RESEARCH ARTICLE

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Print Quality Evaluation in Paperboard Printing Induced by Changes in Viscosity and Screen Parameters

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Abstract

Newer offset printing technologies demand improved rheological properties of inks ensuring predictable printability and runnability. The printing performance of printing technology is a function of raw materials, namely ink and substrate. Interaction between ink and surface of substrate influence densitometric quantities of printed layer. The consistent performance of ink is a function of its rheological properties mainly viscosity. Substrate surface properties such as smoothness, whiteness and color are critical for printability. This paper attempts to analyse variance in percent tone value on print on paperboard by conducting experiments involving three levels each of dot shape and screen ruling. Experiments also yielded a relationship between viscosity and percent tone value increase.

Keywords: Viscosity, Tone Value Increase, Dot Gain Curve, Gray scale.

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Introduction

Offset printing has been a dominant printing technology for printing on paper and paperboards having halftone printing range upto 300 LPI. Surface properties of substrate decide reproducible printing resolution and overall print quality.[1] Offset being an impact based printing technology printed dot enlarges resulting in dot gain. This enlargement depends upon the ink viscosity governing the flow properties.[2] As per ISO 12647-2 the tone value increase in percentage of process ink print increase with screen ruing (LPI) and is different for different dot shape.[1] Offset and letterpress inks are paste inks having less solvent as compared to flexographic and gravure ink. The general range of offset printing ink viscosity is 400-1000 poise and that of flexographic and gravure ink is between 0.5 and 5.0 poise. Thus offset ink much thick viscous and shorter than gravure and flexographic inks. [2]Calendaring process of paper and paper board making enhances gloss and print quality but reduces brightness.The ink penetration in the z-direction into a substrate influences the print quality. The ink penetration affects the print density, mottling and dot gain, common print effects that influence achievable print quality and visual appearance. The pressure in the printing nip and the porosity of the substrate both affect the amount of ink that is pressed into the porous structure of a coating layer during printing.[3]

The common rheological problems are poor trapping, flying or misting, piling and caking and ink backs away from the fountain roller. Of these problems, poor trapping results in shift in print density, affecting print quality.[4] In the case of paper and paper board, a surface-sizing chemical process that applies starch to the substrate improves its printability. Sizing controls the surface energy of substrate, its hydrophilic character, affinity towards different ink and smoothness of paper surface. Print quality is achieved if ink on surface of substrate is optimized to balance absorption and spreading. Sizing results in the application of thin, uniform film of starch added with synthetic sizing agents on surface of paper. The performance of sizing agents depends on starch added with copolymers of styrene identified, maleic anhydride, acrylic acid esters or polyurethane.[4,6]

Common dot shapes used in offset halftone printing are round, elliptical and rhomboidal. The round dot is non-directional so it is less affected by press problems. Dots are round through the tone range reducing single channel moiré issues. All screen angle dots react the same to directional press issues such as slur and doubling. In the Elliptical dot, the optical bump is moderated by being split into two – when the dots first touch at the long width at the 40% tint and then again at the short width at 60%. Directional problems

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Figure 1: Representative Grayscale

on press such as slur and doubling can cause strong tone and color shifts depending on the angle of orientation of the dots relative to the angle of the paper as it travels through the press. Lastly, square dots produce sharp images but are prone to loss of shadow detail due to very thin spaces between shadow dots.[5]

Considerable work has been done in investigating tone value variation with ink viscosity and chemical formulation of paper finish. Moutinho *et al.*[6] used different levels of cationic starch and minor quantities based on styrene copolymers. Application of these size formulations followed by inkjet printing to analyze the impact of size in print quality. However, trials did not consider ink viscosity on print quality. Ivana Jurič *et al.*[7] took substrate surface properties viz., gloss and roughness at their different values and printed to analyse print quality. These experiments neither considered ink viscosity nor sizing amount. J. Lipponen e al. [8] also focused on testing sizing quality of two starch formulations with different concentrations keeping aside ink chemistry and printing inputs. Moutinho *et al.*[6] Ivana Jurič *et al.*[7] and J. Lipponen *et al.*[8] appropriately did not include print inputs such as screen ruling and dot shape. A study by Dragoljub N. et al[9] included an evaluation of mottle, line quality, dot roundness, print sharpness and colour reproduction, but did not consider viscosity treatment and its effect on print quality. Dragoljub N. *et al.*[9] concluded that PVC substrate roughness and other parameters, such as colour properties and reverse side printing, significantly influence print quality. Swati B.[10] conducted experiments to study effect of screen ruling and screen shape on image quality using 3 levels of screen ruling, 6 levels of dot shape without considering ink viscosity as a varying parameter. The present experiment is designed to assess print quality when ink with different viscosities is printed on ivory paper board which is a chemically modified and used for the custom printed paper boxes, particularly for the cosmetic paper boxes, food paper boxes and retail paper boxes.

The discussion on experimental work aimed at measuring print consistency is divided in five sections of this report.

The ink formulation, printability and runnability properties, rheological parameters of ink, ISO standard 12647-2 recommendation about tone value and applicability of screen frequency, dot shape related to offset printing of sheet fed lithographic offset printing technology and the relevant literature are discussed in this section. The information on materials and parameters as identified for the experimental work is presented in the second section along with adequate detailing of the experimental set-up. The third section elaborates observation and subsequent results with the help of appendices and figures. In the fourth section, observation and results are further discussed regarding efficacy and limitations of the experimental setup. The final section combines the observation, result and discussion to draw conclusions as well as scope for up gradation.

Table 1: Parameters

Constant Parameter	*Varying Parameter*	*Total Trials*
Machine Speed-2000 iph	Screen Ruling (LPI) (4) - 150, 175, 200, 240	
Temperature 25 deg C	Dot Shape (3) - Round, Elliptical, Rhomboidal	12
Relative Humidity-60 %		

Methods

During the experimental work, the lithographic offset press of 18×23 inch size known to be involved in frequent process color printing was identified. The actual working condition regarding automation, consumable usage, operating methodology, quality practice and prevalent machine speed was kept unchanged. The identified machine used conventional inking and dampening systems. Ivory card paper of 300 GSM was used as a substrate along with magenta process ink to print a lot of 1000 sheets wherein all important parameters are included. The main parameter is the dot area scale from 0.0 to 100.0% with an increment of 10.0 %. Such control elements are printed with the following parameters. Each plate i.e., image carrier is imaged with 12 different images for 12 trials. The dot area is measured using a densitometer at 2 deg viewer angle and D50 illuminant. Levels of parameter ink Viscosity: 150, 300, and 450 Poise are also considered for printing.

Each trial Ivory board is printed with three levels of ink viscosities. ANOVA is done only for screen ruling and dot-shape treatments. The effect of viscosity on dot gain at 50% is tabulated separately and discussed in the result section along with other observations.

Results

Observed dot area values are measured on dot grayscale for 12 trials and recorded in Appendix A. Similarly, the dot area values for all dot shapes are recorded for three ink viscosity levels and in Appendix B. For ANOVA dot area value at 50% is treated as a response for all 12 trials.

In case of appendix B observed dot area of 50% dot is selected as response variable. The null hypothesis for screen ruling (factor A) and dot shape (factor B) and the interaction effect of screen ruling and dot shape are stated below. Two sample ANOVA is completed as random test and tested for F-distribution values.

The results of ANOVA and F- distribution are shown in Table 2. Figure 2 and figure 3 show f-distribution for respective degrees of freedom for factor A and B, respectively.

Table 2: ANOVA Table

Source	*DF*	*Sum of Square (SS)*	*Mean Square (MS)*	*F Statistic (df1,df2)*	*P-value*
Factor A - rows (A)	3	1079.5573	359.8524	19.676 (3,6)	0.001658
Factor B - columns (B)	2	56.4802	28.2401	1.5441 (2,6)	0.2878
Interaction AB	6	109.7332	18.2889	1.7113 (6,108)	0.1252
Error	108	1154.224	10.6873		
Total	119	2399.9947	20.168		

Figure 4 shows the f-distribution for respective degrees of freedom for the interaction effect between factors A and B. Figures 5, 6 and show cell's average, residual plot and box plot, respectively. Validation found the presented design balanced. As for screen ruling (factor A) the calculated *p-value* is 0.001658 i.e., less than 0.05, the null hypothesis Factor A (Screen Ruling): H0: μ1 = μ2 = μ3 = μ4 is not accepted and in case of dot shape (factor B) the calculated *p-value* is 0.2878 i.e. more than 0.05, the null hypothesis Factor A (Screen Ruling): H0: μ1 = μ2 = μ3 = μ4 is accepted. The p-value for the interaction effect of A and B is 0.1252 and is higher than 0.05 hence null hypothesis is not accepted.

Hypotheses

Factor A (Screen Ruling): H0: μ1 = μ2 = μ3 = μ4
There is no difference in the means of variable A categories.
Factor B (Screen Dot Shape): H0: μ1 = μ2 = μ3
There is no difference in the means of variable B categories.
H0: Interaction (AiBj) = 0 (∀ i = 1 to a, j = 1 to b)

Two sample ANOVA - random test, using F distribution (right-tailed)

As per the values shown in Table 2.

Factor - A (Screen Ruling)

1. H0 hypothesis

Since p-value < α, H0 is rejected. Some of the groups' averages consider to be not equal. In other words, the difference between the averages of some groups is big enough to be statistically significant.

2. P-value

The p-value equals 0.001658, (p (x ≤ 19.676) = 0.9983). It means that the chance of type I error (rejecting a correct H0) is small: 0.001658 (0.17%). The smaller the p-value the more it supports H1.

3. Test statistic

The test statistic FA equals 19.676, which is not in the 95% region of acceptance: [-∞: 4.7571].

4. Effect size

The observed effect size η2 is large, 0.48. This indicates that the magnitude of the difference between the averages is large.

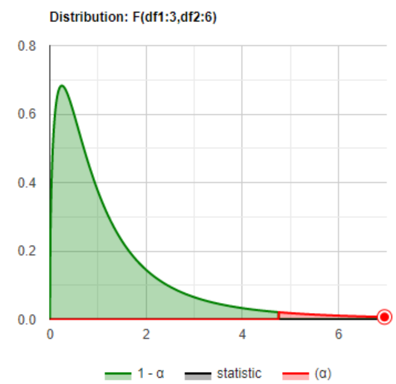

Figure 2: Distribution: F (df 1:3, df 2:6)

Factor - B (Screen Dot Shape)

1. H0 hypothesis

Since p-value > α, H0 cannot be rejected. The averages of all groups assume to be equal. In other words, the difference between the averages of all group is not sufficient enough to be statistically significant. A non-significant result cannot prove that H0 is correct, only that the null hypothesis cannot be rejected.

2. P-value

The p-value equals 0.2878, (p (x ≤ 1.5441) = 0.7122). It means that the chance of type I error, rejecting a correct H0, is too high: 0.2878 (28.78%). The larger the p-value the more it supports H0.

3. Test statistic

The test statistic FA equals 1.5441, which is in the 95% region of acceptance: [-∞: 5.1433].

4. Effect size

The observed effect size η2 is small, 0.047. This indicates that the magnitude of the difference between the averages is small.

Interaction AB (Screen Ruling and Screen Dot Shape)

1. H0 hypothesis

Since p-value > α, H0 cannot be rejected.
The averages of all groups assume to be equal.
In other words, the difference between the averages of all

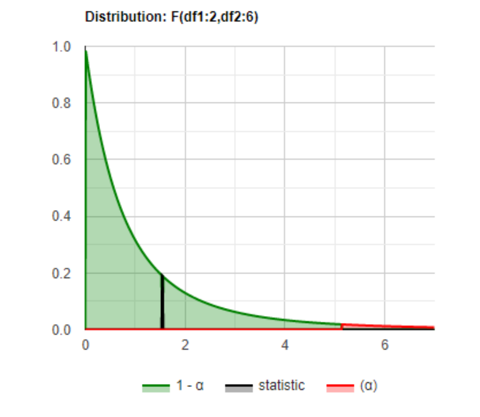

Figure 3: Distribution: F (df1:3, df2:6)

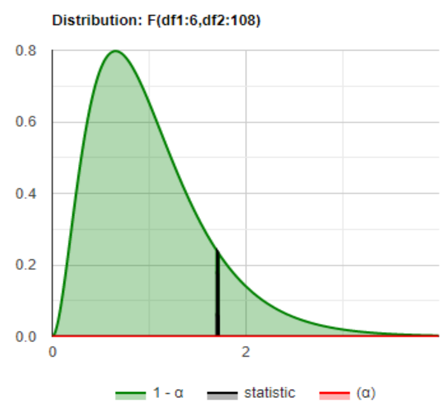

Figure 4: Distribution: F (df1:3, df2:6)

groups is not big enough to be statistically significant.

A non-significance result cannot prove that H0 is correct, only that the null assumption cannot be rejected.2. P-value. The p-value equals 0.1252, (p (x ≤1.7113) = 0.8748). It means that the chance of type I error, rejecting a correct H0, is too high: 0.1252 (12.52%). The larger the p-value the more it supports H0.

3. Test statistic

The test statistic FA equals 1.7113, which is in the 95% region of acceptance: [-∞: 4.2839].

4. Effect size

The observed effect size η2 is medium, 0.087. This indicates that the magnitude of the difference between the averages is medium.

Validation

Outliers- Outliers' detection method: Tukey Fence, k=1.5.
Residuals doesn't contain outliers.
Normality- The assumption was checked based on the Shapiro-Wilk Test. (α=0.05)

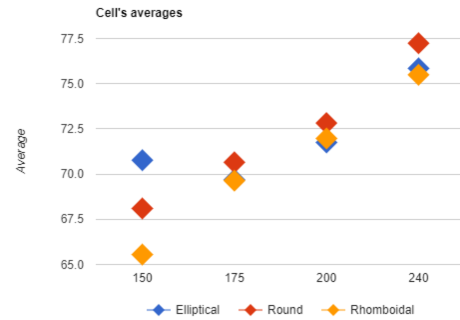

Figure 5: Cell's averages

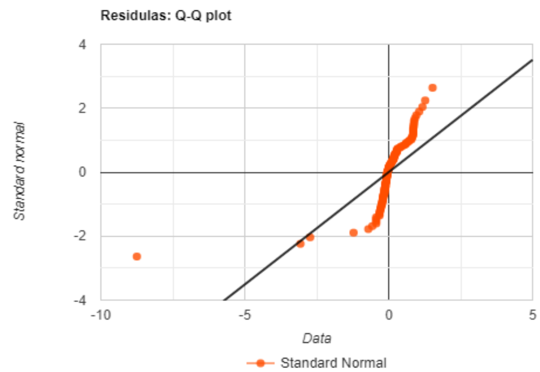

Figure 6: Residuals plot

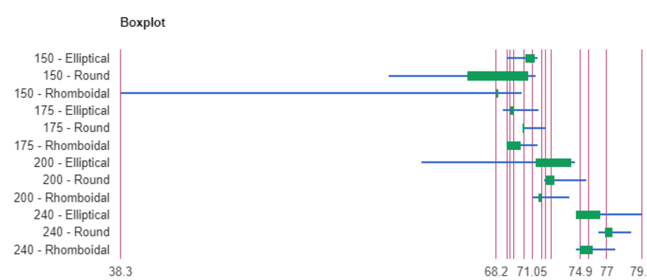

Figure 7: Box Plot

It is assumed that the residuals does not follow a normal distribution (p-value is 0).
The test is considered robust for moderate violation of the normality assumption.
Test power: Factor - A. The test priori power is strong 0.9182
Test power: Factor - B. The test priori power is strong 0.9659
Test power: Interaction. The test priori power is strong 0.9906
Design- Expt design is balanced.

Discussion

Print quality control in printing on Ivory paper, paper board is crucial as it has advantages such as excellent surface, aging-resistant, high color constancy, rigid strong and durable paper, and homogenous paper formation, approved for direct food contact. Ivory paper and board applications include business cards, annual reports, business materials, exclusive packaging, covers, greetings cards, invitation, displays, calendars, certificates, brochures, envelopes, menus, and tickets with RFID. Identifying the significance of the influence of screen ruling and dot shape on tone value or other print quality parameters. Results shown in earlier sections suggest that the screen ruling is a parameter of significance when printing a full-color graphic original. Variation in tone value with screen ruling can affect color balance and gray balance and can result in rejection proof or even job. Paperboard has an advantage over plastic materials in light-blocking properties, although paperboard packages do not block all light.

Conclusion

From the above trials, it is concluded that the higher screen ruling results in higher dot gain in process color and half-tone printing, even on ivory paper. Tone value increase is also more in high screen ruling. Dot shape is not as influential as screen ruling, hence offering flexibility to prepress and press operator. Ink viscosity also shows a considerable influence on tonal reproduction as dot gain increases with decreasing viscosity. This known behavior is quantified and shows that at higher viscosities, the tone value variation is narrowing and opposite can happen when viscosity decreases. Furthermore, Appendix B suggests that between dot shape and viscosity, the dot shape is less influential in affecting value increase i.e. dot gain.

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Appendix A: Measured value of 50% Dot on Ivory Board

150/ Elliptical	*175/ Elliptical*	*200/ Elliptical*	*240/ Elliptical*	*150/ Round*	*175/ Round*	*200/ Round*	*240/ Round*	*150/ Rhomboidal*	*175/ Rhomboidal*	*200/ Rhomboidal*	*240/ Rhomboidal*
71.5	69.4	72.3	76.5	69.1	70.3	72.9	77.0	68.2	69.2	71.8	74.9
69.0	69.7	71.6	75.6	59.6	70.3	72.7	77.5	68.3	70.2	71.8	74.6
70.7	71.6	74.5	79.8	71.4	72.2	75.4	79.0	70.3	71.5	74.1	77.7
71.3	69.7	74.2	74.5	70.8	70.5	72.1	76.8	68.2	69.0	71.5	75.9
71.1	68.7	71.3	74.5	69.0	70.4	72.0	76.3	68.4	69.0	71.1	74.9
70.2	69.5	71.9	76.0	64.3	70.3	72.8	77.2	68.2	69.7	71.8	74.5
71.0	70.6	74.3	77.1	71.1	71.3	73.7	77.9	69.2	70.2	72.8	76.8
70.5	69.3	71.0	75.5	65.9	70.3	72.5	76.9	68.3	69.4	71.5	74.8
71.3	69.7	74.2	74.5	70.8	70.5	72.1	76.8	68.2	69.0	71.5	75.9
71.1	68.7	62.2	74.5	69.0	70.4	72.0	77.0	68.2	69.2	71.8	74.9

Appendix B: Measured value of 50% Dot on Ivory Board

Dot Shape	*Viscosity (Poise)*	*Observed 50% tone value (Screen: 150 LPI)*									
	450.0	68.0	66.1	66.7	66.2	66.1	66.1	66.5	66.6	66.2	68.1
Elliptical	300.0	67.1	65.5	65.9	66.7	68.3	66.1	66.9	65.9	66.7	66.7
	150.0	71.5	69.0	70.7	71.3	71.1	70.2	71.0	70.5	71.3	71.1
	450.0	68.0	67.4	67.6	67.7	67.6	67.8	67.6	67.5	67.4	67.7
Round	300.0	67.9	67.5	69.1	69.7	69.4	68.1	69.4	67.9	69.7	68.9
	150.0	69.1	59.6	71.4	70.8	69.0	64.3	71.1	65.9	70.8	69.0
	450.0	67.2	66.8	66.8	66.8	66.7	66.8	66.8	67.2	67.2	66.0
Rhomboidal	300.0	67.6	67.5	68.6	68.8	68.6	67.9	68.6	67.6	68.8	68.3
	150.0	68.2	68.3	70.3	68.2	68.4	68.2	69.2	68.3	68.2	68.2