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EXPLORATORY STUDIES OF HEAT TRANSFER AND BURNING BEHAVIOR OF FILMS AND FABRICS

by

A. F. Robertson

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U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Exploratory Studies of Heat Transfer and Burning Behavior of Films and Fabrics

by

A. F. Robertson

Abstract

A report of preliminary-exploratory studies is presented of the heat transfer dosage likely to be received by a substrate when exposed to burning plastics and textiles. Two spacing positions of specimen and substrate were investigated 5/16 in. and 1 in. Four different positions with respect to horizontal orientation of the specimen were explored and seven different specimen materials were tested. The results suggest that single drips from a polyethylene film will provide sufficient thermal dosage to cause third degree burns. There is evidence that for the closer spacing the major portion of the thermal dosage takes place through gas and vapor convection and condensation. At the larger spacing radiation plays an important heat transfer role and may account for as much as 40 to 50% of the thermal dosage. It is shown that light fabrics, may when burned, result in disproportionally large (on a weight basis) thermal dosage.

Introduction

In reference 1 the writer argued that since the meagre loss information available shows that most burn injuries involve people who are wearing traditional clothing; there is little that can be done, short of a drastic change in clothing flammability, with confidence that it would reduce the burn injury record. This contention was made in the light of seriously inadequate statistical information on the nature of clothing or fabrics associated with burn injuries. It was suggested, however, that there was one exception to this generalization. This was based on the possibility that through laboratory experiment it could be shown that certain textile or film materials, because of their burning behavior, resulted in significantly more severe heat transfer to the substrate than other materials. It seemed likely that even relatively simple laboratory experiments might be used to shed light on the contention of the medical service that thermoplastic materials when burning caused more severe and damaging burns than cellulosic or non thermoplastic materials.

The experiments described in this paper were performed with the objective of determining whether laboratory measurements could be used to show differences in thermal exposure of substrate when such fabrics were burned. The results have not been conclusive although several interesting features associated with the burn injury hazard have been demonstrated. The results are reported for what they may be worth in guiding direction of future work in this important field.

Prior Work

The work of Webster, Wraight, and Thomas reference 2 had shown that heat transfer from burning fabrics, of even the lightest weight commonly used, would in many cases be sufficient to cause serious burn injuries. The workers also showed that the measured heat transfer was for many fabrics simply a function of specimen weight per unit area.

Dr. Sandholzer with equipment similar to that described by the British performed tests on a variety of fabrics burned in the vertical position. In these measurements the spacing of fabric from the substrate was varied from about 1/4 to 2 inches. Some results of these studies are shown in figure 1 where calorimeter temperature rise is plotted against fabric spacing from the substrate. It will be noted that for the specimens studied, 30 in. length by 4 in. width, the critical spacing was about 3/4 in. At this spacing the heat transfer reaches a maximum value. Closer spacing results in choked combustion between fabric and substrate with reduced heat transfer. Greater spacing involved reduced heat transfer because of reduced convective transfer and ultimate reduction of radiant transfer because of fixed specimen width.

Figure 2 suggests that the maximum heat transfer rate under critical spacing condition for the particular specimen size used is not likely to exceed 50 percent of the expected heat release on combustion of the fabric. This seems reasonable if one considers half the released energy is disipated to surroundings while the other half is available for heating the substrate.

Alverez and Blackshere reference 3 have conducted similar studies but with much larger specimen size. Their specimens were again oriented in a vertical plane. The specimen was 1 ft wide by 6 ft in length. They also varied fabric spacing from substrate and reported a critical spacing on the order of about 1 1/2 in.

This then is the sum of the known experimental work on heat transfer between burning fabric and substrate. The extensive and excellent work of Stoll reference 4 and others on radiant exposure ignition and heat transfer through fabrics will not be reviewed here. One further reference which has become available since this work was completed is presented in reference 5.

Equipment

The form of heat transducer to use for measurements of this type presents a variety of conflicting requirements. Some of these may be enumerated as follows:

1. The device should be capable of measuring heat transfer which would take place to human skin.

2. The device should be of fairly large dimensions but of a fine mesh size so that local variations in heat transfer rate can be measured as imposed by the random variations in burning and drip development.

3. The device should be of nearly uniform sensitivity over its surface area.

4. Since burn injury is a function of total heat transfer it is preferable that a calorimeter type rather than a flux measurement instrument be used.

5. The time constant of the calorimeter should be very long, preferably in the range of minutes.

The compromise selected was to use simple bar type calorimeter plates of known heat capacity. Thermo junctions being placed on their back face and the assembly being supported on a plastic block in such a manner that heat loss through conduction was not excessive. Copper was used for these plates whose dimensions were 1/2 x 1/2 x 1/16 in. The 1/2 x 1/2 surface was exposed, eight plates being arranged in a line. Preliminary experiments showed the desireability of making heat measurements in such a manner that the contribution of radiant transfer to the process could be measured. For this purpose one half of the plates were blackened to produce a high absorptivity while the other half were gold plated for the purpose of rejection of the radiant heat component. The assembly of these plates was mounted in an opening formed in an asbestos cement plate of 10 x 18 x 1/8 in dimensions. The assembly is shown in figure 3. The calorimeter mosaic surface was arranged cross axial to the specimen and about .035 in. above the surface of the asbestos cement plate. A line of No. 6-32 screws of 1 1/2 inch length were placed with the threaded ends uppermost along the length of the plate and separated 6 in. apart. These screws formed a support structure for a fine wire grid used for support of the specimen above the plate and calorimeter during the experiments. The grid used was formed by laying a spacer of the desired dimensions on either side of the screws and winding 0.0005 in. nichrome wire alternatively between the different lines of screws. The thread grooves served as an effective means for maintaining the desired spacing between the wire grid and the substrate. This assembly of cement asbestos substrate, calorimeter mosaic, and specimen support assembly will be referred to in later discussion as the "test rig". This device was supported in the open above a bench on a horizontal bar located about 5 inches from one end, while blocks were used at the other end to permit varying the inclination with respect to a horizontal position.

Heat content changes of the individual calorimeter bars were measured by noting emf changes developed by the various thermocouples. Since 8 of these elements were used in the test rig a simple telephone-relay type scanning device was assembled to record the data developed. This device was assembled in such a way that the cold junction of the thermocouple, was thermally insulated and held nearly constant at room temperature. Scanning was arranged at the rate of one change per second. A jack board was assembled to permit flexibility in the scanning order selected. For many tests the scanning order was arranged to alternate between gold and blackened calorimeter bars. The sequence was started with the two centrally located bars and worked out to the two lateral elements. In other experiments continuous records were made of the emf output of two selected bars usually the two central ones, gold and black surfaced.

Experimental Procedure

Preliminary experiments were performed by burning fabrics on the test rig in a general purpose laboratory module at Gaithersburg. It was soon observed that draft conditions were intolerable even when using a hood the flow through which could be diverted. Because of this the work was moved to a laboratory without the benefit of a continuous ventilation system. In most cases no heating was used as a further precaution against unwanted air circulation. Ambient temperatures during the period of testing were in the approximate range of 60 to 75°F.

The specimens selected for study, Table 1, included four woven textiles and three plastic films. The weight varied from 1.1 oz/yd^2 to 6.4 oz/yd^2. Strips of these materials of 2 in width and 10 to 12 in length were prepared and conditioned in a drum fitted with a fan and open tray with a solution of sodium nitrite in water in the presence of excess salt. Such an arrangement is reported as capable of stabilizing humidity of the air contained at 66% RH. In most instances during the series of tests conditions in the drum were found to vary from 63 to 66% RH. While detailed records were not kept of the room humidity and temperature condition the few measurements made suggest that these were usually in the range of 60-75°F and 40 to 60% RH.

Each experiment was run by removing a conditioned specimen from the drum laying it on the wire grid of the test rig in such a way that it was centered laterally over the calorimeter mosaic with about 3 inches extending above the mosaic. In this way a 7 to 9 inch length could be involved in the burning process prior to reaching the calorimeter. A 0.030 x 0.50 in. stainless steel strip was then laid to cover about 1/4 inch of the specimen along each edge. This strip served two purposes it eliminated the rapid propogation of fire along the edge of the specimen and also served to define a 1 1/2 in fixed width of the specimen for the burn tests. A further benefit derived from these strips was the prevention of specimen movement during the test. In some instances previous experiments had shown that such strips would roll up during the burning process.

The recording and scanning equipment was started and the lower edge of the specimen was ignited with a kitchen match. The progress of the leading edge of the flame on the fabric was observed at 3 or 4 station both visually and with 4 additional thermojunctions that were located on the centerline at 3 in. intervals and just below the specimen surface. These junctions were connected in series and in alternating polarity and recorded on one channel of the dual channel recorder. Observations and notes were made on the recorder charts of the character of burning and other information of special interest in connection with each test. Special attention was given to the manner in which the flame passed the colorimeter mosaic.

Experiments of this type were repeated for each of two grid spacings above the calorimeter plate 5/16 and 1 in, each specimen type, and four test rig angles these included 0°, 4°, 10° and 30°. Although in many instances only a single test was run for a given set of conditions in numerous cases multiple tests were performed to better define specimen behavior. In all, a total of 115 burn experiments were performed.

Experimental Results

Table I presents information on some properties of the materials tested. These materials were secured from the Flammable Fabrics Section and supplies of some of them are still available.

Figures 4, 5, 6 and 7 provide heat transfer data for both 5/16 and 1 in spacing at 0° and 30° inclination respectively. The data plotted here are for mosaic elements either black or gold surfaced adjacent to each other and the centerline of the fabric. Notice that neither the blanket nor vinyl material would propogate fire in the horizontal position and 5/16 spacing arrangement.

Figures 8 and 9 provide an indication of the influence of test rig inclination on the heat dosage resulting from burning both the blanket and print material at a spacing of 5/16 in. Note that the blanket material would not burn continuously for either the 0° and 4° position.

Discussion

Since the various materials tested in this study represent a wide range of weight per unit area a direct comparison of the heat dosage transfer as shown in Tables II and III reflect more than simple changes in materials and structure. Nevertheless, it is interesting to compare the dosages observed. Both tables summarize the maximum dosage as averaged for the number of test conditions replicated. Both tables are for the 30° orientation. Table II is for 5/16 in. spacing while Table I is for 1 in. spacing. Since radiant transfer was not of great importance for the closer only maximum transfer measurements are shown. On the other hand, Table III reports data on both total and total less radiant transfer dosages.

The heat transfer dosages shown in Table II vary from 11 to 36 watts sec/cm^2 for fabrics which differ in weight by a factor of five. Thus when dosages are normalized on a fabric weight basis we find that the very light weight chiffon material shows an unusually large dosage. It may be that this results from the choked burning behavior of the blanket material in the close spacing condition. In another comparison between the polyethylene film materials poly and polynet it is observed that very similar thermal dosages occur. In normalizing these on a weight basis there is a three to one ratio in dosage with polynet showing the greater transfer. This probably results from the effectiveness of the fiber net reinforcement in supporting the burning film resulting in more complete combustion than observed with the non reinforced film which burned with extensive dripping and incomplete combustion. As a result of this while there is, with the exception of the data for the poly specimen, a general linear correlation of heat dosage with specimen weight the normalization of the dosage on a weight basis does not result in a constant specific dosage. It seems apparent that the observed thermal dosage is not related in a simple manner to specimen construction variables, weight, variations, etc.

Considerations of the data shown in Table III yield similar conclusions although the detailed behavior is different. Note that the poly material did not burn and in this case the dosage from the chiffon and vinyl materials was much less than for the others studied.

While it is true that the method of normalization of the dosage data does not account for variation of heat of combustion of the materials studied this should not invalidate the sort of rough comparisons being made.

Before detailed discussion of the figures showing typical heat dosage curves it seems desirable to comment briefly on the thermal behavior of the calorimeter mosaic. One of the requirements placed on the heat dosage meter was simulation of the thermal properties of human skin. Asbestos cement board provides a rough match of the $k\rho c$ product. However, the calorimeter used with its high $k\rho c$ product does not provide a good match. While this mismatch will result in failure to match the true thermal gradient between the fire environment and skin this factor has been neglected in the present study. This fault is considered of only secondary importance because of the very large thermal gradients involved in the burn situation. Thus, a change of the calorimeter temperature of 50 °C is small compared to the temperature excess of the combustion products. It is, however, suggested that with the data available some consideration of calorimeter thickness might be warrented to permit a closer match to the transient thermal properties of skin.

On the basis of the material, mass, and dimensions of each calorimeter mosaic element it has been computed that the thermal sensitivity of the element is equal to 12.9 watt sec/cm^2 mv. Thus a recorder with sensitivity range of about 1/2 to 5 mv. full scale proved adequate for the studies performed. The time constant of the calorimeter plates in cooling was measured as about 100 sec. While this was about twice as long as had been achieved in the first tests it did result in a noticeable drift of indicated heat content after reaching a peak value as shown by the curves of fig 8. In many cases the errors in peak dosages measured would not be seriously affected by this limitation. However for curves such as that for 10° shown in fig 9 this small time constant probably is just marginally acceptable. Variations of thermal sensitivity over the area of a given calorimeter bar were of course considered but the response time to the receipt of a single molten drop on the surface was so fast, about 1.7 mv/sec on maximum sensitivity that it compared closely with the operating speed of the recorder which was about 2.6 mv/sec. The measured time constant for temperature stabilization was less than 0.15 sec. for each bar. Thus local variations in sensitivity of a plate would be of importance only during periods very short compared to the recording times for most of the measurements.

In the process of making these sensitivity tests a molten polyethylene drop was allowed to fall on various positions on the surface of a calorimeter segment. Since the solidified polymer drop could be removed and its diameter measured after cooling it is possible to make estimates of thermal dosage per unit area. For the experimental conditions involved these amounted to dosages of about 14 watt/cm^2 or 3.34 cal/cm^2. This is about twice the dosage required to induce third degree burns for application times in the order of a few seconds. Thus there appears to be ample justification for concern with regard to the hazard of molten drips from materials such as this.

In a similar way most of the heat dosage rates reported in tables II and III are high enough to result in severe skin burns.

Figures 8 and 9 indicate the increasing heat dosage observed as specimen inclination was increased from 0°. Since the data shown in each figure are for a single fabric it is apparent that dosage variation must be a function of the burning conditions imposed as a result of specimen inclination. Certainly for the 5/16 in spacing the stagnation of fuel-rich vapors and smoke beneath the fabric greatly reduced the heat transfer in the 0° and 4° position. In a similar way the heavy blanket material was so greatly influenced by the lack of ventilation that it would not propagate under these same low inclination conditions.

Figures 4 and 5 are reasonably self explanatory and probably do not warrant extensive discussion. It will be noticed, though there are exceptions, that the materials which did burn showed higher heat dosage with 5/16 than with 1 in spacing. Though the data are not shown the choked combustion for the 5/16 spacing in the horizontal condition resulted in little evidence of a significant radiant component in the heat transferred. This situation was changed when a spacing of 1 in was used. Under this condition about 50 percent of the heat transfer took place by a radiant mechanism.

Though the total less radiant component curves were not shown in figures 4 and 5 these have been included in the curves for 30° inclination as shown in Figures 6 and 7. In these two figures the total heat transfer is shown by the solid lines while the total less radiant by the dashed lines. Figure 6 for the 5/16 in spacing seems to suggest the ridiculous situation that when the radiant component is rejected the resultant transfer is increased for many materials. The fact that this situation persists for four of the six materials studied is puzzling. It surely is only explainable on the basis of non uniform burning and dripping behavior. In fact a review of the origional data suggests that, although the general curve shape and signal level recorded was as typical of the fabric as could be determined for the material and test conditions imposed, the fact that the radiant rejection curve was higher was not typical. In drawing the curves more weight was placed on achieving typical shape and signal magnitude curves than the aspect under question. It is suggested that in spite of the abnormalities exhibited there is little radiant contribution to the heat transfer process under the test condition involved. Figure 7 however showing results for the 30° inclination angle tells a different story. Here the radiant transfer component is shown to be consistently significant at a level of about 40 percent of the total transfer.

Figures 8 and 9 show the trends of increasing heat dosage as the inclination angle is increased. This direct relationship only existed at the close spacing. The trend was reversed for the print with 1 in spacing while for the blanket material variations in slope had little influence on heat dosage.

These trends may be seen better in figures 10 and 11 where heat transfer is plotted against sine of the inclination angle. The sine of the angle was used since this provides an indication of the elevation from bottom to top of fabric and thus an indication of changes in buoyancy pressure heads. Figure 10 for 5/16 spacing shows a direct relationship between heat and angle for all materials burned with the single exception of polyethylene. The reversal in trend when spacing was increased to 1 in is shown in figure 11. Peculiarly the polyethylene and polynet materials show a different trend from that of the other materials. The latter effects may not be significant since only three tests are represented by the points plotted for the polynet and only four for the polyethylene materials. The latter was subject to very erratic dripping and therefore deserves further study before the contrary trends are considered important.

Figures 12 and 13 show flame speed data derived from the work done. Although thermocouples were arranged at 3 in intervals just below the fabric surface the recording obtained from their use did not clearly define the time of flame arrival since in most cases heated gas preceeded the arrival of the flame. Thus while some of these data were used for these figures most of the data plotted were based on visual and stop watch timing of the time from ignition to flame arrival at the end of the test specimen. An attempt was made to define this latter event on the basis of the flame position in close contact with the fabric as evidenced by char development on the fabric surface. However for the lighter fabrics which burned rapidly in the inclined position this was not an easy measurement to make with high accuracy. It will be noticed that the data reported include the starting fire development transient and thus are probably significantly lower than flame propogation rates once the fire has fully developed.

All of the data shown on these two figures indicate a least slight increase in flame speed with increasing slope. Chiffon for 5/16 spacing and both chiffon and vinyl for 1 in spacing show great sensitivity to inclination angle.

The latter two reached flame speeds of 8.6 and 7.5 ft/min at 30° angles. The behavior of the vinyl material is especially interesting since it would not propogate at any angle with a 5/16 spacing while it became one of the most flammable materials with a spacing of 1 in. It seems likely that this behavior was associated with the nature of the combustion gases generated.

Before closing it seems desirable to comment briefly on some problems encountered in performing the work reported. First this is dirty work. The calorimeter used was subject to rather heavy polymer degradation product condensation. This was so severe with the 5/16 in. spacing that it was found necessary to frequently clean the calorimeter surface with alcohol. Thus the radiant heat rejection behavior of the gold plated segments was not constant even during a single experiment. As a result, the fraction of heat dosage attributed to radiant transfer is probably conservative.

Because of the need for frequent cleaning not only of condensed volatiles but also polymer drips it was difficult to preserve a thin black oxide layer that had been applied to the total heat transfer bars. Because of this the black bars were blackened with a spray applied flat black paint as required to insure high absorbtivity. This application of paint was made only after complete removal of all prior coatings to insure a very thin layer.

Mention has been made of errors introduced in the experimental results by the influence of drafts in the Gaithersburg laboratories. This was a pronounced effect and was only solved by resort to a laboratory without any mechanical ventilation.

Conclusions

The experiments performed were conducted for exploratory purposes to achieve a general "feel" for the behavior of a variety of film and textile material when burned under a variety of experimental conditions. The conclusions enumerated are thus of a tentative nature and suggestive of general trends rather than exact relationships.

1. The General Purpose Laboratories at Gaithersburg are not suitable, without the use of special air draft damping devices, for useful measurements of open draft free burning of plastic and textile sheets.

2. Because of difficulties with molten polymer drips and condensation of tarry vapors it is most difficult to make precise heat transfer measurements from burning films and fabrics. As a result it seems preferable to use relatively crude surface heat flux transducers but place emphasis on design refinements to achieve minimal heat loss from the calorimeters developed.

3. There is still a need for a homogeneous set of fabrics and films of a variety of fixed weights but varying from each other only in material or structural properties in a simple manner.

4. The radiant transfer of heat from a burning fabric or film to substrate was observed to represent as large as 50 percent of the thermal dosage with spacings of 1 in. For spacings of 5/16 the radiant component was much less, seldom exceeding 25 percent and its significance is questioned.

5. There is evidence that very light fabrics when burned 5/16 in from a substrate can transfer disproportionally high, on a weight basis, heat flux as compared to other heavier fabrics.

6. The molten drip mechanism of heat transfer from burning polyethylene can represent a major fraction of the thermal dosage while heat transfer from single drops of this material provide sufficient heat to cause severe skin burns.

7. Both heat dosage and flame speed are sensitive to small changes in inclination for many materials.

8. The relatively crude exploratory study reported suggests various areas in which more detailed studies would be warranted. Certainly the work completed tends to enhance the concern for the role played by thermoplastic materials during clothing fire accidents.

References

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MATERIALS STUDIED

Specimen	Material	Construction	Weight oz/yd^2
Blanket	Cotton	Brushed plain weave open print 40 x 31	5.4
Print	Cotton	Plain weave Paisley print 64 x 70	3.1
Chiffon	Polyester	Red plain weave 120 x 110	1.1
Polyester	Polyester	Plain weave 100 x 80 Red & White dyed yarns	2.0
Poly	Polyethylene	Clear sheet 9 mill.	6.4
Poly net	Polyethylene Glass yarn	4 x 4 glass net laminated between 2 mill polyethylene films	3.4*
Vinyl	Vinyl	Clear sheet 4 mill.	4.1

*2.28 polyethylene 1.12 glass yarn

Table I Properties of the Materials Studied

AVERAGE HEAT TRANSFER

5/16 Spacing 30°

Specimen	Weight oz/yd^2	Heat Trans. watt/cm^2	Heat Trans. per unit weight
Blanket	5.4	36	6.7
Print	3.1	24	7.7
Chiffon	1.1	11	10
Polyester	2.0	14	7
Poly	6.4	24	3.8
Poly net	3.4	27	12*
Vinyl	4.1		

*Based on polyethylene weight

Table II Average Heat Dosage for Materials Burned at 5/16-Inch Spacing and 30° Inclination.

AVERAGE HEAT TRANSFER

1" Spacing 30°

Specimen	Weight oz/yd²	HEAT TRANS. watt/cm² TOTALS	LESS RAD.	HEAT TRANS. watt/cm²gm TOTAL	LESS RAD.
Blanket	5.4	24	14	4.4	2.6
Print	3.1	11	6.2	3.5	2.0
Chiffon	1.1	2.1	1.4	1.9	1.3
Polyester	2.0	8.8	8.9	4.4	4.4
Poly	6.4				
Poly net	3.4	13	7.2	5.7*	3.2*
Vinyl	4.1	4.4	1.8	1.1	.44

*Based on polyethylene weight

Table III Average Total and Total Less Radiant Heat Dosage for Materials Burned at 1-Inch Spacing and 30° Inclination

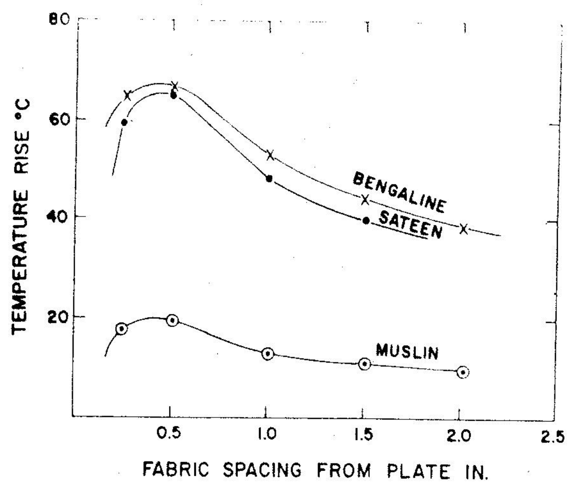

Figure I Calorimeter Temperature Rise Versus Spacing for Three Fabric Specimens Burned In The Vertical Position Data From Sandholzer

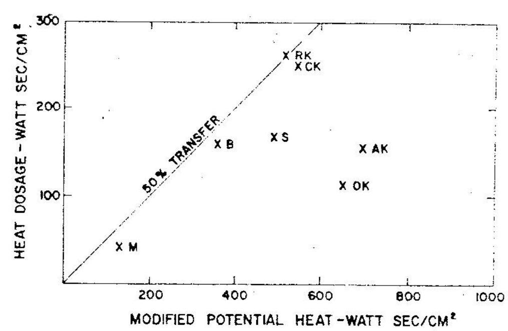

Figure II Heat Dosage Versus Heat Release On Combustion of a Variety of Fabrics

RK	Rayon Knit	33 oz/yd^2
CK	Cotton Knit	32 oz/yd^2
AK	Acrilon Knit	32 oz/yd^2
OK	Orlon Knit	34 oz/yd^2
B	Bengaline	22 oz/yd^2
S	Sateen	29 oz/yd^2
M	Muslin	7 oz/yd^2

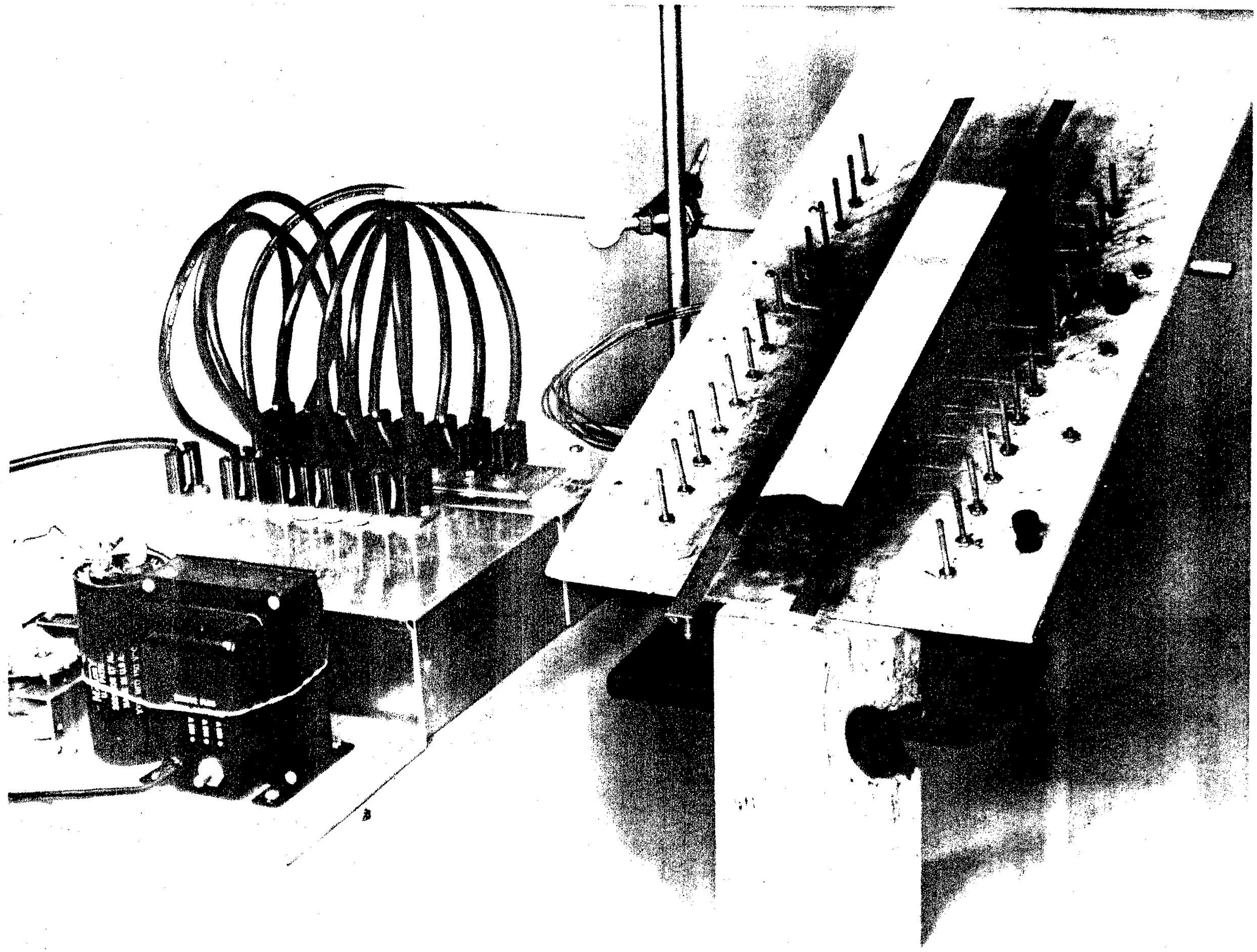

Figure 3 Photograph of Test Rig Set Up for Fabric Test

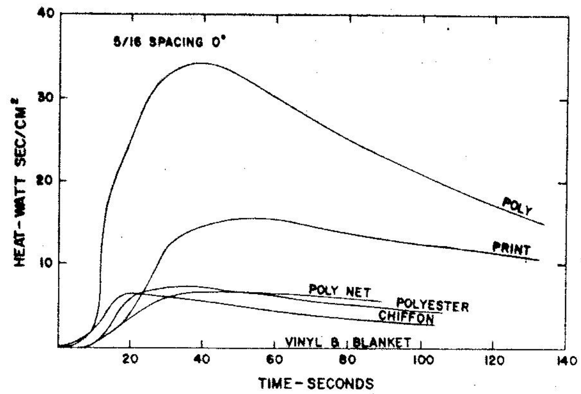

Figure 4 Heat Dosage to Calorimeter With 5/16-Inch Spacing and Horizontal Orientation. The vinyl and blanket material did not continue burning.

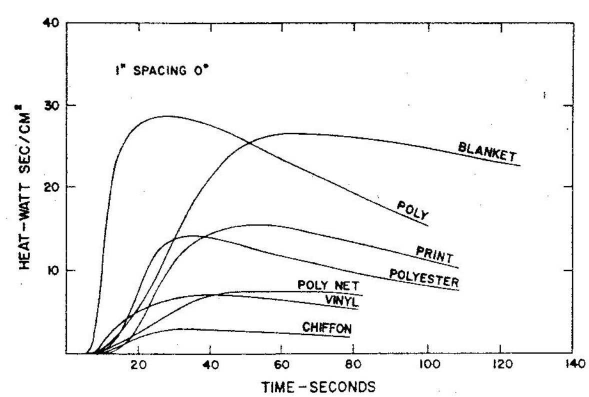

Figure 5 Heat Dosage to Calorimeter With 1-Inch Spacing and Horizontal Orientation.

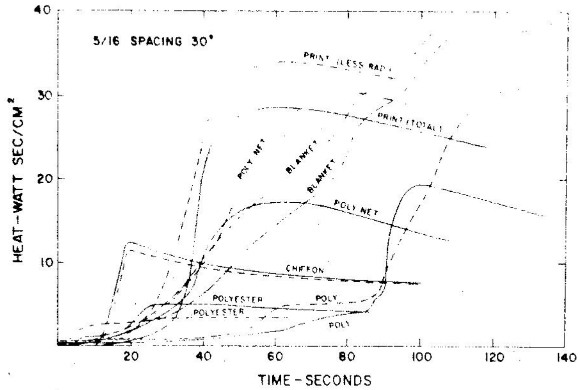

Figure 6 Heat Dosage to the Calorimeter With 5/16-Inch Spacing and 30° Inclination. Solid Lines are for Total Dosage While Dashed Lines Represent Data for Total Less the Radiant Component.

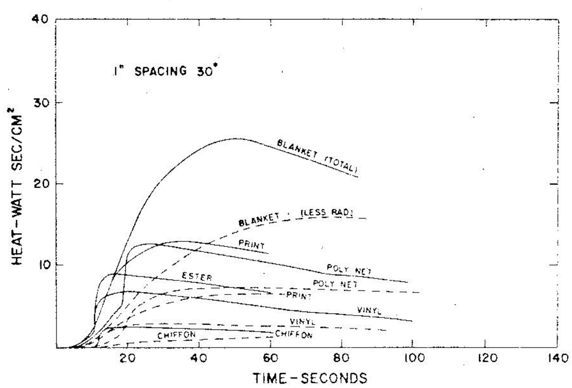

Figure 7 Heat Dosage to the Calorimeter With 1-Inch Spacing and 30° Inclination. Solid Lines are for Total Dosage While Dashed Lines Represent Data for Total Less the Radiant Component.

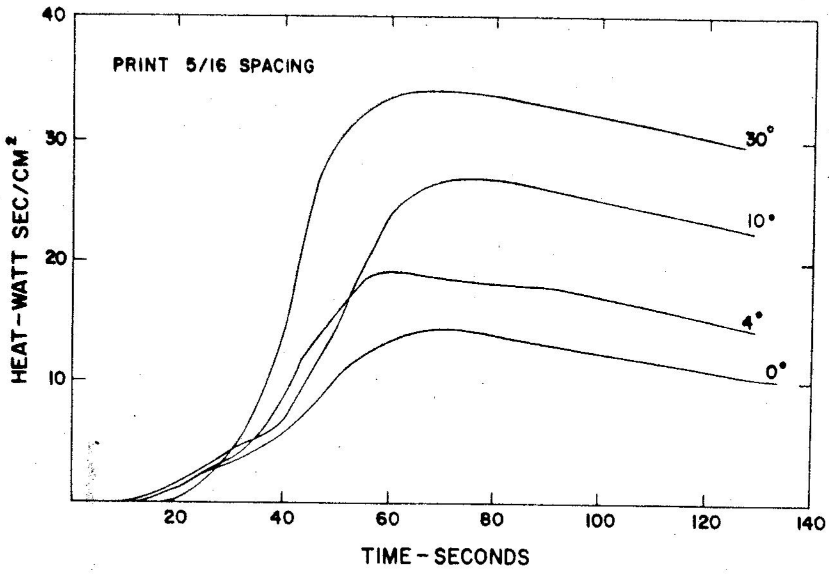

Figure 8 Heat Dosage to the Calorimeter With 5/16-Inch Spacing for the Cotton Print Material Burned at Various Angles of Inclination.

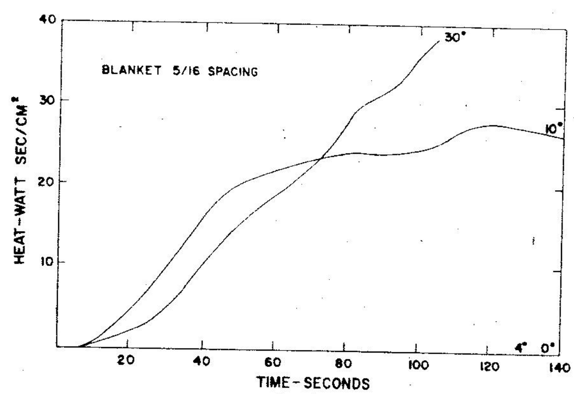

Figure 9 Heat Dosage to the Calorimeter With 1-Inch Spacing for the Blanket Material Burned at Various Angles of Inclination. At 0^{o} and 4^{o} the Blanket Did Not Continue Burning.

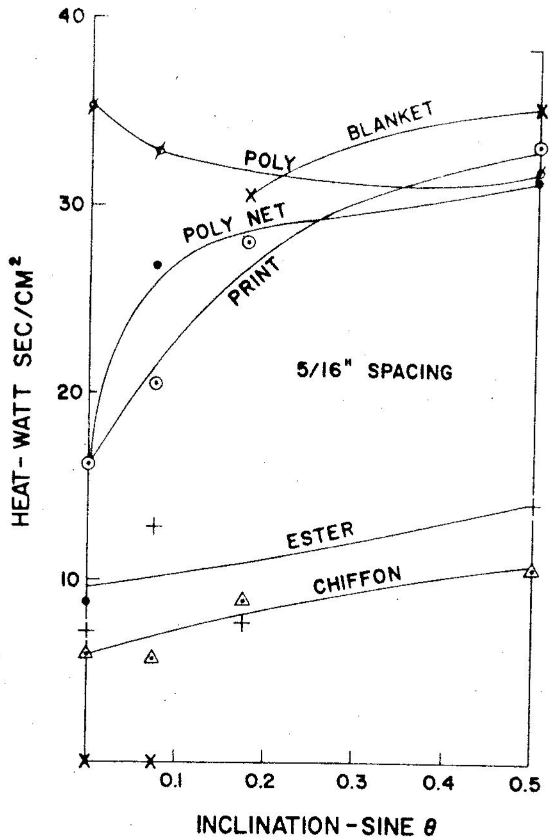

Figure 10 Heat Dosage to the Calorimeter With 5/16-Inch Spacing for Various Materials and Inclination Angles.

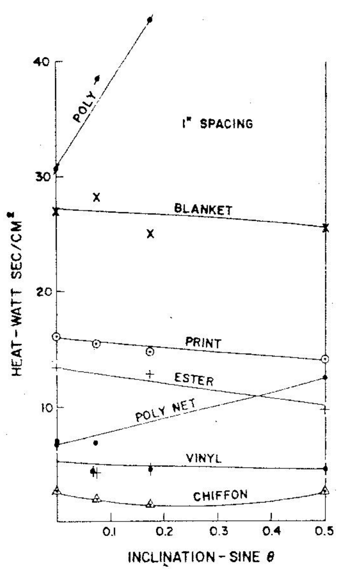

Figure 11 Heat Dosage to the Calorimeter With 1-Inch Spacing for Various Materials and Inclination Angles.

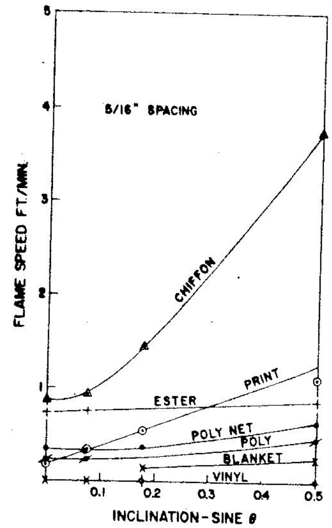

Figure 12 Flame Speed of Various Materials With 5/16-Inch Spacing and Various Inclination Angles.

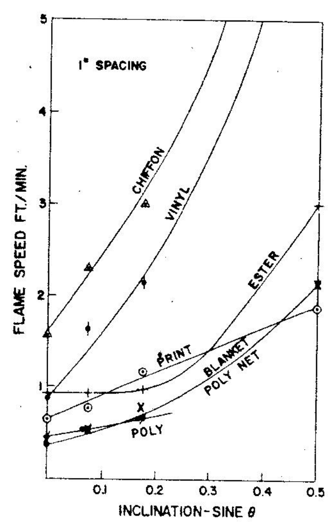

Figure 13 Flame Speed of Various Materials With 1-Inch Spacing and Various Inclination Angles.

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