both laterally and between sheets, in solid and halftone areas. This results in a shortage of substrates and inks, thereby diminishing the productivity and profitability of a business. Optimizing the offset process factors may minimize the wastage. The optimization of the offset process entails identifying the optimal combination of process factors to reduce print mottle in the printing process.

II. RELATED WORK

Roy R. Rosenberger [1] elucidated the functionality of the Stochastic Frequency Distribution Analysis (SFDA) technique for quantifying mottle in a digital image. The SFDA initially assesses the texture properties present in the image and subsequently computes the spatial distribution of that texture. Upon receiving a digital image for analysis, the SFDA initially samples the entire image using a systematic pattern of continuous square target areas with uniform pixel dimensions. The target areas are quantified by pixel luminance values, and the acquired data is concurrently recorded in two databases. One database has the value of "s," while the other holds the mean value MTL for each target area. “s” represents the two-dimensional standard deviation within the designated area. The mean luminance value (MTL) represents the average luminance of all pixels within a designated area, reflecting the overall visual effect of the examined region. The extent of variation in "s" reflects the degree of uniformity among the square targets, whereas the variance of MTL serves as a measure of uniformity in brightness. Upon selecting a region of interest inside the image, the “s” and MTL values are retrieved from their corresponding databases. A region with reduced mottle will correlate with diminished values of σs (standard deviation of “s” values) and Ms (mean of “s” values). This is not always accurate for σm (the standard deviation of MTL values). A mottle number is derived for the inspected picture area by multiplying a scaling factor, the standard deviation of “s” (σs), the standard deviation of “MTL” (σm), and the mean of “s” (Ms) values. To provide an accurate depiction of mottle in a picture, SFDA additionally assesses the spatial distribution of texture mottle. The digital image is now partitioned into larger regions, each comprising an equal number of smaller target areas. The mottle number for each greater target area is computed using the aforementioned algorithm. The final value of spatial mottle is obtained by multiplying the scaling factor, mean, and standard deviation of bigger target mottle quantities. The SFDA surpasses existing technologies in its capacity to manage half-tone mottle and various multi-color flaws, such as back trap mottle and wet trap mottle, through digital imaging and computational power.

Roy R. Rosenberger [2] elucidated the functionality of SFDA in quantifying mottle in polychrome motley pictures. The method has undergone testing on two applications to assess wet-trap mottle. A resolution of 300 ppi has been deemed effective for the analysis of visible mottle. For the investigation of sub-visible mottle, a resolution of 600 ppi or above is recommended. An input is a 24-bit RGB image obtained via a scanner or digital camera. This image comprises three component photos representing the Red, Green, and Blue bands, each with an 8-bit depth. The SFDA can utilize individual color band data or integrate them in a specified configuration to provide a high-contrast image for subsequent analysis. This is crucial for assessing polychrome motley images formed by layering one ink over another. The SFDA examined the image by partitioning it into adjacent tiles, each containing an equal number of pixels. A sequence of tile dimensions, adhering to a binary progression, has been utilized: 2 × 2, 4 x 4, ..., 1024 x 1024 (in pixels). The maximum permissible tile size has been established when the image was unable to support four adjacent tiles of the subsequent size. Each tile dimension corresponded to a certain layer. The mottle has been computed for each layer, forming the mottle profile for the examined image. The final mottle has been derived by averaging the mottle figures across all utilized layers. This has been executed to get the spatial variation component of mottle. Measurements and calculations have been conducted within each tile, resulting in the creation of two databases. One database documented the percentage difference among the brightness values of items inside the tile, while the other recorded their average. The database of average values also served as the foundation for creating a virtual image, over which the subsequent tile size has been applied. The mottle number for a specific layer is defined as the product of the standard deviation and the average of the percentage difference, along with the standard deviation of the averages. The conclusive mottle value for an image has been derived by averaging all the layer mottle values. Two tests have been performed to assess the correctness of the algorithm. The initial experiment focused on quantifying wet-trap mottle. The cyan patch has been overprinted at time intervals of 0, 3, 6, and 9 seconds utilizing an IGT A5 test strip. The patches have undergone visual evaluation by a team of experienced observers, and the samples have been ranked accordingly. Visual specialists identified samples with delays of 6 and 9 seconds as the most inferior. Instrumental evaluation results from the SFDA indicated a trend of heightened mottle with extended time delays. These results aligned with the visual evaluation findings. The second test has concentrated on measuring back trap and water interference mottle. Opaque cyan patches, measuring 165 x 236 mm^2, have been printed at units 2 and 6. The sample printed on unit 2 had several blanket exposures, whereas the specimen printed on unit 6 was exposed to repeated water applications prior to ink transfer. These samples have been inherently created to differ. Consequently, the primary challenge for SFDA has been to quantify mottle in each instance while reliably differentiating between the two samples from distinct units. The results provided by the SFDA distinctly illustrated a disparity between the two units, with Unit 2 exhibiting greater mottle in the samples.

Roy Rosenberger conducted an analysis utilizing gloss mottle measuring. The study comprised two exams. Samples for both tests have been produced on a sheet-fed offset press. Test 1 comprised five coated substrates and one uncoated substrate, each printed with a four-color black patch covering an area of 133 mm × 76 mm. Test 2 was performed on four distinct coated substrates, each printed with an identical patch covering an area of 173 mm × 73 mm. Samples have undergone visual assessment and been ranked by a panel of experienced evaluators. The rankings have been utilized to modify the mottle measuring parameters. The printed photographs were scanned at 300 ppi, and a region measuring 100 mm x 50 mm was designated for mottle study. The range of tile sizes utilized for the test spans from 0.17 mm (2 × 2 pixels) to 5.4 mm (64 x 64 pixels). All photos have undergone analysis using the 'average of all bands' method for color extraction. The visual evaluation revealed a significant disparity in mottling between the two sets. The samples from test 1 had reduced mottle compared to test 2, with the exception of specimen 6, namely the uncoated stock. Consequently, the outcomes derived from the SFDA examination align with the results of the ocular assessment.

Roy Rosenberger, Daniel Clark, and Dale Drake [4] performed a study on the assessment of halftone and back-trap mottle utilizing stochastic frequency distribution analysis (SFDA). The SFDA can examine a specific color band (R, G, B, C, M, or Y) or the average of all color bands in an RGB image. The study characterized print mottle as the irregular reflection or transmission of light from or through a specimen. It has been proposed that mottle is more pronounced in larger photographs than in smaller ones. Two distinct tests have been conducted. Samples for the initial test were produced using a 100% cyan patch on 18-point cover stock with a six-color sheet-fed offset press. Initially, three patches were printed on unit 2, followed by the overprinting of two patches on units 5 and 6, with one patch per unit. This test aims to evaluate the SFDA's capacity to assess the effects of numerous blanket exposures on mottle. Printed samples were scanned at 500 ppi and evaluated using Verity IA 2000. It has been noted that as blanket exposure to wet ink increases, the degree of mottle diminishes. The second test entailed printing patches of C, M, Y, K, R, G, B, CMY, and CMYK, all of identical dimensions, on a four-color sheet-fed offset press. Printing has been conducted on one hundred sheets of five distinct grades of paper, consisting of three coated and two uncoated stocks, from which five sheets have been randomly selected as examples. The objective of this test was to assess the SFDA's capability to measure back-trap mottle on different types of paper. Images were scanned at 500 ppi and processed using the SFDA method, utilizing individual color bands. The mottled values from five representative samples have been averaged for each patch. This produced nine mottling values for each substrate grade. Uncoated stocks demonstrate elevated mottle values for all patches, with the exception of yellow. The data has been subsequently categorized and averaged into RGB and CMY sets. The algorithm has proven effective in differentiating between coated and uncoated sheets and assessing their quality.

III. METHODOLOGY

- A tailored monotone test form has been created, incorporating components such as pictures, step wedges, vignettes, surface/reverse elements, line features, control strips, and solid patches throughout the sheet.
- The test form has been subjected to a computer-to-plate process at a specified screen ruling. Cyan ink has been utilized for printing on 130 GSM coated paper.
- An impartial trial has been conducted in a functioning press room environment.
- The performance of this trial is meant to correspond with the data acquired following the Design of Experiments (DOE). In the initial step, a full factorial Design of Experiments (DOE) was conducted for four parameters: alcohol percentage, machine speed, pressure, and ink tack.
- Two levels are considered for Tack and Pressure in relation to the baseline:

Low (1) and High (2). The print mottle has been assessed using Verity IA Print Target Software, which utilized the SFDA algorithm.

- The DOE has been examined to determine the optimal combination of variables that minimizes print mottle.
- The optimal combination of variables has been re-evaluated to confirm the analytical results from the DOE and thereafter verified for consistency by periodically re-running the optimal combination of variables.

Process Parameters:

The experiment has four variables. The variables, including machine speed, pressure, alcohol percentage, and ink tack, have been adjusted at two levels. This additionally aids in constructing a transfer function (regression) for the response and validating it.

IV. PRODUCTION RUN AND BASELINE

S. No.	Factors	Low Level	High Level
01	Speed (iph)	4000	8000
02	Ink tack	1	2
03	Alcohol %	6	10
04	Nip Pressure	1	2

Table 1: Offset Process Variables

V. PRINT MOTTLE ANALYSIS

The printed solid patches were examined using the SFDA (Stochastic Frequency Distribution Analysis) mottle method using Variety IA Print Target Software. The samples were scanned at 600 PPI with a sensitivity level of 7 for solid mottle assessment.

Production run	Print Mottle
P1	2.52
P2	2.54
P3	2.54
P4	2.58
P5	2.59
Base line	**2.55**

Table 2: Baseline data for Print Mottle

The data obtained from the manufacturing run on coated paper indicated a mean solid mottle of 2.55, hence it has been designated as the baseline. The objective has been established to reduce print mottle.

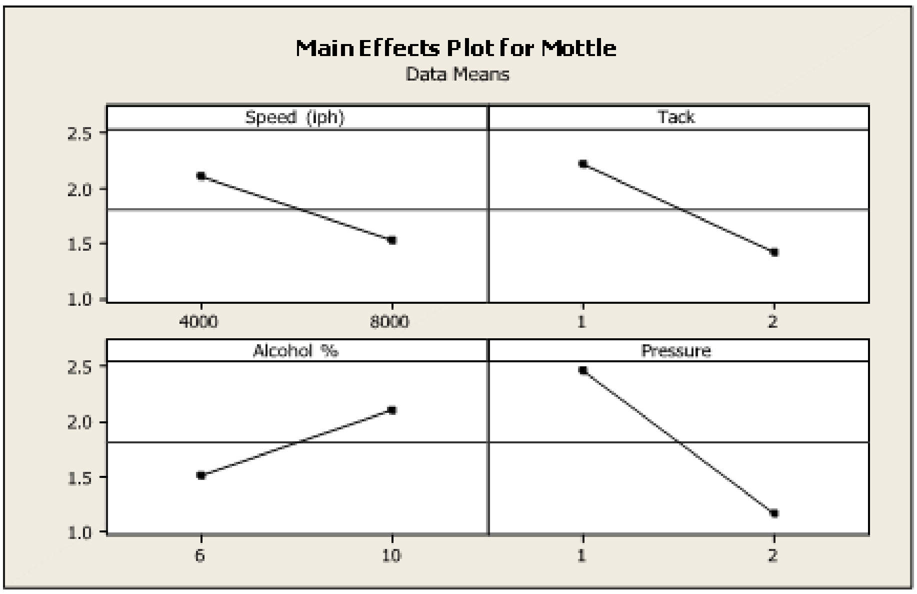

Fig 1: Effect of Process Variables on Print Mottle

The primary effect plot demonstrates that print mottle in solid diminishes with increased levels of speed, ink tack, and pressure, accompanied by a reduced level of alcohol. It illustrates that speed, ink tack, percentage of alcohol, and pressure are key factors in the decrease of solid mottle. A reduced printing speed leads to an increased dwell time in the nip, resulting in enhanced ink spreading due to prolonged contact, which causes uneven ink application and thus elevated print mottle. Increased speed generates a greater shear rate and simultaneously elevates the shear tension in the ink, rendering it resistant to spreading upon transfer to the substrate. Consequently, an increase in speed results in reduced print mottle. The dissemination of low-tack ink is a rapidly emerging trend. This inconsistent ink application results in density variance throughout the transferred regions. Consequently, less tack leads to increased mottle. The high-tack ink demonstrated consistent ink distribution and application, resulting in homogeneous density across the transferred region, which exhibited reduced mottle. The 6% alcohol reduces the surface tension of water, facilitating stable emulsification and ensuring homogeneous ink transfer over the print areas. Increased printing pressure guarantees consistent force distribution across the NIP, leading to homogeneous ink transfer and reduced print mottle.

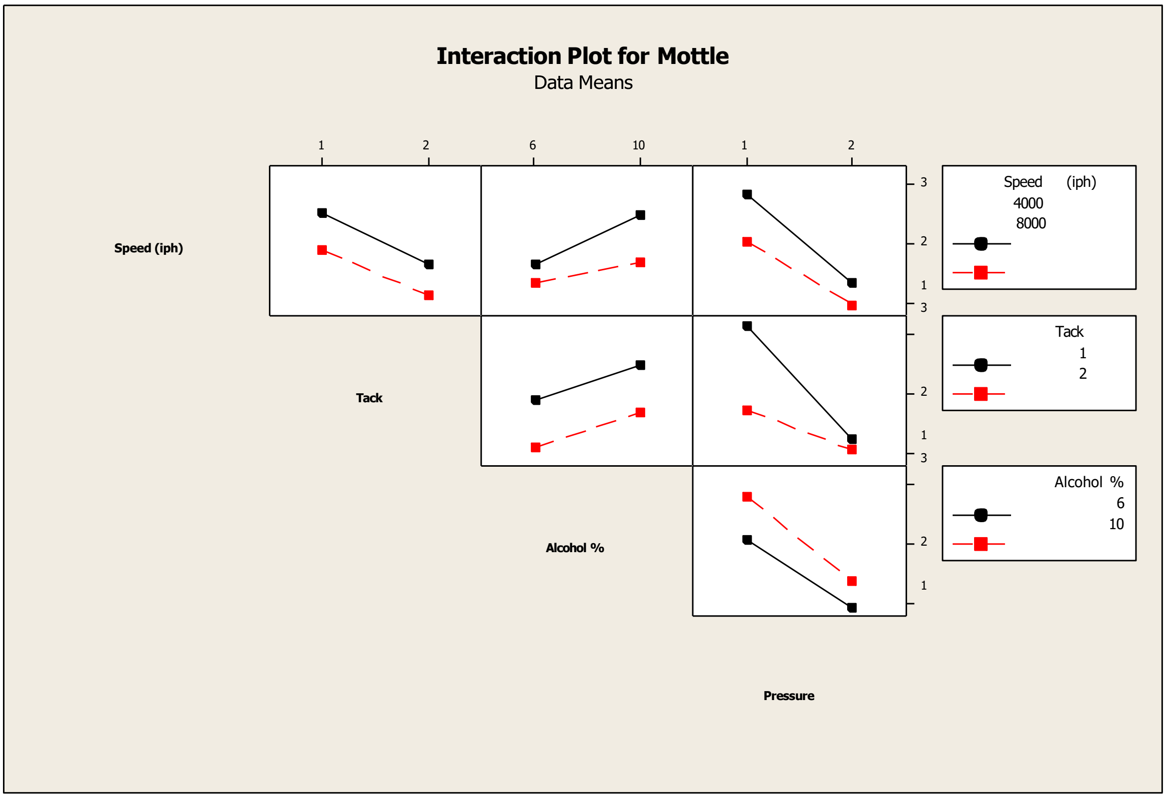

Fig 2: Interaction Plot of Process Parameters on Solid Mottle

The interaction plots demonstrate that the minimum solid mottle is achieved with an interaction of 8000 iph speed, 2 ink tack, 6% alcohol, and 2 printing pressure. The interaction plot illustrates predominantly non-parallel lines, suggesting potential substantial interactions among the components. The interplay of speed with ink tack, alcohol, and pressure exhibits non-parallel and skewed lines, illustrating the potential interactions among these parameters. The interplay between ink tack and pressure reveals a corresponding spot with further increases in levels. The interaction between alcohol and ink tack and pressure exhibits parallel lines, indicating a lack of significant interaction among the factors.

VI. STATISTICAL ANALYSIS FOR PRINT MOTTLE

Table 3 Estimated Effects and Coefficients for Print Mottle

Term	Effect	Coef	SE Coef	T	P
Constant		1.8124	0.01195	151.68	0.000
Speed	-0.5753	-0.2876	0.01195	-24.07	0.000
ink tack	-0.8001	-0.4001	0.01195	-33.48	0.000
alcohol%	0.5923	0.2961	0.01195	24.78	0.000
Pressure	-1.2936	-0.6468	0.01195	-54.13	0.000
speed*tack	0.0547	0.0274	0.01195	2.29	0.032
speed*alcohol%	-0.2376	-0.1188	0.01195	-9.94	0.000
speed*pressure	0.2237	0.1119	0.01195	9.36	0.000
tack*alcohol%	0.0097	0.0049	0.01195	0.41	0.687
tack*pressure	0.6139	0.3069	0.01195	25.69	0.000
alcohol%*pressure	-0.1318	-0.0659	0.01195	-5.51	0.000

Summary of Model

S = 0.0675949 PRESS = 0.222796

R-Sq = 99.66%R-Sq(pred) = 99.21% R-Sq(adj) = 99.50%

The p-value signifies the likelihood of mistake associated with endorsing the observed results. The p- and t-values indicate that all input parameters are significant, with pressure exerting a predominant influence on mottle. Additionally, some two-factor interaction effects have proven significant at the 95% confidence level. The coefficients signify the relative significance of each element to the response (density). The coefficients of pressure (-0.6468) and ink tack (-0.4001) demonstrate the most significant influence on mottle.

Table 4: ANOVA (Analysis of Variance) for Print Mottle

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	23.9627	23.9627	5.9907	1311.14	0.000
Speed	1	2.6473	2.6473	2.6473	579.40	0.000
ink tack	1	5.1216	5.1216	5.1216	1120.93	0.000
alcohol%	1	2.8061	2.8061	2.8061	614.15	0.000
Pressure	1	13.3877	13.3877	13.3877	2930.08	0.000
2-Way Interactions	6	4.0306	4.0306	0.6718	147.02	0.000
Speed*tack	1	0.0240	0.0240	0.0240	5.25	0.032
Speed*alcohol%	1	0.4517	0.4517	0.4517	98.87	0.000
Speed*pressure	1	0.4005	0.4005	0.4005	87.66	0.000
Tack*alcohol%	1	0.0008	0.0008	0.0008	0.17	0.687
Tack*pressure	1	3.0147	3.0147	3.0147	659.82	0.000
Alcohol%*pressure	1	0.1389	0.1389	0.1389	30.39	0.000
Residual Error	21	0.0960	0.0960	0.0046		
Lack of Fit	5	0.0312	0.0312	0.0062	1.55	0.232
Pure Error	16	0.0647	0.0647	0.0040		
Total	31	28.0892				

The ANOVA table for solid mottle on coated paper demonstrates that all primary components are significant, as the p-values are below the α threshold of 0.05. The Sequential Sum of Squares (Seq SS) and Adjusted Sum of Squares (Adj SS) reflect the relative significance of each factor concerning the response (solid mottle). The pressure exhibited the highest Seq SS of 13.3877, indicating its most significant influence in the model. The elevated F-statistic value for pressure signifies that this element exerts a significant influence on solid mottle.

The F-statistic is determined by dividing the factor mean square (MS) by the error mean square (MS). The elevated F-statistics with P<0.05 from the ANOVA table validate the significance of all main effects and interactions among speed, ink tack, alcohol percentage, and pressure on solid mottle at a 95% confidence interval. The R-squared value signifies the model's fit to the data and is computed by dividing the regression sum of squares by the total sum of squares. The elevated coefficient of determination (R-Sq.) signifies that 99.66% of the variability can be elucidated by the model. The adjusted R-squared is an effective metric for evaluating the explanatory capacity of models with varying quantities of predictors. The value increases only if the incorporation of existing components enhances the model to achieve the anticipated change. The adjusted R-squared of 99.50% signifies a substantial enhancement of the model by the incorporation of five components. The minimal difference between R-Squared and Adjusted R-Squared demonstrates a significant regression of the model utilizing five components. The R-Squared (projected) reflects the model's efficacy in forecasting responses for novel observations and is derived from the predicted error for the sum of squares (PRESS) statistics. The maximum R-Squared (predicted) of 99.21% signifies that the model forecasts new observations almost as accurately as it aligns with the current data. A smaller PRESS value of 0.22 signifies superior prediction capability of the model. The absence of fit with $\alpha > 0.05$ signifies that the data aligns effectively with the model. The lack of fit rating of 0.232 indicates the model's accuracy.

VII. CONCLUSION

The analysis of solid mottle indicated the significance of all parameters, including press speed, ink tack, alcohol percentage, and pressure, in reducing print solid mottle. The optimal settings derived from the interactions plot for solid mottle on coated paper are 8000 press speed, 2 ink tack, 6% alcohol, and 2 pressure. The optimal set retrieved has been evaluated for its consistency, demonstrating a solid mottle reduction of 65%. The created model had prediction accuracy over 99%. This validates the model's variability and predictability. The print mottle degrades print quality, leading to production downtime, material wastage, and time loss. Defect identification necessitates explicit inspection protocols. Moreover, it escalates the total expenditure and diminishes the profit margin. Identifying the root cause of mottle occurrence is essential to resolve the issue and eradicate print mottle. The study's findings will mitigate the complications associated with mottle occurrence through the application of optimum print settings. Additionally, it facilitates the establishment of a lucrative enterprise for the printer.

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