EFFECTS OF A HUMID SULFUR DIOXIDE POLLUTED ATMOSPHERE UNDER TWO TEMPERATURE LEVELS ON THE BREAKING STRENGTH OF SEVEN FABRICS

By

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CHAPTER I

INTRODUCTION

Air pollution has been with mankind for centuries. It now reaches all parts of the world and has become one of the main concerns of great nations (8). In President Nixon's State of the Union Message, he said:

> We still think of clean air as free. But clean air is not, and neither is clean water. The price tag on pollution control is high. Through our years of past carelessness we incurred a debt to nature, and now that debt is being called (26).

Studies of air pollution must not stop with the effects on man's physical and mental health nor with plant and animal life, but they must encompass textiles, leather, brick, paint, and other environmental substances which are subjected to air pollution.

This study is concerned with the effect of a sulfur dioxide polluted atmosphere on deterioration of several fibers; namely, acetate, acrylic (Creslan 58), cotton, modacrylic (Dynel), nylon, triacetate (Arnel), and polyester (Dacron 54). These fibers are presently used in clothing fabrics, household textiles and non-textiles such as wigs.

Fabric change due to specific atmospheric elements must be studied under controlled conditions if one is to investigate the relationship between the effects of different factors. Atmospheric conditions chosen for this experiment were high humidity, high sulfur dioxide (SO_2) concentration for a human environment and two temperature levels. Breaking strength was used as a means of determining deterioration of

the fabrics after exposure to the two atmospheres. The specific objectives were to:

1. Develop apparatus to produce high humidity and controlled temperature atmospheres.

2. Determine the presence of acid in a 2 ppm, SO_2 contaminated atmosphere.

3. Evaluate the results of breaking strengths of seven fabrics after exposure to the contaminated atmospheres.

CHAPTER II

REVIEW OF LITERATURE

The history of air pollution dates as far back as seven hundred years ago in various areas of the world. London appeared to be the first recorded city to be concerned with the problem. In 1661, John Evelyn, a notable London citizen, wrote a short volume with a long title: Fumifugium, or, the Inconvenience of the Air, and Smoke of London Dissipated. Together with some Remedies humbly proposed by J. E. Esq., to his Sacred Majesty, and to the Parliament now Assembled. The work was otherwise known as Smoke of London and became the first study of polluted air (30). Although the problem was discussed and brought to the attention of Parliament, no action was taken to clarify the air until the middle of the present century.

Air pollution has reached such heights in the United States now that it is interfering with the desires of man. The Department of Health, Education, and Welfare stated in February 1969 that, "On the basis of the foregoing information and data, it is reasonable and prudent to conclude that sulfur oxides of 300 $\mu g/m^3$ (0.1 ppm) or more in the atmosphere over a period of 24 hours may produce adverse health effects in particular segments of the population (12)." While man is becoming materially wealthier, he is losing his basic human expectations of free clean air and good health free from environmental irritants.

> Most people, for example, want good health, but waste products from industrial and automotive combustion impair respiratory capacity and increase the risk of disease. Similarly, most people also want food, clothing, and shelter in such quantity and quality as will satisfy not only basic physical drives, but also acquired tastes. Here again air pollution has an effect . . . It weakens and discolors textiles and nylon stockings. It brings dirt into homes, and soils furniture, clothing, and draperies (20).

The effects of air pollution are not only costing man his basic human rights, but they are also costing him undetermined amounts of money. Dirty air causes increased laundry and cleaning bills and reduces the life of textiles because of repeated cleanings. Buildings must be repainted, repaired, and cleaned more often, a situation which results in greater depreciation (1, 19). The present cost of reducing air pollution has been estimated to be $60 billion over a five-year period, but to let air pollution continue, at present or increased rates, would be costlier than curbing it now (8).

Soiling of textiles reduces aesthetic appeal and functional effectiveness and increases economic costs. Soiling is influenced by temperature, relative humidity, wind speed, the size and characteristics of the atmospheric particles, construction of the fabric, and fiber content. The resulting soiling may be on the surface or internal. Atmospheric particles with acid components affect textiles differently depending upon their chemical composition.

> Cellulosic fibers, such as cotton, linen, hemp, jute and man-made rayon are particularly sensitive to attack from such substances as sulfurous and sulfuric acids, while animal fibers, such as wool and furs, are more resistant to acid damage (1).

Fibers such as cellulose acetate and some synthetic fibers acquire electrostatic charges which attract airborne particles to the charged textile (1).

Several mechanisms of deterioration are in effect in a polluted atmosphere. Yocum (31) lists them as:

1. Abrasion. Solid particles traveling at high speeds which strike and abrade.

2. Deposition and removal. Surface soiling which causes deterioration by repeated cleaning.

3. Direct chemical attack. Air pollutants which react directly.

4. Indirect chemical attack. Air pollutants which are absorbed internally then convert chemically and produce deterioration from within.

5. Electrochemical corrosion. Deterioration caused by electrical currents. This usually occurs on ferrous metals.

Yocom also lists as factors that influence deterioration: moisture, temperature, sunlight, air movement, and others. Many of these factors interact to cause deterioration which cannot be attributed to one source.

Sulfur oxides are capable of causing deterioration of a variety of textile fibers. Cotton is cellulosic, and Yocom states that it is weakened by SO_2. However, in studies by Fye (10) and Flaskerud (9), cotton showed no loss of breaking strength when exposed to a high concentration of SO_2 in an atmosphere. Nylon has received much publicity (27, 31) as being deteriorated by air pollution. The SO_2 or SO_3 in air pollution has been blamed for this damage to nylon. Several studies (9, 10, 11, 31) have confirmed the deterioration in SO_2 contaminated atmospheres, although the mechanisms of attack have not been determined. Wool is deteriorated by indirect chemical attack, whereby the SO_2 is absorbed into the fiber and is converted to sulfuric acid (H_2SO_4) (31). However, in a study by Flaskerud (9), wool showed no significant deterioration over a 90-day exposure period to an SO_2 contaminated

atmosphere. The deleterious effects or lack of deleterious effects on many other fibers have not yet been determined.

Sulfur dioxide exists in air under many conditions. Whether the SO_2 oxidizes to sulfur trioxide (SO_3) then converts to H_2SO_4 depends on atmospheric conditions surrounding the SO_2 (6). In Sweden, it is estimated that approximately a million tons of concentrated sulfuric acid fall in rain every years. The average pH value of the water in 1967 was 6, but it reached a low of 2.8 during July and August in some areas (15). Rainfall samples collected in the United States showed pH values around 3 (2). High humidity aids the oxidation of SO_2 to H_2SO_4; however, the ratio of H_2SO_4 to SO_2 was lowest in periods of precipitation (2). This might indicate a concentration of H_2SO_4 in rainfall rather than in air during precipitation. Bushtueva's study (2) also showed that as the concentration of SO_2 increased so did the H_2SO_4 concentration, but at a slower rate. Thomas (2) further investigated this ratio and found that the H_2SO_4 concentration increased with an increase in SO_2 up to a critical point at which the H_2SO_4 concentration decreased with an increase in the concentration of SO_2.

> The relationship is dependent partly upon the amount of moisture in the air, partly upon the time the sulfur contaminants have been in the atmosphere, the amount of catalytic particulate matter in the air, the amount (intensity and duration) of sunlight, the amounts of hydrocarbons and oxides of nitrogen, and the amount of directly reactive and absorptive materials in the air, as well as on the extent of recent precipitation (2).

The amount of air pollution particulate matter which fabrics encounter depends upon fabric weave, electrostatic attraction, fiber, and degree of fiber cleanliness. A tight weave offers more resistance to particulate matter than a loose weave at the same rate of air flow. Electrostatic attraction is usually not present, however it may be

present because of spinning or weaving processes. Clean fibers resist particulate matter more than soiled or dust laden fabrics. The general public would want to minimize air particulate attraction in textiles. Nevertheless, many industries study textiles to maximize air particulate adhesion in order to achieve clean air exhaust systems through woven fabric filters. The fabrics most often used are made of cotton, wool, Orlon, and Dacron in plain, twill, and sateen weaves. The fabric may be felted, napped, or smooth depending upon what particulate matter is to be filtered (5). The fact that cotton, wool, Orlon, and Dacron are used appears to indicate that cotton, wool, Orlon, and Dacron are most resistant to deterioration by air particulate pollutants. Although research findings show that cotton is sensitive to sulfur oxides (2, 31), cotton is recommended in many cases for air filtering systems involving SO_2 (5, 6).

Concentrations of sulfur oxides and sulfuric acid vary greatly from place to place. It is often necessary to determine these concentrations which may vary from a few tenths of a part per million in low contaminated areas up to several parts per million during moist days in areas down wind from large industries (16). In studies undertaken at Stanford Research Institute (16), an Anthony Venturi scrubber was used to separate air particulate matter, sulfur trioxide, and sulfuric acid mist. This method appeared to recover 80 percent of the sulfuric acid in atmospheric concentrations below 1 ppm.

In 1936, Coste and Courtier (7) used a method which removed sulfur dioxide from the air sample but did not remove sulfuric acid from the air sample. After the sulfur dioxide was removed from the air sample, the sample was saturated with water vapor; after which the sulfuric

acid was condensed by lowering the temperature. The amount of sulfuric acid in an air sample could be determined by this method; however, the sampling could take place only at a rate of 30 cubic feet in 24 hours.

Weber (29), in 1924, studied quantitative methods of determining fogs and mists, especially acid mists. He suggested filtering the atmosphere through filter paper held tightly between two glass funnels. This method had the disadvantage of working on high industrial concentrations but not on lower atmospheric concentrations.

Mader, Hemming, and Bellin (17) used the same theory in 1950; however, they used acid-free paper in a special holder. The filter paper was then macerated in distilled water of known pH and titrated with sodium hydroxide to determine the amount of H_2SO_4 in the atmosphere. This method was highly successful and accurately measured concentrations as low as 0.000 to 0.009 ppm.

Recently, Scaringelli and Rehme (23) developed a ". . . precise, sensitive and highly selective . . ." method for determining the concentration of sulfuric acid in air. The samples were collected by impact or filtration which separated sulfuric acid from the sulfur dioxide. Separation of the acid from other sulfates occurred as the sulfuric acid was decomposed at controlled temperatures under a stream of nitrogen. The sulfur trioxide, liberated in this process, was converted to sulfur dioxide by reaction with hot copper. The sulfur dioxide was then analyzed either spectrophotometrically, coulometrically, or flame photometrically. This method was highly successful and precise. Sulfuric acid can be measured in the presence of 10 to 100 times as much sulfur dioxide and other sulfates as sulfuric acid.

A study conducted by the Naval Clothing Depot in Brooklyn, New York, and Clearfield, Utah, showed that deterioration of textiles continued with age after exposure to atmospheric elements (18). In that study, cotton sheeting was exposed to the atmosphere under conditions including and excluding sunlight. The fabrics were then stored for different time periods in a conditioning room away from light. Deterioration of the fabrics continued for periods of four and eight months. The acidity of the fabrics decreased during storage over time. Fabrics that were exposed to conditions including sunlight deteriorated less during storage than those that were exposed to conditions excluding sunlight.

CHAPTER III

MATERIALS, APPARATUS, AND PROCEDURES

Materials

Fabrics

Fabrics made from seven of the 28 generic fibers (13) were chosen for the experiment. The fabrics were white standard test fabrics[1] woven of acetate, triacetate, cotton, acrylic, modacrylic, nylon, and polyester (Table I).

TABLE I

DESCRIPTIVE ANALYSIS OF THE TEST FABRICS

Fiber	Weave	Yarns/Inch		Ply Filling	Fiber Form
		Warp	Filling		
Acetate	plain	200	62	one	filament
Triacetate	plain	45	41	one	staple
Cotton	plain	86	77	one	staple
Acrylic	twill	66	47	one	staple
Modacrylic	plain	33	34	two	staple
Nylon	plain	140	68	one	filament
Polyester	plain	66	54	one	staple

[1]Testfabrics Catalogue Issue Number 32P; May, 1969. Testfabrics Incorporated; 55 Vandam Street; New York, New York 10013.

Filter Paper

In a test to discern the presence of acidity during the experiment, four filter papers[2] (Table II) were used to determine which filter paper was most sensitive to acid formed in an atmosphere contaminated with 2 ppm SO_2. It was desirable to have the filter paper as neutral as possible.

TABLE II

DESCRIPTIVE ANALYSIS OF THE FILTER PAPER

Filter Paper Number	Description
597	Moderately rapid. Medium thickness and retention.
602	Very retentive. Dense. Close texture.
604	Very rapid. Medium thickness. Loose texture.
470	Smooth, thick, highly absorbent, combines fast filtering speed with high retention.

Apparatus

Test Chamber

Peters' (21, 22) chamber, constructed of pine and glass was used for exposure of the specimens. The chamber was 61½ inches long, 31¼ inches wide, and 10 inches deep and stood 15 inches off the floor. A fan, for circulating the air through the approximately 11 square feet

[2]S & S Analytical Filter Papers Quick Reference Catalog Number 4. Carl Schleicher & Schuell Company; Keene, New Hampshire.

of chamber area, was located in the center bottom of the chamber.

Some chamber modifications made by Fye (10) to facilitate a continuous flow of controlled atmosphere were used. These modifications consisted of two 1-inch holes at either end of the chamber for atmosphere entrance and exit and three rows of horizontal wires from which to hang the test specimens.

Hygrometers hung at either end inside the chamber provided wet and dry bulb readings of temperature and relative humidity throughout the experiment.

Plastic tubing inserted into the 1-inch exit hole of the chamber carried the exhaust atmosphere through a window.

Gas Dilution Apparatus

The air entering the test chamber was first drawn through a gas dilution apparatus previously used by Fye (10, 11). The apparatus consisted of a blower which drew air in and forced it through a T-shaped duct where it was mixed with SO_2.

Commercial grade SO_2 was dispensed from a Number 3 Matheson gas cylinder[3] through a controlled calibrated flowmeter and into the T-shaped duct. The SO_2 concentration was controlled by a gas regulator. The air and SO_2 were combined in the T-shaped duct, aided by baffles, and passed from the gas dilution apparatus into the test chamber where it circulated and moved out through the exit.

A concentration of approximately 2 ppm SO_2, which is considered a high environmental concentration, was used in this study to try to obtain the maximum effect of an SO_2 polluted atmosphere; and at the

[3]Matheson Catalog Number 26. The Matheson Company, Incorporated; Post Office Box 908, 1920 West J. Street; LaPorte, Texas 77571.

same time, to have a realistic atmospheric condition. Concentrations as high as 1.86 ppm have been measured in Cincinnati (3) and higher concentrations in other cities (25). Such high concentrations of SO_2 have produced adverse effects on the environment (2, 6, 16, 30).

Air Humidifying System

The test chamber was previously found to be satisfactory for exposure of fabrics to polluted atmospheres, and the gas dilution apparatus provided a uniform mixture of SO_2 and air (9, 10, 11). Temperature and humidity controls were still inadequate; therefore, apparatus was devised to produce uniformly high humidity with a range in temperature.

Relative humidity in the chamber was increased by adding an air humidifying system to the gas dilution apparatus. The system consisted of a 20-gallon water container equipped with a heater, float valve to maintain water level, and an air bubbler tube. The air bubbler tube was connected to a pressurized air line, and a water line connected to tap water filled the container.

Standard classroom laboratory pressurized air was dispensed from an air valve through a plastic hose which was attached to the bubbler system. The air was forced through the water; whereby, it was water-filtered as well as humidified. From the water, the air flowed through 9-inch air conditioning ducting for a distance of 24 inches and was then drawn into the blower of the gas dilution apparatus.

The amount of moisture in the air was controlled by the temperature of the water and the amount of air passing through the water, rather than by the water volume. The temperature of the air was controlled by the temperature of the room and the temperature of the water.

The system was not air tight so that the blower could pull maximum air volume into the gas dilution apparatus. The amount of moist air from the humidifying system was regulated according to the amount of moisture available from room air.

Principles of controlling the atmospheric relative humidity in the chamber are those concerning relationships among humidity, dew point, wet-bulb and dry-bulb thermometry, condensation, and vaporization processes (14, 28).

The entire assemblage including test chamber, gas dilution apparatus, and air humidifying system functioned continuously throughout the experiment and is illustrated in Figure 1.

Experimental Procedures

Fabric Sampling

Twenty-five breaking strength specimens, filling direction, were cut from a 1½-yard continuous length of each fabric. The specimens were cut and prepared according to ASTM Standard Methods of Test for Breaking Load and Elongation, ravelled strip method (4).

All specimens of one fabric were randomly drawn and coded to identify fiber content, temperature, age period, and sample number. This gave five specimens from each fabric for each of five temperature-age combinations making a total of 175 specimens. The 175 specimens were assigned at random to a location in the chamber.

Filter Paper Sampling and Exposure

Three samples of each of the four filter papers were exposed to the atmosphere and three of each filter paper were kept as controls to

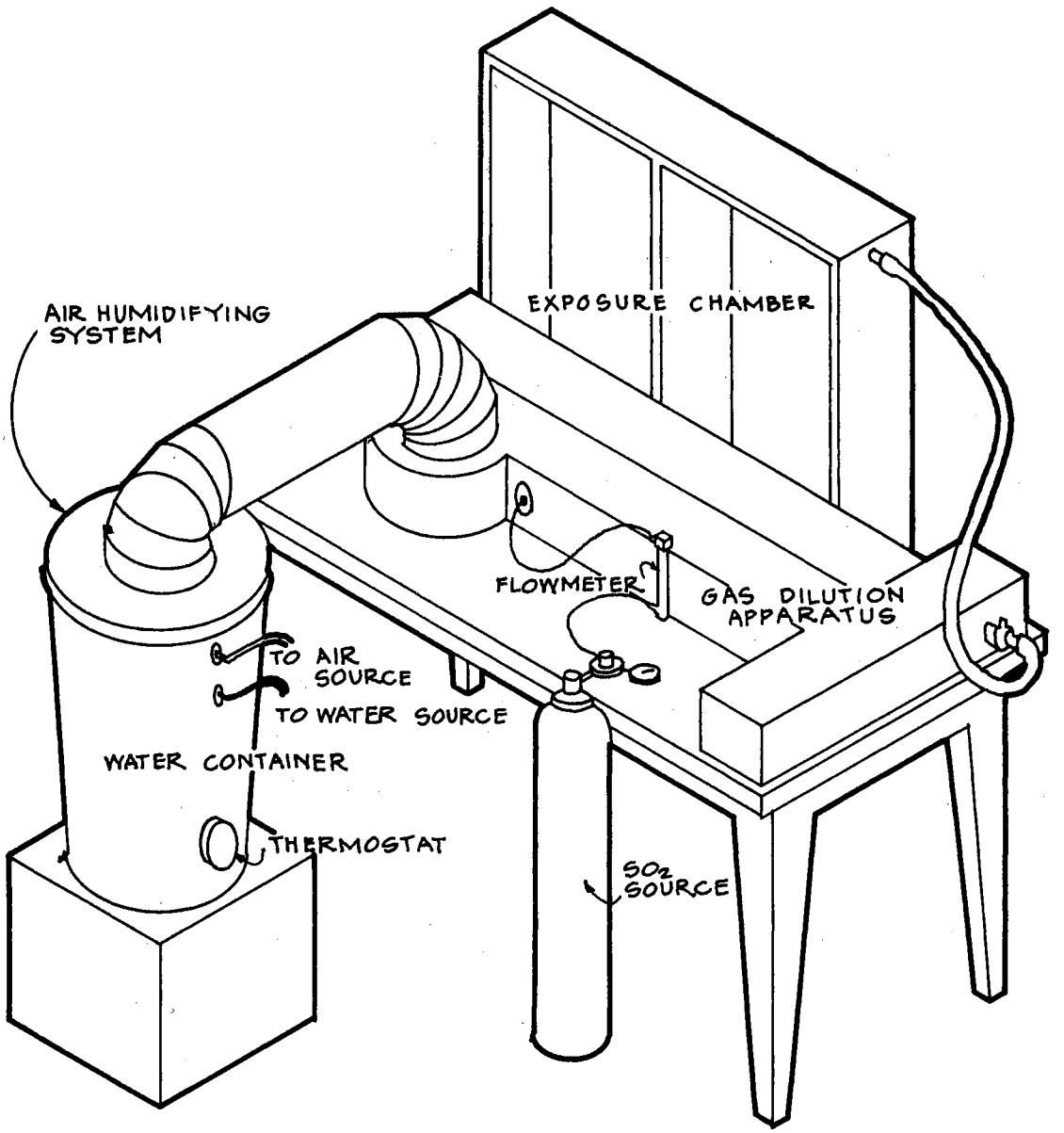

Figure 1. Air Humidifying System, Gas Dilution Apparatus, and the Exposure Chamber

test for atmospheric acidity in the test chamber. After the first exposure period, the one filter paper (470) was chosen since it had the greatest change in pH under exposure conditions as compared to the filter paper used as a control. In the second exposure period, only filter paper 470 was used to determine the atmospheric pH. In the first exposure period and in the second exposure period the filter paper samples were exposed to maximum circulation of contaminated atmosphere.

Exposure of Fabrics

The experiment was conducted in two exposure periods referred to as Phase I and Phase II. Phase I was high temperature (92 ± 2° F), high humidity (95 ± 2%); and Phase II was low temperature (66 ± 2° F), high humidity (90 ± 2%). Each phase ran for a total of 30 days with fabrics sealed in the test chamber for the full time period. The specimens were removed from the chamber and placed in a constant temperature and humidity room. Breaking strength was determined on one half of the exposed specimens, after being conditioned in the room for 24 hours. The other half of the exposed specimens remained in the conditioning room for 30 days; at which time, breaking strength was determined. Specimens exposed to conditions in Phase II were treated similarly. The control specimens were placed in the conditioning room when Phase I specimens were placed in the exposure chamber. Breaking strength was determined on the control specimens after all the Phase I specimens were broken and before any of the Phase II specimens were broken. The 175 specimens were divided as shown in Table III.

TABLE III

NUMBER OF SAMPLES FOR EACH CONDITION OF THE TEST

Fiber	Phase I		Phase II		Control
	Unaged 24 hours	Aged 30 days	Unaged 24 hours	Aged 30 days	
Acetate	5	5	5	5	5
Triacetate	5	5	5	5	5
Cotton	5	5	5	5	5
Acrylic	5	5	5	5	5
Modacrylic	5	5	5	5	5
Nylon	5	5	5	5	5
Polyester	5	5	5	5	5

In each phase, the test specimens were hung vertically from three wires strung horizontally in the chamber. The specimens did not touch and were hung on alternate sides of the chamber so that they were not directly lined up under and over each other. This arrangement allowed maximum circulation of the SO_2 contaminated atmosphere.

The flowmeter was checked daily to maintain the correct concentration of SO_2. Temperature and humidity of the atmosphere were also checked daily and were regulated by increasing or decreasing the amount of air forced through the volume of water and by increasing or decreasing the temperature of the water and of the room.

Testing

The filter paper samples were removed immediately after the chamber was opened. All like filter paper samples were placed in beakers

separating the control from the exposed samples. The papers were covered with 50 milliliters of all quartz, double distilled water pipetted over them. The specimens were in contact with the water approximately 30 minutes, then the pH was measured using a Beckman Expanded Scale pH Meter with a Sargent Glass Electrode and a Beckman Calomel Reference Electrode.

Analysis of Data

Since Peters' work (21) showed that the variation from specimen to specimen was of the same magnitude as her experimental error, this experiment was designed as a factorial arrangement of treatments in a completely randomized design.

CHAPTER IV

RESULTS AND DISCUSSION

Evaluation of Air Humidifying System

The humidifying system had the capability to increase the chamber relative humidity to 100 percent. Air moisture from the air or from the air supply could vary the relative humidity in the chamber; however, the system could compensate for the addition or reduction in air moisture with a small adjustment in the pressurized air valve.

During the 30-day exposure in Phase I, the 95 ± 2 percent relative humidity was maintained except for one day when it reached 98 percent. The temperature for the same period of exposure was 92 ± 2^{o} F except for four days when it ranged between 95^{o} and 98^{o} F.

The relative humidity of the chamber in Phase II was 90 ± 2 percent except for one day when it reached 94 percent. The low temperature for Phase II was more difficult to maintain than the high temperature in Phase I. The temperature was 66 ± 2^{o} F 18 days and ranged between 60^{o} and 72^{o} F the other 12 days. The temperature could be increased by raising the temperature in the water container and in the room, but no cooling system was available to reduce the temperature below that of the room.

Evaluation of Acidity of the Contaminated Atmosphere

The atmosphere in the chamber was tested for acidity immediately after each exposure period. The filter paper samples were tested to indicate acidity but not the amount or kind of acid present.

Table IV shows that in Phase I all filter papers decreased in pH; however, filter paper 470 had the greatest change in pH, which indicated that it was the most sensitive.

Tests after both phases showed a decrease in pH values which indicated that acid was present.

Breaking Strength

The breaking strength means of all fabrics, Table V, showed that variances among specimens for some fabrics were quite different from those for other fabrics. Therefore, the mean squares for specimens treated alike were tested according to Bartlett's Test of Homogeneity of Variances (24). The results of Bartlett's Test led to analyzing the data as three different groups. One group consisted of acetate and triacetate, another of cotton, and the third of acrylic, modacrylic, nylon, and polyester. Acetate and triacetate are man-made fibers but not synthetic, cotton is a natural fiber, and acrylic, modacrylic, nylon, and polyester are synthetic fibers.

Acetate and triacetate control specimens versus exposed specimens gave an F value which lies beyond the 0.01 significance level. Likewise, the interaction between fabrics and control specimens versus exposed specimens lies beyond the 0.01 significance level. The effect of temperature on the breaking strength gave an F value which lies between 0.05 and 0.01 levels. Refer to Table VI for F values.

TABLE IV

MEASURES OF PH OF EXPOSED AND UNEXPOSED FILTER PAPERS IN PHASE I AND PHASE II

Phase I	Buffer pH	Exposed pH	Unexposed pH	Δ pH
All Quartz Double Distilled Water	7.0 ± 0.02		6.14	
Filter Paper 597	7.0 ± 0.02	5.34	6.15	0.81
Filter Paper 602	7.0 ± 0.02	5.14	6.40	1.26
Filter Paper 604	7.0 ± 0.02	5.11	6.40	1.29
Filter Paper 470	5.4 ± 0.05	4.65	6.05	1.40
Phase II				
All Quartz Double Distilled Water	5.4 ± 0.05		6.40	
Filter Paper 470	5.4 ± 0.05	4.30	6.00	1.70

TABLE V

MEANS FOR FILLING BREAKING STRENGTH OF SEVEN FABRICS UNAGED AND AGED 30 DAYS FOLLOWING EXPOSURE TO A HUMID SO_2 POLLUTED ATMOSPHERE AT TWO TEMPERATURES

Fiber	Control (Pounds)	High Temperature Unaged (Pounds)	High Temperature Aged (Pounds)	Low Temperature Unaged (Pounds)	Low Temperature Aged (Pounds)
Acetate	23.08	21.50	21.38	21.26	20.78
Triacetate	16.44	16.94	16.48	16.04	15.56
Cotton	35.78	35.32	33.52	33.76	36.42
Acrylic	45.18	43.54	44.80	40.94	43.60
Modacrylic	74.96	76.96	78.02	77.90	76.58
Nylon	114.72	110.16	111.20	110.64	111.82
Polyester	57.12	54.62	56.16	55.12	54.22

TABLE VI

ANALYSES OF VARIANCE FOR THE THREE GROUPS[a]

Source	Group 1			Group 2			Group 3		
	D.F.	M.S.	Cal. F	D.F.	M.S.	Cal. F	D.F.	M.S.	Cal. F
Total	49	---	---	24	---	---	99	---	---
Fabric	1	352.19	548.7**	-	---	---	3	22336.6	3104.7**
TACM	4	---	---	4	---	---	4	---	---
Control vs Others	1	8.28	12.9**	1	4.20	0.49	1	29.3	4.1
Among Others	3	---	---	3	---	---	3	---	---
Age	1	1.48	2.3	1	0.92	0.01	1	13.3	1.8
Temp	1	4.42	6.9*	1	2.24	0.26	1	6.7	0.9
Age x Temp	1	0.09	0.1	1	24.86	2.93	1	3.4	0.5
TACM x Fab	4	---	---	-	---	---	12	---	---
Fab x Control vs Others	1	5.54	8.6**	-	---	---	3	27.8	3.9*
Fab x Among Others	3	---	---	-	---	---	9	---	---
Age x Fab	1	0.07	0.1	-	---	---	3	4.2	0.6
Temp x Fab	1	0.60	0.9	-	---	---	3	5.2	0.7
Temp x Age x Fab	1	0.07	0.1	-	---	---	3	4.5	0.6
Error	40	0.64	---	20	8.48	---	80	7.2	---

[a]Group 1 = Acetate and Triacetate; Group 2 = Cotton; Group 3 = Acrylic, Modacrylic, Nylon, and Polyester.

*Significant at the 5 percent level.

**Significant at the 1 percent level.

Since the cotton fabric was analyzed by itself, only the relationship between temperature and age was studied. The calculated F for this age-temperature interaction lies between 0.100 and 0.025. The effect of the temperature and age on breaking strength is graphically represented in Figure 4 of Figures 2 to 8.

In the analysis of acrylic, modacrylic, nylon, and polyester fabrics, the calculated F for the control specimens versus the exposed specimens lies between 0.100 and 0.025 levels in significance. The aging factor lies between 0.25 and 0.10, and the interaction between fabrics and control specimens versus exposed specimens lies between 0.05 and 0.01.

The effects of interactions among temperature, age, and fabrics on the breaking strength are shown in Figures 2 to 8. From the graphs one can see how the fabrics reacted to the SO_2 contaminated atmosphere in the presence of high humidity, two temperature levels, and two age periods. It may be seen in the seven graphs that the shape of the surface responses changes from fabric to fabric. This change in shape indicates the presence of interaction among these three factors of temperature, age, and fabric.

If trends in subsequent experimentation should follow the trends here, a practical use may be made of fabrics that increase, decrease, or remain unchanged in sulfur dioxide polluted atmospheres. If subsequent experimentation produces different and/or more variable results, Travnicek's suggestion concerning light and aldehyde content of gases may have a similar application concerning temperature, age, humidity, and sulfur dioxide. Travnicek said:

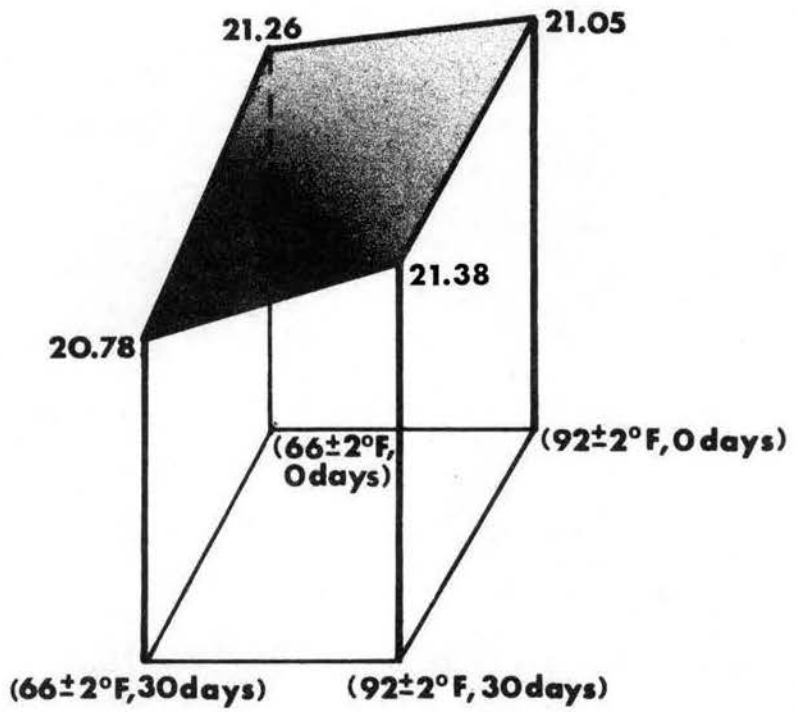

Figure 2. Interaction Surface Response of Temperature, Age, and Fabric on Breaking Strength for Acetate

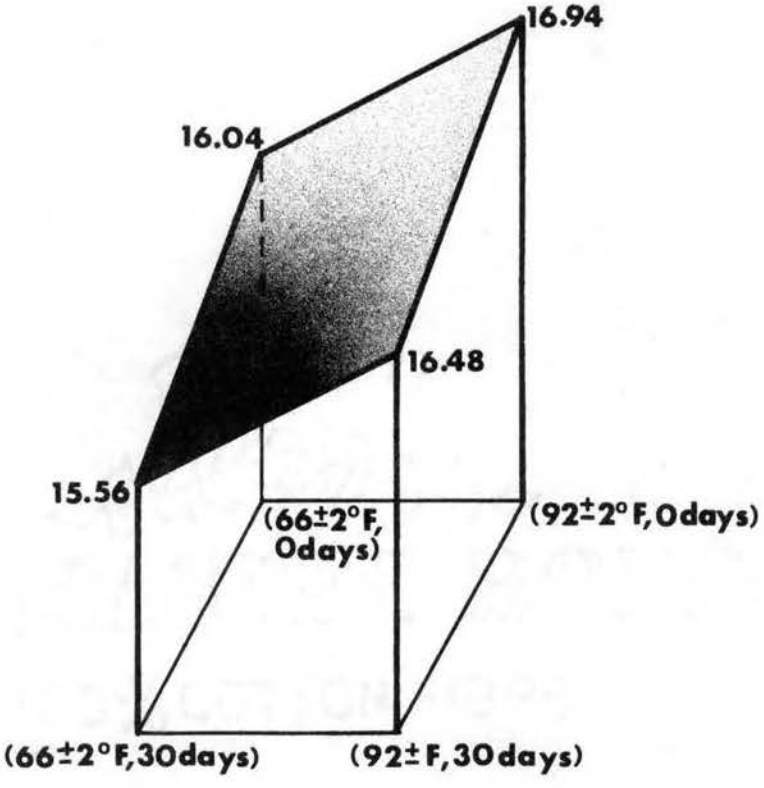

Figure 3. Interaction Surface Response of Temperature, Age, and Fabric on Breaking Strength for Triacetate

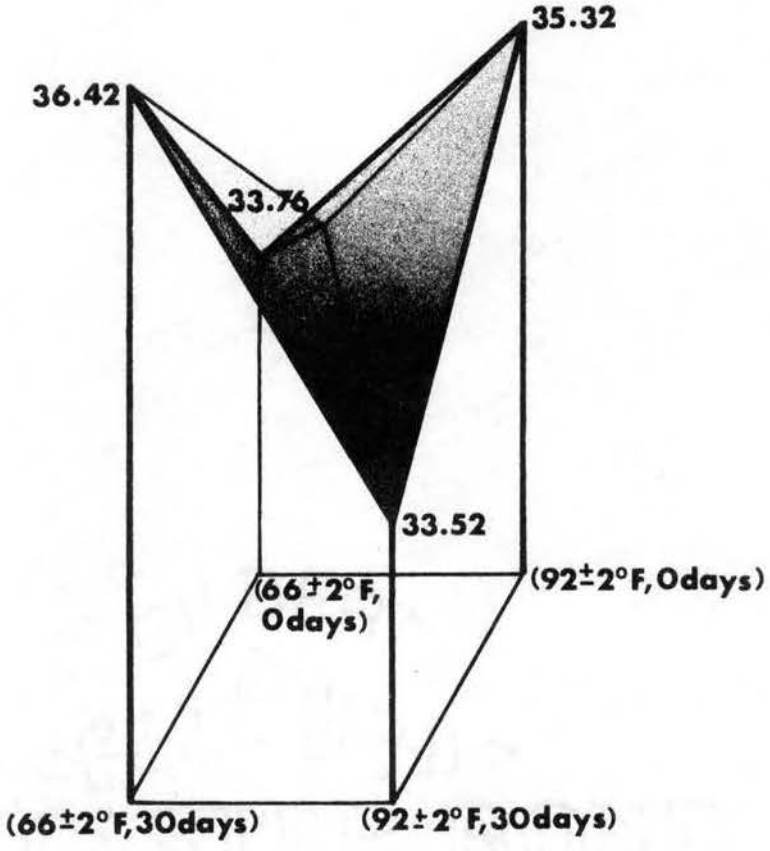

Figure 4. Interaction Surface Response of Temperature, Age, and Fabric on Breaking Strength for Cotton

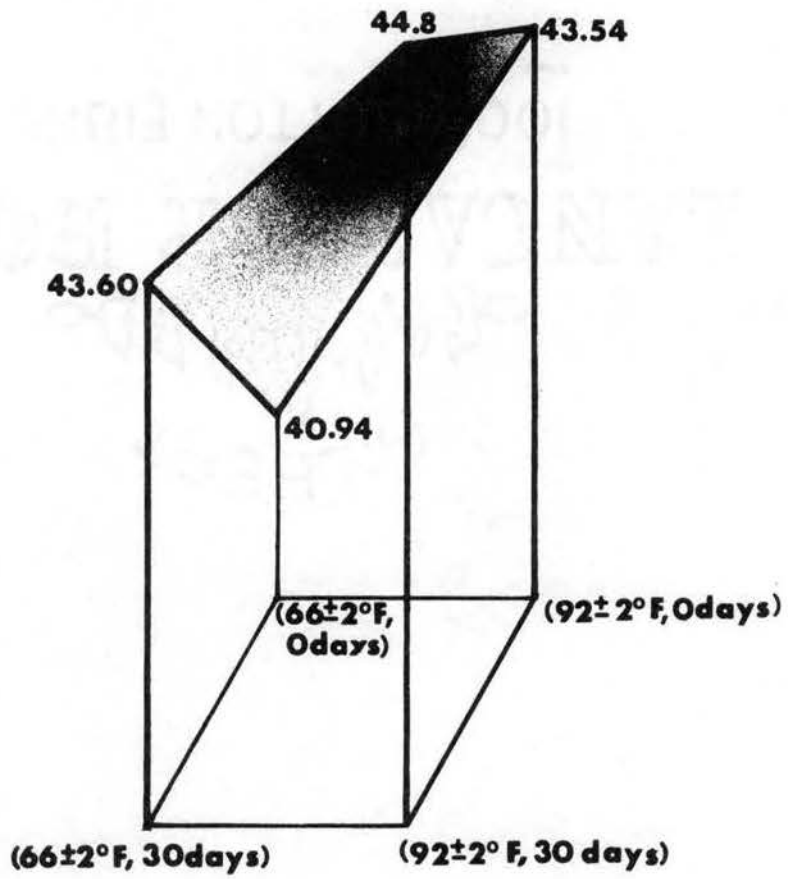

Figure 5. Interaction Surface Response of Temperature, Age, and Fabric on Breaking Strength for Acrylic

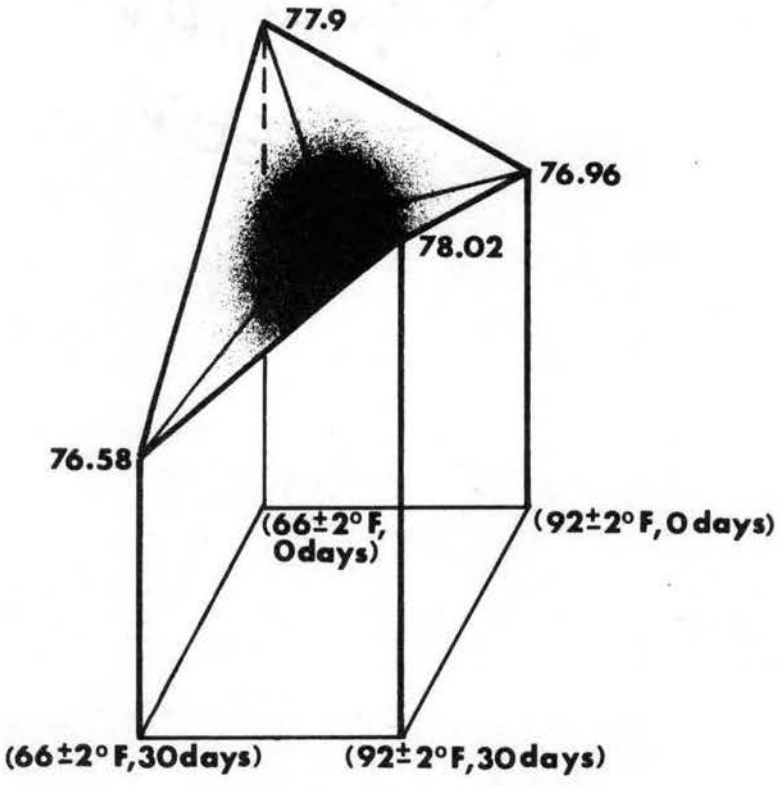

Figure 6. Interaction Surface Response of Temperature, Age, and Fabric on Breaking Strength for Modacrylic

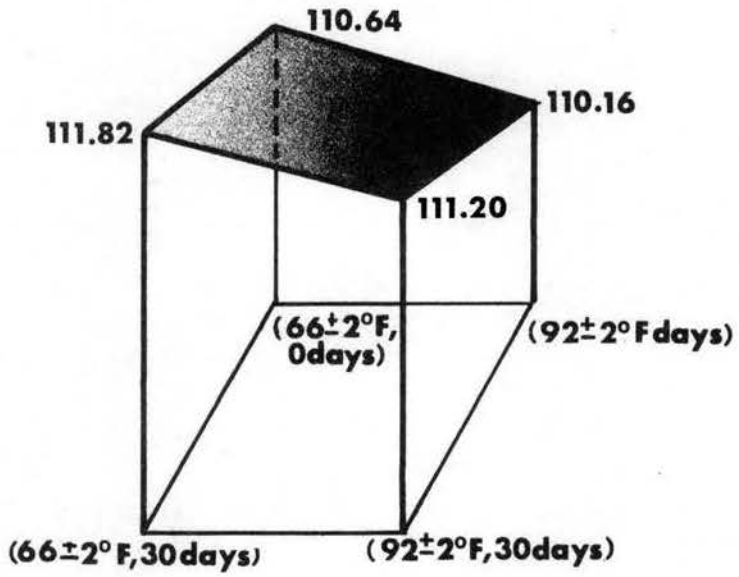

Figure 7. Interaction Surface Response of Temperature, Age, and Fabric on Breaking Strength for Nylon

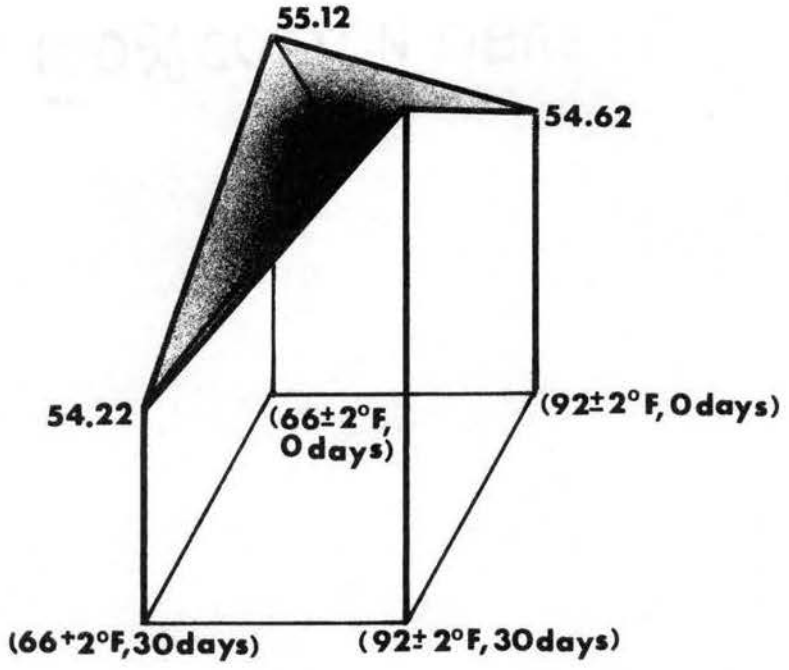

Figure 8. Interaction Surface Response of Temperature, Age, and Fabric on Breaking Strength for Polyester

The interplay of these two reaction systems changes the properties of the fibres (as dependent upon the reaction time) in such a way that the preponderant reaction picture (as measured by the tenacity and break elongation of the fibres, as prime qualities and the toughness and stiffness, as secondary qualities) can easily switch from degradation (molecular weight reduction) to cross-linking and vice versa several times during a 50-hour experiment (27).

CHAPTER V

SUMMARY AND CONCLUSION

Breaking strength specimens from the filling direction of acetate, triacetate, cotton, acrylic, modacrylic, nylon, and polyester fabrics were exposed to a 2 ppm SO_2 contaminated atmosphere. Special apparatus was constructed to produce high humidity with a range in temperature. Phase I of this experiment consisted of a high temperature - high humidity and Phase II consisted of a low temperature - high humidity. Each phase was 30 days in length, after which the specimens were divided into the unaged (conditioned 24 hours) and the aged (conditioned 30 days) groups for testing breaking strength.

After each exposure period, the presence of acid in the polluted atmosphere was confirmed by comparing the pH of a filter paper exposed to the atmosphere against the pH of the control filter paper.

The data were analyzed and the mean squares for specimens within a treatment combination were tested for homogeneity of variance using Bartlett's Test. The variances of these specimens were found to be heterogeneous, therefore the analysis was divided into three groups of fabrics. The groups were: (1) acetate and triacetate, (2) cotton, and (3) acrylic, modacrylic, nylon, and polyester. Within each fabric group a comparison was made between control and average of temperature-age combination. The control data were set aside and the remainder of

the data were analyzed to study the relationship of the effects of temperature, age, and fabrics on the breaking strength.

The analysis showed that each fabric responded differently to the humid SO_2 atmosphere. Graphic representation of the interaction of temperature, age, and fabric on a breaking strength scale appeared to be the most explanatory method of presenting the over-all effects of the polluted atmosphere on each fabric. For a better geometric description, more levels of temperature and age are needed. Acetate, acrylic, nylon, and polyester decreased in breaking strength with exposure; triacetate and cotton decreased in strength in most cases; and modacrylic increased in strength with exposure and age.

Relationships among fibers, fabric constructions, amount of SO_2 atmosphere absorbed and/or adsorbed into or onto fabrics, and chemical changes within the fiber might lead to more answers concerning an increase or a decrease in breaking strengths of fabrics in an SO_2 polluted atmosphere.

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