A Comparison of the Image Stability of Digital Photographic Prints Produced by Various Desktop Output Technologies[1]

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Abstract

Inkjet, thermal dye transfer, and electrophotography are among the technologies currently capable of producing digital photographic prints on the desktop. This presentation examines the various factors that affect the image stability of photographic prints produced by these technologies. In addition to accelerated light fade testing, we will also compare the dark stability of prints as a function of heat, humidity, and ozone.

Introduction

The explosion of digital images available from scanners, digital cameras, and the Internet has driven a commen-surate demand for printing those images. Today, there are multiple technologies available for printing digital images on the desktop in the home and/or office. "Photo quality" inkjet printers are available for under $100 that can print on media ranging from plain paper to heavy weight photographic stock. Desktop color electrophotographic printers, starting at under $1000, offer higher printing speeds and lower cost per page than inkjet, but at this time are optimized for mostly plain paper printing. Thermal dye transfer printers ranging from small format, battery-powered, "card" printers for under $400, to page-size digital photoprinters that retail for as much as $5000, produce prints on special media that very closely replicate the performance of traditional silver halide (AgX) photographs.

These same three technologies have also been proposed for both retail and wholesale digital print services. When these technologies are optimized for printing digital photographs, the image quality is comparable to traditional AgX-based systems. There are concerns regarding image stability and physical durability, however, that have prevented the widespread application of these alternate technologies in the production of photographs intended for long-term storage and/or display. Inkjet, especially, has been the subject of numerous studies for the effect of various environmental factors on long-term display.[1-11] The type of ink (pigment vs dye) and media (porous vs swellable) can have a profound impact on the ability of the photograph to resist the effects of light, heat and humidity, and environmental pollutants such as ozone.

In this report, we compare the image stability of photographic output for a variety of desktop printers that span inkjet, electrophotographic, and thermal dye transfer systems (see Table 1) with respect to the effects of light, ozone, and heat and humidity.

Materials and Methods

Materials

The marking materials (inks, toners, dye donors) were used as recommended by the printer manufacturer, and are representative of products available at retail in the second half of 2001. Likewise, the image receivers were also current-generation, OEM-branded products that most closely matched the look and feel of a traditional photographic print. For the color electrophotographic printers H and I, there is no equivalent photographic paper available. Therefore, we chose to use a synthetic paper marketed by Hewlett-Packard in both printers that is claimed to be especially durable.

Methods

The test targets and test methods have been described previously.[2,4-6,11] The test targets were treated under the following conditions: (a) 80 klux, Plexiglas-filtered cool white fluorescent, 23 $\pm$ 2ºC/50 $\pm$ 3% RH, (b) 5.4 klux, Plexiglas-filtered cool white fluorescent, 23 $\pm$ 2ºC/50 $\pm$ 3% RH, (c) 1.0 ppm ozone, dark, 23 $\pm$ 2ºC/50 $\pm$ 3% RH, (d) dark, free-hanging, 38 $\pm$ 2ºC/80 $\pm$ 3% RH, and (e) dark, free-hanging, 50 $\pm$ 2ºCºC/50 $\pm$ 3% RH. The test targets were monitored periodically by both densitometry and colorimetry and returned for continued treatment. Only the results of conditions (a), (c), (d) and (e) are reported at this time. It has been previously reported that porous inkjet samples treated under condition (b) suffer large apparent reciprocity deviations because of the presence of trace levels of ambient ozone.[11] The results of condition (b) will be reported separately.

Table 1. Desktop printing systems used for this study.

System	Printer	*Paper*	Type*
A	EPSON Stylus Photo 890	EPSON Premium Glossy Photo Paper (S041286 – 2001)	IJ-DP
B	EPSON Stylus Photo 890	EPSON ColorLife Photo Paper, Semigloss (S041500)	IJ-DS
C	KODAK Personal Picture Maker 200	KODAK Ultima Picture Paper, High Gloss (1160753)	IJ-DS
D	HEWLETT-PACKARD Photosmart 100	HEWLETT-PACKARD Glossy Photo Paper (C7890A)	IJ-DP
E	HEWLETT-PACKARD DeskJet 990	HEWLETT-PACKARD Colorfast Photo Paper, Glossy (C7013A)	IJ-DS
F	EPSON Stylus Photo 2000P	EPSON Premium Luster Photo Paper (S041405)	IJ-PP
G	KODAK XLS 8650	KODAK IMAGE MAGIC Paper (w/ KODAK PROFESSIONAL EKTATHERMXTRALIFE Media)	TDT
H	HEWLETT-PACKARD Color LaserJet 4550	HEWLETT-PACKARD LaserJet Tough Paper (Q1298A)	EP
I	LEXMARK C720	HEWLETT-PACKARD LaserJet Tough Paper (Q1298A)	EP

*Key: IJ-DP = inkjet, dye-based ink, porous receiver; IJ-DS = inkjet, dye-based ink, swellable receiver; IJ-PP = inkjet, pigmented ink, porous receiver; TDT = thermal dye transfer; EP = electrophotography.

Results and Discussion

Overview

There are several current international standards for assessing the image stability of print materials with respect to both light- and heat-induced effects on image stability.[12] However, standardized methods do not yet exist for the assessment of the effect of humidity and air pollutants, such as ozone on image stability. Therefore, we have adapted previously described methods for the treatment of inkjet photographic prints with humidity and ozone.[2,6]

Another issue in quantifying the image stability of a photographic print has to do with how change is monitored. Although status A densitometry ("ΔD") is recommended in the ANSI standard,[12a] CIELAB colorimetry ("ΔE") has also been used to compare changes in color quality.[12b,12c,13] In the case of humidity, changes in sharpness have also been noted, in addition to changes in hue and/or density.[1] In this study, we report changes in terms of both ΔD and ΔE for the worst color, referenced to an interpolated starting density of 0.5, corrected for D-min.

General Observations

Tables 2-5 summarize the effects of treatment conditions (a), (c), (d), and (e). It can be seen that in several cases, the worst color as measured by the two methods is different. Also, similar values of ΔD may often correspond to significantly different values of ΔE, depending upon the specific materials and color being measured.[15] The use of either ΔD or ΔE, however, produces similar relative rankings of the test samples in each case. To simplify the following discussion, we have chosen to compare ΔD values in the context of the relative performance of the various technologies.

Table 2. Results for condition (a), 56 days.

System	Colorimetry		Densitometry		Rel. ΔD
	ΔE	Worst color	ΔD	Worst color	
A	30	M	-0.33	M	3.5
B	17	M	-0.21	R(M)	2.2
C	14	Y	-0.17	Y	1.8
D	46	M	-0.48	M	5.0
E	22	M	-0.22	M	2.3
F	7.7	M	-0.10	C	1.0
G	18	R	-0.29	R(Y)	3.0
H	41	Y	-0.45	Y	4.7
I	30	Y	-0.42	Y	4.4

Table 3. Results for condition (c), 56 days.

System	Colorimetry		Densitometry		Rel. ΔD
	ΔE	Worst color	ΔD	Worst color	
A	47	M	-0.49	M	26
B	2.5	R	-0.027	R(M)	1.4
C	32	C	-0.43	C	22
D	46	M	-0.50	M	26
E	3.9	M	-0.048	M	2.5
F	14	B	-0.014	C	7.1
G	3.4	Y	-0.045	Y	2.4
H	2.2	B	+0.019	G(Y)	1.0
I	1.3	Y	-0.020	Y	1.0

Table 4. Results for condition (d), 28 days.

System	Colorimetry		Densitometry		Rel. ΔD
	ΔE	Worst color	ΔD	Worst color	
A	3.5	G	-0.077	C	5.5
B	5.5	G	+0.085	G(Y)	6.0
C	18	G	+0.24	G(Y)	17
D	11	K	+0.16	C	11
E	15	M	+0.18	M	13
F	2.8	B	-0.029	C	2.1
G	2.2	B	-0.048	R(Y)	3.4
H	0.92	R	-0.014	G(Y)	1.0
I	2.3	Y	-0.033	Y	2.4

Table 5. Results for condition (e), 28 days.

System	Colorimetry		Densitometry		Rel. ΔD
	ΔE	Worst color	ΔD	Worst color	
A	3.2	G,R	-0.065	G(Y)	5.5
B	1.3	G	-0.019	C	1.6
C	4.8	R	-0.054	M	4.5
D	11	M	-0.14	C	11
E	0.83	G	-0.012	K(C)	1.0
F	3.4	M	-0.048	C	4.0
G	3.6	Y	-0.056	Y	4.7
H	1.7	Y	-0.020	Y	1.7
I	2.0	Y	-0.016	Y	1.4

In many cases it is also worth noting that a secondary color or neutral exhibits the greatest amount of change. Although the phenomenon of dye-dye interactions (also referred to as "catalytic fade") in secondary colors has been previously reported for light fade studies of inkjet prints,[16] similar phenomena have not been widely reported for other types of image degradation and/or imaging technologies. Thus, it is important to reinforce the need to monitor these colors in addition to the primary colors in these types of tests.

Light Fade

In general, light affects prints that are on display, opposed to those that are being stored. All samples in this study exhibit a noticeable degree of light-induced fade after 56 days of continuous 80-klux exposure (see Table 2). Generally, there is good correlation in a relative sense between densitometry and colorimetry for these results. The IJ-PP system (F) performed the best under these conditions, followed closely by the three IJ-DS systems (B, C, and E). It is interesting to note that although the electrophotographic systems (H and I) show very good light fade resistance through 28 days,[1] both systems exhibit rapid yellow fading between 28 and 56 days of exposure. Overall, compared to the results for the other conditions as summarized in Tables 3-5, there was less differentiation among the different technologies with respect to light-induced image degradation.

Ozone Sensitivity

Ozone has long been known to bleach certain dyes and pigments.[17] It is more likely to affect prints that are displayed without protection to the ambient environment, opposed to prints on display behind glass or those in storage. Other pollutant gases, such as nitrogen dioxide and sulfur dioxide have been reported to be much less damaging to inkjet prints than ozone.[9,18] As evidenced by the data in Table 3, the two EP systems (H, I) are the most stable with respect to ozone, followed closely by the TDT system (G), and then by two IJ-DS systems (E, B). The other three, inkjet systems are significantly more sensitive to ozone, especially the IJ-DP systems (A, D). In fact, the ozone sensitivity of similar Epson printing systems has been recently reported in some detail.[18] Compared to the light fade results for which a range of about 5X in ΔD is observed, ozone-induced fade spans a range of about 25X from best to worst. With respect to ozone fade, it is interesting to note that the pigmented inkjet system (F), (which is the best with respect to light fade), is in the middle of the pack.

Heat and Humidity

Heat and humidity can affect prints that are on display as well as those that are in storage. In contrast to the effects of light and ozone, which primarily result in dye fade and density loss, prolonged exposure to high heat and humidity can result in density gain and/or loss of sharpness in addition to dye fade.[2] Under condition (d), which stresses the humidity sensitivity of the test samples, the EP systems (H, I) are among the least affected by humidity, along with the TDT and IJ-PP systems (F, G). Each of the dye-based inkjet systems (A-E) exhibits higher amounts of density change, with systems B-E all showing a *gain* in density. This is believed to be the result of dye migration, which, in turn, leads to greater area coverage and an apparent increase in density.[2,3] The rate of change for systems D, C, and E follows first-order kinetics, consistent with dye diffusion, with most of the change occurring within the first seven days of treatment.

Although not evident from the data in Table 4, the two IJ-DP systems (A, D) exhibit competition between dye migration and dye fade. All three primary colors exhibit a rapid increase in density followed by a gradual decrease in density over time. Because the samples were treated in a free-hanging mode, and ozone was not specifically excluded from the test chamber, the observed dye fade can be due to trace levels of ambient ozone present in the test chamber environment.[5] It is known that the rate of ozone-induced fade for inkjet prints can be accelerated at higher levels of humidity.[6]

In contrast, condition (e), which emphasizes temperature over humidity, much less change overall is observed. Under this condition, all samples exhibit some density loss, with most systems losing less than about 0.06 density units.

Two of the IJ-DS systems (B, E) are among the best performers, along with the EP systems (H, I). The IJ-PP system (F), the TDT system (G), and the other IJ-DS system (C) are in the middle of the pack, with the two IJ-DP systems (A, D) ranking at the bottom.

Summary

No one system, or technology, performs the best against all of the factors investigated for this study. Although the IJ-DS and IJ-PP systems exhibit superior light fade resistance, they suffer from weaker ozone resistance (C, F) and/or greater humidity sensitivity (B, C, E).

The EP systems are among the best for ozone, humidity, and temperature sensitivity, but are only fair with respect to light fade. It should also be noted, however, that the photographic "look and feel" of the desktop EP systems included in this study suffer when compared to the other systems and traditional silver halide photographs. Higher end digital EP systems may come closer to matching the end-users expectations for quality photographic output.

The thermal dye-transfer system (G), although not the best against any of the test conditions, is in the top five across the board, a distinction shared by no other system. The IJ-DP (A, D) systems rank consistently in the bottom half in each case.

Acknowledgments

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Notes and References

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14. An initial reference density of 0.5 was chosen because several of the systems could not achieve a maximum density of 1.0 or greater across all seven colors.
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Biography

Douglas Bugner received his B.S. in Chemistry from the Ohio State University in 1975, a M.S. in Organic Chemistry from UCLA in 1980, and a Ph.D. in Organic Chemistry from UCLA in 1982. In 1982, Dr. Bugner joined the Chemical Technology Laboratory in the Photomaterials Division of Eastman Kodak Company. In 1988, he accepted an assignment in the Photoconductor Technology Laboratory, and in 1991, he was appointed manager of the Chemical Technology Lab. In 1993, Dr. Bugner established a research effort in the area of inkjet materials, and is currently Senior Laboratory Head, Desktop Commercialization Laboratory, Inkjet Materials and Printing Systems Division, Eastman Kodak Company.

In 1994, Dr. Bugner received the Distinguished Inventor Award, and in 1997, he completed the Executive Development Program at the Tuck School of Business at Dartmouth. He currently holds 57 U.S. Patents, and has authored over 20 scientific publications. He is a member of the American Chemical Society, the IS&T, and the Project Management Institute.