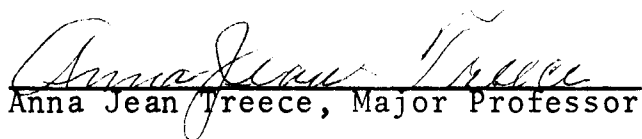
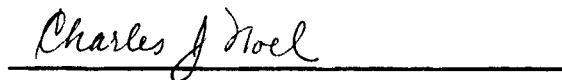


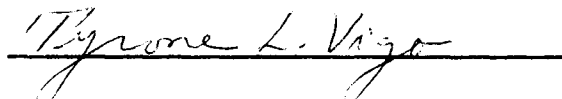
To the Graduate Council:

I am submitting herewith a thesis written by Georgia Elizabeth Self entitled "Flammability Classification and Fire Hazard Determination of Selected Apparel Fabrics." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Textiles and Clothing.


Anna Jean Treece, Major Professor

We have read this thesis
and recommend its acceptance:





Accepted for the Council:



Vice Chancellor
Graduate Studies and Research

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FLAMMABILITY CLASSIFICATION AND FIRE HAZARD
DETERMINATION OF SELECTED APPAREL FABRICS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Georgia Elizabeth Self
August 1979

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ABSTRACT

The first objective of the research was to determine the effect of fabric fiber content and fabric weight (independent variables) on the following variables: maximum heat transfer rate, time to reach maximum heat transfer rate, total heat transfer, time to reach the heat transfer rate of 0.40 joules/cm²/sec, heat transfer at 30-second time intervals, and total burn time (dependent variables). The second objective was to determine the classification of the fabric types according to ignition time and heat transfer rate as specified in the fabric classification system in the draft proposed standard for general wearing apparel.

Ten fabrics were evaluated on the Mushroom Apparel Flammability Tester (MAFT) according to procedures specified in the draft proposed standard. The sample included top and bottom weight fabrics having each of the following fiber contents: acrylic, nylon 66, triacetate, rayon, and wool. The fabrics were tested on a pass/fail basis in terms of end use as shirts/blouses and pants/slacks.

A 5 X 2 analysis of variance was used to evaluate the effects of the two independent variables on each of the six dependent variables. All fabrics passed the MAFT test as defined in the standard. The 10 fabrics did not fall into the same classes as described in the draft proposed standard. The effect of fabric weight was observed

as an increase in the values for maximum heat transfer rate, time to reach maximum heat transfer rate, total heat transfer, and total burn time, with increasing fabric weight.

In relation to potential burn hazard, the safest of the fabrics tested appear to be both weights of nylon 66 and the bottom weight of rayon. Both weights of wool would be relatively safe for use in apparel; only one-third of the total heat transfer occurred during the first 30 seconds of burning. Both weights of triacetate, both weights of acrylic, and the top weight of rayon would be most hazardous in a clothing fire. The high heat transfer rate produced in a short period of time would allow the wearer too little time to react to the fire situation.

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CHAPTER I

INTRODUCTION

Fabric flammability has been a major concern in the United States for many years. Textile fibers commonly used for apparel purposes are inherently susceptible to decomposition by fire (17) and ignite under favorable conditions, constituting a fire hazard. Ignition of textiles causes about 20% of the total loss of life and property caused by all types of fire (25). Perhaps the most important reason for undertaking flammability research is that burn injuries are extremely damaging both physically and mentally to victims and require much time and money for rehabilitation. Early mortality estimates for clothing-related fabric burns numbered approximately 3,000, with more than 150,000 injuries from this cause. In terms of financial loss, annual totals in 1972 exceeded 250 million dollars (12). Recently, an estimated 6,700 deaths per year were caused by fire and flame of all kinds in the U.S., with 500 to 700 of these related to the ignition of clothing (50).

A series of disasters in the 1940's and early 1950's resulted in the loss of many lives from burn injuries sustained from flammable fabrics, including the brushed rayon "torch" sweaters and children's cowboy chaps that flash burned when ignited (18, 34). Undoubtedly, these

tragedies directed public concern toward an awareness of the flammability of textile materials (18), resulting in the passage of the Flammable Fabrics Act in 1953. Under the Act, fabrics were required to pass a 45° angle test of ignition and rate of burn test that were developed under voluntary standards procedures of the National Bureau of Standards (18). All apparel fabrics are subject to the requirements of the Act, which prohibits the introduction or movement in interstate commerce of highly flammable apparel and fabrics (16). The Act was amended in 1967 to cover a wider range of clothing and interior furnishings (22).

Since 1954, two additional standards specifically related to clothing have been enacted. Both are related to the flammability of children's sleepwear. Title 16 CFR 1615 (formerly FF 3-71) became effective in July 1972 and regulates sleepwear sizes 0-6X. Title 16 CFR 1616 (formerly FF 5-74) became effective in May 1975 and regulates sleepwear sizes 7-14 (22). When Title 16 CFR 1615 was passed, burns related to children's sleepwear were 14% of the total clothing-related burns. In 1975, the rate fell to 7%, and by 1977, the rate was only 3%. Similarly, there have been fewer lawsuits involving burned infants. The number of adult cases, however, has not decreased (46).

In 1976, the National Bureau of Standards (NBS) for the Consumer Product Safety Commission (CPSC) proposed

extension of Title 16 CFR 1616 to include the flammability standards for six general apparel clothing categories and the dates for compliance with them. According to the schedule, adult women's nightgowns would have had to meet regulations by September 1, 1976, adult women's robes and housecoats by 1978, adult pajamas by 1979, dresses for all ages by 1980, men's shirts by 1981, and men's and boy's pants by 1981 (30). However this schedule was not met and recommendations are still pending.

The present standard for flammability testing, Title 16 CFR 1610 (formerly CS 191-53), has been criticized because it is too weak. Almost any fabric can pass it, and there is virtually no way to discriminate the hazard potential of fabrics (49). Therefore, new test concepts reflecting a more realistic relationship between the safety of the clothing and the burn potential to the wearer are needed to meet the general apparel flammability standards.

Industry has been working with the CPSC and NBS to define and evaluate reasonable test methods which can be shown to be related to specific hazards that can be identified by injury statistics and research. The objective is to relate accident simulation data to existing tests, including those presently in effect (Title 16 CFR 1610, 1615, and 1616), and to tests proposed by the Federal Government (49).

During the development of the proposed standard for general wearing apparel, several features deemed necessary for more realistic test methods were outlined in the Back-Up Report for the Proposed Standard for the Flammability of General Wearing Apparel (10). These include:

- (a) a vertical, cylindrical specimen closed on top, to simulate, as closely as possible in a laboratory test, the configuration and conditions during burning of real-life garments;
- (b) ignition in the body of the fabric rather than at or near the bottom edge, to allow the flames to spread in all directions;
- (c) pass-fail criteria based on the ease of ignition and the rate of heat transfer to the inside of the specimen;
- (d) a fabric and garment classification scheme so that the relatively hazardous garments (those which cover a large part of the body and/or fit loosely) would be made from relatively safe fabrics, and less hazardous garments (which cover roughly half of the body and/or fit relatively tightly) could be made from those fabrics which transfer more heat to the inside of the specimen and are considered to have a greater injury potential. Present technology does not permit exclusion of such fabrics from the market (10).

The current opinion is that fabrics should be characterized by their ability to produce heat and transfer this heat to a significant percentage of the body over short periods of time. Ignitability and extinguishability as well as garment construction and end use are being considered as important indicators of potential burn hazard (47).

The new proposed standard for general wearing apparel is presently in draft form. Ease of ignition and rate of heat transfer of textile fabrics were selected as the parameters most relevant to the determination of the flammability hazard of apparel fabrics (35). The additional factor of garment configuration was found to influence the severity of burn injury. An analysis by the Flammable Fabric Accident Case and Testing Systems (FFACTS) indicated that loose-fitting garments are involved in more severe burn injuries than are close-fitting garments (50).

The National Bureau of Standards has developed an apparatus called the Mushroom Apparel Flammability Tester (MAFT) which complies with the proposed test criteria and has been evaluated critically by its developers. The MAFT test is more severe than Title 16 CFR 1610 and less severe than Title 16 CFR 1616, causing the standard to be viewed as more realistic than existing standards (28). The test is still being evaluated. Its present use is in research to relate ignition time and heat transfer data to potential burn injury from flammable fabrics. Classification of fabrics by MAFT heat rate values is intended to segregate the less hazardous fabrics from the more hazardous ones (28).

In order to develop a consumer hazard index of flammable fabrics, the following research is proposed to

determine the flammability classification of selected apparel fabric types according to the draft proposed standard. This research contributes to the Southern Regional Textile Project S-109 on textile flammability.

Objectives

- (1) To determine the effect of fabric fiber content and fabric weight on the maximum heat transfer rate, time to reach maximum heat transfer rate, time to reach the heat transfer rate of $0.40 \text{ joules/cm}^2/\text{sec}$, total heat transfer, heat transfer at 30-second time intervals, and total burn time.
- (2) To determine the classification of the fabric types according to the ignition time and heat transfer rate as specified in the MAFT classification system in the draft proposed standard.

Null Hypotheses

H₀₁ There will be no difference in the maximum heat transfer rate, time to reach maximum heat transfer rate, time to reach the heat transfer rate of $0.40 \text{ joules/cm}^2/\text{sec}$, total heat transfer, heat transfer at 30-second time intervals, and total burn time of the five selected fabric fiber contents.

- H₀₂ There will be no difference in the effects of top weight and bottom weight fabrics of the same fiber content on the maximum heat transfer rate, time to reach maximum heat transfer rate, time to reach the heat transfer rate of 0.40 joules/cm²/sec, total heat transfer, heat transfer at 30-second time intervals, and total burn time.
- H₀₃ There will be no difference in the classification of the two weights of each of the five fabric types according to ignition time and heat transfer rates as specified in the MAFT fabric classification system.

Assumptions

- (1) Clothing plays a major role in the potential burn injury to a victim exposed to flame.
- (2) Knowledge of fabric flammability can be acquired by modeling real-life situations in the laboratory; the results of such experiments may increase the understanding of actual clothing-related burn incidents.
- (3) Acrylic, nylon 6-6, tri-acetate, viscose rayon, and wool are representative of apparel fabrics in terms of weight and end-use for pants/slacks-shirts/blouses.
- (4) The procedure and classification system used

with the MAFT are valid means to classify the potential hazard of flammable fabrics.

- (5) The five selected apparel fabric types can be classified into one of the four fabric classes as specified in the draft proposed standard.

Limitations

- (1) All testing was done on the Mushroom Apparel Flammability Tester.
- (2) Exposure time for the ignition test was limited to 1/2 second and 1 second to simulate real-life surface ignition time.
- (3) Time of ignition for the heat transfer test was limited to 3 seconds and 12 seconds.
- (4) Only five woven fabric types were considered.
- (5) The five selected fabric types were limited to two weights representative of weight and end use for pants/slacks-shirts/blouses.

Definitions

Fabric class - Fabric classification of 1, 2, 3, or 4, as determined by the National Bureau of Standards (40). Fabric classification is a range based on the maximum heat transfer rate, from values less than or equal to 0.40 joules/cm²/sec for fabric Class 1 to values greater than 0.40 joules/cm²/sec for fabric Classes 2, 3, and 4. The range for ignition time is from 3 or 12 seconds or greater

for fabric Class 1 to 1/2 second for fabric Class 4. These values are obtained for each fabric from testing on the MAFT.

Fabric type - Fabric denoted by fiber content.

Fabric weight - Weight of fabric in terms of weight and end use for pants/slacks-shirts/blouses.

Fiber content - Fundamental unit comprising a textile raw material (14).

Flammability - Ability to support combustion.

Garment class - Garment classification of 1, 2, or 3, as specified in the draft proposed standard (40). Garment classification is based on the fit and the amount of body surface covered, from loose-fitting, full-cover garments in Class 1 to tight-fitting, half-cover garments in Class 3. Class 4 fabrics are excluded for use in any garment; thus, there are no Class 4 garment requirements.

General wearing apparel - Any clothing intended for wear on the body. This definition includes, but is not limited to, nightgowns, pajamas, robes, dresses, jumpers, caftans, skirts, body suits, body shirts, shells, and tank tops, T-shirts, blouses, shirts, sweaters, sweatshirts, shirt-jackets, smocks, underwear, slips, socks, hosiery, suits, sport coats, blazers, aprons, gloves, hats, overcoats, overjackets, capes, ponchos, shawls, mufflers, wigs, swimwear, and swimwear cover-ups. This definition excludes shoes (40).

Ignition source - Flame produced from the gas, burner, and the gas flow rate as specified in the procedure (40).

Ignition test - Determination of the ease of ignition of a fabric when its surface is exposed to the ignition source for 1/2 or 1 second.

Ignition time - Minimum time required for a specimen to ignite as specified in the procedure (40).

Maximum heat transfer rate - The greatest heat transfer rate transferred from a burning specimen to the test apparatus as specified in the procedure (40).

Mushroom Apparel Flammability Tester (MAFT) - The apparatus developed by the National Bureau of Standards for use in a general flammability standard.

Sample - Set of four specimens (40).

Specimen - Swatch of fabric 32 cm X 61 cm (12.5 X 24 inches) for testing (40).

Time to reach maximum heat transfer rate - Number of seconds required to reach the point at which the greatest amount of heat is transferred from a burning specimen to the test apparatus (40).

Time to reach .40 joules/cm².sec - Number of seconds required to reach the point at which the amount of heat transferred is .40 joules/cm².sec.

Total heat transfer at 30 second intervals - Total amount of heat transferred from a burning specimen to the

test apparatus measured at 30 second intervals during the burning time.

Total heat transfer - Total amount of heat transferred from a burning specimen to the test apparatus.

CHAPTER II

REVIEW OF LITERATURE

Clothing-Related Burn Injuries

The general hazards of fire include injury or loss of human life caused by flames, heat, oxygen depletion, decomposition products either individually or in combination, and property damage. The main hazard of apparel fires is burning of skin (21).

The probability of being burned in a garment fire is related to the probabilities of ignition, continued burning after ignition, and extinguishability. Each of these is determined in turn by interaction among the wearer, the fabric, and the garment (8). Buchbinder found the most frequent reactions of persons involved in apparel fires to be running, beating flames with hands, removing clothing, and dropping to the ground and rolling (33).

The Department of Health, Education and Welfare's Vital Statistics of the U.S. listed total deaths caused by fire and flame of all kinds as 6,714 in 1972, with 542 of these attributable to clothing (32, 50). Because of the growing concern over the flammability problem, the American Testing Materials Institute (ATMI) and the National Cotton Council (NCC) told CPSC that emphasis must be placed on the collection and analysis of serious burn injury data. Knowledge of exact causes of burn injuries and actual extent

of the problem was necessary to determine not only the need for a more stringent flammability standard, but also to which items it should be applied (9).

A major source of burn injury data has been the Nebraska burn study (32). From this study, projections were made of burn injuries estimated to be sustained by each sex. A high proportion of incidents involved ignition of pants and slacks of males aged 10-19 and ignition of shirts and blouses of both males and females aged 20-44. The proportion of males who died as a result of the fire accident was like the proportion of females who died (31). From these data, national projections of clothing-related thermal burns were estimated to be 21,917, far less than the often quoted statistic of 150,000 to 250,000 fabric-related burn injuries each year (32).

Extensive studies on the physiology of burns show that the mechanism by which burns are produced depends on the time rate of heat exposure and not simply on the duration of exposure (7), as well as the area of the body in contact with the heat (13). A large amount of energy delivered over an extended time may produce little or no injury while the same amount of energy delivered instantaneously may produce extensive damage (7).

Burns that result from clothing catching fire are generally more extensive and more severe than other types of burn injuries (23). The deeper the burn, the slower

the recovery (27), and the larger the area of the body suffering second and third degree burns, the greater the probability of death. Burns generated by flame result in a higher death rate than do burns generated by other sources, and the flame does not have to be large for the burn to occur (47).

Heat transfer to the skin tissue rather than flame size is the main cause of the burn. The lower limit of injurious temperatures is about 44° C (5). Injury to skin tissue occurs continuously during the time that the skin temperature remains above 44° C. At a tissue temperature of about 72° C, the skin is destroyed virtually instantaneously (5).

Factors Contributing to Fabric Fire Hazard

Different fabrics afford different degrees of protection to the wearer under conditions of fire. Flame propagation is affected by five major variables: fiber composition, fabric orientation, fabric weight by unit area, garment geometry, and spatial arrangement of layers.

In general, testing has shown that fiber content of fabrics is extremely important in determining fabric class (44). Fiber composition causes significant differences in burning behavior with respect to the physical response of the fabric after ignition. Thermoplastic fibers melt, shrink, drip, and generally do not propagate flame.

Non-thermoplastic fibers continue to burn after ignition. Flame retardant fibers inhibit flame propagation (25).

Fabric orientation greatly influences flame speed. Maximum flame speed occurs in the 90 degree (vertical) orientation. Lateral flame spread generally is much slower (1).

Fabric weight by unit area is an important influence on flame speed. For non-thermoplastic fabrics, the inverse relationship of fabric weight to flame speed has been confirmed (1, 20, 25). Exceptions are fabrics in which yarns or fibers protrude from the fabric surfaces, such as pile or napped fabrics which ignite and burn relatively easily (26). Heavy fabrics provide more calories per square yard, but burn more slowly than light weight fabrics (15, 25, 27). Heavier fabrics require more time until all burning areas are extinguished than lighter fabrics, even though flames spread over larger areas of the latter in a faster time (26, 27, 28). An increase in the fabric weight of the untreated fabric itself will increase ignition time (37).

Garment configuration has been found to influence the severity of burn injury; an analysis by FFACTS indicated that loose-fitting garments are involved in more severe burn injuries than are close-fitting garments (45). Large fabric-skin distances can reduce injury, but produce ample air supply for the fire, while direct

contact between garment and skin can slow or stop fires (27).

Spatial arrangement of layers greatly affects burning behavior of the fabrics. Temperature rise behind a double layer of fabric separated by an air space is less than that behind the same assembly without an air space. This effect increases to an optimal width, diminishing thereafter as convection currents arise between the layers and cause the outer layer to perforate (45). McCullough's findings (36) indicated that fabric assemblies with high percentages of cotton fiber and no air space between the layers yielded the highest heat transfer values. In systems where the two fabric layers were touching, the ignition time for some assemblies increased over their single layer outerwear components or by the same assemblies with more space between their layers. Most of the layered fabric assemblies exhibited a synergistic effect; the flammability hazard associated with assemblies was greater than that expected from the sum of the single layers (36).

Research Using the Mushroom Apparel Flammability Tester

Although several research projects are in progress in which the MAFT is being compared with other flammability test methods, few results have been reported in the literature. The arbitrary heat transfer criterion of 0.40 joules/cm²·sec has been questioned as to whether it actually

distinguished between hazardous and non-hazardous fabrics, or whether it was merely an ultra-safe position from which to begin evaluation (4).

Miller (38) used the convection calorimeter to monitor the heat emitted by burning fabrics. This technique depends on the measurement of the convective air flow induced by the heat source without restrictions on the size, shape, or movement of the sample. A collection of 16 different fabrics was analyzed for heat emission behavior using the convection calorimeter, and again using the MAFT. Although there were a few discrepancies, there was general agreement in the rankings for most of the fabrics.

In another study, the MAFT was used to evaluate Fyrol-treated cotton and polyester/cotton substrates. Results indicated that add-on level to meet Class 1 requirements was about one-half to one-third that required to pass Title 16 CFR 1615 vertical test. The level of flame retardant required on cotton increased as fabric weight increased. The level also increased with more loosely woven goods. With polyester/cotton blends, the flame retardant required increased as polyester content increased (39).

In an earlier study also contributing to the Southern Regional Project S-109, Thompson used top and bottom weight fabrics having each of the following fiber

contents: 100% cotton, 100% polyester, 50% polyester/50% cotton, and 65% polyester/35% cotton. She compared three flammability testers and test methods. The vertical test "failed" six of eight test fabrics, while both the 45 degree angle test and the MAFT test "passed" all eight fabrics. Even though all eight fabrics "passed" the MAFT test, the eight fabrics did not all fall into the same classes as outlined in the draft proposed standard for general wearing apparel. Therefore, the MAFT test would further limit the end use for some of the test fabrics, where the 45 degree angle test would not. Thompson also reported an interaction between fabric fiber content and fabric weight for the 100% cotton fabric. The bottom weight cotton was found to be much safer than the top weight cotton due to a much longer time to reach maximum heat transfer rate for the bottom weight cotton.

Galil and Lomartire (21) criticized the ease of ignition and heat transfer parameters measured by the MAFT because these measurements are apparatus-dependent. Any change in the apparatus design, fabric configuration, or distance of fabric from the thermocouples would produce different results.

Krasny and Peacock (29) compared degree of flammability assessments reported by Galil and Lomartire with the heat transfer rate from burning fabrics, measured on the MAFT. Agreement between the two methods was found for

only a few fabrics, which was expected as the degree of flammability assessment is not a quantitative test.

Smith (44) stressed the need for accuracy and reproducibility assessment of the test method, and reliability assessment of the equipment in constant daily use. More research is required to determine whether the criteria of the standard are set to provide safety with minimum effect on cost, performance, aesthetics, and consumer choice.

Segal and Drake (42) reported favorable results obtained with two complete MAFT instruments built to test for accuracy and reproducibility of results, as well as reliability of instrumentation. Data suggested that reproducible results can be obtained when the sensors are properly constructed, high quality components are used in the sensor signal processor, the transfer rate of the calibration lamps is established and the MAFT is properly calibrated against the lamps.

CHAPTER III

METHODS

Reported in this chapter are the experimental design, description of the sample, measurement of physical properties, and description of flammability testing. The procedures for flammability testing are reported along with statistical analysis of the data obtained in the study.

Experimental Design

A 5 X 2 fully crossed and balanced design was used to test the effects of two independent variables (fiber content and fabric weight) on each of six dependent variables (maximum heat transfer rate, time to reach maximum heat transfer rate, total heat transfer, time to reach the heat transfer rate of 0.40 joules/cm²/sec, total heat transfer at 30-second time intervals, and total burn time) as measured by the MAFT. Four replications from each fabric type were used in the study.

Sample

The five flammable fabrics selected had the following fiber contents: acrylic, nylon 66, triacetate, rayon, and wool (Table I). All fabrics contained no color dyes. Two fabric weights for each of the five fabric types were selected in terms of end use as shirts/blouses or pants/slacks, making a total of 10 fabrics tested. All fabrics

TABLE I
PHYSICAL PROPERTIES OF FABRICS^a

Fabric ^b	Fiber	Weave	Weight ^c (oz/yd ²)	Weight ^c (gm/m ²)	Deniere (warp/fill)	Thickness ^d (inch)	Thread Count ^e (warp/fill)	Fabric Cover K ^f
Triacetate (tw)	staple	plain	5.99	203.39	590 / 630	0.030	41/34	25.37
Triacetate (bw)	filament	plain	7.10	242.12	828 / 630	0.015	37/51	32.17
Nylon 66 (tw)	filament	plain	0.72	26.07	30 / 30	0.003	102/84	14.52
Nylon 66 (bw)	staple	plain	4.12	139.30	183 / 212	0.019	53/57	21.25
Acrylic (tw)	staple	plain	4.75	160.90	396 / 408	0.022	50/42	25.29
Acrylic (bw)	staple	plain	6.43	217.89	697 / 684	0.027	54/43	27.75
Rayon (tw)	filament	plain	2.10	71.16	107 / 111	0.007	106/55	23.06
Rayon (bw)	staple	plain	4.08	138.35	216 / 248	0.016	78/60	28.67
Wool (tw)	staple	plain	3.99	135.23	288 / 275	0.021	61/46	24.71
Wool (tw)	staple	twill	5.45	184.92	414 / 396	0.032	54/49	28.48

^aAll fabrics were purchased from Testfabrics, Inc., P. O. Box 53, 200 Blackford Avenue, Middlesex, N. J. 08846.

btw = top weight; bw = bottom weight.

^cDetermined according to standard procedure ASTM D 1910 (1).

^dDetermined according to standard procedure ASTM D 1777 (1).

^eWeight of 900 cm of yarn X 1000.

^fK(warp) + K(filling) = K(fabric cover).

were purchased from TESTFABRICS, INC., Middlesex, New Jersey.

Measurement

Physical tests were performed according to the following procedures:

Fabric weight. Fabric weight was determined according to ASTM Test Method D 1910-64 (1), using a Mettler balance. The mean weights of 10 5.08 X 5.08 cm squares randomly cut from each test fabric were recorded. The weight in grams was converted to ounces per square yard.

Fabric thickness. Thickness was determined in accordance with procedures specified in ASTM Test Method D 1777-64 (1). Ten randomly selected 5.08 X 5.08 cm squares per fabric were measured on the Electric Low Pressure Thickness Gauge to the nearest 0.001 of an inch.

Thread count. Thread count was determined as specified in ASTM Test Method D 1910-64 (1). The mean number of ends and picks per inch of five randomly selected one-inch areas were counted and recorded for each test fabric.

Yarn size. Fabric strips measuring 10 cm X 45 cm were cut from the warp and fill direction of each fabric. Ten yarns from the warp direction and 10 yarns from the

filling direction were removed from each fabric and weighed on a Mettler balance. ASTM Test Method D 2260-64 (1) was used to determine denier.

Fabric cover. The number of threads per inch in the warp and filling direction was used to calculate cover (K). K was determined for each test fabric using the following formulae:

$$K_w = \frac{N_w}{\sqrt{CC_w}}$$

$$K_f = \frac{N_f}{\sqrt{CC_f}}$$

$$K_{\text{fabric}} = K_w + K_f$$

where N = number of threads designated either warp (w) or fill (f), and CC = cotton count, warp or fill (Table I).

Flammability testing. All fabrics were tested for flammability according to draft 4 of the proposed standard for the flammability of general wearing apparel (38). A Govmark Mushroom Apparel Flammability Tester was used in conjunction with a Custom Scientific Signal Processor (see Figure 1). The Govmark MAFT was reworked in the summer of 1977 to meet latest specifications set forth by the CPSC. The instrument was calibrated prior to each day of testing.

For the measurement of rate of heat transfer, a total of four specimens (two warp and two filling) per replication were randomly selected from each test fabric. The dimensions of the specimen measure 31.75 X 60.96 cm,

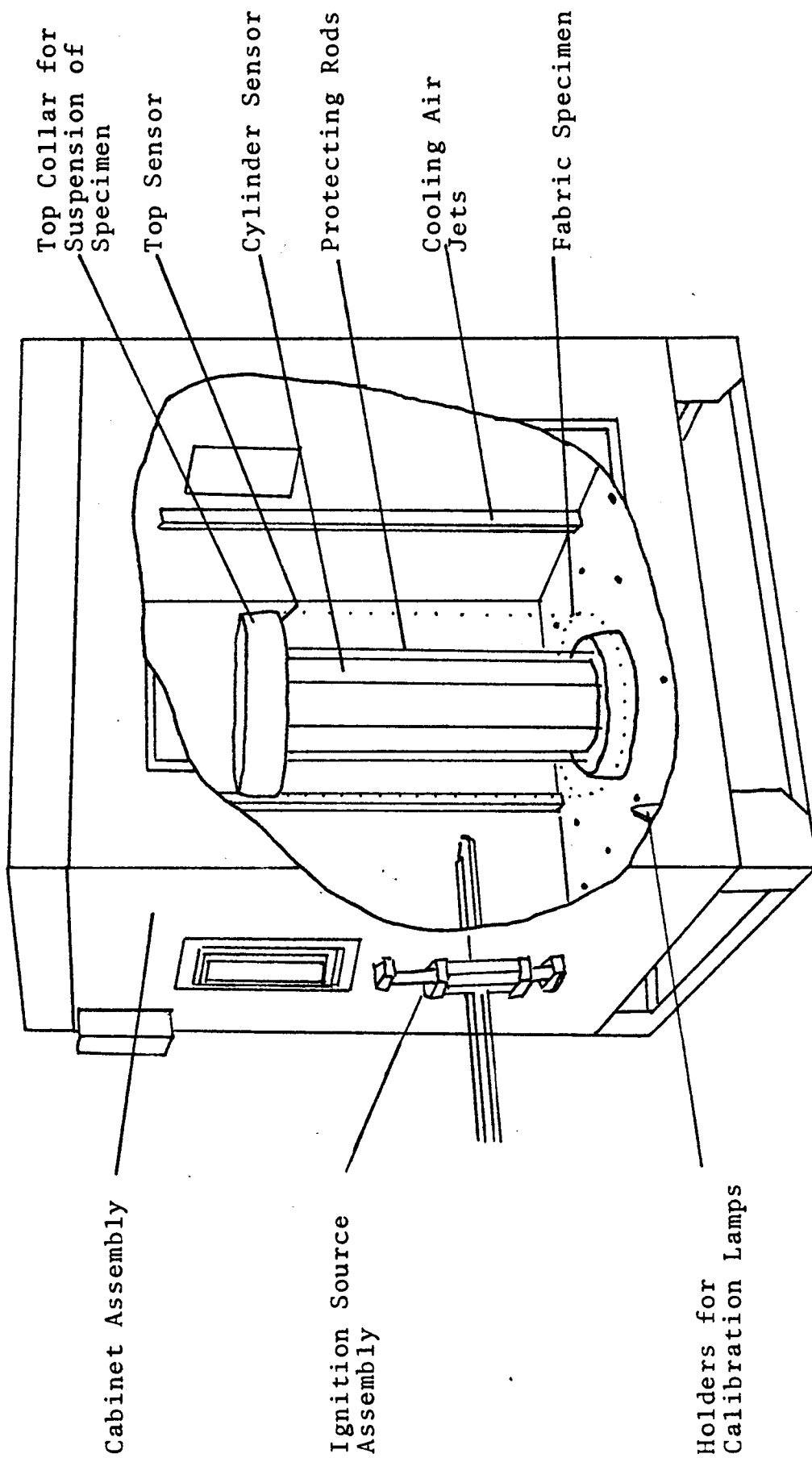


Figure 1. Mushroom Apparel Flammability Tester.

with the shorter dimension indicating the specimen direction (warp or filling).

Procedure

All specimens were conditioned in a room with a constant temperature of $21 \pm 1^{\circ} \text{C}$ and a relative humidity of $65 \pm 2\%$ for a minimum of 8 hours prior to testing. The MAFT is located in a separate unconditioned room; therefore, each specimen was ignited within 60 seconds from the time it was removed from the conditioned room.

For the rate of heat transfer test, each specimen was mounted on the sensor using three metal clips spaced evenly around the specimen supporting collar. The specimens were draped evenly around the sensor, and the free edges of the specimen had a 2.54 cm overlap which was pinned at the bottom with a straight pin.

Specimens were ignited with a 3- or 12-second flame impingement determined by pretesting each fabric. The rate of heat transfer was recorded by the testing recorder at a chart speed of 2.54 cm per minute. The maximum rate of heat transfer for each specimen was taken as the highest point in the graph.

Between specimen burns, residue was removed from the base plate, protecting rods, and cylinder with a spatula, steel wool and a vacuum cleaner. To promote cooling of the sensor assembly between specimen burns, a

23-cm electric fan was used to circulate air through the test cabinet.

The preparation for the measurement of ignition time was identical to that for the measurement of heat transfer rate. Specimens were subjected to the ignition source for 1 second by presetting the timer for the required time. Each specimen was exposed to the ignition source three times or until ignition occurred, whichever was less, in different locations around the circumference of the specimen. Ignition or non-ignition was recorded.

If the sample of four specimens specified by the draft proposed standard ignited with a 1-second flame impingement, a second set of four specimens from that particular fabric was tested in the same manner using a 1/2-second flame impingement. Ignition or non-ignition was recorded.

After completion of the heat transfer test and the ignition tests, the fabrics were classified according to specified criteria as follows: Class 1, Class 2, Class 3, or Class 4. The criteria for fabric and garment classification are outlined in Table II and Figure 2.

Statistical Analysis

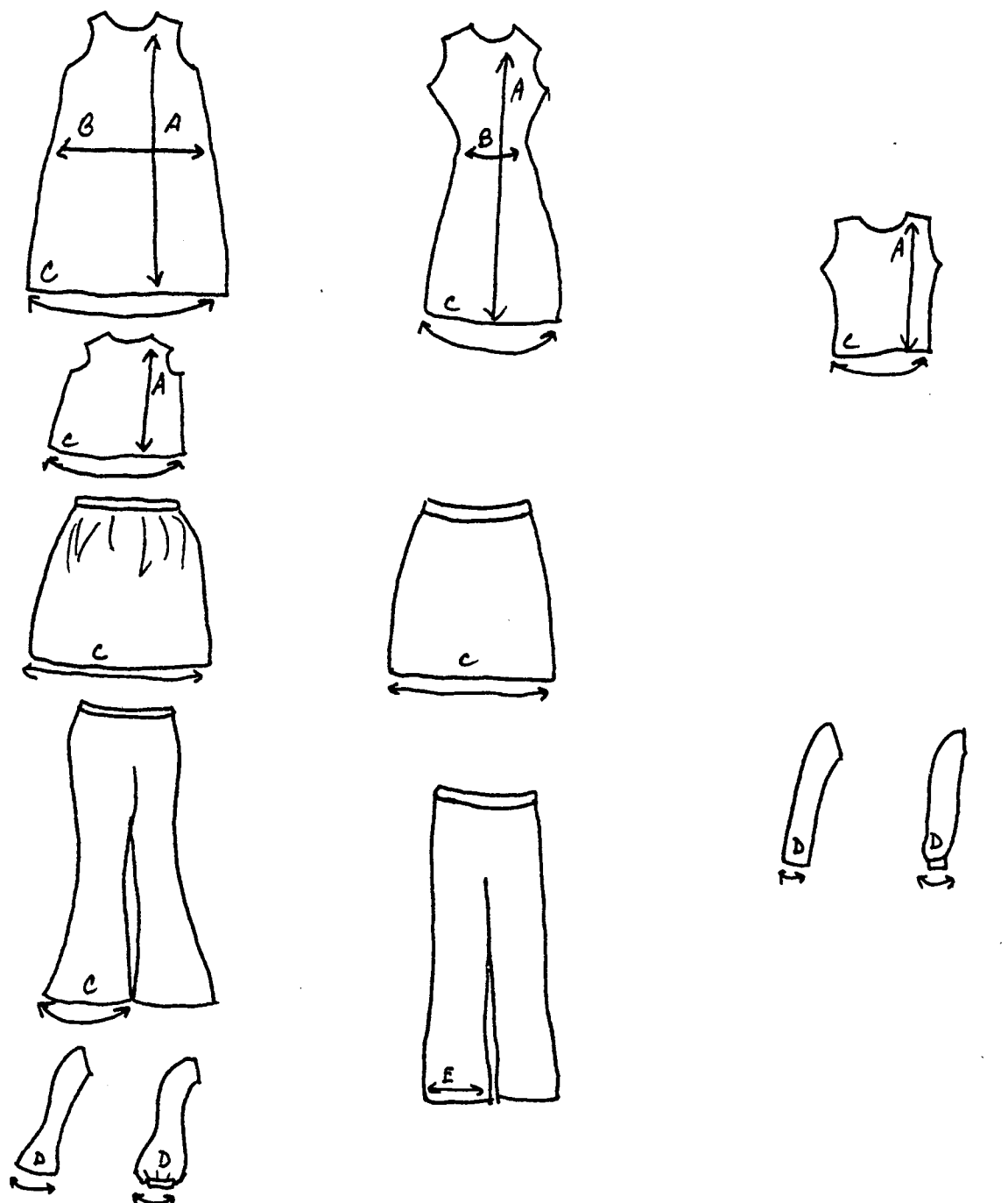
A two-way analysis of variance was used to evaluate the relationship of fabric fiber content and fabric weight on maximum heat transfer rate, time to reach maximum heat transfer rate, time to reach the heat transfer rate of

TABLE II
FABRIC AND GARMENT CLASSIFICATION

Class	Rate of Heat Transfer (joules/cm ² /sec)	Time to Ignite (sec)	Garment Requirements
1	≤ 0.40	3 or 12	Loose-fitting, full-cover garments except raincoats, overcoats. Loose-fitting half-cover garments; all dresses, skirts through children's size 14.
2	> 0.40	1	Tight-fitting, full-cover garments; tight-fitting half-cover garments for the lower body; all garments through children's size 14 except those required to be in Class 1; raincoats and overcoats.
3	> 0.40	$1 > 1/2$	Tight-fitting, half-cover garments for the upper body.
4	> 0.40	$= 1/2$	Excluded for use in any garment.

Note: Full-cover and half-cover garments are defined by shoulder seam-bottom hem distance, and loose-fitting and tight-fitting garments are defined by waist, sweep, sleeve width, and pants leg width dimensions shown in Figure 2.

Source: 40.



Class 1

Class 1 or 2

Class 1, 2, or 3

- A - garment length dimension
 B - waist measurement
 C - sweep dimension
 D - sleeve dimension
 E - sweep dimension of
 pant-like garment (Source: 10)

Figure 2. Garment Classification.

0.40 joules/cm²/sec, total heat transfer, heat transfer at 30-second time intervals, and total burn time, as measured by the MAFT. A significance level of .05 was used in the analysis. Least squares means were examined to determine differences among fabric types for each dependent variable.

The data were best fit to an exponential growth curve of the form $Y = b_0 (1 - e^{-b_1 t})$ where b_0 represents the total amount of heat sensed by the unit and b_1 represents the coefficient of time.

CHAPTER IV

RESULTS AND DISCUSSION

Reported in this chapter are the results of the MAFT test (Table III) and the pass/fail results in terms of end use for each of the 10 test fabrics. Also reported are the effects of fiber content and fabric weight on the maximum heat transfer rate, time to reach maximum heat transfer rate, time to reach 0.40 joules/cm²/sec, total heat transfer, heat transfer at 30-second time intervals, and total burn time, as measured by the MAFT.

Results of MAFT Test

All 10 test fabrics "passed" the MAFT test. A pass rating indicated that the fabric would not be prohibited from use in apparel. Classification of fabrics according to the draft proposed standard ranged from Class 1 to Class 3. The nylon 66 top and bottom weight fabrics received a Class 1 rating. All other test fabrics received a Class 2 rating with the exception of the rayon top weight fabric which received a Class 3 rating.

According to the draft proposed standard, all top weight fabrics excluding rayon could be sold as shirts/blouses and all bottom weight fabrics could be sold as pants/slacks. The rayon top weight fabric which received a Class 3 rating would be used only in tight-fitting

TABLE III
SUMMARY OF MAFT TEST

Variables	Triacetate (tw)a	Triacetate (bw)a	Nylon 66 (tw)	Nylon 66 (bw)	Acrylic (tw)	Acrylic (bw)	Rayon (tw)	Rayon (bw)	Wool (tw)	Wool (bw)
Maximum Heat Transfer Rate (J/cm ² /sec) ^b	1.09	1.42	0.21	0.27	1.92	1.88	1.04	1.24	0.51	0.57
Time to Reach Maximum Heat Transfer Rate (Seconds) ^b	65.63	73.00	11.63	10.31	46.25	72.06	17.44	169.38	20.69	20.38
Total Heat Transfer ^b (J/cm ²)	56.09	65.37	0.89	5.29	58.49	125.91	39.81	180.72	14.33	8.48
Time to Reach 0.40 J/cm ² (Seconds) ^b	9.75	10.44	-	-	8.81	10.81	5.50	33.06	16.63	17.94
Heat Transfer at 120 Seconds (J/cm ²) ^b	54.62	64.08	0.89	4.94	58.49	110.52	39.81	55.98	14.33	8.48
Heat Transfer at 90 Seconds (J/cm ²) ^b	50.52	58.52	0.89	4.42	58.49	82.94	39.80	35.23	14.29	8.48
Heat Transfer at 60 Seconds (J/cm ²) ^b	31.15	31.06	0.89	3.76	53.43	44.47	36.34	19.84	11.73	7.92
Heat Transfer at 30 Seconds (J/cm ²) ^b	10.57	15.75	0.89	2.58	13.85	13.19	17.08	6.74	5.47	5.34
Total Burn Time (Seconds) ^b	123.75	135.19	21.50	72.25	74.25	159.75	76.13	345.25	81.13	73.06
Ignition Time (Seconds) ^c	3	12	12	12	12	12	1>1/2	3	12	12
Combustion Area	Total	Total	None	Partial	Total	Total	Total	Total	Total	Partial

atw = top weight; bw = bottom weight.

^bMean values; N=16.

^cDetermined according to procedure in draft proposed standard (40).

half-cover garments for the upper body.

The pass/fail results in terms of end use for each of the 10 test fabrics in the study, along with results of those fabrics tested by Thompson for Southern Regional Project S-109, are reported in Table IV.

Effect of Fabric Fiber Content and Fabric Weight

The effect of fabric fiber content and fabric weight (independent variables) on the maximum heat transfer rate, time to reach maximum heat transfer rate, time to reach the heat transfer rate of $0.40 \text{ joules/cm}^2/\text{sec}$, total heat transfer, total heat transfer at 30-second time intervals, and total burn time (dependent variables), as measured by the MAFT, was determined using nine separate two-way analysis of variance (ANOVA) (Tables V-XIII).

The main effects and interaction of fabric fiber content and fabric weight were found to be significant for each of the dependent variables with the exclusion of heat transfer 30 seconds after ignition. At 30 seconds after ignition, the main effect of fabric weight was found to be non-significant. Unless examined in an interaction with fiber content, weight alone had no effect on the heat transfer during the first 30 seconds of burning. Fabric weight did have a significant effect on heat transfer at 30-second intervals beyond the first 30 seconds of burning.

Because of the significant interaction of fabric fiber content and fabric weight, further analysis was

TABLE IV
FABRIC CLASSIFICATION INDEX*

Fabric	Class 1	Class 2	Class 3
1. Triacetate (tw)		X	
2. Triacetate (bw)		X	
3. Nylon 66 (tw)	X		
4. Nylon 66 (bw)	X		
5. Acrylic (tw)		X	
6. Acrylic (bw)		X	
7. Rayon (tw)			X
8. Rayon (bw)		X	
9. Wool (tw)		X	
10. Wool (bw)		X	
11. 100% Cotton (tw)		X	
12. 100% Cotton (bw)		X	
13. 100% Polyester (tw)	X		
14. 100% Polyester (bw)	X		
15. 50% Polyester/50% Cotton (tw)		X	
16. 50% Polyester/50% Cotton (bw)		X	
17. 65% Polyester/35% Cotton (tw)			X
18. 65% Polyester/35% Cotton (bw)		X	

*Fabrics 1 through 10 were used in research in this study. Fabrics 11 through 18 were used in research by Thompson (48).

TABLE V

ANALYSIS OF VARIANCE OF FABRIC FIBER CONTENT AND
FABRIC WEIGHT FOR MAXIMUM HEAT TRANSFER RATE

Source	Sum of Squares	df	Mean Square	F
Fiber Content	54.70	4	13.68	264.51*
Weight	0.51	1	0.51	9.92*
Fiber Content X Weight	0.74	4	0.19	3.57*
Error	7.76	150	0.05	
Total	63.71	159		

*Significant at .05.

TABLE VI

ANALYSIS OF VARIANCE OF FABRIC FIBER CONTENT AND FABRIC
WEIGHT FOR TIME TO REACH MAXIMUM HEAT TRANSFER RATE

Source	Sum of Squares	df	Mean Square	F
Fiber Content	151375.35	4	37843.83	84.35*
Weight	53875.60	1	53875.60	120.08*
Fiber Content X Weight	136584.40	4	34146.10	76.11*
Error	67297.75	150	448.65	
Total	409133.10	159		

*Significant at .05.

TABLE VII

ANALYSIS OF VARIANCE OF FABRIC FIBER CONTENT AND FABRIC
WEIGHT FOR TIME TO REACH THE HEAT TRANSFER RATE OF
0.40 J/cm²/sec

Source	Sum of Squares	df	Mean Square	F
Fiber Content	186735.06	4	46683.77	1408.56*
Weight	1593.91	1	1593.91	48.09*
Fiber Content X Weight	4533.19	4	1133.30	34.19*
Error	4971.44	150	33.14	
Total	197833.59	159		

*Significant at .05.

TABLE VIII

ANALYSIS OF VARIANCE OF FABRIC FIBER CONTENT AND FABRIC
WEIGHT FOR TOTAL HEAT TRANSFER

Source	Sum of Squares	df	Mean Square	F
Fiber Content	290074.28	4	72518.57	122.97*
Weight	74765.54	1	74765.54	126.78*
Fiber Content X Weight	121558.44	4	30389.61	51.53*
Error	88457.49	150	589.72	
Total	574855.77	159		

*Significant at .05.

TABLE IX

ANALYSIS OF VARIANCE OF FABRIC FIBER CONTENT AND FABRIC
WEIGHT FOR TOTAL HEAT TRANSFER AT 120 SECONDS

Source	Sum of Squares	df	Mean Square	F
Fiber Content	147312.03	4	36828.01	145.94*
Weight	9210.29	1	9210.29	36.50*
Fiber Content X Weight	15660.04	4	3915.01	15.51*
Error	37852.70	150	252.35	
Total	210035.06	159		

*Significant at .05.

TABLE X

ANALYSIS OF VARIANCE OF FABRIC FIBER CONTENT AND FABRIC
WEIGHT FOR TOTAL HEAT TRANSFER AT 90 SECONDS

Source	Sum of Squares	df	Mean Square	F
Fiber Content	104503.30	4	26125.83	289.47*
Weight	1051.45	1	1051.45	11.65*
Fiber Content X Weight	4790.79	4	1197.70	13.27*
Error	13538.12	150	90.25	
Total	123883.65	159		

*Significant at .05.

TABLE XI

ANALYSIS OF VARIANCE OF FABRIC FIBER CONTENT AND FABRIC
WEIGHT FOR TOTAL HEAT TRANSFER AT 60 SECONDS

Source	Sum of Squares	df	Mean Square	F
Fiber Content	43542.10	4	10885.53	430.96*
Weight	1122.93	1	1122.93	44.46*
Fiber Content X Weight	1881.12	4	470.28	18.62*
Error	3788.82	150	25.26	
Total	50334.96	159		

*Significant at .05.

TABLE XII

ANALYSIS OF VARIANCE OF FABRIC FIBER CONTENT AND FABRIC
WEIGHT FOR TOTAL HEAT TRANSFER AT 30 SECONDS

Source	Sum of Squares	df	Mean Square	F
Fiber Content	3577.95	4	894.49	16.09*
Weight	28.94	1	28.94	0.52
Fiber Content X Weight	1065.79	4	266.45	4.79*
Error	8338.29	150	55.59	
Total	13010.96	159		

*Significant at .05.

TABLE XIII

ANALYSIS OF VARIANCE OF FABRIC FIBER CONTENT AND FABRIC
WEIGHT FOR TOTAL BURN TIME

Source	Sum of Squares	df	Mean Square	F
Fiber Content	494074.84	4	123518.71	154.10*
Weight	267322.50	1	267322.50	333.50*
Fiber Content X Weight	392756.69	4	98189.17	122.50*
Error	120233.88	150	801.56	
Total	1274387.90	159		

*Significant at .05.

completed using graphs of means (Figures 3-11) and least squares means to determine differences between variables. Results of this analysis are further discussed under the following topics: Maximum heat transfer rate, Time to reach maximum heat transfer rate, Time to reach 0.40 joules/cm²/sec, Total heat transfer, Total heat transfer at 30-second time intervals, and Total burn time.

Maximum heat transfer rate. Least squares means analysis indicated there was no significant difference in maximum heat transfer rate for both the top and bottom weight acrylic, both the top and the bottom weight nylon 66, or between the top weight triacetate and the top weight rayon. All bottom weight fabrics differed significantly from each other. The maximum heat transfer rate for bottom weight triacetate was significantly different from all other test fabrics. With the exception of acrylic, mean values for maximum heat transfer rate were higher for bottom weight fabrics than for top weight fabrics of the same fiber content (Table V, Figure 3).

Time to reach maximum heat transfer rate. The time to reach maximum heat transfer rate was similar for both the top and the bottom weight wool and nylon 66, and between the bottom weight triacetate and bottom weight acrylic. Bottom weight rayon exhibited significantly longer time to reach maximum heat transfer rate than did

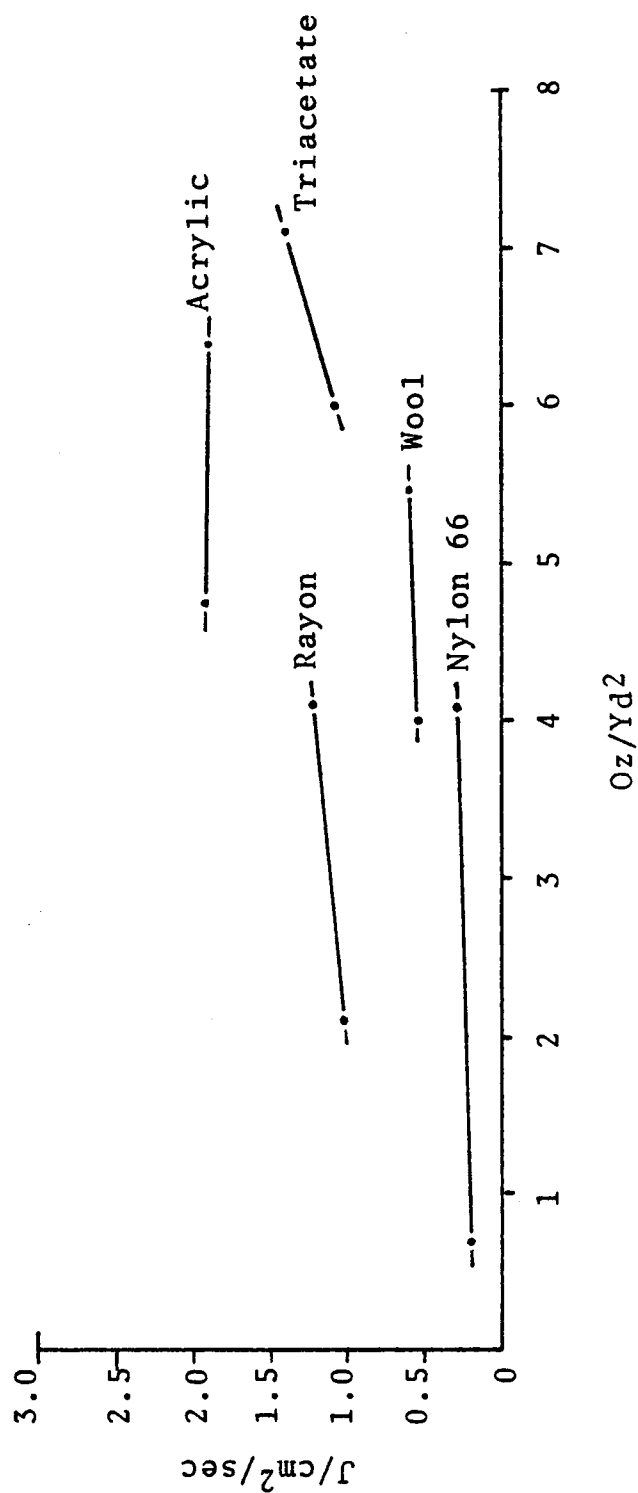


Figure 3. Graph of Means for Maximum Heat Transfer Rate.

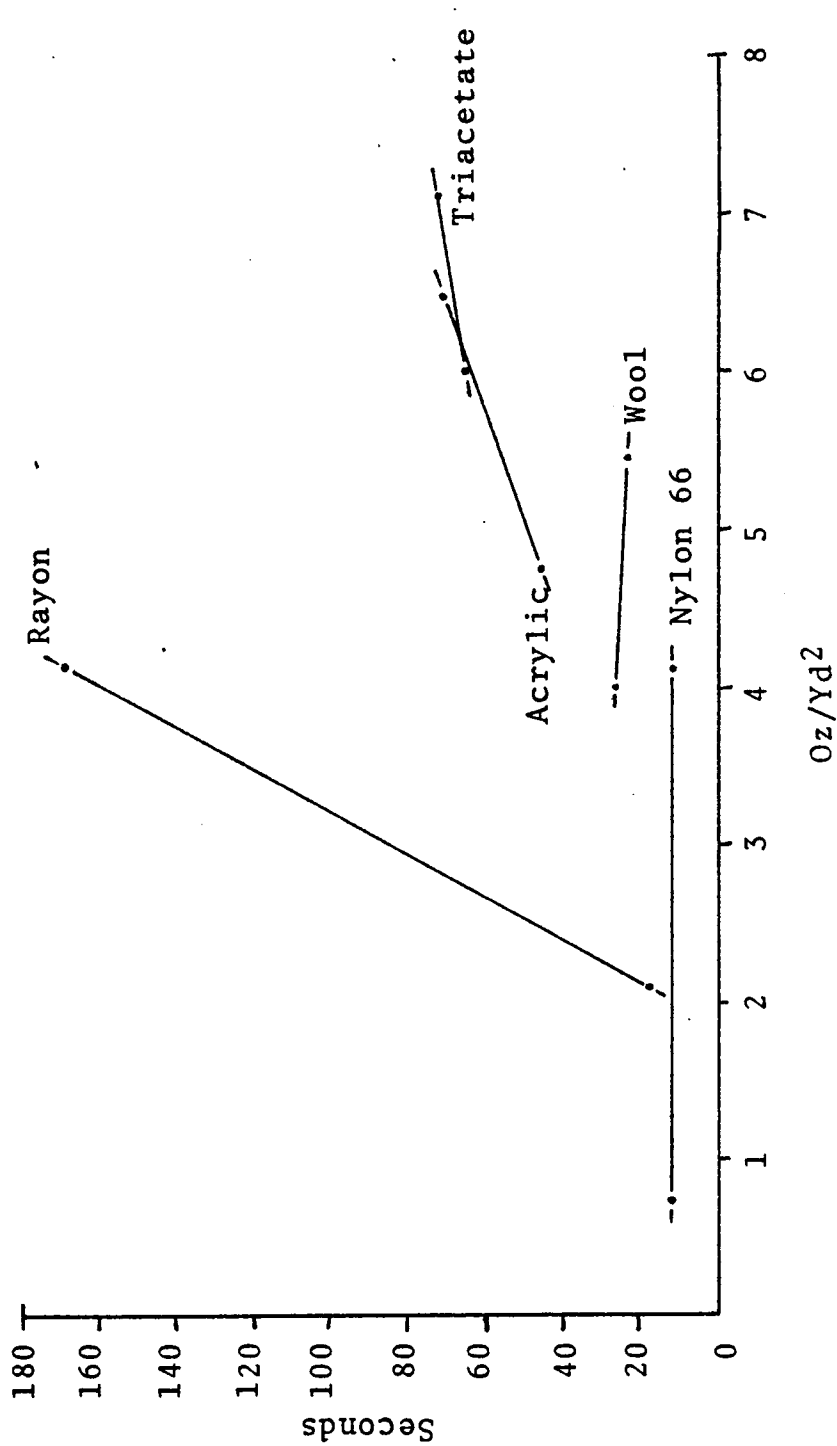


Figure 4. Graph of Means for Time to Reach Maximum Heat Transfer Rate.

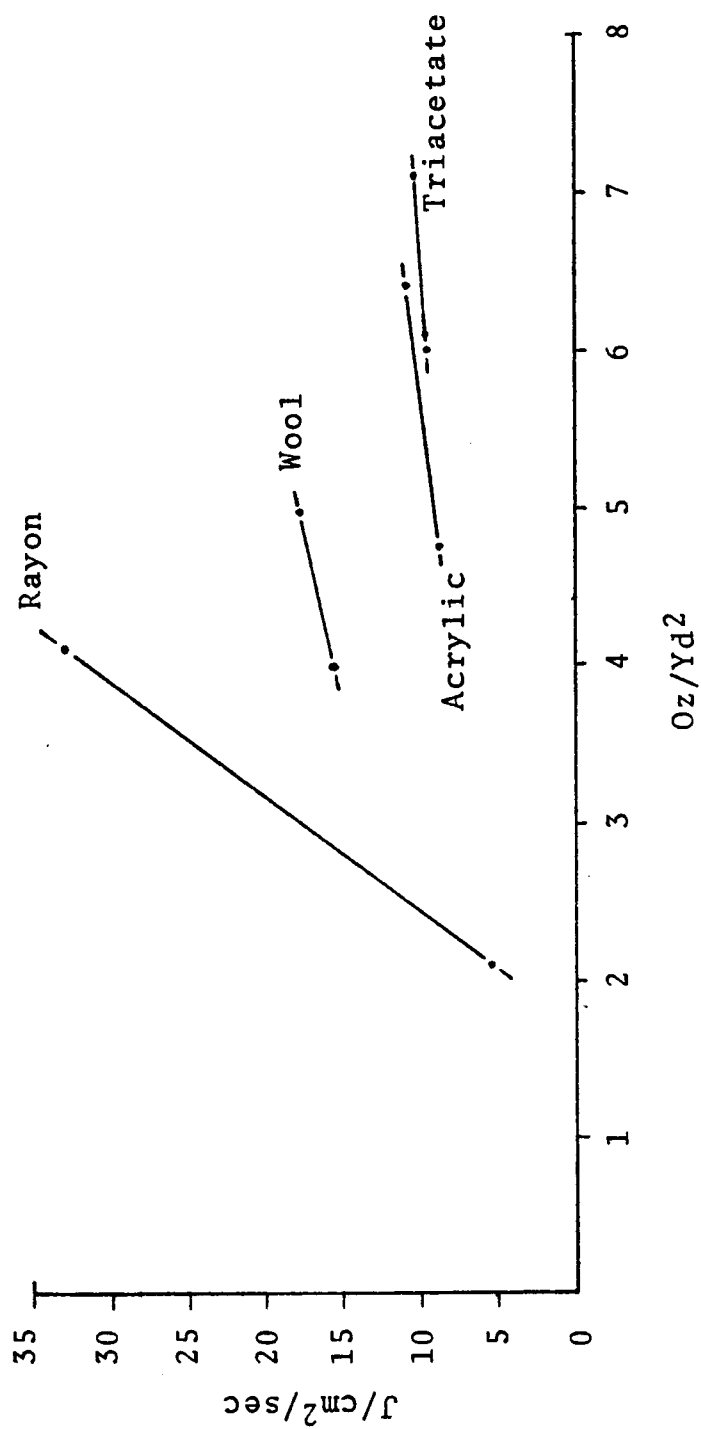


Figure 5. Graph of Means for Time to Reach the Heat Transfer Rate of 0.40 Joules/cm²/sec.

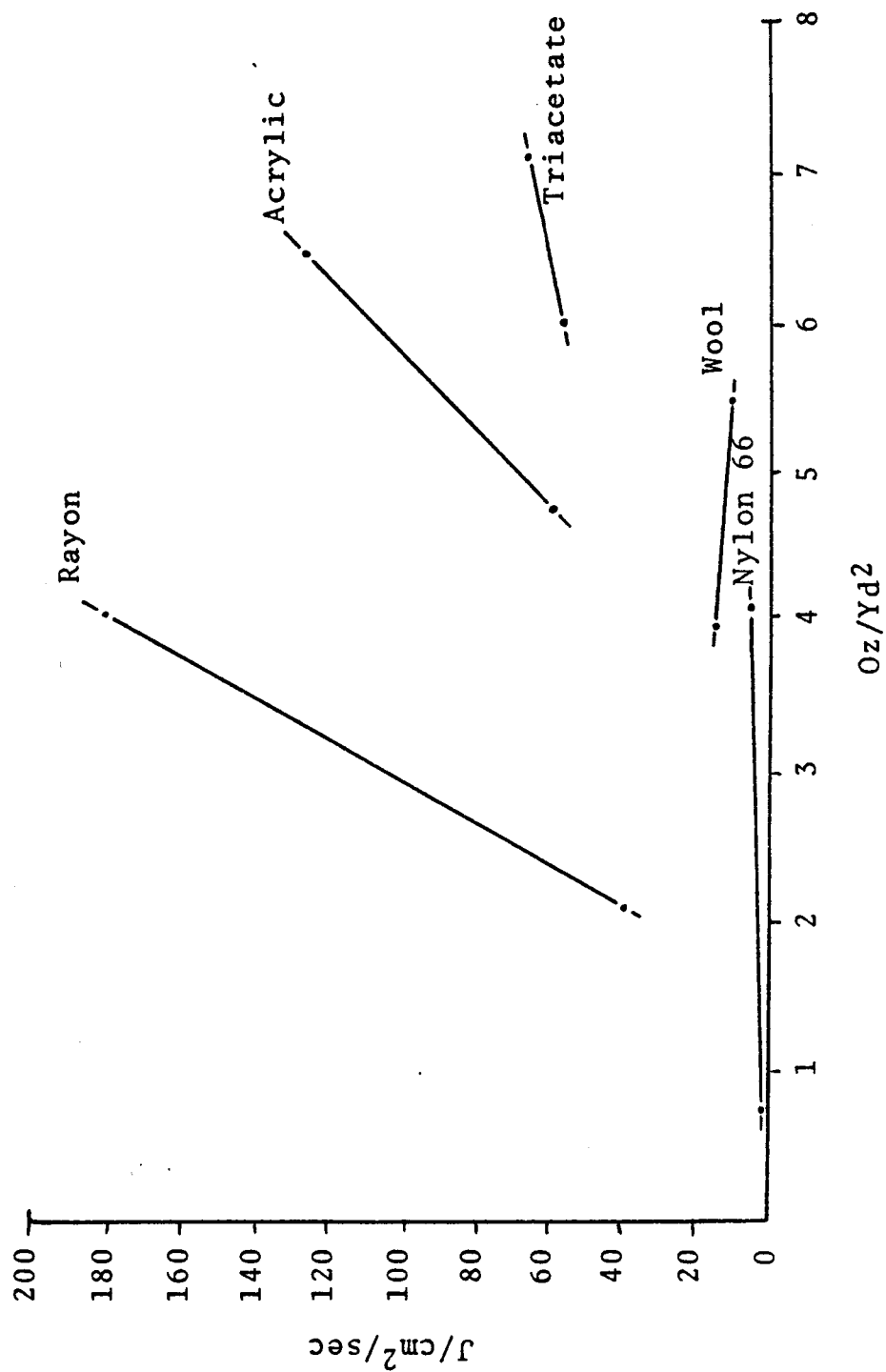


Figure 6. Graph of Means for Total Heat Transfer.

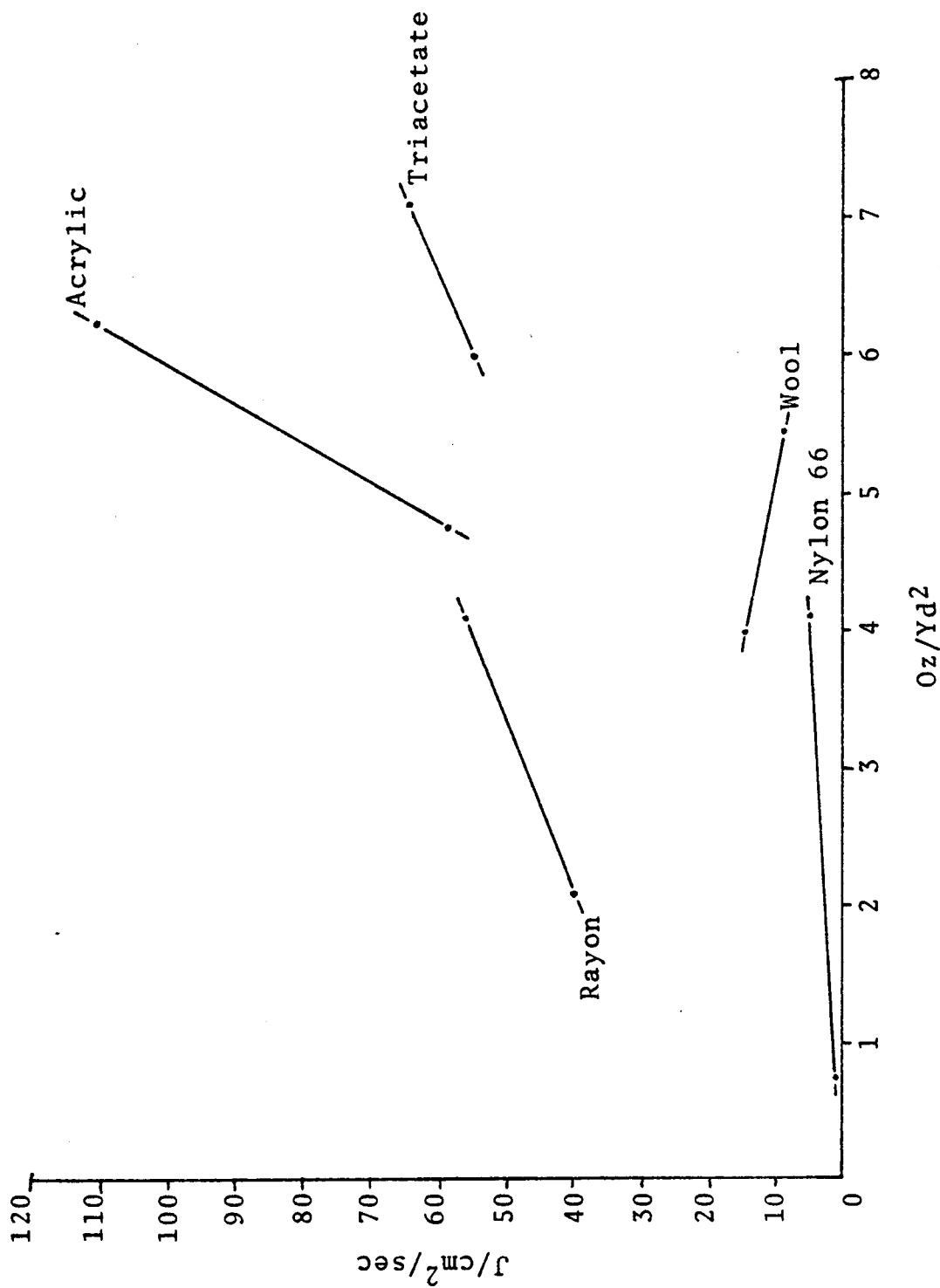


Figure 7. Graph of Means for Total Heat Transfer at 120 Seconds.
 Note: Top weights of acrylic, rayon, and both weights of wool and nylon 66 had total burn times less than 90 seconds.

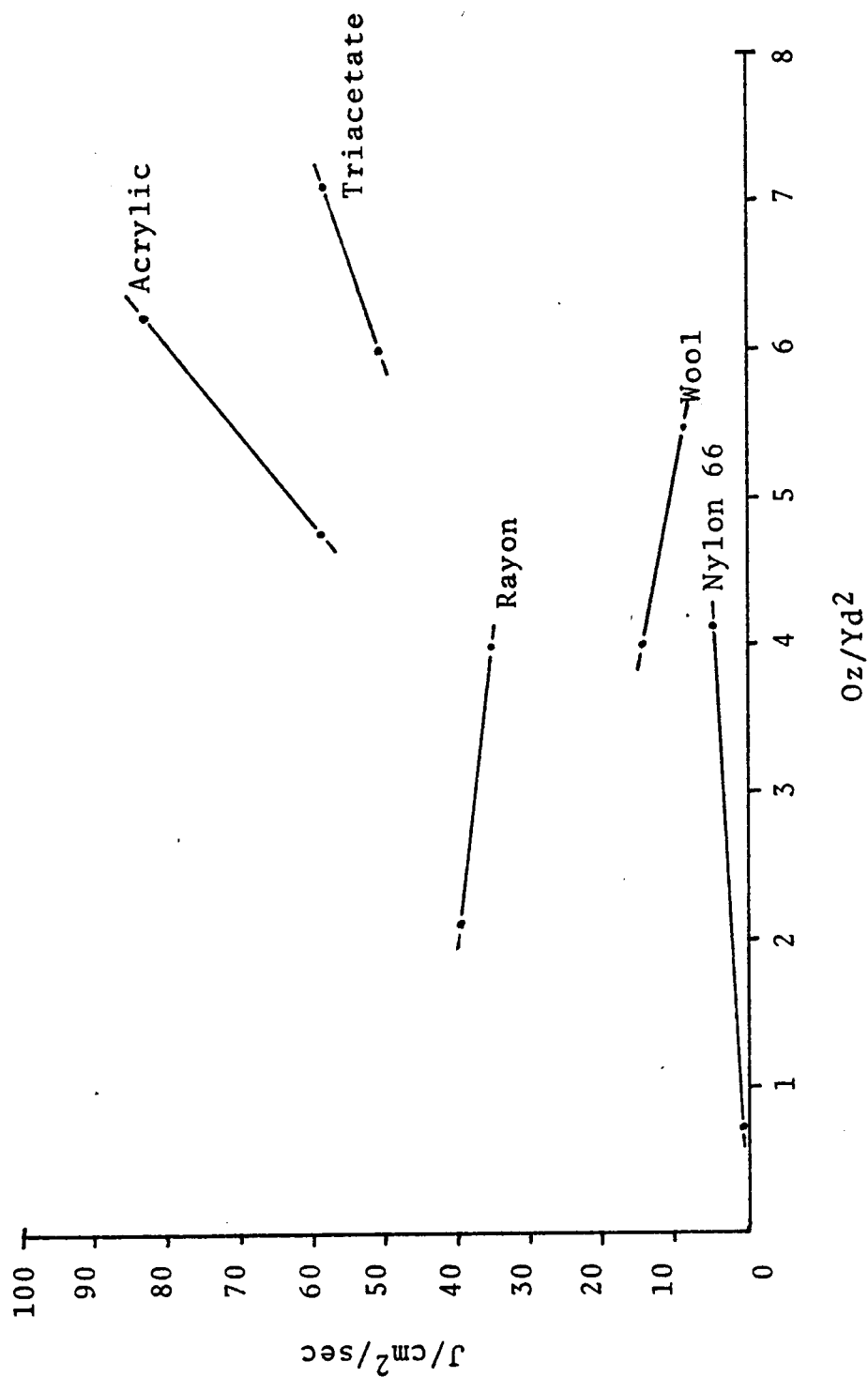


Figure 8. Graph of Means for Total Heat Transfer at 90 Seconds.
Note: Top weights of acrylic, rayon, and both weights of wool and nylon 66 had total burn times less than 90 seconds.

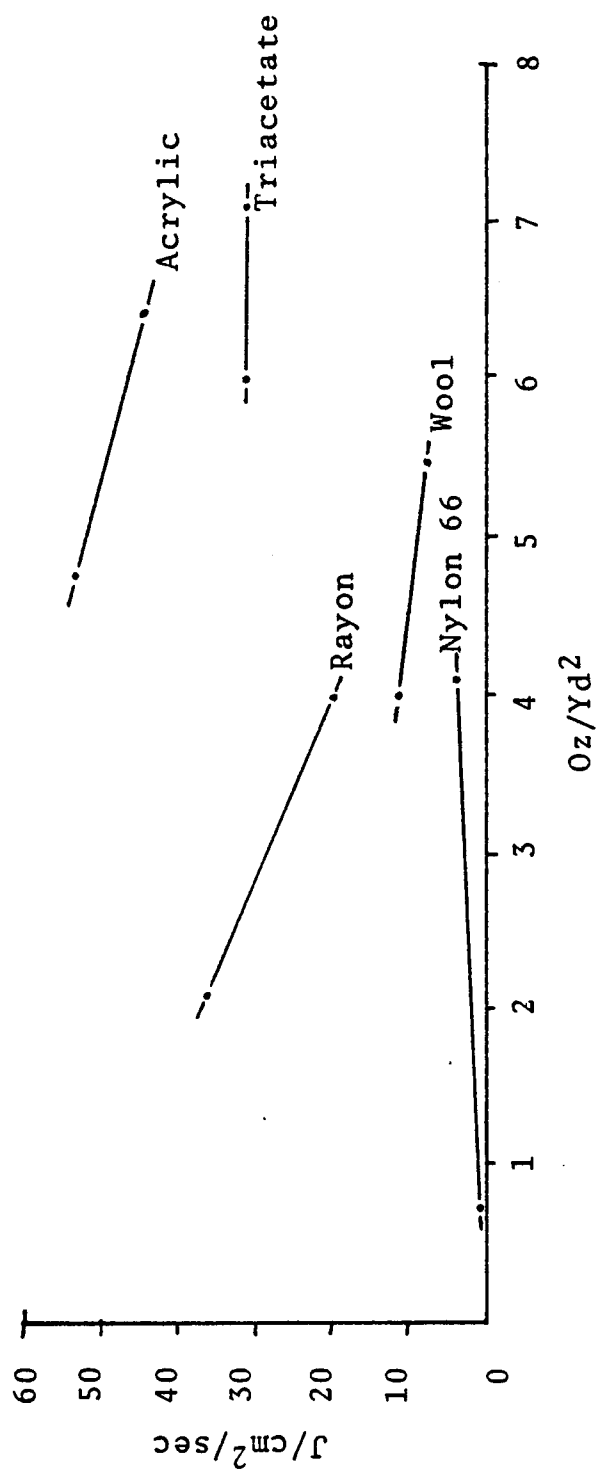


Figure 9. Graph of Means for Total Heat Transfer at 60 Seconds.

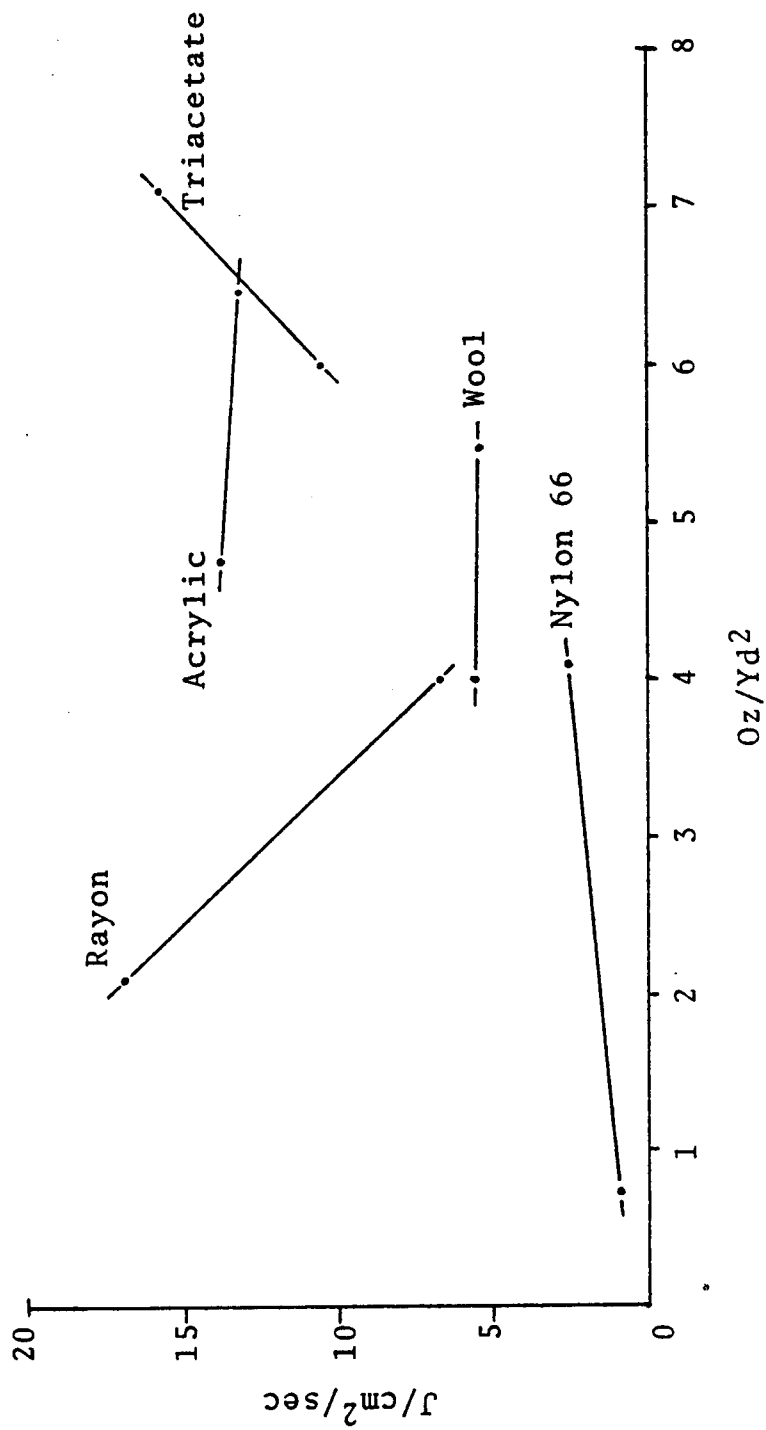


Figure 10. Graph of Means for Total Heat Transfer at 30 Seconds.

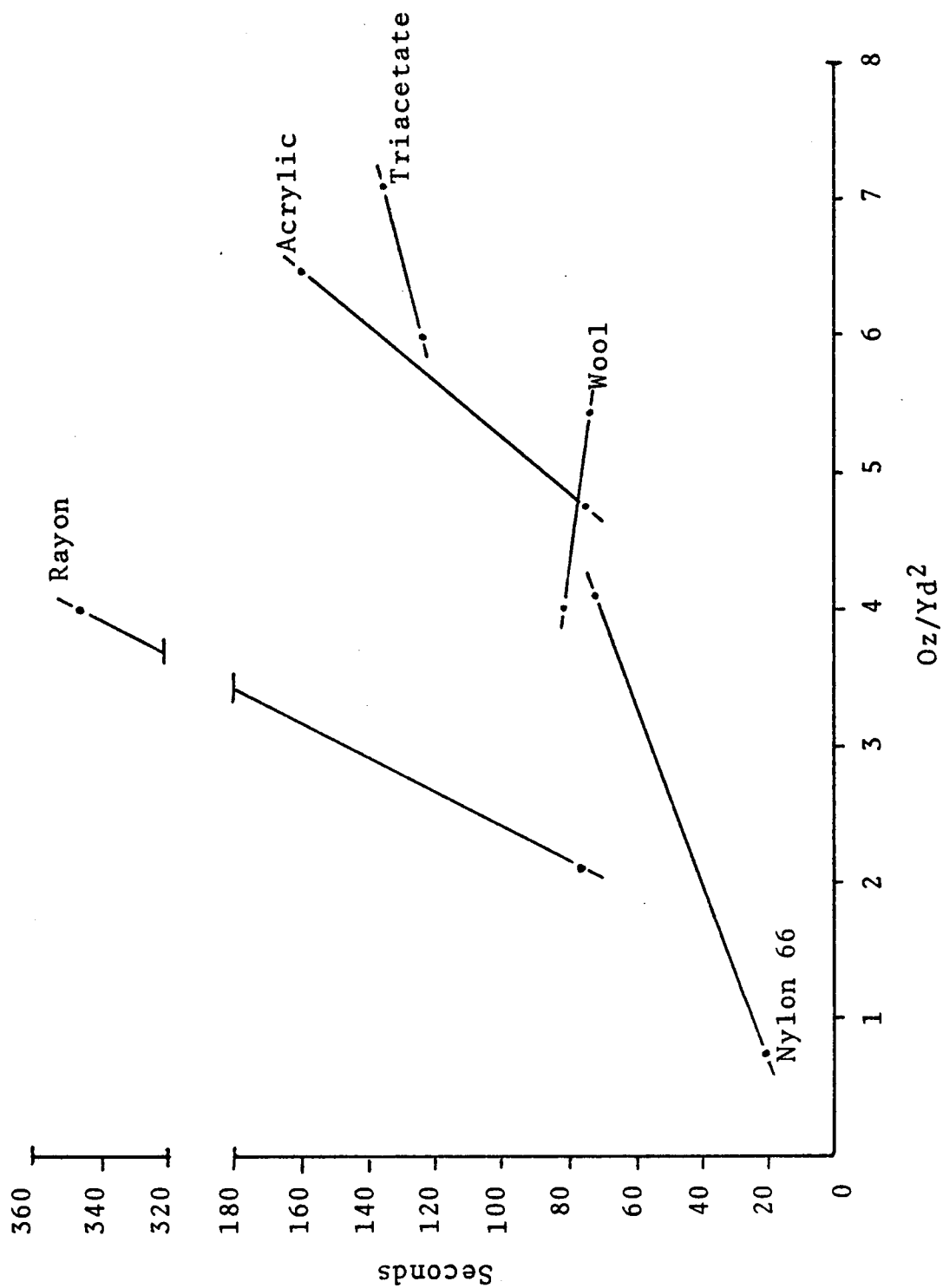


Figure 11. Graph of Means for Total Burn Time.

all other test fabrics. Time to reach maximum heat transfer rate was longer for the bottom weights of rayon, acrylic, and triacetate than for the top weights of the same fabric fiber content. However, for wool and nylon 66, the opposite was true (Table VI, Figure 4).

Time to reach the heat transfer rate of 0.40 joules/cm²/sec. The analysis of the time to reach 0.40 joules/cm²/sec did not include nylon 66, as the maximum heat transfer rate of nylon 66 did not reach 0.40 joules/cm²/sec. All other bottom weight fabrics showed longer mean time to reach 0.40 joules/cm²/sec than did top weight fabrics of the same fiber content. Bottom weight rayon exhibited significantly longer time to reach 0.40 joules/cm²/sec than did all other test fabrics. There was no significant difference in time to reach 0.40 joules/cm²/sec between both the top and bottom weights of wool, or between both the top and bottom weights of triacetate (Table VII, Figure 5).

Total heat transfer. The total heat transfer for both the top and bottom weights was similar for triacetate, nylon 66, and wool. Bottom weight rayon and bottom weight acrylic each had significantly greater total heat transfer than did all other test fabrics. With the exception of wool, all bottom weight fabrics had higher mean total heat values than did top weight fabrics of the same fiber content (Table VIII, Figure 6).

Total heat transfer at 30-second time intervals.

The total heat transfer at 30-second intervals after ignition varied between each test fabric at each test interval. Top weight nylon 66 was excluded from the analysis because the total burn time was less than 30 seconds. Both the top and bottom weight triacetate, and the bottom weights of acrylic and rayon had total burn times longer than 120 seconds and could be evaluated at both the 120- and 90-second test intervals. At 120 seconds after ignition, there was no significant difference in heat transfer between both the top and bottom weights of triacetate and wool. The bottom weight acrylic had significantly greater total heat transfer at 120 seconds than did all other test fabrics (Table IX, Figure 7).

At 90 seconds after ignition, there was a significant difference between the main effects of fabric fiber content and weight. The bottom weight acrylic and top weight triacetate each differed significantly from all other test fabrics (Table X, Figure 8).

All fabrics excluding top weight nylon 66 were included in the analysis at the 60-second test interval. The heat transfer 60 seconds after ignition was similar for the top weight and the bottom weight triacetate. Both the top and the bottom weights of acrylic, rayon, and wool each differed significantly from all other test fabrics. All top weight fabrics differed significantly from each

other, and all bottom weight fabrics differed significantly from each other. All top weight fabrics had higher mean heat transfer values than did bottom weight fabrics of the same fiber content (Table XI, Figure 9).

At 30 seconds after ignition, the heat transfer for the main effect of fabric fiber content was similar for nylon 66 and wool, and for triacetate, acrylic, and rayon. There was no significant difference between weight for each of the fabric fiber contents. When the interaction of fabric fiber content and fabric weight was examined, heat transfer values for the top weight and the bottom weight of all fabrics excluding rayon were found to be similar. Heat transfer values were similar for the bottom weights of triacetate and acrylic, and for the bottom weights of wool and nylon 66 (Table XII, Figure 10).

The amount of heat transferred over time from the burning specimen to the system was best fit to a non-linear function. To examine the relationship between total heat transfer and time, the heat transfer values obtained at 30-second intervals were fit to an exponential growth curve of the form $(HET)_T = b_0(1 - e^{-b_1 t})$ (Table XIV). In this equation, b_0 represents the amount of heat transfer to the MAFT, and b_1 represents the coefficient of time.

When a fabric sample burns, heat transfer increases with increasing burn time. Eventually the burning sample will transfer the maximum amount of heat it can transfer.

TABLE XIV
RELATIONSHIP BETWEEN TOTAL HEAT TRANSFER AND TIME

Fabric ^a	$(\text{HET})^c_T = b_0(1 - e^{-b_1 t})$		R - Square
	b_0^d	b_1^e	
Triacetate (tw)	56.00	0.0161	0.95
Triacetate (bw)	65.00	0.0157	0.90
Nylon 66 (tw) ^b	-	-	-
Nylon 66 (bw)	5.26	0.0215	0.78
Acrylic (tw)	60.00	0.0225	0.93
Acrylic (bw)	125.00	0.0106	0.85
Rayon (tw)	40.00	0.0278	0.97
Rayon (bw)	180.00	0.0026	0.93
Wool (tw)	17.78	0.0158	0.89
Wool (bw)	8.86	0.0328	0.94

^atw = top weight; bw = bottom weight.

^bNylon 66: total burn time = 21.50 seconds. Not included in the analysis.

^c(HET)_T = total heat transfer in joules/cm².

^db₀ = total amount of heat sensed by the MAFT.

^eb₁ = coefficient of time.

The level at which the sample reaches the maximum amount of heat transfer is called the asymptote. At this level, no greater heat transfer will occur, even with an increase in time, because the sample has either burned completely or ceased to burn.

The coefficient of time, b_1 , indicates how rapidly the sample burns. Lower values of b_1 indicate a slower rate of heat transfer to the system. Higher values of b_1 indicate a faster rate of heat transfer; maximum temperatures are reached in a short period of time. Figures 12-20 illustrate the relationship between total heat transfer and time.

Total burn time. The total burn time for the bottom weight acrylic and the bottom weight rayon was significantly longer than that for all other test fabrics. Within the bottom weight fabrics, the total burn time was similar for nylon 66 and wool. With the exception of wool, all bottom weight fabrics had higher mean total burn time values than did top weight fabrics of the same fiber content. Within the top weight fabrics, the total burn time was similar for acrylic, rayon, and wool (Table XIII, page 38; Figure 11).

Intercorrelations among Weight, Heat, and Time

Intercorrelations among weight, heat, and time indicated a strong correlation between total burn time and total

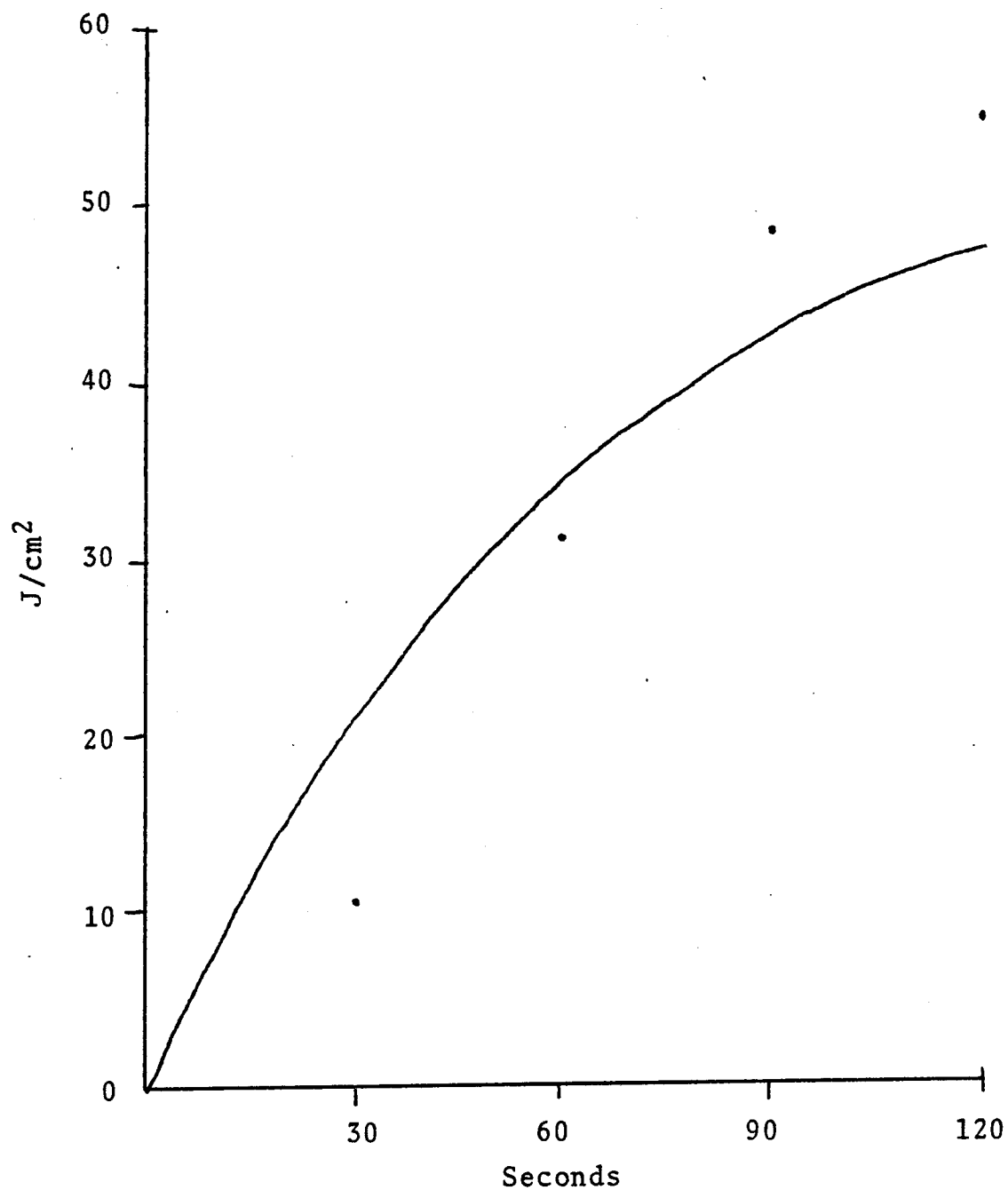


Figure 12. Relationship between Total Heat Transfer and Time for Top Weight Triacetate.

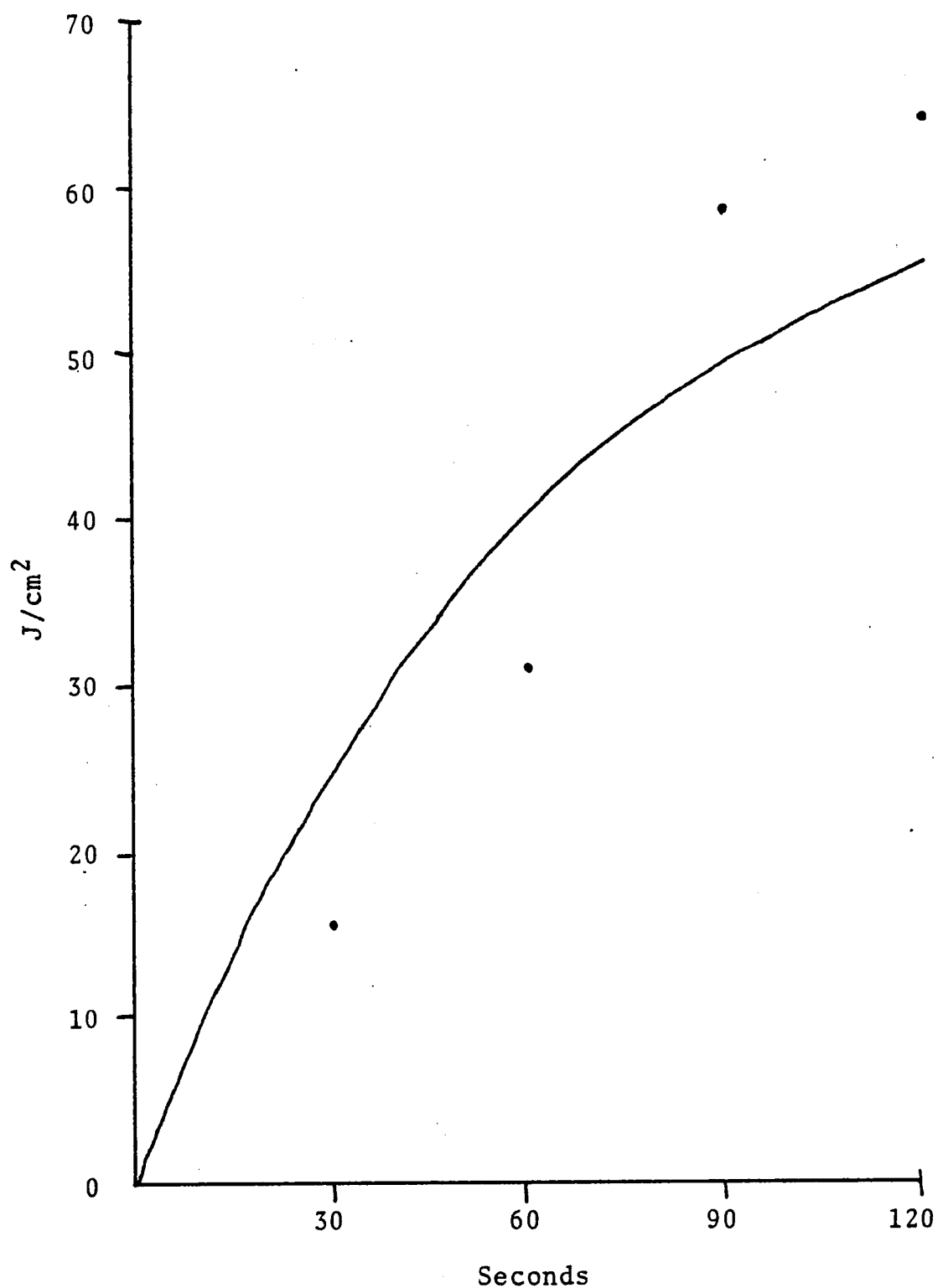


Figure 13. Relationship between Total Heat Transfer and Time for Bottom Weight Triacetate.

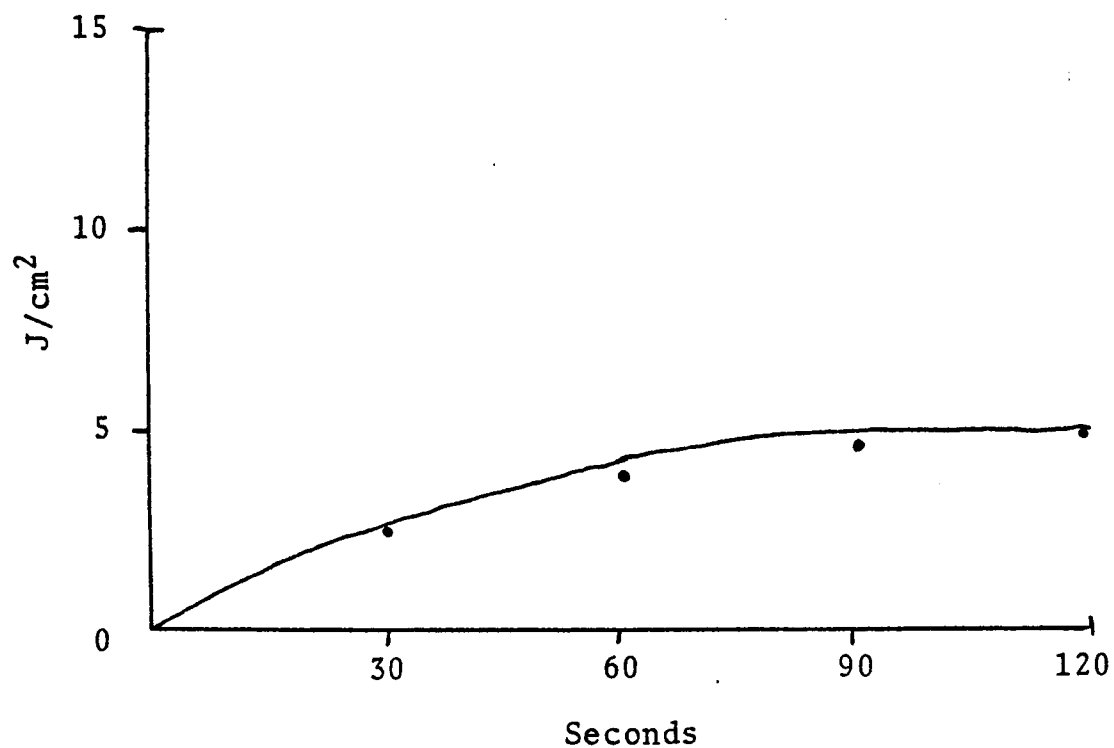


Figure 14. Relationship between Total Heat Transfer and Time for Bottom Weight Nylon 66.

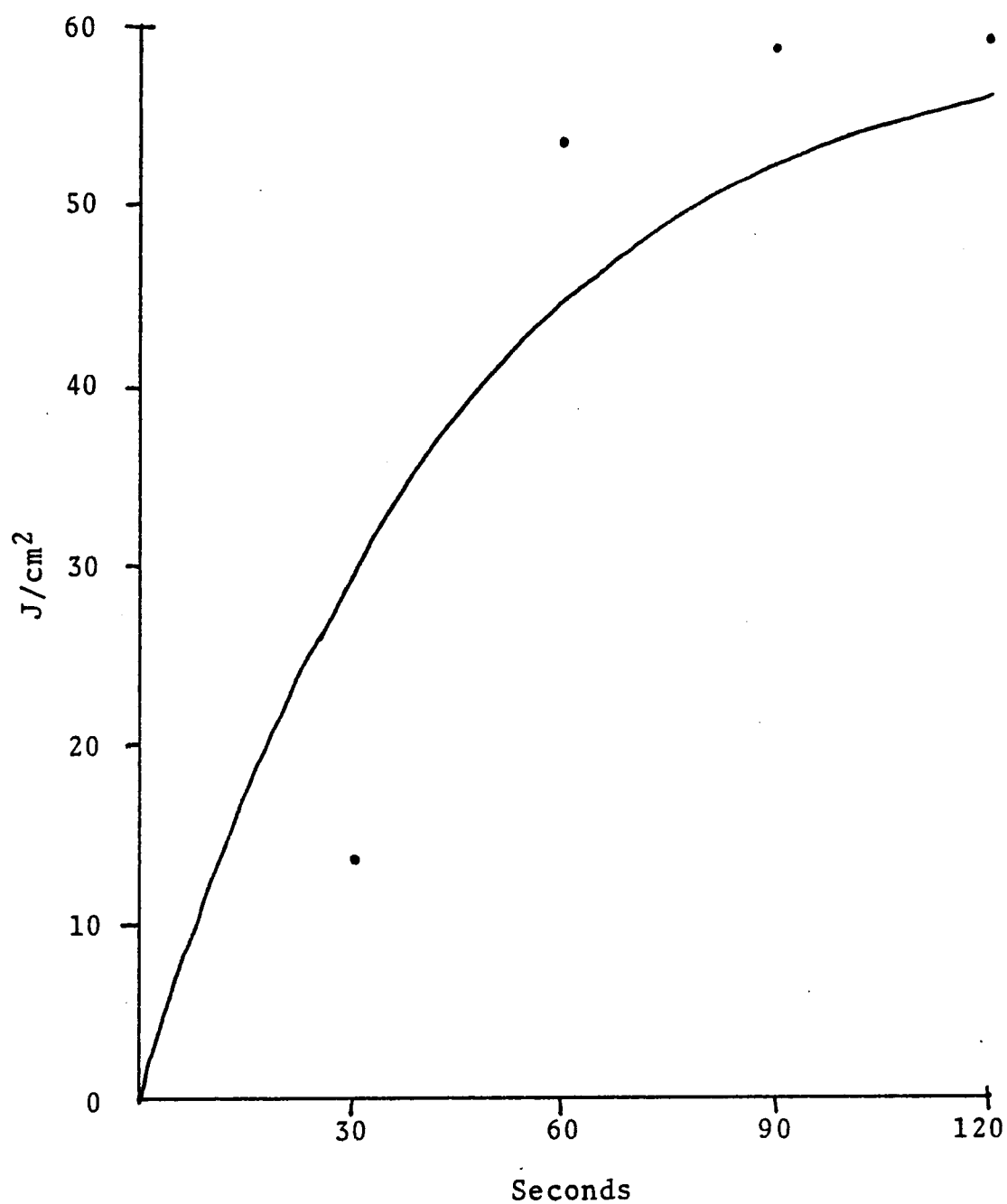


Figure 15. Relationship between Total Heat Transfer and Time for Top Weight Acrylic.

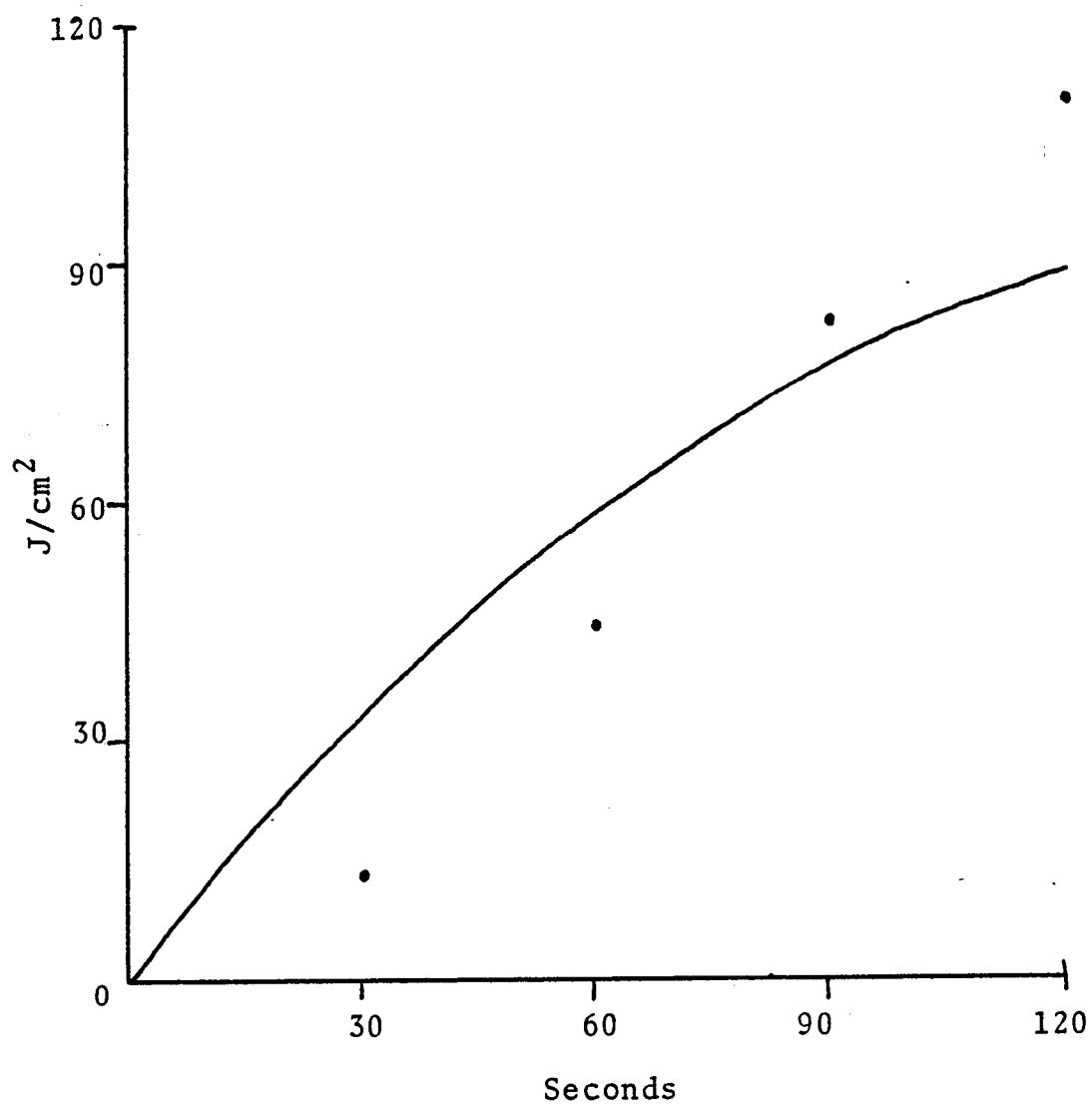


Figure 16. Relationship between Total Heat Transfer and Time for Bottom Weight Acrylic.

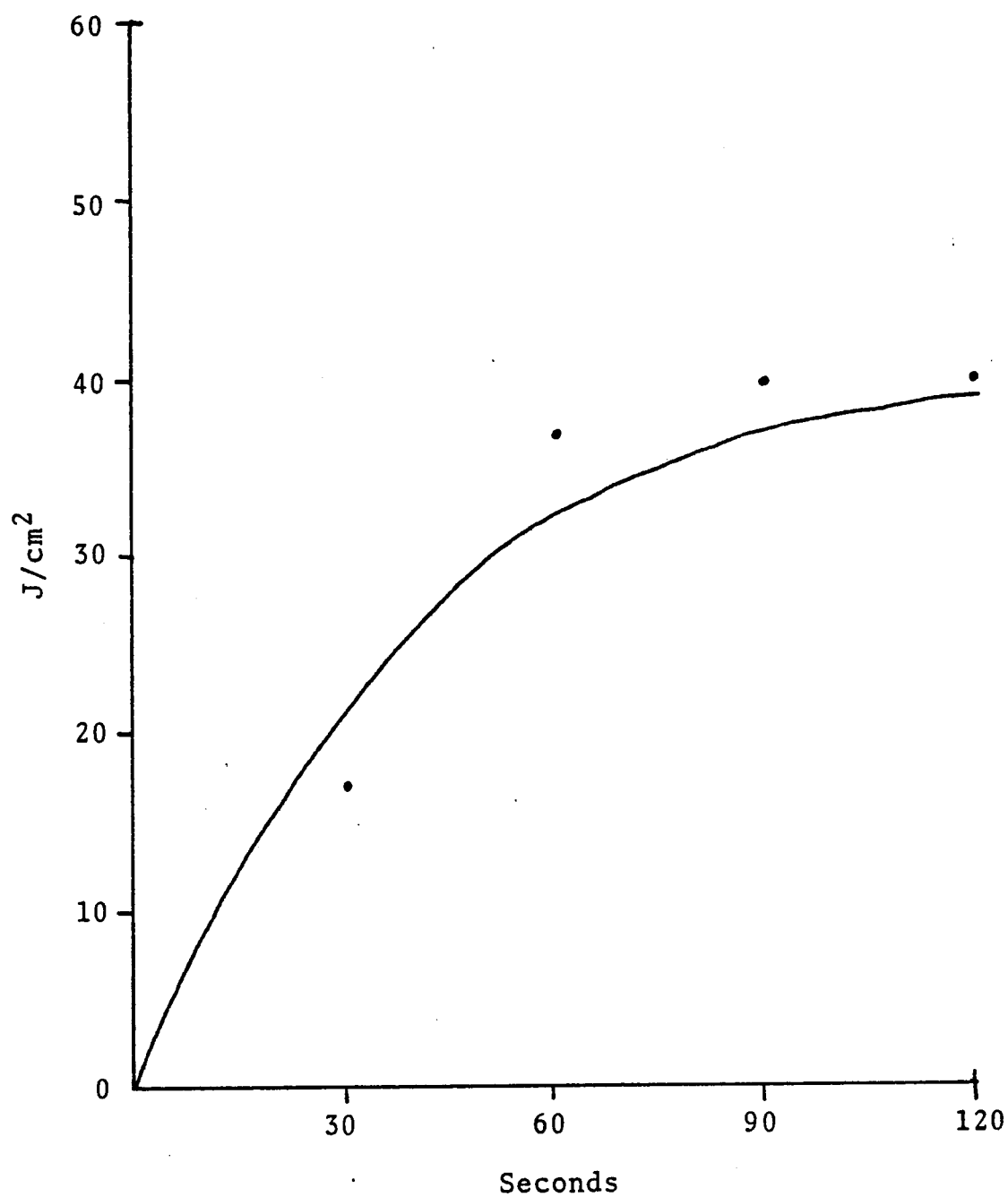


Figure 17. Relationship between Total Heat Transfer and Time for Top Weight Rayon.

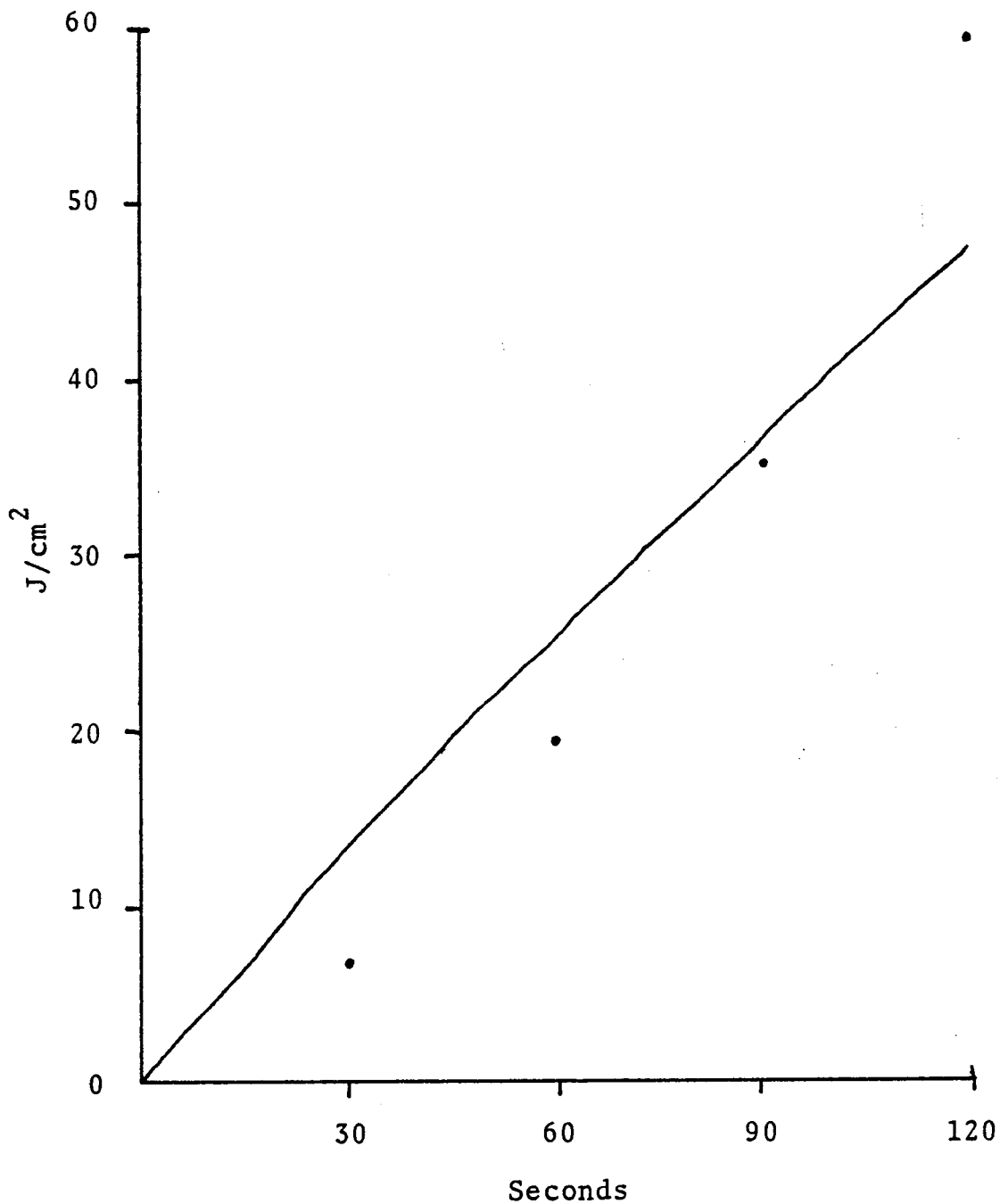


Figure 18. Relationship between Total Heat Transfer and Time for Bottom Weight Rayon.

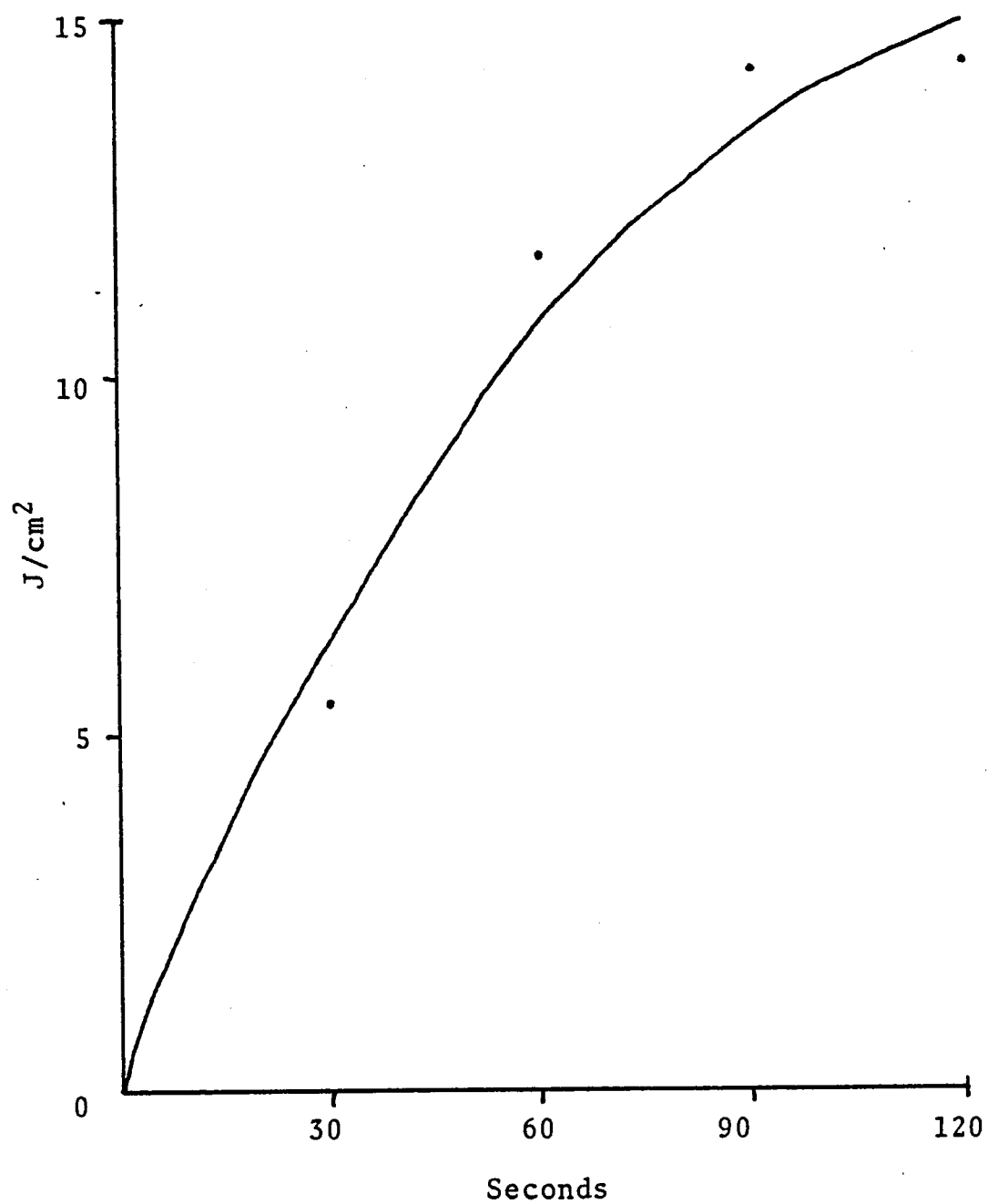


Figure 19. Relationship between Total Heat Transfer and Time for Top Weight Wool.

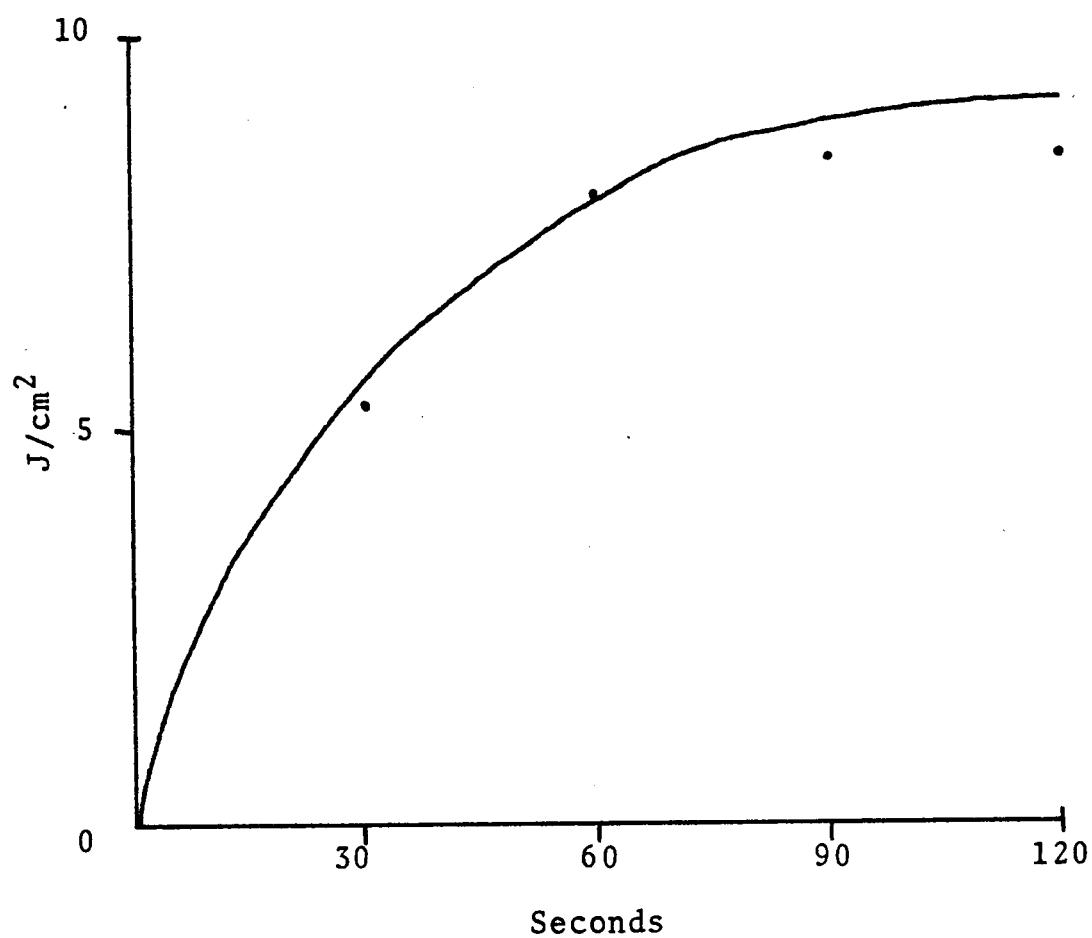


Figure 20. Relationship between Total Heat Transfer and Time for Bottom Weight Wool.

heat transfer, significant at the .001 level. Fabric weight was indirectly related to time to reach $0.40 \text{ joules/cm}^2/\text{sec}$, which was indicated by all test fabrics. The longer the fabric burned, the more heat transfer occurred, although the time to reach the maximum heat transfer rate became longer (Table XV).

Summary of MAFT Test

In summary, both the top and bottom weights of acrylic and triacetate, and the top weight rayon fabrics exhibited higher values for dependent variables than did both weights of nylon 66, bottom weight rayon, and both weights of wool. Both top and bottom weights of acrylic, triacetate, and rayon produced more total heat, and had higher heat values at each 30-second test interval than did both weights of nylon 66 and wool. Both weights of acrylic, triacetate, and rayon burned longer but reached a maximum heat transfer rate after a longer time interval than did nylon 66 and wool. However, both weights of acrylic, triacetate, and the top weight rayon reached $0.40 \text{ joules/cm}^2/\text{sec}$ much faster than did bottom weight rayon and both top and bottom weights of wool.

The top weight nylon 66 fabric did not ignite. It shrank away from the ignition source, melting only while the flame was in contact with the fabric.

The bottom weight fabrics, with the exception of wool, produced higher values for total heat transfer,

TABLE XV
INTERCORRELATIONS AMONG WEIGHT, HEAT, AND TIME

Variables	1	2	3	4	5	6
1. Weight (oz/ yd ²)	-	.315*	.320*	.516*	-.549*	.294*
2. Total heat transfer		-	.855*	.689*	-.333*	.889*
3. Time to reach maximum heat transfer rate			-	.485*	-.228*	.886*
4. Maximum heat transfer rate				-	-.632*	.410*
5. Time to reach 0.40 J/cm ²					-	-.235*
6. Total burn time						-

*Significant at .001.

maximum heat transfer rate, and burned longer than did the top weight fabrics. As fabric weight increased, time to reach 0.40 joules/cm²/sec generally decreased. However, the bottom weight fabrics required a longer time than did top weight fabrics to reach maximum heat transfer rate.

Potential Burn Hazard

The safest of the fabrics tested appeared to be the bottom weight rayon. Even though this fabric had a high rate of heat transfer, the time to reach the maximum heat transfer rate was nearly 3 minutes. Injurious heat transfer rates were not reached until 30 seconds after ignition, which would allow the wearer time to remove the burning garment before severe burn injury could occur. This finding parallels the results obtained by Thompson for 100% cotton (48).

Both the top and bottom weights of nylon 66 would appear to be less hazardous than the remainder of the test fabrics due to the fact that the maximum heat transfer rate, total heat transfer, and total burn time are very low. The non-ignition property of the top weight nylon 66 is desirable in wearing apparel, but the fact that the fabric melts and shrinks away from the flame may be more hazardous to the victim if the melt were to contact the skin. Some of the most severe burn injuries have resulted from heat transfer through molten polymer to the skin (5).

The maximum heat transfer for both top and bottom weight wool was low, and only one-third of the total heat transfer occurred during the first 30 seconds of burning. This is consistent with the known self-extinguishing property of wool. Consequently, the time to reach injurious heat transfer rates could possibly allow the wearer to react before severe burn injury could occur.

Both weights of triacetate, acrylic, and especially the top weight rayon would be most hazardous in a clothing fire. Both weights of triacetate and acrylic produced a high maximum heat transfer rate in a short period of time. Heat transfer rates injurious to skin tissue were reached within 12 seconds, not allowing the wearer much time to react. The top weight rayon would be even more dangerous; injurious heat transfer rates were reached within 10 seconds.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

The first objective of the research was to determine the effect of fabric fiber content and fabric weight (independent variables) on the following variables: maximum heat transfer rate, time to reach maximum heat transfer rate, total heat transfer, time to reach the heat transfer rate of 0.40 joules/cm²/sec, heat transfer at 30-second time intervals, and total burn time (dependent variables). The second objective was to determine the classification of the fabric types according to ignition time and heat transfer rate as specified in the fabric classification system in the draft proposed standard for general wearing apparel.

Ten fabrics were evaluated on the Mushroom Apparel Flammability Tester (MAFT) according to procedures specified in the draft proposed standard. The sample included top and bottom weight fabrics having each of the following fiber contents: acrylic, nylon 66, triacetate, rayon, and wool. The fabrics were tested on a pass/fail basis in terms of end use as shirts/blouses and pants/slacks.

A 5 X 2 analysis of variance was used to evaluate the effects of the two independent variables on each of

the six dependent variables. All fabrics passed the MAFT test as defined in the standard. The 10 fabrics did not fall into the same classes as described in the draft proposed standard. Thus, end use would be limited according to the classification the fabric received. None of the 10 test fabrics received a Class 4 rating which would prohibit its use in wearing apparel.

The effect of fabric weight was observed as an increase in the values for maximum heat transfer rate, time to reach maximum heat transfer rate, total heat transfer, and total burn time. As fabric weight increased, the time to reach the heat transfer rate of $0.40 \text{ joules/cm}^2/\text{sec}$ decreased. When heat transfer was measured at 30-second time intervals, the bottom weight fabrics produced more heat at 120- and 90-second intervals than did the top weight fabrics. At the 60-second interval, all top weight fabrics produced a higher heat transfer than did bottom weight fabrics. Heat transfer at the 30-second interval varied within each fabric fiber content; fabric weight had no consistent effect. Top weight nylon 66 was excluded from the analysis at the 30-second time interval because it did not ignite. The total burn time for top weight nylon 66 was a measure of the time the fabric exhibited heat transfer, not time of actual burning.

Wool proved to be the exception within the weight categories. Top weight wool produced higher values for

all dependent variables with the exception of the maximum heat transfer rate, which is in agreement with previous research (1, 20, 25).

II. HYPOTHESIS FINDINGS

Results from the data collected were analyzed according to the null hypotheses.

H₀₁ There will be no difference in the maximum heat transfer rate, time to reach maximum heat transfer rate, time to reach the heat transfer rate of 0.40 joules/cm²/sec, total heat transfer, heat transfer at 30-second time intervals, and total burn time of the five selected fabric fiber contents.

The maximum heat transfer rate differed significantly between each fiber fabric type for all bottom weight fabrics. Bottom weight triacetate differed significantly from all other test fabrics. For time to reach maximum heat transfer rate, bottom weight rayon and top weight acrylic each differed significantly from all other test fabrics. Top weight nylon 66 and bottom weight rayon each differed significantly from all other test fabrics for time to reach the heat transfer rate of 0.40 joules/cm²/sec. Total heat transfer values of bottom weight rayon and bottom weight acrylic were significantly higher than all other test fabrics. Heat transfer at 30-second

intervals for bottom weight acrylic was significantly higher than all other test fabrics for all test intervals with the exception of the 30-second time interval.

Therefore, the null hypothesis was rejected and the alternative accepted.

H₀₂ There will be no difference in the effects of top weight and bottom weight fabrics of the same fiber content on the maximum heat transfer rate, time to reach maximum heat transfer rate, time to reach the heat transfer rate of 0.40 joules/cm²/sec, total heat transfer, heat transfer at 30-second intervals, and total burn time.

There was a significant difference in maximum heat transfer rate between the top and bottom weights of triacetate and rayon. Acrylic and rayon showed a significant difference between top and bottom weight for time to reach maximum heat transfer rate. There was a significant difference in time to reach the heat transfer rate of 0.40 joules/cm²/sec between the top and bottom weight rayon, and except for the 90-second test interval, rayon consistently showed a significant difference between top and bottom weight for the heat transfer at 30-second intervals. Rayon, acrylic, and nylon 66 each exhibited a significant difference between weights for total burn time.

Thus, the null hypothesis was rejected and the alternative hypothesis accepted.

H₀₃ There will be no difference in the classification of the two weights of each of the five fabric types according to ignition time and heat transfer rates as specified in the MAFT classification system.

Classification of the 10 test fabrics ranged from Class 1 to Class 3. Top weight and bottom weight rayon each fell into different fabric classes.

Therefore, the null hypothesis was rejected and the alternative hypothesis accepted.

III. CONCLUSIONS

Effect of Fabric Fiber Content and Fabric Weight

In relation to potential burn hazard, the safest of the fabrics tested appear to be both top and bottom weight nylon 66 and bottom weight rayon. The non-ignition property of the top weight nylon 66, along with the low maximum heat transfer rate, total heat transfer, and total burn time of the bottom weight nylon 66 make this fiber desirable for use in the more hazardous garment configurations. Even though bottom weight rayon produced a high maximum heat transfer rate, the time to reach that rate would allow the victim to remove the burning garment before serious injury could occur. The low heat transfer rate of both top and bottom weight wool would make it also a relatively safe fabric for use in wearing apparel.

Both weights of triacetate and acrylic, and the top weight rayon would be most hazardous in a clothing fire. The high heat transfer rate produced in a short period of time would allow the wearer too little time to react to the fire situation.

Flammability Testing

All fabrics will burn if exposed to an ignition source for a sufficient length of time (17). Since it does not appear to be economically feasible to make all fabrics flame retardant, perhaps it would be more practical to categorize fabrics according to potential burn injury to the wearer, as recommended in the proposed standard for general wearing apparel (40). Findings based on the 10 fabrics in this study indicate that ignition time and heat transfer as measured by the MAFT are an effective means to distinguish less hazardous fabrics from more hazardous fabrics. Classification of fabrics according to hazard, and coordination of this information with the proposed garment classification system, might possibly be a more realistic method of providing the consumer with more adequate protection from flammable fabrics. Compilation of this information into a hazard index for consumer use would allow the consumer to choose his own degree of protection, without the expense and restrictions imposed in a standard.

Because each fire situation is unique, more research must be done on many more and different combinations of fabric fiber type and weight. Fabrics of various textures and color treatments, as well as layered fabric assemblies constitute areas for further research.

Results of the Nebraska burn study (31) indicated that pants, slacks, shirts, and blouses were most frequently the first fabric item to ignite. This knowledge, coordinated with ignition time and heat transfer information and the garment classification system of the draft proposed standard, could provide to the consumer more protection from flammable fabrics than is currently provided.

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