CONNER, MARY GAIL. Fire Resistance Characteristics of Selected Multiple Layer Fabric Assemblies in Varying Air Conditions. (1974)
Directed by: Dr. Pauline E. Keeney. Pp. 95.

The major purpose of this study was to investigate the burning characteristics of multiple layer fabric assemblies burned in varying air conditions. The fire resistance characteristics of three layer fabric assemblies, with and without air space between layers, was tested in conditions of moving and quiescent air. A fire resistance tester specially designed to incorporate moving air into the testing cabinet was used. The testing procedure followed was #34-1969 of the American Association of Textile Chemists and Colorists.

The experimental fabrics in all outer garment layers were of 100% cotton or 80/20 cotton/polyester and untreated or treated with THPOH-NH_3 or THPOH-Amide. The second layer of the assembly consisted of fabrics of either 100% cotton, 100% nylon, or 65/35 polyester/cotton. A 100% cotton knit or 100% nylon knit comprised the third layer.

Data were collected by measuring afterflame time (in seconds), afterglow time (in seconds), and fabric damage (in inches) of each assembly, and analyzed based upon a randomized factorial design. An analysis of variance was employed to determine the significance of each factor and interaction.

The two fabric types in the outer layer did not influence the burning characteristics of the entire assembly significantly. The factors of space and air velocity served

to increase afterflame time and fabric damage in the interaction with outer layer fabrics.

The flame retardant finishes, THPOH-NH_3 and THPOH-Amide, were ineffective in reducing the flammability of multiple layer fabric assemblies. Data were similar between the two finishes; however, over all factors, the THPOH-NH_3 finish was slightly more effective in curbing the flammability of multiple layer systems. In the interaction with space, as well as garment arrangement, both finishes had higher afterflame times than the untreated assemblies. The flame retardants were more effective in controlling afterglow times in multilayer arrangements.

The factor of spacing between layers resulted in higher afterflame times and fabric damage, but in lower afterglow times. The air circulation between layers fanned the flame, but extinguished afterglow more rapidly in assemblies burned in the open formation.

Slightly moving air current decreased burning characteristics of multiple layer fabric assemblies. Afterflame time, afterglow time, and fabric damage decreased as air velocity increased.

The positioning of fabric within an assembly affected the flammability of that assembly. The same fabrics burned in different arrangements produced different burning characteristics.

FIRE RESISTANCE CHARACTERISTICS OF SELECTED MULTILAYER FABRIC ASSEMBLIES IN VARYING AIR CONDITIONS

by

Mary Gail Conner

A Thesis Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements of the Degree
Master of Science in Home Economics

Greensboro
1974

Approved by

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APPROVAL PAGE

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ACKNOWLEDGMENTS

The writer wishes to thank all persons who provided guidance and encouragement throughout this study. Sincere appreciation is expressed to Dr. Pauline E. Keeney, Professor and Chairman of the Clothing and Textile Area, for continuous aid in advising this thesis.

Appreciation is also expressed to the members of her committee: Dr. Victor S. Salvin, Professor of Home Economics, and Dr. Eunice M. Deemer, Associate Professor of Home Economics, for support and cooperation during this study.

The writer is also grateful to the Southern Regional Research Center, United States Department of Agriculture, who provided funds and materials without which this investigation would not have been possible.

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CHAPTER I

INTRODUCTION

The flammability of textile materials continues to be an important problem to the textile industry, the government and the consumer. From the time that the first federal flammability law was enacted in 1953 until present legislative efforts, protection from flammable textile materials has persistently been sought. Recently, the state of California proposed a law whereby all children's clothing sizes 0-14 must meet flame resistant standards.[1] This newest legislation demonstrates the ever present need for safe and adequate flammability standards.

The past few years have seen the arrival of flame retardant fabrics on the consumer market. Consumers may buy flame retardant sleepwear for children, mattresses, and carpets. With the advent of these first flame retardant treated fabrics, the consumer, as well as other parties involved, must realize the limitations, in addition to the potential of these treated fabrics.

Research continues in an effort to solve many of the problems concerned with flame retardant fabrics. One factor

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[1] "Flammability Standards Still Plague Textile Field," Women's Wear Daily, May 22, 1974, p. 38.

is the reaction of flame retardant treated fabrics worn with other garments. Previous investigations indicate that a flame retardant single garment does not necessarily insure fire protection when the garment is worn in conjunction with other garments which are not flame retardant treated.[2]

The textile industry as well as government and consumer groups are interested in the performance of flame retardant treated fabrics in situations closely approximating actual consumer use. Test methods simulating actual burning situations are being developed. Among these are the use of test mannequins, specialized equipment, and realistic burning environments. It is only in such actual fire environments that the potentials and hazards of fabrics and fabric combinations may be determined. The objectives of part of this study are to determine the extent to which a flame retardant fabric can offer protection from burn injuries suffered in these fire environments.

STATEMENT OF THE PROBLEM

The purpose of this study was to investigate the burning characteristics of multiple layer fabric assemblies burned in varying air conditions.

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[2]Dr. Pauline E. Keeney, "The Effect of Air Velocity upon the Burning Characteristics of Multilayer Fabric Assemblies" (paper presented at the technical meeting of the

The flammability test procedures used to date do not take into consideration multiple layers of fabric. The effect of air currents upon flammability has not been included in the test procedures. Since more than one layer of clothing is usually worn in atmospheres of ambient air, it would be of interest to study these factors.

This investigation was planned as a supplement to Objective 2 of the Southern Regional Research Project S-86,[3] concerned with the burning characteristics of two layers of fabrics, simulating a dress and slip, in varying velocities of air. Results of experimentation indicated that the effectiveness of flame retardant finishes on the outer (dress) garment layer was decreased by the close proximity of a second garment layer. Changes in air velocity also altered the effectiveness of the finishes.

The major purpose of this study was to investigate the burning characteristics of three layer multiple assemblies in varying conditions of air circulation. The objectives of the study were to:

American Association of Textile Chemists and Colorists, New Orleans, Louisiana, October, 1974).

[3]Technical Committee, Southern Regional Research Center. "Manual of Procedures: Performance of Selected Fabrics Treated with Flame Retardant Finishes" (New Orleans: Cooperative State Research Service, 1973), p. 1. (Mimeographed.)

1. Determine the differences in fire resistance of multiple layer (3) fabric assemblies when burned in close proximity and when separated to permit air circulation.

2. Investigate the effect of fiber content in the multilayer arrangement upon burning characteristics.

3. Determine the differences in burning characteristics as influenced by quiescent and ambient air.

It was assumed that flame retardant finishes increase the fire resistance of fabrics. Since two layers of the three layer fabric assembly were not flame retardant treated, it was assumed that they would burn more readily than the treated fabric. It was also assumed that the quiescent air conditions in the cabinet were approximately the same as the standard conditions of the cabinet used in AATCC test method 34-1969.[4]

The following hypotheses were tested:

1. There is no significant difference in the fire resistance characteristics of the selected experimental fabrics (100% cotton and 80/20 cotton/polyester) when burned in multilayer arrangements.

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[4]American Association of Textile Chemists and Colorists, Technical Manual. Vol. 49 (North Carolina: AATCC, 1973), p. 205.

2. There is no difference in the effectiveness of the two fire resistant finishes selected for the outer layer of the fabrics.

3. There is no difference in burning characteristics of the three layer fabric assemblies when burned in "closed" (no space between fabric layers) and "open" (space between fabric layers) formation.

4. There is no difference in the burning characteristics of the fabrics in the multiple layer arrangements when burned in quiescent and in ambient air.

DEFINITION OF TERMS

The following definitions have been included for clarification of terms relating to this study.

Fire Resistance. The American Association of Textile Chemists and Colorists defines fire resistance as the "resistance to flaming, glowing, and smoldering."[5]

Afterflame. Refers to the length of time the specimen flames after the ignition source is removed.

Afterglow. The time the specimen continues to glow after it has stopped flaming.

Fabric Damage. The extent to which the fabric is rendered unusable due to discoloration, fusion or any other abnormal occurrence after the specimen has been tested.

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[5]AATCC, loc. cit.

Multiple Layer Fabric Assembly. An assemblage of fabrics in which there are three equally sized fabric layers.

Garment Arrangement. The combination of the second and third layers of the multiple layer fabric assembly, neither of which are flame retardant treated.

Closed Fabric Spacing. A multiple layer fabric assembly in which each layer is placed directly on top of another, allowing no air circulation between layers.

Open Fabric Spacing. A multiple layer fabric assembly in which each layer is separated from the next by an air space (in this study the air space is one-eighth of an inch wide) allowing air to circulate freely between layers.

$THPOH\text{-}NH_3$. An abbreviation of the chemical compound tetrakis hydroxymethyl phosphonium ammonia.

THPOH-Amide. An abbreviation of the chemical compound tetrakis hydroxymethyl phosphonium urea-trimethylomelamine.

CHAPTER II

REVIEW OF LITERATURE

Interest in flammable textile materials has increased greatly during the past decade. The textile industry is spending millions of dollars annually in research and development of non-flammable textiles. Flammability protection has never before been so extensive. Today's consumer is afforded protection from flammability in carpeting, children's sleepwear, and mattresses. Even though flammability protection has never been so stringent, there are continuing efforts to make textiles even safer.

References consulted for preparation of this chapter traced the development of flammability. Reviewed are sources dealing with: (1) flammability legislation in the United States; (2) the history and theories of flame retardants; (3) the pyrolysis of cellulose, cotton/polyester blends, and nylon; (4) flame retardants for cotton, blends, and nylon; (5) flame retardants used in this study; and (6) multiple layer research.

The annual loss resulting from fabric fires is great. It is estimated that each year 3,000-5,000 people die of burns associated with flammable fabrics. Another 150,000-250,000 persons receive injuries due to fabric fires. The related financial loss in these flammable fabric fires ranges upward of a quarter billion dollars.[1]

A study by the Food and Drug Administration in cooperation with the National Bureau of Standards revealed that, in general, apparel was the most frequently ignited item in textile related fires where the ignition sources included matches, lighters, smoking materials, ranges, heaters, and open fires. Specific apparel items singled out as igniting often were sleepwear and streetwear (pants, shirts, and dresses). It was also noted that ignition of clothing items resulted in a mortality rate four times greater than when other textile items were ignited.[2] Over the years many investigations of this type have produced statistics which have supported the need for flammability legislation.

FLAMMABILITY LEGISLATION IN THE UNITED STATES

The first evidence of flammability legislation in the U.S. came from the state of California in 1945. The California legislature passed a bill on January 27 of that

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[1] Secretary of Health, Education and Welfare, Fourth Annual Report to the President and Congress on the Studies of Deaths, Injuries, and Economic Losses Resulting from Accidental Burning of Products, Fabrics, or Related Materials (Washington: Government Printing Office, 1972), p. 11.

[2] "Flammability Colloquy," American Dyestuff Reporter, LXII (March, 1973), p. 67.

year to prohibit the sale of explosively flammable fabrics. The bill stated:

> It is unlawful to manufacture, sell, or offer for sale any article of wearing apparel, cloth, drapery, or any other fabric or material made from or containing any synthetic fiber which is wholly or in part made from or contains any hazardous explosive or substance in sufficient quantity so as to make such fabric or material more highly flammable than cotton cloth in its natural state.[3]

The law covered toys and miscellaneous items "intended to be used in the household."[4]

The intentions of this bill were favorable. However, the means to compare the flammability of textiles was not clear. A comparison of textiles "more flammable than cotton cloth in its natural state" left doubt as to what fabrics were affected by the law.[5]

In 1953 the first federal Flammable Fabrics Act was passed (Public Law 88). It prohibited the marketing of highly flammable textile materials used primarily in apparel manufacture. The 1953 act was specifically designed to eliminate the so-called "torch" fabrics. It did not cover household textiles such as mattresses, blankets, and bedspreads, nor did it cover toys or imported fabrics.

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[3]Robert W. Little, ed., Flameproofing Textile Fabrics (New York: Reinhold Publishing Co., 1947), p. 395.

[4]Ibid. [5]Ibid.

The Flammable Fabrics Act of 1953 used the 45 degree angle flammability tester developed by the American Association of Textile Chemists and Colorists as standard for testing of fabrics. The AATCC tester measured the rate of flame spread over the surface of a six-inch sample. Responsibility for enforcement of the act rested with the Federal Trade Commission.

In 1967, amidst a rash of destructive fires caused by textile materials, an amendment to the original act was passed. The amendment extended and strengthened the act of 1953 by restricting highly flammable fabrics from all wearing apparel including hats, gloves, footwear, as well as household textiles such as carpets, draperies, and upholstery. The new amendment also covered plastics, rubber, synthetic fibers, foams, interiors of cars, and interlining.[6]

The 1967 amendment to the Flammable Fabrics Act empowered the Secretary of Commerce with the authority to issue flammability standards as deemed necessary. He could issue standards

> including labeling for a fabric, related material, or product that may be needed to protect the public against unreasonable risk of the occurrence of fire leading to

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[6]George L. Drake, "Fire Retardancy: Its Status Today," American Dyestuff Reporter, LX (May, 1971), pp. 43-47.

> death or personal injury or significant property damage.[7]

The Secretary of Commerce was also given the power to conduct research into the flammability of textiles and to develop test methods and devices.[8] The act also provided for a National Advisory Committee for the Flammable Fabrics Act which consisted of representatives from manufacturers, distributors, and consumers.[9]

This amendment to the Flammable Fabrics Act of 1953 set the stage for additional flammability legislation. First to receive a federal flammability standard were carpets and rugs in 1970. Carpet flammability was determined by a test consisting of the ignition of a methenamine pill in the center of a dry carpet sample. Other legislation followed including the Children's Sleepwear 0-6x DOC FF 3-71, and DOC FF 5-73 (7-14), and the mattress standards.

Issued on July 26, 1971, the Children's Sleepwear Standard came as a result of much study of burns involving children, clothing, and ignition sources. This flammability standard was the first to single out specific apparel items as hazardous. The standard called for the flameproofing of any children's wearing apparel sizes 0 to 6x, worn primarily

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[7] U.S. Congress, "Amendment to Flammable Fabric Act," Public Law 90-189, 81 stat. 568 (December 14, 1967), p. 569.

[8] Ibid, p. 573. [9] Ibid.

for sleeping or related activities. Underwear and diapers were not included. The act intended to:

> provide a high and effective level of protection to children approximately five years of age and younger against unreasonable risk of death or injury suffered as a result of ignition and continued burning of sleepwear garments, as defined in the standards, and/or as a result of the continued burning of molten or other materials falling or dripping from the burning garments.[10]

The Children's Sleepwear Standard, which was the most specific to date, set off waves of controversy. The sleepwear manufacturers insisted that the standard could not be complied with for several years. The Secretary of Commerce disagreed. Any garment not meeting the Children's Sleepwear Standard sizes 0-6x by July, 1972 had to be conspicuously labeled, "Flammable (Does Not Meet U.S. Department of Commerce Standard DOC FF 3-71). Should not be worn near sources of fire."[11] Manufacturers had until July 1973 to comply fully with the standards. After that date all children's sleepwear up to size 6x had to meet the flammability standards.

The test method of the Children's Sleepwear 0-6x standard subjected five bone dry samples 3.5 x 10 inches one at a time in a vertical position to a standard flame. The

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[10] "Children's Sleepwear," Federal Register. XXXVI, No. 146 (July 26, 1971), p. 14063.

[11] "Commerce Issues Final Flammability Standard to Cover Children's Sleepwear," Textile Chemist and Colorist, III (September, 1971), p. 39.

char length and residual flame time were measured. The fabric passed the test if the average char length of the five specimens did not exceed seven inches and if no one specimen had a char of ten inches. Also specified was that no one specimen could have a residual flame time greater than ten seconds. The above test was performed on samples cut in both warp and filling directions after they had been washed fifty times. Seams and trim used on the garments were also tested.[12]

It was determined that children's sleepwear in the size range of 7 to 14 created a substantial hazard to the child, so on March 6, 1973 the U.S. Department of Commerce issued the Children's Sleepwear Standard for Sizes 7 through 14 (DOC FF 5-73). The standard was almost identical to the 0-6x standard except that it does not require the measurement of residual flame time. This revision permitted the use of some man-made fibers heretofore not passing the test.

Other differences from the original sleepwear act included a difference in the conditioning of samples. While bone dry conditions were required in the 0-6x standard, conditioning for eight hours at 70±2 F and 65 percent RH was the case in the 7-14 standards. There were other minor

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[12]Ibid.

differences in the test cabinet, gas supply, and sample holders.[13]

The enforcement of the Federal Flammability laws rested with the Federal Trade Commission until 1973. In May, 1973, Congress passed the Consumer Product Safety Act (Public law 92-573) which transferred the enforcement of the Flammable Fabrics Act and related acts from the FTC to a newly formed Consumer Product Safety Commission.[14] The five member commission appointed by the President, and confirmed by the Senate, is responsible for all functions of the Flammable Fabrics Act except for the flammability research and testing done by the National Bureau of Standards. One important provision covered in the CPSA was the requirement that all state flammability regulations be identical to federal regulations. This provision halted conflicting standards that several states such as Texas, New Hampshire, New York, and California had proposed.[15]

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[13] "Standard for the Flammability of Children's Sleepwear Sizes 7 Through 14," Textile Chemist and Colorist, V (April, 1973), pp. 33-38.

[14] "Flammability Colloquy," op. cit., p. 87.

[15] Secretary of Health, Education and Welfare, op. cit., p. 122.

THE HISTORY AND THEORIES OF FLAME RETARDANCE

History

Flame retardance is not a new concept. As early as the fourth century B.C. man tried to reduce the flammability of wood with a vinegar treatment.[16] In the eighteenth century there is evidence that salts such as alum and ammonium phosphate were used to treat theater curtains for flame retardancy.[17] In 1820 Gay-Lussac did research in flame retardancy of linens. He reported that ammonium salts of sulfuric, hydrochloric or phosphoric acids were effective in flame-proofing linen. He also found that salts were even more effective when a mixture of ammonium chloride and ammonium phosphate were used.[18] Gay-Lussac was the first proponent of the coating theory discussed below. Sabattini in 1638 used pigments of clay and gypsum to impart flame retardancy in theater scenery. The first flammability patent was obtained in 1735 by Obadiah Wyld. The patent was for the fire retardant mixture of alum ferrous sulfate and borax.[19]

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[16] G. S. Buck, "Fire Resistant Textiles," Kirk-Othmer Encyclopedia of Chemical Technology 1st ed. (1951), p. 543.

[17] H. Mark and others, Chemical Aftertreatment of Textiles (New York: John Wiley and Sons, 1971), p. 590.

[18] John W. Lyons, The Chemistry and Uses of Fire Retardants (New York: John Wiley and Sons, 1970), p. 166.

[19] Goerge L. Drake, Jr., "Fire Resistant Textiles," Kirk-Othmer Encyclopedia of Chemical Technology 2nd ed. (1966), IX, p. 300.

Further research in flammability was conducted by William Henry Perkins in the early 1900's. Studying flannelette, Perkins came up with a product known commercially as Non-Flam. The retardant employed a mixture of sodium stannate and ammonium sulfate which was absorbed into the cloth. Following treatment the fabric was washed and dried.[20]

Research in flammability slackened until World War II when flameproof canvas was developed for use by the military. The treatment of the canvas consisted of the use of chlorinated paraffins and insoluble metal oxides.[21] The FWWMR finish (Flame, Water, Weather and Mildew Resistant), as it was called, was durable; however, it affected the hand, flexability, and drape of the fabric.[22]

The flameproofing of canvas was typical of early attempts at flame retardancy in which the use of acid chlorides, chlorinated paraffins, and poly(vinyl chloride) used in addition to antimony oxide was common.[23] Extensive research was also applied to phosphorous as a flame retardant in combination with urea, melamine, and dicyanadiamide

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[20]Lyons, loc. cit. [21]Ibid., p. 167.

[22]George L. Drake Jr., "Flame Resistant and Rot Resistant Finishes: Application to Cellulose," American Dyestuff Reporter, LVI (July 15, 1967), p. 560.

[23]H. Mark and others, loc. cit.

formaldehyde. Poor washfastness discouraged their use. Reactions of phosphoryl chloride with ammonia were also researched. It was discovered that this chemical combination yielded a phosphorylamide which polymerized reacting with cellulose.[24]

In 1953, the Southern Regional Research Center developed a highly successful commercial flame retardant. THPC or tetrakis hydroxymethyl phosphonium chloride was formed by the reaction of phosphine formaldehyde and hydrochloric acid.[25] Many other flame retardant finishes have been developed, two of which are used in this experiment and will be discussed in detail.

Flame Retardant Theories

There have been several theories as to how the flame retardant curbs flaming. Physical theories include the coating theory, the gaseous theory, and the thermal theory. According to the coating theory, flame retardance was achieved by the coating action of fusible salts melting on the surface of the fabric. Proponents of the gaseous theory hypothesize that flame retardants decompose in the

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[24]Ibid., p. 591.

[25]J. D. Gutherie, G. L. Drake, and W. Reeves, "Application of the THPC Flame-Resistant Process to Cotton Fabrics," American Dyestuff Reporter, LIV, No. 10 (May 9, 1955), p. 332.

combustion process to form non-volatile gases which mix with the flammable gas, rendering an inflammable mixture. Thirdly, the thermal theory proposes that flame retardants act to dissipate or conduct a large amount of energy away from the flame.[26]

The chemical theories, which are the most universally accepted, include the hydrogen bonding theory and the dehydration of cellulose. In the hydrogen bonding theory, it is proposed that the flame retardant acts to maintain the bonds with water by a link with hydrogen. With the dehydration of cellulose, it is thought that acids formed by certain flame retardants upon burning act as dehydration agents on the cellulose forming carbon and water as combustion products rather than carbon dioxide and water.[27]

THE PYROLYSIS OF CELLULOSE, COTTON/POLYESTER BLENDS AND NYLON

Cellulose

Cellulose is a polymer composed of a series of glucose units. The structure of each glucose unit is the pyranose ring. The ring structure is connected between the

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[26] "Relationships of Flammability Measurements," Textile Chemist and Colorist, I (December 3, 1969), pp. 24-25.

[27] Drake, "Fire Resistant Textiles," op. cit., p. 303.

one four carbon positions resulting in the loss of water and the formation of ether linkages. Cellulose, which is only partially crystalline, contains three hydroxyl groups in each repeating unit. These hydroxyls provide sites for strong hydrogen bonding in the molecule.

When cellulose is brought in contact with high temperatures of 300°C or above, it decomposes into flammable materials. The materials also serve to produce heat which further destroys the cellulose. Depending on the availability of oxygen to support combustion, the cellulose is fully disintegrated.

Pyrolysis of cellulose takes place in two stages. The first stage, thermal decomposition, causes the cellulose to break down into gases, liquids, tars, and solid products. The gases ignite causing the liquids and tars to volatilize. The volatilization of the liquids and tars produce further volatile materials which results in a carbonized residue. This volatilization continues until carbonized residue or char is all that is left.

The second stage in pyrolysis of cellulose is the glowing or flameless combustion. In this stage the carbonized residue left is oxidized and glows until all material is consumed, leaving a light fluffy ash.

Cotton/Polyester Blends

Polyester fibers are made from the chemical combination of ethylene glycol and terephthalic acid which forms polyethylene terephthalate. When polyester fibers, which have a lower melting point than the ignition temperature of cotton, and cotton are blended, the burning characteristics are different.

Research by Tesoro indicates that the blending of polyester and cotton can produce more highly flammable effects.[28] She found that the flammability of a blend of fibers cannot be predicted accurately by the flammability of its component parts. In fact, according to Tesoro and Meiser, cotton/polyester blends have been observed as being more highly flammable than one hundred percent cotton, or one hundred percent polyester.[29] An even more disturbing factor discovered by Tesoro was that treatment of one fiber in a blended fabric did not necessarily produce a decrease in flammability.[30]

The pyrolysis of cotton/polyester blends follows a distinct process. This process has been outlined by Hendrix, Drake, and Reeves. The cotton fibers have a lower

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[28] Giuliana Tesoro, "Flame Retardant Fabrics: Are Researchers on the Right Track?" Textile Chemist and Colorist, I, No. 14 (July 2, 1969), pp. 26-29.

[29] Lyons, op. cit., p. 232.

[30] Tesoro, loc. cit.

decomposition point than the polyester. However, the polyester melts at a lower temperature than cotton decomposes. The result is a wicking action by the cotton. The combustion process of the cotton serves to elevate the temperature to a degree required to decompose the polyester. The polyester furnishes additional fuel to the combustion in the gas phase which in turn increases the rate of combustion.[31]

Nylon

The two most extensively used forms of nylon are nylon 6 and nylon 6,6. Nylon 6,6 is made by the polymerization of hexamethylene diamine and adipic acid. Nylon 6 is made from the polymerization of caprolactam. On pyrolysis almost 95 percent of their products are nonvolatile. In nylon 6, only 5 percent of the products are volatile. Of these volatile products, 50 percent is CO_2, 35 percent is H_2O, and 6 percent is benzene. Nylon 6,6 has similar volatile products with the addition of ammonia.[32]

Nylon itself does not support combustion, but will burn if held in a flame. It will melt away from the flame.

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[31]James F. Hendrix, George L. Drake, and Wilson A. Reeves, "Some Factors Affecting Fabric Flammability as Measured by Oxygen Index," Textile Chemist and Colorist, V, No. 8 (August, 1973), pp. 13-17.

[32]Lyons, op. cit., p. 412.

Molten droplets that can cause severe burns are characteristic of nylon.

FLAME RETARDANTS FOR CELLULOSE, COTTON/POLYESTER BLENDS AND NYLON

Flame Retardants for Cellulose

Flame retardants for cellulose can work according to the dehydration theory and the hydrogen bonding theory. Reeves and others noted that fire retardants work as "dehydration agents" and "chain terminators."[33] The researchers state that the dehydration agents change the direction of the decomposition process of cellulose. The amount of flammable tars and gases is reduced while the amount of char is increased. Fire retardants act also as chain terminators by contributing free radicals such as OH, H, HO_2 to combine with the most active radicals creating a flame retardancy effect.[34]

Durable flame retardants for cotton usually include at least one of the following substances: bromine, phosphorus, chlorine, nitrogen, or antimony. Reeves and others outlined four ways to render cotton flame retardant:

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[33] Wilson A. Reeves and others, "Flame Resistant Polyester/Cotton Blend Fabrics" (paper presented at the Southern Textile Research Conference, Hilton Head, South Carolina, May, 1974).

[34] Ibid.

(1) reactions of compounds with cellulose, (2) addition of compounds to cotton, (3) coating surfaces of cotton with polymers, (4) forming polymers inside the fiber.[35]

Flame Retardants for Cotton/Polyester Blends

Blends of polyester and cotton account for about one third of the total fabric consumption. The use of this blend especially for apparel end uses spans over three billion square yards per year.[36] With such extensive use of this particular blend, research to find adequate flame retardants for it is of major concern.

Research in the flammability of cotton/polyester blends has found that retardants effective on one hundred percent cotton fabric are not necessarily effective on cotton/polyester blends. Reeves and others suggest treatment of cotton/polyester blends with one formula containing two flame retardants as a practical solution.[37] Since the blending of fire resistant and flammable fibers has not given good results, the most feasible and successful method to date is in treating the blended fabric.[38]

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[35] Ibid.

[36] Giuliana Tesoro, "Needed Research on Flame Resistant Polyester/Cellulose Blends," Textile Chemist and Colorist, V (November, 1973), pp. 23-26.

[37] Reeves and others, "Flame Resistant Polyester/Cotton Blend Fabrics," loc. cit.

[38] Ibid.

It appears that phosphorus is a key ingredient in flame retardants for polyester/cotton blends. Tesoro, in her investigations, reported that the use of phosphorus in fire retardants for polyester/cotton was effective. She also noted that when bromine was present in addition to the phosphorus, a smaller amount of phosphorus was needed for effective flame retardance.[39]

Research by Reeves and others showed that effective flame retardance had been achieved with polyester/cotton blends using a combination of THPC urea and poly(vinyl bromide). In this system the THPC urea retardant penetrates the cotton, while the poly(vinyl bromide) serves to coat the polyester and cotton fibers. However, Reeves noted that effective flame retardants for polyester/cotton blends are lacking in aesthetics and durability.[40]

Flame Retardants for Nylon

Some success in the flame retarding of nylon has come about by the use of phosphorus. The process outlined by Lyons involves co-polymerization with a phosphorus

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[39]Wilson A. Reeves and others, "A Comparison of Four Flame Retardants," Textile Chemist and Colorist, I (August 13, 1969), p. 25.

[40]Reeves and others, "Flame Resistant Polyester/Cotton Blend Fabrics," loc. cit.

monomer. The particular retardant had been reported as being highly stable.[41]

Other compounds known to impart flame resistance to nylon include chlorinated compounds. A coating type flame retardant that prevents the nylon from dripping has also been developed. This compound consists of poly(vinyl chloride), Sb_4O_6 and lead oxide. Besides imparting a non-dripping ability, the flame retardant is self-extinguishing.[42]

FLAME RETARDANTS USED IN THE STUDY

$THPOH-NH_3$ Flame Retardant

$THPOH-NH_3$ was developed by the Southern Regional Research Center in New Orleans, Louisiana. It is made by the reaction of THPC and aqueous NaOH. The reactants, in a ratio of 1:1, form an equilibrium. Sodium chloride is a by-product of this reaction. When imparted to cotton fabric, this compound renders it flame retardant with minimal loss in strength or hand.[43]

A pad, dry, cure process is used to apply the $THPOH-NH_3$ finish to cotton. First THPOH is padded onto the

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[41] Lyons, op. cit., p. 415. [42] Ibid.

[43] John V. Beninate and others, "Application of a New Phosphonium Flame Retardant," American Dyestuff Reporter, LVII (December 2, 1968), p. 74.

fabric using pressure in a squeeze roll. Following, the fabric is heated under a forced air condition of 85°C until a moisture content of 10 percent is reached. The fabric is then dried and exposed to ammonia vapor for two to six minutes in an enclosed chamber. The finished fabric is then washed.[44]

The resultant finish forms a highly insoluble polymer inside the cotton fiber. Reaction with compounds which contain active polyfunctional amino groups, the THPOH forms water insoluble polymers. The finish is oxidized for further chemical stability.[45] Cotton with weights ranging from 2.8 oz. per square yard to 8.5 oz. per square yard have been successfully flameproofed by this finish.[46]

Experimentation by Beninate and others indicated that the THPOH-NH_3 finish did not alter many physical properties. There was little strength loss or change in hand reported with the finish. In fact, it was reported that the strength of the finished fabric was usually greater than the unfinished fabric sometimes by as much as 25 percent.[47]

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[44] Ibid., pp. 74-75.

[45] "Cotton Antiflame Finish Won't Hurt Strength and Hand," Textile World, CXXII (November, 1972), p. 52.

[46] Beninate, loc. cit.

[47] Reeves and others, "A Comparison of Four Flame Retardants," op. cit., p. 26.

Breaking strength increased slightly while tearing strength decreased as add-on value increased.[48]

The finish has other positive features. Cotton fabrics finished with THPOH-NH_3 have an increased absorbency of 12 to 15 percent. The finish leaves no odor or discoloration of fabric. It does not give cotton any static properties.[49]

The cotton fabric finished with THPOH-NH_3 cannot be chlorine bleached. Chlorine bleach can adversely affect the fire resistance properties and the strength of the fabric because of chlorine retention within the fiber.[50]

Sunlight also has detrimental effects on the THPOH-NH_3 finish. Exposure to sunlight can gradually weaken the finish. The ultra violet rays are responsible for the degradation of the finish and a subsequent loss of flame retardance.[51]

According to Reeves and coworkers, imparting a THPOH-NH_3 finish to cotton/polyester blended fabric is more

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[48] John V. Beninate and others, "Better Flame Resistant Finish for Cottons," Textile Industries, CXXXI (November 1967), p. 110.

[49] "Cotton Antiflame Finish Won't Hurt Strength and Hand," loc. cit.

[50] Ibid.

[51] L. W. Mazzeno and others, "Degradation of Selected Flame Retardants on Exposure to UV and Elevated Temperatures," Textile Chemist and Colorist, V (March, 1973), p. 43.

difficult than applying it to one hundred percent cotton fabric. Successful flame retardance is achieved in blends when the cotton content is 65 percent or more. With the increase in polyester content, a proportional increase in the amount of finish is needed for adequate flame retardancy.[52]

Washing does not affect the THPOH-NH_3 finish when a phosphate or citrate built detergent is used. However, when washed with detergents containing chlorine bleach, soap, or carbonates, the fire retardancy was impaired.[53]

THPOH-Amide Flame Retardant

THPOH-Amide, also developed by the Southern Regional Research Center, is made by reacting THPOH, urea, and trimethylolmelamine. The reaction takes place during a pad, dry, cure process. The fabric is padded with a water solution of the formula in a molar ratio of 2:4:1 (THPOH: urea: trimethylolmelamine). The wet pick up of the components is about 75 percent. Next the fabric is dried and then cured at an elevated temperature.[54]

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[52] Reeves and others, "A Comparison of Four Flame Retardants," op. cit., p. 25.

[53] "Whither Textile Flammability?" American Dyestuff Reporter, LXII (July, 1973), p. 47.

[54] Wilson A. Reeves and others, "A Comparison of Four Flame Retardants," op. cit., pp. 25-27.

The reaction of THPOH, urea, and trimethylolmelamine at elevated temperatures results in the formation of water insoluble polymers inside the cotton fabric. Treated fabric exhibited good breaking strength; in fact, there was almost no difference in breaking strength between the treated and untreated fabric.[55]

The finish was also reported to have a good tear strength of 73 percent. Resistance to flex abrasion was good as well as the fabric's stability to chlorine bleach. It did not yellow.[56]

The wrinkle recovery factor was especially good. The wash and wear values reported indicated that fabrics treated with this finish exhibit permanent press properties in addition to being flame retardant.[57]

THE FLAMMABILITY OF MULTIPLE LAYER FABRIC ASSEMBLIES

There has been little research done on the flammability of multiple layer fabric assemblies to date. However,

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[55] Ibid.

[56] John V. Beninate and others, "A Conventional Pad-Dry-Cure Process for Durable Flame and Wrinkle Resistance with Tetrakis (Hydroxymethyl) Phosphonium Hydroxide (THPOH)," Textile Research Journal, XXXVIII (March, 1968), p. 269.

[57] Ibid.

research accomplished thus far has revealed some surprising results.

Investigations conducted by Miller and Turner disclose that flammability may either be increased or decreased by the addition of another layer. They found that treated cotton layers did not burn when ignited separately. However, when the two cotton layers were ignited together, they burned rapidly. In cotton systems also, they reported the flammability of the untreated layer was transferred to the treated layer.[58]

Miller and Turner attest that the effect from a flame retardant can be transferred to an untreated fabric. This is the case, they found, with nylon and polyester. The flammability of nylon and polyester double systems were found to be similar. In a combination of one treated layer and one untreated layer of the same fabric, both the nylon and polyester burned slower than when both layers were untreated.[59]

Research conducted by Keeney further illustrates the hazard of multiple layer fabric assemblies. Keeney found that burning characteristics of treated and untreated cotton

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[58]Bernard Miller and Rudolph Turner, "The Transfer of Flame Retardant Effects," Textile Research Journal, XLII (November, 1972), p. 631.

[59]Ibid., p. 632.

and cotton/polyester fabrics were altered by multilayering and changes in air current. Using the flame retardants, THPOH-NH_3, THPOH-Amide, Pyrovatex, and THPC-urea, Keeney found them to be ineffective in maintaining fire resistance in a two layer system.[60]

Afterflame time and fabric damage were the burning characteristics having undesirous effects in a multilayer system. In general, it was reported that a multilayer system exceeded the afterflame time of ten seconds used as criteria in some instances. It was also reported that fabric damage was usually greater than the seven inch char length standard.[61]

Multicomponent research done at the Textile Research Institute showed that thermal and burning characteristics of multicomponents are influenced by the different polymers in the system and their interactions. Their research concurs with Miller and Turner in that the burning characteristics of multilayers may be more or less hazardous than the burning characteristics of single components.[62]

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[60] Pauline E. Kenney, "The Effect of Air Velocity Upon the Burning Characteristics of Multilayer Fabric Assemblies" (paper presented at the Technical meeting of the American Association of Textile Chemists and Colorists, New Orleans, Louisiana, October, 1974).

[61] Ibid.

[62] H. G. Heilweil, ed., "Multicomponent Textile Systems--Thermal-Burning Behavior," Notes on Research (New Jersey: Textile Research Institute, June, 1974).

CHAPTER III

PROCEDURE

This study was undertaken as a part of the Southern Regional Research Project S-86, sponsored by the Cooperative State Research Service of the Agricultural Extension Service of the United States Department of Agriculture. The flame retardant fabrics used were purchased for the experiment by the Technical Committee of Project S-86. The Southern Regional Research Center, United States Department of Agriculture in New Orleans, Louisiana, applied the flame retardant finishes according to specifications. Other non-treated fabrics used in this study were purchased as garments from a mail order house.

Description of Multiple Layer Fabric Assemblies

The multiple layer fabric assemblies consisted of three layers of fabric. Fabrics used in each layer are described below.

First layer fabrics. Fabrics used in the first layer (outer garment layer) were of two types: a 100 percent cotton plain weave print cloth, and an 80/20 cotton/polyester plain weave print cloth. The all cotton fabric had a weight of 2.77 ounces per square yard, and the

80/20 cotton/polyester fabric weighed 2.94 ounces per square yard.[1]

The major investigations undertaken in Project S-86 used four flame retardant finishes. Two of those finishes, $THPOH-NH_3$ and THPOH-Amide, were selected for experimentation in this study. The $THPOH-NH_3$, or non-cross-linking finish, had a concentration of 20 percent on the fabric. The cross-linked finish, THPOH-Amide, had a concentration of 25 percent on the fabric.[2] Both finishes were applied to the two experimental fabric types. Flame retardant finishes were omitted on portions of the fabric to provide untreated fabric as control.

Second layer fabrics. The second layer of the multible layer assembly consisted of samples cut from ladies' white slips purchased at Sears Roebuck and Company. Three different slips were used, a 100 percent cotton plain weave slip, a 100 percent nylon tricot slip, and a 65/35 polyester/cotton plain weave slip.

Third layer fabrics. The third layer of the multiple layer assembly were samples cut from ladies'

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[1]Technical Committee, Southern Regional Research Center, "Manual of Procedures: Performance of Selected Fabrics Treated with Flame Retardant Finishes" (New Orleans: Cooperative State Research Service, 1973), p. 3. (Mimeographed.)

[2]Ibid.

undergarments (briefs). The briefs, also purchased at Sears, were of two types: (1) a 100 percent cotton knit and (2) a 100 percent nylon tricot. The combination of the second and third layers will be referred to as the garment arrangement.

Preparation of Test Samples

Fabrics for all three layers of each multiple layer assembly were cut into 2-3/4 by 10 inch pieces with the longer dimension in the warp or wale direction. The multiple layer system was assembled as follows: (1) first layer--the flame retardant finished or unfinished fabric, (2) second layer--the ladies' slips, (3) third layer--the ladies' undergarments.

Open spacing. In order to investigate multiple layer fabric assemblies with spacing between layers, the frames were modified slightly by the use of metal strips (1 x 10 x 1/8 inches) conforming to the sides of the frame. A diagram of both open and closed assemblies is shown in Figure 1. In the open assembly the layers were kept separated by the metal strips permitting a 1/8 inch air space between layers.

Closed spacing. Fabrics for the closed assemblies were stitched together 1/8 inch from one side of the

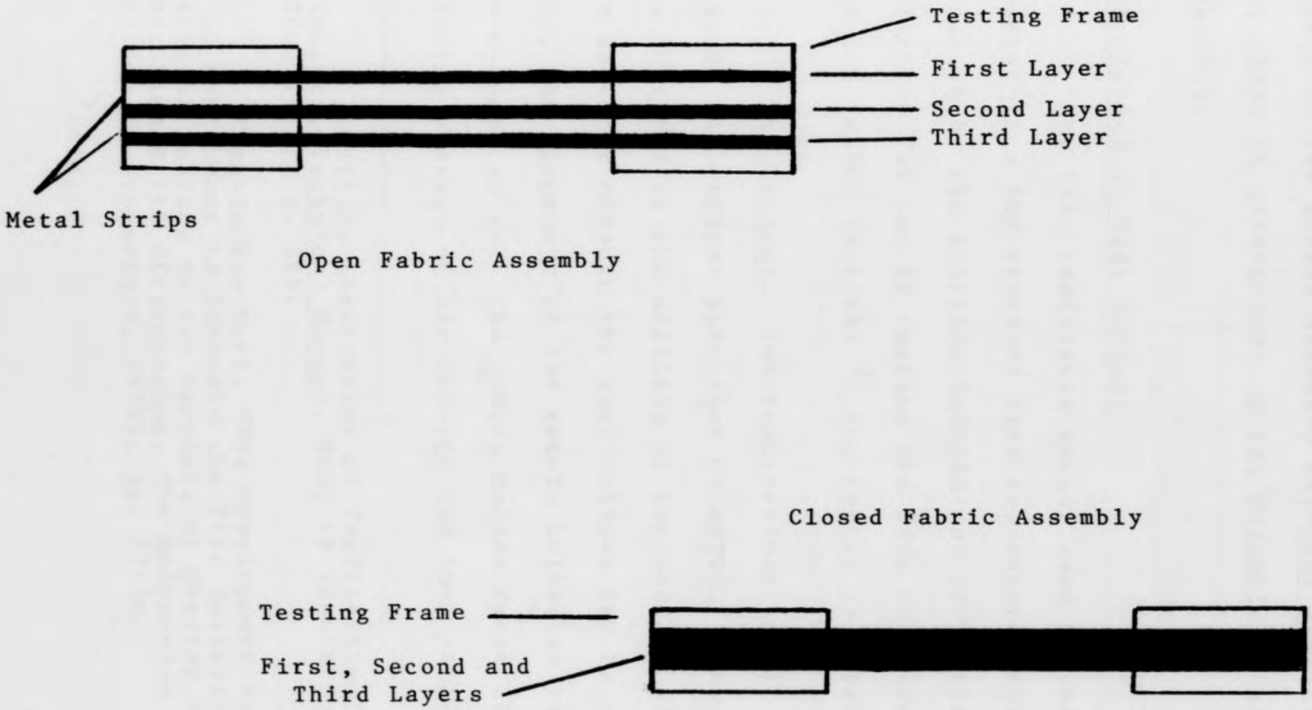

Figure 1

Diagram of Closed and Open Fabric Assemblies arrangement, and put in the testing frames as one unit. The layers of the closed assembly were not separated in any way. The order of arrangement in the assembly is also shown in Figure 1.

Description of Test Cabinet

The fire resistance tester used in this study was adapted from the standard fire resistance instrument accepted by the American Association of Textile Chemists and Colorists for use in testing the fire resistance of textile fabrics (AATCC 34-1969).[3] The tester is shown in Figure 2.

The cabinet. The test cabinet itself is the same size as the cabinet specified by AATCC.[4] The test chamber was modified by the addition of two baffled sides with which air movement through the test cabinet may be regulated. Also, the placement of the sample holder in the test cabinet was changed so that the sample holder faced the baffled side allowing passage of air through the test samples.[5]

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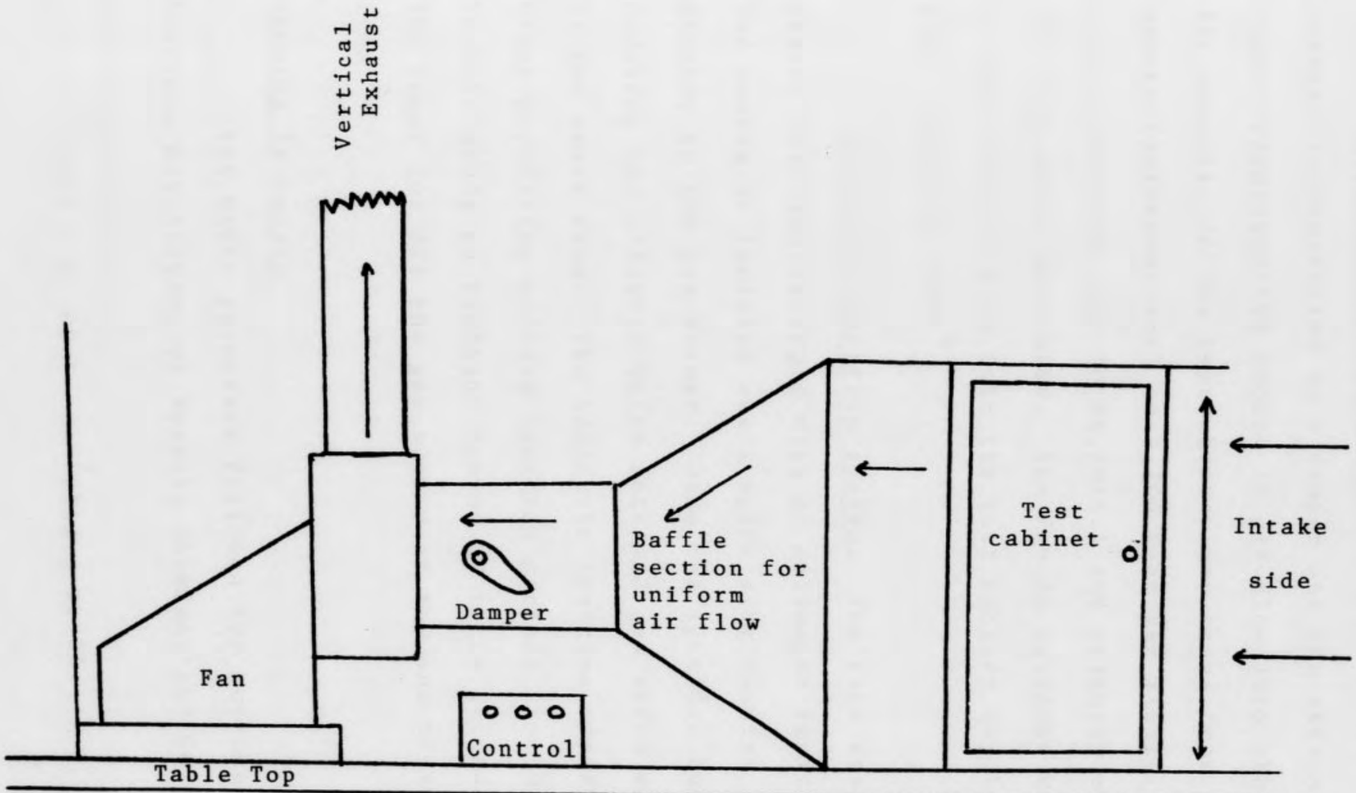
[3] American Association of Textile Chemists and Colorists, Technical Manual, Vol. 49 (North Carolina: AATCC, 1973), p. 205.

[4] Yang-Ja Kim Mori, "The Development and Application of an Instrument to Indicate the Fire Resistance Characteristics of Fabrics in Air Currents of Varying Velocities" (unpublished PhD dissertation, The University of North Carolina at Greensboro, 1972), pp. 37-40.

[5] Ibid.



1/10 of actual size

Figure 2

Diagram of Fire Resistance Testing Equipment

The air movement system. Air flow into the test cabinet is controlled by a damper and fan attachment. The damper regulates the amount of air flow into the cabinet. Air velocity in the test chamber may range from 0 feet per minute (quiescent air) to 1,700 feet per minute. In this study, quiescent air (0 ft./min.) and slightly moving air (97 ft./ min.) were used. The fan is equipped with a switch so that the air flow into the test cabinet may be turned on after ignition time.[6]

Automatic ignition system. The fire resistance tester used was equipped with an automatic ignition system. The source of ignition was a spark plug mounted perpendicular to the gas burner. When the ignition button was pressed, the solenoid valve released gas which was ignited by the spark plug. The automatic ignition system also had a timer permitting uniform ignition periods from 0-30 seconds. In this study an ignition period of three seconds was used. The timer cut off the gas supply at the end of the ignition time.[7]

Burning Procedure

The basic procedure followed for burning was the American Association of Textile Chemists and Colorists

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[6]Ibid., p. 49. [7]Ibid., p. 51.

Vertical Flame Test Method 34-1969 for testing the flammability of fabrics. The cut and assembled samples were placed in an oven at 105°F for one-half hour and then maintained for another half hour in a dessicator for uniform relative humidity. The samples were burned immediately after being removed from the dessicator. The flame was adjusted to a height of one and one-half inches and was placed so that all three layers could ignite simultaneously during the three second ignition period. For those fabrics tested in moving air, the fan was started immediately after the ignition period, drawing air of the specified velocity into the testing cabinet. The duration of time that the sample supported combustion was measured as the seconds of afterflame. The afterglow, reported in seconds, was the time after the flaming ceased to the time the glowing ended. The air current continued to circulate through the test cabinet when both the afterflame and afterglow times were being measured.

Once the afterflaming and afterglowing had ceased, the samples were removed from the holder and measured for fabric damage. For this study a measurement of fabric damage was substituted for the char length of the standard procedure because of the tendency of the multiple layers to fuse and melt together rendering an accurate char length measurement impossible. Fabric damage as defined for this investigation was the extent to which the fabric is rendered unusable due to discoloration, fusion, or any other abnormal occurrence after the fabric had been tested. The fabric damage was measured to the nearest hundredth of an inch on the face of the outer garment layer of the fabric assembly.

Treatment of Data

The multiple layer garment assemblies were observed during burning to note any unusual burning characteristics of the assemblies in the open and closed fabric positions. Unusual occurrences were noted to be used in the explanation of the statistical data.

The data recorded for afterflame, afterglow and fabric damage were analyzed using an analysis of variance. A factorial design of 2 x 3 x 6 x 2 x 2 = 144 with replication was used. A detailed explanation of experimental factors is shown in Table 1.

Table 1

Experimental Factors

Fabrics
1. 100% Cotton
2. 80/20 Cotton/Polyester Blend

Finishes
1. No Finish (Control)
2. THPOH-NH_3
3. THPOH-Amide

Garment Arrangements
1. Second layer 100% Cotton, Third layer 100% Cotton
2. Second layer 100% Cotton, Third layer 100% Nylon
3. Second layer 100% Nylon, Third layer 100% Cotton
4. Second layer 100% Nylon, Third layer 100% Nylon
5. Second layer 65/35 Polyester/Cotton, Third layer 100% Cotton
6. Second layer 65/35 Polyester/Cotton, Third layer 100% Nylon

Air Velocity
1. Quiescent Air (Control)
2. 97 Feet/Minute (Approximately 1 mile per hour)

Fabric Spacing
1. Closed Fabric Assembly
2. Open Fabric Assembly

CHAPTER IV

DISCUSSION OF RESULTS AND DATA ANALYSES

This chapter will present the data gathered on each experimental factor in the study. A general overview of each factor will be discussed including observations and statistical data. A detailed description of interactions is also included.

FACTORS INFLUENCING BURNING CHARACTERISTICS IN MULTIPLE LAYER FABRIC ASSEMBLIES

Outer Layer Fabrics

A 100% cotton print cloth fabric and an 80/20 cotton/polyester print cloth were used in the outer garment layer. Assemblies with the untreated 100% cotton fabric in the outer layer caught the flame rapidly with the flame spreading upwards. The entire sample was consumed. The characteristic afterglow was present in all samples regardless of the garment arrangement. The residue left was in the form of a light fluffy grey ash.

The average afterflame time for the cotton fabric spanning all finishes was 63 seconds. The afterglow continued for almost eight seconds, while average fabric damage was 9.19 inches.

The 80/20 cotton/polyester print cloth ignited rapidly and burned thoroughly. Smoke was profuse and darker than that of the 100% cotton. The untreated blend tended to be fully consumed. Afterglow was present as the second stage combustion, but did not last as long in the 100% cotton fabric assemblies.

The statistical data showed that over all treatments the 80/20 blend had a mean flame time essentially the same as that of the all cotton. The afterglow recorded over all treatments was approximately seven seconds, about one second less than the 100 percent cotton. Fabric damage of the 80/20 blend was slightly higher than that of the all cotton.

Finishes

The two flame retardant finishes chosen for this experiment were THPOH-NH_3 and THPOH-Amide. The combination of factors, layering, air velocity, and spacing affected the flameproofing ability of both finishes. The afterflame time for the fabric assemblies was not affected greatly by the different finishes. However, the afterglow and fabric damage decreased regardless of the finish used. A comparison of the finishes used is shown in Figure 3.

Garment Arrangements

The six different garment arrangements influenced the burning characteristics of the whole assembly regardless of the fabric or finish used. Flaming in all assemblies spread upward at first, as did smoke. In some assemblies

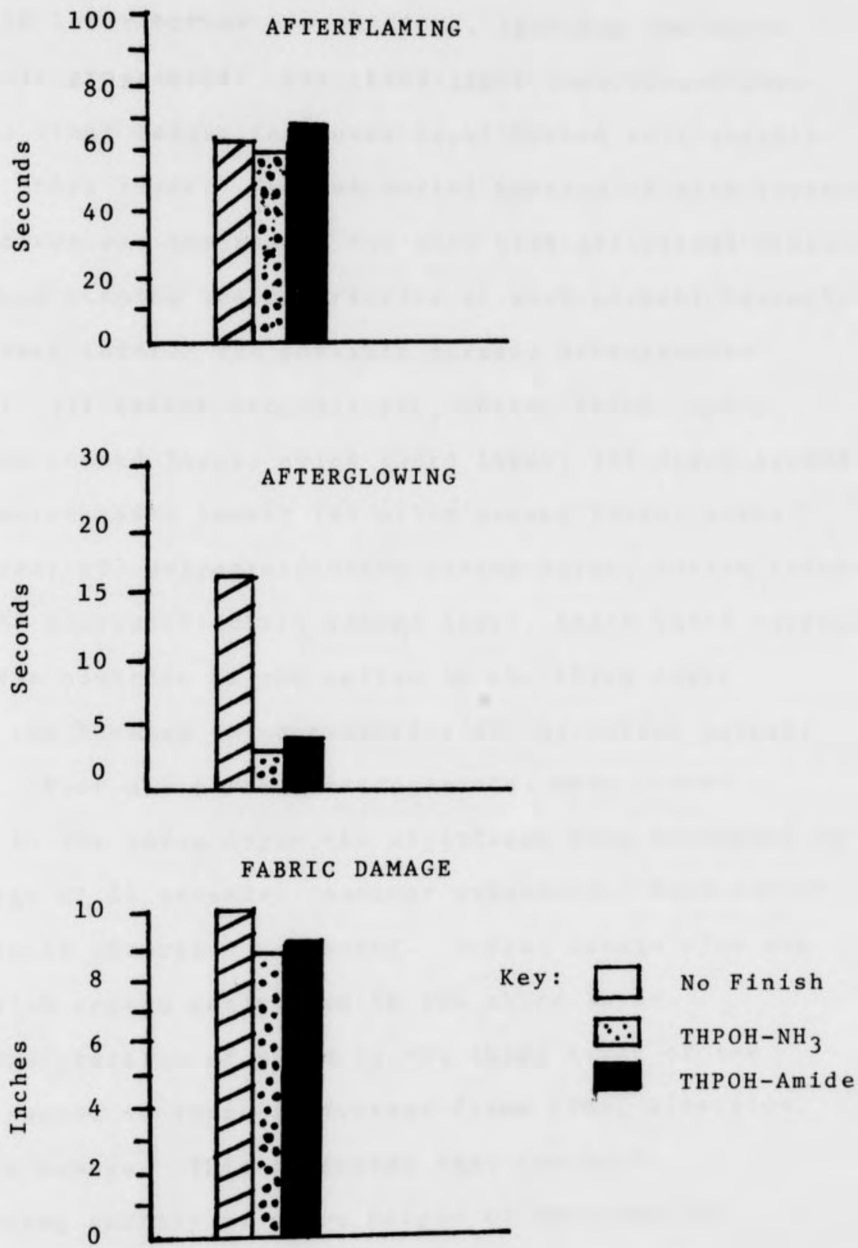

Figure 3

Burning Characteristics of Flame Retardant Finishes the middle layer burned upward first, igniting the third layer as it progressed. The third layer then flamed downward. In other cases, the outer layer burned more quickly than the inner layer. The sequential burning of each layer in some cases was the reason for such high afterflame times. The various burning characteristics of each garment assembly is discussed later. The possible garment arrangements included: (1) cotton second layer, cotton third layer; (2) cotton second layer, nylon third layer; (3) nylon second layer, cotton third layer; (4) nylon second layer, nylon third layer; (5) polyester/cotton second layer, cotton third layer; (6) polyester/cotton second layer, nylon third layer.

The position of the cotton in the third layer affected the burning characteristics of the entire garment assembly. Over all garment arrangements, when cotton appeared in the third layer the afterflame time increased on the average of 21 seconds. Another substantial increase of 10 seconds in afterglow was noted. Fabric damage also was greater with cotton positioned in the third layer.

The position of nylon in the third layer of the assembly seemed to decrease average flame time, afterglow, and fabric damage. This indicates that the self-extinguishing ability of nylon helped to decrease the burning characteristics to lower but still unacceptable levels.

Cotton second layer, cotton third layer. This garment arrangement ignited quickly and was fully consumed. When paired with an untreated outside layer of 100% cotton, the entire fabric assembly burned rapidly with brilliant flaming. The flame time of the arrangement was the highest among all the garment arrangements. Also high was the mean afterglow time which spanned all finishes used in the outside layer. Fabric damage of ten inches was reported over all finishes in this arrangement. The mean afterflame time, afterglow time, and fabric damage for all garment arrangements is shown in Table 2.

Table 2

Mean Afterflame Time, Afterglow Time and Fabric Damage of Garment Arrangements

	Burning Characteristics		
Garment Arrangement	Afterflame* (Seconds)	Afterglow* (Seconds)	Fabric Damage* (Inches)
Cotton-cotton	74.63	10.95	10.00
Cotton-nylon	55.81	2.25	9.91
Nylon-Cotton	73.51	2.84	10.00
Nylon-nylon	43.42	0.44	6.10
Polyester/cotton-cotton	72.77	17.71	9.84
Polyester/cotton-nylon	57.33	9.97	9.47

*Significant at .01 level.

Cotton second layer, nylon third layer. The burning characteristics of this arrangement was governed frequently by the middle layer of cotton. This layer would ignite quickly with the nylon layer; however, the cotton layer seemed to cause the nylon to burn further. The nylon also affected the burning of the cotton layer as shown in the lower flame time. With the third layer of nylon the after-glow time was cut considerably. Fabric damage decreased slightly as a result of the position of nylon.

Nylon second layer, cotton third layer. This garment assembly burned slowly and for a long period of time. Burning proceeded upward with the nylon middle layer dripping to the bottom of the cabinet. The cotton layer seemed to set the pace for the flaming. Nylon flamed considerably, often flaming in one section for a long time. Fusing was also present, with the nylon often fusing to the outer layer of the fabric assembly.

Nylon second layer, nylon third layer. This assembly flamed for the shortest period of all garment arrangements. The characteristic smoke and celery smell of nylon was evident. The nylon ignited and burned influenced by the outer layer. Often the two nylon layers would melt and fuse together, or fuse with the outer layer. Frequently the extent of fusing was dependent on the spacing of the assembly. The statistical data showed that this garment arrangement produced the shortest afterflame and afterglow times and the least amount of fabric damage over all garment arrangements.

Polyester/cotton second layer, cotton third layer. This garment arrangement ignited quickly and burned for a considerable length of time. Accompanying the flaming of this assembly was profuse smoke that ran upward between layers. In several instances the flame worked its way up the cotton layer first, then downward on the polyester/cotton. The finished outer garment layer usually burned the entire length, often fusing with the middle layer of polyester/cotton. The char of the outside layer often had a sparkly appearance when combined with this garment assembly.

The average afterglow of the arrangement was the highest over all other arrangements. Often the afterglow would travel up one layer and down the other. The afterglow also began in the middle of the sample and spread outwards.

Polyester/cotton second layer, nylon third layer. This garment arrangement ignited quickly but had irregular burning patterns. A flaming was noticed in this arrangement that seemed to die out only to burst into flame again. The polyester/cotton middle layer carried the flame with regularity. Burning of all layers together was seen in this arrangement, too. A strong stifling odor often accompanied the combustion of this arrangement.

Spacing

Open fabric spacing. The spacing of one-eighth inch between layers in the assembly created unique burning incidents. Over all, the spacing produced air tunnels between layers, causing the smoke to rush upwards. Spaced samples seemed to flame for a longer period of time. This can be explained by the burning patterns of the samples. Although all three layers were ignited simultaneously, they did not always burn at the same time. Samples were observed in which one layer, often the middle, would burn first, igniting the other two layers in the middle or on top. The spacing supplied air and gave further impetus to samples that burned easily. The result was additional oxygen and rapid combustion.

The low afterglow over all fabrics was noticed in the spaced samples. Air present between layers served to extinguish some afterglow and glowing particles were often seen floating upward with smoke. The effect of spacing on the burning characteristics of open and closed assemblies is shown in Figure 4.

Closed fabric spacing. The samples in the closed fabric assembly seemed to burn as a unit. Each individual

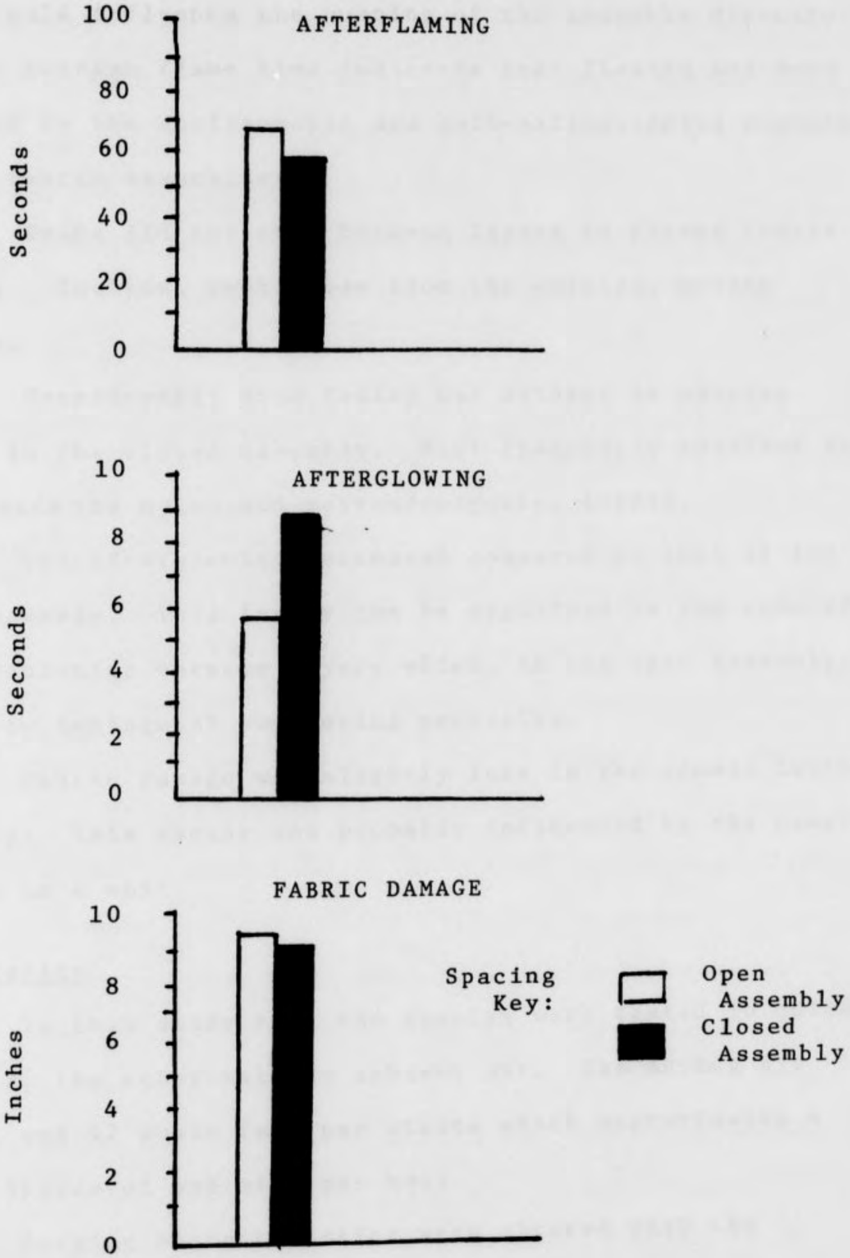

Figure 4

The Effect of Spacing on the Burning Characteristics of Multiple Layer Fabric Assemblies layer could influence the burning of the assembly directly. A lower average flame time indicates that flaming was more affected by the nonflammable and self-extinguishing members of the fabric assemblies.

Smoke did not rush between layers in closed fabric spacing. Instead, smoke rose from the outside, moving upwards.

Considerably more fusing was evident in samples burned in the closed assembly. Most frequently involved in fusing were the nylon and cotton/polyester layers.

The afterglowing increased compared to that of the open assembly. This factor can be explained by the reduced air circulation between layers which, in the open assembly, tended to extinguish smoldering particles.

Fabric damage was slightly less in the closed fabric assembly. This factor was probably influenced by the sample burning as a unit.

Air Velocity

In this study half the samples were tested in quiescent air, the other half in ambient air. The moving air current was 97 cubic feet per minute which approximates a slight breeze of one mile per hour.

Burning characteristics were altered with the introduction of air current. Flame spread was often horizontal with the presence of air. The horizontal flaming traveled slowly up the sample. Air current was also instrumental in producing irregular flaming. When air was present, the flame would often jump from one area to another especially in the spaced assemblies.

The ambient air conditions decreased the over all afterglow time. It was observed that the air flow tended to blow out smoldering particles.

EFFECT OF SPACING ON THE BURNING CHARACTERISTICS OF MULTIPLE LAYER FABRIC ASSEMBLIES

Outer Layer Fabric

Differences in burning characteristics of the two fabric types under different spacing conditions are shown in Figure 5. The open spaced assemblies simulated wearing apparel in which there might be several layers of clothing worn such as a dress, a slip, and an undergarment. Open assemblies had increased afterflame time regardless of the fabric type used. Although the interaction was not significant, it appeared that such spacing would be hazardous. The extra pocket of air between layers fed the flame resulting in a longer burning period.

Afterglow in both the cotton and cotton/polyester fabric types was lower in the open spaced assemblies. The additional air circulation between layers appeared to be responsible for extinguishing the afterglow. Fabric damage in both fabrics was slightly higher in the free air assembly.

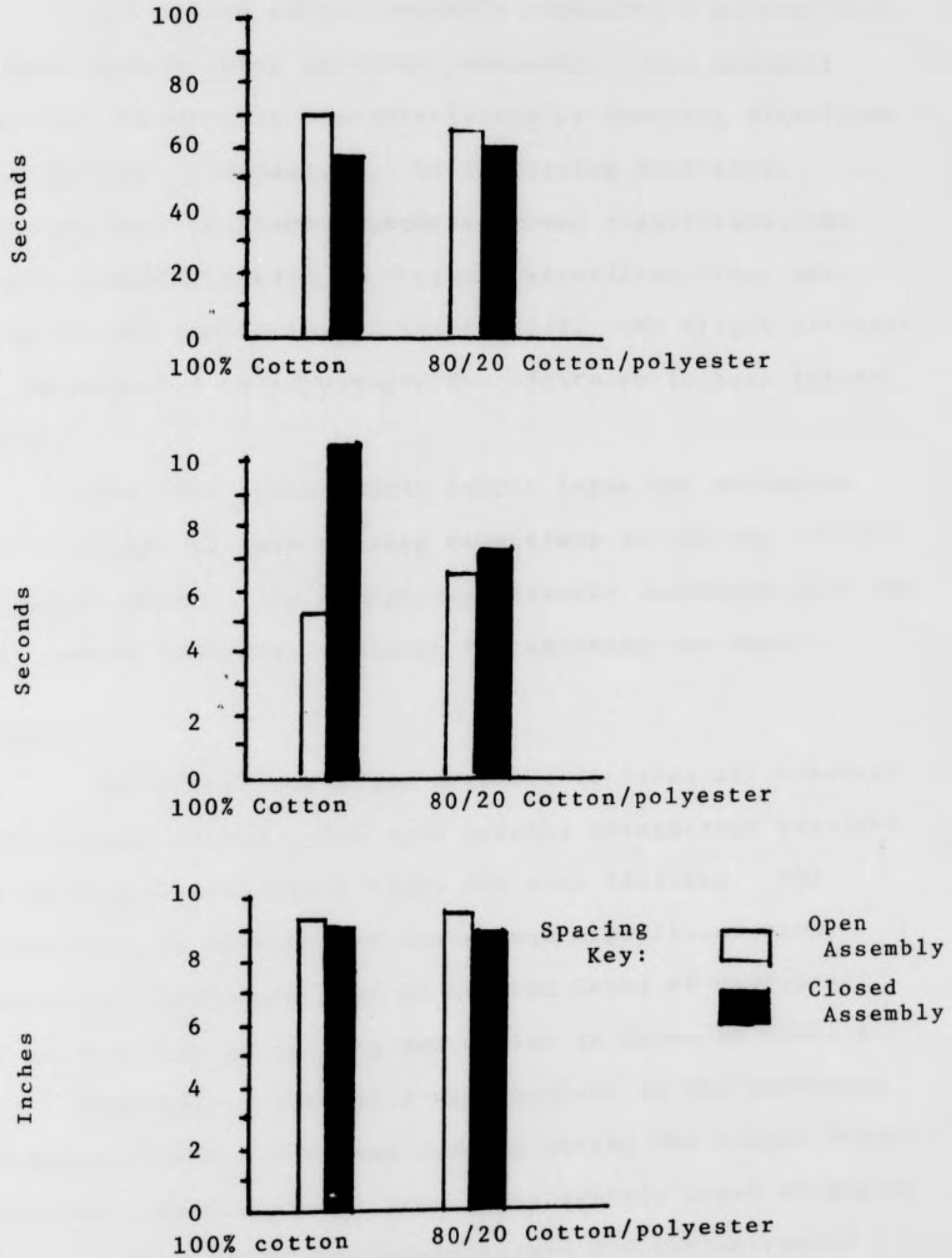

Figure 5

Burning Characteristics of Outer Layer Fabrics in Open and Closed Spacing

The closed fabric assembly simulated a garment with several layers lying in close proximity. This assembly affected the burning characteristics by lowering afterflame time and fabric damage, but by increasing afterglow. Although none of these interactions was significant, the closed assembly seemed to decrease afterflame time, but aided in the smoldering of the fabrics. The slight air circulation served to perpetuate the afterglow in both fabric types.

The 100% cotton outer fabric layer had extensive fabric damage in both spacing conditions as did the cotton/polyester blend. The damage was slightly increased with the open spaced assembly, although the increase was small.

Finish

The afterflame times over all finishes and spacings were at high levels. The open spacing arrangement resulted in the higher afterflame times for both finishes. The interaction of spacing and finish was significant with respect to afterflame time at the .01 level of confidence. The interaction of spacing and finish is shown in Table 3.

Seconds of afterglow were highest in the untreated assemblies, with the closed spacing having the longer afterglow time. Both finishes had a considerably lower afterglow time in both spacing arrangements than did the untreated assembly.

Table 3

Mean Afterflame Time, Afterglow Time and Fabric Damage of Space x Finish (S x F N = 48)

Fabric Treatment	Spacing (Open Assembly)	No Spacing (Closed Assembly)
		AFTERFLAMING* (Seconds)
No Finish	59.2	65.5
$THPOH-NH_3$	68.7	50.1
THPOH-Amide	75.0	58.6
		AFTERGLOWING (Seconds)
No Finish	11.0	20.8
$THPOH-NH_3$	2.7	3.0
THPOH-Amide	3.5	2.9
		FABRIC DAMAGE** (Inches)
No Finish	10.0	10.0
$THPOH-NH_3$	9.0	8.1
THPOH-Amide	8.9	9.0

*Significant at .01 level.

**Significant at .05 level.

Fabric damage was significant to the .05 level as shown in Table 3. In both spacing arrangements the untreated assembly burned the entire length. The $THPOH-NH_3$ finished assembly had a higher fabric damage in the open assembly of almost one inch, while the THPOH-Amide treated assembly had lower fabric damage in the open arrangement.

Garment Arrangement

The interaction of garment arrangement and spacing was significant at the .01 level with respect to afterflame. The all cotton garment arrangement with open spacing produced the highest afterflame time over all arrangements. A decrease of over 30 seconds was noticed in mean afterflame time of the same garment arrangement when burned in a closed assembly. The all nylon garment arrangement had the lowest afterflame time over all other arrangements, both in the closed and open assemblies. The open assembly containing the all nylon arrangement had the lowest afterflame time by 11 seconds. Also worthy of note is the afterflame time of the nylon-cotton arrangement. This arrangement had an unusually high flame time in both open and closed assemblies. The afterflame time of this arrangement was 20 seconds higher than the all nylon arrangement in the closed assembly, and over 39 seconds higher in the open assembly. Again, the higher afterflame time was reported in the open spaced assembly. Mean afterflame times of all garment arrangements interacted with space are shown in Table 4.

The highest afterglow time over all garment arrangements was found in the polyester/cotton-cotton arrangement burned in the open assembly. Data are given in Table 5 and shown graphically in Figure 6. Afterglow was significant at the .05 level in this interaction.

Table 4

Mean Afterflame Time of Garment Arrangement x Space (GA x S N = 24)

Garment Arrangement	Spacing (Open Assembly)	No Spacing (Closed Assembly)
	AFTERFLAMING* (Seconds)	
Cotton-cotton	91.6	57.6
Cotton-nylon	52.4	59.1
Nylon-cotton	76.3	70.7
Nylon-nylon	37.9	48.8
Polyester/cotton-cotton	90.1	55.4
Polyester/cotton-nylon	57.7	56.9

*Significant at the .01 level.

Table 5

Mean Afterglow Time of Garment Arrangement x Space (GA x S N = 24)

Garment Arrangement	Spacing (Open Assembly)	No Spacing (Closed Assembly)
	AFTERGLOWING* (Seconds)	
Cotton-cotton	8.8	13.06
Cotton-nylon	2.6	1.89
Nylon-cotton	2.0	3.69
Nylon-nylon	0.5	0.30
Polyester/cotton-cotton	18.4	17.00
Polyester/cotton-nylon	2.3	17.60

*Significant at the .05 level.

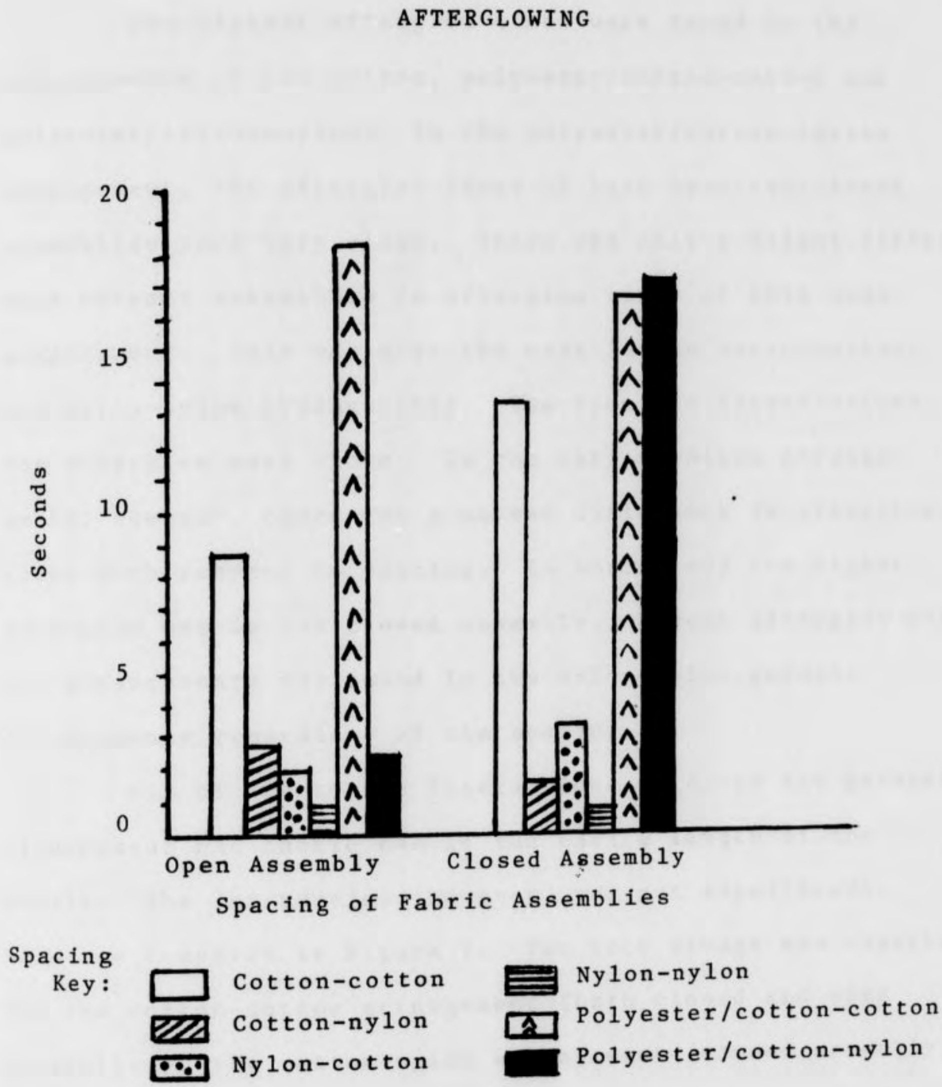

Figure 6

Differences in Afterglow Time of
Garment Arrangement x Space
(GA x S N = 24)

The highest afterglow times were found in the arrangements of all cotton, polyester/cotton-cotton and polyester/cotton-nylon. In the polyester/cotton-cotton arrangement, the afterglow times of both open and closed assemblies were very close. There was only a slight difference between assemblies in afterglow times of this same arrangement. This was also the case in the cotton-nylon, and nylon-nylon arrangements. The open and closed values for afterglow were close. In the cotton-cotton arrangements, however, there was a marked difference in afterglow times with respect to spacing. In both cases the higher afterglow was in the closed assembly. Lowest afterglow over all arrangements was found in the nylon-nylon garment arrangements regardless of the spacing.

Six of the twelve interactions of space and garment arrangement had fabric damage the entire length of the sample. The interaction, however, was not significant. Data are compared in Figure 7. Ten inch damage was reported for the cotton-cotton arrangement (both closed and open assemblies), the cotton-nylon arrangement (closed assembly only), the nylon-cotton arrangement (both closed and open assemblies), and the polyester/cotton-cotton arrangement (open spacing only). The least amount of fabric damage in each assembly was reported in the nylon-nylon garment arrangement. This arrangement reported fabric damage under seven inches.

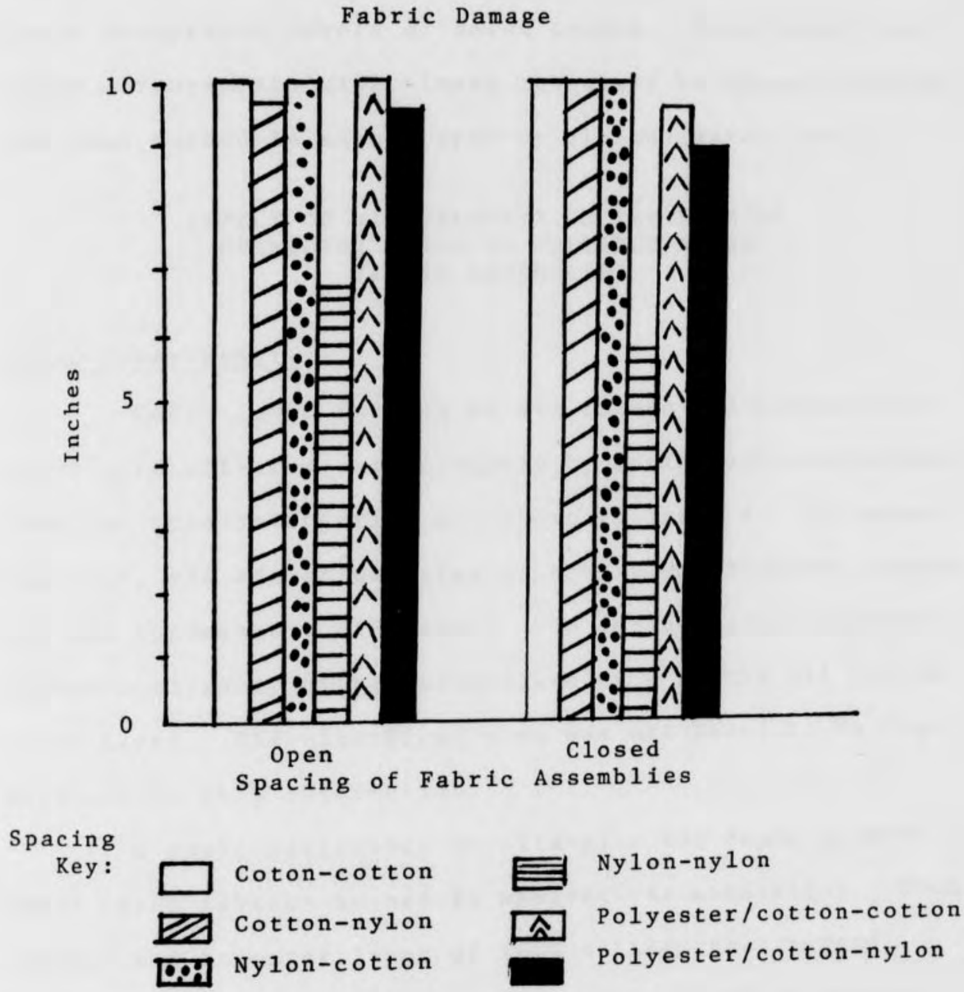

Figure 7

Fabric Damage of Garment Arrangements in Closed and Open Fabric Assemblies (GA x S N = 24)

Although fabric damage was not significant, only two garment arrangements out of twelve had fabric damage below acceptable levels of seven inches. This shows that these arrangements will almost certainly be damaged beyond use when burned in either open or closed assemblies.

EFFECT OF AIR VELOCITY ON THE BURNING CHARACTERISTICS OF MULTIPLE LAYER FABRIC ASSEMBLIES

Outer Layer Fabric

Outer layer fabrics of all cotton and cotton/polyester were affected only slightly by moving air conditions. Data for this interaction are shown in Table 6. In quiescent air, the afterflame time of both types of outer layers was not appreciably different. The ambient air conditions showed a slightly higher afterflame time in the all cotton outer layer. The afterflame time was not found to be significant in this interaction.

A small difference in afterglow was found between outer layer fabrics burned in ambient air conditions. When samples had an outer layer of 100% cotton, they burned approximately three seconds longer than the 80/20 cotton/polyester samples. However, in both the cotton and cotton/polyester samples afterglow continued longer with no air movement present. The values of afterglow in quiescent air was essentially the same for the all cotton and cotton/polyester outer layers.

Table 6

Burning Characteristics of Outer Layer Fabrics in Varying Air Conditions (F x V N = 72)

Fabric Types	Quiescent Air (0 ft./min.)	Moving Air (97 ft./min.)
	AFTERFLAMING (Seconds)	
100% Cotton	64.9	61.2
80/20 Cotton/polyester	64.9	60.5
	AFTERGLOWING (Seconds)	
100% Cotton	8.2	7.5
80/20 Cotton/polyester	8.8	4.7
	FABRIC DAMAGE (Inches)	
100% Cotton	9.2	9.0
80/20 Cotton/polyester	9.2	9.2

Fabric damage over both fabrics and velocity was nine inches in all cases. The interaction was not significant. A slight increase was noted in both fabrics when no air current was present. The ambient air was responsible for the small decrease in fabric damage.

Finish

The interaction of air velocity with finish resulted in the data found in Table 7. All three finishes had high afterflame times regardless of air conditions. Samples containing an untreated outer layer did not necessarily burn longer than those samples with a flame retardant finished layer. In both air conditions samples containing a THPOH-Amide layer burned longer than either of the other samples. The THPOH-NH_3 finished samples had the shortest afterflame time over all finishes and air conditions. On the average the quiescent air conditions had longer afterflame times spanning all finishes. The ambient air conditions produced a lower afterflame time by approximately three seconds.

Table 7

Mean Afterflame Time, Afterglow Time and Fabric Damage of Finishes in Varying Air Conditions (Fin x V N = 48)

Finish	Quiescent Air		Moving Air
		AFTERFLAMING (Seconds)	
No Finish	63.7		61.0
THPOH-NH_3	62.5		56.4
THPOH-Amide	68.5		65.1
		AFTERGLOWING* (Seconds)	
No Finish	21.7		10.1
THPOH-NH_3	0.7		5.0
THPOH-Amide	3.0		3.3
		FABRIC DAMAGE (Inches)	
No Finish	10.0		10.0
THPOH-NH_3	8.8		8.4
THPOH-Amide	8.9		9.0

*Significant at the .01 level.

Afterglow was found to be significant at the .01 level for the interactions of air velocity with finish. Afterglow times in both air conditions was higher in the unfinished samples. Data for afterglow appear in Figure 8 and Table 7. The THPOH-NH_3 samples had little afterglow in quiescent air, while the THPOH-Amide samples had an average afterglow of three seconds. Moving air produced an increase in afterglow time by five seconds in the THPOH-NH_3 finish, while air created a substantial decrease in afterglow time of the untreated layer.

Fabric damage, although not significant, showed a marked difference between finished and unfinished samples. Regardless of air conditions the unfinished samples burned the entire length. The fabric damage of both flame retardants in both air conditions was not substantially different.

Garment Arrangement

The burning characteristics of the garment arrangements were affected by the movement of air. The mean afterflame time, afterglow time, and fabric damage of the garment arrangements are shown in Table 8 and Figure 9.

The factor of afterflame time was significant at the .01 level. In general, over all garment arrangements except the nylon-nylon, the introduction of air decreased afterflame time. In the case of nylon, the moving air served to

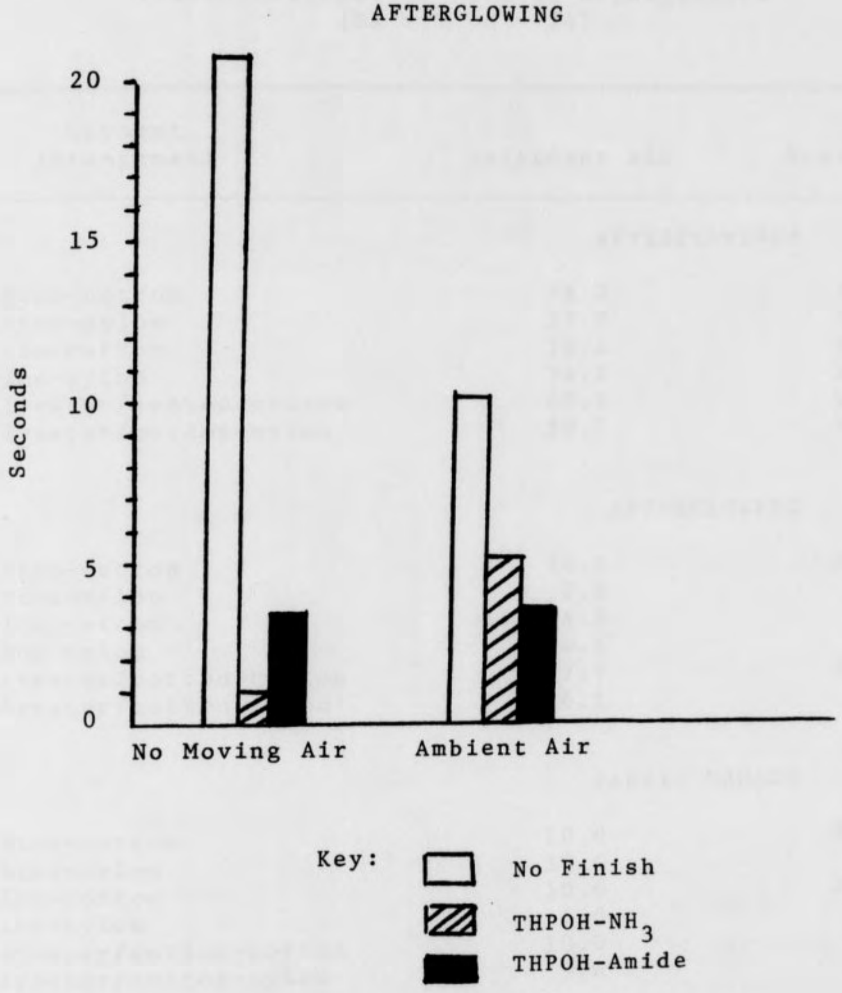

Figure 8

Mean Afterglow Times of Finishes
in Varying Air Conditions
(Fin x V N = 48)

Table 8

The Effect of Air Velocity on the Burning Characteristics of Garment Arrangements (GA x V N = 24)

Garment Arrangement	Quiescent Air	Moving Air
	AFTERFLAMING*	
Cotton-cotton	76.0	73.2
Cotton-nylon	57.9	53.6
Nylon-cotton	76.5	70.4
Nylon-nylon	34.1	52.7
Polyester/cotton-cotton	85.2	60.2
Polyester/cotton-nylon	59.7	54.9
	AFTERGLOWING	
Cotton-cotton	10.1	11.7
Cotton-nylon	2.6	1.8
Nylon-cotton	4.5	1.1
Nylon-nylon	0.1	0.8
Polyester/cotton-cotton	17.7	17.6
Polyester/cotton-nylon	16.1	3.7
	FABRIC DAMAGE	
Cotton-cotton	10.0	10.0
Cotton-nylon	10.0	9.8
Nylon-cotton	10.0	10.0
Nylon-nylon	6.0	6.1
Polyester/cotton-cotton	10.0	9.6
Polyester/cotton-nylon	9.6	9.3

*Significant at the .01 level.

Figure 9

Burning Characteristics of Garment Arrangements in Varying Air Conditions perpetuate the flame an average of eighteen seconds longer. Over all garment arrangements those which had a cotton third layer burned longer in both air conditions. Those arrangements with a nylon third layer burned considerably slower. The highest afterflame time in the quiescent air conditions was found in polyester/cotton-cotton arrangement. The flame time was almost ten seconds higher than the cotton-cotton arrangement in the same air condition. With the introduction of air the cotton-cotton arrangement had the higher flame time (by thirteen seconds) over the polyester/cotton-cotton.

Although afterglow was not significant, there were some obvious differences in the interaction. The highest afterglow time was found in the polyester/cotton-cotton arrangement. This arrangement had essentially the same afterglow time in both quiescent and ambient air.

In general, the afterglow time of all garment arrangements decreased when air was introduced into the testing cabinet. The only exception was in the cotton-cotton garment arrangement which increased slightly in afterglow time under moving air conditions. The lowest afterglow times in both air conditions were reported in all garment arrangements that had nylon in the third layer of the assembly. When cotton was on the outside of the assembly, an increase in afterglow was found regardless of air velocity.

Fabric damage was the full ten inches in four out of the six garment arrangements burned in quiescent air, and in two out of the six burned in ambient air. The lowest fabric damage was reported in the nylon-nylon arrangements in both air conditions. Interesting to note was that in quiescent air complete fabric damage was done to all garment arrangements containing an all cotton layer. Under ambient air conditions fabric damage was highest when the all cotton layer was in the third position.

Spacing

Although air velocity interacted with space was not significant in any case, some important observations were made. The mean afterflame time, afterglow time, and fabric damage are shown in Table 9.

Samples burned in quiescent air with free circulation of air between layers had the longest afterflame time. Open spaced samples burned in moving air conditions resulted in a nine-second reduction of afterflame time. Interesting to note was that while burning in the quiescent atmosphere, the open spaced samples produced an upward rise of smoke. The spaces between layers acted as tunnels through which the smoke rose rapidly. When moving air was introduced into the cabinet, the smoke and flame rushed sidewards thus consuming a wider portion of the sample.

Burned samples showed fabric damage the width of the sample regardless of whether the sample burned the entire length.

Table 9

Burning Characteristics of Open and Closed Assemblies in Varying Air Velocities (S x V N = 72)

Spacing	Quiescent Air	Moving Air
	AFTERFLAMING	
Open	72.0	63.4
Closed	57.9	58.3
	AFTERGLOWING	
Open	6.6	4.9
Closed	10.5	7.3
	FABRIC DAMAGE	
Open	9.4	9.2
Closed	9.1	9.0

Samples in the closed assembly showed almost no difference in afterflame time with respect to air conditions. Afterflame times for the closed assembly were shorter than those for the open assembly. The longer afterflame time could be explained by the tendency of the open spaced layers to burn individually. The closed spaced samples in both air conditions burned as a unit, resulting in lower flame times.

Afterglow times were cut by the ambient air conditions in both the closed and open assemblies. The open spaced assembly had the shorter afterglow time in both air conditions. Samples burned in the closed assembly glowed longer when moving air was not present.

Fabric damage was more than nine inches over both air conditions and spacing. A slight increase in fabric damage was noted with the open spaced assemblies, both in quiescent and moving air. Closed air assemblies under moving air conditions exhibited the lowest fabric damage.

EFFECTS OF GARMENT ARRANGEMENTS ON THE BURNING CHARACTERISTICS OF MULTIPLE LAYER FABRIC ASSEMBLIES

Fabric

The two fabric types used did not have a significant effect on the afterflame time of the various garment arrangements. Data showing the mean afterflame time are found in Table 10. The highest afterflame times were found in those arrangements having cotton in the third layer of the assembly. This was the case regardless of what type fabric was in the outer layer. The longest burning arrangement was the cotton outer layer with the cotton-cotton garment arrangement. The shortest time reported was with the cotton outer layer with a nylon-nylon garment arrangement. In this assembly the nylon acted as the extinguisher of the

Table 10

Burning Characteristics of Garment Arrangements with Different Fabric Types (GA x F N = 24)

Garment Arrangement	100% Cotton	80/20 Cotton/ polyester
	AFTERFLAMING	
Cotton-cotton	78.3	70.9
Cotton-nylon	55.4	56.1
Nylon-cotton	75.4	71.5
Nylon-nylon	40.9	45.8
Polyester/cotton-cotton	77.8	67.6
Polyester/cotton-nylon	50.3	64.3
	AFTERGLOWING	
Cotton-cotton	11.9	10.0
Cotton-nylon	1.7	2.7
Nylon-cotton	1.9	3.7
Nylon-nylon	0.8	0.1
Polyester/cotton-cotton	17.3	18.1
Polyester/cotton-nylon	13.8	6.0
	FABRIC DAMAGE	
Cotton-cotton	10.0	10.0
Cotton-nylon	9.8	10.0
Nylon-cotton	10.0	10.0
Nylon-nylon	5.9	6.2
Polyester/cotton-cotton	10.0	9.6
Polyester/cotton-nylon	9.4	9.5

assembly. However, when paired with the 80/20 cotton/polyester outer layer, garment arrangements containing nylon in the third layer burned longer. The afterflame times of these assemblies containing cotton/polyester in the outer layer and nylon in the third were higher than the same arrangement paired with a cotton outer layer. Thus, it appears that nylon positioned in the third layer of an assembly was more effective in decreasing afterflame time in the all cotton outer layer assemblies.

Afterglow time was not significant; however, several results were interesting to note. The highest afterglow time was found in the cotton/polyester outer layer, paired with a garment arrangement of polyester/cotton-cotton. The same garment arrangement also had a high afterglow time when paired with the all cotton outer layer. In general, afterglow times were lower in both fabric types when nylon was presented in the third layer position. The highest afterglow times came with the various combinations of polyester/cotton in the second layer paired with all cotton in the third layer of the arrangement. In both fabric types the nylon-nylon garment arrangement had little afterglowing.

All cotton in the third layer of any assembly resulted in greater fabric damage regardless of the fabric type used in the outer layer. In all cases except one, assemblies with cotton in the third layer position burned the entire length. The exception was the polyester/cotton-cotton assembly. Lowest fabric damage for both fabric types was found when the nylon-nylon arrangement was present. The interaction of garment arrangement and fabric type was not found to be significant with respect to fabric damage.

Finish

Data for the THPOH-NH_3 and the THPOH-Amide finish show the apparent ineffectiveness of the finishes in curbing afterflame. The afterflame time of the THPOH-NH_3 and THPOH-Amide finished samples was higher than the untreated samples over all garment arrangements. The one exception was the nylon-nylon garment arrangement with an untreated outer layer which burned the longest. Data for the mean afterflame time of finishes x garment arrangement were found to be significant at the .01 level. Values can be seen in Table 11 and Figure 10.

The two flame retardant finishes were more effective in curbing afterflaming in certain garment arrangements. The THPOH-NH_3 finished samples with garment arrangements of cotton-cotton, cotton-nylon, nylon-cotton, and polyester/cotton-cotton burned longer than their unfinished counterparts. The THPOH-NH_3 finished samples with the polyester/cotton-cotton garment arrangement burned forty seconds longer than the same garment arrangement paired with

Table 11

The Effect of Flame Retardant Finishes on the Burning Characteristics of Garment Arrangements (Fin x GA N = 16)

Garment Arrangement	No Finish	THPOH-NH_3	THPOH-Amide
		AFTERFLAMING*	
Cotton-cotton	57.7	76.6	86.4
Cotton-nylon	54.1	59.5	53.7
Nylon-cotton	60.2	79.2	81.0
Nylon-nylon	103.5	4.8	21.8
Polyester/cotton-cotton	47.5	87.4	83.3
Polyester/cotton-nylon	51.1	46.1	74.7
		AFTERGLOWING*	
Cotton-cotton	17.7	5.9	9.2
Cotton-nylon	6.2	0.0	.5
Nylon-cotton	5.7	0.0	2.8
Nylon-nylon	1.3	0.0	0.0
Polyester/cotton-cotton	36.1	11.0	6.0
Polyester/cotton-nylon	28.6	.4	.8
		FABRIC DAMAGE*	
Cotton-cotton	10.0	10.0	10.0
Cotton-nylon	10.0	10.0	9.7
Nylon-cotton	10.0	10.0	10.0
Nylon-nylon	10.0	3.8	4.4
Polyester/cotton-cotton	10.0	9.5	10.0
Polyester/cotton-nylon	10.0	8.4	10.0

*Significant at the .01 level.

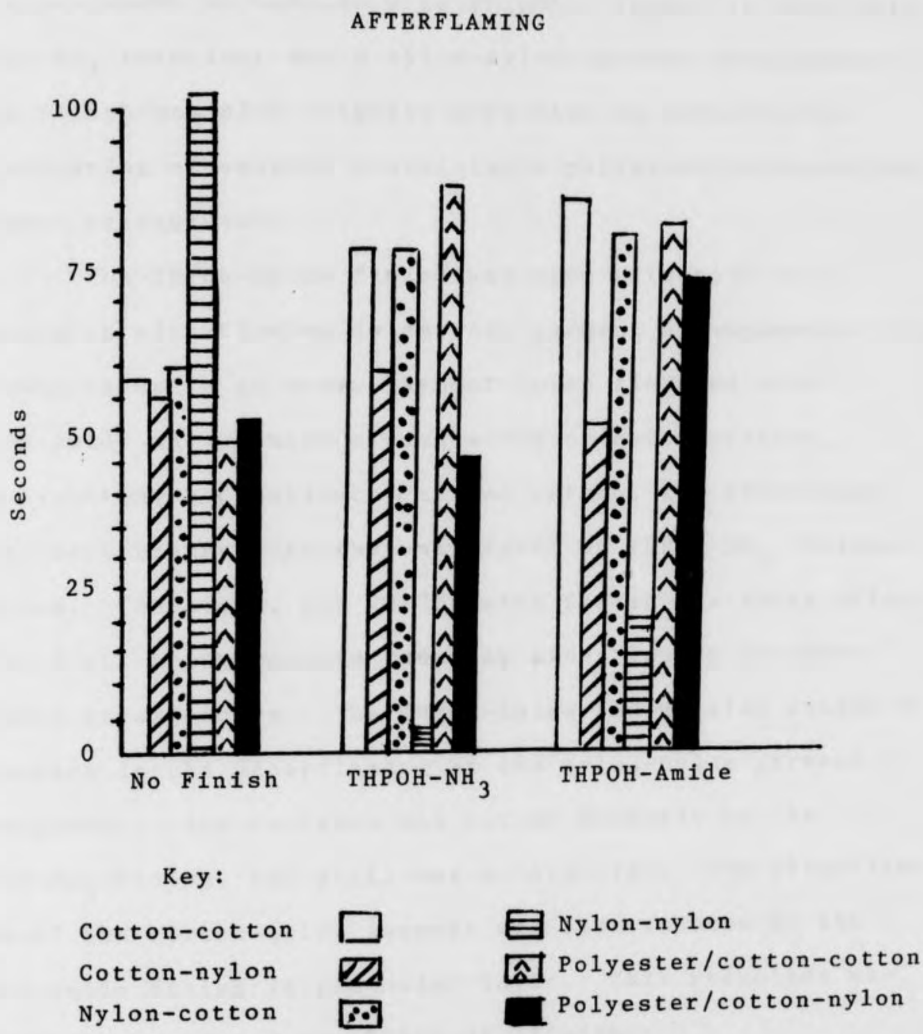

Figure 10

Afterflaming of Garment Arrangements with Various Finishes in Outer Layer

unfinished samples. A significant reduction in afterflame time was shown in samples with an outer layer finished with $THPOH-NH_3$ retardant and a nylon-nylon garment arrangement. This finish was also slightly effective in reducing the afterflaming of samples containing a polyester/cotton-nylon garment arrangement.

The THPOH-Amide finish was more effective in decreasing afterflaming in certain garment arrangements. In assemblies using an outer garment layer finished with THPOH-Amide and garment arrangements of cotton-cotton, nylon-cotton, and polyester/cotton-cotton, the afterflame times were higher than the unfinished or $THPOH-NH_3$ finished samples. Therefore, the THPOH-Amide finish was least effective of all treatments in reducing afterflaming in those garment arrangements. The THPOH-Amide finish also caused a reduction in the afterflaming of the nylon-nylon garment arrangement. The decrease was not as dramatic as the $THPOH-NH_3$ finish, but still was substantial. The afterflame time of the cotton-nylon garment was also reduced by the THPOH-Amide finish in the outer layer. This reduction was greater than that of the $THPOH-NH_3$ finish.

The flame retardant finishes appeared to be more effective in decreasing afterglow times. The interaction of garment arrangement and finish was significant at the .01 level. The mean afterglow for the garment arrangements and finishes are found in Table 11 and Figure 11. The highest afterglow times over all garment arrangements were found in those samples containing an unfinished outer layer. The THPOH-NH_3 finished samples had no afterglow on the cotton-nylon, nylon-cotton, and nylon-nylon garment arrangements. Less than one second of afterglow was reported for the same finish and the polyester/cotton-nylon arrangement. The highest afterglow times with the THPOH-NH_3 finish were in the polyester/cotton-cotton and the cotton-cotton garment arrangements.

The THPOH-Amide finish was less effective in reducing afterglow time than the THPOH-NH_3 finish. Less than one second afterglowing was reported in the cotton-nylon and the polyester/cotton-nylon garment arrangements. The nylon-nylon garment arrangement had no afterglow at all. These data suggest that the THPOH-Amide finish worked most effectively with garment arrangements having nylon in the third layer. Afterglowing in the all cotton garment arrangement with the outer layer finished with THPOH-Amide was higher than either the unfinished or the THPOH-NH_3 finished samples. However, the THPOH-Amide finish was the most effective over all finishes in controlling the afterglowing of the polyester/cotton-cotton garment arrangement.

The factor of fabric damage was extensive over all finishes resulting in a significance level of .01. The mean

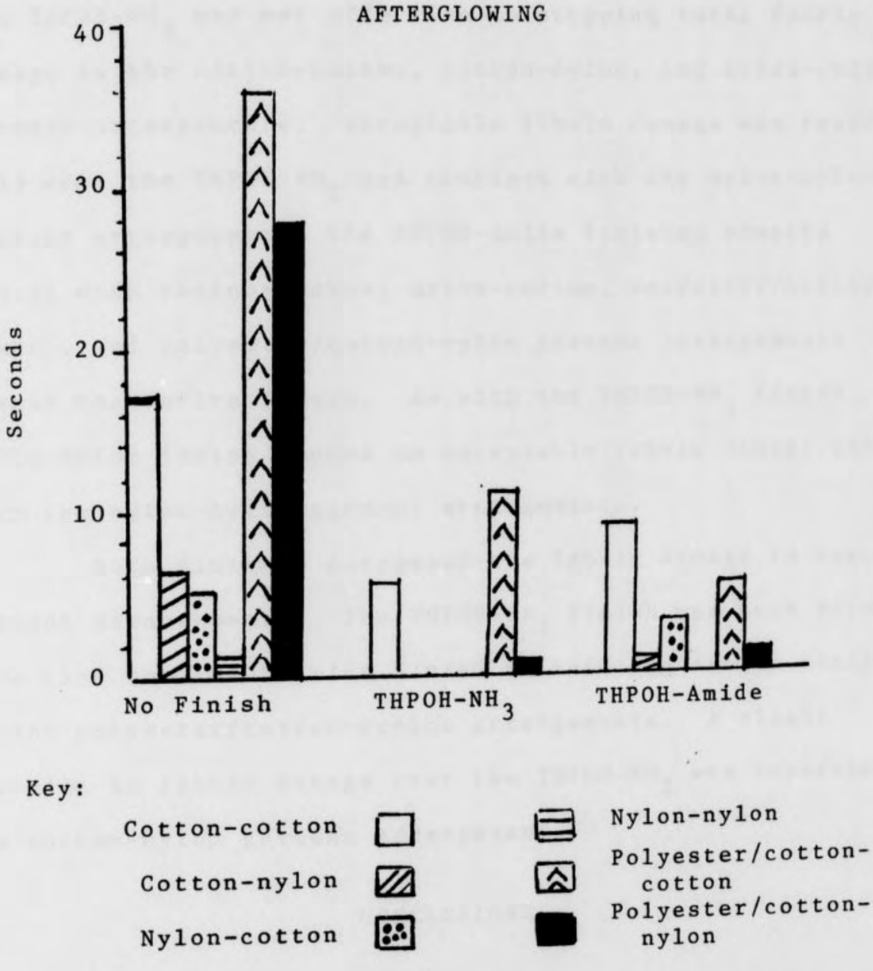

Figure 11

Afterglowing of Garment Arrangements with Various Finishes in Outer Layer fabric damage over all finishes and garment arrangements is shown in Table 11 and Figure 12. Fabric damage was total in all garment arrangements having an unfinished outer layer. The THPOH-NH_3 was not effective in stopping total fabric damage in the cotton-cotton, cotton-nylon, and nylon-cotton garment arrangements. Acceptable fabric damage was found only when the THPOH-NH_3 was combined with the nylon-nylon garment arrangement. The THPOH-Amide finished samples paired with cotton-cotton, nylon-cotton, polyester/cotton-cotton, and polyester/cotton-nylon garment arrangements burned the entire length. As with the THPOH-NH_3 finish, the THPOH-Amide finish showed an acceptable fabric damage level with the nylon-nylon garment arrangements.

Both finishes decreased the fabric damage in certain garment arrangements. The THPOH-NH_3 finish was more effective than the THPOH-Amide finish in reducing fabric damage in the polyester/cotton-cotton arrangements. A slight decrease in fabric damage over the THPOH-NH_3 was reported in the cotton-nylon garment arrangement.

CONCLUSIONS

The conclusions made in this section are discussed in relation to the hypotheses presented in Chapter I.

Hypothesis 1. There is no significant difference in the fire resistance characteristics of the selected

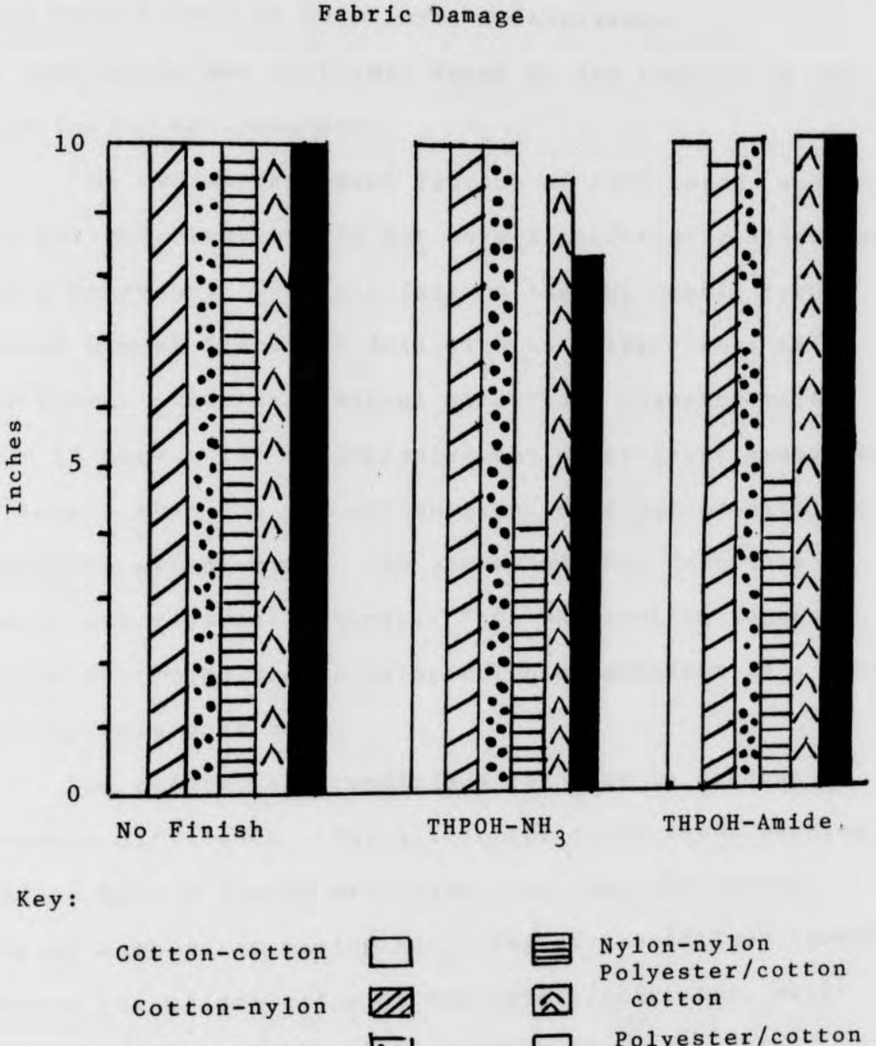

Figure 12

Fabric Damage of Garment Arrangements with Various Finishes in Outer Layer experimental fabrics (100% cotton and 80/20 cotton/polyester) when burned in multilayer arrangements.

This hypothesis was confirmed based on the results of the statistically analyzed data.

The two experimental fabrics of 100% cotton and 80/20 cotton/polyester did not have significantly different burning behavior. Over all factors the two fabric types produced almost identical data with no interactions being significant. However, several situations observed were worthy of note. The cotton/polyester outer layer seemed to burn longer than the all cotton layer when paired with the nylon-nylon arrangement. The smoke and odor from this assembly was especially heavy. This observation suggests that the cotton/polyester-nylon-nylon arrangement is a particularly hazardous one.

The ambient air conditions resulted in another observable difference. The all cotton outer layer samples seemed to have a longer afterglow time than the cotton/polyester samples in moving air. The air conditions tended to hasten the afterglowing of the cotton/polyester, while prolonging it in samples with an outer layer of cotton.

Hypothesis 2. There is no difference in the effectiveness of the two fire resistant finishes selected for the outer layer of the fabrics.

This hypothesis was partially confirmed based on the statistically analyzed data.

The data produced an insignificant difference in afterflame time between finishes used. Those samples with no finish as well as samples having an outer layer finished with THPOH-NH_3 and THPOH-Amide had only slight differences in afterflame time.

Differences in afterglow times of the three finishes were statistically significant at the .01 level of confidence indicating that the unfinished samples had higher seconds of afterglow. The THPOH-NH_3 finished samples produced a significantly lower afterglow time than nonfinished samples; however, the difference between THPOH-NH_3 finish and the THPOH-Amide finish was small. The THPOH-NH_3 had slightly lower afterglow times than the THPOH-Amide finished samples.

Fabric damage was also found to be statistically significant at the .01 level of confidence. All untreated samples had a fabric damage of ten inches. The THPOH-NH_3 samples had a substantially lower incidence of fabric damage. Difference in the mean fabric damage between the two finishes was only two thirds of an inch. Although the two flame retardant finishes aided in decreasing fabric damage, all damage reported was above the accepted limit of seven inches.

Interactions of finish with spacing and garment arrangement were significant at the .01 level of confidence for the factor of afterflame. Afterglow times yielded significant differences in interactions of finish with spacing, air velocity, and garment arrangement.

Hypothesis 3. There is no difference in burning characteristics of the three layer fabric assemblies when burned in "closed" and "open" formation.

This hypothesis was rejected based on the statistically analyzed data. This factor was significant at the .01 level of confidence.

Samples burned in the open formation, permitting air to circulate freely between layers, resulted in higher afterflame times. This phenomenon occurred as a result of the burning behavior of the assembly. Layers in the open assembly burned individually. Erratic burning was also prevalent. The flame was observed as often moving very rapidly from one layer to the next, igniting unburned sections. The moving air conditions also helped to "jump" flames and prolong burning.

The nonflammable and self-extinguishing members of the assemblies were not able to slow down flaming in the open assemblies. The flame retardant layers and the self-extinguishing nylon layers were relatively ineffective in the open spaced formation. Flame jumping brought about by increased air circulation between layers prolonged the burning of the normally self-extinguishing layers. The closed assembly formation, burning as a unit, was able to take advantage of the nonflammable and self-extinguishing layers as a means to curb flaming.

The factors of afterglow and fabric damage were not significant. No significant difference was found in these factors between open spaced assemblies and closed spaced assemblies.

Hypothesis 4. There is no difference in the burning characteristics of the fabrics in the multiple layer arrangements when burned in quiescent and ambient air.

This hypothesis was partially confirmed by the statistically analyzed data.

Over all factors there was no significant difference in the burning characteristics of samples burned in moving air as opposed to those burned without moving air present. However, in the interaction of air velocity with garment arrangement, the afterflame time was significant at the .05 level of confidence. The moving air served to decrease afterflame time significantly. Garment arrangements burned longer with no moving air with one exception. The nylon-nylon garment arrangement burned for a longer period of time in moving air conditions.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

The major purpose of this study was to investigate the burning characteristics of multiple layer fabric assemblies burning in varying air conditions. The investigation was undertaken as a supplement to Objective 2 of the Southern Regional Research Project S-86.

Multiple layer assemblies were burned so as to simulate as closely as possible actual wearing conditions. Previous research had indicated a need for further study in the area of multiple layer flammability. The fire resistance characteristics of three layer fabric assemblies, with and without air spacing between layers, were tested. The assemblies were burned under both quiescent and ambient air conditions.

The basic test procedure followed was the American Association of Textile Chemists and Colorists standard test #34-1969 for the flammability of textile fabrics. The instrument used was a fire resistance tester specially designed to incorporate moving air into the testing chamber.

The fabric assemblies consisted of a three layer arrangement. The outer garment layer had two possible fabrics, a 100% cotton, or an 80/20 cotton/polyester fabric.

The outer layer fabrics were either untreated, or finished with THPOH-NH_3 or THPOH-Amide flame retardants. The second layer of the assembly consisted of fabrics of either 100% cotton, 100% nylon, or 65/35 polyester/cotton. A 100% cotton knit or a 100% nylon tricot comprised the third layer.

The assemblies were burned in open and closed spacing to determine the effect that air circulation between layers had on the burning characteristics of multiple fabric layers.

The laboratory data were collected by measuring afterflame time, afterglow time, and fabric damage of each sample. The data were analyzed based upon a 2 x 3 x 6 x 2 x 2 randomized factorial design, having two fabric types, three finishes, six garment arrangements, two spacings, and two air velocity conditions. An analysis of variance was employed to determine the significance of each factor as well as their interactions.

There were no significant differences found in the burning characteristics of the outer layer fabrics. Assemblies containing both the 100% cotton and the 80/20 cotton/polyester had similar afterflame times, afterglow times, and fabric damage. In the interactions with space, both fabric types behaved the same way. Open spacing served to increase afterflame time and fabric damage of both fabrics while decreasing afterglow. Air velocity affected the experimental fabric types in the same manner also. Afterflame times of both fabrics were essentially the same. The afterglow times of both the 100% cotton and the 80/20 cotton/polyester were higher in quiescent air. Fabric damage was similar also with both fabrics, averaging slightly more than nine inches of damage.

The outer layer fabrics performed similarly when interacted with garment arrangement. In this interaction the burning characteristics depended more on the garment arrangement than the outer layer fabric. A cotton outer layer paired with an all cotton garment arrangement had the highest afterflame time; however, cotton paired with an all nylon arrangement had the shorter flame time.

Afterglow times were not significantly different between fabric types. Assemblies with an all nylon garment arrangement had lower afterglow times regardless of outer layer fabric. Both fabric types had high afterglow times with garment arrangements of polyester/cotton-cotton.

Assemblies burned the entire length when cotton was positioned in the third layer no matter which fabric type was in the outer layer. An all nylon arrangement decreased measurable fabric damage in both fabric types.

The flameproofing ability of both finishes was affected by the factors included in this experiment. Over all, the THPOH-Amide finish was the less effective of the two finishes. The difference between the burning characteristics of the two finishes was small, however. Untreated samples had higher afterglow times and fabric damage, but afterflame times were lower than those reported in samples with THPOH-Amide present.

The interaction of finish with space produced several interesting results. Afterflame times in the open assembly were THPOH-Amide > THPOH-NH_3 > untreated samples. Treated samples had a longer afterflame time by ten seconds or more than the untreated samples. In afterglowing the untreated assemblies had a much higher time in both spacings with both finishes producing similar results. Incidence of fabric damage in open assembles was untreated > THPOH-NH_3 > THPOH-Amide, and untreated > THPOH-Amide > THPOH-NH_3 in closed assemblies.

In the interaction of finish with air velocity the THPOH-Amide finished samples again burned longer than either the THPOH-NH_3 or the untreated samples under both air conditions. Afterglow and fabric damage were highest in the untreated assemblies regardless of air conditions. The THPOH-NH_3 finish was slightly more effective in controlling afterglow in quiescent air, while the THPOH-Amide was more efficient in controlling it in moving air. Fabric damage was essentially the same for both finishes in quiescent air, while the THPOH-NH_3 contained fabric damage better in moving air.

Both finishes were ineffective in curbing afterflaming in the interaction with garment arrangement. Afterflame times for both finishes were higher than afterflame times for untreated samples (the only exception was the nylon-nylon garment arrangement). Flame retardant finishes seemed to be more effective in curbing afterglow in multilayer arrangements. Both finishes had lower afterglow times than untreated assemblies. The THPOH-NH_3 was most effective in curbing afterglow in all arrangements except the polyester/cotton-cotton arrangement. In this arrangement THPOH-Amide was the most effective in decreasing afterglow. THPOH-NH_3 was slightly more effective in stopping fabric damage in the nylon-nylon, polyester/cotton-cotton, and polyester/cotton-nylon arrangements.

The factor of spacing between layers resulted in higher afterflame times, and fabric damage, but lower afterglow times. The extra air circulation fanned the flame, but extinguished afterglow more quickly than assemblies burned in closed assemblies.

In the interaction with garment arrangement, open spaced assemblies had higher afterflame times than closed assemblies in the cotton-cotton, nylon-cotton, polyester/cotton-cotton, and polyester/cotton-nylon arrangements. The closed assembly had higher afterglow times in the cotton-cotton, nylon-cotton, and the polyester/cotton-nylon.

Open and closed spacing had similarly high measurement of fabric damage. Only the all nylon arrangements had acceptable fabric damage in both closed and open assemblies.

Open spaced assemblies had higher afterflame times than closed assemblies in both air conditions. Afterglowing was higher in those assemblies with no air space between layers. Differences in fabric damage between open and closed assemblies in both air conditions were minimal.

Air velocity was effective in decreasing afterflame times in all garment arrangements except the all nylon arrangement. Quiescent air showed higher afterglow times in all garment arrangements except cotton-cotton and nylon-nylon. Fabric damage for garment arrangements was similar regardless of air conditions.

CONCLUSIONS

1. Multiple layer assemblies burn more rapidly when separated permitting air circulation around and between layers. Afterflame times increased while afterglowing and fabric damage decreased in open assemblies.

2. The positioning of fabric within an assembly affects its flammability. The same fabrics burned in different arrangements may produce different burning characteristics.

3. The flame retardant finishes, THPOH-NH_3 and THPOH-Amide are ineffective in reducing the flammability of

multiple layer fabric assemblies. Both finishes had higher afterflame times than untreated assemblies.

4. Slightly moving air current decreases the burning characteristics of multiple layer fabric assemblies. Afterflame time, afterglow time, and fabric damage decreased as air velocity increased.

RECOMMENDATIONS

It is recommended that further research in multiple layers be done. Areas of investigation might include the following:

1. An investigation into the flammability of curtain and drapery fabric in moving air conditions. The role of air conditions could become an important factor in the flammability of curtain and drapes.

2. Experiment with various fabric types in different positions in multiple layer fabric assemblies.

3. The effect air permeability has on each of the experimental fabrics in a multilayer assembly should be investigated.

4. Flammability of multiple layers in a horizontal position is an area to be investigated. The horizontal position of multiple fabric layers might best simulate wearing conditions in a seated position.

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