ORIGINAL SCIENTIFIC PAPER

ACTA GRAPHICA 243

Impact of Electrostatic Assist on Halftone Mottle in Shrink Films

Authors

Akshay V. Joshi

Department of Printing Engineering, P. V. G's College of Engineering and Technology,
44, Vidyanagri, Shivdarshan, Parvati, Pune- 411009, Maharashtra
India
E-mail: joshiakshay1973@gmail.com

Abstract:

Gravure printing delivers intricate print quality and exhibit better feasibility for printing long run packaging jobs. PVC and PETG are widely used shrink films printed by gravure process. The variation in ink transfer from gravure cells on to the substrate results in print mottle. The variation is inevitable and requires close monitoring with tight control on process parameters to deliver good dot fidelity. The electrostatic assist in gravure improves the ink transfer efficiency but is greatly influenced by ESA parameters such as air gap (distance between charge bar and impression roller) and voltage. Moreover, it is imperative to study the combined effect of ESA and gravure process parameters such as line screen, viscosity and speed for the minimization of half-tone mottle in shrink films. A general full factorial design was performed for the above mentioned parameters to evaluate half-tone mottle. The significant levels of both the main and interactions were studied by ANOVA approach. The statistical analysis revealed the significance of all the process parameters with viscosity, line screen and voltage being the major contributors in minimization of half-tone mottle. The optimized setting showed reduction in half-tone mottle by 33% and 32% for PVC and PET-G respectively. The developed regression model was tested that showed more than 95% predictability. Furthermore, the uniformity of dot was measured by image to non-image area (ratio) distribution. The result showed reduction in halftone mottle with uniform dot distribution.

Keywords:

Shrink films, Half-tone mottle, ANOVA, Regression model, Dot fidelity

1 Introduction

Gravure is a widely accepted printing process due to its versatility, flexibility and high print quality. The print mottle leads to print rejections and wastage of ink, substrate and time. The gravure print quality has further improved by endorsing electrostatic assist through elimination/minimization of dot skips. The electrostatic assist and gravure process parameters play vital role in delivering quality print jobs. However, there are some areas that need to be addressed to achieve progressive and consistent print quality. The printability is greatly dependent on ink, substrate and process parameters (Fahlkrantz, 2005). The variation in ink transfer is inevitable and can be controlled by optimization of process parameters. The variation in reproduction of half-tone dots leads to poor print quality. The degree of variation in ink transfer can be gauged by halftone print mottle.

Print mottle can be defined as unevenness in ink transfer which leads to uneven density distribution which creates unpleasant visual appearance for the human eye (Fahlcrantz, Johansson and Aslund, 2003). The unevenness in print density can be evaluated by STFI, discrete wavelet analysis and SFDA techniques (Teleman et al., 2005). Stochastic Frequency Distribution Analysis (SFDA) algorithm calculates mottle from the two-dimensional scanned image where it analyses the properties of texture through each pixel luminance values then calculates the spatial distribution of this texture. It interprets the data according to algorithm designed and outputs an equivalent mottle index value (Rosenberger, 2003). The non-uniformity in optical dot gain also reflects mottle in halftone area (Kawasaki, Ishisaki and Yoshimoto, 2009). The ink transfer from a gravure cell on to the substrate depends on characteristics of ESA semi conductive impression roller such as uniformity of charge distribution, surface and volume resistivity (Doppler., 2003 & Hyllberg., 1993). Higher surface and volume resistivity pose high dissipation of charge and offers high surface charge holding ability (Webster, 1998).

The conductive substrate such as foil and inks are not feasible for gravure printing with ESA, due to poor charge holding capacity that gets leaked immediately, resulting in an electric spark (Zaretsky, Billow and Whitney, 2004). The substrate properties such as topography, smoothness, roughness, absorption and surface energy plays an important role in determining print quality (Velho and Santos., 2010). The topography and roughness variation causes uneven ink spreading and absorption which leads to differential dot structure, density and gloss (Liu, Zhang and Liang, 2013). Higher topography and roughness leads to high print mottle (Olsson et al., 2007). The electrical properties of the substrate show great impact in determining the ESA parameters (George & Oppenheimer., 1987). The introduction of ESA had showed a significant improvement in print quality by eliminating dot skips (Steingraeber, 2012). The influence of electrostatic improves the liquid spreading and wettability on the surface (Wright, 1993). The ink properties such as viscosity and surface tension play a vital role in print quality. Ink with higher surface tension has high cohesion force which resist spreading on the substrate surface resulting in inhomogeneous wetting; thereby the print mottle (Durand, 2012). The surface energy of the substrate determines the spreading, adhesion and wettability of ink on the surface. Lower surface energy leads to less affinity to hold ink on the surface which results in poor adhesion and wettability thereby results in print mottle (Repeta, 2013). The application of ESA current beyond the threshold limits also shows adverse effect in print quality such as whiskering (Gravure Association of America, 2003).

Print rejections can be minimized by optimization of process parameters and simultaneously decline the non-value added operations and cost incurred in it. Hence, there exists a need of research work to be conducted on optimization of ESA and gravure process parameters and its effect on half-tone mottle.

2 Material

2.1 Substrate

PVC and PET-G shrink films (40 μm thickness) were used for the experimental trials. The surface energy of the substrate was determined by testing with standard test liquids i.e. Formamide and Glycerol. The test liquid contact angle on substrate surface was evaluated using Holmarc contact angle meter. Geometric mean equation was employed to estimate the surface energy of the substrate. The surface energy of PVC and PET-G was found to be 35.62mN/m and 37.51mN/m respectively. The substrates electrical properties viz. surface and volume resistivity were tested according to ASTM D257-14 method (ASTM Standards., 2014). The surface resistivity was found to be 0.8 x 1015 Ω and 1.0 x 1015 Ω while volume resistivity was 1.8 X 1016 Ω.cm and 2.0 x 1016 Ω.cm for PVC and PET-G respectively. The PET-G substrate had higher surface energy, surface and volume resistivity as compared to PVC.

2.2 Ink

A solvent based black ink with acrylic resin was used for the experiment. The ink viscosity was measured with #4 ford cup. The viscosity was adjusted using recommended solvent combination of ethyl acetate, toluene and iso-propyl alcohol (IPA) in the ratio of 4:4:2. The target density was set with a tolerance of 5% for the entire experimental trials. The ink surface tension was determined with Kruss K 100 Ring Tensiometer using Du Noüy ring technique. The surface tension of the acrylic ink was found to be 23.77mN/m.

2.3 Layout Design

The layout comprises of image, logo, reverse text, normal text, step wedge, solid patches. The halftone patch (30%) size of 110mm x 95 mm was design to evaluate the ink transfer properties. The uniformity of image to non-image area was analysed at 50% step wedge. Electronic engraving technique was employed for gravure cylinder making.

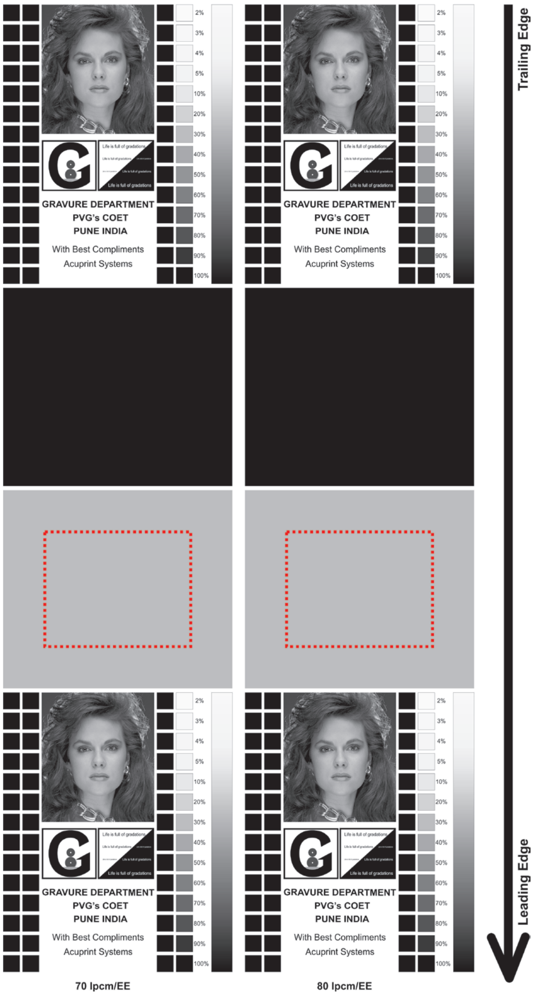


Figure 1: Layout Design

3 Methods

3.1 Experimental Design

The line screen, air gap, viscosity, voltage and speed were the screened parameters for a general full factorial design of experiments (DOE). The DOE includes 216 runs with 2 replicates (108 runs per replicate) for each PVC and PET-G. Table 1 shows the levels of process parameters for the runs.

Table 1: Process Variables and Levels

S. No.	Variables	Unit	Levels		
			Low	Mid	High
1	Line Screen	lpcm	70	-	80
2	Air Gap	mm	3	5	7
3	Viscosity	s	19	-	21
4	Voltage	kV	8	10	12
5	Speed	m/s	1.33	1.67	2

The Table 2 shows equivalent current achieved for a given air gap distance and voltage for both PVC and PET-G films. The resistance was calculated by using Ohm's law (1). The calculated resistance is summation of air gap, impression roller and substrate resistances. The ESA current magnitude generation depends on air gap distance, voltage applied and substrate electrical properties. The PET-G substrate offered high surface and volume resistance; thus, resulting in lower magnitude of current for set air gap and voltage as compared to PVC.

Table 2: Resistance at Different Air Gap and Voltage for PETG and PVC

Air Gap (mm)	Voltage (kV)	PET-G		PVC	
		Current (mA)	Resistance (MΩ)	Current (mA)	Resistance (MΩ)
3	8	0.6	13.33	0.8	10.00
	10	0.9	11.11	1.1	9.09
	12	1.2	10.00	1.4	8.57
5	8	0.5	16.00	0.6	13.33
	10	0.8	12.50	0.9	11.11
	12	1.1	10.90	1.2	10.00
7	8	0.4	20.00	0.4	20.00
	10	0.7	14.29	0.7	14.28
	12	0.9	13.33	1	12.00

$$R = V / I \tag{1}$$

where,

R=Resistance between charge bar and impression roller

V= Voltage or Potential difference between charge bar and impression roller

I = Current

3.2 Sampling and Printing

A sample size of 10 printed sheets per each run was considered for halftone mottle and dot uniformity. The experimental trials were conducted on a roto-gravure machine which was employed with pneumatic loaded impression roller, auto web tension control, top loading ESA charging bar system and ESA impression roller of 80 shore A hardness. The gravure machine had the maximum speed of 2 m/s. An ink mixing roller was dipped in ink pan to avoid foaming and pigment settling.

3.3 Measurement Technique

3.3.1 Halftone Print Mottle

The halftone patches were scanned at 1200 ppi with Epson V700 scanner. The halftone mottle was evaluated using Verity IA Print Target which employed Software Stochastic Frequency Distribution Analysis (SFDA) evaluation technique. The scanned images were analysed with an area of interest (AOI) of 70mm x 55 mm. The algorithm divides the AOI in smaller targets and later each target is analyzed at sub-visible levels. The recorded pixel luminance value is interpreted by software and the mottle index is evaluated.

3.3.2 Dot Uniformity Ratio

The analysis was performed at 50% patch of the step wedge and images were captured using a Microscope at 200X. The captured images were processed through Dexel Imaging V 2.4.4 software. The image and non-image area was evaluated and then ratio was determined.

3.4 Experimental Process

A baseline for halftone mottle was conducted by performing production run for a few days. The Design of Experiments (DOE) was generated for ESA and gravure process parameters. The halftone mottle data was analysed by analysis of variance (ANOVA) and main and interaction plots to spot out the optimal process parameters minimizing half-tone mottle. The developed regression model was tested for new observations to check the predictability of the model.

4 Results and discussion

4.1 Production Run and Baseline

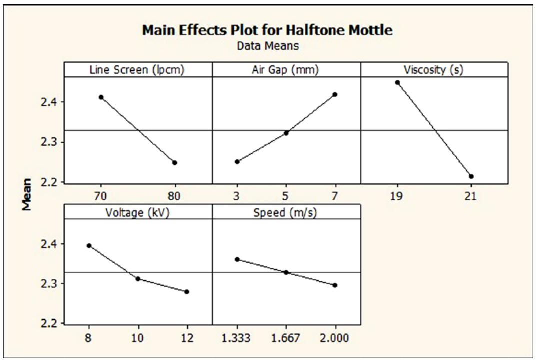
The baseline for halftone mottle was defined by conducting production runs at pre-determined settings for few days on PVC and PETG films. These runs were set at 70 lpcm line screen, 19 sec viscosity, 100 m/min speed, 80 shore hardness and 3.5 kg/cm2 pressure with ESA OFF. The data collected from the production run showed mean halftone mottle as 2.838 and 2.938 for PVC and PETG, hence considered as a baseline. The aim was set to minimize the halftone mottle from the baseline.

4.2 Print mottle

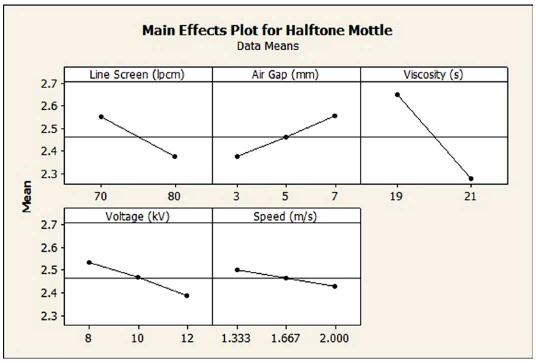
4.2.1 Statistical Analysis

The main effect plots (Fig. 2) suggest the significance of all the parameters on halftone print mottle for PVC and PET-G films. The overall lower halftone mottle was obtained at higher level of line screen, viscosity, voltage, and speed with lower air gap. The lower line screen cell has larger cell opening and corresponding ink volume carrying capacity. This leads to high ink transfer rate under the high net force of impression roller. This causes deterioration of dots resulting in less circularity thereby, high print mottle. The higher line screen cells have low ink volume carrying capacity. The ink distribution was uniform on the substrate under the influence of ESA at higher line screen resulting in sharper dots with good circularity; thereby lower mottle. The halftone cells are very sensitive and highly reactive to change in ESA process parameters.

The ink contains polar molecules which are randomly orientated when no electrostatic force is applied. An applied electrostatic force polarizes the molecules by orienting them in a defined direction due to dipole moments. It helps the ink elevation from the cells and reaches to the substrate surface against the force of gravity. However, the ink evacuation efficiency changes with respect to viscosity and ESA current magnitude.

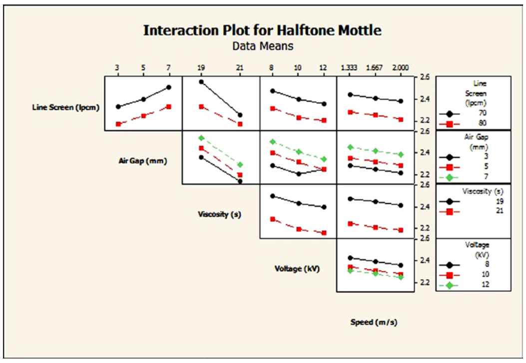


(a)

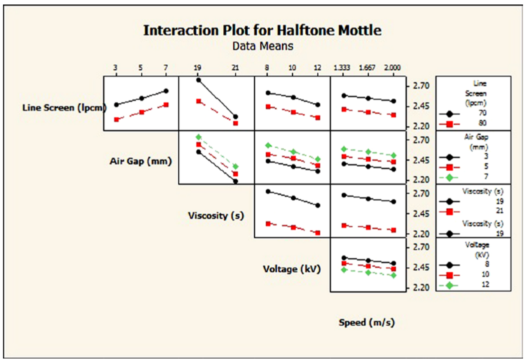


(b)

Fig. 2: Effects of Process Parameters on Halftone mottle on (a) PVC; (b) PETG



(a)



(b)

Fig. 3: Interaction Plots of Halftone Mottle for (a) PVC; (b) PETG

The lower viscosity with ESA shows high ink drift velocity due to low mass content and corresponding low viscous drag force. Thus, ink transfer is high in lower viscosity. The higher ink transferred possesses a higher tendency to spread and thereby causing local variations in reflectance and density leading to print mottle. The higher viscosity of ink has high viscous drag force and ink mass content. Therefore it needs high ESA current to break the inherent resistance and to create dipole movement. Moreover, the high ESA current can be achieved only with lower air gap. The combined influence of higher viscosity which poses less spreading of ink, high voltage with lower air gap resulted in lower halftone mottle. The larger centrifugal force at higher printing speed shows effective ink evacuation from cells.

The interaction plots (Fig. 3) consist of non-parallel lines representing interaction of line screen, air gap, viscosity, voltage and speed. The interaction at 3 mm air gap and 12 kV voltage showed increase in halftone mottle for PVC. It can be postulated to the breakdown of dielectric liquid (ink) beyond 10 kV voltage. The applied voltage is increased beyond the critical voltage of the liquid which results in higher degree of dipole repulsion. The high energy induced in the ink set turbulent or impulsive motion of molecules leading to reproduction of higher distortional dots resulting in whiskering. This slight discrepancy between the desired and actual applied electrostatic force leads to a significant change in dot reproduction which resulted in higher halftone mottle. Moreover, the spacing between cell is relatively high thus dot has more liberty for distortion which leads to higher half-tone mottle. The difference in voltage required for PVC and PET-G has varied due to difference in electrical properties of substrate. The substrate surface and volume resistivity has played a significant role in determining the ESA current. The current generated at 3mm air gap with 12 kV was 1.2 mA and 1.4 mA for PET-G and PVC respectively. The higher ESA current of 1.4 mA for PVC led to dot deformation; thereby resulting in higher mottle in halftone areas. The optimum ESA current magnitude of 1.2 mA with 12 kV voltage for PETG and 1.1 mA with 10 kV for PVC showed improved dot reproduction. The interaction plots indicate reduction in halftone mottle at an interaction of 80 lpcm line screen, 3 mm air gap, 21 s viscosity, 2 m/s printing speed with 10 kV voltage for PVC while 12 kV voltage for PETG; hence considered as best settings.

Table 3: Summary of Model for Halftone Mottle - PVC

Summary of Model
S = 0.0349960 R-Sq = 96.33% R-Sq(adj) = 96.17%
PRESS = 0.278389 R-Sq(pred) = 95.95%

Table 4: ANOVA Table for Regression for Halftone mottle- PVC

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	6.6228	6.6228	0.7358	600.851	0.000
Line screen	1	1.4696	0.3677	0.3677	255.399	0.000
Air gap	1	1.0485	0.0488	0.0488	39.885	0.000
Viscosity	1	3.0442	0.3127	0.3127	300.282	0.000
Voltage	1	0.4881	0.0074	0.0074	6.082	0.014
Speed	1	0.1600	0.1600	0.1600	130.697	0.000
Line screen*Viscosity	1	0.2987	0.2987	0.2987	243.929	0.000
Air gap*Viscosity	1	0.0068	0.0068	0.0068	5.602	0.018
Air gap*Voltage	1	0.1011	0.1011	0.1011	82.582	0.000
Viscosity*Voltage	1	0.0054	0.0054	0.0054	4.431	0.036
Error	206	0.2522	0.2522	0.0012		
Lack of Fit	98	0.1258	0.1258	0.0012	1.097	0.318
Pure Error	108	0.1264	0.1264	0.0011		
Total	215	6.8751				

Regression Equation:

Halftone Mottle for PVC = 15.978 - 0.165 Line Screen (lpcm) + 0.193 Air Gap-0.629 Viscosity + 0.073 Voltage - 0.100 Speed + 0.007 Line Screen*Viscosity - 0.004 Air Gap*Viscosity - 0.008 Air Gap*Voltage - 0.003 Viscosity*Voltage. (2)

Table 5: Summary of Model for Halftone Mottle - PETG

Summary of Model
S = 0.0180193 R-Sq = 99.44% R-Sq(adj) = 99.41%
PRESS = 0.0746733 R-Sq(pred) = 99.37%

Table 6: ANOVA Table for Regression of Halftone mottle- PET-G

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	11	11.7766	11.7766	1.0706	3297.26	0.000
Line screen	1	1.6924	0.5113	0.5113	1574.80	0.000
Air gap	1	1.1765	0.0058	0.00578	17.81	0.000
Viscosity	1	7.4537	0.6709	0.6709	2066.35	0.000
Voltage	1	0.7584	0.0422	0.0421	129.87	0.000
Speed	1	0.1921	0.0055	0.0055	17.05	0.000
Line screen*Air gap	1	0.0016	0.0016	0.0016	5.01	0.026
Line screen*Viscosity	1	0.4447	0.4447	0.4447	1369.60	0.000
Line screen*Voltage	1	0.0037	0.0037	0.0036	11.34	0.000
Air gap*Viscosity	1	0.0152	0.0152	0.0151	46.78	0.000
Viscosity*Voltage	1	0.0356	0.0356	0.0355	109.59	0.000
Voltage*Speed	1	0.0028	0.0028	0.0027	8.52	0.003
Error	204	0.0662	0.0662	0.0003		
Lack of Fit	96	0.0342	0.0342	0.0003	1.20	0.1778
Pure Error	108	0.0320	0.0320	0.0003		
Total	215	11.8428				

Regression Equation:

Halftone Mottle for PETG = 23.796 - 0.206 Line Screen + 0.051 Air Gap - 0.967 Viscosity - 0.216 Voltage - 0.372 Speed + 0.000336111 Line Screen*AirGap + 0.00907481 Line Screen*Viscosity + 0.000505556 Line Screen*Voltage - 0.00314479 Air Gap*Voltage + 0.00785972 Viscosity*Voltage + 0.0131402 Viscosity*Speed. (3)

The ANOVA (Table 4 and Table 6) indicate that all the main factors are significant as the p-values are below α value of 0.05. The higher F-statistics value for viscosity of 300.282 and 2066.35 for PVC and PETG indicates the most significant factor which influences the halftone print mottle. The interaction of voltage with air gap, line screen and speed; viscosity with air gap, voltage and line screen and air gap with line screen were significant in minimizing half-tone mottle at 95% confidence level for both PVC and PETG films. The Table 3 and Table 5 shows a higher percentage of coefficient of determination (R-Sq.) indicating that 96.33% and 99.44% of the variability could be explained by the model for PVC and PETG at 95% confidence level. The adjusted R-Sq of 96.17% and 99.41% indicates significant improvement of the model by using five parameters. The highest R-Sq. (predicted) of 95.95% and 99.37% indicates that the model predicts new observations nearly as well as it fits the existing data.

4.2.2 Verification and Consistency

The best settings (80 lpcm line screen, 3 mm air gap, 21 s viscosity and 2 m/s speed with 10 kV for PVC and 12 kV for PETG) as obtained from the interaction plot was confirmed by conducting a press run and then checked for its consistency by re-running for few days.

From Table 7, a significant improvement is evident from Production run to consistency run in halftone mottle for both PVC and PET-G films. The halftone mottle is minimized by 33% for PVC and 32% PETG.

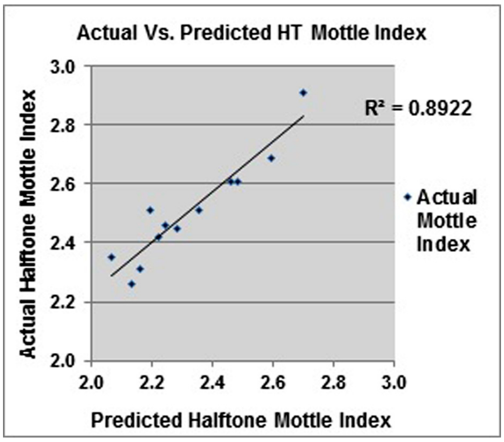
Table 7: Production, Verification and Consistency Run for Halftone Mottle

	PET-G	PVC		
Trials	HT Mottle	Std. Dev.	HT Mottle	Std. Dev.
Production Run	2.938	0.109	2.838	0.085
Verification Run	2.002	0.077	1.961	0.077
Consistency Run	1.98	0.075	1.901	0.081

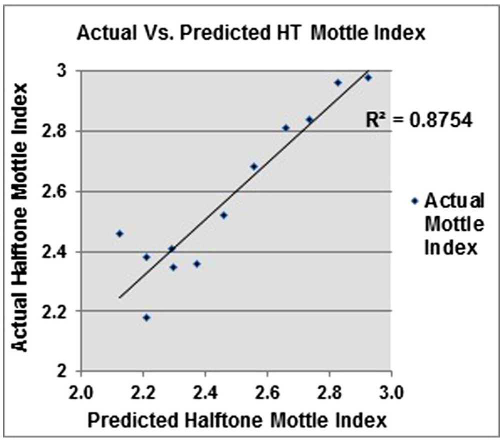
4.2.3 Validation of Model

The model developed through regression analysis was validated by comparing the halftone mottle values as obtained from actual experimental data with the values predicted from regression equation (Eq. 4.1, 4.2).

The plot of actual observations versus predicted values (Fig. 4) shows a correlation coefficient of 0.8922 and 0.8754 for PVC and PET-G respectively. This justifies the prediction ability of the model.



(a)

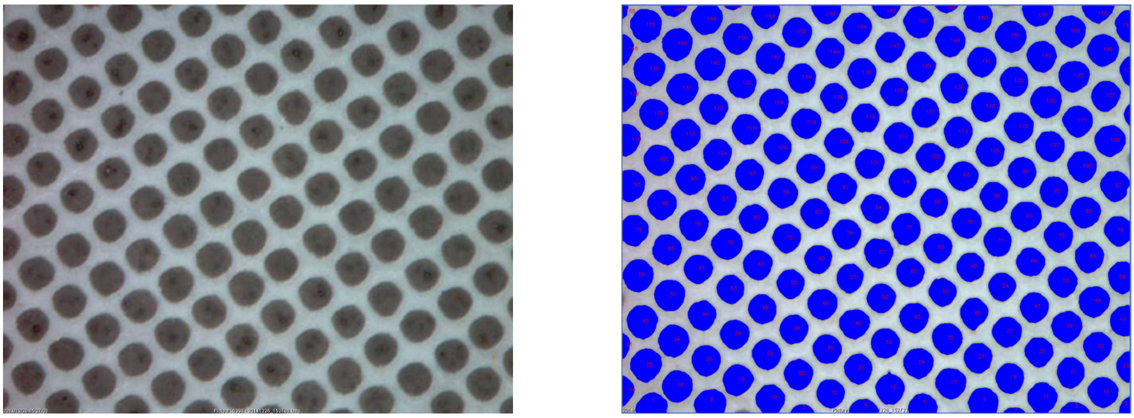


(b)

Fig. 4: Actual Vs Predicted Half-tone Mottle (a) PVC; (b) PETG

4.3 Dot Uniformity: Image to Non-image Area Ratio

The 50% dots from the step wedge were captured by microscope at 200 x magnification. The ratio of image area to non-image was calculated for uniformity of dot distribution (Fig. 5). The ratio of 1 indicates maximum uniform distribution of image to non-image area.



(a) (b)

Fig. 5: Dot structure analysis: Original Captured Image (a); Image after processing (b)

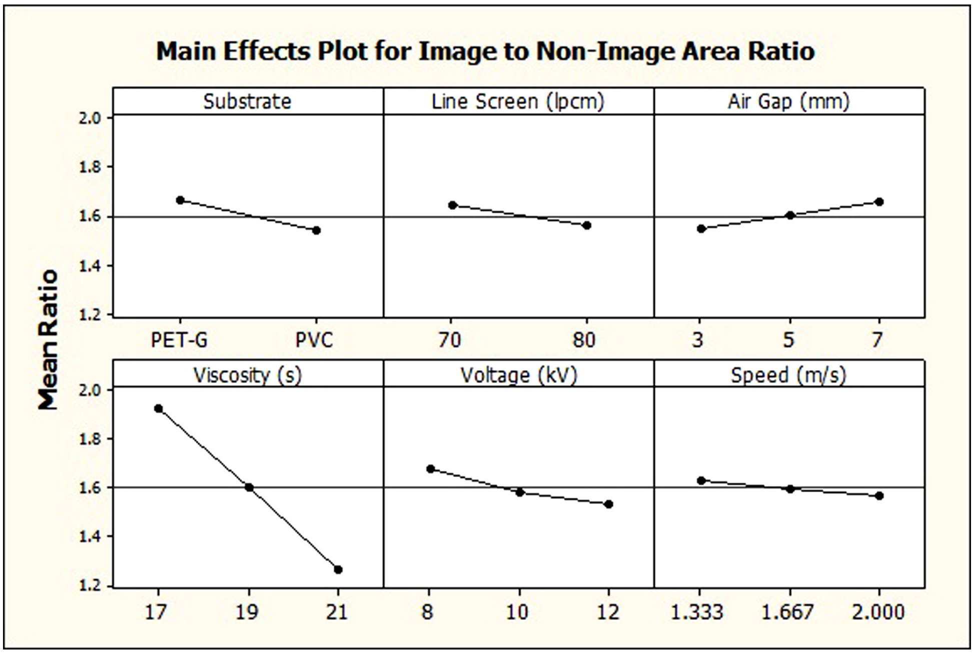


Fig 6: Effect of Process Variables on Image to Non-Image Area Ratio

The main effect plot indicates that higher dot uniformity was achieved at lower air gap with higher levels of line screen, viscosity, voltage and speed for PVC and PET-G. i.e. 80 lpcm line screen, 3mm air gap, 21 s viscosity, 12 kV voltage and 2 m/s speed. Comparatively PVC showed better uniformity ratio than PET-G. It can be manifested to the higher surface energy of PET-G substrate which led to higher spreading. The dot spreading is high at lower line screen due to transfer of high ink volume which affects the dot distribution uniformity. Lower air gap with higher voltage can achieve high electrostatic force magnitude where the ink evacuation from cells is more effective which results in more uniform dot distribution. Also, very less residuals ink is present in the cells. The lower viscosity ink has high tendency to spread which leads to more area coverage and results in uneven distribution of ink. The higher viscosity ink has less solvent content, thus spreading of ink is limited inherently which results in sharper and more uniform ink distribution. Higher speed has larger degree of centrifugal force acting on cylinder. The uniform ink evacuation from cells results in uniform dot distribution.

5 Conclusion

The study aimed to identify the significant factors which affect the halftone print mottle and the goal was to minimize the defect. The design of experiments (DOE) was generated for gravure and ESA process parameters to identify the impact of each parameter on halftone mottle. All the factors were significant in minimizing the half-tone mottle. The interaction of voltage with air gap, line screen and speed; viscosity with air gap, voltage and line screen and air gap with line screen were significant in minimizing half-tone mottle at 95% confidence level for both PVC and PETG films. The halftone mottle was minimized at 80 lpcm line screen, 3 mm air gap, 21 s viscosity, 2 m/s speed and 10 kV voltage for PVC while 12 kV voltage for PETG. The optimal process parameters showed reduction in halftone mottle by 32% and 33% for PET-G and PVC respectively. Furthermore, the developed regression model was tested for new observation which showed more than 95% predictability. In addition, the uniformity of image to non-image area distribution was measured. The halftone area with higher dot uniformity showed reduced halftone mottle.

Poor or uneven ink lay down results in half-tone mottle which causes variation in reflectance resulting in differential ink gloss, density and color on the printed graphics. The half-tone mottle can be minimized and governed by the gravure process parameters. Thus, this research aims to understand the impact of ESA on half-tone mottle for shrink films. The findings of this study shall furnish the gravure printer to utilize the optimal settings to deliver quality print jobs with reduced print waste. The reduction in print waste contributes towards sustainability and helps to reduce possible environmental damage.

6 Acknowledgement

I would like to thank OMNOVA SOLUTIONS INC. for funding the research project and P. V. G's College of Engineering and Technology, Pune, India for providing the laboratory support for the research work. I would like to express my gratitude towards Enulec Electrostatics for sponsoring the ESA system and Rossini for furnishing ESA impression roller. I am thankful to Mr. Roy Rosenberger for his technical support on Verity Mottle software. I am grateful to Manish Packaging, Garware Polyester Ltd., Acuprint Systems Pvt. Ltd. and Flint Group India Pvt. Ltd. for sponsoring PVC, PETG substrates, cylinder and inks.

7 References

ASTM Standards (2014) ASTM D257-14 Standard Test Methods for DC Resistance or Conductance of Insulating Materials. West Conshohocken, PA: ASTM International.

Doppler, A. (2003) Electrostatic Arrangement for Rotogravure and Flexographic Printing Unit. Patent No. 20030066443 A1 Online Source: Available at http://www.google.com/patents/US20030066443 (Accessed on: 30 January 2015).

Durand, Richard, R., Jr. (2012) Surface tension of inks for high speed printing. U.S. Patent No 20120321794. 20 Dec. 2012

Fahlcrantz, C. M., Johansson, P. A., and Aslund, P. (2003) "The influence of mean reflectance on perceived print mottle." Journal of imaging Science and Technology, 47(1), pp. 54-59

Fahlkrantz C.M. (2005), "On Evaluation of Halftone mottle. Doctoral thesis" Doctoral dissertation, KTH School of Computer Science and Communication.

George, H. F., & Oppenheimer, R. H. (1987). Method and apparatus for transferring ink in gravure printing. Patent No. 4697514. Online source: Available at http://www.google.co.in/patents/US4697514#backward-citations (Accessed on: 17 January 2015).

Hyllberg, B. E., (1993) Impression Roller and Method of preparation. US Patent No. 5178071, Online Source: Available at http://www.google.co.in/patents/US5178071 (Accessed on: 5 February 2015).

Kang, K.H. (2002) "How electrostatic fields change contact angle in electrowetting". American Chemical Society, Langmuir, 18 (26), pp. 10318–10322.

Kawasaki. M., Ishisaki. M., & Yoshimoto. Y. (2009). "Investigation into the Cause of Print Mottle in Half-tone Dots of Coated Paper: Effect of Optical Dot Gain Non-uniformity" Tappi Journal, 63(11), pp. 1362-1373.

Liu, G. D., Zhang, M. Y., & Liang, Q. P., (2013) "Study on the Assessment Method of print mottle Using Discrete Wavelet Analysis." Applied Mechanics and Materials, 262, pp. 177-180

Olsson, R., Yang, L., van Stam, J., & Lestelius, M., (2007) "Effects of elevated temperature on flexographic printing." In Advances in Printing and Media Technology, Proceedings of the 34th Research Conference of IARIGAI, Grenoble, France.

Repeta, V., (2013) "Influence of Surface Energy of Polymer Films on Spreading and Adhesion of UV-Flexo Inks." Acta Graphica, 23 (2013)3-4 pp. 79-84.

Rosenberger, R. R., (2003) "Stochastic Frequency Distribution Analysis as Applied to Mottle Measurement." Verity IA LLC, Verity Multifunction.

Steingraeber, J (2012), Advancement in ESA in rotogravure, Gravure Association of America magazine, August, pp. 34-38. Viewed: 5 December 2014, http://www.steingraeber-corp.com/GAA-Summer2012-p34-38(Antistatic).pdf

Teleman, A., Christiansson, H., Johansson, P. Å., Fahlcrantz, C. M., and Lindberg, S. (2005) "Correct measurements of half-tone print mottle on flexo printed linerboard", STFI_Packforsk Report No. 39

Velho, J. & Santos, N. F., (2010) "Surface Topography of Coated Papers: From the Evaluation Process to the Quality Improvement", Materials Science Forum, 636 977-984.

Webster, J. R. (1998). "Thin film polymer dielectrics for high-voltage applications under severe environments" Doctoral dissertation, Virginia Polytechnic Institute and State University.

Wright, G. S., Krein, P. T., & Chato, J. C. (1993). "Factors affecting dynamic electrical manipulation of menisci Industry Applications", IEEE Transactions on, 29(1), pp. 103-112.

Zaretsky, M. C., Billow, S. A., & Whitney, R. A. (2004). Electrostatic assist for coating: the effect of surface resistivity. Journal of electrostatics, 61(1), pp. 31-42.