The Influence of Silica Gel Pigment Levels in Coated Ink Jet Papers

David C. Darwin[*] and R. Trevor Taylor*
GRACE Davison, Columbia, Maryland
and
Philip J. Press
Philip Press, Inc., Columbia, Maryland

Abstract

A statistical design of experiments (DOE) technique has been used to study varying levels of silica gel and polymeric binder in ink jet paper coating formulations. Paper coatings from the DOE showed widely variable print qualities. Computer analyzed image analysis was used to quantify color gamut, linewidth, sharpness, raggedness, bleed, and mottle. Using these data and statistical deconvolution of the DOE response surface, the dependence of each print quality measure on the level of the silica gel in the coating was determined. Generally, higher levels of silica gel result in enhanced print quality, especially in color vividness.

Introduction

Proliferation of ink jet printing continues as a popular color printing technology for small offices and home offices. Along with this comes high growth in customized paper based media used to exchange and store ink jet images.

Paper based ink jet media can be roughly segmented into glossy/photo quality, premium quality matte papers, and general-purpose matte papers. Image quality on the base paper is commonly enhanced through utilization of a coating. In the premium matte segment, papers are often coated with formulations comprised of silica gel plus a water-based polymer binder. The high porosity of silica gel is primarily responsible for wicking ink solvent water away from the coating surface, leaving ink dye molecules at the surface. This type of coating gives the high color vividness and sharp line resolution expected of the premium matte segment.

Growth in digital printing has resulted in concurrent growth in technologies to characterize digital images. Specifically, the development of computer driven, automated image analysis systems has enabled quantification of important image parameters.[1-3] Importantly, this quantifycation allows for comparison between coating formulations and adjustment of these formulations for an optimal printed image.

As pigment is the primary determinant of print quality, it is important to understand the benefits and detriments to print quality when using silica gel as a coating pigment. The coupling of a statistical design of experiments (DOE) technique applied to various silica gel and binder level formulations plus digital image analysis allows determination of trends useful in establishing the proper levels of silica gel in an ink jet coating.

Statistical DOE Methodology

Statistical design of experiments has become an important tool used to minimize experimental work yet to draw statistically valid conclusions, when many interacting variables are concerned.[4-7] When applied to formulation science, DOE begins by defining proportions of ingredients that are constrained by upfront knowledge or assumptions. For example, in this study, mass percentages of silica gel in the coatings are allowed to vary from 20% to 66% (and thus binder content varies from 80% to 34%). These constraints were made knowing low levels of silica gel will not deliver the print quality enhancements expected of the coating, while high levels of silica gel will have insufficient binder to adhere the silica gel to the paper surface.

After the DOE software specified the formulation space, coating samples were prepared to specifications, coated onto paper, printed on with a test target, and image analyzed. The DOE software fits response surface equations expressing each measured print quality attribute as a function of coating composition using data from the image analysis. These response surfaces can be used to predict measures of print quality for any arbitrary coating formulation contained within the formulation space.

Given that multiple binder component proportions are possible, to evaluate the effects of silica gel level on various print outputs it is necessary to choose a composition as a reference. This reference point was selected to be the centroid of the design, which is the composition representing the average over all the formulations in the DOE on a component-by-component basis. From this reference point, the dependence of the chosen print measures on silica gel was generated by the software along a path in formulation space for which the ratio of each binder component to silica gel was the same as at the reference point. These adjusted response curves are plotted as print quality measure vs. silica gel content.

Experimental

Silica Gel-Based Coating: According to proportions generated by the DOE, silica gel from GRACE Davison was mixed in water with binder consisting mainly of polyvinyl alcohol from Air Products and Chemicals, Inc.. Sixty combinations were prepared. Other additives, for example, base, rheology modifier, co-binder, and optical brightener were added to certain formulations. The effects of additives and binder are deconvoluted by the DOE to give print quality results that are dependent only on silica level.

Base Paper: Base paper for coating was an 80 gram per square meter (gsm) sheet. This sheet was uncoated and was not surface sized on the side that was coated with the silica gel-based coating.

Sheet Coater: A laboratory coater manufactured by RK Print-Coat Instruments, Ltd. (Model K202) was employed. This unit "draws down" a coating puddle using a wire-wound rod over the paper surface, leaving a uniform layer of coating behind. In order to compare coatings equally, a constant coat weight of 3 gsm (one-side) was specified. In the usual case, the sheet coater produced a coat weight of higher than 3 gsm. Slight dilution of the coating with water was made until the 3 gsm coat weight was obtained.

Coat Weights: Coat weights of dried and room humidity equilibrated coated papers were measured by mass difference between coated sheets and uncoated sheets of the same base paper. Coat weights are expressed in grams per square meter for a single side.

Ink Jet Printers: HP Deskjet 970 Cxi and Epson Stylus Color 860 ink jet printers were used to print custom print targets for image analysis. A dedicated 450 MHz Pentium III class Windows-based PC system printer running Corel Draw was used to drive the printers.

Print Quality by Image Analysis: An ImageXpert™ (ImageXpert, Inc.) automated image analysis system was employed to measure the print quality parameters discussed below. Algorithms to convert raw data into the parameters discussed above were custom derived, as were the color print targets.

Design of Experiments Software: ECHIP Software (ECHIP, Inc., Hockessin DE) was used to create the DOE. Dependencies of print quality measures on silica gel level were generated from the response surfaces using RS/Explore (Brooks Automation, Chelmsford MA.)

Measures of Color Ink Jet Print Quality

A series of measures useful in evaluating ink jet print quality was published in a prior paper[3]. In brief, the following print measures were used to characterize print quality of the samples from the DOE.

Color Gamut Vector Sum: CIE L*a*b* measurements are obtained on 100% filled color blocks of cyan, magenta, yellow, red, green, and blue (C, M, Y, R, G, B). Plotting a* vs. b* on an x,y plot allows for the generation of vectors which represent the chroma of that individual color. The lengths of these vectors were summed to create a parameter named vector sum. A higher vector sum is desirable.

Linewidth: Linewidth is a measure of the tendency of ink to spread laterally over the surface of a paper. The result is reported in microns. The linewidth of a black, 4 pixel, positive, horizontal line was measured in microns. For a given line target, a lower value of linewidth is desirable.

Bleed: Bleed is a measure of the tendency of black ink to bleed into colored ink when the two are applied in adjoining areas. To quantify bleed, the linewidth of a black line transcending the border of a yellow box on white was measured in microns in both the yellow and white areas. The difference, which defines the bleed, was obtained by subtracting the linewidth in the white from the linewidth in the yellow. Under this definition, both positive and negative values for bleed are possible. A bleed value of zero is desirable. The bleed of a horizontal, 8 pixel line was chosen to be representative.

Raggedness: Raggedness (Tangential Edge Profile) is the average displacement from the best fit edge line of the individual points used to define the line, with the value reported in microns. Lower values are desirable. The raggedness of a black, 8 pixel, positive, horizontal line was chosen to be representative.

Sharpness: Sharpness (Normal Edge Profile) is a measure of the spatial transition from a light area to a dark area and is measured in pixels. A low sharpness value indicates a sharper transition from background to printed area. Lower sharpness values are desired. Horizontal sharpness of a black line was chosen to be representative.

Print Mottle: Mottle is visualized by a blotchy, uneven look in solid image areas. Mottle was characterized by a modified ISO 13660 procedure. Each element in a grid was measured for its average gray value. The gray values were averaged to provide an overall average and standard deviation for the entire block. The standard deviation defines print mottle. Green print mottle was chosen to be representative due to its distinctiveness to the eye. Lower standard deviations are desirable.

Results and Discussion

Adjusted response curves, as described in the Statistical DOE Methodology section above, were used to generate print quality measures vs. silica levels for silica levels ranging from 20% to 66% in increments of 2%. Measurements were made on coated sheets subsequently printed with either the HP or the Epson printer.

Results are presented as print quality measure vs. silica % plots. On each plot is an arrow that displays the optimum direction of the measure.

Figure 1 shows the dependence of color gamut vector sum on silica gel content. The shape of the curves is qualitatively similar for both printers, with the HP printer showing a more pronounced minimum. However, since the best color gamut vector sums are those with the highest values, the important feature of this data is that increasing silica levels result in increasing color gamut vector sum.

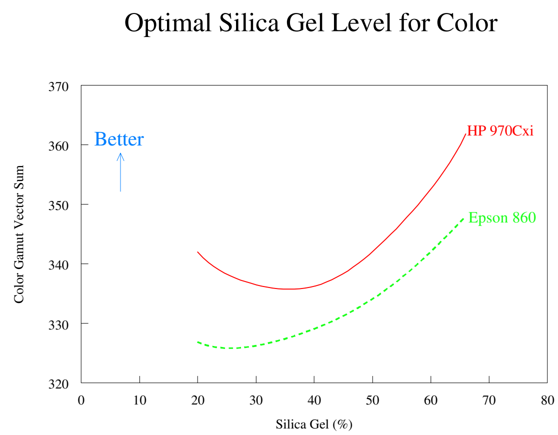

Figure 1. Variation in the color gamut vector sum as silica gel level is varied in a coating formulation on both HP and Epson ink jet printers. Higher levels of silica gel result in higher color.

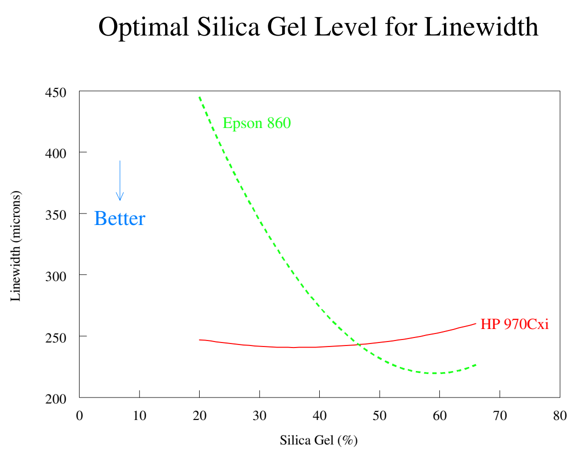

Figure 2. Variation in the linewidth as silica gel level is varied in a coating formulation. Low silica gel levels are especially disadvantageous on Epson printouts.

Figure 2 shows the dependence of linewidth on silica gel content. Here there is a difference between the two printers, with the HP printer showing a desirable minimum in linewidth at 36% while the Epson printer shows decreasing linewidth into the 60% region. Especially interesting is the undesirable linewidth increase in the Epson printer when low levels of silica gel are employed.

Without knowing full details of these printers, it is impossible to determine why there is such a difference. However, it is known that HP printers use a thermal ink droplet mechanism while the Epson printers employ piezo technology.[8,9] Also, there will be differences in the ink compositions. The fact that there exist printer specific optima is an important consideration if designing paper for a specific printer brand.

Figure 3 shows the dependence of bleed on silica gel content. Highlighting another difference between the printers and the coatings, the HP printer gives negative bleed (yellow bleeding into black) while the Epson printer gives positive bleed (black bleeding into yellow). Both printers show maximum bleed in the 40% to 50% silica gel level range, and also that substantially higher or lower silica levels reduce bleed.

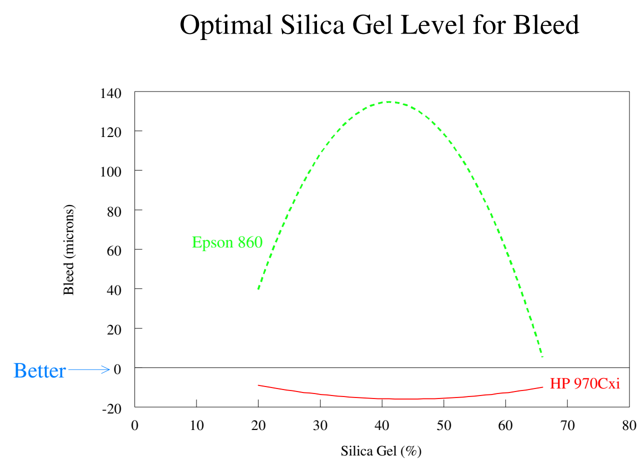

Figure 3. Variation in the bleed as silica gel level is varied in a coating formulation. High or low silica gel levels are favored.

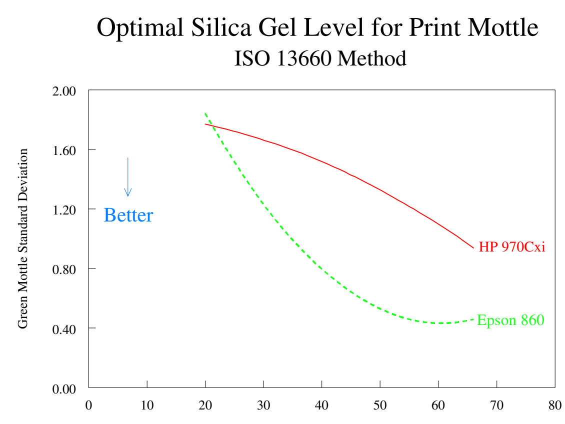

Figure 4. Variation in print mottle as silica gel level is varied in a coating formulation. High silica gel levels are favored for papers coated by laboratory drawdown.

Figure 4 shows the dependence of print mottle on silica gel level. For both printers, high levels of silica gel are preferred. It is important to note that prior results have shown that mottle is the print quality measure which is most dependent on application method.[3]

Similar analyses for sharpness and raggedness show less dependence on silica gel level (not shown). The general trend for these measures is that the measures improve with increasing silica gel content.

Summary results are presented in Table 1. One method to summarize the results is to take the optimal silica gel levels from each measure, for each printer, and average them to arrive at a single "Average Optimum" silica gel level. This simple average method is arbitrary, giving equal weight to each measure. Normalized linear combination weighting can be used to emphasize key visual properties such as color and to de-emphasize less important measures.

Table 1. Summary Optimal Silica Gel Levels (%)

Print Quality Measure	*HP 970 Cxi*	*Epson 860*
Color Gamut	>66	>66
Linewidth	36	57
Bleed	>66	>66
Print Mottle	>66	60
Sharpness	>66	56
Raggedness	47	>66
Average Optimum	**58**	**62**

Conclusion

The function of an ink jet paper coating is to enhance the print qualities of the paper. Thus, it is reassuring that most print quality measures improve as silica gel level is increased. However, the determination that some measures have optima less than the maximum implies that some subjective compromise in silica gel level must be made. This compromise is typically based on a balance of print quality measures resulting in a paper that gives a pleasing print to the human eye. Using an equal weighting of print quality measures investigated here suggests a compromise silica gel level of approximately 58% for an HP optimized coating and 62% for an Epson optimized coating.

In realistic paper coating formulation science, the optimum level of silica gel will also be heavily influenced by factors such as the rheology of the coating, the binding power of the binder system, pH, coating solids level, and other additives. Any of these properties may force the silica gel level away from the print quality optimum, once again forcing compromises. A more extensive DOE could examine these additional variables and constraints.

References

1. Ming-Kai Tse, David J. Forrest, and John C. Briggs, Automated Print Quality Analysis for Digital Printing Technologies, *PPIC/JH '98: The Society of Electrophotography of Japan, Pan-Pacific Imaging Conference Proc.*, (1998).
2. Ming-Kai Tse and Alice H. Klein, Automated Print Quality in Inkjet Printing: Case Study Using Commercially Available Media, *NIP14 Proc*., (1998).
3. David C. Darwin, R. Trevor Taylor, Jesse S. Timmins, and Leon Leaper, Print Quality Evaluation of Silica-Based Ink Jet Paper Coatings: Sheet vs. Continuous Coaters, *NIP 16 Proc.*, pg. 867 (2000).
4. George E. P. Box, William J. Hunter and J. Stuart Hunter, *Statistics for Experimenters*, John Wiley & Sons, New York (1978).
5. T. A. Baltus, Taking the Mystery Out of Design of Experiments, *Injection Molding Magazine. (January 1994).*
6. Ronald D. Snee, Experimenting with Mixtures, *Chemtech* (November 1979).
7. Mark J. Anderson and Patrick J. Whitcomb, Optimization of Paint Formulations made Easy with Computer-Aided Design of Experiments for Mixtures, *J. Coatings Technology* (July 1996).
8. Michael Regan, Marzio Leban, Todd Berdahl, Connie Shell, and Rick Debnam, High Resistivity Materials for Improved Thermal Inkjet Printheads, *NIP 16 Proc.*, pg. 38 (2000).
9. Shinri Sakai, Dynamics of Piezoelectric Inkjet Printing Systems, *NIP 16 Proc.*, pg. 15 (2000).

Biography

David Darwin holds a B.A. degree in Chemistry and Integrated Sciences from Northwestern University, a Ph.D. in Physical Chemistry from the University of California at Berkeley, and an MBA from the University of Maryland, College Park. He has worked for W. R. Grace & Co. in Research and Development and in Technical Service Management since 1989. His project areas have included cements, water soluble polymers, surfactants, colloids, formulations, construction materials, and inorganic adsorbents. He is currently conducting research in the area of matte coatings for ink jet papers for Grace Davison, a business unit of W. R. Grace & Co.-Conn..