Stain Resistance as Part of Image Permanence for Consumer Digital Inkjet and Thermal Imaging Systems – Part 2

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Abstract

Development of a more robust procedure for quantifying unwanted staining of prints caused by accidental spills of common household beverages were presented at the 2007 IS&T Non-Impact Printing Conference. This included a review of methodologies that were currently in the literature plus the pros and cons associated with each. Results from a marketing study that identified categories of top beverages consumed worldwide were described and preliminary results assessing stain severity as a function of beverage were reviewed. Generally speaking, highly colored beverages such as coffee and red fruit punch showed higher levels of staining, and less-colored beverages such as fruit-flavored water or beer exhibited very little staining. What was not expected was the amount of staining observed with a light blue-colored sports energy drink. Although this beverage was not highly colored, the level of staining based on a visual assessment for most media ranged between 0.5 and 2 (where 0 equaled no stain and 5 equaled severe stain). This suggests that stain severity may not be solely related to highly colored beverages. Because of this finding, coupled with the stipulation that beverage brands cannot be cited within an international standard, more work was needed to understand root causes of unwanted staining. This paper will discuss studies implemented to determine whether stain severity can be correlated with factors such as what colorants are present in beverages, and/or the physical and chemical properties such as pH, viscosity, surface tension, and/or conductivity. In addition, preliminary results from a voice-of-the-customer (VOC) study will also be presented to outline what levels of staining would be considered acceptable versus unacceptable.

Introduction

As previously discussed at NIP 23 [1], there were very few literature references that described methodologies for determining unwanted staining of consumer prints caused by accidental spills of common household beverages. Because of this, several experiments were implemented to develop a more robust procedure for assessing/measuring stain resistance and a preliminary method was proposed. This included target design that prevented cross-contamination, identification of liquid beverages as staining agents, methods of application and removal of the staining agent, and quantification of stain severity by utilizing the Delta E2000 metric. In addition, a follow-up paper accepted for publication [2] describes in more detail additional steps taken to make this procedure more robust.

After evaluation of a variety of beverages as potential staining agents across several printer systems, previous results indicated that highly colored beverages tended to stain prints more readily than less colored beverages. One exception to this was that a light blue-colored sports energy drink exhibited higher levels of stain than expected based solely on beverage color. This suggested that stain severity might not be solely related to highly colored beverages. This finding, coupled with the stipulation that beverage brands cannot be cited within an international standard, it was of interest to see whether certain ingredients within beverages could be identified as the cause of the higher levels of staining.

The remaining portion of this paper will summarize studies implemented to determine whether stain severity could be correlated with colorants present in beverages and their physical and chemical properties such as pH, viscosity, surface tension, and/or conductivity. In addition, the design and implementation of a voice-of-the-customer (VOC) study to determine what levels of staining would be acceptable versus unacceptable to an average consumer will also be discussed.

The first section will give a general description of what printer systems and beverages were selected for this study. The next section will describe initial attempts to correlate stain severity with beverage colorant and/or physical properties of beverages. The third section will describe the VOC study and how it was implemented. The fourth section will describe how the data were analyzed and the results will be summarized.

Test Method

Three printer systems were selected based on the level of staining observed from the visual assessment in previous studies [1,2] and are summarized in Table 1. In efforts to be consistent with the previous work, the printer system identifications were retained.

Table 1: Printer Systems

System ID	Ink (Dye or Pigment)	Media (Porous or Swellable)
A	Pigment	Porous
B	Pigment	Porous
E	Dye/Pigment	Porous
D	Dye	Porous

The target used for all studies consisted of colored patches of C, M, Y, K, R, G, and B at three fill levels (100%, 60%, and 20%) and three patches of D-min. The target was printed using driver default settings for each specified printer system and the final print allowed to dry for a minimum of 24 hours before staining. Beverages (staining agents) were allowed to equilibrate to room temperature before staining. Two drops (0.10 mL) of each staining agent were placed at the center of each patch, allowed to stand for 30 s, and blotted off using a dry paper towel. The density and CIELAB data were measured for each color patch before and after staining using a Spectrolino SpectroScan [3] densitometer and a Delta E2000 was calculated for each color and fill level.

Two groups of beverages were selected for subsequent experiments and are summarized in Table 2. The first group was selected in order to determine whether stain severity could be correlated with either the colorant present and/or physical properties of a given beverage. The second group was selected that spanned the range of stain severity (low to high) based on previous work [1,2] for use in the VOC study.

Table 2: Staining Agent Selection

Category	Staining Agent ID	Severity Correlation	VOC Study
Tea	Green Tea	X	X
Carbonated Soft Drinks (CSD)	CSD-cola 1	X	
	CSD-yellow	X	
	CSD-red	X	
	CSD-orange	X	X
Coffee	Black Coffee, brewed	X	X
Fruit Juices	Red Fruit Punch	X	X
Sports/Energy Drinks (SED)	SED-light blue	X	
	SED-blue	X	X
	SED-red fruit punch	X	

Stain Severity Correlation

From previous work [1,2], highly colored beverages such as coffee or red fruit punch showed higher levels of staining. What was unexpected was the amount of staining observed with a blue-colored sports energy drink (SED-blue). Although this beverage is not highly colored, the level of staining on most media ranged between 0.5 and 2. This suggested that stain severity was not solely related to beverages that are highly colored. Because of this, it was of interest to determine whether certain ingredients present in beverages could be identified as the cause for the higher levels of staining. The first ingredients considered were the major colorants (dyes) used in beverages. A subset of beverages was selected that spanned the range of stain severity from 0 to 4.5 on Media D. The colorants present in each of these beverages were recorded and are summarized in Table 3.

Table 3: Stain Severity as a Function of Beverage Colorant

		Main Colorants in Beverages				
Staining Agent ID	**Stain Severity on Media D**[1]	**Caramel**	**Yellow 6**	**Yellow 5**	**Red 40**	**Blue 1**
CSD-yellow	0			X		
CSD-cola 1	0.5	X				
SED-light blue	0				X	X
SED-blue	1					X
CSD-orange	2		X	X	X	
CSD-red	3			X	X	X
SED-red fruit punch	3.5	X			X	
Red Fruit Punch	4.5				X	X

[1]Visual ranking using the expanded scale where 0 = no stain and 5 = severe stain

From these results, one can see that beverages showing higher levels of stain (visual ranking of 2 to 4.5) contain either Red 40 or a combination of Red 40 and Blue 1 dyes. One exception to this was with SED-light blue; this beverage contained both dyes but exhibited no staining on Media D. In addition, the SED-blue showed some stain and only contained Blue 1 dye. Because of these exceptions, more work is needed in order to determine whether or not a correlation exists between stain severity and concentration of beverage colorant. This understanding is needed in order to develop an experimental staining solution that would replace the use of beverage brands as staining agents.

The next factor considered was whether a correlation existed between stain severity and one or more physical and/or chemical properties of the beverages. The properties initially considered included pH (acidity), surface tension (wetting characteristics), and conductivity (electrical conductance). Correlation plots of these physical and chemical properties with the Delta E2000 D-min obtained from prints made with Printer System A were made. No correlation was found to be present between these properties and stain severity [4].

Voice-of-the-Customer (VOC) Study

The initial purpose of this study was to determine what Delta E2000 values represent acceptable versus unacceptable levels of print staining to an average consumer. Leveraging the understanding acquired from previous work, three printer systems and five beverages that spanned the range of stain severity (low, medium, and high staining) were selected. The beverages chosen as staining agents are summarized in Table 2 and included: green tea (low staining), CSD-orange (medium staining), and brewed coffee and red fruit punch (high staining). The SED-blue beverage was also included in this study because it exhibited more than expected staining from previous studies.

In order to further understand what impact colorant and fill level have on stain severity for a given printer system-beverage combination, the 24-patch target was used in place of an actual image. A total of five prints were made for each printer system and stained with the five selected beverages. All printing and staining were done using the methods described above and a Delta E2000 was calculated for each printer system-beverage-color patch combination.

The stained prints were placed in three groups (one printer per group) consisting of five samples within each group in random order. The samples were then placed under a D50 illuminant light source on a viewing table angled at 45º, roughly 16 inches from the viewer (viewing angle 45º). A screen was made to isolate each color patch and placed over the stained sample. An unstained reference print was placed next to each stained sample and used for comparison. Five replicates were included as a fourth group and were sampled from the three previous groups to assess repeatability of each viewer. Viewers were asked to assign a rank of 1 (no stain detected), 2 (stain detected but acceptable), or 3 (stain detected and objectionable). In all, 12 viewers ranked 20 images each with 24 color patches per image.

Analysis and Results

For each of the 24 color patches, the 12 viewer rankings were averaged together. These averages were then compared to the corresponding measured Delta E2000 to determine the correlation of visual ranking from VOC with measured Delta E2000. The ultimate goal is to establish specifications for stain tolerance/acceptability based solely on Delta E2000.

The data for the black color patches are shown in Figure 1. The strong, linear correlation between the two measures of staining allows one to place viewer acceptability specifications on Delta E2000. For example, a measured Delta E2000 value in the range of 4.7 to 10.0 would correspond to a viewer ranking of 2, which represents stain that is visible but still acceptable.

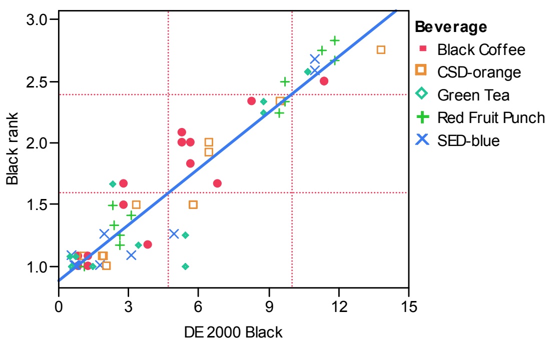

Figure 1. *Visual rank versus Delta E2000 for black patches.*

Similar analysis was applied to the remaining colorants and the viewer acceptability specifications based on Delta E2000 were determined for each and the results are summarized in Table 4.

Table 4: Delta E2000 Limits for Viewer Acceptability

	Delta E2000 Limits[1]	
Colorant	Low	High
Black	4.7	10.0
Cyan	4.6	10.3
Magenta	4.6	9.7
Yellow	3.3	8.1
Red	4.2	10.3
Green	4.7	10.0
Blue	5.0	11.3
Dmin[2]	3.1	9.0
Dmin[3]	2.7	6.8
Average[4]	4.2	9.6

[1]prediction of consumer acceptability
[2]Linear fit, r = 0.70
[3]Quadratic fit, r = 0.92
[4]calculated by averaging all colorants

One exception occurred with the D-min patches. When linear curve fitting was applied to the visual ranking for D-min, poor correlation (R^2 = 0.70) was obtained. Better correlation was achieved when a quadratic curve fitting was applied (R^2 = 0.92).

Interestingly, the lower Delta E2000 limit for the D-min (2.7) and yellow (3.3) patches were significantly less than what was calculated for the remaining color patches (4.2–5.0). This suggested that a consumer would be more sensitive to unwanted staining, color shifts, density losses, etc., when these colorants are present.

In order to establish specifications for stain tolerance/acceptability for images based on Delta E2000, an average was calculated using the limits obtained for each colorant (see Table 4). The proposed Delta E2000 limits were as follows: values less than 4.2 represent little to no staining present; values between 4.2 and 9.6 represent stain that is visible but still acceptable, and values greater than 9.6 represent unacceptable levels of staining.

Conclusions and Future Work

Attempts to correlate the major dye colorant ingredients present in actual beverages with stain severity were found to be inconclusive. To better understand what the relationship is between stain severity and beverage ingredients, future work is planned to look at each colorant separately.

No correlation was found to be present between stain severity and three physical properties of the beverages ((pH (acidity), surface tension (wetting characteristics), and conductivity (electrical conductance)).

Specifications for stain tolerance/viewer acceptability were determined by correlating visual rankings obtained from a VOC study with the measured Delta E2000 metric. Additional analysis of the data from this study is planned.

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References

[1] K. Lawrence, D. Cigna, W. Brattlie, D. Erdtmann, and J. LaBarca, "Stain resistance as part of image permanence for consumer digital inkjet and thermal imaging systems," in Proc. NIP23 and Digital Fabrication, September 2007, pp. 721–725.

[2] K. Lawrence, D. Cigna, W. Brattlie, D. Erdtmann, and J. LaBarca, "Stain resistance method development for consumer digital inkjet and thermal imaging systems-Part 1," Journal of Imaging Science and Technology, accepted for publication (2008)."

[3] Manufactured by GreytagMacbeth™. Settings include: D50 illuminant, 2° observer angle, ANSI A density standard, white base = Abs, no filter.

[4] For more detail, see Figures 9–11 within reference 2 above.

Author Biography

Kristine Lawrence received an Associates degree in Chemical Engineering Technology from Broome Community College in 1982 and a Bachelor's degree in Chemistry from Rochester Institute of Technology in 1989. She has been employed at Eastman Kodak Company in Rochester, New York for 26 years and has worked as a materials scientist/systems evaluator on a variety of digital imaging programs including inkjet, thermal dye transfer, and microencapsulation. She has co-authored 49 issued patents, received a Team Achievement Award in 1990, and was inducted into Kodak's Distinguished Inventors Gallery in 1999. She has co-authored outside publications in NIP12 and the Journal of Medicinal Chemistry. Kristine is currently working at Kodak's Research Laboratories in areas of image permanence and durability, and was a key contributor to the recent launch of Kodak's new inkjet system.