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WERTZ, ELIZABETH DREISBACH. The Whiteness Retention of Flame Retardant Finished Fabrics Laundered with Phosphate and Non-phosphate Detergents. (1974) Directed By: Dr. Pauline E. Keeney. Pp. 92.

Flame retardant finished fabrics available to the consumer, because of increased legislation for his protection, must retain the characteristics deemed desirable to the consumer. One characteristic is that of the maintenance of the original color.

The purpose of this study was to determine the color difference of selected fabrics (100% cotton and 70/30 and 50/50 cotton and polyester blends) treated with selected flame retardant finishes (APO-THPC, THPC-urea-MM, and THPOH-NH3) and laundered 25 times with phosphate detergent and non-phosphate soap. The objectives of this study were to determine whether laundering with the detergents produced color differences in the untreated fabrics, and those treated with flame retardant finishes; to determine, by means of statistical analysis, the significance of color differences; and to determine interactions of the three main factors.

The fabrics and flame retardant treatments were prepared for Regional Research Project SM-38 at the Southern Regional Research Center of the United States Department of Agriculture. The whiteness of flame retardant treated

fabrics and the whiteness of untreated control was measured and recorded before laundering as a basis for comparison at laundering 1, 5, 10, 15, and 25 on the Hunterlab Color and Color Difference Meter to determine color differences after laundering with the phosphate or non-phosphate detergent (AATCC 88C-1973). Results were recorded on the ΔL, Δa, Δb, and ΔE scales and analyzed for variance. Visual tests, under standard conditions were used as a basis for comparison.

Visual examination indicated that the fabrics laundered with phosphate detergent to have a yellow cast while those laundered with the non-phosphate detergent had a blue cast. There was less indication of color change than in the fabrics laundered with the phosphate detergent.

The physical measurement of color made on the Color and Color Difference Meter showed the amount of color difference decreased as the amount of polyester increased. Readings of color difference before laundering were non significant between the fabrics to be laundered with the detergents. Readings of color difference were highly significant at the .001 level:

1. Among the 3 fabrics. (As with the treatments and detergents, the greatest mean color difference occurred at laundering 5).

2. Among the fabrics laundered with the two detergents. (With the exception of laundering 1, the non-phosphate detergent produced greater color difference).

3. Among the fabrics treated with the four flame retardant finishes.

The lowest color difference was found in THPC-urea-MM at 1, 5, and 10 launderings and APO-THPC at laundering 15, and 25. The greatest evidence of color difference was found in the untreated fabrics at laundering 1 and in those treated with THPOH-NH3 at each of the remaining launderings. The THPC-urea-MM showed the least amount of color.

THE WHITENESS RETENTION OF SELECTED FLAME RETARDANT FINISHED FABRICS LAUNDERED WITH PHOSPHATE AND NON-PHOSPHATE DETERGENTS

by

Elizabeth Dreisbach Wertz

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TABLE OF CONTENTS

457489

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The Department of Health Education and Welfare reports that each year 3,000-5,000 persons die and 15,000-250,000 suffer disfiguring injuries from burning clothes, bedding, upholstery and other textile products used in the home. The Consumer Protection and Environmental Health Services, in an investigation of 320 fabric burn cases, report that sheets and blankets account for two-thirds of the burns caused by non-clothing fabric. A disproportionate number of the victims are children, the elderly, and the infirm.[1] Such reports have emphasized the need for precautionary measures to protect consumers of textile products.

The first flammability law enacted was the Fabric Misdescription Act enacted in England in 1913. Its purpose was to protect the consumer from items falsely labeled "flameproof." It was not until 1945 that the State of California passed a flammability law governing the sale of

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[1]Imogene Holloway, "Preventing Child Burns," P.T.A., LXIV (June, 1970), 14-15.

fabrics that were more highly flammable than cotton in its natural state.[2] The original Flammable Fabrics Act of 1953 excluded all but material used for clothing. Because of the dangerously narrow scope of that legislation, the act was amended in 1967 to give the federal government the responsibility to set limits on the flammability of such items as bedding, blankets, carpets, as well as clothing.

Since burning bedding has accounted for two-thirds of the burns caused by non-clothing fabrics it has been suggested that flame retardancy should be a requirement for all sheets and pillow cases. It is, therefore, important that various problems arising out of the flameproofing be considered: the fibers and fiber blends that are best suited for the fabric construction; the effectiveness of the flame retardant finishes available; and problems of odor, harshness to the skin, stability of the finish, whiteness retention and hand. Studies are underway to solve such difficulties.

William Segall, "Flammability Testing and Legislation," American Dyestuff Reporter, LVII (March 11, 1968), 195-98.

STATEMENT OF THE PROBLEM

This study will serve to explore deviations in color of flame retardant finished fabrics caused by home laundering with selected detergents. Previous experimentation studying the effectiveness of flame retardants indicated that discoloration appeared following commercial laundering and dry cleaning. Since measurement of whiteness retention was not included in the study, this apparent color change indicated an area of work worthy of further investigation.[3]

The purpose of this study was to compare the effect of selected home laundry detergents on the whiteness retention of unfinished and flame retardant finished fabrics. The fabrics available for experimentation were those prepared for use in the Southern Regional Research Project, SM-38, sponsored by the Cooperative State Research Service of the United States Department of Agriculture. The detergents selected for experimentation were products available for consumer use.

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[3]Ardis A. Williams, "Effects of Laundering by Professional Services on Selected Flame Retardant Finished Fabrics," (unpublished Masters thesis, University of North Carolina, 1971), p. 26.

Objectives

The objectives of this study were to:

1. Measure differences of whiteness retention of the selected unfinished and flame retardant finished fabrics prior to laundering treatments.

2. Measure differences of whiteness retention of the unfinished and flame retardant finished fabrics following laundering with a phosphate and a non-phosphate home laundry detergent.

3. Determine the differences in whiteness retention of the fabrics as affected by the flame retardant finish, the detergents, and the launderings.

Assumptions

In this study it was assumed that:

1. The laundering procedure used produced results similar to those resulting from home laundering procedures.

2. The changes in whiteness as a result of build-up of detergents were similar to the deposits found in garments after home laundering.

Hypotheses

The hypotheses of this study stated in the null form, were:

1. There was no significant difference at the .001 level of confidence in the whiteness retention of the three selected unfinished and finished fabrics prior to laundering.

2. There was no significant difference at the .001 level of confidence in the whiteness retention of the three selected unfinished and finished fabrics after laundering.

3. There was no significant difference at the .001 level of confidence in the whiteness retention of the selected fabrics laundered with a non-phosphate detergent and those laundered with a phosphate detergent.

4. There was no significant difference at the .001 level of confidence in the whiteness retention of the interactions of fabrics, finishes, detergents, and the number of times the fabrics were laundered.

DEFINITION OF TERMS

The terms defined for this study are as follows:

Flame Retardant Finish. A chemical finish to retard the ignition of a volatile material.

APO-THPC. Letters signifying the compound tris-(1-azir-dinyl) phosphine oxide tetrakis (hydroxymethyl) phosphonium chloride.

THPC-urea-MM. Letters signifying the compound tetrakis (hydroxymethyl) phosphonium chloride urea methylolmelamine.

THPOH-NH3. Letters signifying the compound tetrakis (hydroxymethyl) phosphonium hydroxide ammonia cure.

Home Detergent. A cleansing compound commercially prepared for consumer use.

Phosphate Detergent. A chemical formulation that includes a synthetic surface active agent plus a phosphate builder.[4]

Non-phosphate Detergent. A detergent in which the phosphate builder has been completely removed and replaced by silicates or carbonates.[5]

pH. A measure of the acidity or alkalinity of a substance. The pH scale ranges from 0 to 11 with 7 the neutral point at which the hydrogen ions and the hydroxyl ions exist at the same concentration.[6]

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[4]"Soaps, Detergents, and Why Nobody can say What's Best," (FMC Corporation, New York, June, 1972) p. 1.

[5]Ibid.

[6]E. Trujillo, "Instructions: Model 72 pH Meter," n.p., 1960 (mimeographed).

Turbidity. Matter in suspension in the laundering bath.

Specific Conductivity. Ability of water to carry a charge in the laundering bath.

Water Hardness. Solids in water created by the joining of alkaline earths and mineral salts.

Whiteness Retention. The ability to remain free from discoloration as judged by the use of the standard procedure of the Color and Color Difference Meter.

CHAPTER II

REVIEW OF LITERATURE

Review of the Importance of Flame Retardant Fabrics

Statistics of National Bureau of Standards on fire accidents involving clothing indicate that 38% of the fire accident cases involving children under six are sleepwear accidents. In 85% of these sleepwear accidents the garments worn have been the first item to ignite.[7]

Legislation requiring textile manufacturers to certify that their products meet flammability standards has necessitated an accelerated program of research and development for the textile industry in the area of flame retardants. This is by no means a new area of study. In 1945 the National Retail Merchants Association requested the American Association of Textile Chemists and Colorists (AATCC) to establish a research committee to study the flammability of textile fibers. In this same year the

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[7]"The Innovation: Flame Retardants that Protect Children's Cotton Sleepwear," Textile World, CXXII (December, 1972), 46.

AATCC Research Committee RA-47 on the Flammability of Clothing was organized. In 1953 the Flammable Fabrics Act was passed based upon AATCC Test Method 33 and Commercial Standard CS 191-53, which had been developed from the adverse public opinion of the "torch" sweater made of brushed rayon and also from the California legislation that "banned the sale of all fabrics that were more flammable than cotton in its natural state."[8]

It was not until 1963 that an attempt was made to place the Flammable Fabrics Act under the Federal Trade Commission and to extend the control to such items as baby blankets, blankets and bedding. Suggestions for changes in the existing law resulted in the amendment to the Flammable Fabrics Act of 1953. This new legislation, enacted in 1967, strengthened the existing laws and extended the law to include home furnishings.[9] On July 29, 1971, a standard for childrens' sleepwear was adopted that required all childrens' sleepwear (sizes 0-6X) to pass a vertical flame

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[8]C. A. Baker, "Pyrotechnics of Textile Materials," Modern Textile Magazine, XLIX (November, 1968), 57-62.

[9]J. F. Pacheco and C. P. Carfago, "How Laundering Practices Influence the Flame Retardancy of Fabrics," Textile Chemists and Colorists, IV (November, 1972), 45.

test after 50 home launderings at 140 degrees using AATCC standard detergent.[10] Because of mandatory legislation it has become necessary to develop flame retardants that will make it possible for the present fibers, particularly cellulosics, to meet the standards set up under this legislation.

It has been reported that flame retardants are too expensive to be acceptable to the consumer. Others have claimed that if flame resistance as a fabric property was properly advertised, the housewife and the hotel manager would tend to ignore the higher cost.[11] William White cited the need to develop the following: research, educational programs, and field projects in flame resistance to counterbalance the 10 to 15 percent additional cost.[12]

To be satisfactory as a flame retardant Drake, Perkins, and Reeves reported that a finish must:

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[10]"Problems of Flammable Fabrics," Textile Industries, CXXXI (February, 1967), 86-89.

[11]Ibid.

[12]William White, "The Burning Question: The U. S. Public Health Service Role in Preventing Burns from Clothing and Fabric Fires," American Dyestuff Reporter, LVII (December 4, 1968), 49.

1. Be easy to apply, preferably from water solution;

2. Be effective at low add-ons to avoid excessive increases in weight;

3. Be effective following laundering and dry-cleaning;

4. The fabric must remain air permeable;

5. Be physiologically inactive;

6. Make the fabric resistant to afterglowing;

7. Not change the hand appreciably;

8. Cause little or no loss in strength; and

9. Be reasonable in cost.[13]

According to Gottlieb the theory behind flame proofing is twofold. First is the catalytic decomposition of the substrate which is followed by the reduction of the gaseous products of decomposition. These flame proofing functional finishes for textile fibers fall into two major classifications: (1) additive finishes where lack of durability can be easily obtained by sealing a water soluble

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[13]George Drake, Rita Perkins, and Wilson Reeves, "Special Finishes for Textile Flame Retardant Finishes and Soil Resistant Finishes," Colourage, XVIII (August 26, 1971), 35.

agent into the fiber by resin finishes; permanently enmeshing a reagent to a fiber by crosslinking; and physical modification as a film forming resin skin coated on the surface.[14]

Chemical Structure and Properties of Flame Retardants Used in This Study

It is understandable that no one finish is suitable for all fabrics nor for all uses; therefore, many flame retardants have been developed and used with varying results. Only those flame retardants used in this study will be reviewed.

THPC-urea-MM. Perkins and co-workers reported that durable flame retardants based upon tetrakis (hydroxymethyl) phosphonium chloride (THPC), a water soluble compound produced in high yield from formaldhyde, phosphine and hydrochloric acid were used more than any other types for apparel.[15] Initiating the THPC method, Reeves and Guthrie,

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[14] Irvin M. Gottlieb, "A Theory of Flame-Retardant Finishes," Textile Research Journal, XXVI (February, 1956), 159.

[15] R. Perkins, G. Drake, and W. Reeves, "The Effect of Laundering Variables in the Flame Retardancy of Cotton Fabrics" (paper presented at American Oil Chemists' Society Symposium, New Orleans, Louisiana, April 26-30, 1970).

in their work with Southern Research Center, found that aminized cotton could be made flame retardant when reacted with THPC. To form an insoluble polymer within the fiber, THPC is reacted with a nitrogen containing compound such as urea to form a water soluble "adduct." The fabric must be treated with the adduct, dried and then exposed to ammonia. There will also be some crosslinking with the cellulose.

R. Aenishanslin reported that THPC is a very reliable and effective flame retardant finish. It is resistant to laundering and drycleaning though there is a reduction in tensile strength.[16] It has considerable wrinkle, rot, and mildew resistance. Guthrie and associates reported that softeners improve the hand and the tear strength.[17]

APO. Tris-(1-aziridinyl phosphine oxide) is created by reacting THPC with APO to create a thermosetting resin within the fiber. The fabric is padded through an aqueous solution dried at a low temperature to form crosslinked resin and then washed and dried. By the ammonia curing of

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[16] R. Aenishanslin, "Flame Retardant Finishes," Textile Industries, CXXXIII (November, 1969), 99.

[17] J. Guthrie, G. Drake, and W. Reeves, "Application of the THPC Flame Retardant Process to Cotton Fabrics," American Dyestuff Reporter, XLIV (May, 1955), 328.

the APO, the nitrogen increases the flame retardancy and reduces the strength loss due to heat curing.[18]

APO also combines chemically with the fiber accounting for the exceptional durability of the finish to acids and alkalis and to laundering and drycleaning. Aenishanslin reported that APO caused a loss in tensile strength which was improved by the use of softeners.[19] Perkins, Drake and Reeves pointed out that APO is rot, mildew and crease resistant. Yellowing, an undesirable characteristic of APO, can be reduced by means of peroxide and perborate bleaching.[20]

THPOH-NH3. Tetrakis (Hydroxymethyl) phosphonium hydroxide is treated with an ammonia cure. This retardant is applied by padding the fabric with a solution of THPOH and various auxiliaries. The fabric is partially dried and the partially dried fabric is exposed to ammonia gas. The reaction with ammonia produces water which joins with the

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[18] W. Reeves, V. Bourdette, "Flame Resistant Cotton Fabrics from U.S.D.A.," Textile Industries, CXXVIII (January, 1964), 105.

[19] Aenishanslin, op. cit., p. 101.

[20] R. Perkins, G. Drake, and W. Reeves, "APO-A Versatile Textile Chemical," ARS 72-32 (December, 1964), p. 4.

ammonia to form ammonium hydroxide. It is necessary to have an exhaust system in the reactor to remove water and ammonium hydroxide so as not to form water soluble products instead of insoluble ones. The outstanding feature is the high retention of breaking strength (80-90%). It is applicable to most cotton fabrics as it does not impart stiffness and is satisfactory on fabrics weighing as little as two ounces per square yard. The yellowing associated with APO flame retardants is also associated here but in lesser degree.[21]

The retardants discussed were developed basically for use in the cotton trade but some flame retardants can be used on cotton and polyester blend fabrics. Polyester and cotton blends can be made flame resistant only when both components are treated.[22] The results of a study by Drake, Perkins, and Reeves showed that it is more difficult to retard flaming of blends than it is to retard 100% cotton. If the blend contains at least 65% cotton it can

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[21]"Better Flame Resistant Finish for Cotton," Textile Industries, CXXXI (November, 1967), 11.

[22]William Segall, "An International Look at Textile Flammability," American Dyestuff Reporter, LVIII (March 24, 1969), 24.

be adequately flame proofed. As the percent of polyester increases, the amount of flame retardant needed also increases.[23]

Review of the Types of Detergents for Consumer Use

A detergent has been defined by the Association of Home Appliance Manufacturers as a "laundry product designed to remove, emulsify, dissolve and suspend soil in washing solution."[24] Detergents, though having individual formulations, all contain certain ingredients in common:

1. Surfactants (Surface Active Agents) that improve the wetting action of water and loosens and suspends soil particles.

2. Builders that sequester alkaline earths and mineral salts and aid in the action of the surfactant.

3. Suds control agents that maintain the sudsing characteristics.

4. Silicates that provide the reserve alkalinity for the protection of the washing machine parts.

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[23] Ibid., p.38.

[24] Home Laundry Terms, American Home Laundry Manufacturers Association, Chicago, Illinois, Revised in 1965.

5. Soil redeposition inhibitors that prevent the soil once removed from lodging on the garments.

6. Fluorescent whiting agents that, in union with the cloth, turn ultraviolet light into visible blue light that causes the eye to see a whiter and brighter white.

7. Perfume that leaves the once soiled garment with a clean, fresh smell.[25]

The detergent functions by thoroughly wetting the surface with the water and detergent combination, removing the soil from the surface by breaking the large particles of soil into smaller particles that can be flushed from the fabric. The soil must then be held in suspension so that it will not redeposit on the garment. The hydrophobic portion of the water molecule attaches to the soil while the hydrophilic portion pulls the soil and water combination away from the fiber. Water, temperature and agitation are needed for this action to occur. Factors which may affect the detergency characteristics of a flame retardant finished fabric are:

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[25]American Home Economics Association, Textile Handbook, (Washington, D. C.: AHEA, 1970), p. 80.

1. Detergent--phosphate and non-phosphate

2. Water--hardness, turbidity, pH, and specific conductivity

3. Bleach

4. Temperature

According to soap manufacturers the difference between the phosphate and non-phosphate detergent is in the builder. The phosphate detergent contains approximately 20% tetrasodiumpyrophosphate and 30% trisodiumphosphate. The phosphates are the most satisfactory cleansing agents for the removal of soil. They soften the water by counteracting the mineral salts, suspending the soil and keeping it from redepositing.[26] The phosphate helps to maintain the necessary alkalinity for efficient cleaning.

A non-phosphate detergent contains 50% alkali and the phosphate builder has been completely replaced by silicates and carbonates.[27] FMC testing showed that washing with soap and non-phosphate detergents eliminate flame retardancy in fabrics in several washings but there appeared

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[26] Joyce Roark, "Facts of Detergents," Daily News of Jacksonville, North Carolina, September 29, 1972, p. 8.

[27] Ibid.

to be no harmful effects with the washing with the phosphate detergent.[28] The sequestering action of the phosphate in solution prevented solid residues from forming and depositing on the fabric surfaces in typical home laundering procedures, explaining why phosphates do not impair flame retardancy of the fabric. Scanning electron photomicrographs confirmed that samples laundered with a high carbonate detergent contained encrustation of calcium and carbonate crystals. The resultant build-up acted as a barrier to the flame retardant action.[29]

Flame retardancy can be restored by practices that remove the hard water and detergent or soap residues. Tests made by the FMC Corporation point out that the safest way to remove the residues is by the use of a high phosphate detergent or by supplementing a reduced phosphate detergent with water softners.[30]

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[28]"Soaps, Detergents and Why Nobody Can Say What's Best," FMC Corporation, (June, 1972), p. 2.

[29]"On the Flammability Front: Non-phosphate Laundering and Flame Retardancy," Textile Industries, CXXXVI (November, 1972), 104.

[30]Ibid.

Phosphate and non-phosphate detergents do not alone account for the build-up of minerals. Water, its hardness, its pH, its specific conductance and its turbidity play a role in its relationship as a unit to the detergent and detergency.

Hardness of water varies throughout the country. In addition to the hardness in the water supply, soil on clothes can introduce hardness minerals such as calcium and magnesium into the wash water. It is these minerals that can be picked up by the flame resistant fabric during laundering. The amount of the mineral salts picked up depends on the nature of the flame retardant on the fabric. The mineral salts may be present in the water but it is the specific conductance or the conductivity of the water that allows the charged pick-up of the mineral salts and results in the encrustations of the textile fiber.

It has been concluded by Daigle and associates, that multiple home launderings using built soaps and detergents in areas of even moderately hard water (30ppm) can cause an appreciable amount of insoluble calcium phosphates. Rinsing occasionally in dilute acetic acid helps to retain

flame retardancy by minimizing the adverse effects of the foreign matter build-up.[31]

Perkins and others found that hypochlorite bleach adversely affected the THPC flame retardant finish more than other finishes. Most of the finishes turned yellow and were not as durable when washed with only detergent. THPOH as well as APO passed the flame test after 20 launderings following subjection to hydrogen peroxide oxidation prior to hypochlorite launderings.[32]

Color Evaluation

Hunter stated that the process of observing color involves the physics of light radiation, the physiology of sensation, and the psychology of perception. Light can be defined as visually evaluated radiant energy.[33] Visible energy, whose ranges is from approximately 4000 to 8000

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[31]P. Daigle, W. Reeves, J. Beninate, and G. Drake, "The Effect of Hypochlorite Bleach on Flame Retardant Finishes Based on THPC," (New Orleans: Southern Utilization Research and Development Division, MTST-34), p. 7. (Mimeographed.)

[32]Perkins, Drake, and Reeves, "The Effect of Laundering Variables on the Flame Retardancy of Cotton Fabrics," p. 12.

[33]Hunter Lab, "Light, Objects and Observation," (Fairfax, Virginia: Hunter Lab, n.d.), pp. 2, 12.

angstrom units, is most often measured in wavelengths (symbol λ) and expressed in nanometers. Psychophysical scales devised to measure color as the eye sees it are based upon the properties of absorption and diffusion. These scales, for identification, are based upon an orderly arrangement and established principles of relationships between color. The principles are:

1. Systematic changes in ingredients mixed to make colored materials as in the Martin-Senour Nu-Hue System

2. Arrangement of color samples by observers so that there are visually equal color difference between them as in the Munsell System

3. Systematic changes in the amount of the three primary colored lights mixed to match visually the different colors of the system such as CIE Standard Observer.[34]

The three dimensional arrangement of the tristimulus color base of the L a b and the x y z scales were an advancement of the CIE Standard Observer. The basis of computation of the x y z tristimulus system is the energy distribution, the percent of reflectance, and the response

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[34]Hunter Lab, "Object Color Scales," (Fairfax, Virginia: Hunter Lab, n.d.), pp. 1, 2.

function of the brain. The area under the luminosity curve is equal with the white being 100 and the black being 0. In the xyz system, z is blue (the most important dimension), y is green and x is red.[35] The L a b color and color difference system used in this study was based upon the Adams Chromatic Valance Scales. Hunter explained the basis of computation as lightness and chromaticity including both hue and saturation. The L is an indication of lightness; "a" is an indication of redness or greenness; and "b" is an indication of yellowness or blueness.[36] The numerical measurement of the L a b scales cannot be converted to psychological measurement as the observing conditions, color difference perceptibility and commercial acceptability do not always coordinate.

Hunter also reports that this tristimulus color base has been used in the measurement of whiteness retention. White to the American mind is a color of purity, freshness and of cleanness. Physically, white is highly diffused reflectance and can be developed by bleaching which removes

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[35]Hunter Lab, "Hunterlab Seminar for the Textile Industry," (Fairfax, Virginia: Hunter Lab, February 22, 1973), p. 3.

[36]Ibid., pp. 4-5.

the brown and increases the blue reflectance. It can also be developed by use of dyes which absorb light or by fluoresence induced by blue light.[37]

No references were found which gave specific information as to the use of color measurement to determine the effects of flame retardant finishes on fabrics.

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[37]Richard Hunter, "Instruments and Test Methods for Control of Whiteness in Textile Mills" (paper presented at AATCC National Technical Conference, Atlantic City, N. J., October 1, 1966), p. 6.

CHAPTER III

PROCEDURE

This study was planned to investigate the whiteness retention characteristics of selected fabrics following laundering using two detergents differing in type. The study was planned to supplement Regional Research Project SM-38 of the Cooperative State Research Service of the United States Department of Agriculture. This project was designed to study the effectiveness of selected flame retardant finishes for cotton and cotton blend fabrics.[38]

Description of Fabrics and Finishes

The fabrics used in this study were those prepared for experimentation for the Regional Research Project SM-38 and were all of a plain weave and weighed approximately 3.5 ounces per square yard. The differences in the fabrics were as follows:

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[38]Technical Committee of the Cooperative State Research Service, "Manual of Procedures," n.p., n.d., (Mimeographed.)

Fabric 1 100% cotton content
Thread count 92 warp x 67 filling
Yarn number 25.5 x 33.7
Twist per inch 21.9 x 21.9

Fabric 2 70/30 cotton and polyester blend
Thread count 142 warp x 58 filling
Yarn number 51.7 x 28.6
Twist per inch 28.0 x 17.9

Fabric 3 50/50 cotton and polyester blend
Thread count 146 x 57 filling
Yarn number 51.8 x 42.8
Twist per inch 27.3 x 23.9[39]

Flame retardant finishes were applied to each of the above fabrics by personnel of the Southern Regional Research Laboratory of the United States Department of Agriculture at New Orleans, Louisiana. The three flame retardants and the procedure followed in applying them are as follows:

APO-THPC. Padding of the fabric by two dips and two nips through 30 percent solids of APO-THPC solution under tight squeeze roll pressure resulting in a wet pick-up between 70 and 80 percent. The fabrics were frame dried for three minutes at 85° C., then cured on the frame for four minutes at 140° C. They were then washed on a jig and frame dried.

THPC-urea-MM. Padding of the fabric by two dips and two nips through 40 percent solids of THPC-urea-MM solution under a tight squeeze roll pressure resulting in a wet pick-up between 70-85 percent. The fabrics were dried at 85° C. for

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[39] Ibid.

three minutes on a tenter frame. They were frame cured for three minutes at 150° C. They were washed on a jig and frame dried.

THPOH-NH3. Padding of the fabric by two dips and two nips through 40 percent solids of THPOH-NH3 solution under tight squeeze roll pressure resulting in a wet pick-up between 80-90 percent. The fabrics were tenter frame dried at 85° C. to a moisture content of 20 percent. The fabrics were then exposed to ammonia gas (NH3) in an enclosed jig for 10 seconds. They were then washed on a jig and frame dried.[40]

The three unfinished fabrics and nine finished fabrics were prepared for experimentation by cutting test samples eight inches by twelve inches with the longest dimension in the direction of the warp. The samples were then coded with a laundry pen in preparation for experimentation.

Description of Detergents

The two detergents selected for experimentation were home laundering products manufactured for consumer use. The two detergents, differing in the builder used and in that one was a tallow product and one was a synthetic detergent, were:

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[40]Williams, loc. cit.

Phosphate Detergent. A synthetic detergent with 12.3 percent phosphorus builder in the form of phosphates and a biodegradable surfactant.

Non-phosphate Detergent. A tallow product with a silicate or carbonate builder and a biodegradable surfactant.

Description of Water Determination

In order to simulate laundry conditions of the consumer, Greensboro City water was used. As a part of the experimentation, water specimens collected at the completion of each of the twenty-five wash cycles included:

1. Water at room temperature

2. Water with .5 percent concentration of phosphate detergent at room temperature

3. Water with .5 percent concentration on non-phosphate detergent at room temperature.

With the cooperation of the Greensboro Water Works, information was obtained at the conclusion of each of the twenty-five wash cycles relating to:

1. Water hardness

2. Water specific conductivity

3. Water turbidity

4. Water pH with .5 percent concentration of phosphate and non-phosphate detergent.

Description of Laundering Procedure

The laundering procedure followed was based upon the AATCC Test Method 36-1970, developed by Committee RA-60. Using a chart of random numbers the samples were assigned to a cell and the cells to a block as can be seen in Figure 1. The cell was a one quart jar on which 6 were required to complete a block. Eight blocks, or loading of the launderometer were required to complete one wash cycle in which each sample and each replication were laundered for thirty minutes in a thermostatically controlled research launderometer Model LQ 2. The bath was stable at 120° F. and the sample jars contained .5 percent detergent and 100 ml of water. At the completion of the laundering the samples were given three one minute rinses by hand for the most efficient removal of detergent. The samples were hydro extracted for 30 seconds and pressed for 10 seconds on a steam heated flat bed press. Color change of the sample was measured after 1, 5, 10, 15, and 25 launderings.

Design for Experimentation

The design for experimentation was a four factor analysis with fabric (F), finishing treatments (T), detergents (D), and number of launderings. Each one of the

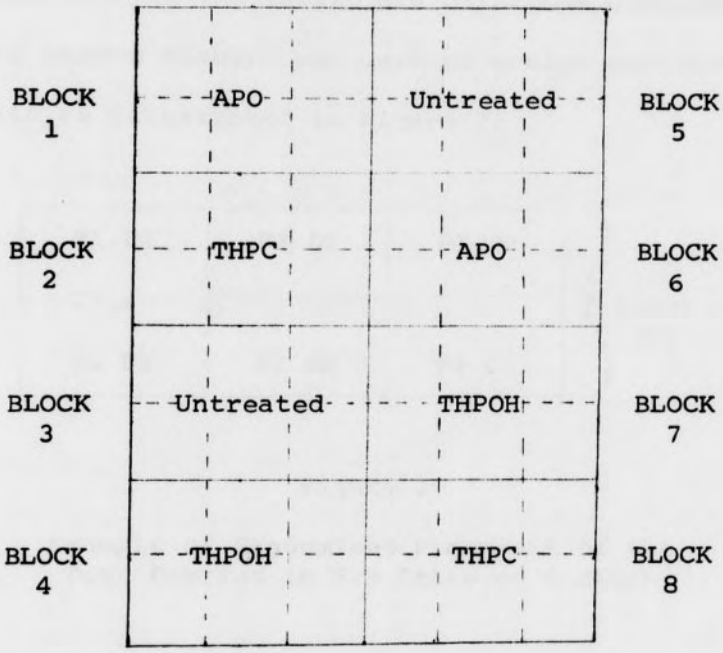

Figure 1

Diagram of Arrangement of Six Cells Within Eight Blocks Representing Flame Retardant Treatments and Replications

blocks shown in Figure 1 was subdivided into six cells which represented the fabric and detergent combinations. A table of random numbers was used to assign combinations to the cells as illustrated in Figure 2.

F1 D1	F3 D2	F1 D2
CELL		
F1 D2	F2 D2	F2 D1

BLOCK (T)

Figure 2

Example of Randomized Placement of the Test Fabrics in Six Cells of a Block

The fabrics were coded in four digits as follows:

First Digit--Treatment

1. No finish-control
2. APO
3. THPC
4. THPOH

Second Digit--Fabric

1. All cotton
2. 70/30 cotton and polyester blend
3. 50/50 cotton and polyester blend

Third Digit--Detergent

1. Phosphate
2. Non-phosphate

Fourth Digit--Laundering

0. Unlaundered
1. One laundering
2. Five launderings
3. Ten launderings
4. Fifteen launderings
5. Twenty-five launderings

A pilot run was made of all procedures of this study to be certain that all variables to be included were feasible and that they would fit into the statistical frame of analysis.

Description of Color Measurement

The measurements of change in whiteness were made with the Hunterlab Model D-25 Color and Color Difference Meter. The Color Difference Meter operates on the L a b and CD scale; whereas "L" indicates lightness, "a" indicates red to greenness, "b" indicates yellow to blueness and the CD Scale indicates the color difference. The CD value was determined from the E scale using the measurements from the control or unlaundered fabrics as the standard.

The Color Difference Meter was standardized to the white block for the color measurement of all control (unlaundered) fabrics. Two readings were made on the L a b and CD scales. These values were used to establish the

basis for the determination of the color differences of all fabrics following 1, 5, 10, 15, and 25 launderings. These differences in reflectance were recorded as ΔL, Δa, Δb, and ΔE values.

Visual Tests

A visual test using the same samples and variables was also made to verify or compare with the results of the instrumental analysis. The Grey Scale was used to evaluate visible differences in whiteness according to the procedure set up by AATCC. The samples were rated three different times by three different individuals.

The samples were placed on a hanger with the phosphate detergent on the left of the standard and the non-phosphate detergent on the right of the standard as is shown in Figure 3. The hanger was placed at eye level on a viewing board at a 5° angle and viewed at a 4 foot distance. The samples laundered in the phosphate detergent and those laundered in the non-phosphate detergent were rated against the standard. Also, noted was the cast of the white: Yellow/White, Blue/White, or Grey/White.

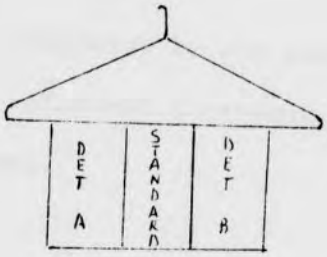

Figure 3

Example of Sample Placement

For the purpose of comparison visual tests were also made using the "daylight" setting of the Macbeth light. The same arrangement of the detergents and samples was used and the cast of white was again noted.

Treatment of the Data

An analysis of variance was used to determine significant differences at the .001 percent level of confidence to confirm or reject the hypotheses stated in the introduction.

A 3 x 4 x 2 factorial design was used to test interactions at each laundering (0, 1, 5, 10, 5, and 25) interval to determine significant differences in the ΔL, Δa, Δb, and ΔE.

Data was presented in figures and tables depicting the significant differences in whiteness retention of the

test specimens as influences by the three main effects: fabric type, flame retardant treatment, and the effectiveness of the detergent.

CHAPTER IV

PRESENTATION OF DATA

The major purpose of this study was to measure the whiteness retention of flame retardant finished fabrics laundered with two selected detergents. The whiteness retention of the selected flame retardant finished fabrics was determined by means of the Hunterlab Color and Color Difference Meter, Model D-25. The results of the instrumental analysis were also compared to visual tests made at laundering 10 and 25.

The flame retardant finished fabrics used in this study were prepared by the Southern Regional Research Center of the United States Department of Agriculture for the Regional Research Project SM-38. The fabrics used were 100% cotton, 70/30 cotton and polyester blend, and 50/50 cotton and polyester blend. The flame retardants prepared and applied by the Southern Research Center included APO-THPC, THPC-urea-MM, and THPOH-NH3. Unfinished yardage of each of the three fabrics was used as a control in determining differences in treatments, making a total of 12 fabric and treatment combinations.

The fabrics were laundered according to a random assignment in a research launderometer using 2 selected commercially available home laundry detergents. The samples were then rinsed, hydro extracted, and steam pressed. The samples were measured on all scales of the Color and Color Difference Meter to determine differences in whiteness before laundering (0) and following 1, 5, 10, 15, and 25 launderings.

The results of this study are presented in two parts. The first part includes the result of visual testing and color characteristics observed. The second part includes the physical measurement of color and the statistical analysis of color differences.

FINDINGS RELATED TO VISUAL TESTS AND OBSERVATIONS

There were distinct differences in the appearances of the three fabrics and the four finishes both before and after laundering. The fabrics used in this study were prepared for experimental purposes and lacked certain finishing processes that would make the hand more acceptable to the consumer. Observations noted during laundering included: loss of excess finish; variation in hand; odor and color change.

Observed Changes in Color

Whiteness is one of the most desirable characteristics to the American consumer. It denotes not only cleanness but also freshness and purity. Visual observations were made at the conclusion of launderings 10 and 25. Observations were made using the standard viewing conditions described in AATCC Test Method 88C-1973. The visual rating of the fabrics laundered with phosphate detergent and non-phosphate soap are shown on Table 1. The laundered flame retardant finished fabrics are compared to the unlaundered control fabrics using AATCC Grey Scale for Staining to determine any variation in color. Also noted was the cast of white: yellow/white, blue/white or grey/white. The information is by nature subjective and is therefore presented in general terms.

There was a change in color with the application of the flame retardant finishes to both the all cotton fabrics and to the blends. With repeated launderings in the launderometer more color change was apparent in both the control and the flame retardant finished fabrics.

Unfinished (control) fabrics. The all cotton fabrics were not as white or bright as either the 70/30 or the

Table 1

Visual Rating of Selected Fabrics Laundered with Phosphate and Non-phosphate Detergents

	10 Launderings		25 Launderings	
	Detergent		Detergent	
	Phosphate	Non-phosphate	Phosphate	Non-phosphate
Control				
All Cotton	4 yw	4-5 bw	4 yw	4-5 bw
70/30 Blend	4 yw	4-5 bw	4 yw	4-5 bw
50/50 Blend	4 yw	4 bw	4-5 yw	5 bw
APO-THPC				
All Cotton	5 yw	5 yw	5 yw	5 yw
70/30 Blend	4-5 yw	4-5 yw	4-5 yw	4-5 yw
50/50 Blend	4 yw	4 yw	4-5 yw	4-5 yw
THPC-urea-MM				
All Cotton	4-5 bw	4-5 bw	4-5 bw	4-5 bw
70/30 Blend	5 bw	5 bw	5 bw	5 bw
50/50 Blend	5 bw	5 bw	5 bw	5 bw
THPOH-NH3				
All Cotton	4-5 yw	4 bw	4-5 bw	4 bw
70/30 Blend	4-5 yw	4-5 bw	4-5 yw	4-5 bw
50/50 Blend	4-5 yw	4-5 bw	4-5 yw	4-5 bw

yw--yellow white
bs--blue white

50/50 blend fabrics. Observation showed both a blue cast and a yellow cast of white which were noted as "bw" and "yw." Both the all cotton and the 70/30 blend of the control group showed that fabrics laundered with non-phosphate detergent rated half a step higher on the grey scale with a blue white cast at both laundering 10 and 25. Fabrics laundered with the phosphate detergent had a yellow white cast. The 50/50 blend fabrics laundered with both the phosphate and the non-phosphate detergents had the same rating of 4; however, fabrics laundered with the phosphate detergent were yellow white and those laundered with the non-phosphate detergent were blue white at the 10th laundering. Following the 25th laundering the non-phosphate detergent produced a blue white coloration which was a half step higher on the rating scale than the yellow white produced by the phosphate detergent.

APO-THPC finished fabrics. The APO-THPC finished fabrics of all cotton laundered with both the phosphate and the non-phosphate detergents rated 5 with a yellow white cast. The 70/30 blend laundered with both phosphate and non-phosphate detergents rated 4-5 with a yellow white cast following laundering 10 and 25. The 50/50 blend was also

yellow white following laundering with both detergents. A 4 rating was given following laundering 10 and a 4-5 following laundering 25.

THPC-urea-MM finished fabrics. Fabrics treated with THPC-urea-MM had a blue white cast at each observation point. The all cotton fabrics laundered with both detergents were rated 4-5 following both 10 and 25 launderings. The two fabric blends rated 5 when laundered with both detergents following 10 and 25 launderings.

THPOH-NH3 finished fabrics. The all cotton fabrics laundered with the two detergents differed in color rating. Following 10 launderings with the phosphate detergent, there was a slight yellow white color (4-5). Laundering 10 times with the non-phosphate detergent produced a blue white cast. Following 25 launderings, both detergents produced a blue white cast. The phosphate detergent produced slightly less color change than the non-phosphate detergent. Both the 70/30 and the 50/50 blend fabrics laundered with the phosphate were yellow white while those laundered with the non-phosphate detergent were blue white. Color changes following 10 and 25 launderings were rated 4-5.

As a matter of interest visual tests were also made on fabrics laundered 25 times using the "daylight" setting of the Macbeth Light. This evaluation is shown in Table 2. The unfinished fabrics laundered with the phosphate detergent had a yellow cast while those laundered with the non-phosphate detergent had a blue cast. The all cotton rated +4-5, or whiter than the original fabric when laundered with both the phosphate and the non-phosphate detergents. The 70/30 blend rated 4 with the phosphate detergent and 5 with the non-phosphate detergent. The 50/50 blend rated 4 with the phosphate detergent and the non-phosphate detergent rated +4-5 which is whiter than the original. The APO-THPC finish applied to all three fabrics and laundered with both detergents was yellow and rated 4 with the exception of the 50/50 blend that was laundered with the non-phosphate detergent and rated 3-4. The all cotton fabric finished with THPC-urea-MM was blue white and rated 4-5 with the phosphate detergent and 5 when laundered with the non-phosphate detergent. The 70/30 blend rated the same as the all cotton fabric except that the phosphate detergent was yellow white. The 50/50 blend was blue white and both the phosphate and the non-phosphate detergent rated 5. The THPOH-NH3 finished fabrics laundered with the phosphate

Table 2

Visual Rating Using the Macbeth Light of Selected Fabrics Laundered with Phosphate and Non-phosphate Detergents

	Laundering 25	
	Detergent	
	Phosphate	Non-phosphate
Control		
All Cotton	+4-5 yw	+4-5 bw
70/30 Blend	4 yw	5 bw
50/50 Blend	4 yw	+4-5 bw
APO-THPC		
All Cotton	4 yw	4 yw
70/30 Blend	4 yw	4 yw
50/50 Blend	4 yw	3-4 yw
THPC-urea-MM		
All Cotton	+4-5 bw	5 bw
70/30 Blend	+4-5 yw	5 bw
50/50 Blend	5 bw	5 bw
THPOH-NH3		
All Cotton	4-5 yw	+ 4 bw
70/30 Blend	4 yw	+4-5 bw
50/50 Blend	4 yw	+4-5 bw

yw--yellow white
bw--blue white
+--whiter than original

detergents were yellow white while the non-phosphate laundered fabrics were blue white. All ratings were 3-4 and above with the all cotton, the 70/30 and the 50/50 blends laundered with both phosphate and non-phosphate detergents.

Changes in Hand and Odor

Hand, or the way a fabric feels, varied among the fabrics used in this study. The application of flame retardants added weight to the fabric and made several fabrics stiff and heavy, since the fabrics were not given a final washing and softening finish. Some of the stiffness and heaviness was lost in the early launderings. The unfinished control fabrics were soft both before and after the 25 launderings. The hand of APO-THPC and THPOH-NH3 finished fabrics would have been acceptable to the consumer before launderings but were softer following laundering. The THPC-urea-MM finished fabrics had a very stiff hand before laundering. The fabrics with this finish remained the stiffest and the harshest of hand after laundering regardless of the fiber content, the type of laundering detergent used, or the number of times laundered.

The flame retardant finished fabrics emitted a repugnant odor during the first laundering. This odor,

like the excess finish, was not a noticeable characteristic of the finishes during the remaining launderings of the fabrics.

Characteristics of Water

Samples of tap water and water with each of the detergents were collected following each of the 25 launderings. With the cooperation of the Greensboro Water Works, these samples were tested for pH, turbidity, hardness, and conductivity.

The pH of the water with the phosphate detergent varied from 9.3 to 9.7 whereas, the pH of the water with the non-phosphate detergent varied from 9.5 to 10.0. The water with the phosphate detergent generally maintained a lower pH than the water with the non-phosphate detergent. The exception was found following laundering 22 where the pH of the water with the phosphate detergent was 9.7 and that of the non-phosphate detergent, 9.5. This was the highest rating of the phosphate detergent and the lowest rating of the non-phosphate detergent.

The specific conductivity of the water tested at 85° F. tended to range from 145 to 150 and was lower than 145 only at one point. This deviation was a specific conductivity of 135 at laundering 8.

The hardness of the water varied from 42-52 parts per million (ppm) which is considered soft water. The water samples read 51 ppm at launderings 13 and 17 and dropped as low as 42 ppm at laundering 20. The average rating throughout the study was 46 ppm.

The rating of turbidity of the treated Greensboro water ranged from .03 to .07. The turbidity tended to fluctuate between .03 and .05 and ranged to .07 at one point (laundering eight).

THE PHYSICAL MEASUREMENT OF COLOR AND THE ANALYSIS OF COLOR DIFFERENCES

The second section of the presentation of data pertains to the measurement of color and color differences using the Hunterlab Color and Color Difference Meter. Using an analysis of variance the measurements from the L, a, b, ΔL, Δa, Δb, ΔE scales of the Color and Color Difference Meter were analyzed statistically. The data from the unlaundered fabrics were treated as the control and the basis for a study of color and color difference. The factors for an analysis of variance of the flame retardant finished fabrics laundered in phosphate and non-phosphate detergent were: 3 fabrics (all cotton, 70/30 and 50/50

cotton and polyester blends), 2 detergents (phosphate and non-phosphate), and 4 treatments (Unfinished, APO-THPC, THPC-urea-MM, and THPOH-NH3). Analysis was made of the interaction of the detergents, fabrics, and treatments at each laundering level. The data pertaining to the mean readings of color difference before laundering and level of statistical significance can be found on Table 3. The mean units of color and color difference and the level of statistic significance of difference after laundering can be found on Tables 4 and 5.

The Color Differences Among Fabrics

The readings made on the selected fabrics before laundering were used as the control for the study. These measurements were based on the color blocks used to standardize the Humterlab Color and Color Difference Meter Model D-25. Before laundering the color measurements on the L, a, and b scales were highly significant at the .001 level of confidence (Table 3). The lightness (L) readings varied with the 70/30 blend being the highest at 88.76 while the 50/50 blend had the lowest lightness reading of 88.26. On the "a" scale (red + to greenness -) the all cotton showed a reading of -0.74. The fabric blends both showed

Table 3

Mean Measurements of Color Differences Before Launderings and Levels of Statistical Significance of Differences

	L Scale	a Scale	b Scale
Fabrics			
All Cotton	88.74	-0.74	3.92
70/30 Blend	88.76	1.85	-1.36
50/50 Blend	88.26	2.25	-2.11
Level of Significance	**	**	**
Detergents			
Phosphate	88.57	1.10	0.21
Non-phosphate	88.59	1.15	0.09
Level of Significance	NS	NS	NS
Treatments			
Control	88.77	2.05	-1.98
APO-THPC	87.79	-0.24	3.88
THPC-urea-MM	87.76	2.23	-1.94
THPOH-NH3	90.09	0.45	0.65
Level of Significance	**	**	**

NS--Non Significant
**--Significant at the .001 level
All readings are positive unless indicated as negative.

Table 4

Mean Units of Color Difference Among Selected Fabrics Following Laundering and Level of Statistical Significance of Differences

	L	a	b	E
	Units of Difference			
Laundering 1				
All Cotton	0.22	2.51	-4.55	5.28
70/30 Blend	0.42	1.38	-2.33	3.09
50/50 Blend	0.24	1.09	-1.82	2.24
Level of Significance	NS	**	**	**
Laundering 5				
All Cotton	1.10	4.29	-8.43	9.53
70/30 Blend	0.68	2.28	-4.20	4.87
50/50 Blend	0.82	1.70	-3.13	3.72
Level of Significance	**	**	**	**
Laundering 10				
All Cotton	1.07	4.13	-8.33	9.37
70/30 Blend	0.62	2.08	-3.65	4.37
50/50 Blend	0.74	1.42	-2.72	3.27
Level of Significance	**	**	**	**
Laundering 15				
All Cotton	1.03	3.90	-7.64	8.66
70/30 Blend	0.61	1.86	-3.24	3.90
50/50 Blend	0.68	1.03	-2.01	2.65
Level of Significance	**	**	**	**
Laundering 25				
All Cotton	1.08	3.15	-7.35	8.83
70/30 Blend	0.51	1.77	-3.25	4.15
50/50 Blend	0.54	1.14	-1.19	2.99
Level of Significance	**	**	**	**

NS--Non Significant
**--Highly Significant at the .001 Level
All readings are positive unless indicated as negative.

Table 5

Mean Units of Color Difference Among Phosphate and Non-phosphate Detergents Following Laundering and Level of Statistical Significance of Difference

	L	a	b	E
	Units of Difference			
Laundering 1				
Phosphate	0.40	1.90	-3.45	4.00
Non-phosphate	0.20	1.42	-2.35	3.07
Level of Significance	NS	**	**	**
Laundering 5				
Phosphate	0.95	2.64	-5.14	5.91
Non-phosphate	0.79	2.86	-5.36	6.17
Level of Significance	**	**	**	**
Laundering 10				
Phosphate	0.87	2.36	-4.57	5.29
Non-phosphate	0.74	2.73	-5.23	6.01
Level of Significance	**	**	**	**
Laundering 15				
Phosphate	0.78	1.95	-3.80	4.54
Non-phosphate	0.76	2.58	-4.79	5.59
Level of Significance	NS	**	**	**
Laundering 25				
Phosphate	0.72	1.56	-3.89	4.90
Non-phosphate	0.71	2.48	-3.97	5.75
Level of Significance	NS	**	**	**

NS--Non Significant
**--Highly Significant at the .001 Level
All readings are positive unless indicated as negative.

positive (red) readings of 2.25 of the 50/50 blend the 1.85 of the 70/30 blend. The "b" scale indicated the contrast in blueness and yellowness of all cotton and fabric blends. The all cotton showed a reading of 3.92 (yellow) while the 70/30 blend and the 50/50 blend were on the blue scale (-1.36 and -2.11 respectively).

Color differences of the fabrics following laundering were highly significant at the .001 level of confidence on the four scales used (ΔL, Δa, Δb, and ΔE). The one exception was the small difference noted in the ΔL readings following the first laundering.

Following each laundering period the mean ΔE readings of the all cotton fabrics were higher than the differences in the fabric blends. The smallest differences were noted in the 50/50 fabric blends. This indicated a decrease in the mean color difference as the polyester content increased. The highest mean difference in color of each of the three fabrics occurred at the fifth laundering period. At this point there was a difference of 9.53 units in the color of the all cotton fabrics as compared with the 4.87 units of the 70/30 blend and the 3.72 units of the 50/50 blend. Even though color differences decreased after

10, 15, and 25 launderings the total differences were not comparable to those at the first laundering.

The same general trends were noted on the ΔL, Δa, Δb scales. With the exception of the small differences in the three fabrics shown by the ΔL scale following one laundering, differences in the all cotton fabrics were greater than those of the fabric blends as read on all three scales. Again the greatest differences were recorded following the fifth laundering period. The tables of ratings are included in the Appendix as Appendixes A through G.

Effect of Detergents upon Color Differences

Two sets of experimental fabrics were prepared. One set was to be laundered with phosphate detergent, the other with a non-phosphate detergent. Readings made of the whiteness of the fabrics prior to laundering indicated no significant differences between the two sets. It was then presumed that differences from the control or unlaundered sets of fabrics would indicate the effect of the detergent upon the fabric whiteness. The effect of the detergents upon the ΔL, Δa, Δb, and ΔE measurements following laundering and the statistical significance of differences in the effect of the two detergents are shown on Table 5.

The total units of color difference (ΔE) between fabrics laundered with the phosphate detergent and those laundered with the non-phosphate detergent were highly significant following 1, 5, 10, 15, and 25 launderings. Following the first laundering, the fabrics laundered with the phosphate detergent showed slightly higher units of difference (4.00) than the fabrics laundered with the non-phosphate detergent (3.07). The reverse was true following each subsequent laundering period with the non-phosphate detergent producing higher units of color difference. The most noticeable color differences were apparent after the fifth laundering. At this point the fabrics laundered with the phosphate detergent showed a mean difference of 5.91 units as compared with the mean of 6.17 units difference of fabrics laundered with non-phosphate detergents.

The differences shown by the ΔL, Δa, and Δb scales were somewhat more varied and indicated more critically the effect of each detergent upon the whiteness of the fabrics. The ΔL scale which indicates the differences in lightness much as they might be perceived by the eye were very small. Differences significant at the .001 level of confidence were noted following 5 and 10 launderings. The ΔL readings of the fabrics laundered with the phosphate detergents were

slightly higher than those of the non-phosphate detergents following each laundering period.

The Δa values indicating the differences in redness (+) or greenness (-) of the laundered fabrics as compared with the unlaundered fabrics were positive. Differences in color influenced by the two detergents were significant at the .001 level of confidence following each laundering period. At the first laundering period the phosphate detergent seemed to produce more difference in redness, however, following 5, 10, 15 and 25 launderings, redness values caused by the non-phosphate detergents were slightly higher.

The Δb scale indicated definite blueness characteristics with differences in the effect of the two detergents. Except for the small difference noted following the 25th laundering, differences between detergents at all other laundering periods were statistically significant. As was found in the preceding scales, the phosphate detergent produced the highest blueness following the first laundering and the non-phosphate detergents the highest blueness following all other launderings. The most noticeable color changes were again apparent following the fifth laundering.

Color Differences of Flame Retardant Treated Fabrics

Before laundering. Measurements of color differences made on the L, a, and b scales were used to indicate the whiteness of the fabrics before laundering and to serve as a control to which color differences following laundering might be compared. These readings were based on the color blocks used to standardize the Hunterlab Color and Color Difference Meter. Readings on the L, a, and b scales made on the fabrics with no flame retardant treatment and on the same fabrics that had been treated with three flame retardants were then analyzed statistically to determine the importance of any differences in whiteness before laundering.

All scales indicated differences in the fabrics. Differences because of the treatments were statistically significant at the .001 level of confidence (Table 3, page 48). Differences in lightness as indicated on the L scale, though statistically significant, were small. These ranged from the 90.0 mean reflectance of THPOH-NH3 fabrics to approximately 87.8 for the APO-THPC and THPC-urea-MM treated fabrics.

More variation was shown in the scales indicating color. The a scale indicated a wide range from red (+) to greenness (-) among the four treatments. The rank order of the four treatments was as follows:

THPC-urea-MM	+2.23
Unfinished	+2.05
THPOH-NH3	+0.45
APO-THPC	-0.24

The b scales, indicating yellowness (+) to blueness (-) showed reflectance values in reverse order. The rank order of the four treatments are as follows:

APO-THPC	+3.88
THPOH-NH3	+0.65
THPC-urea-MM	-1.94
Unfinished	-1.98

<u>After laundering</u>. The laundered fabrics showed considerable difference among treatments on the ΔL, Δa, and Δb scales. The differences following each laundering period were significant at the .001 level of confidence.

The highest mean total color differences (ΔE) were found in the unfinished fabrics laundered one time and in the THPOH-NH3 treatment after each of the remaining

launderings. The lowest total color difference was that of the THPC-urea-MM treatment following 1, 5, and 10 launderings but changed to the APO-THPC treatment following the 15th and the 25th launderings.

The untreated fabrics were consistent in having the highest mean lightness (ΔL) difference at each laundering period.

The greatest evidence of color as indicated by the mean Δa and Δb scales were in the untreated fabrics laundered one time and in the THPOH-NH3 treated fabrics following each of the remaining laundering periods. The least evidence of color was, in the most cases, noted on the THPC-urea-MM finish.

The Interaction of the Fabrics, Detergents, and Treatments

There were interaction among the three factors (fabrics, detergents, and treatments) of this study. The mean ΔE readings showed that the all cotton fabrics with all finishing treatments had the lowest original readings of color difference of the three types of fabrics used in this study. All fabric treatments laundered with both detergents tended to increase in units of color difference through the fifth laundering period. From this point, the

untreated fabric and the flame retardant treated fabrics showed more variation in color difference according to the type of detergent used. Where the color differences of the untreated, the APO-THPC, and the THPOH-NH3 treated fabrics generally decreased in units of color difference, the THPC-urea-MM treated fabrics increased in color differences when laundered with both detergents.

The 70/30 and the 50/50 cotton and polyester blends followed the same general pattern. Prior to laundering all treatments except THPOH-NH3 the 50/50 blend had higher units of color difference than the 70/30 blend. There was a sharp decline in color difference at laundering 1 with the untreated blends. The fabrics laundered in non-phosphate detergent maintained maximum color difference from laundering 5 to laundering 25 with only slight fluctuations; whereas, the fabrics laundered with the phosphate detergent, though they reached maximum color difference at laundering 5, showed a decrease in color difference through laundering 15 and a slight increase at laundering 25.

The blends treated with APO-THPC were much the same as the untreated, with a decrease in color difference at laundering 1 and maximum color difference at laundering 5. The fabrics laundered with phosphate detergent showed a

greater increase in color difference than those laundered with the non-phosphate detergent.

The blends treated with THPOH-NH3 varied more. The 70/30 blend showed an increase in color difference in the fabrics laundered with both detergents. The non-phosphate detergent attained a greater degree of color difference and maintained it throughout laundering while the phosphate detergent decreased in color difference.

The 50/50 blend decreased in color difference at laundering 1 and reached the maximum color difference at laundering 5. From that point the fabrics laundered with both detergents decreased in color difference. The phosphate detergent had a slight increase in color difference at laundering 25, however, this remained considerably lower than the color difference reading of the non-phosphate detergent.

The Interaction of the Fabrics and Treatments

The mean readings of total color difference were highly significant at the .001 level of confidence at all laundering periods. This interaction of fabrics and treatments is shown in Figure 4.

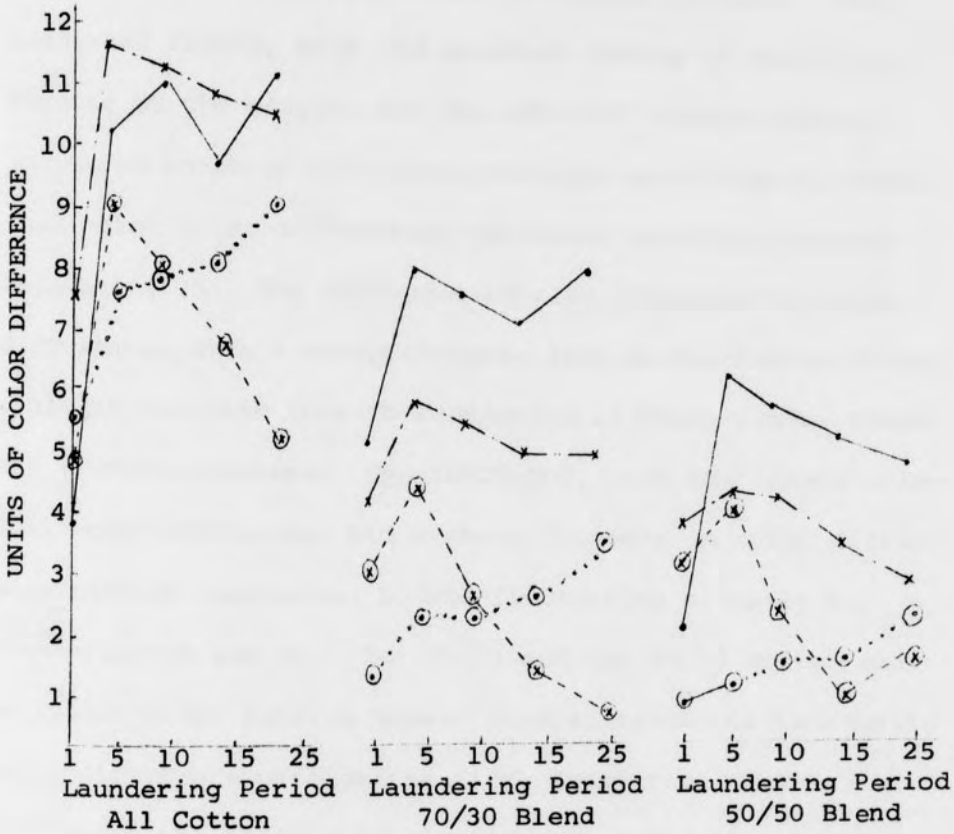

Figure 4

The Interaction of Fabrics and Treatments

Key

Untreated

APO-THPC

THPC-urea-MM

THPOH-NH3

The 100% cotton fabrics finished with the various treatments had a scattered and irregular pattern. The untreated fabric, with the greatest degree of color difference at the origin, and the APO-THPC treated fabric increased in color difference through laundering 5. From that point color differences decreased steadily through laundering 25. The THPC-urea-MM also increased in color difference, with a sharp increase through laundering 5 and a slight increase through laundering 15 when, again, there was a sharp increase. The THPOH-NH3, with the lowest original color difference had a sharp increase in color difference through laundering 10 and fluctuating slightly at laundering 15 and 25. The 70/30 and the 50/50 cotton and polyester blend fabrics showed similar trends of increasing color difference through the fifth laundering period. At this point the treated fabrics in rank order of color difference were: THPC-urea-MM, APO-THPC, untreated, and THPOH-NH3. At laundering 10 and 15 the 70/30 and 50/50 blends treated with APO-THPC decreased in color difference while the THPC-urea-MM increased in color difference.

The Interaction of the Fabrics and Detergents

The significant interaction between the fabrics and the detergents is shown in Figure 5. The interaction

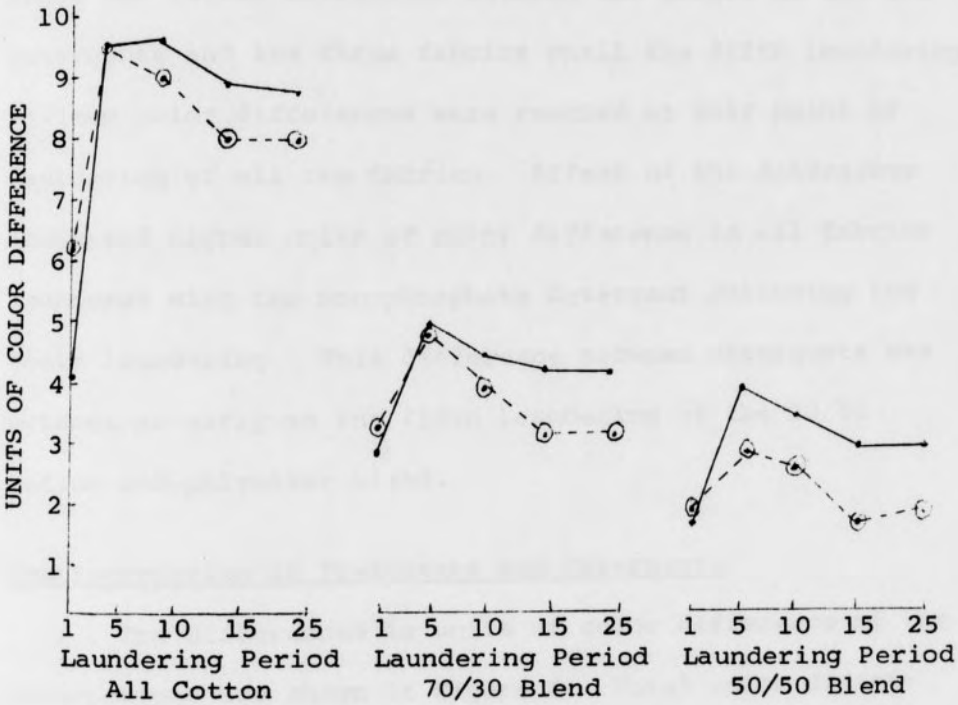

Figure 5

The Interaction of Fabrics and Detergents

Key
Phosphate Detergent ⊙- - - - - -
Non-phosphate Detergent •———

effect indicated higher units of color difference in the fabrics as the cotton content increased. In most cases there was little difference between the effect of the two detergents and the three fabrics until the fifth laundering. Maximum color differences were reached at this point of laundering of all the fabrics. Effect of the detergents indicated higher units of color difference in all fabrics laundered with the non-phosphate detergent following the tenth laundering. This difference between detergents was evident as early as the fifth laundering of the 50/50 cotton and polyester blend.

The Interaction of Treatments and Detergents

The differences in units of color difference of the interactions are shown in Figure 6. Total color differences are non-significant at laundering 1 but, from that point on the readings were highly significant at the .001 level of confidence. Both the phosphate and the non-phosphate detergent had similar trends after laundering 1: THPC-urea-MM, APO-THPC, THPOH-NH3 and the untreated fabric, in rank order of low to high color difference. After laundering 5, though all increase in color difference, THPOH-NH3 showed the greatest increase in color difference

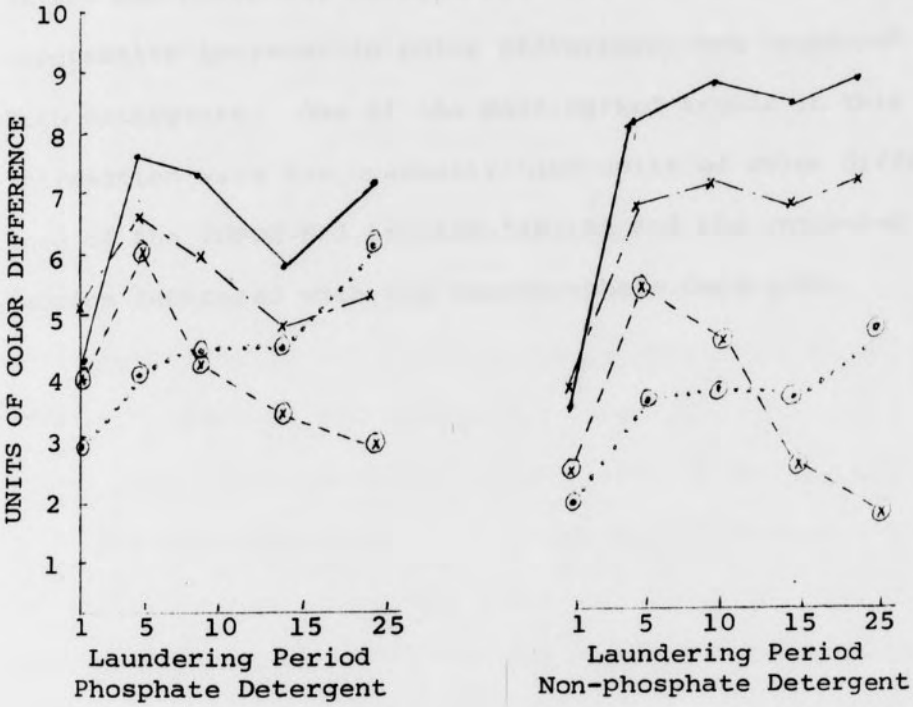

Figure 6

The Interaction of Treatments and Detergents

Key

Untreated	✗ —— · ——
APO-THPC	⊗ - - - - - - - -
THPC-urea-MM	⊙ . . . . .
THPOH-NH3	————————

through laundering 25. There was very slight difference in the APO-THPC treated fabrics laundered with the phosphate or the non-phosphate detergents. The THPC-urea-MM showed a progressive increase in color difference when laundered with both detergents. One of the most marked trends in this interaction were the unusually high units of color difference of the THPOH-NH3 treated fabrics and the untreated fabrics laundered with the non-phosphate detergent.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

Reports of the injuries from burning clothes, bedding, upholstery, and other textile products emphasize the need for precautionary measures to protect the consumers of textile products. The United States as early as 1945 passed legislation which banned the sale of fabrics more flammable than cotton in its natural state. About this same time the need for flame retardant finishes applied so as to react with cellulose and make cotton less flammable was recognized. Flame retardant finishes acceptable to the consumer must give acceptable fabric characteristics such as durability, color retention, pleasant hand and weight. Studies are underway to solve difficulties in these various areas.

The purpose of this study was to measure the whiteness retention of the flame retardant finished fabrics laundered with commercially available phosphate and non-phosphate detergents. The objectives of this study were to

determine whether there were color differences in the fabrics, detergents, and flame retardant finishes and to determine, by means of statistical analysis, the significance of color differences and interactions among the three main factors.

Description of the Fabrics, Treatments, and Detergents

The fabrics used in the study were those prepared for experimentation for the Regional Research Project SM-38. Three fabrics of varying fiber content (100% cotton, 70/30 and 50/50 cotton and polyester blends) were finished by the Southern Research Center with three flame retardant finishes (tris-(1-aziridinyl) phosphine oxide tetrakis (hydroxymethyl) phosphonium chloride, tetrakis (hydroxymethyl) phosphonium chloride urea methylemelamine, and tetrakis (hydroxymethyl) phosphonium hydroxide ammonia cure). One group of the fabrics remained unfinished as the control, making a total of 12 fabrics.

The experimental fabrics were laundered with two types of detergents. The selected detergents were a phosphate detergent and a non-phosphate soap product available for home laundering usage. The two detergents differed

chiefly in the builder. The phosphate detergent had a phosphate builder and the non-phosphate detergent a carbonate builder.

Description of Laundering Procedure and Water Determination

With the use of a chart of random numbers the samples were assigned to fabric and detergent combinations (cells) for loading of the launderometer (blocks). Each sample was placed in a launderometer jar with .5% detergent and 500 ml of water and laundered for 30 minutes in a launderometer at 120° F. At the completion of the laundering the samples were given 3 one minute hand rinses for the removal of detergent. The samples were then hydro extracted and steam pressed. To more nearly simulate the laundering procedures used by the consumer, Greensboro city water was used. Specimens of tap water and water with a .5% of phosphate or non-phosphate detergent were collected after each cycle. These samples were tested for hardness, specific conductance, turbidity, and pH.

Description of Color Measurement

Measurement of color change was made after 1, 5, 10, 15, and 25 launderings on the Hunterlab Color and Color

Difference Meter, Model D-25. This instrument operates on the L, a, b, and E scales. L indicates lightness, the "a" indicates redness (+) to greenness (-), and "b" indicates yellowness (+) to blueness(-). The instrument was standardized by the white and color blocks accompanying the instrument. The unlaundered or control group of fabrics was compared to the standardization blocks and became the control from which the color difference of the laundered fabrics could be determined. The difference was recorded on the Δ L, Δa, Δb, and Δ E scales.

Visual Observation of Color

Visual observations of color and color change were made after laundering 10 and laundering 25, according to the procedure outlines in AATCC Test Method 88C-1973. It was noted that there was change in color with all fabrics with the application of the flame retardant finishes. The fabrics varied in the alteration of whiteness from blue white, to grey white, and to yellow white.

The untreated fabrics laundered with phosphate detergents had a yellow white cast and those laundered with non-phosphate detergents had a blue white cast. The 100% cotton was not as white or as bright as either the 70/30 or the 50/50 cotton and polyester blends.

The APO-THPC treated fabrics had a yellow white cast with both the phosphate and non-phosphate detergent launderings. With this treatment the all cotton remained the same as the original (class 5) while the blends with slightly greater color difference were rated 4-5.

The THPC-urea-MM treated fabrics had a blue white cast throughout. The blends rated the same as the original while the 100% cotton had a slightly more noticeable color difference and was rated 4-5.

The THPOH-NH3 treated fabrics were slightly yellow at laundering 10 when laundered with phosphate detergent, otherwise there was a blue cast with both detergents at both periods.

The visual tests made at the conclusion of laundering 25 using the "daylight" setting of the Macbeth Light were much the same as the tests made using the AATCC Test Method 88C-1973. Generally the flame retardant finished fabrics laundered with phosphate detergent had a yellow white cast and those laundered with non-phosphate detergent had a blue white cast. Fabrics laundered with the phosphate detergent had greater color difference than the fabrics laundered with the non-phosphate detergent.

Physical Measurement of Color and Color Change

Fabrics. The color differences among the fabrics were highly significant at the .001 level of the ΔE scale. Following each laundering period the 100% cotton had higher color difference than the blends. There seemed to be an indication that there was a decrease in color difference as the amount of polyester increased. The highest mean color difference occurred at laundering 5 and from that point to laundering 25 there was a decrease in color difference but not comparable to the decrease drop at laundering 1. The ΔL, Δa, Δb scales follow the same trends as ΔE.

Detergents. The effect of the detergents on color difference was non-significant before laundering and it was therefore presumed that any subsequent differences would indicate the effect of detergents on fabric whiteness. The differences in color were highly significant at the .001 level from laundering 1 to laundering 25. After the first laundering the fabrics laundered with the phosphate detergent showed greater color difference than those laundered in the non-phosphate detergent. All subsequent launderings the non-phosphate laundered fabrics showed greater color difference. The most noticeable color change was at

laundering 5. The Δ L scale showed the phosphate laundered fabrics to be higher in lightness than the non-phosphate laundered fabrics. The Δ a and the Δ b scales follow the same trends as the Δ E readings which are readings of total color difference.

Finishes. The color difference among the finishing treatments was highly significant at the .001 level on all scales. There was more variation in the scales indicating color. The rank order of the color difference of the finishing treatments was in almost reverse order on the Δ a and the Δ b scales. The lowest color difference was found in THPC-urea-MM at laundering 1, 5, and 10 and in APO-THPC at laundering 15 and 25. The greatest evidence of color change was found in the untreated or control fabrics at laundering 1 and in the THPOH-NH3 treated fabrics at each of the following launderings. The THPC-urea-MM finished fabrics showed the least evidence of color.

There were interactions between the three main factors of this study. In most cases these interactions were highly significant at the .001 level. Color differences among each factor and the interactions of factors reached the maximum level at laundering 5 and tended to decrease from that point.

CONCLUSIONS

The results of this study indicate the following conclusions:

1. There were visible color changes following laundering with both phosphate and non-phosphate detergents.

2. There were highly significant color differences among the finished and the unfinished fabrics before laundering. Therefore, Hypothesis 1 stating that there would be no difference in whiteness retention of the finished and unfinished fabrics before laundering was rejected.

3. There were highly significant differences in unfinished and finished fabrics following laundering. Hypothesis 2 was also rejected.

4. There were significant differences in the whiteness retention of the fabrics laundered with phosphate and non-phosphate detergents. Hypothesis 3 was rejected.

5. Hypothesis 4 was also rejected since there were significant interactions of the fabrics, the finishing treatments, and the detergents.

RECOMMENDATIONS

The areas of whiteness retention and flame retardancy are a broad fields of study and have many topics that need

to be developed. Among these are:

1. Determination of the effect of aging upon whiteness retention of flame retardant finished fabrics.

2. Determination of the effect of mineral salts and alkaline earths build-up to color or whiteness retention.

3. Determination of the effect of home care of flame retardant treated fabrics on color retention and permanence of finish.

4. Determination of the effect of optical brightness on the measurement of color.

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BIBLIOGRAPHY

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APPENDIX A

APPENDIX A

Readings on the L and Δ L Scales of Fabrics Laundered with Phosphate Detergent

	Number of Times Laundered					
	0	1	5	10	15	25
L Scale	Percent Reflectance					
Control						
All Cotton	88.8	90.1	90.4	90.7	90.8	90.8
70/30 Blend	88.7	89.4	90.1	90.2	90.1	90.3
50/50 Blend	88.6	89.1	89.6	89.7	89.8	89.9
APO-THPC						
All Cotton	88.3	88.9	89.4	89.0	89.1	88.7
70/30 Blend	87.8	87.9	88.3	88.1	88.4	88.1
50/50 Blend	87.1	87.7	88.4	88.2	88.2	88.0
THPC-urea-MM						
All Cotton	88.9	89.2	89.8	89.8	89.7	89.7
70/30 Blend	87.4	87.2	87.9	87.9	87.7	88.1
50/50 Blend	87.1	87.7	88.0	88.2	88.2	88.3
THPOH-NH3						
All Cotton	88.8	89.3	90.1	90.3	90.0	90.3
70/30 Blend	91.2	91.4	91.8	91.5	91.0	90.0
50/50 Blend	90.0	90.1	90.5	90.4	90.1	89.9
Δ L Scale	Units of Difference					
Control						
All Cotton	-3.7	2.0	1.8	1.7	1.8	1.8
70/30 Blend	-3.8	0.7	1.3	1.4	1.3	1.5
50/50 Blend	-3.9	0.5	1.0	1.0	0.8	1.1
APO-THPC						
All Cotton	-0.6	0.6	1.1	0.7	0.7	0.4
70/30 Blend	-0.8	-0.1	0.3	0.1	0.2	0.2
50/50 Blend	-1.4	0.5	1.2	1.0	1.0	-0.1
THPC-urea-MM						
All Cotton	0.0	0.3	0.8	0.8	0.8	0.7
70/30 Blend	-1.6	0.2	0.9	0.9	0.8	1.1
50/50 Blend	-1.5	0.2	0.8	1.0	1.0	1.1
THPOH-NH3						
All Cotton	-0.5	0.3	1.1	1.2	0.9	1.2
70/30 Blend	2.3	0.3	0.6	0.4	0.0	-0.5
50/50 Blend	1.4	0.1	0.5	0.3	0.1	0.0

All readings are positive unless indicated as negative.

APPENDIX B

APPENDIX B

Readings on the L and ΔL Scales of Fabrics Laundered with Non-phosphate Detergent

	Number of Times Laundered					
	0	1	5	10	15	25
L Scale	Percent Reflectance					
Control						
All Cotton	89.0	90.0	90.7	90.8	90.8	91.0
70/30 Blend	88.7	89.4	90.1	90.2	90.1	90.3
50/50 Blend	88.6	89.1	89.6	89.7	89.8	89.9
APO-THPC						
All Cotton	88.3	88.9	89.4	89.0	89.0	88.7
70/30 Blend	87.8	87.9	88.2	88.1	88.4	88.1
50/50 Blend	87.1	87.7	88.4	88.2	88.2	88.0
THPC-urea-MM						
All Cotton	88.9	89.2	89.8	89.8	89.7	89.7
70/30 Blend	87.4	87.2	87.9	87.9	87.7	88.1
50/50 Blend	87.1	87.7	88.0	88.2	88.2	88.3
THPOH-NH3						
All Cotton	88.8	89.3	90.1	90.3	90.0	90.3
70/30 Blend	91.2	91.4	91.8	91.5	91.0	90.6
50/50 Blend	90.0	90.1	90.5	90.4	90.1	89.9
ΔL Scale	Units of Difference					
Control						
All Cotton	-3.5	1.1	1.7	1.8	1.9	2.0
70/30 Blend	-3.8	0.5	1.2	1.1	1.3	1.5
50/50 Blend	-3.8	0.5	1.0	0.9	1.2	1.1
APO-THPC						
All Cotton	-0.6	-1.3	0.6	0.3	0.2	-0.2
70/30 Blend	-0.5	-0.4	0.3	0.2	0.1	-0.2
50/50 Blend	-1.3	0.3	1.1	0.7	0.5	0.1
THPC-urea-MM						
All Cotton	0.1	-0.5	0.6	0.5	0.5	0.7
70/30 Blend	-1.7	-0.4	0.5	0.7	0.7	1.0
50/50 Blend	-1.4	-0.2	0.6	0.9	0.8	1.0
THPOH-NH3						
All Cotton	0.0	0.0	1.2	1.4	1.4	1.9
70/30 Blend	2.3	2.7	0.3	0.1	0.4	-0.6
50/50 Blend	1.3	0.1	0.3	0.1	0.0	0.0

All readings are positive unless indicated as negative.

APPENDIX C

APPENDIX C

Readings on the a and Δ a Scales of Fabrics Laundered with Phosphate Detergents

	Number of Times Laundered					
	0	1	5	10	15	25
a Scale	Percent Reflectance					
Control						
All Cotton	0.2	4.7	5.2	4.6	4.2	4.0
70/30 Blend	2.8	4.5	4.8	4.3	4.1	0.0
50/50 Blend	3.0	4.8	4.2	4.1	3.3	3.5
APO-THPC						
All Cotton	-2.6	0.0	1.6	1.1	0.7	0.1
70/30 Blend	0.8	2.5	3.1	2.3	1.8	1.1
50/50 Blend	0.8	2.3	2.8	1.9	1.2	0.7
THPC-urea-MM						
All Cotton	0.2	3.0	3.7	3.8	4.0	4.4
70/30 Blend	3.0	3.6	3.8	4.0	4.1	4.3
50/50 Blend	3.4	3.6	3.9	3.6	3.9	4.2
THPOH-NH3						
All Cotton	-0.8	1.2	3.6	3.1	2.6	3.2
70/30 Blend	0.8	2.9	4.3	4.3	3.7	4.1
50/50 Blend	1.4	3.0	4.1	4.0	3.5	3.7
Δ a Scale	Units of Difference					
Control						
All Cotton	1.0	4.4	5.0	4.3	3.9	3.8
70/30 Blend	3.5	1.7	1.9	1.5	1.2	1.1
50/50 Blend	3.8	1.7	1.1	1.0	0.3	0.4
APO-THPC						
All Cotton	-1.6	2.7	4.4	3.8	3.4	2.8
70/30 Blend	-2.1	1.7	2.3	1.6	1.0	0.3
50/50 Blend	-2.3	1.2	1.7	0.8	0.1	-0.3
THPC-urea-MM						
All Cotton	0.0	2.7	3.4	3.6	3.8	2.0
70/30 Blend	0.1	0.7	0.8	0.9	1.1	1.4
50/50 Blend	0.4	0.2	0.5	0.3	0.5	1.4
THPOH-NH3						
All Cotton	-1.0	2.1	4.4	4.2	3.4	4.1
70/30 Blend	-2.1	2.2	3.4	3.6	3.0	3.4
50/50 Blend	-1.6	1.5	2.7	2.6	2.1	2.3

All readings are positive unless indicated as negative.

APPENDIX D

APPENDIX D

Readings on the a and Δ a Scales of Fabrics Laundered with Non-phosphate Detergent

	Number of Times Laundered					
	0	1	5	10	15	25
a Scale	Percent Reflectance					
Control						
All Cotton	0.2	2.8	5.6	5.7	5.5	5.3
70/30 Blend	2.8	4.4	5.5	5.4	5.4	5.3
50/50 Blend	3.0	4.4	5.1	5.1	5.0	5.0
APO-THPC						
All Cotton	-2.7	-0.9	1.2	0.9	0.5	-0.1
70/30 Blend	0.9	2.0	3.0	2.4	1.7	1.1
50/50 Blend	1.3	2.5	2.9	2.2	1.3	0.6
THPC-urea-MM						
All Cotton	0.2	2.6	3.2	3.1	3.2	3.6
70/30 Blend	3.0	3.4	3.8	3.5	3.6	3.9
50/50 Blend	3.5	6.7	3.8	3.5	3.6	3.8
THPOH-NH3						
All Cotton	-0.8	0.9	4.5	4.9	4.9	5.1
70/30 Blend	0.7	2.3	4.8	5.0	5.0	5.0
50/50 Blend	1.4	2.3	4.7	4.9	4.8	4.7
Δ a Scale	Units of Difference					
Control						
All Cotton	1.0	2.5	5.5	5.4	5.4	5.3
70/30 Blend	3.5	1.6	2.7	2.5	2.5	2.4
50/50 Blend	3.8	1.4	2.1	2.0	1.9	1.8
APO-THPC						
All Cotton	-3.0	1.8	3.9	3.6	3.2	2.6
70/30 Blend	-1.9	1.1	2.1	1.5	1.0	0.3
50/50 Blend	-1.7	1.4	1.8	1.1	0.2	-0.2
THPC-urea-MM						
All Cotton	0.0	2.3	2.9	2.8	2.9	3.4
70/30 Blend	0.1	0.5	0.8	0.6	0.7	0.9
50/50 Blend	0.4	0.2	0.3	0.0	0.1	0.3
THPOH-NH3						
All Cotton	-1.1	1.6	4.8	5.2	5.2	5.3
70/30 Blend	-2.1	1.5	4.1	4.3	4.4	4.3
50/50 Blend	-1.6	0.9	3.3	3.5	3.4	3.3

All readings are positive unless indicated as negative.

APPENDIX E

APPENDIX E

Readings on the b and Δ b Scales of Fabrics Laundered with Phosphate Detergent

	Number of Times Laundered					
	0	1	5	10	15	25
b Scale	Percent Reflectance					
Control						
All Cotton	1.3	-7.2	-8.2	-7.3	-6.8	-6.6
70/30 Blend	-3.3	-6.7	-7.4	-6.8	-6.4	-6.4
50/50 Blend	-3.9	-7.1	-6.4	-6.4	-5.0	-5.6
APO-THPC						
All Cotton	9.2	4.1	0.9	2.1	3.2	4.6
70/30 Blend	1.4	-1.3	-2.3	-0.9	-0.1	2.0
50/50 Blend	1.6	-1.1	-2.1	0.0	1.1	2.3
THPC-urea-MM						
All Cotton	1.3	-3.8	-5.6	-5.8	-6.1	-6.7
70/30 Blend	-3.1	-4.2	-5.1	-5.3	-5.5	-6.2
50/50 Blend	-4.1	-4.4	-5.0	-5.3	-5.5	-6.0
THPOH-NH3						
All Cotton	3.6	-0.2	-4.6	-4.4	-2.7	-4.2
70/30 Blend	-0.3	-4.3	-6.8	-6.7	-5.2	-6.1
50/50 Blend	-1.3	-4.0	-6.1	-5.7	-4.5	-4.5
Δ b Scale	Units of Difference					
Control						
All Cotton	2.2	-8.0	-9.9	-9.0	-8.4	-8.2
70/30 Blend	-2.5	-3.4	-4.1	-3.5	-3.1	-3.1
50/50 Blend	-3.2	-3.1	-2.5	-3.4	-1.0	-1.7
APO-THPC						
All Cotton	7.7	-5.3	-8.5	-7.3	-6.2	-4.9
70/30 Blend	4.8	-2.6	-3.6	-2.0	-0.8	0.5
50/50 Blend	5.5	-2.0	-3.1	-1.1	0.2	1.2
THPC-urea-MM						
All Cotton	0.0	-5.2	-7.3	-7.5	-7.9	-8.4
70/30 Blend	0.3	-1.2	-2.3	-2.3	-2.5	-3.2
50/50 Blend	-0.7	-0.3	-0.9	-1.2	-1.4	-1.9
THPOH-NH3						
All Cotton	2.2	-3.8	-8.1	-8.3	-6.3	-7.8
70/30 Blend	3.0	-4.0	-6.5	-5.5	-4.9	-5.9
50/50 Blend	2.6	-2.6	-4.8	-4.4	-3.2	-3.2

All readings are positive unless indicated as negative.

APPENDIX F

APPENDIX F

Readings on the b and Δb Scales of Fabrics Laundered with Non-phosphate Detergent

	Number of Times Laundered					
	0	1	5	10	15	25
b Scale	Percent Reflectance					
Control						
All Cotton	2.1	-4.6	-10.7	-10.9	-10.7	-10.8
70/30 Blend	-2.6	-3.0	- 5.2	- 5.1	- 5.1	- 5.2
50/50 Blend	-3.2	-2.4	- 4.1	- 4.1	- 3.9	- 4.1
APO-THPC						
All Cotton	8.1	-2.5	- 7.0	- 6.4	- 5.4	- 0.3
70/30 Blend	4.6	-1.4	- 3.0	- 1.9	- 0.6	- 0.7
50/50 Blend	4.2	-2.5	- 3.2	- 1.8	- 0.3	- 1.2
THPC-urea-MM						
All Cotton	0.0	-4.0	- 6.1	- 6.0	- 5.6	- 6.8
70/30 Blend	0.3	-0.3	- 1.5	- 1.5	- 1.6	- 2.4
50/50 Blend	-0.4	-0.1	- 0.5	- 0.6	- 0.5	- 1.4
THPOH-NH3						
All Cotton	2.2	-3.1	- 9.9	-11.1	-10.5	-11.5
70/30 Blend	3.0	-2.6	- 7.3	- 7.3	- 7.2	- 7.3
50/50 Blend	2.5	-1.5	- 5.9	- 5.9	- 5.8	- 0.0
Δ b Scale	Units of Difference					
Control						
All Cotton	1.3	-3.6	- 9.0	- 9.2	- 9.0	- 9.1
70/30 Blend	-3.4	-6.4	- 8.5	- 8.5	- 8.4	- 8.5
50/50 Blend	-3.9	-6.4	- 8.0	- 8.0	- 7.9	- 8.0
APO-THPC						
All Cotton	9.5	7.0	2.5	3.0	4.1	5.2
70/30 Blend	1.2	-0.1	- 1.6	0.0	0.7	2.1
50/50 Blend	0.3	-1.5	- 2.1	- 0.7	0.9	2.3
THPC-urea-MM						
All Cotton	1.3	-2.7	- 4.4	- 4.3	- 4.3	- 5.2
70/30 Blend	-3.0	-3.4	- 4.5	- 4.4	- 4.6	- 5.1
50/50 Blend	-4.1	-4.2	- 4.6	- 4.7	- 4.6	- 5.1
THPOH-NH3						
All Cotton	3.6	0.5	- 6.4	- 7.7	- 7.0	- 8.0
70/30 Blend	-0.4	-3.0	- 7.5	- 7.6	- 7.4	- 7.6
50/50 Blend	-1.4	-2.8	- 7.1	- 7.2	- 7.1	- 6.4

All readings are positive unless indicated as negative.

APPENDIX G

APPENDIX G

Readings on the ΔE Scale of the Fabrics Laundered with Phosphate and Non-phosphate Detergent

	Number of Times Laundered					
	0	1	5	10	15	25
	Percent Reflectance					
Phosphate Detergent						
Control						
All Cotton	4.4	9.1	11.3	10.1	9.4	9.2
70/30 Blend	5.8	3.8	4.7	4.1	3.6	3.7
50/50 Blend	6.3	3.6	2.9	2.8	1.5	2.1
APO-THPC						
All Cotton	8.0	6.0	9.6	8.3	7.2	5.7
70/30 Blend	5.4	3.2	4.3	2.6	1.5	0.8
50/50 Blend	6.1	2.4	3.7	1.7	1.0	1.5
THPC-urea-MM						
All Cotton	0.2	5.9	8.1	8.4	8.8	9.4
70/30 Blend	1.6	1.4	2.6	2.7	2.9	3.7
50/50 Blend	1.9	0.6	1.3	1.6	1.8	2.8
THPOH-NH3						
All Cotton	2.5	4.3	9.3	9.4	7.2	8.9
70/30 Blend	4.3	4.6	7.4	6.6	5.7	6.9
50/50 Blend	3.4	3.1	5.6	5.2	3.8	4.0
Non-phosphate Detergent						
Control						
All Cotton	4.2	5.4	12.1	12.3	12.1	12.2
70/30 Blend	5.8	3.5	6.0	5.8	5.8	5.9
50/50 Blend	6.2	2.8	4.7	4.6	4.5	4.6
APO-THPC						
All Cotton	8.7	3.4	8.0	7.4	6.3	4.7
70/30 Blend	5.0	1.9	3.7	2.5	1.3	0.9
50/50 Blend	4.7	2.8	3.9	2.2	0.7	1.3
THPC-urea-MM						
All Cotton	0.1	4.7	6.8	6.7	6.3	7.6
70/30 Blend	1.8	1.1	1.8	1.7	1.9	2.9
50/50 Blend	1.7	0.8	0.9	1.1	0.8	1.5
THPOH-NH3						
All Cotton	2.4	3.5	11.0	12.3	11.8	12.8
70/30 Blend	4.4	5.2	8.4	8.5	8.4	8.5
50/50 Blend	3.2	1.7	6.7	6.9	6.8	6.1

All readings are positive unless indicated as negative.