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Sponsor: Whirlpool Corporation

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Technical Matters

H. D. Merchant, Manager
Advance Dept.; Laundry Group
Whirlpool Corporation
Upton Drive
St. Joseph, Michigan 49085

Contractual Matters (thru OCA)

Defense Priority Rating: n/a

Assigned to: Textile Engineering (School/Laboratory)

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Date: 4/12/78

Project Title: Whirlpool Fellowship in Textile Engineering (Research Support Account) OtH

Project No: E-27-652

Project Director: Dr. Walter C. Carter

Sponsor: Whirlpool Corporation

Effective Termination Date: 12/10/77

Clearance of Accounting Charges: 12/10/77

Grant/Contract Closeout Actions Remaining:

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CA–4 (3/76)

THE EFFECTS OF BLEACHING VARIABLES ON THE SOILING AND SOIL REMOVAL CHARACTERISTICS OF COTTON FABRICS

A THESIS

Presented to

The Faculty of the Division of

Graduate Studies

by

Belinda Faye Johnson

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Textiles

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E-27-658
Final Rpt.

THE EFFECTS OF BLEACHING VARIABLES ON THE SOILING AND SOIL REMOVAL CHARACTERISTICS OF COTTON FABRICS

Approved:

Walter Carter, Chairman

David Brookstein

David Gentry

Date approved by Chairman: Nov. 28, 1977

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Finally, to my special friends whom I had to put second because of this goal but never complained, thanks.

DEDICATION

This thesis is dedicated to my parents, Benjamin and Ozelle Johnson who educated me in the technique of success, perserverance.

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SUMMARY

It has been shown that commercially produced soil cloth used to evaluate the performance of washing machines possesses large variations in amount of soil present on the cloth. These variations may be attributed to variations in the preparational process of bleaching that the cotton fabric is subjected to prior to soiling. Differences in bleaching may cause changes in electrostatic forces on the textile fabric or soil particles resulting in an ease or difficulty in soiling or soil removal. The variables in bleaching studied in this work are the concentration of bleaching agent, the time of bleaching, and the temperature of bleaching.

It was found that none of the variables affected the degree of soiling, but the degree of soil removal increased with an increase in the concentraiton of bleaching agent and the time of bleaching.

CHAPTER I

INTRODUCTION

Evaluating the cleaning ability of a commercial washing machine is of major importance to its manufacturer. The proper assessment is necessary to assure the production of an efficient product that will completely satisfy customers and overshadow competitors while being low in cost and high in energy savings.

The evaluation process for a typical washing machine is a complicated procedure because of the many variables which are involved through machine design and consumer use. Among the many factors that are taken into account when rating a washing machine is its agitator system-size, shape, stroke angle and stroke speed, fabric type - natural or synthetic, load size - small, medium, large, load composition - light-weight to heavy garments, load movement - rotational or back and forth, water temperature - cold, warm, hot, detergent type - phosphate or non-phosphate, and power consumption.

The Association of Home Appliance Manufacturers (AHAM) developed a standard performance evaluation or soil removal procedure for household washers. Its purpose is to standardize the testing method in order to eliminate misunderstanding between manufacturer and consumers. The method consists of attaching swatches of mass produced soil cloth to specified positions on individual garments that are washed in the test machine. An initial light reflectance (R_s) of each soil swatch is measured using a reflectometer before they are attached to the garments, and a second reflectance reading (R_w) is taken of the swatches after the wash cycle. The amount of soil removed by the washer is calculated by converting the reflectance change of the soil swatches to percent soil removed.[6]

Because the change in reflectance values of soil swatches does not have a linear relationship with the amount of soil removed, the Kubelka-Munk equations are used that relate reflectance to light scattering and absorbancy.[1] These equations are:

$$\frac{k}{s} = \frac{\left(1 - \frac{R}{100}\right)}{2\,\frac{R}{100}}$$

where: k = coefficient of absorbency
s = coefficient of light scattering
R = observed reflectance

$$\frac{\left(\frac{k}{s}\right)_s - \left(\frac{k}{s}\right)_w}{\left(\frac{k}{s}\right)_s - \left(\frac{k}{s}\right)_u} \times 100 = \%\ \text{soil removal}$$

where: s = soiled cloth
w = washed cloth
u = unsoiled cloth[6]

It can readily be seen that in using the AHAM procedure, the most important variable in soil removal evaluation is the soil cloth itself. The soil cloth is of such great importance because it is the amount of soil present on the soil cloth before laundering and the amount of soil present on the soil cloth after laundering that determines the performance rating of a washing machine. This fact leads to a closer look into the method of preparation of the soil cloth.

Commercially soiled cloth is made from lightweight 100% cotton fabric with carbon black of a specified fineness dispersed in oil applied to it. The method of application is by immersion of the fabric either in an aqueous dispersion of carbon black or an organic solvent dispersion of carbon black.[10] Before the cotton fabric is soiled, it is subjected to many other processes which are discussed below. These processes are all part of the preparation for soiling.

Unfinished cloth, as taken from the loom is greyish in color and contains a variety of impurities which must be removed. These include (1) impurities introduced in the sizing of the yarn before weaving; (2) "motes" or small particles of the cotton plant, i.e., bits of stem, leaves, and outside covering of the cotton seed; (3) the natural impurities occuring in the fiber such as oil and wax, pectose and pectin, proteins and simpler related nitrogen compounds, organic acids, mineral matter, and natural coloring matter.[13]

The first step in the finishing process consists of singeing or gassing the cloth to remove lint and loose threads by rapidly drawing the fabric over hot plates or through gas flames at about 1500 degrees Fahrenheit. Immediately after singeing, the cloth is immersed in an aqueous bath for desizing, commonly referred to as the quench bath. This process achieves the removal of starch by enzyme treatment at temperatures below 50 degrees Centigrade of dilute mineral acids such as sulphuric acid (H_2SO_4), or polyvinyl alcohol (PVA) with a surface active agent and an emulsifier. The fabric is allowed to remain in this quench bath for several hours under conditions necessary for the solubilization of size and washing. After washing, scouring takes place, which is carried out by either a continuous process or batchwise as in Kiers, to complete the removal of motes, sizing, waxes and other foreign materials. Scouring is accomplished by putting the fabric into a bath containing 4.0% sodium hydroxide (NaOH), a wetting agent and a chelating agent for one (1) hour at 212 degrees Fahrenheit. Following scouring, the fabric is thoroughly washed.[2]

The natural yellow color that the cotton fabric has is now removed by bleaching with hydrogen peroxide (H_2O_2) at high temperatures or sodium hypochlorite (NaCℓO) at low temperatures followed by a third washing and drying. The bleaching step in the preparation of cotton piece goods is very critical because the incidence of cotton fibir damage is most likely to occur at this point through the formation of oxycellulose. Complete control of the bleaching process is important to obtain a fabric whose coloring matter is destroyed by the bleaching agent while subjecting the cellulose fiber to minimum attack. Because of the importance of bleaching control, further consideration is now given to the effect of bleach on the chemical structure of cellulose.

Evidence determined through experimental analysis has shown the cellulose molecule to be a linear polymer consisting of β-glucose residues. The repeating unit in the cellulose molecule is the cellobiose unit, which connects the two glucose units as shown in Figure 1.[7]

In the oxidation process that takes place when cellulose is treated with a bleaching agent such as H_2O_2 or $NaC\ell O$, the cellulose molecule is attacked at carbons 2, 3, and 6, resulting in the formation of oxycellulose (Figure 2).[4] This attack also makes the molecule susceptible to cleavage of the oxygen-carbon 1 bond.

The presence of oxycellulose has been found to be detrimental to the uniform reception of certain dyes, when occuring in the least trace because the carboxyl group creates an unfavorable electrical situation or high negative charge, which repels the negatively charged dye anion and thus prevents the adsorption of the dye. For this reason, dyebaths must have high ionic strength or high electrolyte concentration to overcome the unfavorable electrical repulsion.[8]

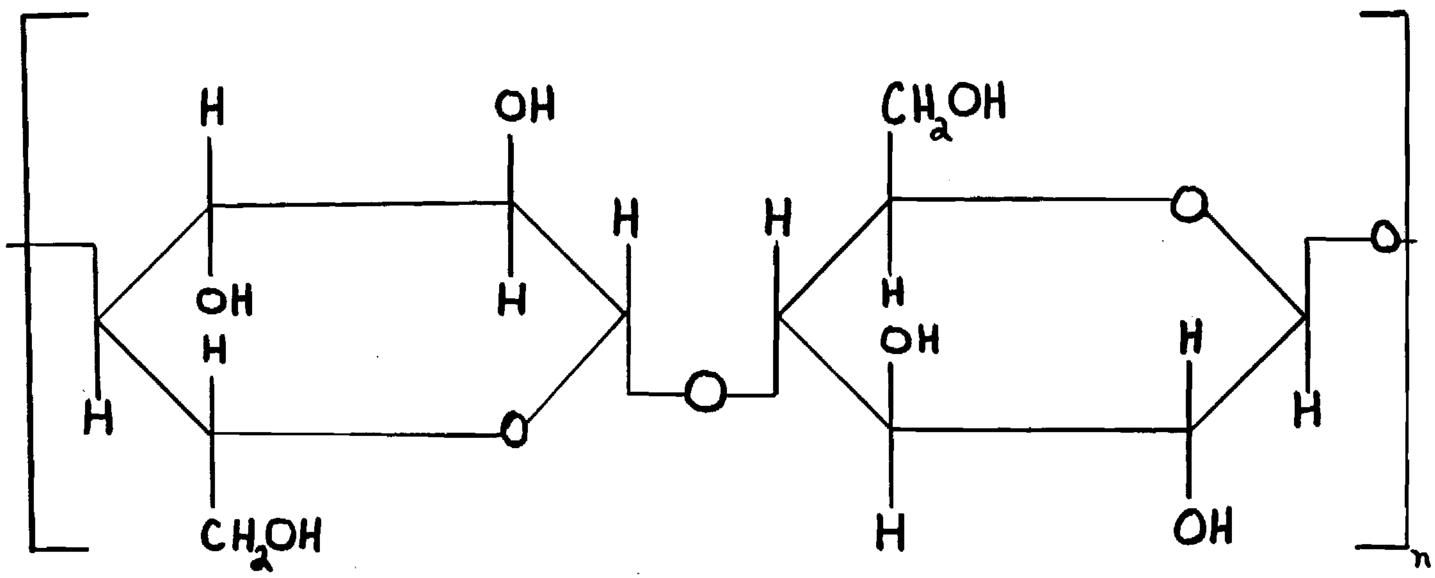

Figure 1. Cellobiose Repeating Unit

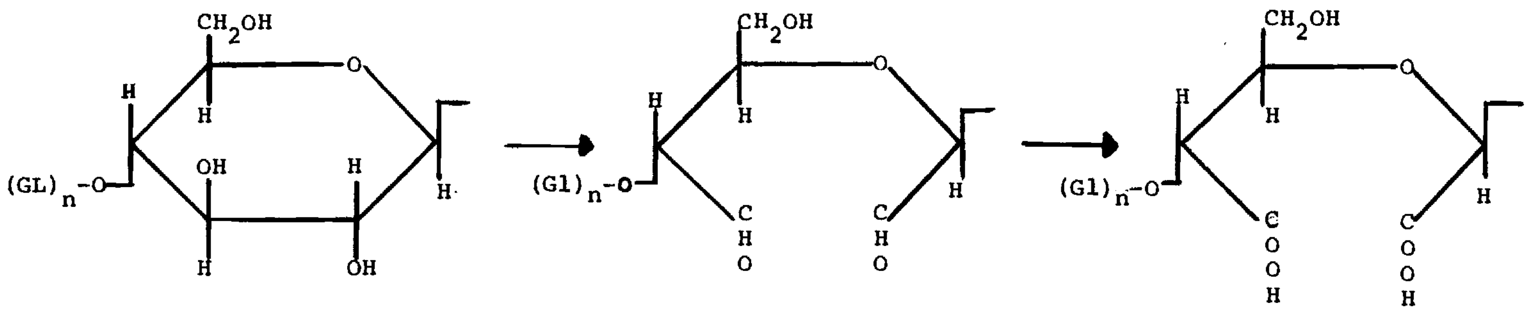

Figure 2. Oxidation Process

It is known that the number of carboxyl groups present in bleached cotton depends on the severity of the bleaching conditions. Thus it would be expected that the magnitude of the charge on the fiber will depend on the number of such groups.

The question now arises as to whether cotton bleached under varying conditions of severity, and accordingly having varying numbers of carboxyl groups, will be variable with respect to the amount of soil picked up in the soiling process of the soil cloth or the amount of soil released from the soil swatches in the washing evaluation test of the machine.

These possibilities lead to an examination of the bleaching process of standard soil cloth. The objective of this investigation is to determine to what extent bleaching conditions used in the preparation of cotton fabric affect its soiling and soil removal characteristics. The bleaching variables examined in this study are: (1) the concentration of the bleaching agent, (2) the time of bleaching and (3) the temperature of bleaching.

CHAPTER II

EQUIPMENT

Fabric

The cotton fabric used in this study was purchased from Testfabrics, Inc., Middlesex, New Jersey. The 80 x 80 plain weave fabric was scoured but unbleached. This cloth was chosen because it is similar in construction and state of finishing as used for commercial soil cloths.

Bleaching Agent

Sodium hypochlorite (NaCℓO) was used as the bleaching agent. It was obtained in the readily prepared form of Clorox bleach. The concentration of NaCℓO in Clorox bleach is 5.25%, corresponding to 5.00% "available chlorine".

The common bleaching agents used commercially are sodium or calcium hypochlorite or peroxy compounds. The most widely used peroxy compound is H_2O_2. NaCℓO was chosen for use in this study because it is more convenient to handle and more consistent in composition.[13] The results obtained by using either of the bleaching agents are identical.

Bleaching Apparatus

The bleaching process was carried out in a four-liter glass beaker placed inside of an eight-gallon stainless steel bucket. A gas burner was used to heat the bleach bath.

Diano Automate Reflectometer

All reflectance readings were made using the Diano/ LSCE Automatic System. Sample readings were made relative to a standard barium sulphate plate set to 100% reflectance.

Instron Tensile Tester

Tensile strength measurements were made on samples of the bleached fabric using the Instron Tensile Tester.

Chemical Tests

To investigate the degree of chemical damage caused by bleaching, two tests for carboxylic groups were made. (1) Turnbull's Blue Test using ferrous sulphate and potassium ferricyanide and (2) Methylene Blue Absorption using the cationic dye methylene blue.

Soiling Material

The soiling solution used was an Oil Dag mixture containing 1 mℓ Oil Dag (oil dispersion of graphite), 1 mℓ Wesson Oil, and 625 mℓ perchloroethylene.

Atlas Laboratory Wringer

The Atlas Laboratory Wringer was used to apply the soiling solution (Figure 3).

Drying Frame

To eliminate soil migration on the samples, a horizontal drying position was employed. The samples were dried on a wooden frame with nails driven through it to hold the soiled

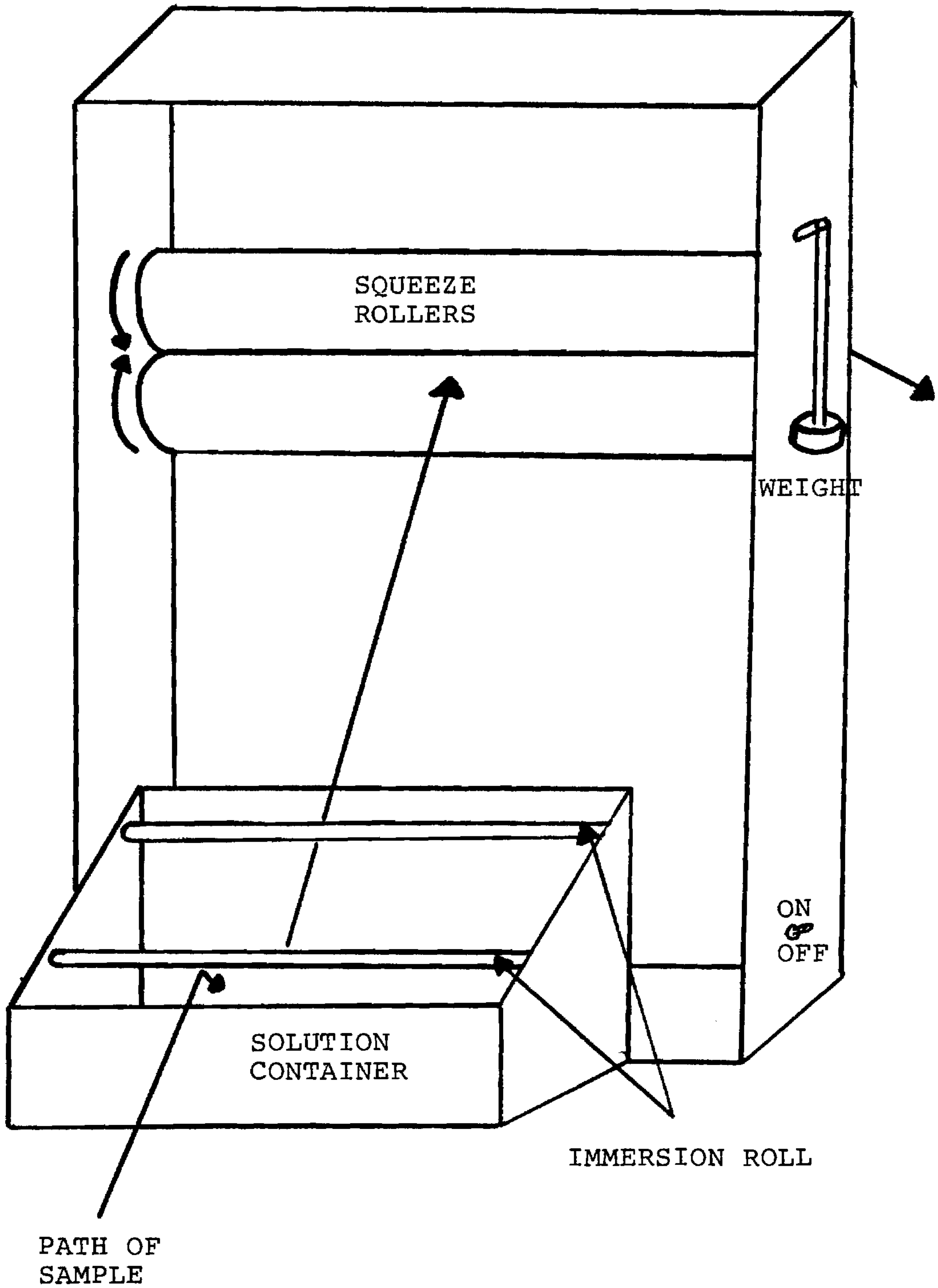

Figure 3. Atlas Laboratory Wringer

samples rigid (Figure 4).

Terg-O-Tometer

Laundering of the samples was done in the Terg-O-Tometer. The instrument is equipped with a temperature regulating control for the water and agitation rate control.

Detergent

The Standard American Home Appliance Manufacturers detergent was used for all laundering.

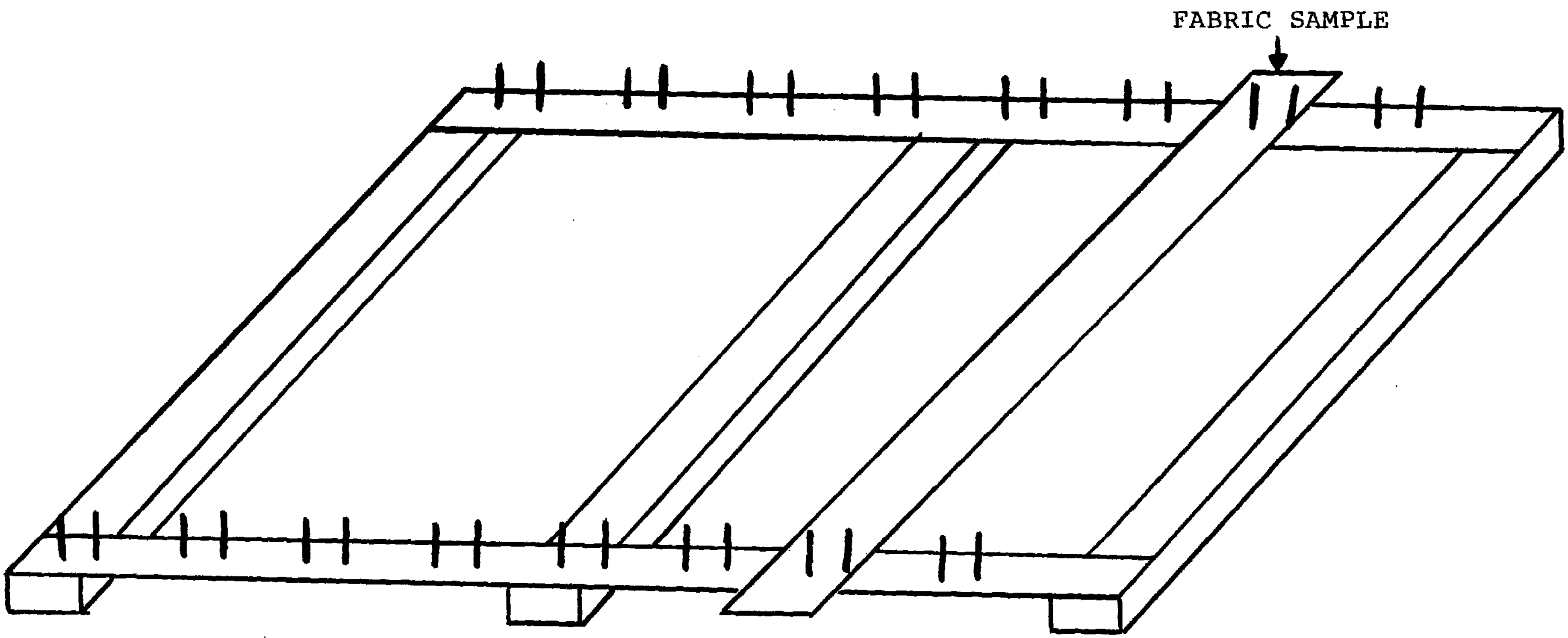

Figure 4. Drying Frame

CHAPTER III

EXPERIMENTAL PROCEDURE

Bleaching Variables

To obtain fabric bleached to different extents, but still within acceptable limits of whiteness, strength and water absorption, the bleaching conditions in Table 1 were used.

Table 1. Bleaching Variables

1. Concentration of Bleaching Agent - $NaC\ell O$ (g/ℓ):

   .050
   .100
   .200

2. Time of Bleaching - (hrs):

   0.5
   2.0

3. Temperature of Bleaching - (°F):

   80°
   105°

The 3x2x2 design of the experiment formed 12 different bleaching procedures. One replication of each bleaching process was made to determine the reproducibility of the experimental procedure, resulting in a total of 24 bleachings for the entire study. Table 2 lists each bleaching process, its experimental number and the order of bleaching.

Bleaching Method

The bleachings were done in a random order, all of which were carried out in a similar fashion, varying only the concentration of bleach, the time of bleaching, and the temperature of the bleach bath.

The weight of the fabric was 4.1 oz. per yard and a liquor to fiber ratio of 30:1 was established. The bleaching process was carried out in a glass beaker placed in a stainless steel bucket that was filled with enough water to keep the temperature of the bleach bath constant. The bucket was placed on top of a gas burner. After the water in the beaker reached the required temperature, the NaCℓO was poured into the water. The initial pH of the liquor is about 11.5, but usually falls during the bleaching below 9. To counteract this change in pH, the bleach bath was buffered between 10 to 11 by the addition of 5 grams per liter of sodium carbonate (Na_2CO_3).[12]

After sufficient stirring to evenly distribute the bleach and pH buffer, 1 yard of the cotton fabric was added to the bath and allowed to remain for the specified time. During the bleaching process, the fabric was agitated and temperature checked periodically.

Table 2. Bleaching Processes

Order of Bleaching	Experimental Number	Bleaching Condition: Conc. of NaOCℓ (g/ℓ)	Time (hr)	Temp. (°F)
15th	1	.050	.5	80°
21st	2	.100	.5	80°
2nd	3	.200	.5	80°
7th	4	.050	.5	105°
16th	5	.100	.5	105°
17th	6	.200	.5	105°
6th	7	.050	2.0	80°
5th	8	.100	2.0	80°
20th	9	.200	2.0	80°
1st	10	.050	2.0	105°
14th	11	.100	2.0	105°
4th	12	.200	2.0	105°
		REPLICATION		
12th	13	.050	.5	80°
18th	14	.100	.5	80°
19th	15	.200	.5	80°
10th	16	.050	.5	105°
22nd	17	.100	.5	105°
11th	18	.200	.5	105°
23rd	19	.050	2.0	80°
8th	20	.100	2.0	80°
9th	21	.200	2.0	80°
13th	22	.050	2.0	105°
3rd	23	.100	2.0	105°
24th	24	.200	2.0	105°

After sufficient stirring to evenly distribute the bleach and pH buffer, 1 yard of the cotton fabric was added to the bath and allowed to remain for the specified time. During the bleaching process, the fabric was agitated and temperature checked periodically.

After completion of bleaching, the fabric was removed from the bath and carried through a rinsing process that consisted of three 5 minute rinsings in 6 liters of H_2O at room temperature, one 10 minute rinse in 6 liters of H_2O with 0.5 grams per liter of sodium bisulfite ($NaHSO_3$) at room temperature, followed by one 5 minute rinse in 6 liters of H_2O at room temperature. The $NaHSO_3$ was added to the fourth rinse to function as an anti-chlor which would react with all remaining $NaC\ell O$.

The cloth was allowed to drip dry by hanging vertically on a clothes line.

Reflectance Readings of Bleached Samples

The bleached fabric was cut into five 5"x44" strips of cloth and numbered. Reflectance readings were taken using the Diano Automatic Reflectometer at five (5) different areas of each sample. The sample was folded in such a manner that a total of 8 layers of cloth were used for each reading to eliminate background variation. Table 3 shows the reflectance values of the bleached samples and Table 4 the k/s values of the Bleached Fabric sample.

Table 3. Reflectance Values of Bleached Fabric Samples

Experimental Number[1]	R_B^2 (%) Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
1	91.08	90.13	91.27	90.3	90.65	90.69
2	93.06	93.4	93.54	93.54	93.67	93.44
3	93.36	94.78	94.84	95.04	95.11	94.63
4	92.56	91.28	93.52	93.25	93.10	92.74
5	94.60	94.87	95.08	94.9	94.92	94.87
6	95.72	95.86	95.90	95.58	95.70	95.75
7	93.74	94.87	94.96	94.71	95.00	94.66
8	95.75	95.93	94.91	95.76	95.82	95.63
9	96.24	96.25	95.98	95.72	96.32	96.10
10	93.93	93.73	94.18	95.29	95.33	94.49
11	95.72	96.64	96.78	96.80	96.45	96.48
12	96.77	96.89	96.73	97.04	96.39	96.77
		REPLICATION				
13	91.14	91.53	91.60	91.26	91.69	91.44
14	94.15	94.08	93.35	93.71	94.0	93.86
15	94.56	94.88	94.74	94.14	94.66	94.60
16	93.66	92.80	92.95	93.64	93.14	93.24
17	95.79	95.65	95.7	95.4	94.91	95.69
18	95.34	95.44	95.16	95.46	95.62	95.4
19	93.82	93.90	93.85	93.84	93.98	93.88
20	94.72	95.14	93.06	95.18	94.93	94.61
21	95.23	95.41	94.3	95.4	95.27	95.12
22	95.64	94.43	95.40	95.48	95.58	95.31
23	96.86	96.67	95.65	96.94	96.79	96.58
24	96.74	96.33	96.72	96.72	96.82	96.67

[1]Refer to Table 2 for identification of experimental number.

[2]Each number represents the average of 5 reflectance measurements.

Table 4. k/s[1] Values of Bleached Fabric Samples

Experimental Number[2]	k/s[3]	Experimental Number[2]	k/s[3]
1	.0048	13	.0040
2	.0023	14	.0020
3	.0015	15	.0015
4	.0028	16	.0025
5	.0014	17	.0010
6	.0009	18	.0011
7	.0015	19	.0020
8	.0010	20	.0015
9	.0008	21	.0013
10	.0016	22	.0011
11	.0006	23	.0006
12	.0005	24	.0006

[1] $$k/s = \frac{1 - \left(\frac{R}{100}\right)^2}{2\left(\frac{R}{100}\right)}$$

[2] Refer to Table 2 for identification of experimental number.

[3] Each number is the k/s value of the average R_B value of 25 reflectance measurements.

Tensile Strength Test

Damage to the cotton fiber was determined by the ravelled strip tensile test, which was carried out using the Instron Tensile Tester. Five (5) strips in the warp direction and three (3) strips in the filling direction were tested. The results of this test can be seen in Table 5.

Chemical Damage Test

The degree of oxidation was assessed by carrying out the Methylene Blue Absorption test and Turnbull's Blue test. Both tests are used to detect the presence of carboxyl groups in chemically damaged cellulose.

The Methylene Blue test was carried out by placing 1" squares of each bleached fabric into a solution containing 0.175 grams per liter methylene blue and 2 grams per liter sodium borate at 70°C for 15 minutes followed by rinsing.

The Turnbull's Blue test was carried out by immersing 1" squares of each bleached fabric into a solution containing 10 grams ferrous sulfate per liter of H_2O at room temperature for 5 minutes followed by thorough washing with H_2O. They were then immersed in a solution containing 10 grams potassium ferricyanide per liter of H_2O at room temperature, followed by a wash in H_2O.

Soiling Procedure

The amount of soiling solution necessary for the soiling of all specimens was prepared initially. 250 mℓ of the soiling

Table 5. Tensile Strength Values

Experimental[1] Number	Warp Tensile Strength (lbs) Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
1	49.5	48.8	49.0	49.8	47.3	48.9
2	41.0	44.0	42.5	46.8	43.5	43.6
3	46.0	48.6	46.8	46.5	45.0	46.6
4	45.0	45.3	47.0	46.0	46.5	46.0
5	44.4	43.0	47.5	47.2	46.3	45.7
6	41.3	42.5	42.6	44.1	45.0	43.1
7	45.0	42.5	42.3	40.1	45.2	43.0
8	47.0	45.2	41.8	45.0	40.3	43.9
9	44.4	45.2	44.5	45.6	42.5	44.4
10	42.0	42.3	45.0	42.4	43.5	43.0
11	46.5	44.8	46.6	44.5	45.3	45.54
12	40.8	40.0	38.0	40.0	41.5	40.1
		REPLICATION				
13	43.5	47.0	45.4	44.8	45.0	45.14
14	46.8	42.0	43.0	40.5	48.0	44.06
15	46.0	44.0	46.1	49.0	47.1	46.44
16	42.0	48.0	46.0	48.1	48.0	46.4
17	33.0	49.6	45.0	44.8	44.1	43.3
18	47.5	48.0	50.0	50.8	49.5	49.16
19	51.5	51.4	46.2	49.8	48.7	49.5
20	48.5	49.8	50.5	46.0	45.7	48.1
21	44.5	48.5	47.8	48.8	46.6	47.2
22	51.2	49.0	48.5	47.0	51.5	49.4
23	48.0	49.0	45.5	48.1	48.5	47.8
24	47.2	48.5	51.1	48.0	48.2	48.6

[1]Refer to Table 2 for identification of experimental number.

Table 5. Tensile Strength Values (Continued)

Experimental[1] Number	Filling Tensile Strength (lbs) Sample 1	Sample 2	Sample 3	Average
1	36.5	36.5	38.1	37.0
2	36.4	40.5	42.5	39.8
3	36.5	38.0	39.0	37.8
4	37.5	37.0	34.0	36.2
5	37.0	32.5	37.5	35.7
6	35.5	40.2	37.5	37.7
7	31.6	32.5	33.5	32.5
8	28.5	30.1	31.2	29.9
9	30.8	35.5	34.5	33.6
10	36.0	35.3	33.0	34.8
11	39.9	39.5	38.4	39.3
12	32.5	30.8	29.8	31.0
	REPLICATION			
13	41.3	44.0	41.1	42.1
14	40.5	47.0	44.0	43.8
15	35.8	37.6	46.3	39.9
16	42.8	41.0	44.3	42.7
17	39.0	40.9	43.8	41.2
18	35.8	36.0	35.5	35.8
19	45.7	44.5	43.0	44.4
20	35.6	36.6	41.2	37.8
21	35.0	35.0	33.6	34.5
22	40.5	40.0	41.0	40.5
23	43.5	32.5	35.0	37.0
24	38.9	38.6	39.4	39.0

[1]Refer to Table 2 for identification of experimental number.

solution was poured into the solution container of the Atlas Laboratory Wringer. The fabric sample was inserted, numbered end first, under the raised immersion roll and then allowed to be gripped by the squeeze rollers. The immersion roll was lowered onto the fabric and soiling proceeded at a constant rate. The amount of nip force applied to the cloth through the squeeze rollers by the weight was 690.5 grams. After every soiling, 25 mℓ of the soil solution was added to the bath and stirred to keep it at a constant level.

After application of the soil solution, each sample was dried horizontally on the drying frame.

Reflectance Readings of Soiled Samples

Soiled samples reflectance readings (R_s) were taken at approximately the same places that the bleached samples reflectance readings were taken using the same method of folding and placement in color eye as done for bleached samples. Table 6 lists the R_s values and Table 7 the k/s values of the average R_s readings.

Laundering Procedure

Washing of samples was carried out using the Terg-O-Tometer method. Each sample was placed in a solution of 1.6 grams of Standard AHAM detergent per 1000 mℓ H_2O at 54°C and agitated for 10 minutes at 100 R.P.M. Samples were rinsed in 1000 mℓ H_2O for 5 minutes at 40°C and agitated at 100 R.P.M. Samples were squeezed, air dried in a horizontal position and pressed to eliminate wrinkles that could cause faulty reflectance

Table 6. Reflectance Values of Soiled Fabric Samples

Experimental Number[1]	R_s^2 (%) Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
1	42.47	42.31	42.24	42.54	43.53	42.62
2	44.26	44.0	43.96	42.98	42.96	43.63
3	43.91	43.29	43.70	43.73	44.00	43.73
4	43.59	43.4	43.26	43.69	44.12	43.61
5	44.11	44.89	44.94	44.52	44.69	43.63
6	43.55	43.69	44.47	44.55	42.24	43.70
7	43.58	43.25	43.23	43.28	43.95	43.46
8	44.24	42.92	44.02	43.46	43.38	43.60
9	43.89	43.30	43.09	43.92	43.13	43.47
10	43.6	43.84	43.62	43.92	44.6	43.92
11	44.25	44.62	44.26	43.54	43.56	44.05
12	43.47	43.58	43.86	43.90	43.72	43.69
			REPLICATION			
13	43.1	43.52	43.85	43.41	43.64	43.50
14	44.63	43.65	44.89	43.79	44.04	44.20
15	44.23	43.74	44.03	43.78	43.64	43.88
16	43.33	44.02	43.22	42.98	43.36	43.88
17	43.9	44.29	44.54	43.79	43.48	44.0
18	44.11	43.98	44.30	43.76	43.73	43.98
19	43.08	43.12	42.76	43.54	43.48	43.40
20	43.99	43.33	43.50	43.21	43.64	43.53
21	43.95	44.17	43.54	43.86	44.58	44.02
22	43.54	43.9	43.32	43.38	43.12	43.45
23	43.53	44.18	44.42	43.63	69.14	43.87
24	43.23	43.75	43.76	44.26	44.58	43.92

[1]Refer to Table 2 for identification of experimental number.

[2]Each number represents the average of 5 reflectance measurements.

Table 7. k/s[1] Values of Soiled Fabric Samples

Experimental[1] Number	k/s[3]	Experimental[2] Number	k/s[3]
1	.3863	13	.3669
2	.3642	14	.3522
3	.3620	15	.3589
4	.3646	16	.3695
5	.3435	17	.3564
6	.3627	18	.3569
8	.3678	19	.3691
8	.3648	20	.3663
9	.3676	21	.3559
10	.3580	22	.3680
11	.3553	23	.3591
12	.3629	24	.3580

[1] $k/s = \frac{\left(1-\frac{R}{100}\right)^2}{2\left(\frac{R}{100}\right)}$

[2] Refer to Table 2 for identification of experimental number.

[3] Each number is the k/s value of the average R_s value of 25 reflectance measurements.

readings.

Reflectance Readings of Washed Samples

Washed samples reflectance readings (R_w) are taken at approximately the same places that R_β and R_s readings were taken and in the same manner. Table 8 lists the R_w values and Table 9 the k/s values of the average R_w readings.

Table 8. Reflectance Values of Washed Fabric Samples

Experimental[1] Number	R_w^{2} (%) Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
1	64.48	64.91	64.18	63.41	63.76	64.15
2	67.5	67.15	66.75	65.63	65.52	66.51
3	67.62	69.16	70.23	68.53	69.15	68.94
4	65.02	66.51	66.92	65.32	66.86	66.13
5	69.24	68.04	68.57	68.33	68.16	68.47
6	68.87	69.13	70.03	67.8	69.22	69.01
7	66.63	66.62	66.15	67.06	68.10	66.91
8	66.91	68.49	66.49	68.58	69.14	67.92
9	70.65	68.64	68.92	68.88	67.60	68.94
10	67.38	67.42	67.63	66.28	66.0	66.94
11	69.30	70.59	69.26	69.59	69.40	69.63
12	71.38	70.92	69.96	71.17	69.57	70.6
		REPLICATION				
13	65.28	65.0	65.0	65.04	65.53	65.17
14	65.92	66.53	64.95	63.93	65.08	65.28
15	66.65	66.30	69.39	68.74	68.49	67.91
16	66.69	66.0	65.23	67.10	65.74	66.15
17	68.14	66.7	67.3	67.03	67.60	67.35
18	70.06	70.07	70.65	70.86	69.67	70.26
19	66.82	66.15	65.85	66.54	65.95	66.26
20	69.05	70.23	68.32	69.17	68.97	69.15
21	70.18	70.66	69.68	70.38	70.33	70.25
22	66.07	66.78	66.20	66.18	65.65	66.18
23	67.63	68.01	69.18	69.15	69.67	68.73
24	66.95	66.45	68.21	68.86	67.21	67.54

[1]Refer to Table 2 for identification of experimental number.

[2]Each number represents the average of 5 reflectance measurements.

Table 9. k/s[1] Values of Washed Fabric Samples

Experimental Number[2]	k/s[3]	Experimental Number[2]	k/s[3]
1	.1002	13	.0931
2	.0843	14	.0923
3	.0670	15	.0758
4	.0867	16	.0866
5	.0726	17	.0791
6	.0696	18	.0629
7	.0818	19	.0859
8	.0758	20	.0688
9	.0670	21	.0630
10	.0816	22	.0864
11	.0662	23	.0711
12	.0612	24	.0780

[1] $k/s = \dfrac{\left(1 - \frac{R}{100}\right)^2}{2\left(\frac{R}{100}\right)}$

[2] Refer to Table 2 for identification of experimental number.

[3] Each number is the k/s value of the average R_W value of 25 reflectance readings.

CHAPTER IV

DISCUSSION OF RESULTS

The effects of variables in bleaching on the soiling and soil removal characteristics of cotton fabrics was determined through reflectance measurement techniques and all conclusions were based on the statistical analysis of the measurements.

The amount of light reflected by a sample is influenced by numerous parameters such as sample properties, the illuminating light, illuminating orifice, surface texture of the sample, polarization and absorbance of the sample.[15] Although the human eye is the most adequate instrument with which to determine reflectance regardless of the properties of the sample, the impression received by the human brain cannot be converted into a physical value for evaluation. To get a physical value, a man-made instrument must be used, such as a reflectance spectrophotometer and colorimeter. The spectrophotometer is a double beam instrument having a sphere geometry that alternately compares the sample to a standard such as white barium sulphate ($BaSO_4$) which uniformly reflects light at all wavelengths. The spectrophotometer gives as output a graph that breaks up the reflected light from the sample as a function of wavelength and the colorimeter provides the measurement of X, X', Y, Z (red, green and blue) trichromatic values.[3] The results obtained are expressed as percentage reflectance as compared with the reflectance of barium sulphate. The Y value, also referred to as the lightness-darkness characteristics of the sample, was used for the determination of soil pickup and soil removal.

Because of the many variables that could be introduced through fabric construction that would have an effect on the reflectance of the sample, every effort was made to take the reflectance measurements after each bleaching, soiling and washing procedure at the same place on each sample. This qualifies the ruling out of differences in soil pickup and soil release that could be attributed to the geometrical properties of yarns and fibers, such as yarn crimp, yarn size and yarn twist.

For each of the 12 bleaching conditions, 25 reflectance measurements were taken on the fabric samples after the three respective experimental procedures of bleaching, soiling, and washing. The values obtained were analyzed for differences within and between the 12 conditions of bleaching.

A statistical analysis of the average tensile strength values in Table 10 indicated that none of the variables of bleaching or combination of variables caused a significant difference in breaking strength in the warp or filling direction of the fabric at a 95 per cent confidence interval.

Evaluation of the chemical test results was made through a visual examination of the amount of stain produced by the test reagent. In the Methylene Blue test, cellulosic fibers

Table 10. Average Tensile Strength of Bleached Fabric Samples for Each Bleaching Variable

Bleaching Variables	Warp	Filling
Concentration of Bleaching Agent - NaCℓO(g/ℓ)	Pounds	Pounds
.050	46.42	38.78
.100	45.26	38.06
.200	45.70	36.16
Time of Bleaching (hr.)		
0.5	45.71	39.14
2.0	45.88	36.19
Temperature of Bleaching (°F)		
80°	45.90	37.76
105°	45.68	37.56

containing oxycellulose stain heavier than normal and in the Turnbull's Blue test, the portions of the fiber which contain carboxylic groups show up blue.[4] The visual analysis of the test results in this study showed no substantial difference in chemical damage by altering the bleaching processes.

The analysis of variance of the average reflectance values for the 24 bleachings, Table 11, proved the effects of each of the variables, concentration of bleaching agent, time of bleaching, and temperature of bleaching, made a significant difference in the whiteness of the cotton fabric at the 95 per cent confidence interval, along with the combination effect of concentration and time. Variability within each bleaching process was minimal because the standard deviations ranged from a low of .20 to a high of .91, as seen in Table 12.

From this analysis, it is concluded that the tensile strength and fiber chemical structure of the 12 fabrics that had been carried through the 12 different bleaching processes were not severely damaged or damaged to any varying degree. The only difference in the fabrics that could be found by varying the bleaching processes was in degrees of whiteness. As each variable was increased, a whiter fabric was produced without an appreciable altering of its mechanical or chemical properties.

This fact gave conclusive evidence that at the time of soiling, the fabrics differed only in degree of whiteness,

Table 11. Average Reflectance Values of Bleached Fabric Samples for Each Bleaching Variable

Bleaching Variables	R_{β} (%)
Concentration of Bleaching Agent - NaCℓO(g/ℓ)	
.050	93.31[1]
.100	95.15[1]
.200	95.63[1]
Time of Bleaching (hr.)	
0.5	93.86[1]
2.0	95.53[1]
Temperature of Bleaching (°F)	
80°	94.06[1]
105°	95.33[1]

[1]Statistically significant at a 95% probability level.

Table 12. Mean Reflectance Values and Range of Reflectance Values for Bleached Fabric Samples

Bleaching Condition			R_β (%)			Standard Deviation
Conc. of NaCℓO (g/ℓ)	Time (hr.)	Temp (°F)	Low	X[1]	High	σ
.050	0.5	80°	89.41	90.69	91.97	.64
.100	0.5	80°	92.92	93.44	93.96	.26
.200	0.5	80°	93.29	94.63	95.97	.67
.050	0.5	105°	90.92	92.74	94.56	.91
.100	0.5	105°	94.45	94.87	95.29	.21
.200	0.5	105°	95.35	95.75	96.15	.20
.050	2.0	80°	93.66	94.66	95.66	.50
.100	2.0	80°	94.75	95.63	96.51	.44
.200	2.0	80°	95.58	96.10	96.62	.26
.050	2.0	105°	92.81	94.49	96.17	.84
.100	2.0	105°	95.62	96.48	97.34	.43
.200	2.0	105°	95.91	96.77	97.27	.25
			REPLICATION			
.050	0.5	80°	90.88	91.44	92.00	.28
.100	0.5	80°	93.20	93.86	94/52	.33
.200	0.5	80°	94.04	94.60	95.16	.28
.050	0.5	105°	92.42	93.24	94.06	.41
.100	0.5	105°	95.21	95.69	96.17	.24
.200	0.5	105°	94.98	95.4	95.82	.21
.050	2.0	80°	93.32	93.88	94.44	.28
.100	2.0	80°	92.95	94.61	96.27	.83
.200	2.0	80°	94.18	95.12	96.06	.47
.050	2.0	105°	94.35	95.31	96.27	.48
.100	2.0	105°	95.56	96.58	97.6	.51
.200	2.0	105°	96.13	96.67	97.21	.27

[1]The mean value of 25 reflectance readings.

with each sample remaining within the acceptable range of whiteness for use in soil cloth production. A whiteness of 86.0% or higher is considered good for bleached cotton fabrics.[11]

The analysis of variance of the average soiled samples reflectance values for the 24 bleachings, Table 13, showed that the variable, concentration of bleach, had a slight effect on the soiling of the cloth at a 95 per cent confidence interval, based on a F ratio of 3.89. The calculated F ratio of the effect of the concentration of bleach variable in soiling was 6.56. Because the calculated ratio was low, it was suspected that this variable did not have a true effect on the soiling of the cloth, but could possibly be attributed to the varying degrees of whiteness in the fabric before soiling.

To test this hypothesis, an analysis of variance was carried out on the amount of soil pickup on the fabric samples of each of the 12 different bleaching processes. The soil pickup values in Table 14 were obtained by subtracting the k/s bleached samples values from the k/s soiled samples values, Table 15 and 16 respectively.

In this analysis, none of the variables produced an effect on soil pickup because there was no statistical difference in the amount of soil present on each of the fabrics. Therefore the effect of concentration of bleach that was present in the analysis of the soiled reflectance values is attributed to the difference in fabric color caused by varying the

Table 13. Average Reflectance Values of Soiled Fabric Samples for Each Bleaching Variable

Bleaching Variables	R_s(%)
Concentration of Bleaching Agent-NaCℓO(g/ℓ)	
.050	43.42[1]
.100	43.94[1]
.200	43.80[1]
Time of Bleaching (hr.)	
0.5	43.74
2.0	43.70
Temperature of Bleaching (°F)	
80°	43.57
105°	43.85

[1]Statistically significant at a 95% probability level.

Table 14. Average k/s Values for Soil Pickup of Fabric Samples for Each Bleaching Variable

Bleaching Variables	$k/s_{S.P.}$[1]
Concentration of Bleaching Agent-NaCℓO(g/ℓ)	
.050	.3662
.100	.3564
.200	.3596
Time of Bleaching (hr.)	
0.5	.3599
2.0	.3616
Temperature of Bleaching (°F)	
80°	.3632
105°	.3584

[1] $\frac{k}{s}_{S.P.} = \frac{k}{s}_{soiled} - \frac{k}{s}_{bleached}$

Table 15. Average k/s Values of Bleached Fabric Samples for Each Bleaching Variable

Bleaching Variables	k/s_B[1]
Concentration of Bleaching Agent - NaCℓO(g/ℓ)	
.050	.0025
.100	.0013
.200	.0010
Time of Bleaching (hr.)	
0.5	.0022
2.0	.0011
Temperature of Bleaching (°F)	
80°	.0020
105°	.0012

[1] $$\frac{k}{s} = \frac{\left(1 - \frac{R}{100}\right)^2}{2\left(\frac{R}{100}\right)}$$

Table 16. Average k/s Values of Soiled Fabric Samples for Each Bleaching Variable

Bleaching Variables	k/s_S[1]
Concentration of Bleaching Agent-NaCℓO(g/ℓ)	
.050	.3688
.100	.3577
.200	.3606
Time of Bleaching (hr.)	
0.5	.3620
2.0	.3627
Temperature of Bleaching (°F)	
80°	.3652
105°	.3596

[1] $\frac{k}{s} = \frac{\left(1 - \frac{R}{100}\right)^2}{1\left(\frac{R}{100}\right)}$

bleaching process and not in the amount of soil picked up.

The soiling technique was designed to insure uniform soiling within each bleached sample. The statistical analysis of soil pickup proved that the amount of soil present was the same for each sample and the amount of soil was evenly distributed throughout each sample as shown by the standard deviation values in Table 17.

Washing of the samples was also carried out uniformly, holding all conditions constant, enabling any differences in amount of soil removed to be attributed to the bleaching process the cloth was subjected to prior to soiling.

The analysis of variance of the average reflectance values of the washed samples from the 24 bleachings, Table 18, showed the variables, concentration of bleach and time of bleaching, had a significant effect on the amount of soil removed at a 95 percent confidence interval. The standard deviation of the washed samples reflectance values, Table 19, within each bleaching process ranged from .98 to 2.06. The deviation within each bleaching process ranged from .98 to 2.06. The deviation within each sample was higher in washing and soiling than bleaching because the washing and soiling processes were carried out individually on each of the five, 5" x 44", samples from a bleached cloth, as opposed to each bleaching process that treated the entire one yard length of cloth.

To examine soil removal by the American Home Applicance Manufacturers standards[6], per cent soil removal was calculated,

Table 17. Mean Reflectance Values and Range of Reflectance Values for Soiled Fabric Samples

Bleaching Condition Conc. of NaCℓO (g/ℓ)	Time (hr.)	Temp (°F)	R_s (%) Low	$\overline{X}$[1]	High	Standard Deviation σ
.050	0.5	80°	41.1	42.62	44.14	.76
.100	0.5	80°	42.07	43.63	45.19	.78
.200	0.5	80°	42.73	43.73	44.73	.50
.050	0.5	105°	42.49	43.61	44.73	.56
.100	0.5	105°	43.17	44.63	46.09	.73
.200	0.5	105°	41.6	43.7	45.8	1.05
.050	2.0	80°	42.26	43.46	44.66	.60
.100	2.0	80°	42.12	43.60	45.08	.74
.200	2.0	80°	41.57	43.47	45.37	.95
.050	2.0	105°	42.46	43.92	45.38	.73
.100	2.0	105°	41.85	44.05	46.25	1.10
.200	2.0	105°	41.89	43.69	45.49	.90
			REPLICATION			
.050	0.5	80°	42.0	43.50	45.0	.75
.100	0.5	80°	42.52	44.20	45.88	.84
.200	0.5	80°	42.26	43.88	45.5	.81
.050	0.5	105°	41.5	43.38	45.26	.94
.100	0.5	105°	42.56	44.0	45.44	.72
.200	0.5	105°	42.34	43.98	45.62	.82
.050	2.0	80°	41.76	43.40	45.04	.82
.100	2.0	80°	41.91	43.53	45.15	.81
.200	2.0	80°	42.56	44.02	45.48	.73
.050	2.0	105°	41.87	43.45	45.03	.79
.100	2.0	105°	42.59	43.87	45.15	.64
.200	2.0	105°	42.08	43.92	45.76	.92

[1]The mean value of 25 reflectance readings.

Table 18. Average Reflectance Values of Washed Fabric Samples for Each Bleaching Variable

Bleaching Variables	R_w (%)
Concentration of Bleaching Agent-NaCℓO(g/ℓ)	
.050	65.99[1]
.100	67.88[1]
.200	69.18[1]
Time of Bleaching (hr.)	
0.5	67.11[1]
2.0	68.25[1]
Temperature of Bleaching (°F)	
80°	67.28
105°	68.08

[1]Statistically significant at a 95% probability level.

Table 19. Mean Reflectance and Range of Reflectance Values for Washed Fabric Samples

Bleaching Condition Conc. of NaClO (g/l)	Time (hr.)	Temp (°F)	R_w (%) Low	$\bar{X}^1$	High	Standard Deviation σ
.050	0.5	80°	61.77	64.15	66.53	1.19
.100	0.5	80°	63.77	66.51	69.25	1.37
.200	0.5	80°	66.24	68.94	71.64	1.35
.050	0.5	105°	63.06	66.13	69.21	1.54
.100	0.5	105°	65.45	68.47	71.49	1.51
.200	0.5	105°	66.35	69.01	71.67	1.33
.050	2.0	80°	64.63	66.91	69.19	1.14
.100	2.0	80°	71.26	67.92	71.26	1.67
.200	2.0	80°	66.36	68.94	71.52	1.29
.050	2.0	105°	63.18	66.94	70.7	1.88
.100	2.0	105°	66.43	69.63	72.83	1.60
.200	2.0	105°	68.4	70.6	72.8	1.10
			REPLICATION			
.050	015	80°	62.83	65.17	67.51	1.17
.100	0.5	80°	62.2	65.28	68.36	1.54
.200	0.5	80°	64.35	67.91	71.47	1.78
.050	0.5	105°	63.87	66.15	68.43	1.14
.100	0.5	105°	64.57	67.35	70.13	1.39
.200	0.5	105°	67.96	70.26	72.56	1.15
.050	2.0	80°	64.3	66.26	68.22	.98
.100	2.0	80°	66.65	69.15	71.65	1.25
.200	2.0	80°	67.87	70.25	72.63	1.19
.050	2.0	105°	63.52	66.18	68.84	1.33
.100	2.0	105°	64.65	68.73	72.81	2.04
.200	2.0	105°	63.42	67.54	71.66	2.06

[1]The mean value of 25 reflectance readings.

Table 20. Average % Soil Removal Values of Washed Fabric Samples for Each Bleaching Variable

Bleaching Variables	% S.R.[1]
Concentration of Bleaching Agent-NaCℓO(g/ℓ)	
.050	76.73[2]
.100	78.95[2]
.200	81.35[2]
Time of Bleaching (hr.)	
0.5	78.15[2]
2.0	79.88[2]
Temperature of Bleaching (°F)	
80°	78.65
105°	79.37

[1] $$\frac{\frac{k}{s}_{soiled} - \frac{k}{s}_{washed}}{\frac{k}{s}_{soiled} - \frac{k}{s}_{unsoiled}} \times 100 = \%\text{ soil removal}$$

[2] Statistically significant at a 95% probability level.

Table 20, and the values were statistically analyzed. This analysis of variance for each bleaching process showed the concentration of bleach and the time of bleaching as having a significant effect on soil removal.

A committee formed by the American Association of Textile Colorists and Chemists (AATCC) to study fabric soiling drew the following conclusions concerning the effects of electrostatic forces in textile soiling:[5]

1. Most particles are uncharged and are not drawn to fabrics by virtue of their own electrostatic conditions.
2. Frictional forces and other naturally occurring conditions can probably induce static charges of short duration on many soil particles. If these particles come close to a textile before the charges are dissipated, they may be drawn into direct contact.
3. Uncharged particles may be strongly attracted to fabrics which have become charged.

The results from this study indicate that electrical forces are present in the laundering procedure as have previous studies which showed electrostatic forces to be important factors in the direct adhesion of soil to textiles. Cellulose and protein fibers are negatively charged under laundering conditions and solid particles in suspension in the washing solution acquire a charge which may be either position or negative depending on the chemical nature of the particles and on the pH of the solution[9]. Evidently, the charge acquired by the soil particles was negative because of the increase in soil removal with the increase in bleaching severity.

CHAPTER V

CONCLUSIONS

From the experimental results, it can be seen that the degree of bleaching within the range of bleaching variables studied had no effect on soil pickup (Table 14). It should be pointed out that these results may differ in an exhaust technique of soil application in which the soil solution is completely depleted before the addition of fresh soil solution.

The degree of bleaching had a slight but significant effect on soil removal (Tables 18 and 20). The bleaching variables that produced the effect were the concentration of bleaching and the time of bleaching. The effect produced was that of an increase in soil removal as the concentration of bleaching agent and the time of bleaching increased. The temperature of bleaching was also expected to have an effect on soil removal but did not show up in this study.

Increased bleaching produced a slight increase of carboxyl groups that affected the electrical charge between the fabric and soil in laundering. Although the visual examination of the chemical tests results did not show an observable difference in the amount of carboxyl groups between the bleaching processes, a slight difference could be present.

It is probable that the negative fiber charge increases with bleaching because of the increase of carboxyl groups, causing a trend toward a greater ease or difficulty of removal. Analysis of these experiments showed the trend to be toward a greater ease of soil removal.

The conclusion that is drawn from these experiments is soil particles have a negative charge and the laundering process creates a situation of easy dissociation between the two negative charges.

CHAPTER VI

RECOMMENDATIONS

Because the effect of the concentration of bleaching agent and the time of bleaching was small at the variable levels used in this study, further investigation into their effect on soiling and soil removal should be carried out using greater differences.

A study that looks into soil removal properties of fabrics bleached to different extents with the addition of electrolytes to the wash bath could also be beneficial. Addition of electrolytes to the laundering process would decrease the negative fiber charge, and therefore decrease the electrical repulsion forces, allowing for a decrease in soil removal.[14] This study could give insight into the effect of H_2O softeners and detergent additives in the wash cycle.

The controls of the U.S. Testing Company on the preparation of unfinished cotton fabrics used in soil cloth production should be checked. Although the soil removal differences caused by varying the bleaching processes are slight, they are significant and should be brought to the attention of soil cloth suppliers.

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