INFORMATION TO USERS

THE DEVELOPMENT AND APPLICATION OF AN INSTRUMENT TO

INDICATE THE FIRE RESISTANCE CHARACTERISTICS OF

FABRICS IN AIR CURRENTS OF VARYING VELOCITIES

by

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CHAPTER I

INTRODUCTION

The most critical issue in the textile industry at
the present time is the flammability of textile fabrics.
Since man's discovery and utilization of fire, combustible
materials have been a great concern, especially when the
materials occur in a fine state of division. This is par-
ticularly true of textile fibers which are easily ignited
and readily combustible.

For centuries flammable textile fabrics have been a
serious problem to the consumers of the United States and
also to the consumers of many other countries, yet the tex-
tile fibers used most extensively are highly combustible.
Only asbestos fibers, glass fibers, and mineral wools are
considered fire resistant. Among the man-made fibers, nylon,
polyesters, and vinylchloride copolymers tend to resist
flaming but do melt and cause serious burns.

Many people have suffered injury from the accidental
burning of clothing and household fabrics. An estimate of
the Department of Health, Education and Welfare reported
that 150,000 persons were burned and about 10,000 persons
perished each year in accidents that set clothing afire.

Thousands more were burned in fires involving bedding and other home furnishing fabrics.[1]

The first governmental regulations applied to flammability of fabrics was enacted in England in 1908. Although the United States for many years, had been concerned with fabrics which were considered dangerously flammable, legislation controlling such fabrics was not passed until 1953. This law was amended in 1967 to extend the coverage to include home furnishing fabrics and other apparel items such as gloves and footwear. The amendment was effected as a means of protecting consumers against injurious flammable fabrics. The Act also provides closer supervision and authority, stated in the Act as follows:

> . . . if the Secretary finds that any such fabrics, related material, or product is so highly flammable as to be dangerous when used by consumers for the purpose for which it is intended, he may under such conditions as the Secretary may prescribe, withdraw, or limit the exemption for such fabric, related material, or product.[2]

This strict governmental regulation has encouraged textile research personnel to increase the efforts to produce chemicals which will be effective as flame retardants by reducing the propagation of flame and the prolonged

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[1]Earnest R. Kaswell, "Some Thoughts and Information on Nonflammable Products," Journal of the American Association of Textile Chemists and Colorists, IV, 1 (January, 1972), 34.

[2]U.S. Congress, Public Law 90-189, 90th Congress, S. 1003 (December 14, 1967).

glowing of fabrics. Attention has also been directed to the revision or development of test procedures which will be more effective in controlling the hazards of flammable fabrics.

Research personnel of the textile industry, health and medical professions, and government agencies as well as leaders of consumer groups are all concerned with these problems. In order to test the flammability of fabrics and the effectiveness of finishes, testing should simulate the conditions in which the fabrics are to be used. Therefore, there is a need for the development of test methods which will predict accurately the fabric performance in an environment as close as possible to actual burning conditions.

STATEMENT OF THE PROBLEM

This investigation was concerned with the development of an instrument and testing procedure which would indicate the fire resistance characteristics of fabrics under varying conditions of air velocity.

There are several testing methods which are widely used in the United States and in England. Regardless of the number and variety of testing methods, there have been obvious evidences of the inadequacy of these testing procedures. Goldberg, an eminent textile consultant, reported

that there are clear evidences that many fabrics have burned
and caused serious injury even though the fabrics had passed
approved flammability tests.[3] Such information supports the
need of more realistic testing procedures.

The two most frequently used tests to indicate the
fire resistance of clothing and household fabrics are per-
formed under relatively air-free conditions. The instrument
developed for this study concerned with the introduction of
measurable velocities of air would permit the measurement
of fabric flammability under different conditions of air-
flow. Such conditions would apply to apparel and home fur-
nishing fabrics. It would be particularly valuable in eval-
uating the fire resistance of curtain and drapery fabrics.

To evaluate the developed instrument, it was neces-
sary to compare the flammability of fabrics by using the
fire resistance tester recommended by the American Associa-
tion of Textile Chemists and Colorists and the developed
instrument, and also to compare the flammability of selected
fabrics in different air velocities. Any correlation found
between these variables would suggest the usefulness of the
developed instrument.

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[3]J. B. Goldberg, "You Can't Win Them All," _Textile
Industries_, CXXXII, 7 (July, 1968), 120.

Objectives

The specific objectives of this research were as follows:

1. To develop an instrument to simulate more closely burning conditions and fire resistance characteristics of fabrics in moving air.

a. To develop a measurable air movement system as a modification of the instrument currently used in the standard test for fire resistance of textiles (AATCC Test Method: 34-1969).

b. To evaluate the experimental fire resistance tester by comparing the fire resistance of selected fabrics burned in both the standardized and the experimental instruments.

2. To determine the effect of different air velocities on the burning characteristics of fabrics.

a. To compare the fire resistance characteristics of selected fabrics of varying fiber content with no flame retardant applied.

b. To compare the fire resistance characteristics of these same fabrics following treatment with different types of flame retardants.

It was assumed that the fire resistance characteristics of fabrics were objectively measurable qualities.

Hypotheses

The following hypotheses were formulated and tested:

Hypothesis A. No different test performance exists between the standard instrument and the experimental instrument at the air-free condition.

Hypothesis B. Burning characteristics of the fabrics tested are dependent upon air velocities.

Hypothesis C. Burning characteristics of the fabrics tested are dependent upon fiber contents. This dependency may interact with air velocity testing conditions.

Hypothesis D. Burning characteristics of the fabrics tested are dependent upon the flame retardant treatments applied. This dependency may interact with air velocity conditions.

DEFINITIONS OF TERMS AND ABBREVIATIONS
USED IN THE STUDY

Definitions

The terms used for the objective laboratory tests of fire resistance of fabrics are defined as follows:

Afterflame time. The time the fabric specimen continues to flame after the source of flame is removed, expressed to the nearest 0.1 second.

Afterglow time. The time the fabric specimen contin-
ues to glow after it has ceased to flame, expressed to the
nearest 0.1 second.

Char length. The distance from the edge of specimen
exposed to the flame to the end of the tear made through the
center of the charred area expressed to the nearest 0.5 inch.

Abbreviations

The following abbreviated terms have been used
throughout the study.

APO-THPC. Abbreviation of (1-aziridinyl) phosphine
oxide-tetrakis (hydroxymethyl) phosphonium chloride.

THPC-urea-MM. Abbreviation of tetrakis (hydroxy-
methyl) phosphonium chloride-urea-methylolmelamine.

THPOH-NH$_3$. Abbreviation of tetrakis (hydroxymethyl)
phosphonium hydroxide-ammonia.

100 percent cotton. The term used to describe all
cotton fabric.

70/30 blend. Abbreviation of a 70 percent cotton
and 30 percent polyester blend.

50/50 blend. Abbreviation of a 50 percent cotton
and 50 percent polyester blend.

Standard instrument. The test instrument that has been standardized by the American Association of Textile Chemists and Colorists to test fire resistance of textile fabrics (AATCC Test Method: 34-1969).

Experimental instrument. The test instrument that has been developed for this study to test fire resistance of textile fabrics.

CHAPTER II

REVIEW OF LITERATURE

The current emphasis on legislation regulating the sale of flammable fabrics is not a new development. Due to the burning characteristics of cotton fibers and other cellulosic products, attempts to control the hazard have been of concern for many years.

The most pertinent literature dealing with flammable textiles was reviewed in this chapter to provide a background knowledge for this research. References reviewed were grouped under the following headings: (1) historical review of legislation or other attempts to control flammable fabrics, (2) characteristics of the burning of cellulosic fabrics and the theory of flame retardants, (3) types and performances of flame retardants, and (4) testing procedures for flammable fabrics.

HISTORICAL REVIEW OF LEGISLATION OR OTHER ATTEMPTS TO CONTROL FLAMMABLE FABRICS

Flammability is one of the most important properties of fabrics because it is so frequently directly concerned with human life. Little can be done to prevent the possibility of physical and economic loss from burning fabrics.

Despite the number of accidents caused by flammable fabrics, legislative action regulating production of such fabrics had not been taken until the early part of the twentieth century.

Recognition of the Problem of Flammable Fabrics in England

The first official consideration of the problem of flammable fabrics was made in 1908 in England following the introduction of highly flammable cotton flannelette used for children's night-wear which contributed to the number of fire accidents. At this time a Home Office Enquiry was instituted to consider apparel fire accidents. As a result, the Fabrics Misdescription Act was passed in 1913 to protect consumers from the sale of fabrics which were misrepresented as being flameproof.

From 1913 until the end of World War II, because of worldwide economic depression and the war conflicts, flammable textiles were of little interest except for special military end-use purposes. This need of flameproofing textiles for the armed forces, however, stimulated research into the possibility of producing durable or permanent flame retardants.[1]

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[1] F. Ward, "The Principle and Practice of the Flameproofing of Textiles," _Journal of the Society of Dyers and Colourists_, LXXI, 10 (October, 1955), 570.

Legislation in the United States

On January 27, 1945, the California State Legislature
passed a bill governing the manufacture or sale of flammable
or explosive fabrics. According to Labarthe, the bill made
it:

> . . . unlawful to manufacture, sell or offer for
> sale any article of wearing apparel, cloth, drapery,
> or 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 other
> substance in sufficient quantity so as to make such
> fabric or material more highly flammable than cotton
> cloth in its natural state . . . any toy, tool, or
> other article designed for use or intended to be
> used in any household or place of abode, containing
> such hazardous or highly flammable substance.[2]

The statement "more highly flammable than cotton"
left vague and uncertain the interpretation as to what
fabrics were to be considered flammable, and, therefore, the
law was unenforceable. A tentative amendment was offered by
the California State Fire Marshal to restrict the Act to:
(1) articles of wearing apparel with pile or brushed fabric
surface, (2) cellulosic nitrate or celluloid buttons, orna-
ments, and toys, and (3) stuffed toys. According to
Labarthe, it was proposed that:

> The sale in that state of a garment containing any
> cellulose nitrate product, or containing a fabric that
> will flash at 400° F under specified test conditions,
> would be unlawful . . .[3]

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[2]J. Labarthe, Jr., "Application to Civilian Fabrics,"
Flameproofing Textile Fabrics, ed. R. W. Little (New York:
Reinhold Publishing Corp., 1947), p. 395.

[3]Ibid., p. 396.

On January 6, 1948, the California Inflammable Act became effective after considerable cooperative study by the American Association of Textile Chemists and Colorists Flammability Committee, the National Retailer Dry Goods Association and other interested groups. The Act forbade the manufacture or sale of any textile item intended to be worn on the person which failed to meet the prescribed test.

The question of flammability of fabrics was again dormant until 1951, when the public was faced with a flood of the so-called "torch" sweaters. As a result of this hazard, the 1953 Flammable Fabrics Act was enacted by the Congress. The Act was only designed to prevent the marketing of "torch" clothing. Maleng reported that, at this time, Congress rejected the plea of the Federal Trade Commission that blankets, bedspreads, lap robes, upholsteries, draperies, stuffed toys, rugs and household textiles generally, be placed under the protective coverage of the Act.[4]

The Act of 1953 was very narrow in scope and there was disturbing evidence of widespread distribution of dangerously flammable fabrics which were beyond the reach of the law. The Federal Trade Commission and the Department of Commerce played influential supporting roles in urging Congress to expand this 1953 law so that home furnishings,

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[4]N. K. Maleng, "Flammable Fabrics: Congress Takes a New Look," American Dyestuff Reporter, LVI, 13 (June 19, 1967), 449.

footwear, hats, gloves, and interlining fabrics could be covered.

In July 1967, the Flammable Fabrics Act of 1953 was amended to strengthen the limited terms of the Act and provide a comprehensive fire safety law. According to Segall, the amended Act gives the Secretary of Commerce authority to:

1. Revise and strengthen current standards of flammability and to develop new standards.

2. Extend the scope of the Act to all personal and household fabrics considered to present fire hazards.

3. Authorize continuing case studies by the Department of Health, Education, and Welfare to determine the extent and effects of personal injury and economic losses caused by accidental burning.

4. Conduct research, in cooperation with appropriate public and private agencies, into the flammability of products, fabrics and materials, and develop appropriate measures for flammability control.[5]

It has been recognized that the implementing of this law will require further technological development in the textile industry as well as new standards and better testing methods.

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[5]William M. Segall, "Flammability Testing and Legislation," American Dyestuff Reporter, LVII, 6 (March 11, 1968), 197.

CHARACTERISTICS OF THE BURNING OF CELLULOSIC
FABRICS AND THE THEORY OF FLAME RETARDANTS

The Burning of Cotton Fibers

About 97 percent of cotton fiber is cellulose, and cellulose contains 1,4-glucosidic linkages. The glucosidic linkage, a chemical combination of aldehyde and alcohol groups, can be broken down by heat, acids, oxidizing agents, enzymes, and light.

When cotton fiber burns, the process involves many steps of disintegration and oxidation like most organic materials. Schuyten and others reported two stages of complete burning of cotton, which are thermal decomposition and glow.[6]

Heuser used the terms "pyrolysis" or "destructive distillation" to describe the decomposition of cellulose at an elevated temperature.[7] Thermal decomposition of cotton begins at temperatures above 300°C, and as the result, an aqueous distillate, tar, and gases are produced. The aqueous distillate contains the tarry products, which are increased by the increase in temperature. When the temperature

[6]H. A. Schuyten and others, "Some Theoretical Aspects of the Flameproofing of Cellulose," Advances in Chemistry Series, No. 9 (June, 1954), 8.

[7]Emil Heuser, The Chemistry of Cellulose, (New York: John Wiley & Sons, Inc., 1944), p. 545.

is elevated to 450°C, the production of tar is about 52 percent. Phenols, being the main content of the tarry products, may, at high temperatures, act as catalysts to transform aliphatic compounds into aromatic compounds which can give rise to highly flammable gases under the influence of heat. The heat of the combustion causes the flame to travel over the unburned surface of the fabric and raises the temperature so that more gases are continuously supplied as a support for the flame.

Liquid and tarry products volatilize in part to give more fractions which burn producing a carbon residue generally called a char. This process continues until only carbonaceous material is left.

Following the flame, as the second reaction, is the slow oxidation of the carbonized residue of fabric structure. This secondary oxidation, or afterglow, normally continues until the entire fabric is reduced to a light, fluffy ash. Even if the flame becomes extinguished, the glowing may continue beyond the charred portions of the fabric and slowly consume the unburned cellulose.

Webster and others studied the heat transfer from burning fabrics. They concluded that all cellulosic fabrics transferred sufficient heat to cause serious burns. The study also stated that the maximum heat transfer rate was dependent upon the temperature of the gases in the flame and largely independent on the rate of spread of the flame.

Although the time required to burn a unit length of cellu-
losic materials was directly proportional to the weight, in
the case of a heavier fabric, a greater total heat dose was
obtained because of the increased weight even though the
flammability was reduced.[8]

Theoretical Aspects of Flame Retardants for Cellulosic Fabrics

Flame retardant finishes have not been widely used
commercially because of high processing costs, changes in
appearance and feel, non-permanency, and the serious disad-
vantage of lowering original fabric quality. They also tend
to affect other finishes and colors that have been applied
to the fabric. But, because of the recent demand, there has
been intensive research conducted on retardants and theories
of application.

A report of the Textile Research Institute stated the
objective of the application of flame retardants on textiles
as follows:

> . . . to render them difficult to ignite and to cause
> them to feed the flame so inefficiently that it is spon-
> taneously extinguished when the igniting flame is re-
> moved . . . the textile is so finished that it will
> neither propagate a flame nor exhibit prolonged glowing.[9]

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[8]C. T. Webster and others, "Heat Transfer from Burn-
ing Fabrics," Textile Industries, LIII, 1 (January, 1962),
T29.

[9]The Fireproofing of Textiles, A research report of
the Textile Research Institute (New York: Textile Research
Institute, Inc.), July, 1943, p. 1.

The most pertinent research in relation to the theory of the mechanisms of flame retardants have considered two major aspects, physical and chemical theories. Physical theories include: (1) glass-like coating, (2) evolution of non-combustible gases, and (3) thermal theory. Chemical theories include: (1) hydrogen bonding formation at high temperatures, and (2) catalytic dehydration of cellulose to carbon and water.

Coating theory. The flame resistant properties of fabrics can be achieved by applying a layer of decomposable material onto the surface of fabric which can be fused at ignition temperatures, excluding the fiber from the sources of flame and the oxygen of the air, so that further combustion or support of the flame can be prevented. As the coating excludes the oxygen from cellulose, it also cuts down the escape of flammable gases. The highly flammable tars of decomposition become entrapped in the solid form and are not available for further combustion reactions.

The coating theory is supported by known melting points of some of the effective inorganic compounds such as borophosphate complexes, borax, boric acid, aluminum sulfate, and diammonium hydrogen phosphate.[10]

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[10]G. S. Buck, Jr., "Fire Resistant Textiles," Kirk-Othmer Encyclopedia of Chemistry Technology, IX (2nd ed.; New York: John Wiley & Sons, Inc., 1965), p. 303.

Gas theory. The gas theory is the manner in which the finish affects the release of combustible gases during the burning of cellulose. Buck specified that the purpose of the application of finishes in this case was to increase non-combustible gases such as carbon dioxide, while decreasing flammable gases such as carbon monoxide and hydrocarbon gases.[11]

The inorganic carbonates and halids, and the ammonium salts when decomposed evolve large quantities of relatively non-flammable, inert gases. These serve to dilute the highly combustible atmosphere by surrounding the thermally decomposing substrate and decrease its flammability.

Thermal theory. This theory is based on the physical mechanism of flame retardants which absorb heat at the time of ignition, so that the temperatures of fabric are retained below the dissociation point.

Coppick suggested two possible hypotheses concerning the thermal theory. The first hypothesis presumed that the chemical materials absorb heat, and change their internal structure. When the finishing agent acts to dissipate the heat of combustion of cellulose, the temperature is kept below the critical level at which the flame can continue. This action of chemicals is due to the endothermal nature

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[11]Ibid., p. 304.

of the change that takes place near the flaming tempera-
ture. The fusion, sublimation, or decomposition of
retardants may absorb considerable energy which otherwise
would contribute to the continuing propagation of the
flame. This hypothesis is only applicable to those
retardants which can fuse, sublimate, and decompose.

The second hypothesis is related to the action of
chemicals in conducting the incident heat away from fibers.
This affects the fabric in the vicinity of the edge of
the flame so that it never can reach its combustive
temperature.[12]

Hydrogen bonding formation. As mentioned in the
previous section, when cotton is exposed under high
combustible temperature, water molecules are volatilized
to permit thermal degradation of cotton, resulting in a
small fraction of combustible tarry products.

Although flame retardant treated cotton gives
substantially the same decomposition products upon burn-
ing as does untreated cotton, the proportion of tar, and
thus, the amount of flammable gas available from tar is
sharply reduced. On the other hand, the amount of solid
char is correspondingly increased.

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[12] R. W. Little (ed.). Flameproofing Textile
Fabrics. (New York: Reinhold Publishing Corporation,
1947), p. 47.

To prevent or decrease the production of combustible tarry products, a non-volatile component should be used. According to Little, some flameproofing materials have hydrogen bonding energies which can hold adjoining hydroxyl groups between cellulose molecules at a high temperature.[13] When chemicals such as inorganic sulfate phosphates, and sulphamates are applied to cotton fiber, these provide sufficient hydrogen bonding activity to promote strong linkages even at extremely high temperatures.

Catalytic dehydration on Cellulose. Since cotton is a polyalcoholic material, it is subjected to catalytic dehydration by the reaction with acid or basic catalysts. Some flame resistance is achieved by the catalytic dehydration of cellulose through the reaction of the retardant with cellulose via the carbonium ion mechanism:

$$(C_6H_{10}O_5)n \longrightarrow 6nC + 5nH_2O$$

The interpretation of this mechanism is that, by the application of certain flame retardants, carbon contents are confined to the solid phase. These non-volatile carbon fragments prevent flaming.

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[13]Robert W. Little, "Flameproofing," Textile Chemicals and Auxiliaries, ed. Henry C. Speel (New York: Reinhold Publishing Corp., 1952), p. 422.

TYPES AND PERFORMANCE OF FLAME RETARDANTS

Development of Flame Retardants

In the twentieth century, it is difficult to realize that interest in fireproofing was recorded as early as the seventeenth century. One of the earliest fireproofing treatments was recorded in the book by Sabattini in 1638. He recommended the use of "caly and plaster of Paris" in the paint applied to canvas. In September 1684, the records of "Early Science at Oxford" reported that "Merchant Wayt's account of his piece of incombustible cloth was read."[14]

The first comparative investigation of the possibilities of flameproofing fabrics appears to have been carried out by Gay-Lussac in 1821 at the instigation of Louis XVIII of France. In his study, Lussac treated linen and hemp fabric, and concluded that salts which gave off non-flammable vapors on heating or covered the fabric with a glossy layer were the most effective finishing agents.

In 1859, Versmann and Oppenheim reported that among a large number of chemicals he studied, only five salts and mixtures (sodium tungstate, ammonium sulfate, ammonium chloride and ammonium phosphate) were found to have effective and practical values. In the same year, Versmann and

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[14]Ward, op. cit., p. 659.

Oppenheim also patented a flameproofing process by the pre-cipitation of stannic oxide in the fiber.[15]

Perkin developed the "Non-Flam" process which was also known as the "Perkin Process" in 1912. This was be-lieved to be earliest work on the production of permanently flameproofing cellulose. Perkin stated that, by this process, the problem of permanently flameproofed cotton flannelette had been solved successfully. In this process, stannic oxide was precipitated by a two-bath process employing solu-tions of sodium stannate and ammonium sulfate.[16]

In 1932, the use of vinyl chloride resin was patented by Snyder, and Leatherman patented chlorinated diphenyl de-rivatives in 1933. In 1939, Clayton and Heffner also pat-ented the use of zinc borate in chlorinated paraffin. In 1942, Clayton suggested the use of antimony oxide in chlori-nated paraffin.

The FWWMR (Flame, Water, Weather, and Mildew resist-ant) finish was most important for military use during World War II. This finishing agent was either the antimony oxide chlorinated paraffin or the vinyl chloride type which also was used as a flame resistant finish for cotton in industrial applications. The finish was applied to outdoor products

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[15]Ibid., p. 570.

[16]Ibid., p. 570.

such as fabrics for tents and tarpaulins. Even though it was durable throughout the service life of these textile products, it affected the hand, drape, flexibility, and color of fabric inasmuch as add-ons up to 60 percent were required to meet adequate flame resistance. The finish, however, retained its flame resistance after four to five years of outdoor weathering.[17]

The task of developing effective flame retardant finishes for cotton is difficult because the finishes must meet many requirements, such as: ease of processing, maintenance of original desirable fiber properties, resistance to laundering and dry cleaning, and reasonable cost. However, many attempts have been made to achieve the flame-proofing of textile products.

Flame resistant resins are either water-soluble or insoluble. Water soluble finishes penetrate into the fibers and interact chemically to precipitate the flame resistant finish on and within the fibers. The water-insoluble finishes of the nature of flame resistant waxes and resins coat the surface of textiles or react chemically with the functional groups of fibers to impart flame resistant constituents.

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[17]G. L. Drake, "Flame Resistant and Rot Resistant Finishes: Application to Cellulose," American Dyestuff Reporter, LVI, 15 (July 17, 1967), 560.

Cellulosic fabrics are also flameproofed by impregnation with various salts. Non-durable flame resistant finishes consist of inorganic salts, -borates, diammonium phosphate, ammonium sulfamate, -chloride, and -sulfate- which are applied from an aqueous solution.[18] The inadvertent wetting destroys the property of the finishes and usually stiffens the fabric and reduces its physical strength.

The durable finishes modify the cellulose fiber by chemical reaction with its molecule. They include copolymers of vinylchloride, vinyl acetate and chlorinated paraffin - generally used in conjunction with antimony trioxide. Such finishes adversely affect the color, the physical strength of the fiber, and the feel or hand of the fabric.

In the earliest stages, interest was confined almost entirely to water-soluble salts, such as borax, boric acid, diammonium phosphate, ammonium sulfate, and a mixture of ammonium chloride and ammonium phosphate.

Today, there are numerous chemical compounds which have been considered for use as flame resistant finishes. The chemical structure and performance characteristics of those retardants which have been applied to the experimental fabrics used for this study are reviewed in this section.

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[18] Richard Zimmerman, "Flame Resistant Cotton Textiles," Textile Industries, CXXVI, 96 (June, 1962), 112.

Development and Characteristics of Retardants Used in the Study

THPC-urea-MM flame retardant. In 1953, tetrakis (hydroxymethyl) phosphonium chloride was developed at Southern Regional Research Laboratory by treating phosphine with an aqueous solution of formaldehyde hydrochloric acid. In 1955, Guthrie, Drake and Reeves reported the process of applying THPC to cotton fabrics. They stated that the treatment could be applied on standard chemical-finishing equipment, and suggested to apply an aqueous solution of THPC, urea and methylolmelamine to a fabric under a padder with pressure. The use of methylolmelamine was desirable to impart water solubility which resulted because of available methylol groups. Urea was used to combine with the hydrochloric acid formed during the polymerization and thus to prevent acid tendering. They concluded that eight-ounce twill containing about 16 percent of the THPC resin would pass the vertical fire resistant test. The amount of resin would also impart durable flame resistance and glow resistance, as well as considerable wrinkle resistance and rot or mildew resistance.[19]

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[19]J. D. Guthrie, G. L. Drake and W. Reeves, "Application of the THPC Flame-Resistant Process to Cotton Fabrics," American Dyestuff Reporter, ILIV, 10 (May 9, 1955), 332.

The polymer-forming properties of THPC was reported in 1956 by Reeves and Guthrie. They reported that when aminized cotton was moistened with a dilute aqueous solution of THPC, it reacted with the amine groups of aminized cotton to produce a flame resistant chemically modified cellulose. The condensation reaction between the amino group of aminized cellulose and hydroxymethyl groups of the THPC which is attached to the electronegative phosphorous atom was represented as follows:

$$Cellulose - OCH_2CH_2NH_2 + (HOCH_2)_4PCl \longrightarrow$$

$$Cellulose - OCH_2CH_2-N-CH_2-\overset{\overset{\displaystyle O}{|}}{\underset{\underset{\underset{\underset{H}{|}}{O}}{\underset{|}{CH_2}}}{P}}-CH_2-N-CH_2CH_2O - Cellulose*$$
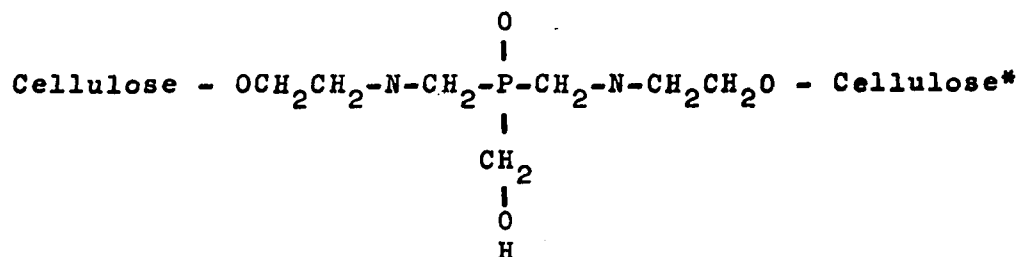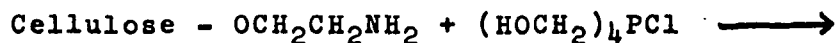
THPC has been experimented with in combination with compounds such as amide, ammonia, bromoform and cyanamide. The stiffness and loss of strength in THPC treated fabrics were somewhat reduced by cross-linking agents such as triazine or cyclic ethyleneurea. When THPC was used with

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*Wilson A. Reeves and J. D. Guthrie, "Intermediate For Flame Resistant Polymers: Reactions of Tetrakis (Hydroxymethyl) Phosphonium Chloride," Industrial and Engineering Chemistry, ILVIII (January, 1956), 64.

polyvinyl chloride, the finished fabric imparted a soft
hand, and the fabric was as strong or stronger than un-
treated fabrics.[20]

APO-THPC flame retardant. In 1956, the Southern
Regional Research Laboratory again announced one of the
most highly effective and durable flame resistant compounds
of this (1-aziridinyl) phosphate oxide and tetrakis (hydroxy-
methyl) phosphonium chloride. APO-THPC is not a mere
combination of two flame retardants, but a new thermosetting
resin. APO was prepared by reacting ethylenamine with
phosphorus oxychloride, and the reaction was represented
as follows:

$$POCl_3 + 3HNCH_2 CH_2 + 3R_3N \longrightarrow$$

$$OP(NCH_2 CH_2)_3 + 3R_3 N \cdot HCl$$
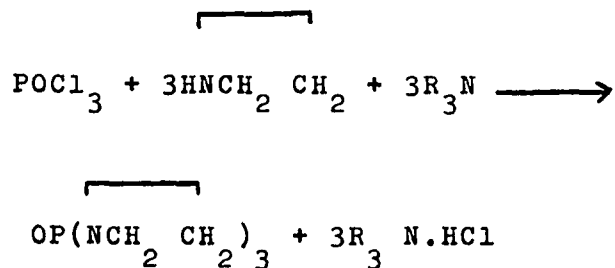
APO reacted with THPC forms highly flame resistant
thermosetting resins since the phosphonium structure in
THPC has been converted to a phosphine oxide structure by
heat, either in alkaline or acid conditions. With an

[20]
George L. Drake, "Flame Retardants and Their
Application to Textiles," Bulletin of New York Academy
of Medicine, ILIII, 8 (August, 1967), 659.

addition reaction, one of the aziridinyl rings of APO was opened by one of the methylol groups of THPC to form a stable ether-type bond, and still two aziridinyl rings and two methylol groups which also would react. In this reaction manner, highly cross-linked polymerization occurred:

$$OP(\overline{NCH_2CH_2})_3 + (HOCH_2)_4PCl \longrightarrow$$

$$(\overline{CH_2CH_2N})_2\overset{O}{\overset{\|}{P}}\underset{H}{N}CH_2CH_2 - O - CH_2\overset{O}{\overset{\|}{P}}(CH_2OH)_2 + HCl + HCHO$$
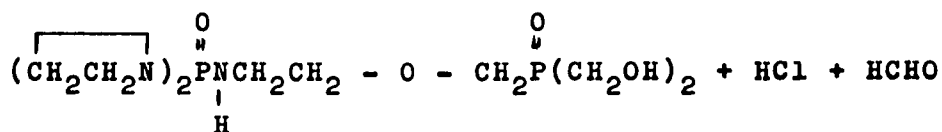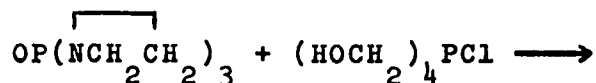
The application of APO-THPC on cotton fabrics showed good flame-resistance with eight percent add-ons. The flame resistance was durable with only slightly changed hand after 15 launderings with synthetic detergent. However, the resin actually improved the abrasion resistance of fabrics. The flame resistant fabrics were also resistant to chlorine bleach, rot and mildew.[21]

Even though the APO-THPC treatment was believed to be suitable for many industrial applications because it required smaller amounts of retardants, the deterioration by outdoor weathering presented another problem. To overcome this

[21]Wilson A. Reeves and others, "Flame Retardants for Cotton Using APO- and APS-THPC Resins," Textile Research Journal, XXVII, 3 (March, 1957), 261.

problem, Drake and others applied a wax and anti-mildew finish and a vinyl coating to an APO-THPC treated cotton duck. They found that the vinyl coating offered protection from the weather for the flame resistant finish, as well as improved rot and mildew resistance. However, due to the aging, the phosphorus content of the fabric was decreased and the fabric was stiffer.[22]

Decossas, Sojcik, and Kleppinger indicated desirable outstanding features of APO-THPC treated cotton fabrics: durability in repeated dry-cleaning and laundering, glow and flame resistance, production of pliable chars when exposed to flame and heat, susceptibility to further finishing treatment, and only slight changes in texture, hand, and appearance with some crease resistance.[23]

THPOH-NH$_3$ flame retardant. Tetrakis (hydroxymethyl) phosphonium hydroxide is the hydroxy derivative of THPC. Beninate and coworkers, in experimentation with this compound reported the performance characteristics in reaction with urea and trimethylolmelamine on cotton fabrics. They concluded that an adequate flame resistance was obtained when

[22]George L. Drake, Jr., and others, "Flame Resistant Duck Defied Weather," Textile Industries, CXXX, 12 (December, 1966), 192.

[23]K. M. Decossas and others, "Flame Resistant Cottons," Textile Industries, CXXX, 7 (July, 1966), 136.

a molar ratio of 2:4:1 (THPOH:urea:trimethylolmelamine) was applied to cotton fabrics. With resin add-ons of 15-19 percent, only minimal losses in tear and breaking strength were observed which could be improved by the use of softeners. The treated fabric also provided wash-wear and permanent press properties as well as durable flame resistance. Furthermore, little or no yellowing of treated fabric was observed when sodium hypochlorite bleaches were used.[24]

THPOH was also discovered to be useful as a flame retardant when it was mixed with ammonia. This treatment was even effective in lightweight cotton fabrics, exhibiting good strength properties and soft hand. The flame resistance remained after 25 launderings. Unlike other flame retardants mentioned previously, this particular resin treatment did not impart any crease resistance to cotton, however, yellowing by chlorine bleach was lesser in degree than other retardants.[25]

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[24]J. V. Beninate and others, "Conventional Pad-Dry-Cure Process of Durable Flame and Wrinkle Resistance with Tetrakis (Hydroxymethyl) Phosphonium Hydroxide (THPOH)," Textile Research Journal, XXXVIII, 3 (March, 1968), 272.

[25]J. V. Beninate and others, "Application of a New Phosphonium Flame Retardant," American Dyestuff Reporter, LVII, 25 (December 2, 1968), 985.

TESTING METHODS FOR THE FLAMMABILITY AND
FIRE RESISTANCE OF TEXTILES

Numerous testing procedures and apparatus have been introduced to measure the flammability and fire resistance of fabrics with respect to the performance characteristics of flame retardants as well as their influence upon other desirable fiber and fabric properties.

In general, desirable qualities and characteristics of flame resistant fabrics are: (1) to not ignite, flame or glow easily, (2) flame is prevented from spreading over the surface of fabrics, (3) reasonably low burning rate, (4) resistance to thermal degradation, (5) durability to repeated drycleaning and laundering, and (6) little or no changes of desirable fabric properties. Therefore, it is essential for a fire resistance or flammability test method to be able to test such characteristics. However, the variety of characteristics such as fiber chemical structure, fabric construction, as well as the service conditions which the fabric may be expected to meet make it rather complicated to test all the factors with a simple test procedure and interpret the results in a general manner.

There are several testing methods for the flammability and fire resistance of fabrics which are widely used in the United States and England. The Fire Resistance Test is one of the most accepted methods in the United States,

and the only test in which the fabric sample is suspended
vertically. By this test, a sample strip is suspended
vertically so that the lower edge hangs 3/4 inch above a
1 1/2 inch luminous flame of the top of a Bunsen or Tirrell
burner. The flame is removed after the ignition time, and
the duration of continued afterflame time, afterglow time,
and the char length are measured in a draft-free cabinet.
The test procedure is described as being:

> . . . designed for measuring the fire resistance
> of textile fabrics when a flame is applied to one edge.
> Because of its severity, this test method is primarily
> applicable to fabrics that have been treated for fire
> resistance or fabrics made from inherently flame
> retardant fibers.[26]

This vertical burning test has been incorporated in-
to many specifications, among which are AATCC-34, ASTM
D-626, CCC-T-191 (Federal), NFPA-701-31, -345 (Army),
24-C20 (Navy), City of Boston, New York City, and Califor-
nia. Even though the specifications differ slightly in the
size of sample, exposure time, type of gas used, number of
samples tested, and conditioning of samples, the application
of principles are alike.

Most of the specifications allow an afterflaming
maximum of two seconds and an average char length of 3-1/2

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[26]"AATCC Test Method 34-1969 Fire Resistance of
Textile Fabrics," _Technical Manual of the American Associa-
tion of Textile Chemists and Colorists_, ILVII (Research.
Triangle Park, 1971), p. 204.

inches, with a maximum of 4-1/2 inches for any one strip. Buck stated that the reproducibility of the test as a measure of flame resistance was generally superior to its reproducibility on measurements of char length or afterglow time.[27]

The AATCC flammability tester was developed after World War II and has been more widely used than any other rate-of-burning device. In the Flammability of Clothing Textiles testing method, the fabric sample is inclined at a 45 degree angle. It is indicated that:

> This test is designed to indicate textiles which ignite easily and once ignited, burn with sufficient intensity and rapidity to be hazardous when worn. The method can be applied to the testing of textiles generally; however, the scale of evaluation is applicable only to textiles used for apparel, . . .[28]

In this test procedure, the fabric 6 x 2 inch sample is clamped in a rack inclined at a 45 degree angle, and the bottom surface of fabric is exposed to a microjet burner flame for one second.

A partial critique of the present method of this flammability test is that a fabric which failed to ignite in a one-second ignition time may actually be involved in a fire accident. Also, the time to burn a sample fabric should be measured in all cases.

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[27]Buck, op. cit., p. 556

[28]Technical Manual of the American Association of Textile Chemists and Colorists, op. cit., p. 206.

The British standard test method, B. S. 2963:1958, specified two flammability test procedures; (1) the vertical strip method, and (2) the 45 degree angle method. In the vertical strip test, a sample six feet long and 1-1/2 inches wide is hung vertically and exposed to a flame 1-1/2 inches in length. The flame resistance rating is measured in seconds by calculation 2.0 x t; where t is the time in seconds for the propagation of the flame from the lower to the upper edge of the sample. The test method is applicable:

> . . . to fabrics, of all constructions which are in the form of flat sheets or may, by cutting, be converted to flat sheets. The methods proposed are not intended for the assessment of flameproof fabrics for industrial use. . . .[29]

The Methenamine Pill Test is another method recently issued by the government as a standard procedure for testing carpets, rugs and all materials which would be exposed to use as floor coverings. According to this procedure, a 12-inch square sample is held in a 9-inch diameter metal ring so that the 8-inch surface of the sample is exposed under the flame horizontally.[30]

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[29]British Standard Methods of Test for the Flammability of Fabrics: B. S. 2963:1958, (London: British Standard Institution, 1958), p. 4.

[30]R. Weinstein, "Current Legislative Requirements and Test Methods for Flame Retardancy," Journal of the American Textile Chemists and Colorists, III, 2 (February, 1971), 50.

Aside from the procedures described, there are many other test methods which have been designed to measure the flammability of textiles in one way or another. Some of these are, the Horizontal Burning Test, the English Semi-Circle Test, and Inverse Vertical Test, and the Canadian Ease of Ignition Test. Segall reported at the meeting of the Information Council on Fabric Flammability that 36 test methods have been compiled on the books of various sponsoring organizations. These 36 test methods are divided into 17 fire resistant tests for fabrics that are not expected to burn; and 6 newly proposed tests that had not been accepted by any sponsoring organization.[31]

To complete the evaluation of fire resistance of textiles, many other tests in addition to the fire resistance or flammability test are employed. These tests include durability to laundering and/or dry-cleaning, strength loss, stiffness and hand, toxicity, and others necessary for the satisfactory end use of textile products.

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[31]"36 Fabric Flame Tests Fail to Narrow Some 'Serious Gaps': Segall," Daily News Record, (New York, October 22, 1968), p. 19.

CHAPTER III

PROCEDURE

This study was undertaken to develop a modified fire resistance testing instrument for textiles in which different measurable air velocities were introduced, and also to test the performance and effectiveness of the instrument on specially treated experimental fabrics.

Regardless of the types of testing methods, most flammability and fire resistance tests are performed under relatively quiescent atmospheric conditions. Most fire accidents, however, do not occur in such draft-free conditions. None of the testing procedures in current use provides for the evaluation of flammability in moving air.

FIRE RESISTANCE TESTING EQUIPMENT USED

Description of the Fire Resistance Tester

The fire resistance testing instrument, manufactured by the United States Testing Company and accepted as the standard equipment for testing the Fire Resistance of Textile Fabrics according to the test method established by the American Association of Textile Chemists and Colorists (AACTT Test Method 34-1969), was used for a part of the research and as a model for the design of the experimental

instrument. This instrument and test method were designed
to measure the fire resistance of fabrics that had been
treated for fire resistance or for fabrics made from inher-
ently flame retardant fibers.

Cabinet. The cabinet was constructed of sheet metal
12 inches deep by 12 inches wide, and 30 inches high, with
a hinged glass door on the front of the instrument.

Burner. A Bunsen burner, approximately six inches
in height and 3/8 inch inside diameter, was equipped with a
pilot light attachment. The burner was placed within a
metal frame affixed to the floor of the cabinet so that the
burner might be placed under the fabric for the specified
ignition time and then withdrawn to the right front corner
of the cabinet.

The test method recommended the use of propane gas
with a fuel control valve to adjust gas pressure, and thus
regulate flame height.

Sample holder. A sample 10 inches by 2-3/4 inches
in size was mounted on a sample holder and suspended from
the top of the cabinet. This holder was a metal frame which
held the sample along its two vertical edges covering 3/8
inch of the sample width along each edge and exposing two
inches of fabric width to the flame.

Specifications for Experimental Fire Resistance Tester

As a part of the research for this study an experimental fire resistance testing instrument was designed to be basically similar to the standard fire resistance test cabinet, but to permit the introduction of measurable velocities. The design of this experimental instrument is shown as Figure 1.

Testing cabinet. The cabinet was designed to have the same dimensions as the standard tester and be made of sheet metal or stainless steel. However, both side walls of the cabinet were baffled, so that the air flow could be controlled if desired. The sample holder was placed facing the side of the cabinet rather than the front so that the sample would be fully exposed to the air passing through the cabinet.

Air movement system. The purpose of the experimental instrument was to introduce an air movement system to the contemporary tester. Air velocities varying from approximately one to 10 miles per hour were proposed to be achieved by means of an automatically controlled fan, which could be started after the fabric sample was exposed to the flame for the desired ignition period, and a damping system to control the amount of air drawn through the cabinet.

Vertical exhaust

84"

Test cabinet

Intake

side

30"

Baffle section for Uniform air flow

Damper

Fan

Control

Table top
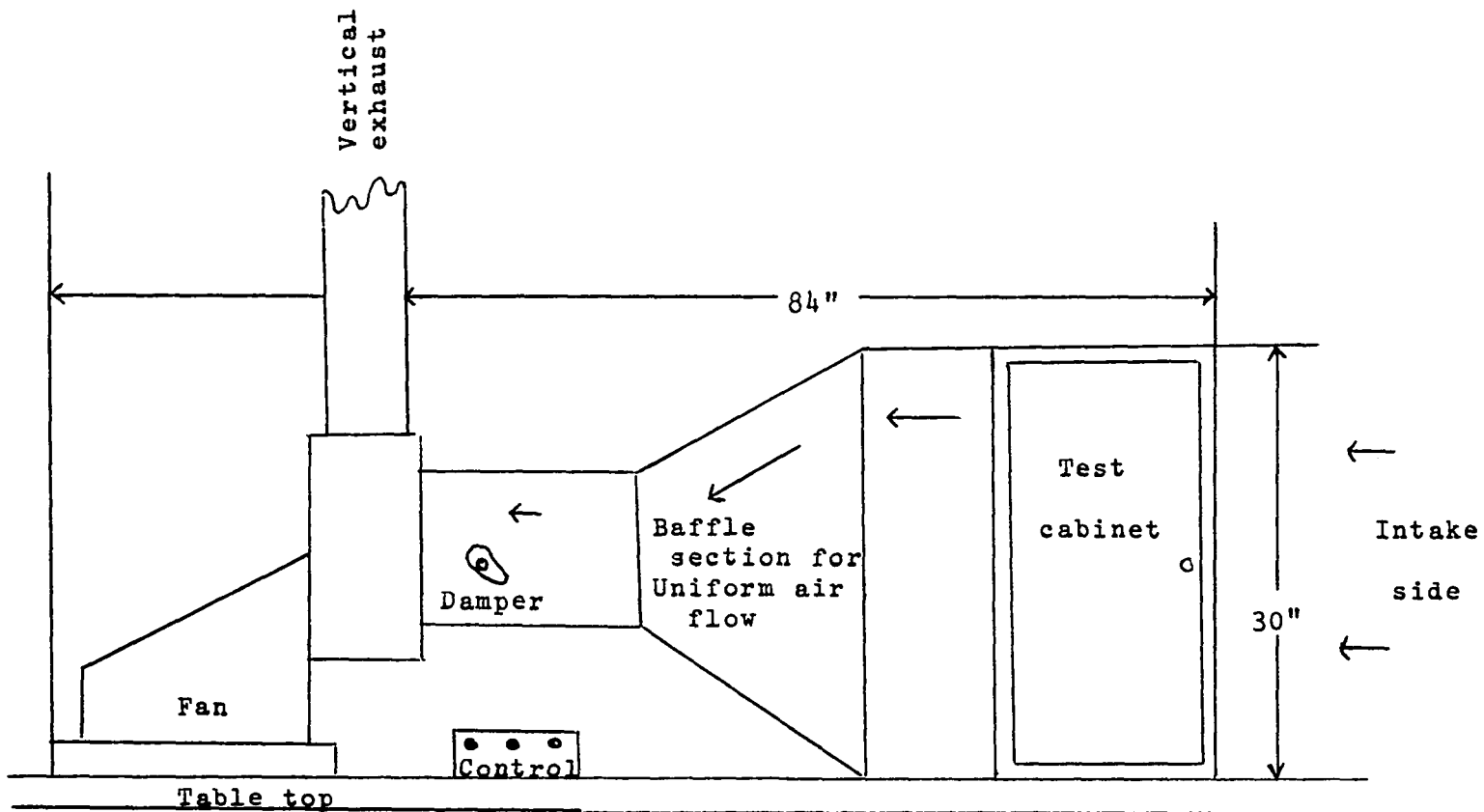
Depth (front to back) 18"

1/10 of actual size

Figure 1

Design of Experimental Fire Resistance
Testing Instrument

Automatic ignition system. To eliminate the need of lighting the burner for each test or changing the position of the burner, an automatic ignition system was specified. In this way, the gas burner could be placed in a fixed position and the gas flow and flame height would be controlled.

PROCEDURES FOR MEASURING FIRE RESISTANCE

All samples were conditioned under standard conditions of 70° ± 2° Fahrenheit and 65 ± percent relative humidity for at least eight hours. Since the equipment could not be placed in a laboratory with standard laboratory conditions, samples to be burned were carried in a desiccator containing a saturated aqueous solution of sodium nitrite ($NaNO_2$) to maintain 66 percent relative humidity at 68° Fahrenheit.

Standard Fire Resistance Test Procedure

The fuel control valve attached to the gas cylinder was adjusted to produce a flame 1-1/2 inches high. Following the adjustment of gas flame, a fabric sample 10 inches by 2-3/4 inches was mounted in a sample holder. The sample holder was hung vertically in the cabinet facing the front glass so that 3/4 inch of the lower end of the fabric would be in contact with the flame. Since most fabrics burn in a vertical direction, only the warp direction of the fabrics was tested. The door was closed tightly and the burner

placed under the center line of the fabric sample which was then exposed to the flame for 12 seconds.

Three measurements were made to indicate fire resistance: (1) the afterflame time of the fabric was measured in seconds from the time the burner flame was removed until the flaming had completely ceased, (2) following flaming, the fabric was permitted to glow and smolder until the sample extinguished itself. This afterglow time was also measured in seconds, and (3) the char length was measured after the sample was removed from the sample holder. The hook of a weight of appropriate size for the fabrics being tested was inserted in the sample on one side of the charred area 1/4 inch from the outside edge and 1/4 inch from the lower edge. Then the sample was torn by grasping the corner of the cloth at the opposite edge of the char from the load and gently raising the sample and weight clear of the supporting surface. The char length was measured in inches.

Experimental Fire Resistance Test Procedure

The test procedure used with the experimental instrument was also based on the procedure of the standard fire resistance test. The flame height of 1-1/2 inches was adjusted by the fuel control valve. The timer was set for a 12 second ignition period so that the burner with automatic ignitor, which was placed under the center line of fabric sample, would support combustion (igniting flame) for only

12 seconds. The sample (10 inches by 2-3/4 inches in warp direction) was mounted on a sample holder and hung vertically in the cabinet, facing the side. The door was closed tightly, the ignition button pressed, and the sample was exposed to the flame.

Samples were tested in varying air velocities by adjusting the opening of the damper. At the end of the ignition period, the fan was started and air circulated through the cabinet until afterglowing ceased.

Fire resistance was indicated by determining (1) afterflame time, (2) afterglow time, and (3) char length which were measured in the same manner as in the standard test procedure.

MEASUREMENT OF FIRE RESISTANCE
OF SELECTED FABRICS

The experimental fabrics were those selected for the Southern Regional Research Project SM-38, sponsored by the Agricultural Experiment Stations of six southern states as a part of the Cooperative State Research Service of the U.S. Department of Agriculture.[1] Flame retardant finishes were applied at the Southern Utilization Research and Development

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[1]"An Evaluation of Certain Flame Retardant Finishes on Selected Apparel Textiles," (Manual of Procedures, Regional Research Project, SM-38), (Mimeographed.)

Division of the United States Department of Agriculture,
New Orleans, Louisiana.

Description of Fabrics Tested

Three fabrics of different fiber content were used:
(1) 100 percent cotton muslin, (2) a 70 percent cotton and
30 percent polyester blend broadcloth, and (3) a 50 percent
cotton and 50 percent polyester blend broadcloth. The phys-
ical characteristics of these fabrics are shown in Table 1.

Table 1

Properties of Experimental Fabrics Used

Properties	Experimental fabrics		
Fiber content	100% cotton	50/50 blends	70/30 blends
Thread count			
Warp	92	146	142
Filling	67	57	58
Thickness (.001")	.010	.009	.009
Yarn number (tex)			
Warp	16.7	11.4	11.4
Filling	17.5	14.0	20.7
Twist per inch			
Warp	21.9	27.3	28.0
Filling	21.9	23.9	17.9
Weight (oz/yd^2)	3.49	3.07	3.49
Weave	Plain	Plain (rib)	Plain (rib)

Description of Finishes Applied to Fabrics

Three types of flame retardant finishes were applied to the fabrics described above. They were: (1) APO-THPC, (2) THPC-urea-MM, and (3) THPOH-NH$_3$.

When the treated fabrics were compared with untreated fabrics, apparent visible differences in color and stiffness were noticed.

APO-THPC treated fabric blends retained their whiteness but the 100 percent cotton fabric was slightly yellowed. The texture of the 100 percent cotton, however, was almost as soft as the untreated fabric, while the two blended fabrics were slightly stiffer than the untreated fabrics.

All three fabrics treated with THPC-urea-MM appeared to have an excellent whiteness retention, but were extremely stiff. Of these, 70/30 blends seemed to have the most stiffness, and the 100 percent cotton the least.

THPOH-NH$_3$ treated fabrics were the most discolored of all flame retardant treated fabrics. The 100 percent cotton fabric had the most extreme discoloration. Fabrics treated with this finish were softer than those treated with other finishes and were only slightly stiffer than the untreated fabrics.

Testing Conditions

Each fabric was tested in the standard and experimental fire resistance instruments. The four conditions under which the fire resistance was tested were:

Instrument	Air velocity
Standard	Quiescent (approximately 0 miles per hour)
Experimental	Quiescent (approximately 0 miles per hour)
Experimental	Approximately one mile per hour
Experimental	Approximately three miles per hour

STATISTICAL TREATMENT OF THE DATA

Three replications of each of the 12 experimental
fabrics were used. Each fabric was assigned a code number
so that fabric samples could be grouped and tested in any
of six sequences: ABC, BCA, CBA, ACB, BAC, CAB. Therefore,
there was a total of 144 samples (48 treatments x 3
replications). These 144 samples were randomized for the
laboratory testing of fire resistance.

The laboratory data obtained from the measurement
of fire resistance were analyzed based upon a completely
randomized design with a 3 x 4 x 4 factorial arrangement
of treatments. All factorial combinations of three fabric
types, four treatments, and four testing conditions were
used in the study.

Analyses of variance were employed to test the
significance of the fabric types, treatments and testing
conditions as well as interactions between these factors.

Correlation coefficients were also employed to
determine whether the three factors of fire resistance:

afterflame time, afterglow time, and the char length, had any significant relationship to each other. For this purpose, all possible two-way correlations of these factors were studied separately.

The design for a three level factorial analysis of fire resistance of fabrics is shown in Table 2.

Table 2

Design for a Three Level Factorial Analysis of
Fire Resistance of Fabrics

Fabrics	Instrument and air velocities				Totals
	Standard	Experimental			
	Quiescent	Quiescent	1 mile per hr.	3 miles per hr.	
	(Number of test samples)				
Untreated					
100% cotton	3	3	3	3	12
70/30 blends	3	3	3	3	12
50/50 blends	3	3	3	3	12
APO-THPC					
100% cotton	3	3	3	3	12
70/30 blends	3	3	3	3	12
50/50 blends	3	3	3	3	12
THPC-urea-MM					
100% cotton	3	3	3	3	12
70/30 blends	3	3	3	3	12
50/50 blends	3	3	3	3	12
THPOH-NH$_3$					
100% cotton	3	3	3	3	12
70/30 blends	3	3	3	3	12
50/50 blends	3	3	3	3	12
Totals (Number of test samples)	36	36	36	36	144

CHAPTER IV

DISCUSSION OF RESULTS AND DATA ANALYSES

This chapter describes the completed experimental fire resistant testing equipment and the application of this instrument in measuring the burning characteristics of selected experimental fabrics in four different air velocity testing conditions. The discussion of results and data analyses can be subdivided into three parts: (1) a description of the completed instrument, (2) burning characteristics of the experimental fabrics, and (3) statistical analysis of the data.

DESCRIPTION OF THE COMPLETED INSTRUMENT

This instrument and testing procedure were designed to provide for the measurement and evaluation of the fire resistance of textile fabrics in different air velocities. The testing procedure would be applicable to apparel and household fabrics that have been treated for fire resistance, fabrics made from inherently fire resistant fibers, and fabrics that have not been treated for fire resistance.

The concept of this test method was based on the standard test method for the fire resistance of textiles, recommended by the American Association of Textile Chemists

and Colorists. This instrument was designed to permit wide variations in air flow and an automatic ignition system. Other features of the test were the same as the standard procedure. A photograph of the completed apparatus is presented in Figure 2.

Description of the Completed Experimental Instrument

Test cabinet. The cabinet constructed of stainless steel type 302 was 14 inches wide, 14 inches deep, and 30 inches high, with a vertical hinged glass door in the front. Two screw type knobs attached to the glass door secured the closing of the door. The right sidewall of the cabinet was baffled for air intake, and the left sidewall, also baffled, was connected to a galvanized exhaust fan system.

Exhaust fan system. A belt driven junior fan was installed to provide air flow of approximately 100 to 1,700 feet per minute air velocity through the test cabinet. The speed of the fan was controlled by a damper which was placed in the air duct between the test cabinet and the fan. The desired air velocity was set by this damper control before testing. The damper was controlled from the top of the machine where the eight damper openings are indicated as shown in Figure 3.

Figure 2

Photograph of Completed Experimental Instrument
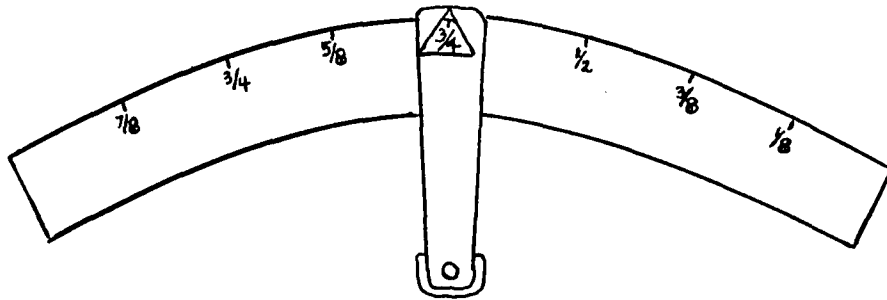
Figure 3

Diagram of Damper Control

Automatic ignition system. An ignition system was developed to eliminate the need for a pilot flame and to control the gas flow automatically, therefore allowing uniform flame characteristics in different test periods. The ignition electrode was a standard porcelain insulated spark plug taken from a 1963 Corvair automobile. The ignition transformer was fixed on the center rear of the test cabinet. As soon as the starter button was pressed, the ignition sparked and at the same time the solenoid valve was opened to supply gas to support the flame. A timer automatically cut off the gas supply at the end of the predetermined period of time. The timer permitted ignition periods ranging from one to 30 seconds. For this experimentation an ignition period of 12 seconds was used.

Gas burner. A Bunsen burner six inches high with a
3/8 inch inside diameter tube was used. The burner was not
in a fixed position and the height of the burner could be
altered freely if necessary by an adjustable screw under-
neath the burner. However, to position the burner in the
cabinet so that the center of burner was placed under the
exact center of the test sample, a square mark was drawn on
the floor of the cabinet to indicate the desired position.
The burner was connected to the ignition transformer and
to the gas cylinder by rubber tubing.

Sample holder. The sample holder used was the same
as those recommended in the American Association of Textile
Chemists and Colorists Fire Resistance Test Method. This
sample holder, a pair of inverted U-shaped aluminum frames,
was 15 inches in height and four inches in width. A sample
was placed between this pair of frames to prevent curling of
the edge of the sample when exposed under flame. The holder
was hung in a vertical position in the cabinet facing the
sidewall and exposing a sample width of two inches to the
flame.

Procedure for Use of the Apparatus

Before mounting the sample holder in the cabinet, the
flame height and desired air velocity were adjusted. To
regulate the flame height, the gas gauges were opened,

allowing gas to flow through the rubber tubing. The ignitor was started and the flame height regulated. Igniting was repeated several times to be certain that the flame height of 1-1/2 inches was constant. The sample holder was placed in the cabinet and the glass door closed. The time, set for 12 seconds, was started as the ignition button was pressed. The ignition was automatically shut off after 12 seconds. At the same time the exhaust fan was started. The exhaust fan need not be used when testing if a quiescent atmosphere is desired.

Measurement of afterflame, afterglow, and the char length of test fabrics was performed according to the procedure described in this chapter. It was found that the use of a dual hand stop watch for timing provides more accuracy in timing to the nearest 0.2 second the afterflame and afterglow of test samples.

The char length was measured after the test sample was removed from the sample holder by the procedure outlined in this chapter. Char length was measured to the nearest 0.01 inch, from the center of torn lower edge to the end of the tear.

Standardization of Air Velocity of Experimental Instrument

The experimental fire resistance testing instrument was designed to provide eight different air velocities controlled by adjustment of the damper opening. To standardize

air currents, the air velocity of each damper opening was measured by an anemometer. Ten measurements were made at three different heights of the fabric sample to be: (1) the point of ignition, (2) center of sample, and (3) the top of the sample. The mean scores of the air velocity of eight different damper openings at three different heights are shown in Table 3.

Table 3

Mean Air Velocities of Damper Openings at
Different Sample Heights

Damper opening	Mean in feet/minute		
	Flame point	Center	Top
1/8	93.9	96.7	100.0
1/4	226.1	229.9	232.2
3/8	400.1	401.1	403.8
1/2	528.5	529.7	536.0
5/8	748.6	756.3	753.8
3/4	1155.5	1168.0	1165.5
7/8	1522.1	1531.0	1528.5
Open	1646.3	1653.0	1664.0

An analysis of variance was made to determine the significant effects and interaction effects between three different sample heights and eight different damper openings.

A significant effect was found within the different damper openings while no significant effects were found within the different sample heights. It was also found that there was no significant interaction effect between the sample heights and the damper openings (Appendix A).

The analysis indicated that the air velocity in the test cabinet could be considered even regardless of the height at which the fabric sample might be placed. Therefore, air velocities of the eight different damper openings were standardized by calculating the mean scores of air velocity over three different sample heights as shown in Table 4.

Table 4

Standardized Damper Opening Main Effect
Means (Air Velocities)

Damper openings	Standardized air velocity (feet/minute)
1/8	96.9
1/4	229.4
3/8	401.7
1/2	531.4
5/8	752.9
3/4	1163.0
7/8	1527.2
Open	1654.4

The burning characteristics of treated and untreated
fabric samples used in this study were observed as the 12
fabrics were tested under varying conditions of air veloci-
ties. A detailed record of the burning characteristics is
reported for each fabric as it was burned in a draft-free
environment. Differences noted when air was introduced
have been summarized since the major differences were be-
tween the three untreated fabrics of varying fiber content.

Burning Characteristics of Fabrics in Quiescent Atmosphere

100 percent cotton, untreated. The flame was caught
by the fabric very readily; however, the flame spread rather
slowly over the fabric surface. Afterglow also was rather
slow, forming grey and light ashes which dropped to the
floor of the cabinet as they ceased to glow.

100 percent cotton, APO-THPC treated. The fabric
supported a flame only during the ignition period. The
flame spread slowly over the fabric surface as long as the
ignition flame was supported. The charred area showed a
dark brown edge.

100 percent cotton, THPC-urea-MM treated. There was
no spread of the flame since the fabric burned only during
the ignition period. The charred area of the fabric showed
dark brown edges. A grey smoke stain remained on the fabric
surface.

100 percent cotton, THPOH-NH₃ treated. The flame was extinguished as soon as the ignition flame ceased. The burned sample showed a definite shape of the flame in the black charred area. The sample burned with a very strong odor and gave off a bright yellow smoke.

70/30 blend, untreated. The entire fabric burned strongly and rapidly. Thin black ashes remained as a residue.

70/30 blend, APO-THPC treated. The fabric burned with a dense black smoke. During the ignition period, the heat spread over the fabric surface even though it was beyond the reach of the flame. The entire fabric surface was charred leaving black stains and black ashes with dark brown edges.

70/30 blend, THPC-urea-MM treated. The fabric burned with light grey smoke, supporting the spread of the flame only during the ignition period. The charred border was shrunk slightly and had yellow brown edges.

70/30 blend, THPOH-NH₃ treated. During the ignition period the fabric burned with strong odor, and a moderate spread of flame. Bright yellow stains and black ashes were left on the fabric sample.

50/50 blend, untreated. The flame, caught immediately by the fabric sample, rapidly spread over the surface of the fabric with an intense flame and dense smoke. Large and stiff bead-like particles were left at the edge of the flame.

50/50 blend, APO-THPC treated. The fabric sample supported a spread of the flame as long as the ignition flame was in contact with the fabric. Shiny ashes and black smoke stains were visible over the entire sample surface.

50/50 blend, THPC-urea-MM treated. The fabric burned with a strong flame during the ignition period, producing a dense smoke. Burning left dark brown stains over the fabric surface and a shiny charred area.

50/50 blend, THPOH-NH$_2$ treated. This fabric also burned intensely during the ignition period. The spread of the flame over the fabric surface was quite rapid. Light yellow stains and black smoke stains were left on the entire fabric surface.

Burning Characteristics in Air

The visible and apparent differences of burning characteristics in different air velocities were found only in the case of untreated fabric samples. It was evident that

as the air velocity increased, the speed of burning as represented by the afterflame time decreased. However, the time of afterglow varied within the fabrics of different fiber content. The 100 percent cotton fabric showed a definite decrease of the afterglow time as the air velocity increased. The 70/30 blend appeared to have increased afterglow time as the air velocity increased. The time of afterglow of the 50/50 blend did not decrease or increase consistently with the changed air velocities.

Since all untreated fabric samples showed complete burning during the ignition period, there was no measurable char length. All treated fabric samples failed to show any afterflaming or afterglowing after the ignition period. Therefore, afterflame time and afterglow time were not measurable on these treated fabrics.

Measurements of afterflame, afterglow and char length of all fabrics in all atmospheres are presented in Tables 5, 6, and 7, respectively.

STATISTICAL ANALYSES OF THE DATA

In order to determine the fire resistance of test fabric samples, three independent factors were measured: afterflame time, afterglow time, and the char length. The laboratory data obtained from the above three types of measurements were analyzed based upon a 3 x 4 x 4 factorial arrangement of treatments with three fabric types, four

Table 5

Mean Afterflame Time of Selected
Experimental Fabrics

Equipment, air velocity and fiber content	Flame retardant treatment			
	Untreat.	APO-THPC	THPC-urea -MM	THPOH-NH$_3$
	(Time in seconds)			
Standard				
100% cotton	9.8	0.0	0.0	0.0
70/30 blends	7.1	0.0	0.0	0.0
50/50 blends	10.6	0.0	0.0	0.0
Experimental, 0 feet/minute				
100% cotton	9.6	0.0	0.0	0.0
70/30 blends	8.2	0.0	0.0	0.0
50/50 blends	10.5	0.0	0.0	0.0
Experimental, 97 feet/minute				
100% cotton	4.2	0.0	0.0	0.0
70/30 blends	4.0	0.0	0.0	0.0
50/50 blends	5.1	0.0	0.0	0.0
Experimental, 230 feet/minute				
100% cotton	3.4	0.0	0.0	0.0
70/30 blends	4.1	0.0	0.0	0.0
50/50 blends	14.4	0.0	0.0	0.0

Table 6

Mean Afterglow Time of Selected
Experimental Fabrics

Equipment, air velocity and fiber content	Flame retardant treatment			
	Untreat.	APO-THPC	THPC-urea -MM	THPOH-NH$_3$
	(Time in seconds)			
Standard				
100% cotton	18.7	0.0	0.0	0.0
70/30 blends	5.0	0.0	0.0	0.0
50/50 blends	0.7	0.0	0.0	0.0
Experimental, 0 feet/minute				
100% cotton	23.0	0.0	0.0	0.0
70/30 blends	5.0	0.0	0.0	0.0
50/50 blends	0.7	0.0	0.0	0.0
Experimental, 97 feet/minute				
100% cotton	16.7	0.0	0.0	0.0
70/30 blends	5.8	0.0	0.0	0.0
50/50 blends	11.9	0.0	0.0	0.0
Experimental, 230 feet/minute				
100% cotton	2.8	0.0	0.0	0.0
70/30 blends	13.3	0.0	0.0	0.0
50/50 blends	5.0	0.0	0.0	0.0

Table 7

Mean Char Length of Selected
Experimental Fabrics

Equipment, air velocity and fiber content	Flame retardant treatment			
	Untreat.	APO-THPC	THPC-urea -MM	THPOH-NH$_3$
	(Char length in inches)			
Standard				
100% cotton	10 BEL*	4.4	4.8	5.1
70/30 blends	10 BEL	5.4	5.8	6.3
50/50 blends	10 BEL	6.5	5.9	9.0
Experimental, 0 feet/minute				
100% cotton	10 BEL	4.3	4.9	5.0
70/30 blends	10 BEL	5.8	5.0	5.6
50/50 blends	10 BEL	6.6	5.7	7.1
Experimental, 97 feet/minute				
100% cotton	10 BEL	4.3	4.6	4.6
70/30 blends	10 BEL	4.7	4.9	5.7
50/50 blends	10 BEL	6.2	5.4	6.8
Experimental, 230 feet/minute				
100% cotton	10 BEL	3.0	3.7	3.6
70/30 blends	10 BEL	5.0	4.0	4.7
50/50 blends	10 BEL	5.9	4.5	7.2

* BEL   Fabrics burned entire length.

treatments, and four testing conditions. The four testing
conditions were slightly altered from those indicated in
Chapter III, following the standardization of air velocities
for the experimental instrument. The four conditions chosen
for the laboratory tests were:

1. Standard instrument and quiescent atmosphere

2. Experimental instrument and quiescent atmosphere
(0 feet per minute air velocity)

3. Experimental instrument and scarcely perceptible
air current (approximately 97 feet per minute air velocity)

4. Experimental instrument and a perceptible air
current (approximately 230 feet per minute air velocity).

Since three independent measurements were made for
each fabric sample, analyses of variance employed to test
significant main and interaction effects of fabric types,
treatments and air velocities are discussed according to the
fire resistance characteristic measured: (1) afterflame
time, (2) afterglow time, and (3) char length. Furthermore,
correlation coefficients between the above three types of
fire resistance characteristics measurements were calculated.

Analysis of Afterflame Time

An analysis of variance was employed to test the sig-
nificance of fiber content, treatments, and testing condi-
tions on the afterflame time of fabrics with the laboratory
data obtained from the measurements of afterflame time. Due

to the important and significant fact that all treated fabric samples were extinguished immediately after the ignition period, resulting in no measurement of afterflame time, it was concluded that the afterflame time was unaffected by differences in fiber content or air velocities. The following discussion, therefore, mainly concerns untreated fabrics (Appendix B).

All untreated fabrics burned completely, and the afterflame time was definitely affected by the fiber content of the fabrics. The time in seconds needed to burn samples completely is indicated in Table 8.

Table 8

Mean Afterflame Time of Fabrics with Different
Fiber Contents (Untreated Fabrics)

Fiber content	Average afterflame time in seconds
100% cotton	6.76
70/30 blends	6.05
50/50 blends	9.41

The air velocity in the test cabinet also made a significant difference on the duration of the afterflame time of the untreated test samples. The mean afterflame time was 9.60 seconds in both the standard instrument and the 0 feet per minute air velocity of the experimental instrument.

Afterflame time was the shortest in 97 feet per minute air velocity, followed by 230 feet per minute air velocity (Table 9).

Table 9

Mean Afterflame Time in Different
Air Velocity

Equipment and air velocity in feet/minute	Mean afterflame time in seconds
Standard	9.60
Experimental 0	9.60
Experimental 97	4.44
Experimental 230	6.31

The flame retardant treatment also made a significant difference in afterflame time. The untreated samples showed significantly higher afterflame time (mean=7.49 seconds). Since all three types of treated fabrics showed no afterflaming, there was no way of differentiating between the three treatments.

A significant interaction effect was indicated between the fiber contents and different air velocities. As the air velocity in the cabinet increased, the duration of afterflame time decreased in the 100 percent cotton and the 70/30 blends. The 50/50 blends showed decreased afterflame time

from the 0 feet per minute air velocity to the 97 feet per
minute air velocity; however, the afterflame time was great-
ly increased at the 230 feet per minute air velocity. In
both the standard and the experimental instruments with no
air velocity, the 50/50 blends indicated the longest after-
flame time whereas the 70/30 blends showed the lowest
(Figure 4).
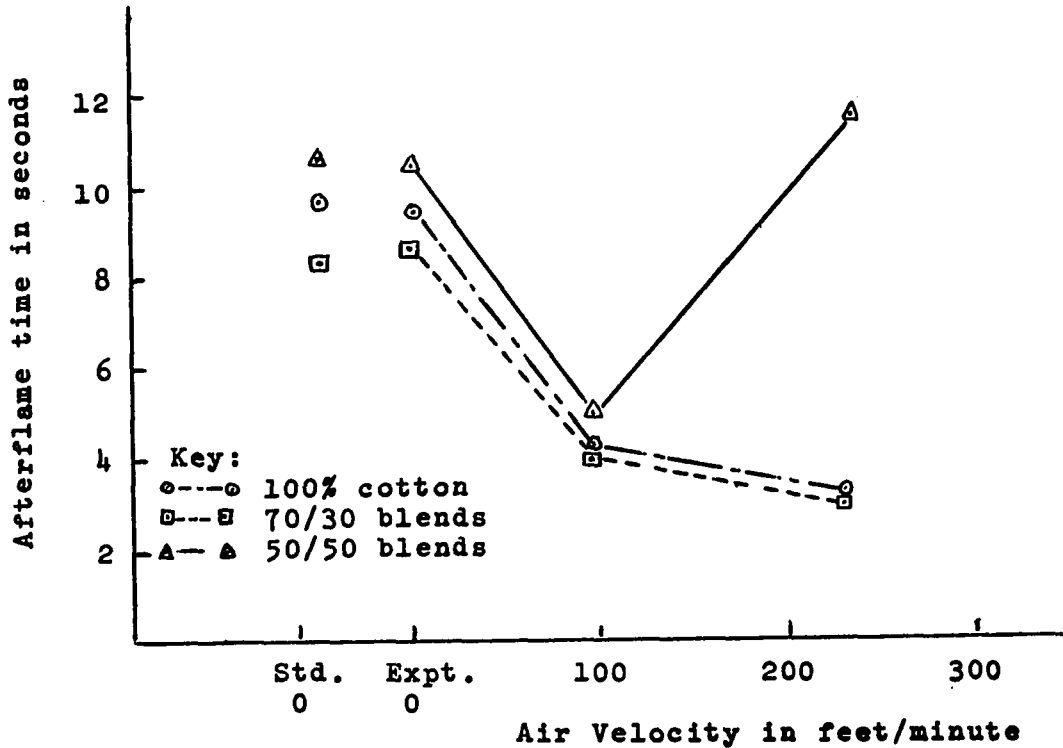
Figure 4

Interaction Effect Between Fiber Content and
Air Velocity (Afterflame Time)

An interaction effect between fiber content and fire retardant treatments was significant because of the significant differences in both fiber content and treatment variables. Untreated 50/50 blends showed the highest afterflame time (mean = 9.41 seconds) while 100 percent cotton fabrics had the lowest afterflame time (mean = 6.76 seconds). Mean afterflame time of untreated 70/30 blends was 8.21 seconds.

The interaction effect between test conditions and treatments was also significant. The lowest afterflame time was obtained by all types of treated fabrics in all air velocities. The highest afterflame time was obtained by untreated fabrics in both the standard and experimental instruments in no air velocity.

A significant interaction effect was shown between fiber content, treatments, and testing conditions. Untreated 50/50 blends showed the highest afterflame time at 230 feet per minute air velocity (Table 10).

Analysis of Afterglow Time

Laboratory data obtained from the measurements of afterglow time were analyzed to determine the significance of main effects and interaction effects of test conditions, fiber content and treatments on the afterglow time. As indicated in the preceding section, fabric samples treated with flame retardants exhibited no afterglowing. For this reason, the following discussion is mainly concerned with untreated fabrics (Appendix C).

Table 10

Order of Duration of Afterflame Time

Order	Fiber content	Equipment and air velocity in feet/minute	Treatment	Mean in seconds
1	50/50 blends	Experimental 230	Untreated	11.43
2	50/50 blends	Standard and experimental 0	Untreated	10.07
3	100% cotton	Standard and experimental 0	Untreated	9.22
4	70/30 blends	Standard and experimental 0	Untreated	8.54
5	50/50 blends	Experimental 97	Untreated	5.10
6.	100% cotton	Experimental 97	Untreated	4.23
7	70/30 blends	Experimental 97	Untreated	4.0
8	100% cotton	Experimental 230	Untreated	3.36
9	70/30 blends	Experimental 230	Untreated	3.13
10	All treated fabrics in all velocities - no afterflame time			

Fiber content of fabric samples made a significant difference in afterglow time. It was indicated that 100 percent cotton fabrics had the highest afterglow time while 50/50 blends had the lowest afterglow time. It was interesting to note that afterglow time decreased as the cotton content decreased (Table 11).

Table 11

Mean Afterglow Time of Fabrics of
Different Fiber Content

Fiber content	Mean afterglow time in seconds
100% cotton	15.31
70/30 blends	7.79
50/50 blends	3.67

Differences in air velocities did not seem to have any significant effect on afterglow time at .05 significance level. At .01 significance level, this main effect was significant, and the order of the duration of afterglow time was, 97 feet per minute air velocity > 0 feet per minute air velocity > standard instrument > 230 feet per minute air velocity.

Flame retardants applied to test fabrics made a significant difference on afterglow time. All treated fabrics failed to glow, resulting in 0.0 second of afterglow time

measurement. Untreated fabric samples showed high and varied afterglow times with a mean of 8.92 seconds.

The interaction effect between fiber content and air velocities was significant. As tested in both the standard and experimental instruments with 0 feet per minute air velocity, afterglow time increased as the cotton fiber content of fabrics increased. The afterglow time of the 100 percent cotton fabric decreased as the air velocity in the test cabinet increased. However, 70/30 blends indicated increased afterglow time as the air velocity increased. The 50/50 blends were not consistent, showing the highest afterglow time at 97 feet per minute air velocity and the lowest at the standard and experimental instruments at 0 feet per minute air velocity (Figure 5).

Interaction effects between fiber content and treatments also made a significant difference on afterglow time due to the great significance in both variables.

The interaction effect between various air velocities in the test cabinet and the treatments made no significance on afterglow time at .05 significance level. However, there was a difference at .01 level. At this level, the untreated fabrics indicated the highest afterglow time at 97 feet per minute air velocity, and lowest at 230 feet per minute air velocity.
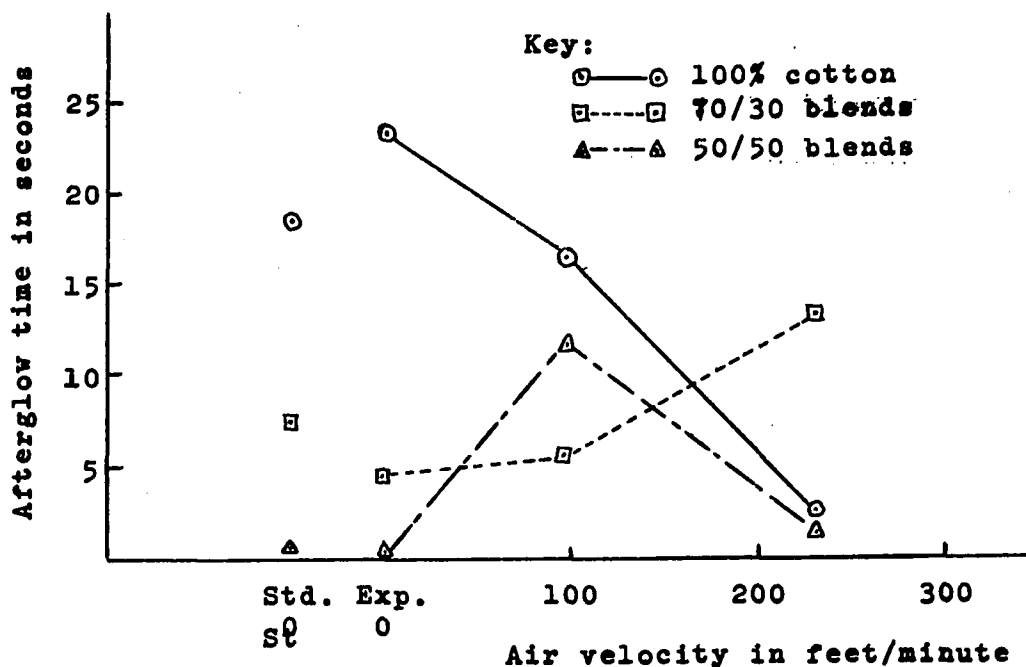
Figure 5

Interaction Effect Between Fiber Content and
Air Velocity (Afterglow Time)

A significant interaction effect was indicated be-
tween fiber content, treatments, and air velocities. All
treated fabric samples showing no afterglow in all air ve-
locities resulted in the lowest afterglow time. The highest
afterglow time was noted on the 100 percent cotton fabric in
standard and experimental air velocity conditions of 0 feet
per minute. The same fabric showed decreased afterglow time
as air velocity in the cabinet increased, which, in this
case, indicated that the spread of glowing was most rapid at
the higher air velocity. Untreated 70/30 blends showed
somewhat lower afterglow time than the 100 percent cotton

fabric in both the standard and the experimental 0 feet per minute air velocity. Unlike 100 percent cotton fabrics, the 70/30 blends showed increased afterglow time as the air velocity in the cabinet increased.

Analysis of Char Length

The char length of test samples was measured in inches after each sample was exposed under the flame. An analysis of variance test was made to determine the main effect and interaction effects of fiber content, flame retardant treatment and testing condition to the char length. All untreated fabrics burned completely. For statistical purposes, the char length of these fabric samples was considered to be maximum and a measurement of 10 inches was used to indicate differences in treatments (Appendix D).

The fiber content of test fabrics made a significant difference on the char length. As indicated in Table 12, the 50/50 blends had the highest char length while 100 percent cotton fabrics showed the lowest char length.

Table 12

Mean Char Length of Fabrics with Different
Fiber Content

Fiber content	Mean char length in inches
100% cotton	4.33
70/30 blends	5.23
50/50 blends	6.42

Air velocity in the test cabinet also affected the char length measurement of fabric samples significantly. As revealed in Table 13, the char lengths of fabric samples were highest both in the standard and experimental 0 feet per minute air velocity. The char length decreased as the air velocity in the cabinet increased. It seemed to indicate that faster air velocity in the cabinet reduced the surface heat of test samples. This may have helped to control the spread of the flame over the fabric surface and reduced the char length.

Table 13

Mean Char Length of Fabrics in Different
Air Velocities

Instrument and air velocity in feet/minute	Mean char length in inches
Standard 0	6.92
Experimental 0	6.67
Experimental 97	6.41
Experimental 230	5.93

Flame retardant treatments applied to the fabric contributed a significant effect on the char length. As can be noted in Table 14, untreated fabrics which burned entire length received the highest char length rating.

Among treated fabrics, it was revealed that fabrics treated with THPOH-NH$_3$ had the highest char length while the lowest char length was obtained by THPC-urea-MM treated fabrics.

Table 14

Mean Char Length of Fabrics with Different
Flame Retardant Treatments

Treatment	Mean char length in inches
Untreated	10.00
APO-THPC	5.16
THPC-urea-MM	4.92
THPOH-NH$_3$	5.83

No significant interaction effect was found between the fiber content of fabric and the air velocities in the test cabinet. A significant interaction effect did exist between the fiber content and the treatments applied to the fabric. As indicated in Figure 6, all untreated fabrics showed 100 percent char length regardless of the fiber content. Fabrics of 50/50 blends were the highest in the char length in all types of treatments while 100 percent cotton fabrics showed the lowest char length when the fabrics were treated with flame retardants. It was also found that the THPC-urea-MM treatment resulted in the lowest char length

in all types of fabrics. In general the THPOH-NH$_3$ treatment resulted in the highest char length. An exception was the 100 percent cotton fabric treated with APO-THPC treatment which showed the lowest char length.
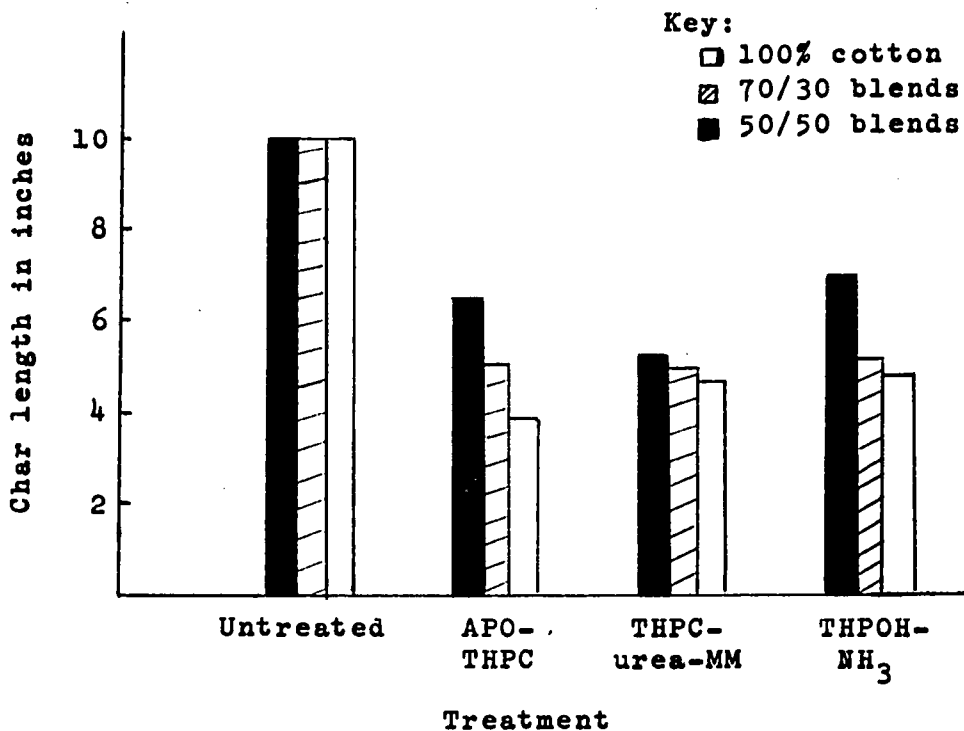
Figure 6

Interaction Effect Between Fiber Content and Treatment

No significant interaction effect at .05 significance level existed between the air velocity in the test cabinet and the treatment of fabrics (Figure 7). However, a significant effect was shown at .01 level. As mentioned before, all untreated fabrics showed 100 percent char length in all

types of air velocities. When fabrics were treated with flame retardants, the char length decreased as the air velocity in the cabinet increased.
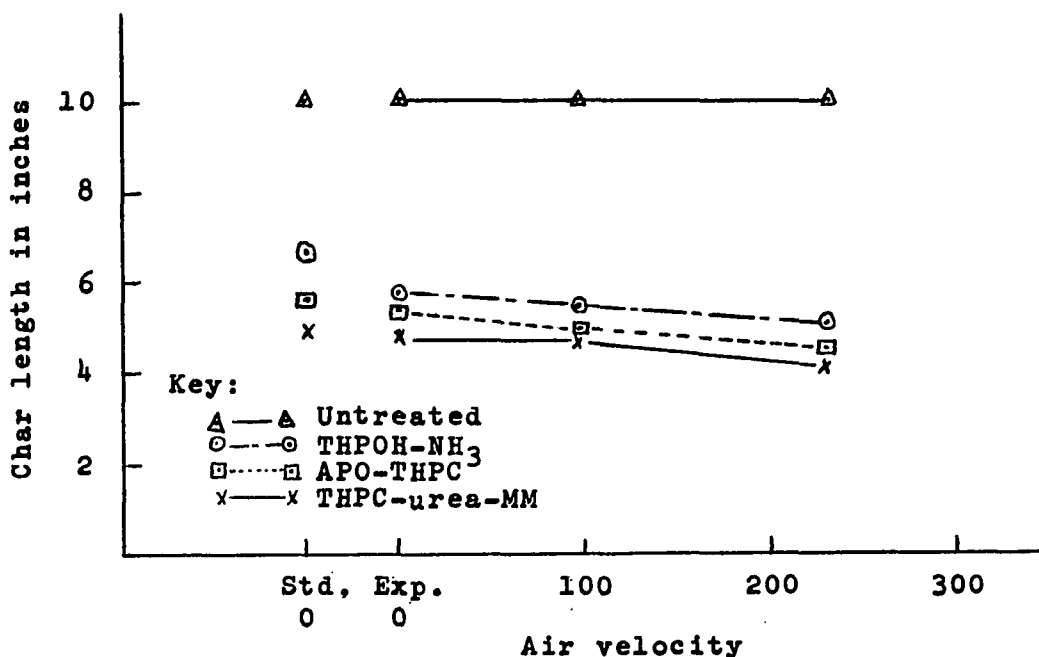
Figure 7

Char Length as Affected by Air Velocity
and Treatment

No significant interaction effect was found between the fiber content, treatments, and air velocities.

Comparison of Standard Instrument and Experimental Instrument in the Draft-Free Conditions (0 Feet Per Minute Velocity)

It was important to investigate differences between the quiescent condition of the standard instrument and the 0 feet per minute air velocity condition of the experimental

instrument. The experimental instrument was designed to have all possible similarities of test performances as the standard test instrument when 0 feet per minute air velocity was used. To achieve this purpose, a t-test was employed to the laboratory data obtained from the three types of fire resistance tests.

Since treated fabrics showed no afterflame time and afterglow time, only the laboratory data obtained from untreated fabrics were used to compare the afterflame and afterglow time of standard and experimental instruments. Similarly, only the char length measurements of treated fabrics were used to compare the standard and the experimental instruments since untreated fabrics were completely burned and resulted in 100 percent char length regardless of the fiber content and air velocities.

As shown in Table 15, all t-tests indicated no significant differences between the two types of testing instruments. This Table also shows that no significant differences in testing performance existed between the standard instrument and the experimental instrument at 0 feet per minute air velocity.

Correlation Between Afterflame and Afterglow

As a whole, no significant correlation was indicated between the afterflame and afterglow in all fabric samples tested (r = -.15). However, a significant correlation

Table 15

Mean Difference (t-test) Between Standard
Instrument and Experimental Instrument
at 0 Feet Per Minute Air Velocity

Test and treatment	Fiber content	Mean		t
		Standard	Experimental	
Untreated, afterflame time in seconds	100% cotton	9.83	9.60	0.23 NS*
	70/30 blends	8.37	8.70	-0.33 NS
	50/50 blends	10.63	10.50	0.07 NS
Untreated, afterglow time in seconds	100% cotton	18.67	23.13	-0.61 NS
	70/30 blends	7.40	4.70	1.92 NS
	50/50 blends	0.77	0.33	0.43 NS
APO-THPC treated, char length in inches	100% cotton	4.44	4.25	0.71 NS
	70/30 blends	6.13	5.82	0.54 NS
	50/50 blends	6.53	6.61	-0.22 NS
THPC-urea-MM treated, char length in inches	100% cotton	4.76	4.89	-0.24 NS
	70/30 blends	5.43	5.01	0.46 NS
	50/50 blends	5.89	5.74	0.27 NS
THPOH-NH_3 treated, char length in inches	100% cotton	5.05	4.96	0.23 NS
	70/30 blends	6.25	5.57	0.51 NS
	50/50 blends	8.49	7.14	2.15 NS

*Not significant at .05 level.

between the two factors was found when correlation coeffi-
cients for the fabrics with different fiber contents were
calculated separately.

Fabrics of 100 percent cotton had a positive corre-
lation between the afterflame time and the afterglow time,
that is, as the afterflame time increased, the afterglow
time increased (r = .59). On the contrary, 50/50 blends
had a significantly negative correlation, that is, the after-
glow time increased as the afterflame time decreased (r =
-.82). The 70/30 blend fabrics did not show any significant
correlation between the afterflame time and the afterglow
time.

CONCLUSIONS

The conclusions made in this section are discussed in
relation to the hypotheses proposed in the first chapter of
this study.

Hypothesis A. No different test performance exists
between the standard instrument and the experimental instru-
ment at the air-free condition.

This hypothesis was confirmed based on the results
obtained from the statistical analysis.

All test samples indicated no significant difference
of fire resistance when tested with two instruments regard-
less of the types of fiber and the treatments. However,

some limitations of this statement should be cleared as fol-
lows: (1) since all treated fabrics showed no afterflame or
afterglow, the laboratory data obtained from the untreated
fabrics were used to compare the afterflame time and the
afterglow time of two instruments; (2) comparisons of char
length in the two instruments were made only with the data
obtained by treated fabrics since all untreated fabrics
burned completely. To make the above statement absolute,
it should be mentioned that from the results of an analysis
of variance made with all laboratory data including 0 feet
per minute afterflame and afterglow times as well as 100
percent char length measurements, no significant difference
was indicated between two instruments.

Hypothesis B. Burning characteristics of the fab-
rics tested are dependent upon air velocities.

This hypothesis was partly confirmed from the results
obtained from the laboratory data.

All treated fabrics showed no afterflame, therefore
the afterflame time was recorded as 0.0, indicating the low-
est afterflame time in all air velocities. As far as un-
treated fabrics were concerned, afterflame time was the
longest when tested both in the standard instrument and the
experimental instrument at the draft-free condition.

Afterflame time was the shortest at the 97 feet per
minute air velocity, and the next was 230 feet per minute

velocity. From the observation of the actual test, after-flame was retarded by the higher air velocity. At this velocity there is more rapid intake of outside cool air to reduce the higher temperature in the test cabinet.

Different air velocities in the test cabinet did not affect the afterglow time of test samples at .05 significance level.

Difference of air velocities in the test cabinet contributed significantly different char length on test fabrics. An equally high char length was indicated when tested both in the standard instrument and the experimental instrument at the draft-free condition. The char length was definitely decreased as the air velocity in the cabinet increased. As mentioned previously, the surface heat of the fabric was decreased by faster air velocity in the cabinet which contributed to reduce spread of char on the fabric surface.

Hypothesis C. Burning characteristics of the fabrics tested are dependent upon fiber contents. This dependency may interact with air velocity testing conditions.

This hypothesis was partly confirmed from the results obtained from the laboratory data.

The afterflame time of all treated fabrics regardless of the fiber content was 0.0 seconds, resulting in the lowest afterflame time. Among untreated fabrics, the 50/50

blends showed the highest afterflame time while 70/30 blends had the lowest afterflame time. As the air velocity in the cabinet increased, the duration of afterflame time decreased in the 100 percent cotton and 70/30 blends. The 50/50 blends were not consistent.

All untreated fabrics with different fiber contents were the lowest in afterglow time. The order of afterglow time from the highest to the lowest was untreated 100 percent cotton > untreated 70/30 blends > untreated 50/50 blends. Afterglow time increased as the cotton content of fabrics increased when tested in both the standard and experimental instruments. The afterglow time of the 100 percent cotton fabric decreased as the air velocity in the test cabinet increased. The 70/30 blends indicated increased afterglow time as the velocity increased. The 50/50 blend fabric showed no consistent effects.

All untreated fabrics of different fiber contents were represented as having the highest char length since they burned the entire length. The 100 percent cotton fabric showed good fire resistance, resulting in the lowest char length while 50/50 blend fabrics had the highest char length. No significant interaction effect was revealed between the fiber content and the air velocity.

Hypothesis D. Burning characteristics of the fabrics tested are dependent upon the flame retardant treatments applied. This dependency may interact with air velocity conditions.

This hypothesis was confirmed from the results obtained by the laboratory data collected.

None of the treated fabrics showed any afterflame regardless of fiber content. Therefore, all flame retardant treatments were regarded as equally effective in all test fabrics. The lowest afterflame time was obtained by all treated fabrics in all air velocities.

There was no afterglow in treated fabrics of different fiber contents. The effectiveness of the treatments is considered to be equal.

All untreated fabrics burned their entire length with the highest recorded measurement of char length. A significant difference was shown between the three different types of treatments. The THPOH-NH$_3$ treatment had the highest char length among treated fabrics and the THPC-urea-MM treatment had the lowest char length. In general, 100 percent cotton fabrics indicated the lowest char length, and 50/50 blends showed the highest char length when flame retardant treatment was applied. The char length was decreased as the velocity in the cabinet increased.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

The major purpose of this study was to develop an experimental fire resistance testing instrument which was designed to be basically similar to the standard fire resistance testing instrument (AATCC 34-1969), but to permit the introduction of measurable air velocities to simulate more closely burning conditions and fire resistance characteristics of fabrics in moving air.

The eight different air velocities, ranging from 0 to approximately 1,700 feet per minute, were controlled by a damper opening system attached to the top of the instrument. An automatic ignition system was developed to simplify the testing procedure as well as to allow uniform flame characteristics in different test periods.

This test procedure would be valuable to evaluate the fire resistance characteristics of apparel and household fabrics, particularly curtain and drapery fabrics.

Selected fabrics of cotton and cotton/polyester blend which were treated with flame retardants were used to evaluate the experimental instrument by means of comparing fire resistance of these fabrics using both the standard and the

experimental instruments. In addition, fire resistance
characteristics of selected fabrics were investigated
under selected air velocities in relation to the fiber
content and flame retardants treated to these same fabrics.

Prior to the performance of laboratory testing
with fabric samples, eight different air velocities were
standardized. The eight types of air velocities that the
experimental instrument could produce from the eight damper
settings were: 0, 97, 230, 400, 530, 750, 1163, 1527, and
1655 feet per minute. In this particular study only three
different air velocities were tested: 0, 97, and 230 feet
per minute velocities.

Twelve different fabric samples were tested to
evaluate fire resistance. A 100 percent cotton fabric,
a 70/30 blend and a 50/50 blend were treated with APO-THPC,
THPC-urea-MM, and THPOH-NH$_3$ flame retardant treatments.
Untreated fabric samples were also tested to indicate their
burning characteristics and to indicate the effectiveness
of the experimental instrument.

The laboratory data of fire resistance tests were
collected from two instruments by measuring afterflame time,
afterglow time, and the char length independently. The
collected data were analyzed based upon a 3 x 4 x 4
factorial completely randomized design with three fabric
types, four treatments, and four air velocity testing
conditions.

Analyses of variance were employed to determine the signifi-
cance of air velocity testing conditions, fabric types, and
treatments as well as the interactions between these factors.

Regardless of the fiber content and testing conditions,
all treated fabrics showed no afterflame. Among the untreat-
ed fabrics, the 50/50 blends indicated the highest after-
flame time whereas the 70/30 blends were the lowest. After-
flame time was equally highest both in the draft-free
condition of the standard instrument and the 0 feet per
minute velocity of the experimental instrument; and the low-
est when 97 feet per minute air velocity was introduced.

All treated fabrics resisted afterglow regardless of
the fiber content and in different air velocities. Among
untreated fabrics, the afterglow time of test samples de-
creased as the cotton content of fabric increased. The
interaction was significant between the air velocity of the
testing instrument and the fiber content. The 100 percent
cotton fabrics showed the highest afterglow time in both the
draft-free condition of the standard instrument and the 0
feet per minute velocity of the experimental instrument.
Next highest afterglow time was indicated by the 70/30 blend,
and the 50/50 blend showed the lowest afterglow time. After-
glow time was decreased as the air velocity was increased
with 100 percent cotton fabric, while the afterglow time of the
70/30 blend was increased as the air velocity decreased. The
50/50 blend indicated the highest afterglow time at 97 feet

per minute air velocity and the lowest at the standard condition and the 0 feet per minute velocity of the experimental instrument.

All untreated fabrics were burned completely in all air velocities regardless of the fiber content. Among treated fabrics, the char length was the highest with the 50/50 blend and the lowest with the 100 percent cotton fabric. The air velocity in the cabinet seemed to influence the char length of the test fabrics significantly. As the air velocity in the cabinet increased, the char length decreased. This seemed to indicate that the supply of fresh air helped to decrease the surface temperature of burned fabrics to prevent further charring. When the fabric was treated with THPOH-NH$_3$ retardant the char length was the highest, while THPC-urea-MM treatment resulted in the lowest. In addition, the 50/50 blend treated with THPOH-NH$_3$ had the highest char length, and the 100 percent cotton fabric with APO-THPC treatment resulted in the lowest char length.

When a t-test was performed to determine the similarity or differences of actual testing conditions between the draft-free condition of the standard instrument and the 0 feet per minute air velocity of experimental instrument, no significant difference was found.

No significant relation was found between afterflame time, afterglow time and the char length.

CONCLUSIONS

1. It was possible to develop an instrument that would test fire resistance of textiles under varying velocities of air.

2. The test performance between the draft-free condition of the standard instrument and the 0 feet per minute air velocity condition of the experimental test instrument is approximately the same.

3. Different air velocities introduced to the testing instrument significantly influence the burning characteristics of treated and untreated fabrics, with the exception of the afterglow time. Char length particularly decreased as the air velocity in the cabinet increased.

4. Differences in fiber content of the fabric influenced the fire resistance. Afterflame time was the highest with 50/50 blends and the lowest with 70/30 blends. Afterglow time was the highest with the all cotton fabrics and the lowest with 50/50 blends. Char length was the highest with 50/50 blends, and the lowest with 100 percent cotton fabrics.

5. Different types of flame retardant treatments applied to the fabric made significantly different results. Untreated fabrics definitely showed the highest afterflame and afterglow times. The THPOH-NH$_3$ treatment provided the

highest char length, while the lowest char length was obtained with the THPC-urea-MM treatment.

RECOMMENDATIONS

It is recommended that the instrument developed be used in further research. Specific areas of investigation might include the following:

1. Performance characteristics and reproducibility of results of the experimental instrument could be further confirmed by having several operators for laboratory testing using the same fabric samples. In this study, one operator performed all tests, and the performance characteristics were measured only by comparing similarities and/ or differences between the standard instrument and the experimental instrument.

2. Experiment with a greater variety of fabrics, such as: other proportions of cotton and polyester blends, fabrics of other man made fibers, and fabrics varying in structure using the experimental instrument.

3. The effect of air velocity upon the fire resistance characteristics of multi-layers of fabrics should be investigated. The multi-layers represent fabrics typical of those used as undergarments as well as cotton and polyester blends for apparel use.

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APPENDIXES

APPENDIX A

Summary of Analysis of Variance from the Data
Obtained by Measurement of Air Velocities
in Different Sample Heights (n=3)
and Damper Openings (n=8)

Source of variance	Degree of freedom	Mean squares
Sample height	2	.0011 NS*
Damper opening	7	5.4923 **
S.H. x D.O.	14	.0001 NS
Error	216	.0011
Total	239	

* not significant at .05 level

** significant at .05 level

APPENDIX B

Summary of Analysis of Variance from the Data
Obtained by Measurement of Afterflame Time
(Untreated Fabrics)

Source variance	Degree of freedom	Mean squares
Fiber content	2	33.9809 **
Air velocity	3	58.8492 **
F. x A.	6	10.9653 **
Error	24	2.1095
Total	35	

** significant at .05 level

APPENDIX C

Summary of Analysis of Variance from the Data Obtained by Measurement of Afterglow Time (Untreated Fabrics)

Source of variance	Degree of freedom	Mean squares
Fiber content	2	414.65 **
Air velocity	3	47.1084 NS*
F. x A.	6	161.1937 **
Error	24	15.9221
Total	35	

* not significant at .05 level

** significant at .05 level

APPENDIX D

Summary of Analysis of Variance from the Data Obtained by Measurement of Char Length (Treated Fabrics)

Source of variance	Degree of freedom	Mean squares
Fiber content	2	36.6859 **
Air velocity	3	8.5159 **
Treatment	2	7.4616 **
F. x A.	6	0.2517 NS*
F. x T.	4	3.1688 **
A. x T.	6	1.2611 NS*
F. x A. x T.	12	0.1751 NS*
Error	72	
Total	107	

* not significant at .05 level

** significant at .05 level