

Assessment of Plain Paper Printability by Office Ink Jet Printers

Lesley J. Barker, Gina M. Garro, Cheryn A. Kwasnik and Kate Johnson*
Cytec Industries Inc., Stamford, Connecticut, *KDY Inc.
Nashua, New Hampshire

Abstract

This paper describes tests which have been developed to measure a number of quality metrics relevant to ink jet printing on plain paper. Analytical test targets were printed on paper manufactured with different levels of surface and internal sizing treatment according to a statistical design. The prints were made using several commercially available ink jet printers. Images of microscope and scanner targets were analyzed using ImageXpert™, an image analysis system. The resulting data could be used to optimize sizing levels for maximum effectiveness in achieving good print quality performance.

Introduction

To be useful in today's office, plain paper needs to perform well when printed by ink jet printers as well as by laser printers and copiers. Most ink jet printers use aqueous inks, so this presents a problem to the paper manufacturer, as plain paper is naturally rough, porous, and hydrophilic. During the past decade, paper manufacturers and suppliers to the paper industry have spent considerable effort to develop plain paper grades which provide good ink jet print quality. Important to this effort is the capability to measure print performance effectively.

A set of criteria was provided to paper producers by Hewlett Packard in 1993 to help set quality standards for solid print and text quality with their ink jet printers.[1] At the same time, print quality evaluation by image analysis was shown to be an effective tool in the optimization of paper performance.[2] The need for effective print quality assessment of ink jet printing has continued as printer technology has developed, and particular attention has been paid to automatic methods based on image analysis. These methods use a lens or microscope in conjunction with a video camera to capture the print target image. More recently, the potential of scanner-based systems has been explored.

This paper describes analysis of images obtained both with a microscope and with a scanner. Targets were printed on mill-produced paper prepared as a statistical set with different sizing levels. A number of quality parameters for print test images of these test targets were obtained and effects on the print quality parameters were then evaluated with respect to the paper sizing treatment, and also with respect to the effectiveness of the test.

Experimental Section

Statistical Design

In order to predict the sizing treatment that would provide optimum performance, a statistically designed production series of a plain paper grade was prepared. This consisted of six paper conditions with different combinations of internal and surface size levels. The schematic for this experimental design is shown in Figure 1 and the specifications of sizing treatment for the six conditions is presented in Table 1. Table 1 also compares sizing performance of the paper samples in terms of ink penetration time and water contact angles. Design-Expert® software by Stat-Ease® was used to analyze print quality response data according to the statistical model.

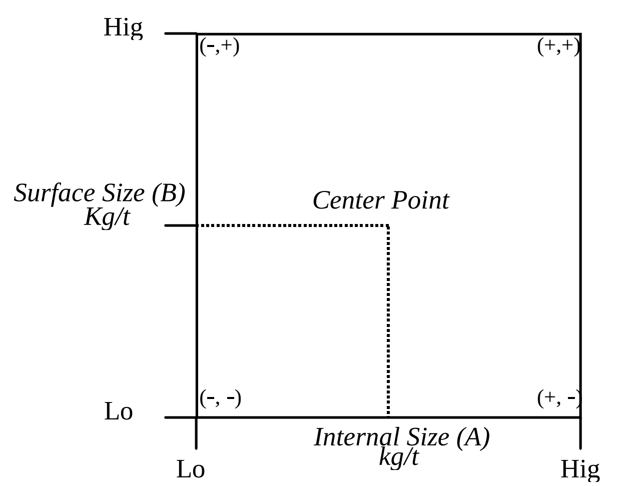

Figure 1. Statistical Design

Printing

Samples were printed with two test targets, one designed for microscope evaluation, and one for scanner evaluation. The microscope test targets were printed with four different ink jet printers, using the low resolution, plain paper settings. As this investigation was not intended to be used as a comparison of printers, these printers are simply designated Printer A, Printer B, Printer C & Printer D. The scanner test target was printed with Printer A only. In the case of the microscope target, two test targets were printed per page, and two experimental sheets were evaluated. For the scanning test, one target was printed on five pages for each experimental condition. For the purposes of this work, front paper surfaces only were evaluated.

Image Acquisition

Digital images of the printed test targets were obtained using a microscope and a scanner: The microscope configuration included an Olympus® SZ11 zoom microscope with 5x lens and objective magnification 2x, ring light fiber optic illumination, and a Sony® XC-75 monochrome video camera with image size of 768 x 494 pixels. The scanner was a UMAX Astra 1200S operating at 600dpi in gray mode with gain correction of 88%.

Image Quality Analysis

In order to assess objectively the effects of sizing treatment on substrate printability, the images collected from the samples were analyzed using the ImageXpert™ image analysis system. The measurement was made robust to slight variations in sample brightness and image position by using the average gray value of the background of each sample to adjust the threshold automatically. Dynamic locators were used to adjust for small changes in the field of view due to sample position variations.

Solid area quality was evaluated using three metrics: Optical Density, Black Uniformity and Black Mottle. Optical Density was obtained from the translation of digital count data through a transfer curve relating scanner gray values and density values of a calibration target measured with a RD 1200 Macbeth® Densitometer (Figure2). Black Uniformity was evaluated by calculating the standard deviation of the gray averages of an array of 12 2mm x 2mm squares. Mottle was quantified by determining the number of light clusters with areas of 2-10 pixels and areas of 10-100 pixels (calibration: 1pixel = 0.04298 mm) that were 5 gray levels different from the average gray value of the solid area. Higher numbers of clusters are indicative of solid areas that appear more uneven and mottled.

Ink wicking along and between paper fibers creates unintentional line growth and uneven edge formation. Several metrics were used in this analysis to capture the various effects of wicking, including focus, resolution (CTF), raggedness, and area. Text Focus was assessed by calculating the sum of the squares of the differences in gray values of any two adjacent pixels (horizontal or vertical) within a region of interest placed over a block of text and indicates the sharpness of the image. Contrast Transfer Function (CTF) was measured for both horizontal and vertical line arrays. CTF was calculated by taking the ratio of the difference between the maximum and minimum gray values in the line array pattern and the difference between the global maximum as measured in background (unprinted) areas and global minimum as measured in a solid area (pattern max-min/global max-min). An ideal CTF has a value of 1. Average line width was measured for both horizontal and vertical black and cyan lines. Wider lines indicate increased line growth. Character Area was measured for a set of “H” characters. Larger areas indicate increased wicking. Edge raggedness was quantified by calculating the average magnitude of the difference between the actual positions of a set of points along an edge and the best-fit line through those edge points. Raggedness is a measure of positional variations in the tangential edge profile (“TEP”) and tends to increase with increased wicking.

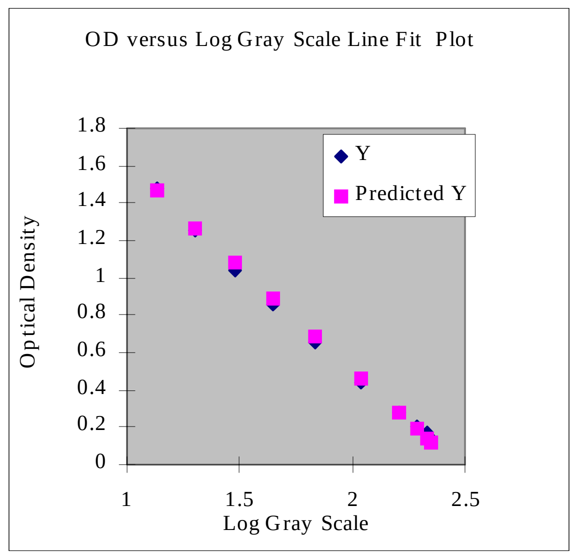

Figure 2. Transfer Curve from Gray Scale to Optical Density

Table 1. Paper Sizing Treatment and Measurement

Internal size, kg/t, Variable A		1.00	0.60	0.80	0.60	1.00	0.80
Surface Size, kg/t, Variable B		0.25	0.25	0.75	1.25	1.25	0.75
Sizing, ink penetration time, s	Mean	232	135	219	221	331	286
	Standard deviation	25	17	41	20	41	27
Initial contact angle, degrees	Mean	107.8	101.4	109.2	106.9	108.8	110.8
	Standard deviation	3.6	3.6	2.1	2.5	1.3	1.7
1 minute contact angle, degrees	Mean	97	84.7	99.6	94.2	99.3	101.5
	Standard deviation	2.3	3.3	4.1	4.8	1.7	4.2

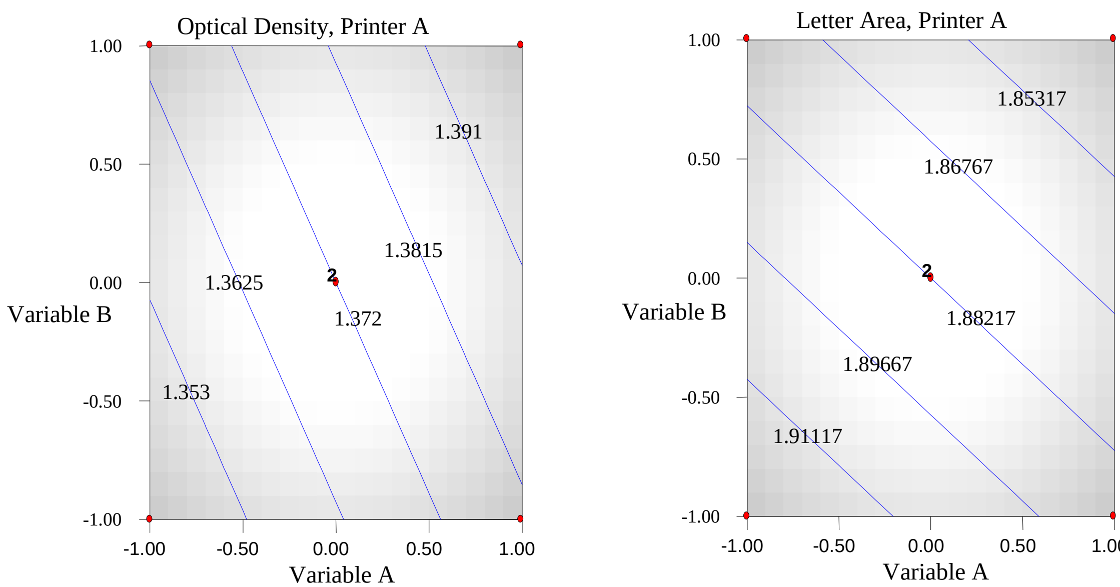

Figure 3. Examples of Design-Expert Plots showing Response Surface Contours

Table 2. Summary of Image Analysis Data

Internal Sizing, Variable A	High	Low	Center	Low	High	Center	Center Point	Mean of All
Surface Sizing, Variable B	Low	Low	Center	High	High	Center	Average	Treatments
Image Analysis (scanner) -								
Black Optical Density	1.341	1.303	1.336	1.330	1.348	1.338	1.337	1.333
Black Uniformity, mm	0.0062	0.0081	0.0051	0.0043	0.0047	0.0073	0.0062	0.0060
Black Mottle 2-10, No. of clusters	193	222	199	190	181	192	195.5	196
Black Mottle 10-100, No. of clusters	45	64	50	46	42	48	49	49
Text Focus	189.5	184.5	192.2	191.1	192.9	191.6	191.8	190.3
CTF (narrow vertical)	0.924	0.91	0.934	0.934	0.931	0.929	0.932	0.927
CTF (narrow horizontal)	0.997	0.982	0.997	0.982	0.996	0.993	0.995	0.991
Black/white vertical line width, mm	0.495	0.499	0.494	0.490	0.494	0.492	0.493	0.494
Black/white horizontal line width, mm	0.493	0.495	0.494	0.491	0.492	0.490	0.492	0.492
Cyan/white vertical line width, mm	0.380	0.386	0.377	0.383	0.380	0.384	0.381	0.382
Cyan/white horizontal line width, mm	0.361	0.371	0.363	0.367	0.366	0.372	0.367	0.367
Black/yellow vertical line width, mm	0.625	0.592	0.605	0.592	0.635	0.613	0.609	0.610
Black/yellow horizontal line width, mm	0.589	0.564	0.577	0.575	0.604	0.586	0.582	0.583
Cyan/yellow vertical line width, mm	0.410	0.414	0.391	0.396	0.397	0.397	0.394	0.394
Cyan/yellow horizontal line width, mm	0.386	0.399	0.391	0.396	0.397	0.397	0.394	0.394
Image Analysis (microscope) -								
Letter area printer A, mm2	1.886	1.938	1.866	1.872	1.851	1.860	1.873	1.882
Letter area printer B, mm2	2.051	2.091	2.030	2.030	2.015	2.033	2.031	2.042
Letter area printer C, mm2	1.874	1.887	1.887	1.894	1.876	1.887	1.887	1.884
Letter area printer D, mm2	1.847	1.956	1.871	1.888	1.871	1.901	1.886	1.889
Raggedness, Printer A , mm	0.0103	0.0131	0.0113	0.0111	0.0101	0.0108	0.0110	0.0111
Raggedness, Printer B , mm	0.0095	0.0099	0.0079	0.0075	0.0074	0.0078	0.0080	0.0083
Raggedness, Printer C , mm	0.0123	0.0121	0.0112	0.0129	0.0120	0.0119	0.0120	0.0121
Raggedness, Printer D, mm	0.0204	0.0198	0.0180	0.0170	0.0183	0.0178	0.0180	0.0185

Table 3. Summary of Normalized Data

Internal Sizing, Variable A Surface Sizing, Variable B	Good is Hi or lo?	High Low	Low Low	Center Center	Low High	High High	Center Center	Center Point Average	Standard Deviation
Black Optical Density	hi	**100.6**	97.8	**100.3**	99.8	**101.2**	**100.4**	**100.3**	1.2
Black Uniformity	lo	104.2	136.1	**85.7**	**72.3**	**79.0**	122.7	104.2	25.5
Black Mottle 2-10	lo	**98.4**	113.2	101.4	**96.9**	**92.3**	**97.9**	**99.7**	7.1
Black Mottle 10-100	lo	**91.5**	130.2	101.7	**93.6**	**85.4**	**97.6**	**99.7**	15.8
Text Focus	hi	99.6	96.9	**100.9**	**100.5**	**101.4**	**100.7**	**100.8**	1.6
CTF (narrow vertical)	hi	99.7	98.2	**100.8**	**100.8**	**100.4**	**100.2**	**100.5**	1.0
CTF (narrow horizontal)	hi	**100.6**	99.1	**100.6**	99.1	**100.5**	**100.2**	**100.4**	0.7
Black/white vertical line width	lo	100.3	101.1	**99.9**	**99.2**	100.0	**99.5**	**99.7**	0.6
Black/white horizontal line width	lo	100.2	100.4	100.3	**99.8**	**99.9**	**99.5**	**99.9**	0.3
Cyan/white vertical line width	lo	**99.6**	101.1	**98.9**	100.4	**99.7**	100.5	**99.7**	0.8
Cyan/white horizontal line width	lo	**98.6**	101.1	**99.0**	100.2	**99.7**	101.4	100.2	1.1
Black/yellow vertical line width	lo	102.4	**96.9**	**99.2**	**97.1**	104.0	100.4	**99.8**	2.9
Black/yellow horizontal line width	lo	101.1	**96.9**	**99.1**	**98.6**	103.7	100.5	**99.8**	2.4
Cyan/yellow vertical line width	lo	**99.8**	100.7	**99.4**	100.6	**99.6**	**99.9**	**99.7**	0.5
Cyan/yellow horizontal line width	lo	**98.0**	101.1	**99.1**	100.4	100.7	100.7	**99.9**	1.2
Letter area printer A	lo	100.2	103.0	100.2	**99.5**	**98.3**	**98.8**	**99.5**	1.6
Letter area printer B	lo	100.5	102.4	**99.4**	**99.4**	**98.7**	**99.6**	**99.5**	1.3
Letter area printer C	lo	**99.5**	100.1	100.1	100.5	**99.6**	100.2	100.1	0.4
Letter area printer D	lo	**97.8**	103.5	**99.0**	**99.9**	**99.1**	100.6	**99.8**	2.0
Raggedness, Printer A	lo	**92.3**	118.2	101.3	100.2	**91.2**	**96.8**	**99.1**	9.8
Raggedness, Printer B	lo	114.3	118.8	**94.7**	**90.2**	**88.7**	**93.2**	**94.0**	13.1
Raggedness, Printer C	lo	102.1	100.4	**93.0**	106.7	**99.6**	**98.2**	**95.6**	4.5
Raggedness, Printer D	lo	110.1	106.7	**97.0**	**91.6**	**98.6**	**96.0**	**96.5**	7.0

Results and Discussion

A summary of data obtained for the quality performance metrics is given in Table 2, and a normalized set of the same data follows in Table 3. The first six data columns in each table show the means of the individual quality metrics for the six different paper conditions for the statistical set with sizing variables A (internal size) and B (surface size). With some quality parameters (e.g. Optical Density) a "good" value is high, whereas for others (e.g. Character Area) a low value is better. This distinction is shown in the second column of Table 3. Responses that are favorable in comparison with the overall average are shown in bold. Thus, looking at a whole column of data, it is possible to assess whether the performance across all the tests was on the whole good or bad. With this set of data, the "high-high" and "center point" conditions gave rise to the most favorable performance. For more precise evaluation, the effect of variables A and B on each individual metric can be plotted as response surface contours to help in predicting and optimizing performance. Examples are shown in Fig. 3.

Conclusions

1. Higher doses of both surface size and internal size improved ink jet print quality performance of plain paper.
2. A combination of moderate doses of both types of sizing was more favorable than a high dose of one type of sizing.
3. Both scanner and microscope image analysis tests distinguished paper performance and could be used to predict and optimize print performance of paper.
4. A scanner-based image analysis system offers the potential for automation of many types of quality test, provided that calibration and performance controls are built–in. Evaluation of the most effective measurement techniques should continue.

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