12-1997

The Effect of Antioxidant Addition on Lightfastness of Color Ink Jet Printing

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THE EFFECT OF ANTIOXIDANT ADDITION ON LIGHTFASTNESS OF COLOR INK JET PRINTING

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A Thesis submitted
in partial fulfillment of
the course requirements for
The Bachelor of Science Degree

Western Michigan University

Kalamazoo, Michigan

December 1997

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ABSTRACT:

Fluorescent office lighting has been shown to fade ink jet colors. Fading of ink jet dyes is a problem when the shelf life of documents is important. For effective, low cost ink jet printing, the color quality of the printed paper must be maintained for a duration of time. Research in hot melt adhesives has shown a reduction of color loss associated with the use of antioxidants.

During this thesis, a coating formulation was tested with and without an antioxidant present. The antioxidants tested were alpha tocopherol / vitamin E, and sodium thiosulfate. The addition rate was varied at 2.65 % and 5.17 % to determine which addition rate was required to produce the best color fastness.

Coated paper samples were printed with a color test pattern utilizing the primary colors: red, yellow, blue and black.. The paper samples, printed with the test pattern, were analyzed with the brightimeter to determine their initial color values (L, a, b) and brightness.

The samples were aged using an accelerated aging device, the fade-ometer, to test the ability of the antioxidants to resist fading under fluorescence. It has been determined that the duration of 12 hours of 500 W/m^2 is equivalent to one month of sunlight in Michigan in the month of June. The fade-ometer times were chosen to be 12, 24 and 36 hours of exposure representative of 1, 2 and 3 months of normal exposure. The L, a, b values of the samples were measured after each aging period. To determine the ability of the antioxidant to reduce color loss, all brightimeter values of each antioxidant coating were compared against all brightimeter values of the non-antioxidant coating.

Both the basesheet and the coated sheets, after aging, were tested for brightness, and color difference (L, a, and b). The results were compared to determine the surface effects of the coating on the substrate during time. Also, the results were compared to determine which antioxidant level minimizes color loss.

The importance of this project was to determine the extent of color loss that is prevented by the use of antioxidants. Color ink jet printing must have the ability to resist color loss for a duration of time.

Color fastness of the paper is important and should be maintained for a duration of time. Improved color fastness was shown to exist in paper samples coated with a low level of antioxidant. Both antioxidants, vitamin E and sodium thiosulfate, decreased the color loss associated with accelerated aging conditions in the fade-ometer.

INTRODUCTION:

Ink jet printing is a non-impact means of printing. Small droplets of ink are sprayed onto the paper surface at a very high velocity. The printer, ink and substrate form a printing system. As these components are varied, ink jet quality will change (2).

Color ink jet printing aims to produce a product which resembles photographic quality at a considerably lower cost. With ink jet printing on the rise, the interactions within the printing system (printer, paper and ink) need to be evaluated (4). One interaction that proves to be a problem is the inability of the dyes to resist fading (1).

The light fastness of the paper is a function of the light fastness of the dye being used (5). Light fastness is the ability of a dye to resist color fading when exposed to light. The brightimeter is a color measuring device that measures the light reflected from the sample and the results are completely objective. The results are given in three variables, the L , a, and b values. The "L" value gives the darkness of the paper sample. As the "L" value increases, the color lightens and fades. The "a" value represents a change in color from red (+a) to green (-a). As the "a" value decreases, the paper color changes from red to green. Also the red color fades as the "a" value decreases. In addition, the "b" value represents a change in color from yellow (+b) to blue (-b). As the "b" value decreases, the paper color changes from yellow to blue. Also, the yellow color fades as the "b" value decreases (6).

Fluorescent office lighting has been shown to fade ink jet colors. Fading of ink jet dyes is a problem when the shelf-life of documents is important. For effective, low cost ink jet printing, the color quality of the printed paper must be maintained for a duration of time.

Research in hot melt adhesives (lines of glue) has shown a reduction of color loss associated with the addition of antioxidants. During this thesis, coating formulations were tested with and without an antioxidant present to determine the ability of the antioxidant to reduce color loss associated with ink jet printing. The two antioxidants tested were vitamin E and sodium thiosulfate. The addition rate of the antioxidant was varied to determine its affect on color fastness. The addition rates tested were low and high addition levels, 2.65 % and 5.17 %, respectively.

Ink jet substrates fade when exposed to fluorescent lighting because of the chemical reactions that take place between the two mediums. The fluorescent rays energize the ink jet dyes and cause them to be oxidized. Oxidization occurs because of a transfer of electrons during a reaction. Since the dyes react with the light source, they lose electrons and begin to break down. As the dyes break down, the color the dye can reflect diminishes and color loss is prevalent. Antioxidant agents function to reduce the rate of oxidization of a medium by chemically reacting with the substrate (14). The antioxidants chosen were vitamin E and sodium thiosulfate.

BACKGROUND:

According to Jaffe, Luttman and Crooks (5), the light fastness of any dye does not immediately affect the color capabilities of an ink, but the long range potential of the color can be severely restricted. Any dye that is considered for an ink should have sufficient archival properties to sustain an image after exposure to light. Archival properties of paper are important for the consumer to know; therefore, the correct paper will be chosen to give an effective product (5).

According to Lyne and Aspler (3), the substrate plays an important role in determining the image quality in ink jet printing. The substrate must be able to absorb the ink quickly to avoid image smearing and multiple droplet splattering. The papers function is to accept the ink, prevent spreading of the ink drop, and help dry the ink (2).

Multiple droplet splattering results in improper color mixing and a feathering of ink being transferred to the paper. The ink penetration is a function of the paper. Inks should be deposited near the paper surface to maximize the color density and minimize color show through. Paper should have a hydrophilic, highly porous surface if it is to absorb the ink droplets quickly without ink spreading, wicking or color show through (3).

Antioxidants have been shown to produce substrates that when printed with multi-color inks produce a lightfast image (7 & 8). These coating formulations typically consist of a water expansible colloidal clay, silica, and a water insoluble synthetic binder.

According to Pollart, Schubring and Spalding (7), the coating should consist of 100 parts by weight of a pigment composed of 70 to 90 parts by weight of a water-expansible colloidal clay of a montmorillonite type and 10 to 30 parts by weight of a finely divided silica having a surface area of at least 250 m2/g and an oil absorption value greater than about 175 g/100 g and 5 to 20 parts by weight of a water insoluble synthetic resin binder (7).

Pollart, Schubring and Spalding (7) tested eleven different coating formulations. The eleventh coating formulation was shown to have the best printing and writing qualities. Therefore, this formulation was chosen to be used for this thesis. The formulation consists of 75 point bentonite clay, 25 point fine silica, and 10 point styrene-butadiene copolymer latex.

The coating formulation was tested with the presence of an antioxidant and without an antioxidant to determine the effect of the antioxidant on light fastness. It is expected that the presence of the antioxidant will reduce the color loss due to accelerated aging.

The antioxidants tested were alpha tocopherol / vitamin E and sodium thiosulfate. Vitamin E has been shown to prevent oxidative degradation when applied to extrusion coating polymers (12). Also, vitamin E was chosen because it is an FDA approved substance. Therefore, use in food packaging would be permissible. In addition to vitamin E, sodium thiosulfate was also tested due to its cost effectiveness compared to vitamin E.

Color loss of ink jet printing exists during both natural ultraviolet light exposure (typical office setting) and accelerated exposure. A correlation between natural and accelerated conditions is necessary before the two can be compared. It was found that 12 hours of 500 W/m^2 exposure is equivalent to one month of radiation by the sun in Michigan in the month of June. Therefore, the fade-ometer was set for 12 hours of 500W/m^2 per fading time (9). According to Greifzu, R. (10), during accelerated testing the variables are intensified so as to speed up reactions which occur slowly under normal conditions.

Accelerated conditions aim to reach a more rapid conclusion as to the properties being tested. It is essential that the physical processes which occur during accelerated testing are the same as those which occur under normal conditions.

The importance of this thesis is to produce a coated ink jet substrate that will provide a high quality product when used in multi-colored ink jet printers. The future of ink jet printing relies on its ability to produce a quality product which is resistant to color loss for the duration of time specified.

OBJECTIVES:

Fluorescent lighting has been shown to fade color ink jet papers. In this thesis, four objectives were attempted:

1) Determine the degree of color loss associated with a known coating formulation for ink jet papers under accelerated aging conditions.

2) Determine if the addition of either antioxidant to the known coating formulation reduces the color loss associated with accelerated aging conditions.

3) If the antioxidant is shows to reduce color loss, determination of the degree of color steadfastness.

4) Determine which addition rate produces the best color fastness.

METHODOLOGY:

Five coating formulations were made, two with the presence of vitamin E, two with the presence of sodium thiosulfate and one without. Each antioxidant formulation were tested at two different addition rate, a low rate and a high rate, 2.65 % and 5.17 % respectively. Table 1 shows the formulation makeup for all the coating colors produced.

Table 1. Formulation Makeup					
	Control	Vit E low	Vit E high	Sod Th low	Sod Th high
Clay	68.20%	66.40%	64.70%	66.40%	64.70%
Silica	22.70%	22.10%	21.60%	22.10%	21.60%
SBR	9.10%	8.85%	8.53%	8.85%	8.53%
Vit E	0	2.65%	5.17%	0	0
Sod Th	0	0	0	2.65%	5.17%

The paper samples were coated with coating using draw down coating techniques. The coat weight for each sample was approximately 6.5 g/m². The paper samples from each formulation were analyzed using the brightimeter to determine their initial color difference and brightness. The samples were then aged using the fade-ometer at 500 W/m² for 12 hours at 62° C. After the samples were aged for 12 hours, their 12 hour color difference and brightness readings were taken. The samples were aged again for 12 hours at 500 W/m² and retested for color difference and brightness. This procedure was repeated to collect data for 0 time, 12 hours, 24 hours and 36 hours.

The manipulated variables were addition rate, and antioxidants. The controlled variables were coat weight and the control formulation, without antioxidant present. The paper properties that were tested included: brightness(TAPPI 452), and color difference (L, a and b values).

The purpose of the brightness measurements is to determine the brightness of white, or near-white of paper. Brightness is a commonly used term for the numerical value of the reflectance factor of a sample with respect to blue light. The brightness is tested at directional reflectance of 457nm (13).

The Hunter L, a, b scale is a system for specifying how one sample diffes in color from another. A perfect white has a "L" value of 100, while a perfect black has an "L" value of zero. A plus value of "a" indicates redness and a minus value, greenness. A plus value for "b" indicates yellowness and a minus value, blueness. Since most color work involves matching one sample to another, the quantity of interest is usually the color difference between two samples, one of which is taken to be the standard. In the L, a, b color system, the total color difference between a standard and a sample can be computed with the following equation:

The goal in color matching is to reduce the E to as small as possible(6).

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

Flow charts of the experimental design follow:

Figure 1. Control

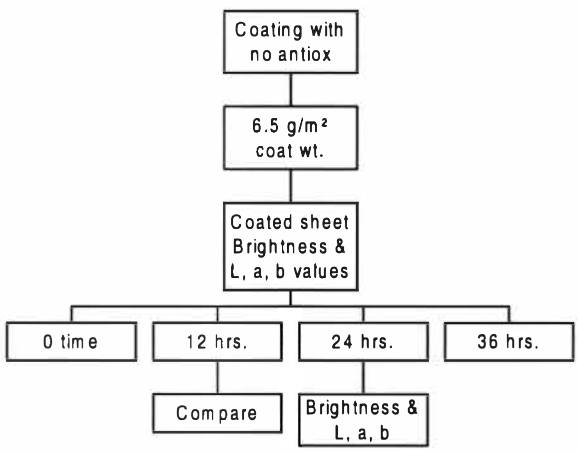
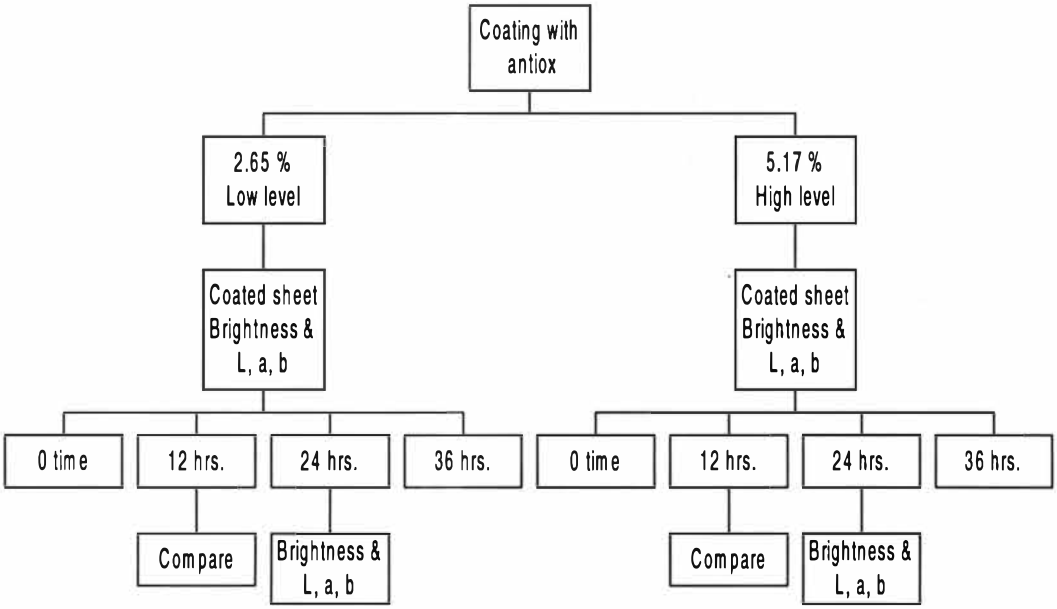


Figure 2. Antioxidant



EQUIPMENT:

For this thesis, the use of many materials was needed. The fade-ometer in the pilot plant was utilized for the accelerated testing. A rod for draw down coating methods was utilized. The brightimeter in the pilot plant paper testing lab will be utilized to analyze the color loss and brightness of all samples.

BUDGET:

Fade-ometer	Available in Paper Testing lab
Paper	Funded by Pilot Plant
Printer	Available in Pilot Plant
Brightimeter	Available in testing lab
Coating Supplies:	
Bentonite Clay	Donated
Silica	Donated
SBR latex	Donated
Vitamin E	$10
Sodium Thiosulfate	Donated

FUNDING:

Rod for draw down coating	Loaned from Fort James
Printer	Department Funded / 6 hours
Brightimeter	Department Funded / 6 hours
Coating Supplies	Donations
Paper Testing	10 – 20 hrs., personal time

RESULTS:

Tables 1 through 5 are the results collected during this experiment. Although, the standard deviations are not shown in the following graphs, the entire data sheet with standard deviations is attached in Appendix II. Graphs 1 through 3 give graphical representation of this experiment, and can be found imbedded in the discussion section of this report.

Table. 1 Control sheet					
Sample	Control				
Color	Time	L	a	b	Brightness
Red	0	36.0	54.2	14.2	8.4
Yellow	0	79.8	-8.3	47.7	13.1
Blue	0	22.6	19.2	-65.8	22.6
Black	0	14.5	0.3	0.8	2.0
Basesheet	0	84.9	-0.7	2.1	65.0
Color	Time	L	a	b	Brightness
Red	12	41.6	47.4	15.3	8.4
Yellow	12	79.2	-7.5	43.8	13.1
Blue	12	24.2	10.7	-46.6	22.6
Black	12	14.2	0.4	0.8	2.0
Basesheet	12	84.8	-1.1	6.3	65.0
Color	Time	L	a	b	Brightness
Red	24	46.2	41.0	15.0	11.4
Yellow	24	79.4	-6.0	40.7	17.0
Blue	24	27.8	6.0	-34.6	21.8
Black	24	17.2	0.0	0.4	2.9
Basesheet	24	83.5	-1.0	7.5	61.6
Color	Time	L	a	b	Brightness
Red	36	49.1	37.9	16.0	13.1
Yellow	36	79.7	-7.5	38.5	19.7
Blue	36	27.5	5.5	-32.1	20.4
Black	36	14.3	0.1	0.8	2.0
Basesheet	36	82.5	-1.4	8.5	58.8

Table 2. Vitamin E high level					
Sample	Vit E				
Color	Time	L	a	b	Brightness
Red	0	35.8	54.5	14.2	5.7
Yellow	0	79.5	-8.1	47.6	8.8
Blue	0	22.6	18.8	-65.4	27.3
Black	0	14.5	0.3	0.8	2.1
Basesheet	0	85.7	-0.7	2.4	71.0
Color	Time	L	a	b	Brightness
Red	12	40.9	46.9	14.5	8.4
Yellow	12	78.8	-7.1	43.8	12.7
Blue	12	24.2	10.3	-46.4	22.6
Black	12	14.3	0.3	0.6	2.0
Basesheet	12	84.2	-1.2	6.1	64.4
Color	Time	L	a	b	Brightness
Red	24	44.9	42.5	14.6	10.8
Yellow	24	78.9	-5.6	41.2	16.0
Blue	24	27.8	5.7	-34.7	21.8
Black	24	17.2	0.1	0.3	2.9
Basesheet	24	83.3	-0.8	7.9	60.8
Color	Time	L	a	b	Brightness
Red	36	47.6	39.3	15.9	12.0
Yellow	36	79.0	-7.1	39.4	18.0
Blue	36	27.3	5.3	-31.9	20.4
Black	36	14.5	0.3	0.7	2.1
Basesheet	36	82.9	-1.4	9.2	58.7

Table 3. Vitamin E low level					
Sample	Vit E				
Color	Time	L	a	b	Brightness
Red	0	35.5	54.5	14.5	5.4
Yellow	0	79.6	-6.9	46.5	10.4
Blue	0	22.3	19.5	-65.6	27.0
Black	0	15.6	0.3	1.0	2.4
Basesheet	0	86.0	-0.8	2.7	71.2
Color	Time	L	a	b	Brightness
Red	12	40.7	49.1	15.5	7.7
Yellow	12	79.4	-6.0	43.2	14.0
Blue	12	24.0	11.0	-46.4	22.3
Black	12	15.5	0.3	0.9	2.3
Basesheet	12	84.9	-1.0	6.1	65.4
Color	Time	L	a	b	Brightness
Red	24	43.9	46.1	16.3	9.2
Yellow	24	79.4	-5.1	41.1	16.6
Blue	24	25.3	6.5	-38.8	20.9
Black	24	15.4	0.6	0.7	2.4
Basesheet	24	84.3	0.5	6.2	64.5
Color	Time	L	a	b	Brightness
Red	36	47.1	42.5	16.7	11.1
Yellow	36	79.8	-4.8	39.1	19.4
Blue	36	26.8	6.6	-33.0	20.3
Black	36	15.3	0.6	0.6	2.4
Basesheet	36	84.8	0.9	6.7	64.9

Table 4. Sodium Thio high level					
Sample	Sod Th				
Color	Time	L	a	b	Brightness
Red	0	35.7	54.7	14.0	5.8
Yellow	0	79.5	-7.5	47.0	9.5
Blue	0	22.4	19.1	-65.9	27.2
Black	0	15.5	0.3	1.1	2.3
Basesheet	0	85.8	-0.6	2.3	71.3
Color	Time	L	a	b	Brightness
Red	12	42.0	46.8	15.3	8.6
Yellow	12	79.2	-6.9	44.0	12.8
Blue	12	24.0	10.7	-47.4	22.6
Black	12	15.2	0.2	1.0	2.2
Basesheet	12	83.9	-1.3	6.0	63.9
Color	Time	L	a	b	Brightness
Red	24	46.6	40.4	15.4	11.5
Yellow	24	79.2	-5.6	41.2	16.2
Blue	24	27.6	6.1	-35.3	21.8
Black	24	17.7	0.2	0.4	3.0
Basesheet	24	84.3	-1.1	8.1	62.1
Color	Time	L	a	b	Brightness
Red	36	49.4	36.6	16.5	12.9
Yellow	36	79.3	-7.2	39.7	18.0
Blue	36	26.7	5.8	-32.5	19.9
Black	36	15.4	0.2	0.9	2.3
Basesheet	36	82.7	-1.6	8.9	58.6

Table 5. Sodium Thio low level					
Sample	Sod Th				
Color	Time	L	a	b	Brightness
Red	0	35.2	54.1	14.7	5.2
Yellow	0	79.7	-6.4	46.4	10.6
Blue	0	22.0	20.1	-65.7	26.6
Black	0	15.9	0.3	1.0	2.4
Basesheet	0	86.0	-0.8	2.7	71.2
Color	Time	L	a	b	Brightness
Red	12	41.5	47.3	16.1	7.8
Yellow	12	79.4	-6.1	43.1	14.2
Blue	12	23.6	12.0	-47.4	22.2
Black	12	15.7	0.4	0.9	2.4
Basesheet	12	84.8	-1.1	5.6	65.8
Color	Time	L	a	b	Brightness
Red	24	45.5	43.8	16.6	10.0
Yellow	24	79.6	-4.9	41.0	16.9
Blue	24	25.2	9.4	-39.2	21.0
Black	24	15.7	0.7	0.7	2.5
Basesheet	24	84.9	0.8	5.4	66.5
Color	Time	L	a	b	Brightness
Red	36	47.9	40.3	17.2	11.3
Yellow	36	79.7	-5.3	38.9	19.5
Blue	36	26.6	7.4	-33.5	20.2
Black	36	15.7	0.6	0.8	2.4
Basesheet	36	84.1	0.4	6.3	64.0

DISCUSSION:

The coated sheets are printed with the primary colors test pattern. A copy of the test pattern can be found in Appendix I. Once printed with the test pattern, the samples are placed in the fade-ometer which fades the sheets of paper. After the initial 12 hour exposure time, the sheet begins to yellow and the inks begin to fade. Once the sheets have been exposed to 36 hours in the fadeometer, the red and yellow colors fade and become washed out. The blue ink square fades to a darker blue color with time. The black ink square on the sheet shows minimal fading. The red ink square turns from a vibrant red to a washed out pink color, while the yellow ink square fades into a light yellow color. Also, the blue ink square fades in color from a medium blue to a dark blue.

Figure 1. Brightness of basesheet vs. Time

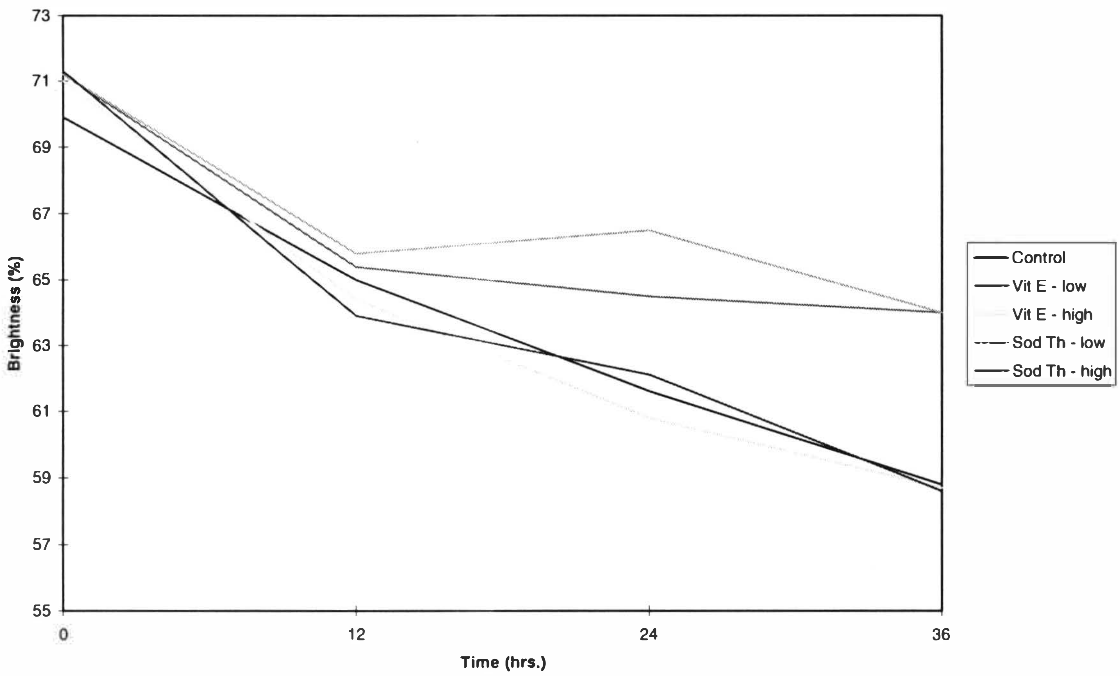
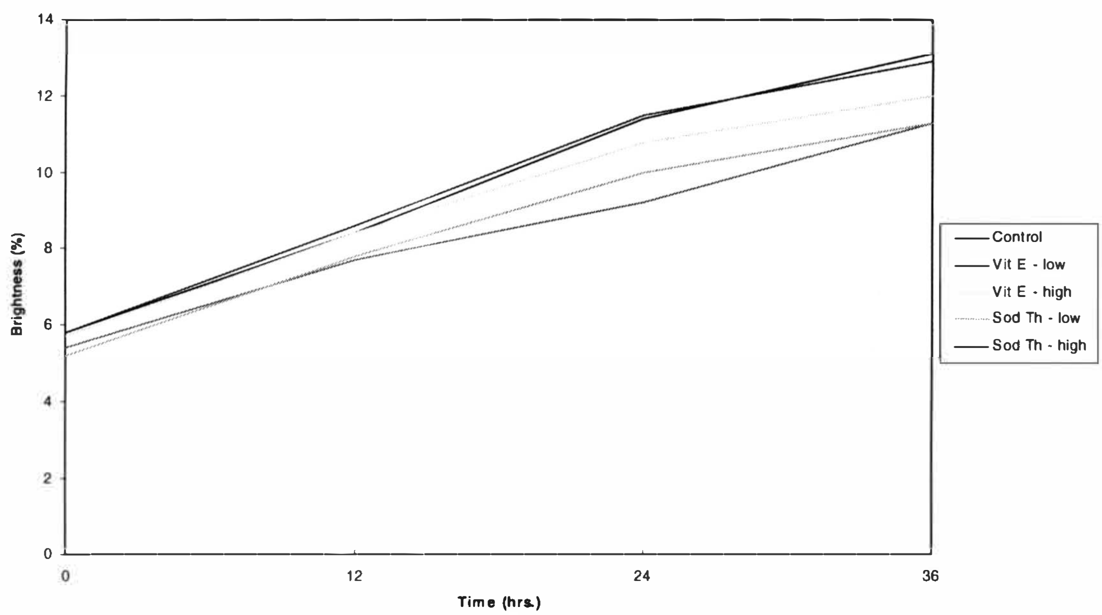


Figure 1 shows the effect of time on the basesheet's brightness. As the time in the fade-ometer increases, the basesheet starts to yellow. The brightness is shown to fade with increased time. Decreasing brightness can be explained because as the sheet becomes more yellow, the brightness decreases. Figure 1 graphically shows the least brightness loss occurs with the use of either antioxidant at low levels. Similar brightness losses are shown to occur with the use of antioxidants at high levels and the control without any antioxidant.

The ink brightness should increase with time. As the ink starts to fade, less color is available and more light is shown to come through the sample. Color fastness is determined by the inks ability to resist fading and small increases in brightness could occur. Therefore, the best color holdout would be shown with the samples that produced the smallest changes in brightness.

Figure 2a. Brightness (red) vs. Time



The results of brightness of red versus time is shown in Figure 2a. As the time increases, there are three formulations that shown minimal brightness change. The least brightness change is shown with low levels of vitamin E and sodium thiosulfate. Also, the high level of vitamin E has reasonable color fastness.

Figure 2b shows the effect of brightness on yellow versus time. The best color fastness is shown with the samples whose brightness changes the least over time. The high levels of sodium thiosulfate and vitamin E are shown to reduce brightness gain. The best color fastness for yellow is shown with high levels of an antioxidant present.

Figure 2b. Brightness (yellow) vs. Time

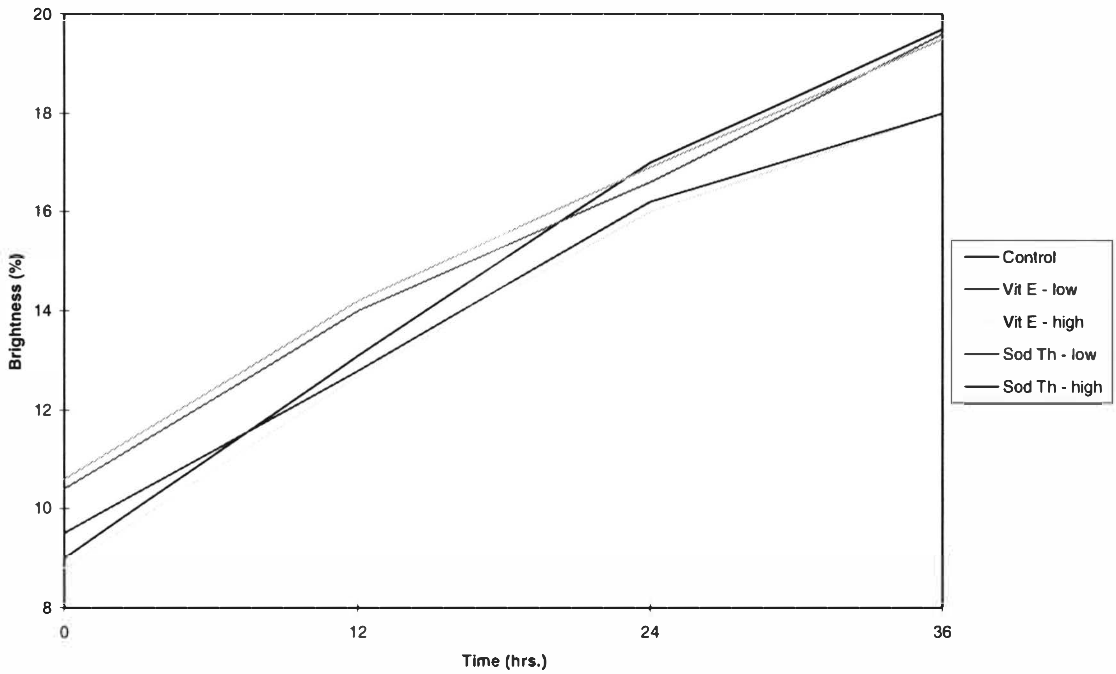
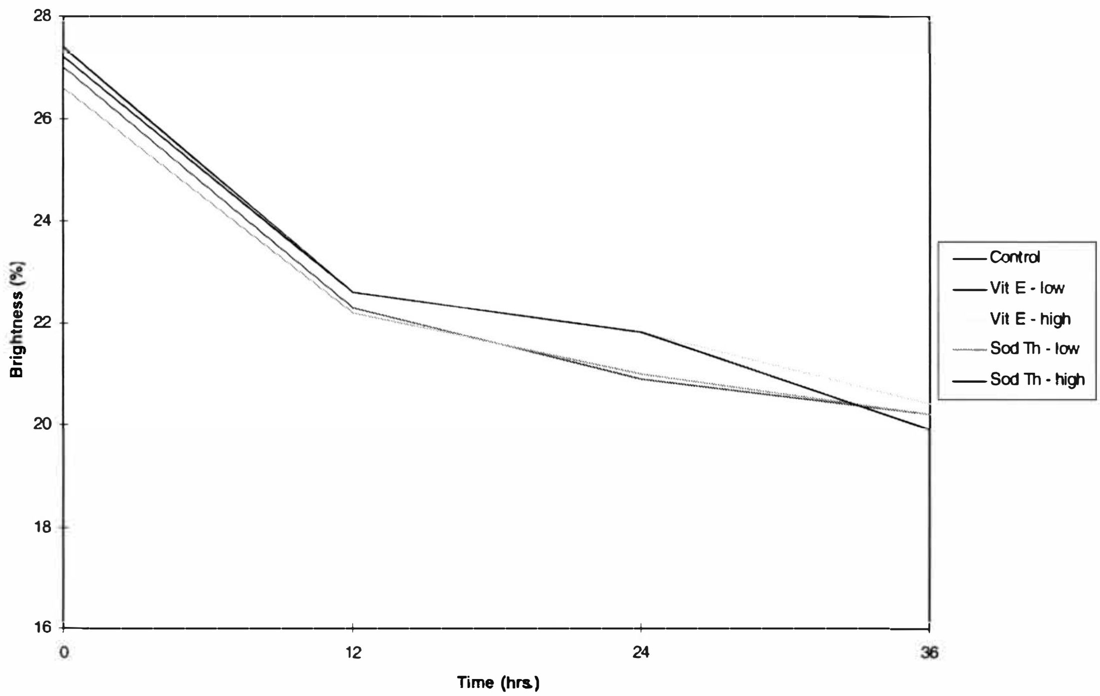


Figure 2c graphically presents the effect of brightness on blue versus time. The brightness of the color blue decreases as the time increases. All formulations are shown to behave similarly and only small differences between them can be determined. Vitamin E and sodium thiosulfate at high levels show slight improvement over the low levels of antioxidants and the control. This graph shows that all the formulations are similar.

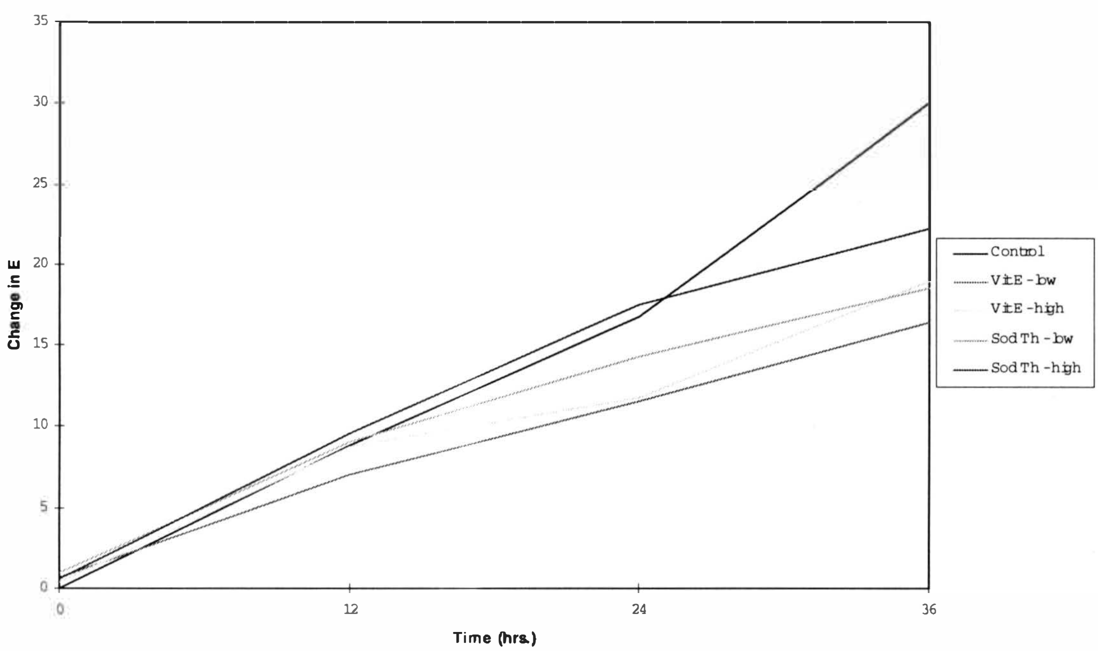
Figure 2c. Brightness (blue) vs. Time



As the sheet is exposed to increasing time in the fade-ometer, the "L" value of color difference increases as the color starts to fade and color loss occurs. Since the L value increases, color loss increases. The "a" value is an indication of the color change from red (+a) to green (-a). The "b" value is an indication of color change from yellow (+b) to blue (-b). Therefore to measure the amount of color steadfastness, the ink should be resistant to change over a duration of time. Since this experiment is dependent on the determination of the color difference between two samples, the ΔE color difference expression will be used. The standard color sample was the control, while the comparison sample was the sample tested.

Figure 3a shows as the time increases, the red color is shown to fade as indicated by the increase in the E value. All formulations with antioxidants are shown to improve the color stability of the red color over the control. The least amount of fading exists with vitamin E at both high and low levels and sodium thiosulfate at a low level. All four formulations are shown to improve the color fastness of the ink as compared to the control.

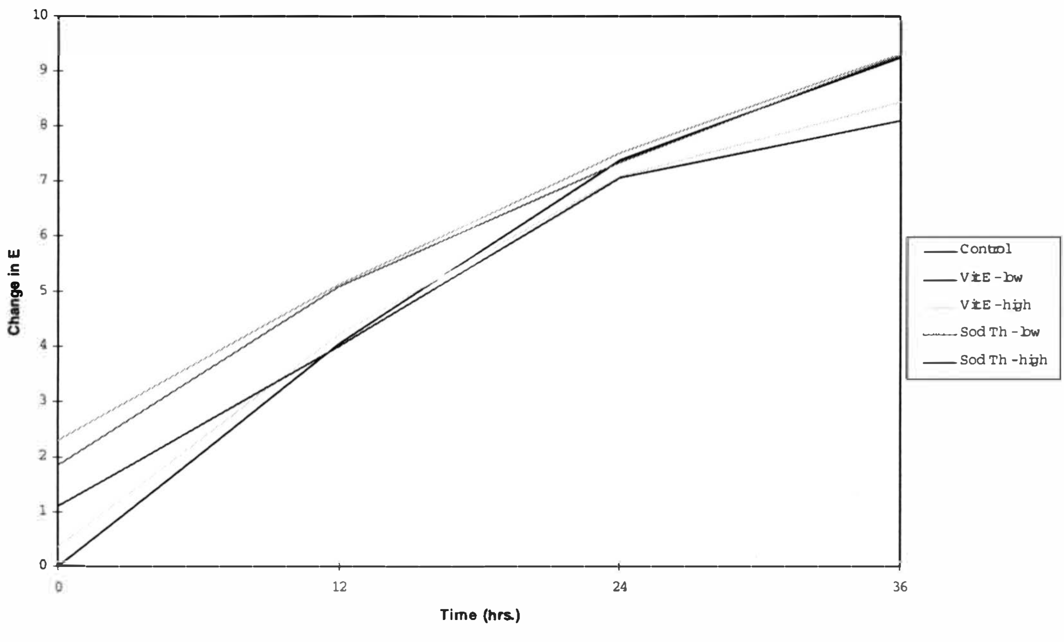
Figure 3a. E (red) vs. Time



Also, the yellow color is affected by an increase in time in the fade-ometer. The change in E values is also graphed for the color yellow. If no color loss were to occur, then the E value would not change and be a straight line. Since it is know that color loss occurred for all samples, the E value for all formulations will change. The least amount of color loss is shown from the samples that have the smallest changes in E values.

Figure 3b shows the effect of yellow E values versus time. As the time increases, the least amount of E change is shown in the two formulations which have the greatest amount of antioxidant. Both high level of vitamin E and high level of sodium thiosulfate show improved color stability over the low levels and the control. Therefore for the best color stability for yellow, a high level of antioxidant are needed.

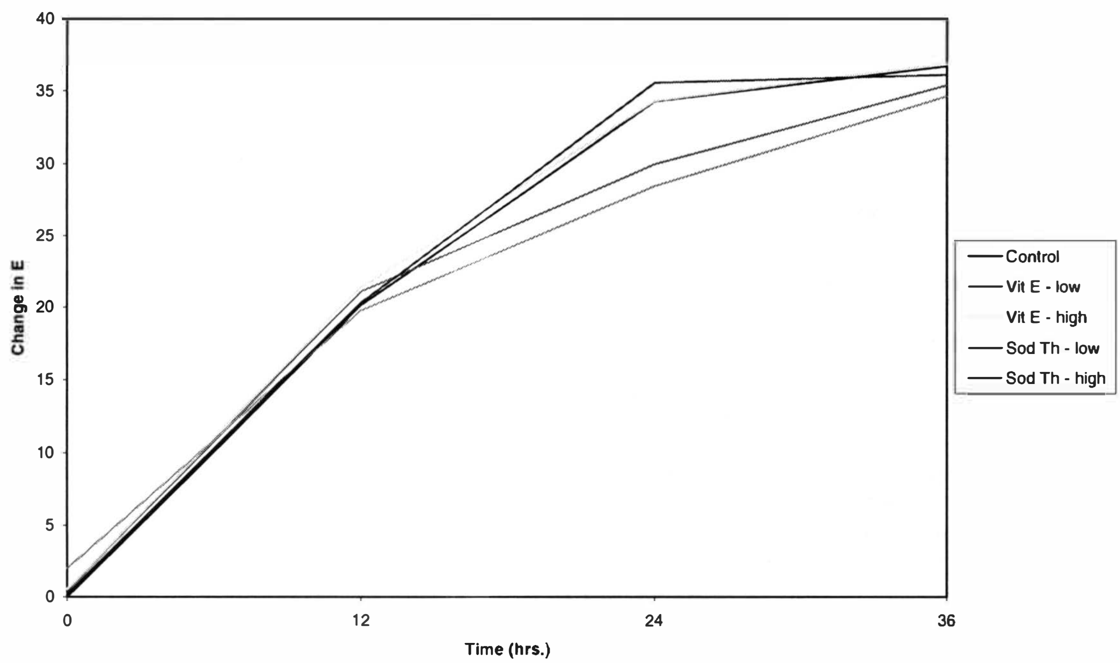
Figure 3b. E (yellow) vs. Time



Figures 3a and 3b have shown color stability to be achieved by the addition of an antioxidant in colors red and yellow. Also, the color stability of blue should be considered. As stated previously, the antioxidants' E value should be smaller than the control. The E value for black will not be compared. The reasons for not graphing black E values is because the color black did not change much in color over time. The initial values for black at zero time were very similar to the final values at 36 hours.

Figure 3c graphically presents the effect of E change of blue versus time. The best color stability is shown from the low addition levels of antioxidants. The figure shows the high levels of antioxidants to be similar to the control. This deviates from the expectation that an antioxidant improves the color stability of paper. It can be explained by experimental error.

Figure 3c. E (blue) vs. Time



CONCLUSIONS:

Graphical representation showed as the duration of time increased, the brightness of the basesheet decreased. The samples that resulted in the lowest changes in brightness, were the most color fast samples. The least change in brightness was shown to result in the two formulations with low levels of vitamin E and sodium thiosulfate present.

The brightness of the color red was affected by an increase in time. As the time increased, the brightness increased. The resulting brightness increase resulted from the fact that the color intensity decreased and the color faded. As the color faded, more light could penetrate through the sample. The color fastness of the paper is dependent on the paper resisting changes in brightness. The samples that showed the least amount of brightness increase was the low levels of sodium thiosulfate and vitamin E. Also, the high level of vitamin E was shown to have an improvement over the control. The brightness of the color yellow also increased with an increase in time. There were two samples that produced the least color loss; the high levels of both sodium thiosulfate and vitamin E. Both vitamin E and sodium thiosulfate (at high levels) allowed the oxidation rate of the dye to be decreased. This is evident by the ability of these two formulations to have smaller increases in brightness as compared to the control. The lightfastness of the color blue versus time reacted differently than yellow or red. During the intermediate time periods (12 to 30 hours), the low levels of both antioxidants were shown to help retain the intensity of the color. The longest duration of time resulted in most samples having a similar final brightness. With that said, low levels of antioxidant produce the most satisfactory color fastness during most of the duration of time.

The change in E value is defined as the amount the sample changes from the original value, control. The addition of antioxidants should improve the color stability of the samples and reduce the change in E. All coating formulations were shown to increase the color stability of the red color. Also, the addition an of antioxidant to a coating formulation was shown to improve the color fastness of the yellow color at all addition levels. The best color fastness was to shown for the color blue when the low levels of an antioxidant were added. For all color samples, color stability for antioxidants was increased over the control.

Color fastness of a paper is important and should be maintained for a duration of time. Improved color fastness was shown to exist in paper samples coated with a low level of an antioxidant. Both antioxidants, vitamin E and sodium thiosulfate, decreased the color loss associated with accelerated aging conditions in the fade-ometer.

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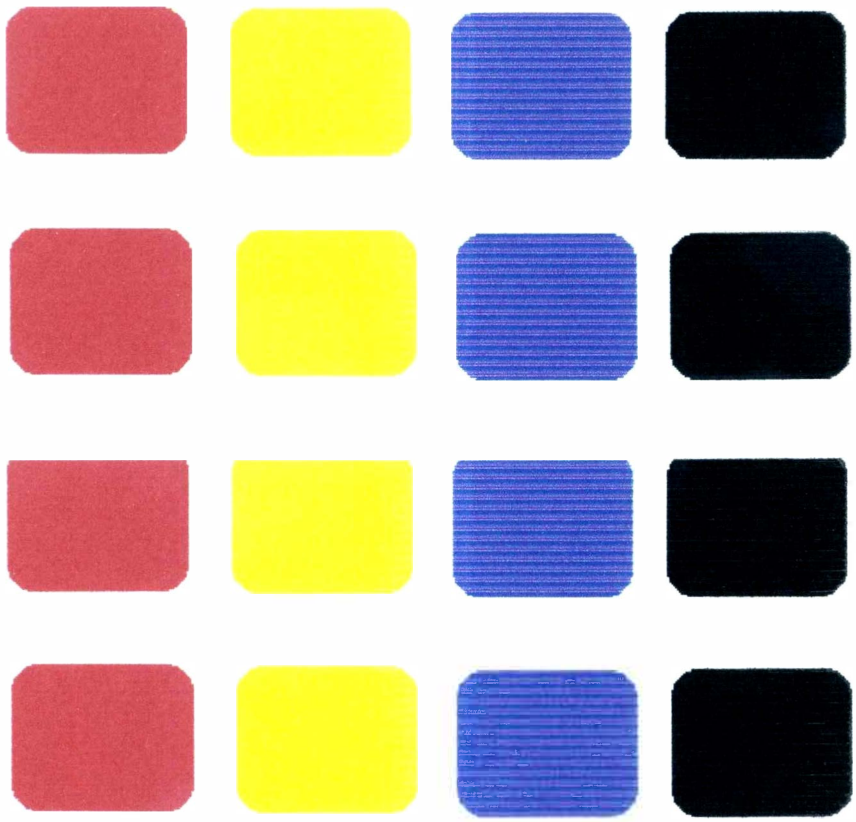
APPENDIX I

Primary Color Print Pattern



APPENDIX II

Raw data and standard deviations

Sample	Control								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	0	36.0	0.21	54.2	0.66	14.2	0.25	5.8	0.06
Yellow	0	79.8	0.23	-8.3	0.56	47.7	0.63	9.0	0.95
Blue	0	22.6	0.22	19.2	0.21	-65.8	0.46	27.4	0.20
Black	0	14.5	0.21	0.3	0.05	0.8	0.05	2.1	0.05
Basesheet	0	84.9		-0.7		2.1		69.9	

Sample	Control								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	12	41.6	0.22	47.4	0.57	15.3	0.21	8.4	0.12
Yellow	12	79.2	0.21	-7.5	0.37	43.8	0.40	13.1	0.69
Blue	12	24.2	0.20	10.7	0.25	-46.6	1.04	22.6	0.46
Black	12	14.2	0.20	0.4	0.14	0.8	0.09	2.0	0.04
Basesheet	12	84.8		-1.1		6.3		65.0	

Sample	Control								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	24	46.2	0.32	41.0	0.59	15.0	0.14	11.4	0.16
Yellow	24	79.4	0.32	-6.0	0.45	40.7	0.43	17.0	0.85
Blue	24	27.8	0.05	6.0	0.20	-34.6	0.97	21.8	0.46
Black	24	17.2	0.15	0.0	0.04	0.4	0.03	2.9	0.05
Basesheet	24	83.5		-1.02		7.51		61.57	

Sample	Control								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	36	49.1	0.12	37.9	0.59	16.0	0.14	13.1	0.16
Yellow	36	79.7	0.30	-7.5	0.29	38.5	0.61	19.7	1.02
Blue	36	27.5	0.17	5.5	0.04	-32.1	0.59	20.4	0.36
Black	36	14.3	0.22	0.1	0.13	0.8	0.06	2.0	0.06
Basesheet	36	82.5		-1.4		8.5		58.8	

Sample	Sodium Th high								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	0	35.7	0.29	54.7	0.31	14.0	0.18	5.8	0.14
Yellow	0	79.5	0.20	-7.5	0.17	47.0	0.60	9.5	0.36
Blue	0	22.4	0.21	19.1	0.24	-65.9	0.40	27.2	0.17
Black	0	15.5	0.19	0.3	0.21	1.1	0.02	2.3	0.07
Basesheet	0	85.8		-0.6		2.3		71.3	

Sample	Sodium Th high								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	12	42.0	0.13	46.8	0.33	15.3	0.12	8.6	0.10
Yellow	12	79.2	0.33	-6.9	0.16	44.0	0.36	12.8	0.38
Blue	12	24.0	0.23	10.7	0.16	-47.4	0.32	22.6	0.28
Black	12	15.2	0.42	0.2	0.29	1.0	0.14	2.2	0.13
Basesheet	12	83.9		-1.3		6.0		63.9	

Sample	Sodium Th high								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	24	46.6	0.25	40.4	0.45	15.4	0.09	11.5	0.17
Yellow	24	79.2	0.10	-5.6	0.16	41.2	0.08	16.2	0.11
Blue	24	27.6	0.10	6.1	0.13	-35.3	0.46	21.8	0.30
Black	24	17.7	0.16	0.2	0.04	0.4	0.01	3.0	0.05
Basesheet	24	84.3		-1.1		8.1		62.1	

Sample	Sodium Th high								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	36	49.4	0.36	36.6	0.41	16.5	0.08	12.9	0.25
Yellow	36	79.3	0.11	-7.2	0.09	39.7	0.13	18.0	0.13
Blue	36	26.7	0.23	5.8	0.17	-32.5	0.39	19.9	0.20
Black	36	15.4	0.31	0.2	0.07	0.9	0.09	2.3	0.08
Basesheet	36	82.7		-1.6		8.9		58.6	

Sample	Sodium Th low								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	0	35.2	0.11	54.1	0.24	14.7	0.24	5.2	0.16
Yellow	0	79.7	0.12	-6.4	0.20	46.4	0.46	10.6	0.51
Blue	0	22.0	0.32	20.1	0.30	-65.7	0.44	26.6	0.38
Black	0	15.9	0.33	0.3	0.13	1.0	0.12	2.4	0.08
Basesheet	0	86.0		-0.8		2.7		71.2	

Sample	Sodium Th low								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	12	41.5	0.36	47.3	0.49	16.1	0.08	7.8	0.21
Yellow	12	79.4	0.20	-6.1	0.16	43.1	0.16	14.2	0.17
Blue	12	23.6	0.37	12.0	0.22	-47.4	0.79	22.2	0.58
Black	12	15.7	0.15	0.4	0.06	0.9	0.05	2.4	0.05
Basesheet	12	84.8		-1.1		5.6		65.8	

Sample	Sodium Th low								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	24	45.5	0.38	43.8	0.49	16.6	0.27	10.0	0.18
Yellow	24	79.6	0.18	-4.9	0.26	41.0	0.40	16.9	0.49
Blue	24	25.2	0.64	9.4	0.15	-39.2	0.85	21.0	0.67
Black	24	15.7	0.12	0.7	0.15	0.7	0.02	2.5	0.04
Basesheet	24	84.9		0.8		5.4		66.5	

Sample	Sodium Th low								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	36	47.9	0.36	40.3	0.44	17.2	0.24	11.3	0.23
Yellow	36	79.7	0.24	-5.3	0.11	38.9	0.30	19.5	0.44
Blue	36	26.6	0.83	7.4	0.32	-33.5	1.06	20.2	0.72
Black	36	15.7	0.12	0.6	0.09	0.8	0.07	2.4	0.04
Basesheet	36	84.1		0.4		6.3		64.0	

Sample	Vitamin E high								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	0	35.8	0.12	54.5	0.20	14.2	0.25	5.7	0.09
Yellow	0	79.5	0.06	-8.1	0.18	47.6	0.24	8.8	0.30
Blue	0	22.6	0.10	18.8	0.11	-65.4	0.18	27.3	0.07
Black	0	14.5	0.30	0.3	0.09	0.8	0.08	2.1	0.07
Basesheet	0	85.7		-0.7		2.4		71.0	

Sample	Vitamin E high								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	12	40.9	0.17	46.9	2.51	14.5	0.24	8.4	0.08
Yellow	12	78.8	0.22	-7.1	0.15	43.8	0.29	12.7	0.25
Blue	12	24.2	0.20	10.3	0.11	-46.4	0.41	22.6	0.20
Black	12	14.3	0.37	0.3	0.06	0.6	0.05	2.0	0.10
Basesheet	12	84.2		-1.2		6.1		64.4	

Sample	Vitamin E high								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	24	44.9	0.19	42.5	0.06	14.6	0.24	10.8	0.07
Yellow	24	78.9	0.10	-5.6	0.05	41.2	0.19	16.0	0.24
Blue	24	27.8	0.29	5.7	0.11	-34.7	0.52	21.8	0.24
Black	24	17.2	0.29	0.1	0.16	0.3	0.09	2.9	0.09
Basesheet	24	83.3		-0.8		7.9		60.8	

Sample	Vitamin E high								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	36	47.6	0.28	39.3	0.35	15.9	0.20	12.0	0.15
Yellow	36	79.0	0.17	-7.1	0.09	39.4	0.17	18.0	0.13
Blue	36	27.3	0.43	5.3	0.18	-31.9	0.56	20.4	0.35
Black	36	14.5	0.39	0.3	0.10	0.7	0.09	2.1	0.09
Basesheet	36	82.9		-1.4		9.2		58.7	

Sample	Vitamin E low								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	0	35.5	0.13	54.5	0.49	14.5	0.26	5.4	0.19
Yellow	0	79.6	0.22	-6.9	0.41	46.5	1.15	10.4	1.29
Blue	0	22.3	0.59	19.5	0.50	-65.6	0.70	27.0	0.64
Black	0	15.6	0.33	0.3	0.09	1.0	0.11	2.4	0.10
Basesheet	0	86.0		-0.8		2.7		71.2	

Sample	Vitamin E low								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	12	40.7	0.30	49.1	0.58	15.5	0.29	7.7	0.31
Yellow	12	79.4	0.37	-6.0	0.37	43.2	0.94	14.0	1.35
Blue	12	24.0	0.85	11.0	0.31	-46.4	0.49	22.3	0.85
Black	12	15.5	0.09	0.3	0.03	0.9	0.05	2.3	0.02
Basesheet	12	84.9		-1.0		6.1		65.4	

Sample	Vitamin E low								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	24	43.9	0.37	46.1	0.52	16.3	0.16	9.2	0.24
Yellow	24	79.4	0.33	-5.1	0.22	41.1	1.12	16.6	1.54
Blue	24	25.3	0.79	6.5	4.11	-38.8	0.69	20.9	0.61
Black	24	15.4	0.18	0.6	0.11	0.7	0.05	2.4	0.05
Basesheet	24	84.3		0.5		6.2		64.5	

Sample	Vitamin E low								
Color	Time	L	St D - L	a	St D - a	b	St D - b	Brightness	St D - Bri
Red	36	47.1	0.36	40.3	0.44	17.2	0.24	11.3	0.23
Yellow	36	79.8	0.24	-5.3	0.11	38.9	0.30	19.5	0.44
Blue	36	26.8	0.83	7.4	0.32	-33.5	1.06	20.2	0.72
Black	36	15.3	0.12	0.6	0.09	0.8	0.07	2.4	0.04
Basesheet	36	84.8		0.4		6.3		64.0	