Photo Imaging with Ink Jet Inks

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Abstract

Both dye-based and pigment-based aqueous ink jet inks are capable of providing excellent photo quality in the current generation of low drop volume high resolution small office home office (SOHO) ink jet printers, especially when printed on special coated glossy ink jet photo papers. However, no one system delivers the perfect balance of color, image quality, physical durability, glossy uniformity, and image permanence.

The primary factors causing color fade and loss of image permanence in dye-based ink jet inks are environmental conditions such as light, heat, air quality, and humidity. Dye inks printed on microporous photo media undergo color fade much more rapidly than on polymeric nonporous coated photo media, with a significant color changed observed sometimes in a matter of weeks.

When image permanence is required for photo printing, pigment-based ink jet inks are the choice. One of the remaining image quality issues with pigment inks is non-uniform gloss. For photographic and other high definition imaging, uniform high gloss is desirable to enhance the perception of clarity and sharpness of the image. When a significant difference in gloss occurs between inked and unprinted areas (media), the image appears to have "flat", non-shiny areas in the photo print. In our studies of gloss uniformity, we found nonuniform gloss also can occur with dye-based ink jet inks printed on glossy media.

This paper will summarize our studies of gloss as function of ink formulation parameters: colorant (pigment or dye), dispersant type/dispersion process (pigment), vehicle (co-solvents, surfactants) and water. This gloss study included a variety of glossy media types. Additionally, the color gamut of current pigment inks printed on glossy photo papers will be reviewed.

Introduction

The rapid conversion from analog to digital photography is well underway for the amateur photographer.[1] On a monthly basis, digital cameras appear to increase in quality ("megapixel" resolution and features) and decrease in price. Also, low cost high quality scanners easily convert photographs from analog to digital. Reasonably priced, powerful PCs are available to process the large image data files generated by these digital devices. High speed data transfer and inexpensive high capacity data storage devices (e.g. CD-R) along with user friendly image processing software all support this rapid conversion to digital photography. Finally, inexpensive SOHO ink jet printers with excellent photo quality are readily available from a large number of vendors, making home printing of high quality photos a reality.

Status of Inks for Photo Printing

Both thermal (TIJ) and piezo (PIJ) drop-on-demand (DOD) ink jet SOHO photo printers provide excellent photo quality by jetting small drop volumes at high spatial resolution. The dots generated in the image are "invisible" to the human eye thereby reducing or eliminating image graininess. The color tonal scale is improved by adding dilute inks (e.g. light cyan or light magenta) or by producing variable drop sizes. Both dye-based and pigment-based aqueous ink jet inks can be reliably jetted from these photo printers and stunning photo quality images can be produced when all system components are optimized: ink, media, software (print modes, color management), hardware (print-head, printer).

Currently, dye or pigment inks cannot deliver 100% of the image quality and image permanence properties desired for ink jet photos. The performance status is summarized in Table 1.

The number one shortcoming of dye-based inks is image permanence. Although the degree of image permanence and the methods for accelerated testing of image permanence of ink jet photo prints continues to be hotly debated and explored, pigment inks are clearly the preferred choice for image permanence compared to dye inks.[2-5]

One of the remaining challenges in developing pigment inks for ink jet photo printing is achieving uniform high gloss on photo glossy media. In terms of technical goals, the ink-media system should deliver:

1. High gloss
2. Uniform gloss for all colors
3. Uniform gloss over entire tonal scale
4. High media gloss that matches gloss of printed areas

Mismatched or non-glossy areas in the image appear "flat".

In this study, our goal was to understand the cause and degree of gloss non-uniformity with dye and pigment inks printed on photo glossy media. In particular, we wished to understand gloss as a function of ink formulation parameters such as colorant (dye or pigment), pigment dispersant, pigment dispersion process, binders, other vehicle components (humectants, cosolvents, surfactants). Our investigation also involved studying gloss as function of media type, drop volume, and print modes.

Table 1. Status of Dye & Pigment Ink for Photo Printing on Glossy Photo Media

Property	Dye (D)	Pigment (P)
Ink Stability	Yes	Yes
Jettability	Yes	Yes
Jet Reliability	Yes	Yes
Machine Compatibility	Yes	Yes
Color Gamut	Yes	Yes
Image Permanence	***No*** ***D << P***	Yes
Physical Durability	Media Dependent	Media Dependent
Image Quality:		
Dot Size, Spread	Yes	Yes
Spatial Resolution	Yes	Yes
Bleed, Coalescence	Yes	Yes
Gloss	Yes & No, Media Dependent	Yes & No, Media Dependent
Gloss Uniformity	Yes & No, Media dependent	***No***

Prior to launching into our study, we wished to address the following questions:

1. What glossy media should we include in our study?
2. What is the gloss status of current commercial photo ink / media / printer systems?
3. Do pigment inks have poor gloss uniformity on all types of glossy media? What about dye inks?

Other image quality properties of ink jet photo prints such as of distinctness of image (DOI) and color shifts under different viewing conditions (illumination, angle, etc), often referred to as “bronzing” and “metamerism”, are currently being investigated in our laboratories but are beyond the scope of this discussion.

Experimental

Our gloss test pattern consisted of CMYKRGB color patches with a tonal scale from 0% (media) to 100% for each color. The commercial (2001) photo printing systems investigated are shown in Table 3. Gloss was first studied using the ink, print heads, media, print modes (“best”, “high quality”, “photo”) supplied and recommended by each vendor. We then did “cross-over” experiments, interchanging ink and media of different vendors. Our experimental inks were prepared by varying ink formulation parameters. Epson 980 and HP970 printers were used to print PIJ and TIJ experimental inks, respectively. A BYK-Gardner gloss meter was used to measure 60 and 20 degree gloss.

Approximate thirty commercially available glossy media were evaluated initially and then narrowed down to a manageable representative set of four.

Color targets containing 704 color patches were printed under the same conditions as used in our gloss study. CIELab values were measured using a Gretag Spectrolino spectrophotometer with D50 illuminant, 2^{o} observer. Color gamuts (cubic color units) for each system were calculated and are summarized in Table 4.

Results and Discussion

Ink jet photo media carries the final image and is comprised of an ink receptive layer (IRL) coated on to a substrate.[6] The role of the IRL is to (1) aid drying by absorbing the ink vehicle, and (2) control the spread and penetration of the colorants. The two most common IRLs used in commercially available ink jet photo glossy media are (1) nonporous polymer-based IRLs, often referred to as “swellable polymer” (P) media, and (2) porous particulate-based IRLs also known as “microporous” (MP) media. Hydrophilic polymer coatings comprise the IRLs of nonporous, swellable polymer media. Inorganic particles bound in a hydrophilic polymer matrix forming a microporous structure comprise the IRLs of MP media.

Table 2 summarizes the key differences we found in our study of commercially available photo glossy media.

Table 2. Summary of Photo Glossy Media Properties

Media Property	P	MP
Dry time (touch)	5 – 30+ min	< 10 sec
Dry time	24 hours+	“24 hours”
20 degree gloss	50 – 70	15 – 25
60 degree gloss	80 – 90	20-50
Color gamut	Good	Good
Wet Smudge	Very poor-poor	Good
Waterfastness	Poor-Moderate	Good-Excellent

The direction of photo glossy media development is moving from swellable polymer to microporous with its superior properties. However, only low to medium gloss can be achieved with microporous media.

Table 3 summarizes the gloss performance of the commercially available photo printers. We included one large format printer using HPUV pigment inks in order to study an additional commercial pigment ink set. This table shows that the only commercially available systems that provide uniform gloss are dye inks printed on microporous glossy media. The dye ink system printed on swellable polymer glossy media caused gloss to decrease with increasing ink coverage/unit area. For both pigment ink systems printed on microporous glossy media, gloss increased as ink coverage/unit area increased.

In order to better understand the ink's contribution to the image gloss performance, we did an extensive investigation of colorant (dyes, pigments), dispersants, dispersion process, binders and vehicles. In our experiments, we also removed the colorant and jetted colorless inks:

- vehicle only
- water only
- vehicle containing polymeric binder

on to the glossy media. The results are summarized as gloss as a function of % area fill in Figure 1 for swellable polymer glossy media and Figure 2 for microporous glossy media.

Table 3. Gloss of Commercial Photo Printing Systems

Printer	Ink	Media	Media Type	Uniform Gloss?
Epson 2000P	Pigment CcMmYK	Premium Semigloss S041331	MP	No, Inks Add Gloss
Epson 1270	Dye CcMmYK	Premium Glossy S041286	MP	YES
Canon BJC8200	Dye CcMmYK	Photo Pro	MP	YES
HP P1100 & DJ970C	Dye CMY Pigm. K	Premium Plus, C6831A	P	No, Inks Decrease Gloss
HP DJ2500CP LFP	HPUV Pigment CMYK	Gloss UV Media, C6795A	MP	No, Inks Add Gloss

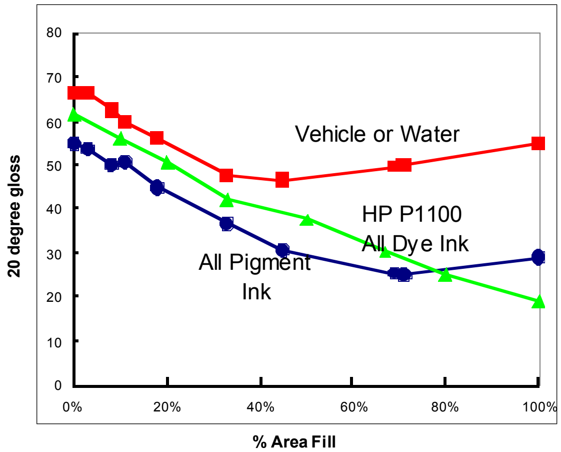

Figure 1. Gloss (20 Degree) Results on Swellable Polymer Media (HP C6831A)

For swellable polymer media (Figure 1), the following trends were observed:

1. All aqueous liquids and inks decreased the gloss or "damaged" the IRL of the media in terms of lowering the gloss with increasing ink coverage/unit area.
2. Both dye inks and pigment inks lower gloss.
3. Magnitude in which the gloss was lowered was strongly media dependent.
4. The commercial HP P1100 PhotoSmart system does not have uniform gloss.
5. Formulating to achieve good overall image quality is difficult with swellable polymer media.
6. Difficult to formulate aqueous inks and achieve high uniform gloss when media is "damaged" by water itself.

The polymers used in the IRL of P media swell after absorbing the ink vehicle. Once the media has dried, the polymer coating does not returned to its original form, hence the gloss differential. This was confirmed by microscopy of vehicle-only and water-only jetted prints.

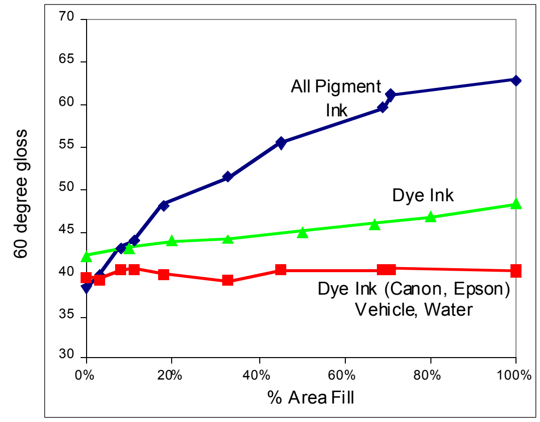

Figure 2. Gloss (60 Degree) Results on Microporous Media (Epson S041286)

The observed trends were different for microporous glossy media (Figure 2):

1. MP media gloss is lower than the P media gloss.
2. Dye inks slightly increase or do not effect the gloss and gloss remains low but uniform.
3. Vehicle-only and water-only colorless inks are rapidly absorbed into by the IRL of the MP media and do not effect the gloss.
4. All pigment inks tested (commercial and experimental) as well as polymeric binder containing colorless inks add gloss to the media, sometime increasing the gloss dramatically by more than 40 gloss units at 100% ink coverage.
5. It is much easier to formulate inks for microporous media for good overall image quality.

Images printed with pigment inks on MP paper cannot achieve uniform high gloss since the unprinted areas (media) have low gloss. In other words, no amount of ink formulation work involving color-containing pigment ink and black pigment ink will solve the problem of gloss uniformity on MP paper.

For photo ink jet printing, the preferred combination is pigment ink for image permanence and microporous media for superior properties. Therefore, the solution to gloss uniformity must come from other means than ink formulation. Several approaches for achieving uniform high gloss with pigment photo inks are discussed below.

Approach 1: Increase the Gloss of MP Media

It is relatively easy to reduce the gloss of an IRL in a photo media but very difficult to raise it as in the case of microporous media.[6] The major factors that impact the gloss of MP media are surface roughness and the size and relative refractive indices of the particles and pores. Very fine, colloidal particles and the production of very smooth surfaces may lead to increased gloss of microporous media.

Approach 2: Laminate or Clear Liquid Overcoat

A simple approach to achieving uniform high gloss is to laminate the photo print with a glossy film. A variation on this involves completely covering the photo print with a glossy polymeric solution that is jetted or sprayed over the image. Laminates and overcoats are currently used in large format graphic arts ink jet printing and provide improved gloss and gloss uniformity as well as improved physical durability. These approaches are unlikely for low cost photo printers and not practical for SOHO photo customers.

Approach 3: Multifunctional IRLs

Another approach involves making the IRL of the media multifunctional so in addition to capturing and drying the inks, the media undergoes a transformation upon post treatment (e.g. heat and pressure) to create a transparent smooth reflective glossy surface in the finish print (7). The disadvantage of this approach is increased printer cost, perhaps prohibitive for SOHO photo printing.

Color Gamut

In parallel with our gloss studies, we measured the color of the commercial photo printing systems along with an experimental DuPont pigment ink set (GP) and the HPUV LPF inks. The color gamuts were calculated and are summarized in Table 4.

This data show when printing on glossy ink jet photo media, pigment ink (HPUV) can achieve equivalent color gamut as the commercial dye ink systems on their respective media. The Epson 2000P pigment inks and an experimental DuPont GP pigment inks have larger color gamuts than the commercial dye ink photo systems.

Conclusion

Pigment-based ink jet inks can provide image permanence, excellent color, and photo image quality in the current low drop volume high resolution SOHO photo printers. Given the current coating technology used in the IRLs of ink jet photo glossy media, it has been very difficult to achieve uniform high gloss through pigment ink formulation changes in spite of years of effort. Improvements in glossy media specifically designed for pigment ink are required to raise the level of media gloss to that of the printed area. If this is not possible, assistance is required to solve the remaining gloss uniformity issues through alternative approaches such as lamination, clear overcoats, or post-treatment of the printed image.

Table 4. Color Gamut of Commercial Photo Printing Systems

Printer	Ink	Media	Media Type	Color Gamut
Epson 1270	Dye CcMmYK	Premium Gloss S041286	MP	585623
Canon BJC8200	Dye CcMmYK	Glossy Pro	MP	558772
HP P1100	Dye CMYK	Premium Plus, C6831A	P	563383
HP DJ2500 LFP	HPUV Pigment CMYK	Glossy UV Media, C6795A	MP	554405
HP DJ2500 LFP	HPUV Pigment CMYK	Mitsubishi IJ UF120	MP	545146
Epson 2000P	Pigment CcMmYK	Premium Semigloss S041331	MP	666646
DuPont GP Ink	Pigment CMYK	Glossy UVC6795A	MP	739761

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Biography

Dr. Sandra Issler is a senior research associate with the DuPont Company. Sandra received her B.Sc. (1981) in chemistry from the University of Waterloo and both M.S. (1983) and Ph.D. (1985) in inorganic solid state/physical chemistry from Cornell University. After a post-doctorate, Dr. Issler joined DuPont Imaging Systems in 1987 and worked on new medical x-ray imaging systems. She is the co-inventor of the Ultra-Vision™ medical x-ray film/screen system and recipient of the company's Marketing Excellence Award in 1993. In 1995, she joined Performance Coatings where she is involved in a variety of ink jet ink programs including formulation and testing of inks for large format, SOHO, photo, and digital textile printing. Dr. Issler holds an assortment of publications and patents in the field of imaging and is a member of IS&T.