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Stain Resistance Method Development for Consumer Digital Ink Jet and Thermal Imaging Systems. Part I

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Abstract. *Methods for determining overall print permanence or image stability for digital ink jet and thermal photographic prints have been well defined and are used to represent typical "long-term, home storage conditions" for consumer prints. What these methods do not take into consideration are instances where a consumer might accidentally spill substances onto unprotected prints, resulting in unwanted staining. Typical substances can range from high staining materials such as coffee to lower staining materials such as milk. In these instances, damage caused by unwanted staining could certainly impact the long-term preservation of consumer prints. To date, the only existing international standards for this type of image degradation include an ASTM procedure for stain resistance and an ISO procedure for water resistance. This article will discuss the importance of considering stain resistance as part of long-term image permanence criteria for digital consumer color prints and shortcomings associated with the current international standards. Emphasis will be placed on the rationale and development of a more robust procedure for stain resistance and a final method proposal will be made. In addition, application of the proposed method will be discussed and the results from this for several digital ink jet and thermal imaging systems will be summarized. © 2008 Society for Imaging Science and Technology.*
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INTRODUCTION

In today's society, many consumers have "gone digital," whereby their "important or precious moments" are captured using digital cameras, and prints are made with either home ink jet or thermal printers. With this shift from conventional silver halide (AgX) capture/professional imaging to digital capture/home printing by consumers, it was necessary to develop procedures that would predict how long digital prints imaged at home by consumers might last. This can also be referred to as overall print permanence or image stability. For the scope of this article, overall print or image permanence can be defined as all methods necessary to predict how long a consumer print might last once printed. The factors typically used to determine this have included: light (office or daylight illumination), environmental gas (ozone stability), moisture (exposure to high humidity), and heat (album or dark storage at elevated temperatures). These methods have been well documented by several individuals as well as companies for home ink jet and thermal printer systems.[1,2]

What has not been well documented in the literature relates to the category of "print or image durability." Print durability can be defined with respect to damage that affects the physical integrity of the print and/or degradation of the image on the print. Factors that can contribute to this type of damage include: excessive moisture causing the print to curl or cockle; image degradation caused by smudging, fingerprinting, scratching/scuffing, or colorant bleed; and staining of prints caused by accidental spills of common household beverages such as coffee or smearing with foods like peanut butter. With the shift to consumer home printing, there is an increasing likelihood that the overall print quality or image durability could be impacted by one or more of the above-mentioned factors. If a consumer does not take extra precautions to protect their prints from this type of degradation, the outcome could be that the print is rendered "unacceptable."

Another consideration deals with the limited number of procedures available that can quantify this type of print or image degradation. In fact, there are only two international standards for this type of image degradation in the literature (an ASTM procedure for stain resistance[3] and an ISO procedure for water resistance).[4] As a result, many companies rely on very qualitative metrics to rate image durability, and do not always include this metric as part of the overall image permanence ratings.

The remaining portion of this article will focus on one aspect of image durability: stain resistance. The first section will present an overview of what methods are currently being used to describe stain resistance and will briefly describe advantages and disadvantages for each. The next section will describe steps taken to develop a new test procedure for staining of printed images taking into consideration the positive attributes from current methods in conjunction with the development of a more quantitative method of analysis. The philosophy used in the selection of printer systems for this study will then be explained in the third section. For the scope of this article, a "printer system" refers to making prints using the default driver settings for the particular ink-media combination recommended for that printer. The fourth section will outline how beverages were selected, leveraging data from an international marketing study.[5] From this marketing study, the top eight beverage

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categories were selected and 2–4 brands from each category were used as potential staining agents. A preliminary screening and visual assessment of each beverage on a variety of articles was done and the results summarized. The next several sections will describe the steps taken to develop a more robust procedure including: target design, quantification of stain severity, and method of application (including time duration and removal), impact of colorant fill level, and attempts to correlate stain severity with physical properties of the beverages.

A smaller subset of beverages will then be used to evaluate stain resistance across several ink jet, one thermal home, and one digital silver halide printer systems. The results from this study will be tabulated with a final method proposal. The last section will capture conclusions from these studies along with a proposal of future work needed to move toward development of an international ISO standard for stain resistance.

LITERATURE/HISTORICAL BACKGROUND

As mentioned earlier, there are only two international standards currently in the literature that are used to describe image permanence as a function of image durability (one for stain[3] and the other for water[4] resistance). In addition, Wilhelm Imaging Research briefly describes two additional tests for water resistance (water drip and a water drip with gentle wiping) as part of their procedure for determining water resistance.[6] At first glance, one might think that water and stain resistance are "one and the same" in that most common household beverages that could stain a print are also water based. Although this may be true in some cases, there are other instances where prints having "good water resistance" may still be vulnerable to staining when exposed to the range of substances consumers typically have in their home environments. In an article published by Sony researchers,[7] the authors describe the use of coffee as part of their method for assessing water resistance. The test involves soaking half of a printed image in coffee and when removed, illustrates how the treated side of the image becomes "stained." This raises the question of whether the prints are truly water resistant or are just more prone to staining with liquids that are highly colored.

In a technical brief published on Epson's website for DURABrite™ Ultra inks,[8] there is a very general description of a procedure for water-resistance illustrating damage to text of varying colors caused by an excess of moisture or accidental spills. This method is limited to describing water resistance.

Although the ISO procedure for water resistance[4] takes into consideration several types of damage related to durability, it does not include any metric for capturing unwanted staining of prints that could occur when using water-based solutions that are highly colored, such as coffee or red fruit punch. In addition, it lacks a quantitative method for analysis causing any results that are reported to be very subjective.

For these reasons, it became evident that an evaluation method was needed to differentiate water resistance from stain resistance. The ASTM procedure for stain resistance[3] is currently the only published international standard for this type of image degradation. In addition, the only other literature references found for stain resistance were within two U.S. patents[9] and the test procedures described in both were very similar to the ASTM methodology.

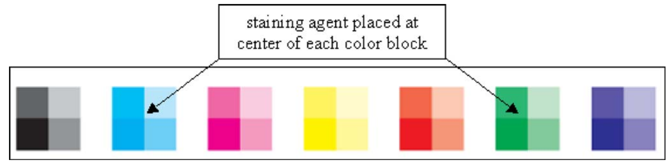

Figure 1. Example of block of colorant from ASTM test target.

A brief description of the ASTM procedure for stain resistance is as follows. The test target is composed of blocks of colorant containing patches at four density fill levels (see Figure 1). A measured amount of a staining agent (beverage or food) is placed at the center of each block of colorant so that it wets all density patches within that block of color.

The staining agents were allowed to stand at room temperature for approximately 15 min, and then blotted off using a dry paper towel followed by gently wiping with a moistened paper towel. The analysis involved a visual ranking process whereby the treated target was compared to an untreated target and assigned a score ranging from one (no change) to four or five (significant stain and/or removal of colorant).

In attempting to follow this procedure, several challenges became apparent. First of all, the treatment time was too long and would not necessarily reflect what would happen if a consumer spilled something on their print. Second, the color patches were too close together, resulting in uneven wetting of each color patch along with cross-contamination caused by colorant bleed. Another concern was the use of a moist paper towel to remove the excess staining agent. This could confound the results because of the introduction of water into the test procedure. Last, the method of analysis was very subjective and, as stated earlier, may vary between different individuals performing the test.

Currently, Eastman Kodak Company has several test procedures that evaluate ink-media performance as a function of print durability, one of which includes stain resistance of ink jet and thermal consumer prints. This procedure differs from the ASTM procedure as follows: shorter treatment times (30 s in place of 15 min), dry-dabbing excess staining agent (in place of wet wiping), and utilization of Delta E2000[10] calculations to quantify the amount of stain present (in place of a visual rank). This Delta E metric was chosen as the most recent calculation method. The test target was quite different from the ASTM method in that it contained patches of red, green, and blue at only one fill level (70%), along with D_{min}. This target was quite limiting in that the highest level of staining tended to occur in the lower density regions of a print. Because of these shortcomings, a new method for stain resistance was needed to incorporate the positive attributes of existing methods with necessary modifications.

Table I. Printer systems used for stain resistance test development.

System ID	Ink (Dye or Pigment)	Media (Porous or Swellable)
A	Pigment	Porous
B	Pigment	Porous
C	Dye	Swellable
D	Dye	Porous
E	Dye/Pigment	Porous
F	Dye	Porous
G	Pigment	Porous
H	Thermal	Thermal
J	AgX	AgX

NEW PROCEDURE DEVELOPMENT

The next six sections will describe steps taken to develop a more robust procedure for stain resistance. The ultimate goal would be to develop an international standard for describing stain resistance that differentiates from water resistance and more closely simulates how a consumer's print might be impacted by accidental spills of common household beverages. For the scope of this article, the test development will focus on the use of only liquids and beverages as staining agents. Any modifications to this procedure that would broaden the test development to include typical household foods, such as mustard or peanut butter, will be the topic of a future article.

In an effort to determine the validity of the proposed test methodology, staining agents were evaluated using prints made from a variety of home ink jet printer systems. Printer systems were selected from what is currently in the marketplace and spanned the range of ink (dye or pigment based) and media (porous or swellable) technologies. One thermal and one silver halide system were also included to represent additional digital output systems for comparison purposes. Because the focus of this article is test development and not benchmarking, the printer manufacturers will not be disclosed with any results but will only be generically referenced (see Table I).

BEVERAGE SELECTION AS STAINING AGENTS

The next step involved selecting beverages as potential staining agents that would span typical beverages found in a consumer's household. The ASTM procedure does specify use of coffee and cola in addition to fruit punch as part of its procedure. Two questions to consider at this point are: do these three beverages adequately represent what consumers might accidentally spill on their prints, and second, do these liquids span the range of stain severity (low staining to high staining)?

In order to address the first question, data were collected from an international marketing study by Beverage Marketing Corporation to determine what the top beverage categories were worldwide.[5] The projections presented in this article were determined by Beverage Marketing Corporation and based on data collected from industry executives, trade, and research organizations from over 200 countries. A comparison was made between actual volumes from 2005 with projections out to 2010, and the results were quite similar. Because of this, only the projections for 2010 were used to determine what the top beverage categories are worldwide and the results are found in Table II.[11]

Table II. Top beverage categories worldwide[a] (source: Beverage Marketing Corporation).

Category	2010[b] Rank	Thousands of Hectoliters	Thousands of Gallons	Share of Volume
Milk	1	2,785,000.00	73,524,000.00	5.60%
Tea	2	2,565,500.00	67,729,200.00	5.20%
Bottled Water	3	2,050,000.00	54,120,000.00	4.10%
CSDs[c]	4	1,907,000.00	50,344,800.00	3.80%
Beer	5	1,715,490.00	45,288,936.00	3.40%
Coffee	6	1,408,687.00	37,189,336.20	2.80%
Fruit Beverages	7	554,800.00	14,646,720.00	1.10%
Wine	8	263,000.00	6,943,200.00	0.50%
Distilled Spirits	9	180,100.00	4,754,640.00	0.40%
Subtotal		13,429,577.00	354,540,832.20	27.00%
Others[d]		36,297,944.50	958,265,733.80	73.00%
Total		49,727,521.40	1,312,806,566.00	100.00%

[a]Categories ranked by size of consumption volume.
[b]Projected global beverage market.
[c]CSDs refers to carbonated soft drinks.
[d]Includes all beverages, commercial and noncommercial, like tap water.

In a press release dated March 7, 2007, Beverage Marketing Corporation described what the future beverages in the United States would be, and included carbonated soft drinks (CSDs), sports beverages, bottled water, ready-to-drink tea and coffee, fruit beverages, and energy drinks.[12]

Keeping the above-mentioned statistics in mind, two to four brands of beverages were selected from the top seven categories and used as potential staining agents. An additional category was added to cover the energy and sports drink arena. Whenever possible, brands that were classified as being "top sellers" for their category were used.[12]

PRELIMINARY SCREENING AND VISUAL ASSESSMENT

Because the beverages that were selected had different consistencies, wetting properties, and varied in acidity (pH range 2.2–7.1), it was of interest to evaluate each one on a variety of media associated with the printer systems listed in Table I. This was done as a quick screen to determine how robust the application, time duration, and removal method for each beverage would be. One drop (0.05 mL) of each beverage was placed on the D_{min} region of the selected ink jet media, allowed to sit for 30 s, and then dabbed off with a dry paper towel. In a presentation at IS&T's NIP23,[13] a visual ranking process was used to quickly assess the level of

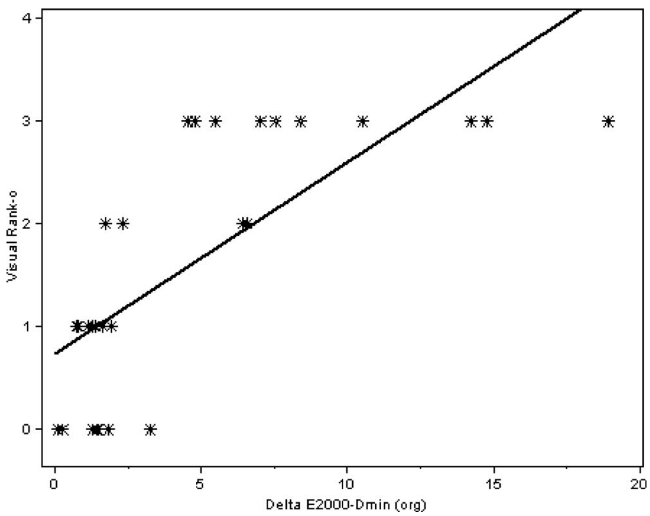

Figure 2. Bivariate fit of original visual rank scale and Delta E2000 D_{min} for Media A.

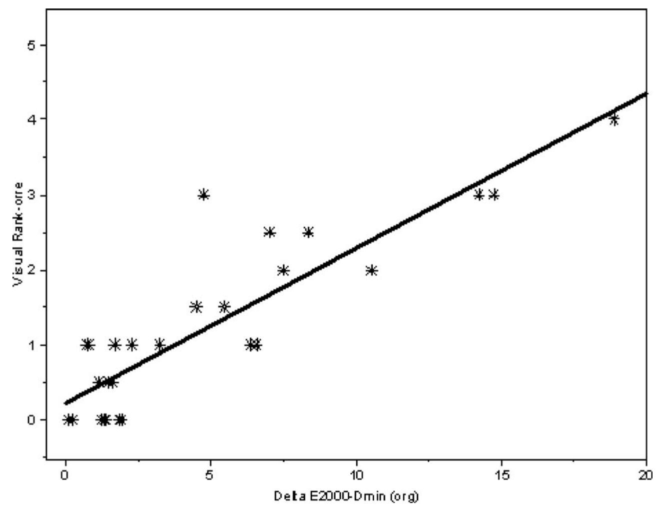

Figure 3. Bivariate fit of expanded visual rank scale and Delta E2000 D_{min} for Media A.

stain present (stain severity) for each beverage-media combination where 0=no stain; 1=light amount of stain; 2=moderate staining; and 3=high level of staining. During the course of additional testing, this scale (which will be referred to as the "unexpanded scale") was found to be too narrow, making it difficult to differentiate stain severity of the various beverages being evaluated. To illustrate this, a plot of the visual rank using the unexpanded scale as a function of the Delta E2000 D_{min} for Media A is shown in Figure 2.

With the upper limit of 3 for the visual rank, it was not possible to differentiate increasing levels of Delta E2000 beyond 7. This resulted in a low correlation ($r=0.78$) between the two measures. Because of this, a new ranking scale was created based on 0 (no staining) and 5 (highest level of staining) among the given set of samples. When the samples were re-ranked using this expanded scale of 0–5, the correlation obtained was much better ($r=0.88$), as illustrated in Figure 3. This methodology used to correlate the visual ranking with the Delta E2000 metric will be discussed further in the upcoming section on quantification of stain severity.

Based on these results, the visual ranking scale was expanded from 0 (no staining) to 5 (severe staining), and the results from this preliminary screening process are summarized in Table III. In addition, results for Media H (Thermal) and Media J (AgX) were also added to Table III for comparison.

With the exception of chocolate milk, yogurt smoothie, and vegetable juice (see Table IV), all other beverages worked well as potential staining agents. The chocolate milk, yogurt smoothie, and vegetable juice were problematic in that they were difficult to remove with a dry paper towel and tended to leave either a hazy film and/or solid residue on the media surface. Because these beverages were problematic, they were dropped as viable staining agents. Another observation was Media C tended to become tacky when wet, causing the paper towel to physically stick to the media surface during the removal process. This caused the media surface to either peel off and/or become deglossed (hazy) in the stained area. As a result, all beverages on Media C were given a higher ranking and the final removal method will need to stipulate how to evaluate swellable media when dealing with liquids as staining agents.

Bottled water and beer categories showed very little to no staining across all of the media variations evaluated. Because of this, these categories were dropped as potential staining agents.

Highly colored CSD's and fruit juices showed higher levels of stain and were usually independent of media type. CSD-yellow, CSD-red, and CSD-orange showed more differentiation of stain severity as a function of media type and will be considered as potential staining agents in the final beverage selection.

Teas generally showed intermediate levels of staining with the hot black tea (brewed) showing the highest levels of stain. Because coffee in any form (cold, room temperature, or hot) showed more staining than teas; brewed coffee will be considered as a potential staining agent in the final beverage selection.

As expected, highly colored sports/energy drinks (SED's) such as SED-red fruit punch, showed higher levels of staining. What was not expected was the amount of staining observed with SED-blue. Although this beverage is not highly colored, the level of staining on most media ranged between 0.5 and 2. This suggests that stain severity may not be solely related to beverages that are highly colored. Because of this, it was of interest to see whether certain ingredients within 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 the results are summarized in Table IV.

From these results, one can see that beverages showing higher levels of stain (visual ranking from 2 to 4.5) contain

Table III. Stain severity results using expanded visual rank scale.

Category Ranking	Staining Agents-SA (by Brand)	SA Temp	Stain Severity Visual Ranking using Expanded Scale[a] Media A	Media B	Media C[b]	Media D	Media E	Media F	Media G	Media H	Media J
Milk (cat #1)	Chocolate Milk	15C	1	1	2	0	0.5	0	1	1	0.5
	Strawberry Yogurt Smoothie	8C	1	1	2	0	0	0	0	1	0.5
Tea (cat #2)	Green Tea	23C	0	0	2	0	0	0	0	0	1
	Iced Tea	23C	0	0.5	2	0	1	0.5	0	0	0
	Black Tea. Brewed	23C	1	0	2	2	2	1.5	2	0	2
	Black Tea Brewed	45C	1	1	2	2	2	1.5	2	0	2.5
Bottled Water (cat #3)	Raspberry Flavored Water	23C	0	0	2	0	0	0	0	0	0.5
	Vitamin Water	23C	0	0	2	0	0	0	0	0	0
Carbonated Soft Drinks-CSD's (cat #4)	CSD-Cola 1	23C	0	1	2	0.5	1	0	1	0	2.5
	CSD-Cola 2	23C	0	1	2	0	1	0.5	1	0	2.5
	CSD-Cola 3	23C	0	1.5	2	0.5	1.5	1	1	0	3
	CSD-Yellow	23C	0	0	2	0	0	0	0	0	0
	CSD-Red	23C	1.5	1.5	3	3	2.5	2.8	2.8	0	3.5
	CSD-Orange	23C	1.5	0.5	2	2	1	1.5	1.5	0	2.8
Beer (cat #5)	Beer 1	23C	0	0	2	0	0	0	0	0	0
	Beer 2	23C	0	0	0	0	0	0	0	0	0
Coffee (cat #6)	Black Coffee, Brewed	23C	1.5	1.5	2	3	3	2.5	3	0	2
	Black Coffee, Brewed	45C	2	2.5	3	3	3	2.5	3	0	2.5
	Expresso, Black	45C	4	4	3.5	4.5	5	5	4.2	0	3.5
	Espresso w/Cream	14C	1.5	1	2	2	3	2	3	1	1
Fruit and Vegetable Juices (cat #7)	Red Fruit Punch	23C	2	2.5	3.5	4.5	3.5	4	4	0	3
	Grape Juice	23C	3	4	5	5	5	5	5	0	3
	Orange Juice	23C	0	0	2	0.5	0	0	0	0	0
	Vegetable Juice	23C	1	1	2	1.5	3	3	1.5	0	0
Sports/Energy Drinks-SED's (New Age)	SED-light blue	23C	0	0	2	0	0.5	0.5	1	0	1
	SED-blue	23C	0.5	0	2	1	1	1	1	0	1.5
	SED-red fruit punch	23C	1.5	1.5	2	3.5	3	2	2.5	0	4.5
	SED-green	23C	0	0.5	2	1	0.5	1	1	0	1
	SED-gold	12C	0	0	2	0	0	0	0	0	0

[a]Visual ranking of D_{min} regions of media using expanded scale where: 0 to 1 = no or slight staining; 2 to 3 = moderate levels of staining and 4 to 5 = high level of staining.
[b]Swellable media.

either Red 40 and/or Blue 1 dyes. The exception to this was with SED-light blue; this beverage contained both dyes but exhibited no staining on Media D. Because of this, more understanding is needed before a correlation can be made between stain severity and beverage colorant. Results from this additional work will be discussed in a future article.

TARGET DESIGN

Because of the limitations of existing targets that were previously described, a new test target was designed. The target incorporated the positive attributes of the ASTM target (multiple colors at different fill levels) but differed in that all density patches were separated from one another (see Figure 4). This arrangement prevented cross contamination of the colorants. The dimension of each patch was made small enough (2.0 mm in diameter) to minimize uneven wetting of the patch and yet large enough for more accurate reading by a densitometer. In addition, three patches containing no colorant (D_{min}) were added to the target to simulate regions of prints that have no colorant present, such as a white wedding dress or white bath towel.

QUANTIFICATION OF STAIN SEVERITY

The next step taken as part of the test development process was to determine whether the Delta E2000 metric would be suitable for quantifying stain severity. As mentioned earlier, better correlation of the visual ranking process with the Delta E2000 metric was obtained for Media A when the visual ranking scale was expanded from 0–3 to 0–5. This same methodology was applied to the remaining media

Table IV. Stain severity on Media D as a function of beverage colorant.

Beverage	Stain Severity on Media D[a]	Beverage colorants				
		Caramel	Yellow 6	Yellow 5	Red 40	Blue 1
CSD-yellow	0			×		
CSD-cola 1	0.5	×				
SED-light blue	0				×	×
SED-blue	1					×
CSD-orange	2		×	×	×	×
CSD-red	3			×	×	×
SED-red fruit punch	3.5	×			×	
Red Fruit Punch	4.5				×	×

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

Table V. Correlation comparison between original and expanded visual ranks scales.

System ID	Media (Porous or Swellable)	Correlation (r) of Visual Rank (VR) to Delta E Metric[a]			
		Original Sample		New Sample	
		"Unexpanded" VR scale	"Expanded" VR scale	"Unexpanded" VR scale	"Expanded" VR scale
A	Porous	0.73	0.88	0.76	0.83
B	Porous	0.76	0.91	0.75	0.76
C	Swellable[b]	0.61	0.61	0.77	0.77
D	Porous	0.80	0.82	0.90	0.96
E	Porous	0.80	0.80	0.90	0.95
F	Porous	0.70	0.76	0.87	0.90
G	Porous	0.80	0.78	0.87	0.94
H	Thermal				NA[c]
J	AgX				0.89

[a]Correlation was calculated as the square root of the r^2 statistic obtained using a linear fit model of visual rank (VR) for all beverages to the calculated Delta E2000 metric (JMP 5.1 software).
[b]Media became tacky when wet giving similar VR for each beverage; no correlation made.
[c]Little to no staining occurred with most beverages; no correlation made.

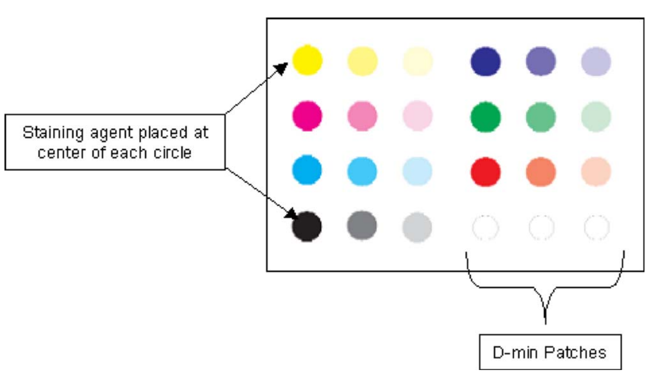

Figure 4. Proposed stain target.

variations (original samples), and the results comparing the unexpanded and expanded visual ranking scales are summarized in Table V. The trends observed for the remaining media variations (Media B–G) were similar to what was obtained for Media A.

To further confirm this trend, new samples were prepared as before, whereby one drop of each beverage was placed on the D_{min} region of all media variations (including Media H & J), allowed to sit for 30 s, and dabbed off with a dry paper towel. The stained samples were allowed to dry at room temperature overnight, and the Delta E2000 metric was calculated for each beverage-media combination.

The correlations made comparing the unexpanded and expanded visual ranks for the new samples as a function of Delta E2000 D_{min} are also summarized in Table V. Results were again consistent with what was obtained for the origi-

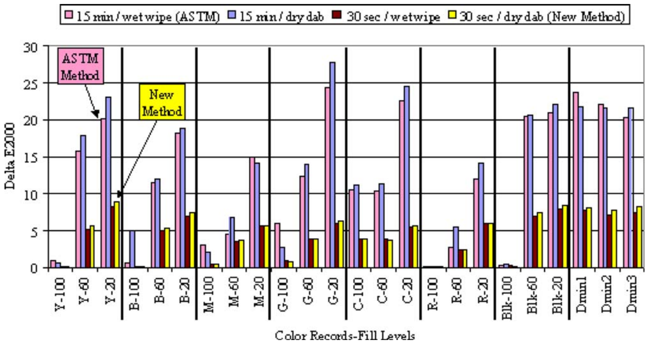

Figure 5. Stain severity as a function of treatment time and removal methods.

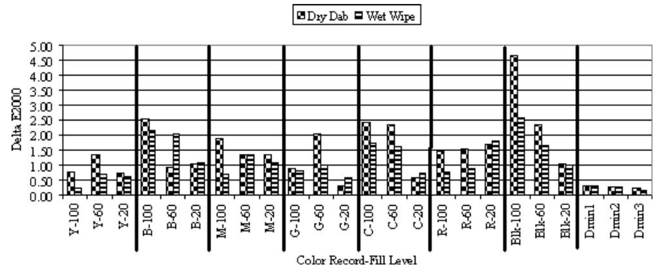

Figure 6. Removal method using yogurt smoothie as staining agent.

nal samples, whereby better correlations with the Delta E2000 metric were obtained when the visual ranking scale was expanded to 0–5. Because Media C (swellable) became tacky when wet, similar levels of staining for all beverages were obtained, resulting in the correlation values being quite low. When media variations exhibited little to no staining (see Table III; Media H), no correlation could be made between the visual rank and the Delta E2000 metric. Because of this, correlations made between the visual ranking and the Delta E2000 metric will be limited to media that are porous and span a wider range of stain severity as a function of beverage.

The above-presented results for media A, D–G, and J confirmed the use of the expanded visual ranking scale obtained during the preliminary screen.

DETERMINATION OF PREFERRED METHOD FOR STAINING

In an effort to determine what the preferred method for staining would be, a 2×2 experiment was designed using red fruit punch as the staining agent with prints made using "Printer System A" (see Table I). The two variables investigated were treatment time (15 min-ASTM versus 30 s-new method) and removal methods (wet wipe-ASTM versus dry dab-new). Analysis involved collecting density and CIELAB values for all patches before and after staining using a Spectrolino SpectroScan[14] densitometer. A Delta E2000 was calculated based on the CIELAB differences before and after staining. The results from this experiment are illustrated in Figure 5 and conclusions are as follows.

The first observation was that the level of staining increased when the color density fill level decreased. This was true for all color records, and in most cases, the D_{min} patches where no colorant was present tended to show the largest amount of stain. For both removal methods, the longer treatment times (15 min) yielded significantly higher levels of staining across all color records and fill levels relative to the shorter treatment time (30 s).

When comparing removal methods, differences were seen only at the 15 min treatment time where the "wet wipe" tended to show slightly lower levels of staining relative to the "dry dab" method. One potential cause for this difference was that "wet wiping" of the stained target introduced water into the test method and removed more of the staining agent than when using the "dry dabbing" technique. Interestingly, at the 30 s treatment time, the removal method (wet wipe versus dry dab) had no impact on the amount of staining. For these reasons, it was decided to set the treatment time at 30 s and to use the dry dab method for the removal of excess staining agents from the surface of the prints.

One exception to using the dry dab method of removal was with problematic beverages such as milk-based products and juices with high pulp content. As previously mentioned, these beverages tended to leave a hazy film on the surface of the print, making it difficult to remove using the dry dab method. Because the removal method had no impact on the stain severity at the shorter treatment times, the wet-wipe removal method in theory could be used in this type of situation giving a more consistent result. In order to confirm this, a small experiment was done comparing the two removal methods, keeping the treatment time the same (30 s) and using the strawberry yogurt smoothie beverage as the staining agent. Prints were made using the new test target (Fig. 2) with the driver default settings for "Printer System A." The results from this study are illustrated in Figure 6.

As can be seen from Fig. 6, the results could be very different depending on which method of removal was used. The dry dab method tended to give higher results because the hazy residue could not be completely removed, whereas the wet wipe method did remove the film. Because of this, if problematic beverages were to be selected as staining agents, a stipulation for use of the wet wipe method of removal would need to be included in the final method proposal.

Another aspect of the test development was to determine what impact colorant fill level had on stain severity when using the Delta E2000 metric. Prints again were made using the new test target and the driver default settings for Printer System C (swellable) and Printer System D (porous). In an effort to see differences, red fruit punch (higher staining beverage) was selected as the staining agent. The treatment time was kept at 30 s and the dry dab method of removal was used. The Delta E2000 for each color patch-fill level combination was calculated from the CIELAB reads before and after staining, and the results summarized in Figure 7.

Generally speaking, when dealing with porous media, higher levels of stain were noted as the colorant fill level decreased with the highest level of stain occurring at D_{min}.

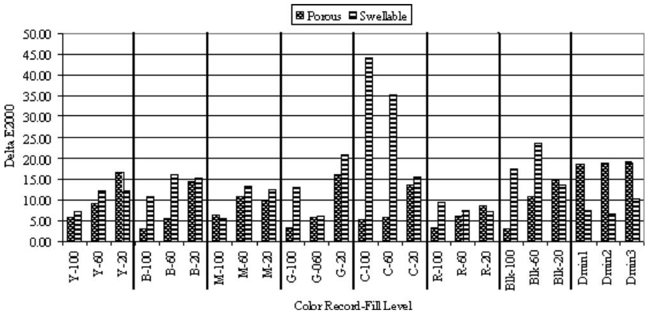

Figure 7. Delta E2000 comparisons as a function of fill level for porous and swellable media.

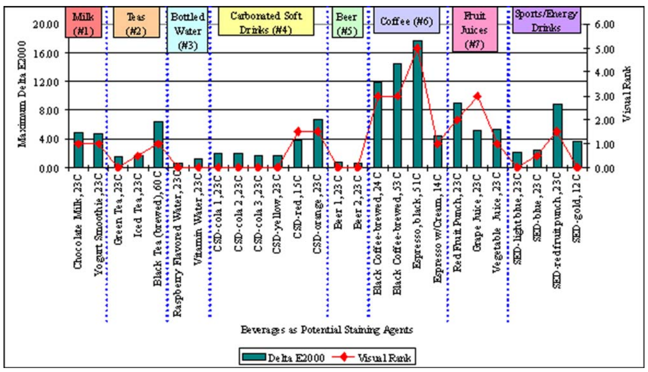

Figure 8. Maximum Delta E2000 as a function of beverage using Printer System A.

Interestingly, when dealing with swellable media, the trend was the opposite in that the media tended to become tacky when wet, causing the colorant to be removed from the media surface. Although this can be somewhat alleviated by use of the wet wipe removal method, further work is needed in the method development when dealing with swellable media.

The last phase of method development was to verify whether the Delta E2000 metric would be suitable for quantifying stain severity on printed images using the same beverages from the visual assessment study. Prints were made using the new test target (Fig. 2) for Printer System A and the default driver settings for that printer-media combination. All prints were allowed to dry at room temperature overnight. Each target was then read before staining using a Spectrolino SpectroScan densitometer, then two drops (0.10 mL) of every beverage (staining agent) were placed on each color patch, allowed to stand for 30 s, and any excess liquid was then blotted off using a dry paper towel. The targets were then allowed to dry at room temperature for 24 h before rereading, and a Delta E2000 was calculated for each color patch and recorded. The maximum Delta E2000 across all color patches was determined for each beverage and the results plotted (see Figure 8).

The results from this study both confirmed observations made during the preliminary screen using the unprinted media and further validated the use of Delta E2000 as a metric for quantifying stain severity.

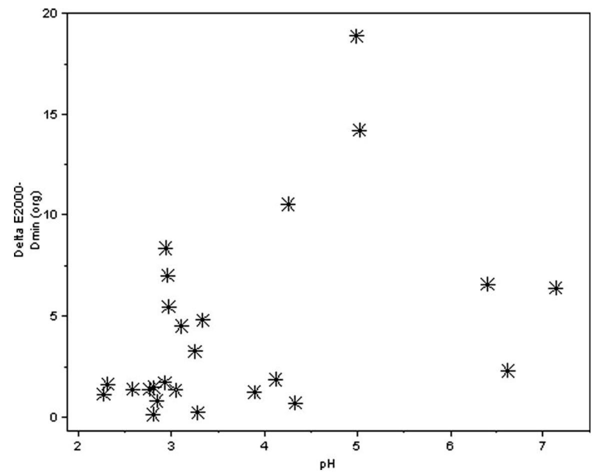

Figure 9. Bivariate fit of beverage pH and Delta E2000 D_{min} for Media A.

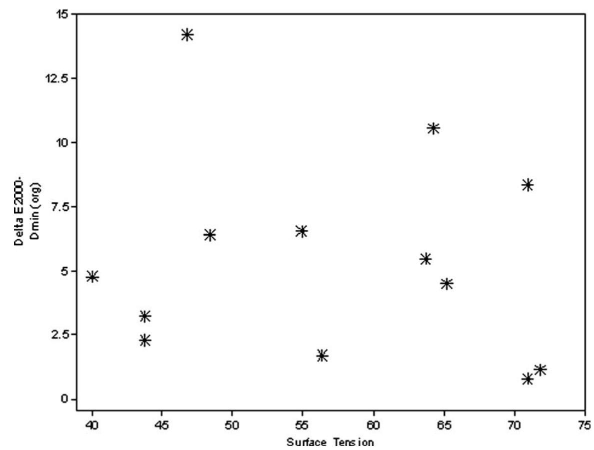

Figure 10. Bivariate fit of beverage surface tension and Delta E2000 D_{min} for Media A.

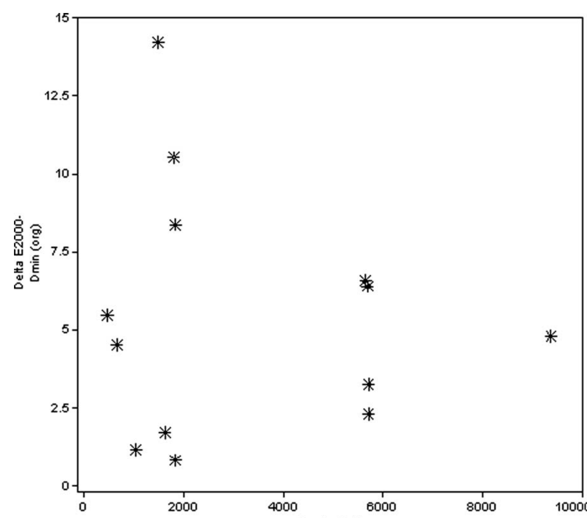

Figure 11. Bivariate fit of beverage conductivity and Delta E2000 D_{min} for Media A.

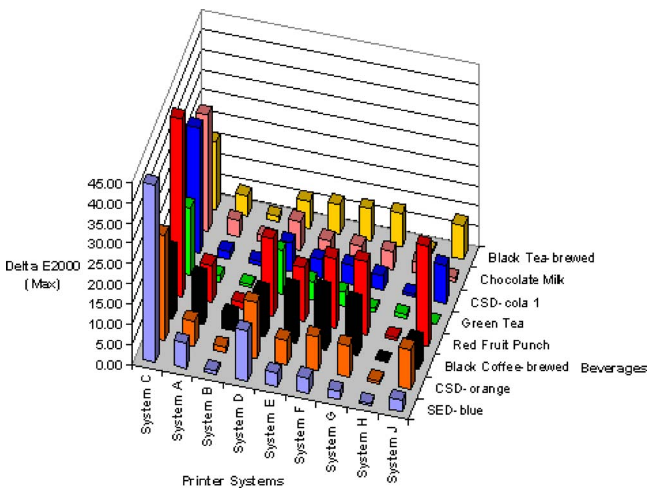

Figure 12. Stain severity as a function of beverage-printer system combination.

Before a subset of beverages could be recommended for use in the final test method, it was of interest to see whether a correlation could be made between stain severity and one or more physical properties of the beverages. The physical properties initially considered included pH[15] (acidity), surface tension[16] (wetting characteristics), and conductivity[17] (electrical conductance). Correlation plots of the Delta E2000 D_{min} obtained from the visual assessment study of prints made with Printer System A as a function of these physical properties were made (Figures 9–11).

From these results, no correlation was present between the Delta E2000 D_{min} metric and the three physical properties investigated. Because of this, the final beverage selection for the scope of this article was based solely on stain severity. Beverages selected for the final method validation that spanned the range of stain severity included: chocolate milk, green tea, black tea (brewed), CSD-cola 1, CSD-orange, black coffee (brewed), red fruit punch, and SED-blue sports drink.

METHOD VALIDATION AND RESULTS

The last segment needed to complete the test development was to apply the subset of beverages selected earlier, and evaluate them across additional ink jet, thermal, and silver halide printer systems. All beverages were allowed to equilibrate to room temperature (23°C) before beginning the experiment. The maximum Delta E2000 was calculated for each beverage-printer system combination, and the results are summarized in Figure 12.

From these results, one can see that a wide range of stain severity was achieved across all printer system-beverage combinations. Printer System C exhibited the highest level of stain independent of beverage type, whereas Print Systems B and H showed the lowest levels of stain. Generally speaking, highly colored beverages such as coffee, red fruit punch, or highly colored CSDs showed more staining than the green tea (very little color). Interestingly, although the SED-blue beverage is not highly colored, several systems showed fairly high Delta E2000 values caused by color changes that occurred with some of the color records when treated. The beverages that span the range of severity as well as represent those most commonly found in consumers' homes were: black coffee (brewed), red fruit punch, CSD-orange and SED-blue.

FINAL METHOD PROPOSAL

Based on the work presented, the final method proposed for staining of printed images is as follows: The proposed target consisted of colored patches (2.0 mm in diameter) of C, M, Y, K, R, G, B at three fill levels (100%, 60%, and 20%) and three patches of D_{min}. All patches must be separated to prevent cross contamination. The target would then be printed using driver default settings for the printer system of interest and the final print allowed to dry for a minimum of 24 h before staining.

Beverages that were selected as staining agents include: black coffee (brewed), red fruit punch, CSD-orange and SED-blue. These beverages were found to span the range of stain severity and represent those most commonly found in consumers' homes.

The preferred method of applying the staining agent is as follows: two drops (0.10 mL) of each staining agent is placed at the center of each patch, allowed to stand for 30 s, then blotted off using a dry paper towel.

Data collection and method of analysis: the density and CIELAB data were measured for each color patch before and after staining using a Spectrolino and a Delta E2000 was calculated. The stain severity reported for a given printer system should include the maximum Delta E2000 across all patches and corresponding color record.

CONCLUSIONS AND FUTURE WORK

With the shift to printing digitally captured photographs in consumers' households, determination of print durability as part of the overall print permanence has become extremely important. Several factors that contribute to print quality or image durability were discussed. In addition, literature searches uncovered very few internationally accepted methods of analysis that could quantify the numerous factors that contribute to print or image degradation.

This article discussed preliminary steps taken toward developing a more robust procedure for stain resistance caused by accidental spills of common household beverages. Marketing studies identified top beverage categories currently consumed worldwide. Method selection was based on the ability to differentiate between unwanted staining of images and water damage. The preferred method to date involves printing a target containing color patches at three density fill levels, placing two drops (0.10 mL) of a staining agent at the center of each patch for 30 s, then blotting off using a dry paper towel. The level of staining present was determined by calculation of the maximum Delta E2000 from CIELAB reads before and after staining across all color patches. Preliminary work attempting to correlate stain severity with pH, surface tension, and conductivity showed no trends. Additional work is planned to implement a "voice of the customer" study that will aid in determining what Delta E2000 values represent acceptable versus unacceptable levels of print staining to consumers.

The preferred beverages of choice that spanned the range of stain severity and covered beverages most commonly found in consumers' homes were: black coffee (brewed), red fruit punch, CSD-orange, and SED-blue. Initial attempts to correlate stain severity as a function of beverage colorants (dyes), showed that beverages containing either Red 40 and/or Blue 1 dyes showed higher levels of staining. One exception to this was SED-light blue, which contained both dyes, and showed little to no staining on most media variations. Future work is planned to try to understand these differences. Once this is determined, a recommendation would be made to better describe the CSD and SED categories for use in an international standard.

The preferred method of removal for problematic beverages such as milk or juice with pulp was determined to be a wet wipe. Although these beverages will not be considered as staining agents, this work gave additional insight on what removal method could be used for solid substances such as peanut butter.

Future work is planned that will describe further method development to include use of these substances. Additional work is also planned to better quantify stain severity when printing with swellable media.

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[13] K. Lawrence, D. Cigna, W. Brattlie, D. Erdtmann, and J. LaBarca, "Stain resistance as part of image permanence for consumer digital ink jet and thermal imaging systems", *Proc. NIP23 and Digital Fabrication* (IS&T, Springfield, VA, 2007) pp. 721–725. For the scope of this and future articles, all beverages used as staining agents will be identified generically.

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

[15] Corning Pinnacle 530 pH meter.

[16] Kruss Static Surface Tensiometer, model K10ST measured in units of dynes/cm.

[17] VWR Conductivity meter measured in units of microsiemens per centimeter.