THE SUSCEPTIBILITY OF ANTIMICROBIAL AGENTS TO LIGHT DEGRADATION AND THEIR INFLUENCE ON DYE FADING

by

Diana Gail Johnson

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Approved by:

Barbara M Kagan

Major Professor

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INTRODUCTION

Antimicrobial agents are applied to textile for a variety of reasons, including aesthetic, hygienic, health, and medical (16, 26, 53, 73, 75). These compounds protect textiles from deterioration and discoloration caused by microorganisms, protect the wearer or user from infections, or reduce the transmission of diseases from person to person by textile items. In addition, antimicrobial agents inhibit the growth of organisms which produce offensive odors. To be effective, antimicrobial agents should be durable, effective against select microorganisms, compatible with other finishes and dyes present, and non-toxic to man (32).

Antimicrobial finishes are applied to a variety of textile products including underwear, socks, hospital gowns, towels, and carpeting which vary in fiber content and construction. Carpeting provides a favorable habitat for a large variety of microorganisms; and with increasing use of carpeting in hospitals, schools, and other institutions, a growing need for effective antimicrobial finishes for carpeting has developed. Studies (60) have shown that consumers are willing to pay over a dollar more per square yard for carpets treated with antimicrobial agents. Most antimicrobial agents work by leaching or diffusing into the surrounding environment. However, these finishes lack durability to washing and cleaning and have limited

effectiveness against specific microorganisms. Recently, developed are antimicrobial agents which covalently bonded to the fiber. These finishes impart permanent antimicrobial properties without leaching into the environment.

Some disadvantages exist in the use of antimicrobial finishes. For example, quaternary ammonium compounds have been reported to adversely effect the lightfastness of select dyes (59). In addition, pool chemicals for controlling bacteria growth and disinfectants such as air deodorizers and household sprays have been found to discolor dyes (62). Limited research has been completed on the influence of antimicrobial agents on the fading of acid dyes and their susceptibility to light degradation. The purpose of this study was to investigate the effect of light on the durability and performance of select antimicrobial agents, and the effect of these agents on the lightfastness of acid dyes.

REVIEW OF LITERATURE

Antimicrobial agents have been used since antiquity to reduce textile deterioration and to prevent the growth and spread of pathogenic organisms. The ancient Egyptians, for example, used spices and herbs to preserve the fine fabrics in which they wrapped mummies. The Romans are known to have used cedar oil as a preservative (53). In 1935, a German scientist, Domagk, reported the development of an antimicrobial agent based on quaternary ammonium compounds. This finish was applied to uniforms worn by German soldiers in World War II. These troops were reported to have fewer secondary infections following wounds and injuries (53).

Antimicrobial treatments are used for a variety of reasons including aesthetic, hygienic, health, and medical (16, 17, 53, 73, 75). These finishes are applied to textiles to retard the growth of bacteria and fungi which can cause damage to fibers or contribute to the spread of infections and diseases. In general, the growth of bacteria is usually associated with the transmission of diseases and infections. However, fungal growth is associated with textile rot and decay, resulting in strength losses, discoloration, and the production of foul odors (10). The desire for odor free textiles is illustrated by the growing market of carpet deodorizers which retails approximately $100 million annually.

In addition, the spread of infections and disease by microorganisms on surfaces and in the air can be controlled by the use of antimicrobial agents. It has been shown that pathogenic organisms can be transmitted from person to person by contact with soiled textile items. Especially dangereous are diseases of the skin and intestinal or respiratory tracts (73). The use of antimicrobial finishes in hospitals, schools, sanitariums, hotels, and motels greatly reduces the spread of infections and communal diseases.

Microbial attack is generally classified as chemical damage because organisms secrete enzymes which degrade the fiber. The growth of fungi or mildew on textiles is noted as discoloration, but is usually accompanied by a slow loss of strength. In addition to discoloration, microorganisms may alter a textiles affinity for dyes. Microbial degradation can sometimes occur simultaneously with light degradation, especially in outdoor fabrics such as outdoor carpet, tents, and cordage. Textiles treated with antimicrobial finishes exhibit less strength loss and retain their appearance longer when exposed to microorganisms than untreated fabrics.

The increased use of carpeting in hospitals, schools, and other institutions has created a greater need for durable effective antimicrobial finishes for carpeting. Hospitals regularly use antimicrobials as part of their periodic maintenance of both carpeting and hard flooring. Most

compounds used for cleaning and disinfecting work by leaching or diffusing into the surrounding area. Two disadvantages of these treatments are their lack of durability against washing and cleaning and limited effectiveness against specific microorganisms which often requires the application of combinations of antimicrobial agents (31).

Carpeting

Carpeting which has been used in homes for many years, because of its ease of care and durability, offers many advantages over hard flooring materials, such as reduction of noise, improved visual appearance, reduced maintenance cost, and increased comfort and safety (5). Carpeting introduces color into an interior and constitutes a major environmental surface (52). Factors to be considered in the selection and serviceability of carpeting generally include wear, abrasion, and crush resistance (resiliency), soil repellency and cleanability, and insulative properties (62).

Carpeting was traditionally made from wool; however, in the last forty years, traditional woven wool carpeting has been replaced by tufted carpeting containing man-made fibers. Nylon is used in 85% of the carpets produced today. Other fibers used in carpet production include polyester, acrylic, olefin (polyproplene), and wool (in order of market share). The commercial importance of nylon as a major carpet fiber is attributed to its good wear and abrasion resistance,

compressional resiliency, ease-of-care properties, and low cost as compared to other fiber types. Some undesirable characteristics of nylon fibers include easy soiling due to its oleophilic nature, discoloration by ultraviolet light, and nondissipatation of electrostatic charges (62).

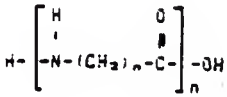
Nylon

Nylon is defined by the Textile Fibers Identification Act (69) as a manufactured fiber in which the fiber-forming substance is a long-chain synthetic polyamide in which less than 85% of the amide (-C-N-) linkages are attached directly to two aromatic rings, compared to aramids in which at least 85% of the amide linkages are attached directly to two aromatic rings. Both nylon 6 and nylon 6,6 are produced by the melt spinning process in which the polymer is melted and extruded into a cooling bath where it solidifies into ribbon form. The nylon ribbon is then cut into chips to facilitate easy storage, blending, and transportation. After blending, the nylon chips are melted and extruded through a spinnerette into a cooling stack. The filaments are then cold drawn to orient the polymer chains and develop fiber strength and fineness. A range of properties can be produced for nylon fibers, depending on the end-use.

Chemistry

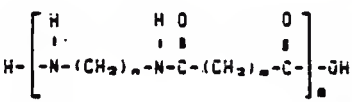
Polycaproamide (nylon 6) and polyhexamethylene adipamide (nylon 6,6) are the two most widely used synthetic polyamide

fibers. The structural repeat unit for alaphatic polyamides is generally represented as:



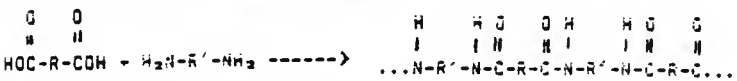
Usually polymers with this structural repeat unit are referred to as poly (w-amino acids or lactams), or as nylon-n (e.g. nylon 6 in which n=6) (62).

The structural unit for diamines and dicarboxylic acids is:



Polymers with the above structural unit are referred to as nylon nm such as nylon 6,6 where n=6 and m=6 (62).

The polymerization of polyamides can be obtained by two different methods. The first method consists of polymerization of a monoamino-monocarboxylic acid (e.g. 6 amino caproic acid, $H_2N(CH_2)_5$-COOH, or their amide forming derivatives). In the other method, diamines are reacted with dicarboxylic acids as shown below:



Where R and R' are hydrocarbon groups.

Nylon 6 is polymerized from caprolactam, whereas nylon

6,6 is produced by reacting hexamethylene diamine and adipic acid to form a polyamide. Nylon 6,6 and nylon 6 both have 6 carbons between each amide group. Polyamides usually are distinguished by the number of carbons present in each repeat unit.

Physical Properties

Since nylon is a man-made fiber, its diameter, cross-sectional shape, and physical properties can be controlled during manufacturing. For example, nylon generally is produced in medium to high tenacities ranging from 4.5-5.8 gf/denier for nylon 6,6 and 5.6-7.0 gf/denier for nylon 6 (41). Typical deniers for carpet fibers range from 13-18 (3, 64). Nylon also has high elasticity. The most significant factors contributing to the success of nylon as a major carpet fiber are it's high abrasion resistance and resiliency which are related to its inherent strength and elongation properties.

The cross-sectional shape of nylon fibers which affects such properties as soil retention, appearance, hand, surface texture, and luster, is determined by the spinnerette shape, extrusion condition, and methods of spinning. Common cross-sectional shapes for fibers include circular or oval, triangular, dog-bone, U shaped, and hollow (35). However, in nylon carpeting, the fiber cross-sections are usually trilobal or Y-shaped. Trilobal fibers generally have

increased covering power, a more silk-like feel, and increased luster over other cross-sectional shapes (35). The increased luster is due to light being reflected from one lobe to another, as well as from the surface of the fiber. In addition, this cross-section causes fibers to appear more opaque and reduces "apparent soiling." Light is deflected or scattered from the fiber surface by the lobes reducing fiber transparency (35). Other properties which effect the soiling properties of nylon are its poor electrostatic properties and oleophilic nature.

Nylon also has good chemical resistance and is not affected by alkalies and most organic solvents. However, various phenols which are found frequently in household disinfectants do damage nylon. Nylons are also damaged by mineral acids such as hydrochloric, nitric, and sulfuric acids (41). These acids cause nylon to disintegrate or dissolve almost immediately. Acid fumes in the air of industrial regions have been known to weaken the fiber to the point of disintegration (62).

Nylon, like other synthetic fibers, is resistant to damage by most insects and microorganisms. However, some insects, such as ants, carpet beetles, and roaches will cut or eat away nylon if trapped beneath the textile (41). Microorganisms do not damage nylon fibers, but textiles made from nylon may be made unserviceable by staining and odors

which accompany microbial growth on adjacent natural fibers, food stains, or dyes and finishes on the fibers. Nylon, like most synthetic fibers, has a greater retentivity for microorganisms than do natural fibers (38).

Carpet Construction

Presently 85% of carpets produced are tufted carpets, followed by woven, and to a much lesser extent fusion bonded, knitted, and needle-punched carpeting (3). Tufting is the fastest and most economical method of manufacturing carpet. Simply stated, tufted carpets are produced by needles which insert loops of yarn into a backing material, usually made of polypropylene or jute. The needles which often number over 1,000 can be adjusted to vary the height of individual loops to create numerous styling effects (66). If a cut pile is desired rather than a loop pile, a knife is used in conjunction with the needles. In order to hold the loops in place, a layer of liquid latex is applied to the underside of the backing material (66).

Two carpet types produced by weaving are the Wilton and the Axminster. Wilton carpets are produced on a Wilton loom which has a Jacquard attachment and can utilize up to six different colors (35). These carpets are known for their durability and intricate patterns (3, 35). Axminster carpets are formed by drawing pile yarns from small spools and weaving them into the ground warp and filling. This method

offers the advantage of limitless color use and design possibilities (3).

A newer method of carpet construction, fusion bonding, embeds the pile yarn into a liquid backing which usually is a vinyl compound. As the backing solidifies, the tuft becomes fused or bonded. The main advantage of this technique is the degree of tuft-bind achieved between the pile and backing (3). Knitted carpet is formed by looping the pile and backing yarns together. These carpets usually are produced in solid colors or tweeds and have a relatively flat low pile (3). In the needle punching process, pile fibers are entangled in a loosely woven carrier fabric by barbed needles. This method was orginally developed for the production of indoor/outdoor carpets (3).

Carpet Finishing

According to Robinson (66), the main functions of carpet finishing are to repair defects and to enhance the appearance and functional properties of the carpet. After tufting or weaving, carpets usually proceed through mechanical finishing processes including brushing, shearing, steaming, inspection, and mending. Brushing reduces pilling and removes loose fibers from the pile of the carpet. The shearing process is done to even up the pile, while steaming removes wrinkles and creases from the carpeting and causes yarns to untwist or "bloom". During inspection, knots are removed and missing

tufts are sewn in by hand.

Next, a backing is applied to the carpet in order to impart adequate tuft-bind (i.e., the measure of force required to pull one tuft of the pile out of the carpet) and strength (3). Generally, the back-coating consists of latex or resin which locks tufts into place. Other common backing materials include polyvinyl alcohol, rubber, and polyacrylate. A secondary woven backing made of jute, polypropylene, etc. also may be applied to the carpeting to enhance strength and dimensional stability (66).

After backing, other finishes such as soil repellants, antistats, flame retardants, and antimicrobial agents may be applied to the carpeting by spraying. This technique consists of spraying the finish onto the carpet through jets spaced across the width of the carpeting. Many manufactures prefer to add these agents at the fiber stage because of the disadvantages of spray finishing (i.e., resistance to penetration by the pile and clogging of spray nozzles causing skips in application) (3). However, many finishes are applied as topical finishes by the carpet mill.

With the increase of computer use in the home and office more attention has been directed toward reducing the static propensity of carpeting. Carpets may be designated as residential and non-electronic carpeting, carpeting for areas where electronic equipment will be used, or as carpeting for

production areas. Static propensity of carpeting is affected by many factors (i.e., fiber type, environmental conditions, and moisture present). Most antistatic agents function by improving the rate of dissipatation of an electrical charge. This can be accomplished by the use of electrically conductive fibers (i.e., metal or carbon containing fibers), conductive latex backings, and hygroscopic fibers and finishes. Hygroscopic finishes which are becoming increasingly important include organic salts, sulfonates, phosphate esters, tertiary amines, quaternary ammonium compounds, and polyethylene glycols. These compounds differ in durability and performance. The static propensity of the carpet fibers also affects soiling characteristics by attracting or repelling soil particles.

Soil repellant and soil release topical finishes are numerous and vary in quality and price. The fluorocarbon compounds are the most effective, but also the most costly. Other compounds commonly used as soil repellant finishes include silicone, pyridinium, and triazine compounds. These finshes can work by coating the surface of the fibers to prevent soil from embedding in cracks or convolutions or by enhancing the soil release properties of the fiber. Other methods for producing soil repellent textiles include blockage of dye sites to prevent absorption of stains such as grape juice or modifying the fiber surface by

transesterfication, partial hydrolysis, or grafting a soil repellant compound to the surface. The most widely used fiber producer or mill applied soil repellant finishes for carpeting are 3M's Scotchguard and Dupont's Teflon both of which contain fluorocarbons. In addition, commercial after market (post treatment) anti-soiling carpet protectors are available which contain fluorocarbons, siloxanes, fluorocarbon/siloxane mixtures, acrylic copolymers, colloidal metal particles or silica, etc.

Flammability of carpets is extremely important both at the residential and commercial levels. Flame retardant finishes on textiles generally promote complex char formation and/or prevent further degradation or production of volatiles. Generally, flame retardant compounds contain antimony, phosphorus, nitrogen, chlorine, or bromine. Presently, the two most important durable flame retardant compounds are halogen/antimony systems and phosphorous/nitrogen based compounds.

As previously mentioned, antimicrobial finishes are becoming increasingly important in carpet production and marketing. These agents can work by leaching and diffusing into the surrounding area, or they may be permanently bonded to the fiber, killing the microorganism by interruption of the cell wall. The major classes of antimicrobial agents used on textiles are the organo-silanes, organo-metallics,

organo-phenols, and quaternary ammonium compounds.

Chemistry of Dyestuffs

Today, the majority of textiles produced are dyed either at the fiber, yarn, or fabric stage. Textile producers select dyes on the basis of chemical structure of the substrate, requisite fastness properties, method of application, etc. Dyes may be classified by origin (natural or synthetic), application class, or chemical structure. A specific chemical class of dyes may be found in several application classes (62, 70).

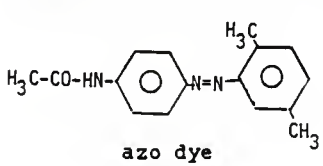
The first synthetic dye was discovered in 1856 by William Perkin (70). Since then, thousands of synthetic dyes have been developed, and considerable research has been conducted to determine the molecular structure of dyes in an attempt to correlate chemical structures with properties, substrate affinity, and application parameters (70).

Dyes are colored because they selectively absorb various wavelengths of visible light. Chemical groups or chromophores give substances potentiality for color (70). Nitro, nitroso, azo, and carbonyl are a few examples of chromophores. These chemical groups are assisted by other functional groups referred to as auxochromes which include amine, substituted amine, hydroxyl, sulphonic, and carboxy groups. In general, the greater the number of chromophores present in a dye, the darker the color (70).

The fiber type determines a textile's affinity for specific dye classes. Crystallinity, molecular orientation, and chemical composition of the fiber also affect its ability to absorb dyes. For example, nylon 6 has a greater proportion of amorphous regions and more amino end groups than nylon 6,6. For these reasons, nylon 6 exhibits higher rates of dye absorption, and better leveling properties than nylon 6,6 (70). Nylon can be dyed using most disperse, acid, chrome, metallized, and basic dyes.

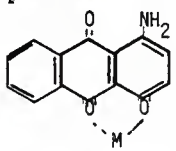
Disperse Dyes

Disperse dyes were orginally developed for acetate fibers. Today they are used in dyeing acetate, polyester, acrylic, and polyamide fibers. Disperse dyes usually are primary, secondary, and tertiary amines of amino azo benzenes, or amino anthraquinones (62). In most instances, disperse dyes are azo (mainly monoazo) or anthraquinone compounds substituted by NH_2 or NRR' in which R and/or R' are $-CH_2-CH_2-OH$, $-CH_2-CH_2-CN$, or similar groups designed to balance hydrophobic or hydrophilic properties.



azo dye

C. I. Disperse Yellow 3



anthraquinone dye

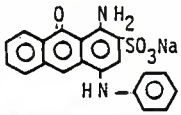
C. I. Disperse Red 15

Disperse dyes are brought to a state of suspension in a

dyebath by adding water and a suitable dispersing agent. The colored particles attach to the fiber surface and then dissovle into the fiber. If disperse dyes are applied to polyester or nylon at low temperatures or if high energy disperse dyes are used, carriers often are required to facilitate dye uptake and to achieve the required depth of shade (42, 68, 70). A combination of high temperatures and high pressures through thermolsoling eliminates the need for carriers.

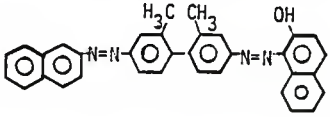
Acid Dyes

Acid dyes are anionic compounds, usually available to the dyer in salt form. These dyes generally are applied to the fiber from solutions containing mineral or organic acids such as sulfuric acid, formic acid, acetic acid, or ammonium sulphate. Acid dyes are used on protein, modified acrylic, and nylon fibers containing nitrogenous basic radicals which provide sites for ionic bonding. Important chemical classes of acid dyes include nitro, nitroso, monoazo, diazo, quinoline, triphenyl, methane, xanthene, anthraquinone, and azine compounds (70).



anthraquinone dye

C. I. Acid Blue 25



diazo dye

C. I. Acid Red 99

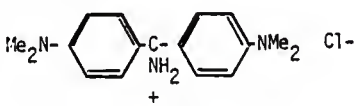
Three main application methods are used to apply acid dyes, based on the acidity of the dyebath and concentration of the electrolyte. Acid Leveling Dyes are applied at a low pH (<3.5) with sulphuric acid. Glauber's salt is used in the dyebath as a retarding agent to control the rate of dye exhaustion. Milling Acid Dyes are applied using acetic acid to maintain the pH of the dyebath between 3.5 and 5.5. As in Leveling Dyes, retarding agents also are used to reduce the rate of exhaustion. In applying Super Milling Dyes or Neutral Acid Dyes, ammonium acetate or ammonium sulfate is used to maintain the required pH of 5.5-7.0. Glauber's salt is not used in this method, since it accelerates rather than retards the rate of exhaustion. The lightfastness and washfastnesses of the Super Milling Dyes are usually greater than dyes from the other two methods (70).

Other Dye Application Classes

Although nylon fibers can be dyed using chrome, metallized, and basic dyes, they are not as commonly used as acid or disperse dyes. Chrome dyes belong to the mordant dye class and require a chromium salt in order to form an insoluble compound within the fiber. Chrome dyes generally are used to dye protein fibers, especially wool. Metallized dyes are a special class of chrome dyes where the chromium or other metal ion has been introduced into the dye molecule during manufacturing. The metal complexes with the dye to

form relatively insoluble dyestuff. Metallized dyes are primarily used for dyeing wool with techniques similar to that of acid dyes (41).

Basic dyes can be used on cationic dyeable carpet yarns for styling purposes such as bidyes or tridyes and to acheive differential dyeing effects (62). These dyes are salts of organic bases. Basic dyes have a direct affinity for silk, wool, nylon, casein, and related fibers. The dye molecule is positively charged (cation) and forms ionic bonds with anionic dye sites in the fiber.



C. I. Basic Yellow 1

Colorfastness of Dyes

Commercially, sucessful dyes must possess adequate fastness properties to a variety of agents. Fastness to light, cleaning, atmospheric contaminants, and the presence of other chemicals (i.e., acne medicines, pesticides, and other textile finishes) which may degrade or alter the chemical structure of the dye needs to be considered when selecting dyestuffs for carpeting and other textile end-uses. Dyes within the same application and chemical class may differ considerably in fastness properties, and the same dye may have different fastness properties when applied to

different fiber types.

When dyes degrade, they may exhibit a change in shade (hue) and/or a loss in depth of shade (62). Colorfastness of dyed fibers may be affected by the chemical structure of the dye (i.e., structure of chromophore, functional groups present, and their position) and the physical state of the dye (i.e., the molecular weight and size and shape of the dye molecule). The more finely a dye is dispersed within the fiber, the more rapidly it can fade. Ideally, dyeing conditions will produce large aggregates within the fiber. Since large aggregates expose a smaller surface area of the dye to air and light, fastness is usually improved. In addition to the parent auxochromic groups, chemical dye structures also may affect the fastness properties of the dye. The introduction of different substituted functional groups such as amino, amino-hydroxyl, amino-chloro, and amino-carboxyl groups often results in a decrease in lightfastness properties. Shakara and Ghettas (67) reported that hydroxyl and amino groups tend to accelerate fading of azo dyes, and alkylation of the amino groups will accelerate it further. Chlorine and bromine atoms as well as sulfonic and carboxylic groups will retard fading with the last being the most powerful (67).

The position of substituents also affects the lightfastness of a dye. In azo compounds, nitro groups

substituted in ortho or meta positions with respect to the -N=N- center will decrease lightfastness. However, nitro groups substituted in the para position may increase or decrease lightfastness within the compound. Intermolecular hydrogen bonding increases lightfastness of azo dyes, while intramolecular hydrogen bonds decrease lightfastness (67).

Many environmental and chemical factors are known to cause fading of dyed textiles. The intensity and spectral distribution of light to which a dyed textile is exposed, the dye type, substrate, and external factors (i.e., temperature, relative humidity, and atmospheric contaminants) will influence fading in textiles. Light causes fading of dyes by altering the electronic state of the dye molecules so that they may react with surrounding elements such as oxygen in the air or with the fiber itself.

Gas or fume fading of textiles has been observed in many industrial and urban areas where appreciable amounts of smoke, sulfur dioxide, and nitrogen oxides are present in the atmosphere. Most fading caused by nitrogen oxide gases occurs on the amino groups present in select dye molecules, especially anthraquinone disperse dyes (21). The amount of fading is dependent upon the neucleophility of the amino or alkyamino groups present in the dye structure (62). First, the gas must be absorbed into the fiber, after which it reacts with the dye molecule. Initially diazotization of

primary amino groups in the dye molecule will occur, followed by nitrozation of the secondary amino groups. Finally fading will occur due to oxidation of the dye molecule (62).

Ozone (O_3) also has been reported to cause fading in dyed textiles. The majority of ozone fading complaints of nylon came from the Gulf Coast states where humidity and temperature are high most of the year (42). High humidity and temperature may contribute to ozone fading of dyes (42). Moore et al (56) reported that the ozone fading of acid and disperse dyes in polyamides correlates with disorption behavior. Typically dyed materials which exhibit poor washfastness are rapidly faded by ozone. Ozone is a more powerful oxidizing agent than nitrogen dioxide, since it can easily react with nucleophilic groups such as those that react with nitrogen dioxide (62).

The washfastness of dyes is dependent on the size of the dye structure and the method of dye-fiber association. Dye molecules with a larger chemical structure are more resistant to washing, compared to smaller dyes that are more readily removed. Hydrogen bonding offers less substantivity and resistance to washing than covalent or ionic bonding. Although the washfastness of dyes is not as important in carpeting as in other textiles, dyes in carpeting should withstand regular cleaning. Steam cleaning and shampooing are two common methods of carpet cleaning which expose the

carpet to moisture and cleaning agents.

The fastness properties of dyes also maybe affected by many different chemicals with which they come in contact with during manufacturing or use. Allied-Signal, Inc. (45) has found that many dyebath auxiliaries will adversely affect the lightfastness of carpet dyes. Cationic agents, particularly fatty amines, were found to be the most detrimental to the lightfastness properties of dyed nylons. Other chemicals which affect lightfastness properties include staple overfinishes, ultraviolet absorbers, and metal salts (45). For example, low grade mineral oils used as staple overfinishes which are applied before heatsetting and dyeing can reduce lightfastness. These mineral oils are usually yellow in color. Antiozonants which have been used for many years to reduce gas fading of textiles also may produce negative effects on the lightfastness of dyes on nylon (45). Most of these compounds contain amines of some type.

Ultraviolet light absorbers in concentration of 1 to 2% o.w.f. (on weight of fabric) will improve the lightfastness of acid dyes. They usually are applied to nylon during the dyeing operation. It has been reported that nylon carpeting treated with UV absorbers usually can withstand an additional exposure of up to 20 AFU's (AATCC Fading Units) (45). In the automotive industries, metal salts are added to the a dyebath to increase lightfastness (2, 45). Some zirconium based

fungicides also may improve light and weather resistance of dyed fabrics when exposed outdoors (18).

Spot or localized fading has been linked to a number of substances which come into contact with carpeting during consumer use. These substances include spot cleaning agents, laundry bleaches, and kitchen and institutional cleaners. Spot fading occurs when a small portion of carpet is faded noticeably, compared to the rest of the carpet. Chlorine based chemicals may cause yellow spotting and cause dyes to fade to an off white color (62). In addition to cleaners, spot or localized fading may occur due to other substances being spilt on the carpet such as plant foods, fertilizers containing organophosphates, dandruff shampoos containing sulfur compounds, and tile cleaners with strong detergents (62). All of these substances contain chemicals that may react with the dye or fiber, causing fading and/or deterioration of the carpeting.

In the last few years, numerous carpet discoloration complaints have been associated with acne medicines and pet care medicines containing benzoyl peroxide. Benzoyl peroxide, a strong oxidizing agent, is insoluble in water and cannot be easily washed off skin or out of fabrics. Very low concentrations (0.2%) of this chemical are capable of destroying most dyestuffs in carpeting. The reaction of benzoyl peroxide on dyes often results in a bright yellow

stains on polyester, cellulosic, or polyolefin fibers. On blue carpet the spots usually appear slightly pink (15, 62). Face creams used for the removal of freckles, birthmarks, and other darkened areas in the human skins have also been found to fade dyes (62).

Other chemicals which may cause fading in dyes include quaternary ammonium compounds, pool chemicals, and disinfectants. Cationic softeners such as quaternary tertiary amines have been reported to cause discoloration and yellowing of textiles (59). Quaternary ammonium compounds are used as temporary or semidurable antibacterial agents in hospitals, schools, and other institutions. Discoloration of dyed fibers also may result from pool chemicals used for cleaning and controlling bacterial growth (62). Disinfectants such as air deodorizers and houshold sprays containing phenolic chemicals are solvents for some fibers and dyes (62).

Microorganisms

Microorganisms may prosper in any environment, including soil, water, air, plants, animals, and man (34, 36). In textiles, microorganisms will grow more abundantly in areas where soiling and spills occur frequently. Soiled areas provide the organisms with nutrients and moisture needed for growth. In hospitals, microorganisms are found abundantly on blood and urine stained textiles. Yarn and fabric construction characteristics such as type of weave, threads per inch, etc., also may affect the number and type of organisms present (7). Microorganisms may grow on the surface of fabrics, be attached to fibers, be held mechanically in the interstices of the fabrics, or held within the fibers themselves (27, 63).

Microbial growth on textiles may result in textile rot and decay and contribute to transfer of diseases (50). Strength loss in textiles is often due to enzymatic digestion of a substrate by fungi. In addition, fungi are associated with discoloration of textiles and odor production. Bacterial contamination of textiles is usually associated with the spread of diseases from individual to individual.

Microorganisms are generally small and simple in structure. Most are unicellular organisms or aggregates of independent cells showing little, if any, specialization of function. However structural simplicity does not indicate

physiological simplicity. Microorganisms perform the same fundamental tasks which "higher organisms" do with their multi-celled structures (i.e., utilization of food, energy formation of new protoplasm, and reproduction) (14). The seven principal types of microorganisms include bacteria, mold or fungi, protoza, algae, yeasts, rickettsiae, and viruses (34, 36). These organisms differ widely in nutritional habits, structure, size, and chemical composition.

Bacteria

Bacteria were first described by Van Leeuwenhoek in 1683, but critical studies of these organisms did not begin until the early nineteenth century (34). Since their discovery, bacteria have been classified using many different methods. These organisms may be identified by their genomes, proteins, cell components, or morphology. Traditionally, bacteria have been identified by their morphology, staining characteristics, and physiology (13).

Cell shape is one of the first characteristics used in bacteria identification. Most bacteria may be characterized as bacillary (rod shaped), coccus (spheres), vibrio (comma shaped), spirillum (rigid sine-curve shaped), and spirochete (flexible spring shaped). These cells may exist singly, in chains, or in clumps (13).

Bacteria may also be divided based on the type of cell

wall they have by using a Gram stain. This staining technique consists of treating the organism with an aniline dye, crystal violet, followed by a solution of iodine. Next the organisms are treatd with ethyl alcohol, and then treated with a counter stain, safranin. If crystal violet is removed by the alcohol, the organism is designated as gram negative, but if the dye is not removed the organism is designated as gram positive.

Gram positive organisms are predominantly pathogens in humans and mammals. They also have industrial uses such as in food preparation and synthesis of antibiotics and certain insecticides (13). A gram positive coccus, Staphylococcus aureus which is commonly used in testing the effectiveness of antimicrobial finishes on textiles is found living as a commensul on normal skin and often is in the noses of healthy people (8). This organism causes a highly infectious type of bronchio pneumonia, sepsis in accidental or surgical wounds and burns, and acute pyogenic (pus producing) infections in man. Staphylococcus aureus also causes deterioration of cotton fibers. Damage from this organism appears as transverse and helical cracks, fissures, surface etching, pitting, and partial or complete dissolution of the outer wall of the fiber (10).

Gram negative bacteria differ from gram positive bacteria by having an additional cell membrane between the

outer cell wall and the plasma membrane. This is a broad group that includes primarily human pathogens (13). Escherichia coli is a rod shaped gram negative bacteria. This organism inhabits the gastrointestinal tract of mammals and may cause intestinal diseases (13).

Generally, bacteria present only a minor threat to textile fibers. Bacteria usually are less important than fungi in the breaking down of cellulosic textiles. However, under anaerobic conditions where fungi are active, bacteria may cause oxidation of cellulose by the secretion of toxins (12). Bacteria do promote the spread of disease and infection. As previously noted, the human body is inhabited by Staphylococcus aureus and other bacteria, many of which may be transferred to textiles during wear or use. These soiled textiles may become the medium for the spread of diseases. Staphylococcal infections that have swept entire hospital wings are thought to have been assisted by contaminated bedding (12). In addition, bacteria may be tranferred from textile items during laundering. With growing emphasis on energy and water conservation (i.e., cold wash temperatures and recirculation of water), the transfer of microorganisms in laundry becomes more problematic (54). Bacterial transferral also may occur during drycleaning, since textiles are not generally sterilized by chlorinaterd solvents (9).

Fungi

Fungi usually are larger than bacteria, and only about 100 are considered pathogenic to man. However, fungi can have determintal effects on both the appearance and properties of textiles. Two important groups of fungi are molds and yeasts. Molds grow by branching filaments or hyphae which interlace to form a vegetative meshwork or mycelium (14). Molds are either saprophytic or parasitic in nature. Saprophytic molds feed on nonliving organic matter such as stored food and textiles. Parasitic molds generally attack plants, although a few species may cause disease in animals and man (14). Some fungal colonies cause spotting of cloth, either by addition of their own pigments or by chemical reactions with dyes applied to the fabric. The chief textile mildews are the genera Penicillium, Mucor, Aspergillus, Fusarum, and Trichoderma. Cotton deterioration during storage is usually caused by species of Stachybotrys (33).

Yeasts are large microscopic organisms which generally multiply by budding. Yeasts can grow in acid to slightly alkaline environments at moderate temperatures. Although these organisms can grow without oxygen, their rate of reproduction is greater when oxygen is present (14). Yeast are extensively used in the manufacture of alcohol and alcoholic beverages and in bread making. These organisms

also can cause spoilage, especially in items containing sugar (14).

Moisture, warm temperatures, and poor ventilation contribute to mildew growth and damage on textiles which may result in (33) discoloration with a musty odor and loss in fabric strength. The characteristic musty smell is generally the first sign of mildew growth on textiles, followed by the appearance of colored spots formed by the growing hyphae. These yellowish brown stains usually can be brushed off, but the hyphae growth of the mildew inside the material remains (33). Characteristic colors of species of mildews will appear with the sporebearing organisms. Some typical examples are greenish stains produced by Penicillium chrysogenum, and brown stains by Aspergillus niger (33). Strength loss usually results from the enzymatic digestion of the substrate and the hyphae penetrating the lumen of cellulosic fibers causing cracks and fissures within the cell wall (45).

Protozoa and Algae

Two other principal groups of microorganisms are protozoa and algae. Protozoa are considered by many to be a unicellular animal. There are approximately 30,000 species of protozoa which vary in size, form, and mode of life (34). Some protozoa are only slightly larger than bacteria, while others are visible to the naked eye. Protozoa may be found

abundantly in soil, fresh water, or sea water and usually have minimal adverse effects on textiles.

Algae are the simpliest chloraphyll-containing plants and are predeominantly aquatic in nature. These organisms obtain nutrients through the process of photosynthesis. Microscopic, single cell species of algae may be found in many shapes including sperical, rod, clubs, and spirals. Multicellular species exhibit great variation in complexity and shape. Some algae which appear to be multicellular are actually simple aggregations of single identical cells held together by a slimy gelantinous outer coat (14). These organisms often present a problem on marine and outdoor textiles.

Viruses and Rickettsiae

Both viruses and rickettsiae are parasitic and pathogenic to man. Animal viruses display considerable tissue specificity. They may infect the skin, nerve tissue, respiratory tissue, and gastrointestinal tract. Bacterial viruses only infect certain species and often a single strain of bacterium (14). Primarily rickettsiae are parasites of arthropods and can be found in some wild rodents. Many can affect man, producing diseases of very high mortality. Neither viruses nor rickettsiae have detrimental effects on textiles.

Microbial Growth

Microorganisms are able to grow on the surface and the pile of fabrics, in the interstices of the fibers, or within the fiber itself. Factors reported to influence the survival of microorganisms include genetic differences between strains of microorganisms, physiological characteristics of microorganisms, mode of exposure, temperature, relative humidity, light, fiber type, fabric construction, and chemical finishes (55, 78). For example, natural fibers such as cotton, wool, and silk are more readily damaged by microorganisms than synthetic fibers. However, there are presently no chemically unaltered natural or synthetic fibers which are inherently microbiostatic (73). A study by Isoard and Crance (39) claims that while synthetic fibers are more resistant to microbial growth, they show a greater retentivity of bacteria than do natural fibers. The presence of natural secretions or textile auxilaries and the degree of preliminary fiber damage will influence the severity of microbial attack and the structure of the microbial community. In addition, construction of textiles (i.e., thickness, mass per unit area, weave) will affect the number of organisms within textiles (7).

Carpeting is an extremely agreeable habitat for microorganisms, especially when fortified by nutrients from foreign substances such as food spills, pet wastes, cleaning

residues, hairs, and even some dyes, resins, and afterfinishes found on synthetic fibers (30, 52). Moisture can be obtained from obvious sources such as spills, floods, and water leaks. Less obvious sources are heating and cooking fumes, humidity, perspiration, and condensation which may provide moisture to facilitate microbial growth (50).

Other environmental factors which are important to microbial growth include humidity, pH, temperature and exposure to light, and other stimuli present in the environment. When humidity is increased, the death rate of most bacteria increases (55, 79). Exposure to daylight, low intensity ultraviolet radiation, or fluorescent lights often increase the death rate of bacteria (55, 78).

Fiber type also affects the persistance of bacteria in textiles. The physical characteristics of the fibers themselves such as the scales of wool fibers and the twisted convolutions of cellulose fibers undoubtedly influence the attachment of bacteria (78). It also is thought that the electrical charges on the surface of the fabric and the bacterial cell are important in bacterial adherence. Yarn type, weave, and moisture content of a fabric also influence the persistance of bacteria in textiles.

Microorganisms can be removed from textiles by a variety of methods with the most common method being laundering in hot alkaline solutions containing bleach (73). However, the

use of lower temperature washing and drying conditions and the increase use of commercial laundry facilities have resulted in greater transferrance of microorganisms from textiles during laundering. In the drycleaning processes, Banville and McNeil (9) found that steam finishing and pressing appeared to kill more bacteria than other stages of cleaning. However, the type of steam treatment given to different articles varies too much to be relied on for disinfection.

In hosptitals, textiles are generally autoclaved or gassed with ethylene oxide to reduce microorganisms. Industrial processes often use ionization radiation (65). Reagan et al (65) studied the potential effect of microwaves as a sterilizing technique. They found that certain types of vegetative cells (i.e., Staphylococcus aureus, and Escherichia coli) can be eliminated by microwave energy with a 7-minute exposure time. Microorganisms also may be released from fabrics by movements such as bedmaking, dressing, sorting laundry, and excercising (53). However, these movements only release the microorganisms, transferring them to other surfaces without killing them.

Microbial Degradation

Microbial growth can cause a variety of spoilage phenomena in textiles, including odor production, fiber tendering, strength loss, and variable pigmentation (50).

Factors which affect the rate of decay by microorganisms are the same factors that govern their growth such as temperature, pH, moisture, nutrient availability and other environmental factors. Damage from microorganisms may occur at any stage of textile production.

Cellulosic Fibers

Plant fibers, such as flax and cotton, consist largely of cellulose. The enzyme cellulase, which is produced by the growth of organisms on cellulose substrates, enables microorgansism to attack these fibers. How this process occurs is not clearly understood. Two stages seem to be involved in which the crystalline micelli is broken down first, followed by hydrolysis of the cellulose to cellobiose. Hydrolysis may occur either in an endwise or random manner, depending on the organisms attacking the fiber (34). Cellulose degradation occurs when the cell wall of the fiber is penetrated by the growing fungal hyphae. The hyphae grow in the lumen, eroding the fiber from within. Bacteria, on the other hand, generally attack from the outer surface of the fiber to which they become closely attached. Bacteria seem to be less important than fungi in cellulose breakdown. However, in anaerobic conditions where fungi are less active, bacteria become more important. Under these conditions, bacteria may cause oxidation rather than hydrolysis of cellulose (34).

Cotton fibers are contaminated by microorganisms from the soil during growth. Counts of as many as 58 millon bacteria and 400,000 fungi per gram of fiber have been recorded (36). Generally, processing of cotton is carried out under conditions of high relative humidity which favors fungal growth.

Unlike cotton, bast fibers must be separated from the remaining stem tissues before spinning. This is done by a retting process in which microorgansisms are allowed to break down the tissues, leaving the fibers intact. However, the process must be controlled so that the fibers themselves are not damaged by the organisms. Long vegetable fibers such as flax have a higher degree of molecular order (crystallinity) and are less reactive. Thus, these fibers are more slowly degraded by microorganisms (43).

Animal Fibers

Because animal fibers are proteinaceous, the microorganisms which caused spoilage on wool are different from those which attack cotton and flax. Both silk and wool fibers show more resistance to microbial attack than either cotton or flax. The growth of microorganisms on wool usually results from fiber surface impurities and, in general, require very high humidities (43). Some species of Penicillium and Aspergillus form colored stains on the fibers which are difficult to remove. Although the common form of

microbial degradation of wool is discoloration, some organisms may attack the fiber by entering between the scales. Actinomycetes decompose keratin, causing a loss of mechanical properties and structure. Attack of this nature is believed not to occur unless the fiber has been previously damaged by mechanical or chemical means. Proteolytic bactera and fungi may degarade wool by rapidly loosening the cuticular scales, decomposing the intercortical matrix, and dissociating the spindle shape cortical (43). The natural grease in raw wool provides nutrients for organisms. Clean wool appears somewhat resistant to attack without the grease to support the organisms. Silk gum has sufficient nitrogeneous matter to support mold growth which can degrade the fiber (33). Degummed silk is less susceptible to microbial attack than cellulose fibers due to the removal of nutrient polysaccharides during the degumming process.

Synthetics

As stated previously, synthetic fibers are resistant to microbial attack. Spoilage caused by microorganisms may occur on these fibers due to degradation of applied resins, dyes, and finishes or by natural fibers used in conjunction with synthetic fibers. Synthetic fibers, however, do show a greater retentivity for microorganisms than natural fibers (39, 73).

Antimicrobial Agents

In the last few decades, the prevention of microbial attack on textiles has become increasingly important to consumers and textile producers. Concern has focused on both the actual degradation of the fibers and deterioration of the asethetic properties of the fabric. Hence, many antibacterial, antifungal, and antimicrobial finishes have been developed which vary in durability and effectivenss against microorganisms. The term antimicrobial agent is applied to chemicals intended for preventing, destroying, or controlling the growth of microorganisms. These agents can be broken down into bacteriostats or fungistats which inhibit the growth of microorganisms, and bacteriocides or fungicides which actually kill the microorganisms (74).

Most antimicrobial agents work by interrupting the metabolic or life processes within the microbial cell. Most organisms have a cell wall and often a cell capsule which acts as a barrier to toxins (77). Generally, unbound antimicrobial agents diffuse from the fabric and must be consumed by the microorganisms in order to be effective. Bound antimicrobial agents function by interrupting the cell membrane, killing the organisms on contact (77).

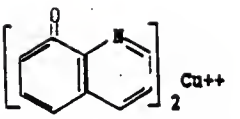
Numerous classes of chemical compounds have been utilized at one time or another to impart antibacterial activity to textiles and to disinfect or sanitize them (9,

25). Many of these compounds produce antimicrobial activity by leaching or diffusing into the surrounding environment, but they lack durability to washing, cleaning, and shampooing (76). Agents currently being used on carpeting can be divided into three basic chemical groups organo-metallics, organo-silanes, and phenols (11).

Metal and Organo-metallic Salts

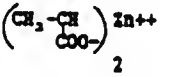
Metal and organo-metallic salts are well known for their antibacterial and antifungal properties and demonstrate satisfactory use as antimicrobials on a number of textile products, especially those containing polyester, cotton, and other cellulosics. These heavy metal compounds contain Hg, Ag, Cu, Zn, etc. and are used as fungicides on outdoor fabrics, such as tents and awnings and to a lesser extent on apparel items, because of their adverse effect on color and odor. Both the anion and the metal cation influence the overall antimicrobial properties. Organo-metallics form coordinated bonds with the hydroxyl groups on cellulose and are effective at low concentrations. For example, when used as mildew inhibitors, only about 1% metal based on fabric weight is required (1).

Copper-containing compounds are widely used as fungicides. For example, copper-8-quinolate is used in finishing tents and tarps. It frequently is applied in conjuction with water repellent finishes.



Copper-8-quinolate

Zinc-containing compounds such as zinc chloride ($ZnCl_2$) and zinc acrylate, also are used as antimicrobials for textiles. Zinc chloride is a soluble salt which can be deposited on the fabric to impart fungicidal properties. Zinc acrylate, on the other hand, is produced by grafting or polymerization of acrylates on the cellulose in conjunction with Zn++ and Cu++ to impart bactericidal properties.



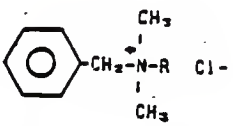
Zinc acrylate

Zirconium compounds when exposed to weathering demonstrate only minimal fungicidal properties. Zirconium acetate may be reacted with peroxides (18) or other active antimicrobials such as pyrithiones (58) to produce durable antimicrobial finishes.

Quaternary Ammonium Salts

Quaternary ammonium salts or onium salts are an important class of antimicrobial agents. Generally, the quaternary ammonium salts containing three short chain,

alkyl/aryl groups and a long chain alkyl group (i.e., alkyl dimethylbenzyl ammonium chloride) are the most effective (45, 49). Common quaternary ammonium compounds used on textiles include quaternary ammonium naphthanate, alkylbenzyldimethyl ammonium chloride, dodecyldimethylbenzyl ammonium cyclopantante carboxylate (1).

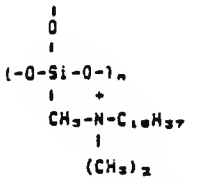


Alkyl dimethylbenzyl ammonium chloride

Where R = C8 - C18

These compounds are used as bactericides in deodorants and skin anticeptics, as disinfectants and sanitizing rinses in laundering, and as antimicrobial finishes for textiles. Textile applications for quaternary ammonium compounds include surgical bandages made of cellulosic fibers, nylon carpeting, and other apparel and interior furnishing textiles containing fiberglass, polyester, and other synthetic fibers. Quaternary ammonium compounds function by disrupting the delicate cell membrane and, therefore, do not need to be absorbed in a solution to kill bacteria (28). The high solubility of these compounds creates difficulty when trying to produce a durable antimicrobial finish for textiles.

However, natural and man-made fibers can be made permanently microbiostatic by treating with organosilicone polymers containing pendant quaternary ammonium groups (73). These compounds fall into the classification of organo-silanes.



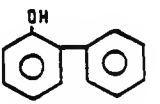
3-Trimethyloxysilylpropyldimethyloctadecyl ammonium chloride

Pioneered by Dow Corning, these organo-silicone compounds contain silanol groups (HO-Si-) which give permanency to the finish. Isqith et al (40) found that a number of substrates of medical and economic importance exhibited durable antimicrobial activity when treated with organosiloxane quaternary ammonium chloride. This finish is applied to the surface using two processes. First a rapid process coats the substrate with the cationic species. An ion exchange takes place where the cation of the finish replaces water on the surface of the fiber. After coating the surfaces, the finish polymerizes to impart permanent antimicrobial properties to both reactive and unreactive surfaces (48). On surfaces where silane can react, covalent bonding occurs, and it is

possible to have both intermolecular polymerization and copolymerization simultaneously (48).

Phenolic Compounds

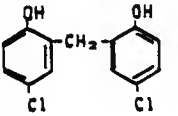
A wide variety of phenolic compounds are used as disinfectants and fungicides/bactericides for apparel, military and outdoor fabrics (29, 47). Common phenolic compounds used on textiles include hexachlorophene, dihydroxydechlorodiphenyl methane, and orthophenyl phenol. When used as mildew inhibitors on textiles, about 1 to 2% o.w.f. of the compound is required (1). For antibacterial finishes, concentrations in the range of 0.2% owf have been used (1). These compounds are intensely toxic by virtue of protein denaturization. Proteins are precipitated by 1 to 2% phenol (48). While organic matter will not reduce their activity, none are effective against bacterial spores.



o-phenyl phenol

Phenol and thiophenol compounds are forms of germicidal agents and, historically, were sprayed in operating rooms as disinfectants. Today, various phenol derivatives are used to impart antimicrobial properties. The effectiveness of phenolic compounds usually is increased by halogens on the

ring which increases the polarity of the phenolic -OH group. Phenol compounds substituted with chlorine and other halogens are found to be active against both bacteria and fungi on polyester and cellulosic materials. Dichlorophene is an example of a wide spectrum, phenolic antimicrobial which is marketed under the trade name, G-4 TechnicalR by the Givaudan Corporation.



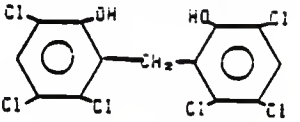
Dichlorophene

(2,2'-dihydroxy-5,5"-dichlorodiphenyl methane)

Dichlorophene generally acts as a dihydric phenol and is easily acetylated and benzolated. An active bactericide and fungicide, dechlorophene works upon the oxidase-reductase system of the microbial cells. While other phenolic compounds may cause undesirable odors, acid hydrolysis, and color changes in textiles (29). Collins and Purkess (16) state that dichlorohene does not adversely affect dyes or fibers.

Biphenols such as bithional, dichlorophene hexachlorophene have been applied to fibers by several methods to

produce durable antibacterial finishes (74).

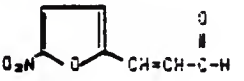


Hexachlorophene

Durable antimicrobial activity has been obtained by grafting 2-methyl-5-vinylpyridine onto mercerized cotton and rayon, and then immersing the fabric in hexachlorophene.

Other Antimicrobial Agents

Nitrofuran which belongs to the organic class of antimicrobials is probably one of the most widely investigated agents used as durable antimicrobial finishes.

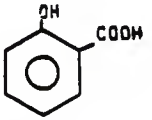


3-(5-nitro-2-furyl) acrolein

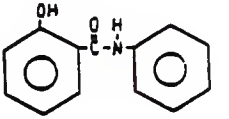
Nitrofuran is used as a fungicide and bactericide on both natural and synthetic fibers (73). This finish is claimed to have durability and a broad spectrum of antimicrobial activity due to the addition of a nitro group in the 5-position of the furan ring. Nitrofurans act by interrupting the enzymatic metabolic processes of the microbial cell. There also is some evidence that the nitrofurans interfere

with the carbohydrate cycle by which the cells obtain their energy, thereby starving the microbes (71).

Salicylanilides are used as fungicides and bactericides in outdoor fabrics and as components in size bath formulations. These compounds are derivatives of salycilic acid, and many are chlorinated or brominated such as tetrachloro salicylanilide.



Salicylic Acid



Salicylanilides (general structure)

Mechanisms of Antimicrobial Finishes

Three basic mechanisms proposed by Vigo (11) for the production of antimicrobial finishes include the controlled release mechanism, a barrier blocking action, and the regeneration principle (11). The majority of antimicrobial finishes are produced using the controlled release mechanism in which small amounts of finish sufficient to inhibit the growth or kill microbials are released from the fabric. Microencapsulation is a controlled release mechanism where the antimicrobial agents is placed between two layers of a

plastic barrier. The agent will migrate to the surface of the fabric in the presence of moisture or during degradation by ultraviolet light. The acetalated fiber, Letilan, produces antimicrobial activity by the slow relase of the nitro compound in the presence of moisture (11).

The second mechanism uses a barrier or blocking action to prevent microbial growth. A physical barrier may be produced by using a film or coating to prevent microorganisms from reaching the fabric. Usually high add-ons are required for suitable effectiveness. Another type of barrier may be produced which achieves inhibition of microbial growth by direct surfact contact between a bonded antimicrobial agent and the organisms (11).

The third mechanism is based upon Gagilardi's regeneration model (11, 25). In this method, a chemical agent, which is not in itself an antimicrobial, is reacted with fibers. This chemical is chosen to react with other chemicals present in the end-use environment (i.e., bleaching agents during laundering or ultraviolet radiation during light exposure). A known antibacterial compound is then applied to the fabric where it dissociates and theoretically imparts permanent antimicrobial activity to the fabric. This mechanism is represented as follows:

$$FAX \langle ==== \rangle FA + X$$

Where: F = Fiber

A = Non antibacterial chemical

X = Antibacterial compound

As X is consumed on the fabric by the inhibition of microbial growth, new FAX is formed between residual FA, and a new X present in the ambient conditions.

In addition to the regeneration principle, Gagilardi (25) describes several methods for the production of antibacterial finishes of controlled durability, including fiber reaction method, thermosetting bacterostatic resins, coordination polymers, ionic bonding, and resin bonding. In the first method, a cation of known antimicrobial active groups (e.g., silver, mercury, or zinc) are bonded onto a fiber reactive functional groups by using an intermediate such as paracarboxyphenol and sulfomethylated urea. Thermosetting antibacterial agents are an extension and modification of the first method where an ionic salt of anionic functionality is reacted in situ on the fibers with a thermosetting agent. In the third method, coordination compounds of heavy metals such as iron, chromium, nickel, silver, and copper may be used to produce durable antibacteral agents. Effectiveness depends on the proper choice of nitrogenous base and metal, organo-metal, and quaternary cations.

Ionic bonding can utilize both cationic and anionic active bactericidal or bacteriostatic agents. Antimicrobial finishes are produced by one or two-step reactions, depending on the fiber. The basic principle is that a salt formation between fiber and antibacterial agent occurs. The antibacterial activity depends on the solubility constant of the salt formed with the fiber polymer and the specific antibacterial efficiency of the agent present in associated form on the fiber. Durability of the finish depends on the rate of hydrolysis of the fiber-agent bond in laundering. The resin bonding principle is used for the primary application in the case of water insoluble antibacterial agents such as the heavy metals, quinolates, trialkyl tin soaps, etc. This method is not good for agents which are water soluble in alkaline wash conditions.

Properties of Antimicrobial Finishes

In evaluating antimicrobial finishes, many factors need to be considered. These finishes should be durable, have selective activity towards undesirable organisms, be compatible with other finishes and dyes, and be nontoxic to man. Durability requirements of a finish will change with the end-use of the textile. Fabrics which will be cleaned or laundered frequently as in hospitals need to be more wash fast than those which are cleaned less frequently. Textiles exposed to the outdoors (i.e., outdoor carpeting, tents, and

canvas) should be durable to the effects of rain, light, and atmospheric contaminants.

Selective activity of a finish is defined by Vigo et al (73) to mean that specific microorganisms, harmful in the end-use of the textile, are either killed or inhibited in their growth. The type of organisms to be inhibited will change according to fiber type, finishes, and dyes applied to the textile, and end-use environment. Unbound antimicrobials may become ineffective against certain organisms due to adaption of the organisms. Adaptation occurs when the concentration of the active ingredients of antimicrobials becomes diluted below effective levels due to diffusing or leaching. Under these conditions microorganisms are able to adapt or build up a tolerance to these antimicrobials, causing highly resistant strains to develop (38).

One of the most essential properties of an antimicrobial finish is nontoxicity towards man. Because of the potential toxicity of some compounds used as antimicrobial agents, their use and sale are governed by the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) which is administered by the Environmental Protection Agency (EPA), Office of Pesticide Programs (38). This act provides guidelines for registration, application, and inspection and restricts transportation and experimental use of pesticides in the United States. Some organo-tin compounds are being studied

By the EPA and have been banned in Japan and some European countries (38). Organo-tin compounds have been used as antimicrobial agents for textiles.

In addition to durability, selective activity, and nontoxicity towards man, antimicrobial agents should not adversely affect or react with other finishes or dyes which are applied prior to or in combination with the antimicrobial finishes. Reaction with other finishes may adversely affect the hand and/or physical properties of the fabric or may damage the fiber itself. A decrease in the performance characteristics of either the finishes or, more noticeably, an alteration in the color or decrease in colorfastness of the textile may result.

Tests for Antimicrobial Finishes

Both quantitative and qualitative tests have been developed for determining antimicrobial activity of finishes. Quantitative methods usually involve the sterilization of fabrics which are then inoculated with the test organism. The inoculated fabrics are incubated, and the determination of bacteria or fungi on the fabric is made by colony counts or retrieval of microorganisms (74). Qualitative tests usually are evaluated by noting the presence or absence of microbial growth. The parallel streak method is a qualitative test where the antimicrobial activity is measured by the area or zone of inhibition caused by the diffusion of

the finish. This test procedure is described in AATCC Test Method 147-1982, Antibacterial Activity of Fabrics, Detection of: Parallel Streak Method (1). It has been used to evaluate the effectiveness of a wide range of both gram positive and gram negative bacteria and is applicable for testing resistance of fungi. To conduct the test, specimens of the test fabric are placed in contact with agar which has been streaked with an inoculum of the test organism. After incubation, a clear area of interrupted growth underneath and along the sides of the test piece indicates antimicrobial activity of the fiber (1).

Probably the most widely used qualitative test is the agar plate method described in AATCC Test Method 90-1982, Antibacterial Activity of Fabrics, Determination of: Agar Plate Method and AATCC Test Method 30-1981 Fungicides, Evaluation on Textiles: Mildew and Rot Resistance of Textiles (1). In this method, sterilized specimens are placed on AATCC agar which has been seeded with a test organism. After incubation, a clear area of no growth adjacent to the specimen indicates antimicrobial activity of the fabric, while the growth of organisms indicates little or no antimicrobial properties (1). In addition to zone of inhibition, loss in breaking strength (%) can be used to determine the amount of microbial degradation of the textile. This method is unsuitable for materials with finishes and

coatings that produce impervious or impermeable films, antibacterial agents which are not readily diffusible through agar, fabrics with a long nap that prevents contact with agar, and materials treated with antibacterial agents that react with culture medium. The agar plate and parallel streak methods are not suitable for evaluating some of the newer antimicrobial finishes that are based on immobilized or slowly diffusing technologies (51, 52).

The soil burial test described in AATCC Test Method 30-1981, Fungicides, Evaluation on Textiles: Mildew and Rot Resistance of Textiles, requires a fabric to be buried in soil for a certain amount of time and then evaluated for microbial growth (1). Deterioration caused by fungi can be evaluated according to loss in breaking strength and/or by visual appearance such as tears or yellowing. Two problems exist with this method. The first is that soil varies with geographical location. While some attempts have been made to produce a standard soil for this method, none of the suggested soils have been completely accepted. The second problem is the change in climatic conditions between geographical areas as well as from season to season.

In addition to testing antimicrobial proeperties of the compounds on the fabrics, the agents themselves may be tested in solution (24). Stock solution (1.0% w/v) are prepared using a suitable solvent, diluted to concentrations of 1:500,

1:1,000, and 1:10,000 with the appropriate medium, sterilized, then poured into large (150 x 15 mm) disposable petri dishes. After solidification in an incubator at 37oC overnight, the agar surface will be inoculated with the actively growing broth cultures of the test organisms. The agar plates are then incubated at 37oC for four days, then observed under incandescent and ultraviolet light. Growth is recorded as positive or negative.

Another method which has been used in the textile industry for evaluating antimicrobial treatments is an odor test in which swatches treated with antimicrobial finishes are inoculated with test organisms and a small amount of artificial urine. The specimens are then incubated and evaluated according to the type and amount odor produced.

In addition to the above qualitative tests, semi-quantitative and quantitative test methods have been developed for the determination of antimicrobial properties of textile and finishes. The Majors Test is a semi-quantitative test procedure for evaluating bacteriostatic activity (1). The amount of growth of the test organism in a highly buffered medium held in the interstices of the fabrics is estimated by titrating the amount of acid or alkali produced from the medium substrate (glucose or urea) by the test organism.

In 1962, Herbert Quinn (63) developed a quantitative

test method for evaluating the antimicrobial properties of fabrics. In this method, the fabric specimens are sterilized or laundered to remove microorganisms, inoculated with test organisms, dried, placed in sterile agar plates covered with a thin layer of agar, and incubated. The antimicrobial activity of the fabric is determined by bacterial colony counts. This method may be used for testing bacteria, fungi, and yeast.

A limitation of the Quinn Test, according to Lashen (44), is that it is too difficult to run, since the colonies are not easily visible, and the possibilty for diffusion of the microbial agent is not minimized. Hence, Lashen developed a modified procedure in which the test fabric is suspended rather than embedded in the culture medium. Fabrics are sterilized by washing in a detergent and then suspended tautly and horizontally in petri dishes by means of wire hangers with hooks. After autoclaving, AATCC agar is applied slowly and uniformly to the fabric surface, the specimens are incubated for 48 hours at 37oC, and colony counts are taken on both sides of the fabric surface. Bacteria and fungi may be used in this test.

Vigo and Benjaminson (74) described a tenatative test method developed by the EPA for testing carpet sanitizers. Samples of carpet containing dried bacterial inoculum are sprayed with a sanitizer, scrubbed for a specified period of

time, and allowed to dry for one hour. The specimens are then incubated, and the reduction of microorganisms is determined. The microorganisms are recovered by using a cylinderical tube with a centered guide tube or by using a lens method.

Another quantitative test method is described in AATCC Test Method 100, Antibacterial Activity of Fabrics, Evaluation of (1). In this procedure, test and control samples are inoculated with the test organism, incubated, and then the bacteria are eluted by shaking in a known amount of liquid. After determining the number of bacteria present in this liquid, the percentage reduction is calculated. Because the test organisms are physically pad-applied, it is often difficult to obtain a uniform distribution of the inoculum on some strongly hydrophobic fibers due to low absorption.

Because of the problems associated with AATCC Test Method 100, other test are being developed and evaluated by AATCC. One such test is a Micro-pad technique (27). In this method fabric specimens are wetted out in a phosphate buffer, padded to remove excess moisture, inoculated with the organism, and incubated for four hours in an air-tight container at 37oC. After incubating, the specimens are placed in a capped Erlenmyer flask containing 100 ml of a neutralizing broth. The flasks are then shaken in a wrist action shaker for 10 minutes. Two 1:10 serial dilutions are

completed on the medium in the flasks, and duplicated plate counts are performed on the solution in the flask and for both dilutions. The percent reduction of organisms is calculated based on the control.

Dow Corning has recently developed a test method, Dow Corning Corporate Test Method (CTM)-0923, Antimicrobial Activity Dynamic Test of Surfaces, for evaluation of immobilized antimicrobial agents (5, 22, 51). In this test method, a sterile buffer solution is inoculated with 5 ml of a test organism (bacteria, fungi, or yeast) and placed in Shaker bath where they are kept in constant, uniform contact with the test fabric during a one hour contact time. Duplicated plate counts are performed on the solution in the flask and on two serial dilutions. The percentage reduction of the organism is calculated as shown below.

$$\text{Reduction, \%} = \frac{\frac{B + C}{2} - A}{\frac{B + C}{2}} 100$$

Where: A = Count per milliliter for the flask containing the treated substrate after the specified contact time.
B = "0" contact time count per milliliter for the flask used to determine "A" before the addition of the treated substrate.
C = "0" contact time count per milliliter for the untreated control substrate.

Colony counts are done to determine the antimicrobial activity. When using this method, caution must be taken with materials which readily diffuse in water. These materials

may be diluted beyond their useful concentration during the test giving false negative results (23). This method is particularly applicable in testing antimicrobial properties on carpeting.

Use of Antimicrobial Agents on Carpeting

The growth of microorganisms on carpeting may result in fiber degradation, staining, development of foul odors, and the spread of disease and infection (32). The increase use of carpeting in institutions (i.e., hospitals, schools, sanitariums) and consumers' desire for protection from microbial deterioration of textiles has increased the need for antimicrobial finishes on carpeting. A variety of chemical classes of an antimicrobial agents have been used to impart antimicrobial properties to carpeting. Sandoz Chemicals Corporation and Dow Corning Corporation both have patents on quaternary silane-organo compounds. In particular, Dow Corning markets an antimicrobial finish known as Slygard with the active ingredient 3-trimethoxysilyl-propyldimethyloctadecyl ammonium chloride. This particular agent is effective against microorganims when physical contact occurs, but will not diffuse into the environment. Sandoz Chemicals Corporation also markets a quaternary silane salt, SanitizedR Brand Requat, having durable bacteriostatic, fungistatic, and algaestatic properties.

Phenolic compounds currently on the market include G-4

Technical, dechlorophene, produced by Givaudan Corporation; Sanitized Brand SYG, a phenyl ether/halogenated phenol, marketed by Sandoz Chemical Corporation; and Vikol THP, 2,4,4'-trichloro-2'hydroxydiphenyl ether, produced by Vikon Chemical Corporation. A combination of organo-metallic and organo arsenicals are used in Morton Thiokol's Ventron Division Products such as Vinyzene SB1 PS, which is used in Badische's Zeftron 500 ZX nylon (11). Interface Flooring Inc. markets a phosphate amine antimicrobial which is applied to carpeting in the PVC layer of their fusion bonded carpet construction (11). Allied-Signal Inc. has produced an inherently antimicrobial fiber for carpeting, called Halofresh, in which and antimicrbial compound is added to the spinning dope.

Parameters for Selection of Antimicrobial Agents

The selection of antimicrobial agents for specific end-uses requires the consideration of many different parameters. Antimicrobial agents vary in their spectrum of biological activity, durability to cleaning, cost, stability to light and climatic conditions, irritation and toxicity to the user, ease and uniformity of application, and effects on other fiber properties (7, 30). All of these factors must be considered in the selction of an antimicrobial finish for a specific end-use.

Consideration of the cost of an antimicrobial agent

includes both added production cost and the consumer's willingness to pay for the finish. In 1980, over $557 million were spent on disinfectants, air deodorizers, and carpet fresheners, demonstrating the consumer concern about odors caused by microbial growth (30). In addition, studies have shown that consumers are willing to pay over a dollar more per square yard for carpets treated with antimicrobial agents (60). Antimicrobial agents will vary in cost, according to the chemical composition and formulation.

In addition to product costs, method of application also is an important factor to be considered when selecting an antimicrobial agent for a specific end-use. Many antimicrobial agents can be applied using conventional wet processing equipment (i.e., pad-dry-cure methods or exhaustion from aqueous solutions). Other antimicrobial finishes can be applied by vapor phase treatments, fiber encapsulation, incorporation into the polymer during fiber production, or attachment to a resin carrier (74). The type of bond formed between the finishing agent and substrate depends on the chemical structure of the fiber as well as that of the antimicrobial compound (74). The substance may simply be deposited as an insoluble product on the surface of the textile, associated by primary or secondary valence forces (i.e., hydrogen, ionic, coordinate, and covalent bonds), or reacted with other finishes as thermosetting

resins (26, 46, 57, 74).

All antimicrobial agents are expected to have selective activity towards undesirable microorganisms. Specifically, the agent should inhibit the growth of or kill microorganisms harmful to the end-use of the textile (72). The effectiveness of the antimicrobial agent against specific organisms may vary, however, according to the fiber type, finishes and dyes applied to the textile, and the end-use environment. Generally, a compound that is effective against the greatest variety of organisms is the one that should be used because of the diversity of microbial contaminants residing on any surface (31).

The durability of an antimicrobial agent may be affected by cleaning processes, exposure to light, and climatic conditions. Many unbound antimicrobials lack durability to cleaning due to their high water solubility. In order to be functional, enough moisture must be present for these agents to diffuse from the substrate, leaving enough agent in the substrate for continued effectiveness of residual activity. However, many unbound antimicrobials are so water soluble that after only one cleaning, they may be removed from the fiber in sufficent amounts to be rendered ineffective (4). Antimicrobial agents which are chemically bound to the fiber usually have more permanent antimicrobial properties. Durability to light, air contaminants, and climatic

conditions are especially important in outdoor textiles. Light rays can break or alter bonds within the chemical structure of the finish, rendering it ineffective. Air contaminants (i.e., nitrogen oxides, sulfur dioxide) may interact with the finish. Rain and high humidity may increase moisture levels equal to that of cleaning processes, removing unbound antimicrobials from the fiber.

Toxicity and irritation to the user is probably the most essential parameter to consider. The safety and toxicity of unbound antimicrobial treatments vary considerably, depending on the specific chemistry involved (31). Many organo-tin compounds, for example, must be handled with great care because of their potential toxicity (31). All of the bound antimicrobials on the market today have very favorable toxicological profiles (31).

Finally, antimicrobial agents should not adversely affect other fiber properties or finishes and dyes applied prior to or in combinations with antimicrobial finishes. It has been found that some organo-metallic finishes have an odor or are sensitive to light, while some quaternary ammonium compounds reduce the lightfastness of dyes (59). Reactions with other finishes may adversely affect the hand and/or physical properties of the fabric or may damage the fiber itself.

The Purpose of This Study

Two important properties of antimicrobial finishes are their durability and compatibility with other finishes and dyes present on fabrics. As stated previously, the durability of antimicrobial agents is affected by many variables such as moisture, climatic conditions, and light. Light may degrade the finish by braking or altering chemical bonds, rendering the finish ineffective. Collins and Purkess (16) found that compounds which absorb ultraviolet light will exhibit a decrease in their antimicrobial activity. However, limited studies have been completed on the light stability of antimicrobial agents used on carpeting.

In addition, some antimicrobial agents have been reported to discolor or increase fading of dyes when exposed to light (19). However, zirconium based fungicides seem to inhibit light degradation of dyes (18). Even though the effect of antimicrobial finishes on the lightfastness of dyed textiles has been briefly noted in the literature, limited studies have been completed on carpet dyes. The purpose of this study is to investigate the durability to light of select antimicrobial agents and the effect of these agents on lightfastness of acid dyes applied to nylon 6 carpet yarn.

EXPERIMENTAL PROCEDURES

This study investigated 1) the influence of six commercial antimicrobial agents on fading of six acid dyes and fiber yellowing on Anso IV nylon 6 knitted test sleeve and 2) their susceptibility to light degradation. In order to determine the deleterious effect of antimicrobial agents on the lightfastness of carpet dyes, the specimens were exposed in an Atlas Xenon Weather-Ometer, and then evaluated instrumentally and visually. The antimicrobial agents also were applied to undyed nylon and evaluated as to their effectiveness after light exposure by using a modified agar plate method.

Fabric

The fabric selected for this research was a knitted test sleeve constructed of Anso IV nylon 6 (Allied Signal Corporation), two ply carpet yarns. This construction was chosen, because the pile yarns of carpeting would interfere with the accurate measurement of antimicrobial properties. Construction characteristics for the test sleeve were determined by using ASTM D-3887-80, Standard Specifications for Knitted Fabrics and ASTM D-1244-81, Standard Practice for Designation of Yarn Construction (see Table 1) (13).

Table 1. Fabric Parameters

Fiber Content	nylon 6
Yarn Construction	S-twist 2 ply filament
Fabric Count (wales x courses/inch)	12 x 8
Cross-section	Y-shaped (trilobal)

Sample Preparation

Before dyeing and finishing, 20 g samples were serged to prevent raveling, scoured with a 0.5% solution of Triton-X 100 in an Atlas Launder-Ometer at 80 C for one hour, rinsed twice with distilled water for 10 minutes in the Launder-Ometer, and screened dryed. Specimens measuring 6.4 cm x 6.4 cm (2 1/2 in X 2 1/2 in) were prepared for accelerated light exposure. All specimens were store at a standard atmosphere for testing (21 $\pm$ 1 C and 65 $\pm$ 2% RH) before and after exposure to light.

Dye Selection and Application

Dye selection was based on the results of a survey conducted by Dr. Barbara Reagan which was sent to all the carpet mills listed in the CRI Membership Directory. Twenty-eight carpet mills completed the survey. Six acid dyes (two yellows, two reds, and two blues) were selected for evaluation which were among those most widely used to dye nylon carpeting.

Although most carpet colors are achieved by mixing together two or more dyestuffs, the fabric specimens were

only dyed with one dye type at the 0.5% o.w.f. concentrations in an Atlas Launder-Ometer at 100 C for one hour. After dyeing, the samples were rinsed twice with distilled water in the Launder-Ometer for 20 minutes and then screen dryed. The C.I. generic names and chemical classes of dyes are given in Table 2.

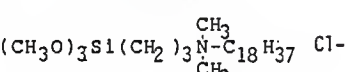
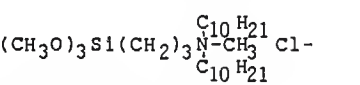
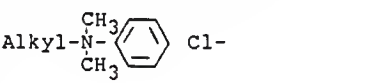
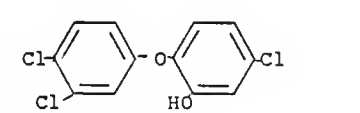
Antimicrobial Selection and Application

The antimicrobial agents evaluated in this study represent three of the major chemical classes of finishes used on carpeting (i.e, organo-silanes, organo-metallics, and phenolic compounds). The finishes were chosen based on availability, chemical classification, and use on carpeting. Finishes #1 and #2 were organo-silane compounds with quaternary ammonium pendent groups. These finishes are bonded to the fiber rendering them nonleachable. Organisms are killed on contact due to interruption of the cell membrane by the finish. Finish #1 differs from #2 in the structure of the quaternary ammonium compound (see Table 3). Finishes #3-6 were leachable nonbonded antimicrobial agents. Finish #3 was a quaternary ammonium compound with a benzene ring connected to the nitrogen applied in conjunction with a tributyl tin oxide which is an organo-tin compound. Finishes #4 and #5 were phenolic compounds. In finish #4, the phenolic compound was designated as a mixture of phenyl ethers and halogentaed phenols with no distinct chemical

Table 2. Acid Dyes Evaluated

C.I. Generic Name	Chemical Class
C.I. Acid Yellow 49	----
C.I. Acid Yellow 219	Disazo
C.I. Acid Red 299	Disazo
C.I. Acid Red 361	Monoazo
C.I. Acid Blue 277	Anthraquinone
C.I. Acid Blue 324	Disazo
Undyed	----

Table 3. Antimicrobial Agents Evaluated

Finish	Active ingredient	Recommended o.w.f (%)	Chemical Structure
#1	3-trimethoxysiyl-propyldimethyloctadecyl methanol ammonium chloride	0.5% (a.i.)	
#2	3-(trimethoxysilyl) propyldidecylmethyl ammonium chloride	1.0% (a.i.)	
#3	n-alkyl dimethyl benzyl ammonium chloride with a tributyl tin oxide	0.15% (prod) 0.15% (a.i.)	
#4	phenyl ether/ halogenated phenol	0.75% (prod)	*
#5	2,4,4'-trichloro-2'hydroxy diphenyl ether with a tributyl tin oxide	0.75% (a.i.) 0.15% (a.i.)	
#6	tributyl tin maleate	0.3% (a.i.)	
#7	untreated		

a.i. = based on percent active ingredient
prod. = based on product
* chemical structure was not available

whereas finish #5 was a chlorinated diphenyl ether with two benzene rings linked together by an oxygen atom. Finish #6 was an organo-tin compound (Table 3). These finishes currently are available on the market for use on carpeting.

The finishes were applied to 5 g dyed specimens of the knitted test sleeve by spraying using a 3 oz. chromist aerosol sprayer held 18 cm from the specimen face. Prior to treatment, the specimens were mounted individually with straight pins on a 0.3 cm thick styrofoam board covered with Saran wrap, which was changed between finishes. The board was suspended from a ring stand. Separate chromist sprayers were used for each of the finishes to avoid contamination.

Two grams of the finish was applied to obtain the manufacturer's recommended o.w.f. Finishes #1, #2, #4, and #6 were screen dryed after application, while finishes #3 and #5 were dried at 120 C and 110 C, respectively, as recommended by the manufacturer. In finishes #3 and #5, 1 g of each compound (i.e., phenolic or quaternary ammonium compound and organo-tin compound)was applied to obtain the recommended o.w.f. The antimicrobial finishes evaluated and their application parameters are given in Tables 3.

Organisms Evaluated

The test organisms selected for this study were Staphylococcus aureus (gram positive bacteria/ATCC #6538) and Escherichia coli (gram negative bacteria/ATCC #8739). These

organisms are commonly cited in the literature for testing the antimicrobial properties of textiles. For example, Staphylococcus aureus is recommended in AATCC's test methods for evaluating the antimicrobial properties of textiles (1).

Light Exposure

The specimens were mounted in Atlas Fade-Ometer masks (#12-7123-01), and exposed to 0, 40, 80, 160, and 320 AFU's (AATCC Fading Units) in a Xenon-Arc Weather-Ometer, Model 25-WT, following the procedures in AATCC Test Method 16E-1982, Colorfastness to Light: Water Cooled Xenon Arc Lamp, Colorfastness to Light (1). The dyes evaluated had lightfastness ratings from 5 to 7. A soda-lime outer filter and a borosilicate inner filter were used in the Weather-Ometer to simulate exposure behind glass. Xenon Reference Fabric (XRF) was used to monitor and control the number of AFU's to which the specimens were exposed. Two samples of XRF were used for each exposure to monitor differences between the lower and upper rows of the specimen rack because preliminary tests showed that the bottom row of specimens faded less than the upper row.

During the pretests, it was found that the Xenon Weather-Ometer could not be maintained at the specified 30% relative humidity. Hence, a 65% ± 5% relative humidity was maintained during light exposure. However, at this higher humidity, 20 AFU's on the XRF was obtained in 15 clock hours

which is still within the range prescribed by the test method (20 AFU's in 20 ± 5 clock hours).

Evaluation of Color

Color change in the specimens was evaluated instrumnetally with a Hunter D25-M colorimeter and visually with the AATCC Gray Scale for Color Change. Five L*a*b* readings were taken on each specimen and averaged together prior to calculating the total color difference in $\triangle E$ units. Total color difference was determined by taking the difference between L*, a*, and b* values for the exposed and unexposed samples, squaring these values, adding them together, and then calculating the square root. L*, a*, b* values correspond to the lightness/darkness, redness/greenness, and blueness/yellowness axes on a three dimensional color solid. Each specimen was backed with two layers of knitted test sleeve (of the same color) prior to instrumental evaluation to decrease variation due to the porosity of the fabric. To monitor machine variations between readings, L*a*b* readings for a set of woven cotton stanadards of yellow, blue, red, and green were taken along with each set of specimen readings.

Visual evaluations of color change were performed as specified in AATCC Evaluation Procedure 1, Gray Scale for Color Change (1). Three trained observers visually rated the specimens with the AATCC Gray Scale in a Macbeth Lablight,

the average rating for each specimen was calculated.

Evaluation of Antimicrobial Properties

Undyed nylon was used to evaluated the reduction in effectiveness of the antimicrobial finishes after exposure to light because some dyes possess antimicrobial properties which could influence the results of the study. The nylon specimens were scoured, treated with the antimicrobial agents, and exposed to 0, 20, 40, and 80 AFU's of xenon light as previously described. The antimicrobial properties of the treated and untreated specimens were evaluated subsequent to light exposure and compared to the unexposed specimens.

Selection of a suitable test method to evaluate the antimicrobial properties of the finishes was a difficult task. Bonded and unbonded antimicrobial finishes function on different principles which are traditionally tested by different means. Finishes which are bonded to fabrics do not leach and only kill those organisms with which they come into direct contact. However, unbonded agents do leach but are generally unstable to agitation in liquid media which is used in many test methods.

Pretest

Orginally, the Dow Corning Corporate Test Method (CTM-0923), Antimicrobial Activity Dynamic Test of Surfaces was selected. After further consideration it was decided that the test would not be adequate for evaluating unbound

antimicrobial agents (i.e., they would become diluted, rendering them less effective). Following discussions with individuals in the textile industry and in microbiology, pretests were conducted, using a preposed modification of AATCC Test Method 100-1981, Antibacterial Finishes on Fabrics, Evaluation of. Several runs were completed to gain familiarity with the test method and to improve the pipetting technique. During these trials, it was discovered that the unbound agents were removed from the specimens during the wetting out stage. Therefore, the specimens were wetted out by placing them in a petri dish for 15 minutes and covering with 15 ml of phosphate buffer. In the Micro-pad Method, a 24 hour broth containing Staphylococcus aureus is diluted in two 1:10 dilutions (Figure 1). Specimens, wetted out in a phosphate buffer, were inoculated with 0.5 ml of the test culture, then incubated for four hours in a closed container with water at the botton at 37 C. After incubation, the inoculated specimens were placed in capped Erlenmyer flasks containing 100 ml of D/E neutralizing broth, Difico Laboratories (Figure 2). The flasks were shaken at maximum speed in a wrist action shaker for 10 minutes. At the end of this time, two 1:10 dilutions were made from the media in the flask, and duplicate plates were made from the flasks and both tubes. The plates were incubated at 37 C for 24 hours, and then colony counts were completed.

An additional pretest was conducted using unfinished specimens in order to determine the percent recovery of organisms after application to the fabric. Controls were constructed by straight dilutions from the inoculum that was used to inoculate the specimens. Colony counts from the treated specimens were compared with the controls, and the percent recovery was computed (Table 4). According to Gettings (44), a recovery of 75% or better is needed for a reliable test. A 16.9% recovery was obtained with the substrate evaluated in this test (Table 4).

In order to determine if this low percentage recovery was due to the fabric, an additional test, using the same procedure, was conducted on untreated specimens of mercerized cotton, bleached cotton, nylon 6 knitted test sleeve, nylon 6,6 knitted test sleeve, nylon 6 tricot knit, and an acetate film. Colony counts for these materials after the test ranged from an average of 1.54×10^6 colonies for the nylon 6 knitted test sleeve to 2.6×10^9 colonies for the acetate film, yielding 51.5% and 8.6% recovery, respectively (see Table 5). When the acetate film was inoculated, the inoculum beaded up and rolled off into the petri dish. This could account for the low percentage recovery obtained. Another test was conducted to determine if the size of the inoculum affected the percent recovery in which unfinished samples were inoculated with 0.1 ml and 0.5 ml of inoculum.

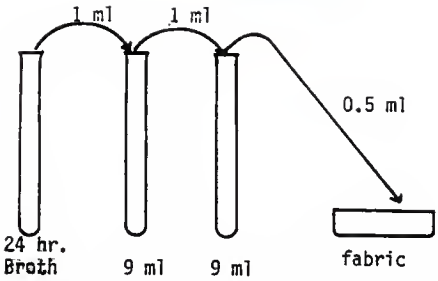


Figure 1. Initial Dilutions for Micro-pad Test Method

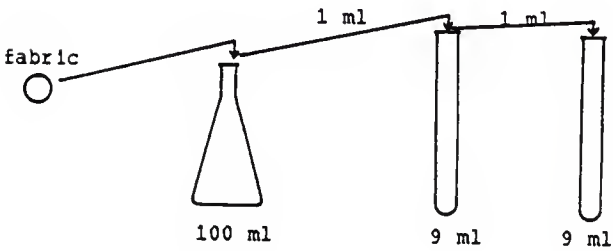


Figure 2. Dilutions Occurring During Recovery of the Organisms

Table 4. Recovery of S. aureus from Untreated Samples in Micro-pad Technique

Sample	Plate	Number of Organisms Recovered Dilutions Flask	Tube 1	Tube 2
1	a	>300	300	32
	b	>300	243	28
2	a	>300	324	35
	b	>300	322	22
3	a	>300	224	52
	b	>300	305	18
Average			285.83	31.6

Controls from inoculum

Dilution	Plate	No. of Organisms	Average
10^3	a	>300	
	b	>300	
10^2	a	224	
	b	138	181
10^1	a	110	
	b	47	75.35

Percent Recovery

$$\frac{6.12 \times 10^8}{3.62 \times 10^6} \times 100 = 16.9\%$$

Controls were constructed for each inoculum base (i.e., 0.1 ml and 0.5 ml), and the present recovery calculated for each. In this test, a higher percent recovery was obtained for the larger inoculum size (i.e., 0.5 ml) (see Table 6).

This test method had many steps which could incorporate variabilty in the results. During the four hour incubation time, death or growth of cells could occur on the fabric. Dilution in the wetting out step is never accounted for, and many microbiologist postulate that percent recovery of the organisms is not an accurate test parameter due to the variability of cell growth. In addition, Hsieh et al (59) working with cotton found that agitation increased bacterial cell-fiber interaction, thus increasing bacterial adherence to fibers. In the Micro-pad method, agitation and wetting out of the samples are two major steps. Therefore, a lower percentage recovery may be inherent to the method.

Because of these drawbacks, another pretest was completed using a modified agar plate method in which S. aureus was spread over the agar rather than seeded throughout the agar. Since bonded antimicrobial agents must come in contact with the organisms, it was felt this might be a viable method. To conduct the test, agar was poured into petri dishes, allowed to solidify, and streaked with the Staphylococcus aureus. The test specimens were then placed faced down on the agar and topped with a metal ring to

Table 5. Recovery of S. aureus from Untreated Samples in Micro-pad Technique

Fabric	Plate	Number of Organisms Recovered Dilutions			Organism Recovery, %
		Flask	Tube 1	Tube 2	
Mercerized	a	>300	>300	67	
Cotton	b	>300	>300	76	47.8
Bleached	a	>300	>300	46	
Cotton	b	>300	>300	74	40.1
Nylon 6,6	a	>300	>300	70	
Sleeve	b	>300	>300	71	47.2
Nylon 6	a	>300	>300	68	
Sleeve	b	>300	>300	86	51.5
Nylon 6	a	>300	>300	36	
Tricot	b	>300	>300	66	34.1
Acetate	a	>300	79	10	
Film	b	>300	93	16	8.6

Controls from inoculum

Dilution	Plate	No. of Organisms	Average
10^2	a	148	
	b	172	
	c	129	146.66
10^1	a	26	
	b	22	
	c	20	22.67
10^0	a	9	
	b	10	
	c	0	6.33

prevent curling at the edges. The petri dishes were then incubated for 24 hours at 37 C. After incubation, the fabric specimen and ring were removed from the dish, and a zone of growth or no growth was noted. The bonded antimicrobial agents (#1 and #2) left a clear zone the size of the specimen, while leachable antimicrobial agents (#3-6) left a zone of inhibition around the specimen. Since this test detected antimicrobial properties for both unbonded and bonded antimicrobial agents and was easy to complete, it was chosen for the evaluation. Leachable antimicrobial agents will inherently have larger zone diameters, compared to bonded antimicrobials. For this reason, effectiveness of the antimicrobial finishes should not be compared solely on zone diameter but on the decrease in zone diameter over exposure levels.

The actual steps for the modified agar plate method were as follows. A tube containing 9 ml of nutrient broth (Difico Laboratories) was inoculated with the organisms taken from an agar slant and incubated for 24 hours. After 24 hours, the sterile nutrient agar was poured into 100 ml petri dishes to form agar plates. The plates were allowed to cool for 15 minutes. Next, the cooled agar plates were inoculated with 0.1 ml of the 24 hour inoculated nutrient broth. The inoculum was spread evenly over the surface of the agar with a sterile, glass, L-shaped rod. The fabric specimens were

Table 6. Recovery of S. aureus from Untreated Specimens using 0.1 ml and 0.5 ml Inoculum: Micro-pad Technique

Sample	Plate	Number of Organisms Recovered Dilutions		
		Flask	Tube 1	Tube 2
0.1/1	a	>300	240	20
	b	>300	218	22
0.1/2	a	>300	287	18
	b	>300	276	25
0.5/1	a	>300	206	15
	b	>300	167	17
0.5/2	a	>300	189	22
	b	>300	188	18

Controls from inoculum

0.5 ml of inoculum 5.6×10^6
0.1 ml of inoculum 8.9×10^6

Percent Recovery

0.5 ml of inoculum $\frac{3.6 \times 10^5}{5.6 \times 10^6} \times 100 = 64.28\%$

0.1 ml of inoculum $\frac{2.12 \times 10^6}{8.9 \times 10^6} \times 100 = 23.87\%$

placed face down on the agar and a metal ring was placed on top to prevent the edges from curling and to hold the specimen in contact with the agar. Three specimens were evaluated for each finish/organism combination. The prepared petri dishes were incubated for 24 hours, then the fabric specimens and metal ring were removed and autoclaved. The dishes were evaluated for growth and no growth, and the diameter of the zone of no growth was measured. The dishes were incubated for another 24 hours to see if the organisms were killed or if they were merely inhibited. At the end of this time, the petri dishes were evaluated as above.

In order to establish some visual controls, fabric specimens were treated with the antimicrobial agents at various concentrations (0.5 g, 1.0 g, 2.0 g, and 4.0 g), and the modified agar plate method was completed on each of the specimens using both organisms. These dishes also were evaluated for growth or no growth, and measurements were taken on the diameter of the zone of no growth.

Statistical Analysis

In total, the variables evaluated in the study of the influence of antimicrobial finishes on fading of acid dyes included seven dye types (six dyes plus one undyed nylon fabrics), seven treatments (six antimicrobial agents plus the untreated), and five exposure times resulting in a 7 x 7 x 5 factorial design. Analysis of Variance and Duncan's Multiple

Range Tests were used to distinguish which test variables and levels therein had a significant effect on the colorfastness of the dyed and finished nylon samples.

In total, the variables evaluated in the study of the susceptibility of antimicrobial finishes to light degradation included seven treatments (six antimicrobial agents plus the untreated controls), two organisms, and four exposure times, yielding a 6 x 2 x 4 factorial design. Analysis of Variance and Duncan's Multiple Range Tests were used to distinguish test variables and levels therein which had a significant effect on lightfastness of the antimicrobial agents. Chi-square analyses were completed on the variable growth to determine the probability of no growth for the various finishes and exposure levels.

RESULTS AND DISCUSSION

This study evaluated the influence of six antimicrobial agents on the fading of six acid dyes applied to nylon 6 carpet yarn, the extent to which they caused fiber yellowing in the undyed substrate, and their susceptiblity to light degradation. To evaluate the effects of the antimicrobial agents on the lightfastness and appearance of the dyed and undyed nylon, treated and untreated specimens were exposed to 0, 40, 80, 160, and 320 AFU's in a Xenon Weather-Ometer, then evaluated visually with the AATCC Gray Scale for Color Change and instrumentally with a Hunter colorimeter. A modified agar plate method was used to determine if xenon light reduced the effectiveness of the antimicrobial agents on undyed nylon specimens after 20, 40, and 80 AFU's of exposure.

Effects of Antimicrobial Finishes on the Lightfastness of Dyes and Fiber Yellowing: Visual Evaluation

After each of the four xenon exposure periods, the amount of fading and discoloration in the dyed and undyed nylon specimens was evaluated by three trained observers using the AATCC Gray Scale for Color Change. This is a 5-point scale, ranging from 5 (negligible or no change) to 1 (much change), which is widely used in the textile industry for visually assessing color change in textiles.

The variables in this study were dye type (six acid dyes plus the undyed nylon = 7), treatment (six antimicrobial finishes plus the untreated control = 7), xenon exposure level (40, 80, 160, and 320 AFU's = 4 levels), and replication (two). Based on the results of the Analysis of Variance Test, all of the main effects (except replication) and second and third order interactions were significant at the $p<0.05$ level (see Table 7). However, the variables that had the greatest influence on color change were exposure level and dye type. Discussed below are the general observations related to the main effects as well as the second and third order interactions.

Xenon Exposure Level

The mean AATCC Gray Scale for Color Change ratings decreased after each subsequent exposure (40, 80, 160, and 320 AFU's), indicating a progressive increase in fading. However, the specimens differed in the extent and rate of fading, depending on the dye type and treatment. The mean Gray Scale ratings for the four xenon exposure levels ranged from 4.9 after 40 AFU's of exposure to 3.2 after 320 AFU's (see Table 8). After the first two xenon exposures, the extent of fading in the specimens treated with the antimicrobial finishes was similar to that which was observed in the untreated controls. In particular, the mean Gray Scale ratings for the seven treatments ranged from 4.9 to 4.6

Table 7. Analysis of Variance Test on Gray Scale Ratings*

Source of Variation	Degrees of Freedom	Sum of Squares	F-value
Replication	1	1.07	3.03
Dye	6	186.46	88.02
Finish	6	26.18	12.35
Dye*Finish	36	81.64	6.42
Replication*Dye	6	2.86	1.20
Replication*Finish	6	3.27	1.54
Replication*Dye*Finish	36	12.71	1.12
Exposure	3	456.96	482.29
Exposure*Dye	18	189.49	33.33
Exposure*Finish	18	20.02	3.52
Exposure*Dye*Finish	108	43.26	1.27

*AATCC Gray Scale for Color Change

Table 8. Mean Gray Scale Ratings for Xenon Exposure Levels

Xenon Exposure (AFU's)	Mean Gray Scale Rating
40	4.9
80	4.6
160	4.0
320	3.2

*AATCC Gray Scale for Color Change

and from 4.7 to 4.3 after 40 and 80 AFU's of exposure, respectively, indicating few differences in the amount of fading between the untreated and treated specimens (see Table 9). A greater range in treatment means for the six antimicrobial agents and untreated controls was observed after 160 and 320 AFU's. In addition, the adverse effects of selected antimicrobial agents became more apparent with longer exposure periods.

Treatments

(Antimicrobial Agents and Untreated Controls)

The mean Gray Scale ratings and the Duncan's Multiple Range Test results for the seven treatments [six antimicrobial agents (#1-6) and untreated controls (#7)] are presented in Table 10. Overall, the least amount of fading occurred in the untreated controls, followed by finishes #6, #2, #5, #1, #4, and #3 (greatest color change or lowest Gray Scale rating). However, there was no significant difference in the mean Gray Scale ratings associated with the untreated controls (#7) and finishes #6 and #2 which were organo-tin and organo-silane compounds. The mean ratings for the other antimicrobial finishes (#5, #1, #4, and #3) were significantly lower than those observed for treatments #7, #6, and #2. After each xenon exposure level, the lowest Gray Scale rating was observed in the specimens treated with antimicrobial agent #3, indicating that it consistently

Table 9. Mean Gray Scale Ratings for Treatments within Each Xenon Exposure Level

Finish	Mean Gray Scale Ratings Light Exposure (AFU's) 40	80	160	320
#1	4.9	4.7	3.8	3.1
#2	4.9	4.6	4.1	3.5
#3	4.9	4.3	3.6	2.7
#4	4.6	4.5	3.9	3.0
#5	4.8	4.6	3.9	3.2
#6	4.9	4.6	4.1	3.5
#7 (untreated)	4.9	4.7	4.2	3.6

Table 10. Duncan's Multiple Range Test on the Mean Gray Scale Ratings for Treatments

Finish	Mean Gray Scale Rating	Grouping
#7 (untreated)	4.3	A
#6	4.3	A
#2	4.3	A
#5	4.1	B
#1	4.1	B
#4	4.0	B
#3	3.9	C

caused the greatest increase in dye fading (see Table 9).

Dye Type

Six acid dyes and the undyed nylon were evaluated in this study to determine the extent to which antimicrobial agents increased fading rate and discoloration during light exposure. The mean Gray Scale ratings for these seven dye types within each of the four xenon exposure levels are presented in Table 11, and the means and Duncan's Multiple Range Test computed over all exposures are presented in Table 12.

Overall, C.I. Acid Yellow 219 faded the least, resulting in a mean Gray Scale rating (4.8) that was significantly higher than those associated with the other dye types (see Table 12). It also had the highest mean rating after 80, 160, and 320 AFU's of xenon exposure. The next highest Gray Scale means for the seven dye types were observed for the undyed specimens and C.I. Acid Blue 324.

Most of the antimicrobial agents caused no appreciable change in the undyed nylon during light exposure. However, the nylon specimens treated with finish #4 exhibited a distinct yellowing on the undyed nylon after only 40 AFU's of light exposure which is common for phenolic compounds (19).

Among the seven dye types evaluated, C.I. Acid Red 299 and C.I. Acid Red 361 exhibited the greatest amount of fading. The means for these dyes were significantly lower

Table 11. Mean Gray Scale Ratings for Dye Types within Xenon Exposure Levels

Dye Type	Mean Gray Scale Ratings Light Exposure (AFU's) 40	80	160	320
C.I. Acid Yellow 49	4.9	4.7	3.8	2.6
C.I. Acid Yellow 219	4.9	4.9	4.8	4.8
C.I. Acid Red 299	4.8	4.3	3.1	2.2
C.I. Acid Red 361	4.9	4.5	3.4	2.2
C.I. Acid Blue 277	4.9	4.6	3.9	3.0
C.I. Acid Blue 324	4.9	4.7	4.3	3.5
Undyed	4.6	4.4	4.3	4.5

Table 12. Duncan's Multiple Range Test on the Mean Gray Scale Ratings for Dye Types

Dye Type	Mean Gray Scale Rating	Grouping
C.I. Acid Yellow 219	4.8	A
Undyed	4.5	B
C.I. Acid Blue 324	4.4	B
C.I. Acid Blue 277	4.0	C
C.I. Acid Yellow 49	3.8	C
C.I. Acid Red 361	3.6	D
C.I. Acid Red 299	3.5	E

than those observed for the other dye types, overall and after 160 and 320 AFU's of exposure.

The differences among the Gray Scale means for seven dye types were greater after 160 and 320 AFU's of xenon light, compared to the lower levels of exposure. For example the means associated with 40 AFU's ranged from only 4.9 (C.I. Acid Yellow 40 and 219, C.I. Acid Red 361, and C.I. Acid Blue 277 and 324) to 4.6 (undyed control). Whereas those associated with 320 AFU's ranged from 4.8 (C.I. Acid Yellow 219) to 2.2 (C.I. Acid Red 299 and 361). Hence, apparent differences in fading among dyestuffs was influenced by the amount of light exposure.

Second and Third Order Interactions

As indicated in the Duncan's Multiple Range Test, all of the second and third order interactions were significant. Hence, the amount of fading that occurred in the nylon specimens was influenced by exposure level, treatment, dye type, as well as interactions among these variables. The mean Gray Scale ratings, based on two replications, for the seven dye types within each treatment are given in Tables 13 (40 AFU's), 14 (80 AFU's), 15 (160 AFU's), and 16 (320 AFU's). Few differences were observed among the means for the individual dye type/treatment combinations after 40 or 80 AFU's of xenon exposure. After 40 AFU's of exposure, all dye type/treatment combinations (except for the undyed specimens

Table 13. Mean Gray Scale Ratings for Dye Types within Treatments after 40 AFU's of Xenon Light Exposure

	Mean Gray Scale Rating						
	Treatment						
Dye Type	1	2	3	4	5	6	7
1	5.0	5.0	5.0	4.6	4.9	5.0	4.8
2	5.0	5.0	5.0	4.9	5.0	5.0	4.9
3	4.8	4.9	4.7	4.6	4.6	4.8	4.9
4	4.8	4.8	5.0	4.9	4.9	4.9	4.9
5	4.9	4.9	5.0	5.0	4.8	5.0	5.0
6	4.9	4.8	5.0	5.0	5.0	4.9	4.8
Undyed	4.6	5.0	5.0	3.5	4.5	5.0	4.9

Table 14. Mean Gray Scale Ratings for Dye Types within Treatments after 80 AFU's of Xenon Light Exposure

	Mean Gray Scale Rating						
	Treatment						
Dye Type	1	2	3	4	5	6	7
1	4.6	4.5	4.6	4.8	4.8	4.8	4.7
2	5.0	4.8	4.8	4.8	5.0	4.8	5.0
3	4.5	4.3	4.1	4.8	4.1	4.2	4.2
4	4.8	4.5	4.1	4.8	4.7	4.4	4.6
5	4.8	4.7	4.2	4.8	4.6	4.3	4.6
6	4.7	4.6	4.3	4.7	4.8	4.8	4.9
Undyed	4.8	4.8	4.4	3.0	4.6	4.6	4.6

Table 15. Mean Gray Scale Ratings for Dye Types within Treatments after 160 AFU's of Xenon Light Exposure

	Mean Gray Scale Rating						
	Treatment						
Dye Type	1	2	3	4	5	6	7
1	3.1	4.0	4.1	3.3	3.7	4.5	4.8
2	4.8	4.8	4.5	4.8	4.9	4.7	4.8
3	2.9	3.2	2.5	4.3	2.8	3.3	3.1
4	3.4	3.9	2.9	3.7	3.3	3.4	3.3
5	3.6	4.2	3.2	4.3	3.4	4.1	4.4
6	4.2	4.4	3.3	4.7	4.5	4.6	4.8
Undyed	4.6	4.3	4.6	2.8	4.5	4.4	4.8

Table 16. Mean Gray Scale Ratings for Dye Types within Treatments after 320 AFU's of Xenon Light Exposure

	Mean Gray Scale Rating						
	Treatment						
Dye Type	1	2	3	4	5	6	7
1	2.3	2.8	2.3	1.1	2.8	3.7	3.1
2	4.8	4.3	4.7	4.8	5.0	4.8	4.8
3	2.0	3.0	1.3	2.3	1.6	2.5	2.6
4	1.9	2.8	1.4	1.8	2.3	2.4	2.4
5	3.0	3.3	2.3	3.6	2.6	2.8	3.6
6	3.2	3.7	2.2	4.3	3.7	3.9	3.9
Undyed	4.8	4.8	4.5	3.5	4.5	4.5	4.8

treated with antimicrobial agent #4) had Gray Scale values that ranged from 4.5 to 5.0, indicating no appreciable color change which was expected since carpet dyes usually have good lightfastness. Only the undyed nylon treated with antimicrobial agent #4 had a mean rating of less than 4.1 after 80 AFU's of exposure.

After 320 AFU's exposure, antimicrobial finish #1 (an organo-silane) and antimicrobial finish #3 (a quaternary ammonium compound applied along with an organo-tin compound) decreased in Gray Scale ratings (i.e., increased fading) of all dyes, except C.I. Acid Yellow 219 (disazo) and the undyed specimen when compared to the untreated specimens. In addition, finish #3 caused greater fading in C.I. Acid Red 299 (disazo) than all the other treatments. Antimicrobial finish #4 (a phenolic compound) yellowed the undyed specimen after only 40 AFU's exposure, but the yellowing decreased with added exposure to xenon light. Decreased yellowing with continued light exposure is common to phenolic compounds (19). This finish also greatly increased the fading of C.I. Acid Red 299 (disazo) and C.I. Acid Red 361 (monoazo), compared to the untreated controls. Antimicrobial finish #6, an organo-tin compound had no appreciable effect on the color of most of the dyes. This finish actually decreased fading in C.I. Acid Yellow 49, compared to the untreated controls. However, finish #6 significantly increased the fading of C.I.

Acid Blue 277. The results for antimicrobial finish #2 (an organo-silane) were similiar to that observed with finish #6 in that it had minimal influence on the fading of the majority of the dyes and appeared to have a protective effect or reduce fading in the acid red dyes. Figure 3 compares finish/dye combinations aftter 320 AFU's of light exposure.

Effects of Antimicrobial Agents on the Lightfastness of Dyes and Fiber Yellowing: Instrumental Evaluation

The amount of fading and discoloration in the dyed and undyed nylon 6 specimens also was evaluated instrumentally after each of the four xenon exposure levels (40, 80, 160, and 320 AFU's). Five L*a*b* readings per specimen were averaged prior to calculating total color difference in ΔE units. The ΔE values for the inidvidual specimens are presented in Tables B1-B6 (Appendix B).

Differences among the ΔE values for the individual specimens were larger than the Gray Scale ratings which are based on a five-point scale. Similar results were obtained for the two methods of evaluation, except that the magnitude of color change was greater for the blue dyes, compared to the red dyes when the specimens were evaluated instrumentally.

Based on the results of the Duncan's Multiple Range Test, all of the main effects and second and third order

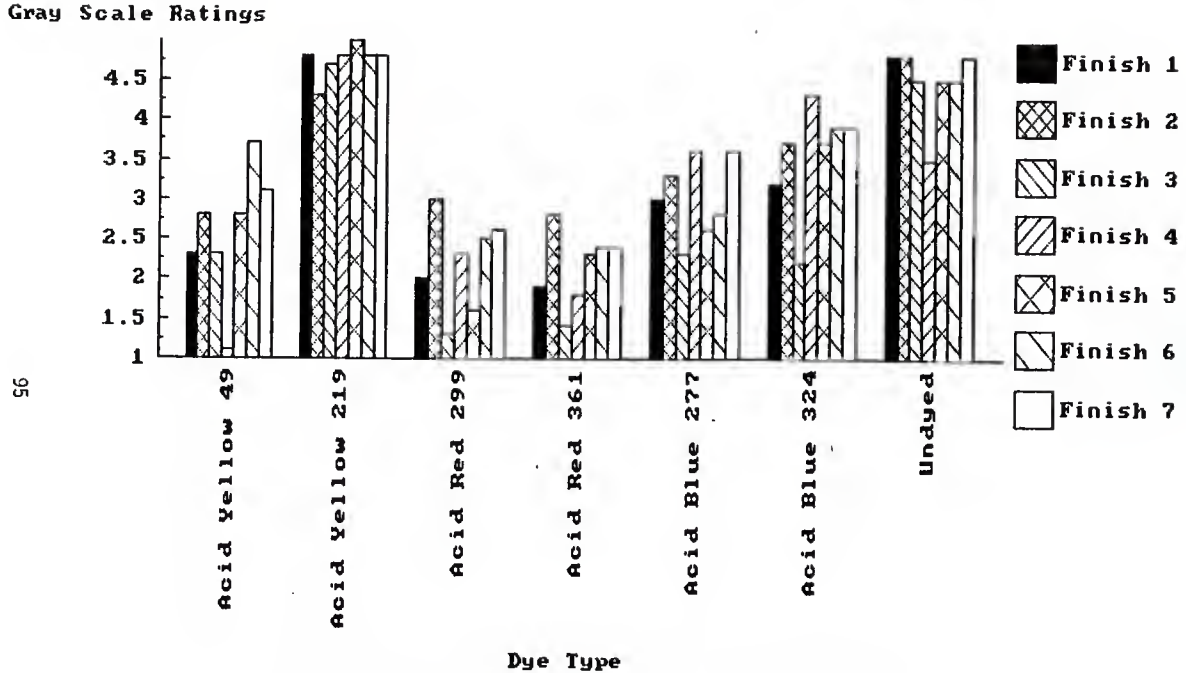


Figure 3. Mean Gray Scale Ratings for Dye Types and Treatments after 320 AFU's of Xenon Light Exposure

interactions had a significant effect on the Δ E values obtained for the dyed and undyed specimens (see Table 17). Hence, the colorimetric values were influenced by dye type, treatment (antimicrobial finishes), and xenon exposure level.

Xenon Exposure Level

The mean ΔE values for the four exposure levels were similar to the Gray Scale ratings in that they indicated a progressive increase in fading (see Table 18). The mean ΔE for 40 AFU's of xenon light exposure was 1.8, compared to the significantly larger mean of 12.3 for 320 AFU's.

After 40 AFU's of exposure, little fading was observed in the majority of the specimens, and all the mean ΔE's for the seven treatments were less than 2.0, except for antimicrobial finishes #3 and #4 which had mean ΔE values of 2.4 and 3.0, respectively (see Table 19). Similarly, minimal fading occurred in the specimens after 80 AFU's of exposure. All of the treatment ΔE means were less than 2.0, except those associated with antimicrobial finishes #3 and #4.

As previously discussed, appreciably greater fading occurred in the specimens after 160 and 320 AFU's of exposure, and all the mean Δ E's for the seven treatments were greater than 5.0 after 320 AFU's of exposure.

Table 17. Analysis of Variance Test on Color Difference (ΔE) Means

Source of Variation	Degrees of Freedom	Sum of Squares	F-value
Replication	1	20.32	4.26
Dye	6	3886.54	135.72
Finish	6	563.69	19.68
Dye*Finish	36	1060.07	38.50
Replication*Dye	6	17.19	3.75
Replication*Finish	6	67.79	14.77
Replication*Dye*Finish	36	171.82	6.24
Exposure	3	6426.81	2800.91
Exposure*Dye	18	3427.92	248.99
Exposure*Finish	18	191.66	13.92
Exposure*Dye*Finish	108	567.90	6.87

Table 18. Mean Color Difference (ΔE) Values for Xenon Exposure Level

Xenon Exposure (AFU's)	Mean ΔE
40	1.8
80	3.0
160	5.8
320	12.3

Table 19. Mean △E for Treatments within Each Xenon Exposure Level

Finishes	Mean △E Light Exposure (AFU's) 40	80	160	320
#1	1.4	2.6	5.2	11.8
#2	1.6	2.8	5.4	11.3
#3	2.4	4.1	7.6	16.1
#4	3.0	4.1	7.7	15.3
#5	1.3	2.6	5.3	11.4
#6	1.3	2.3	4.6	9.8
#7 (untreated)	1.4	2.5	4.7	10.0

Table 20. Duncan's Multiple Range Test on Mean △E Values for Treatments

Finish	Mean △E	Grouping
#3	7.8	A
#4	7.5	A
#2	5.3	B
#1	5.3	B
#5	5.2	B
#7 (untreated)	4.6	B
#6	4.5	B

Treatments

(Antimicrobial Finishes and Untreated Controls)

The results of the Duncan's Multiple Range Test on the mean ΔE values for the seven treatments were similar to those obtained for the Gray Scale ratings. The mean ΔE for antimicrobial agent #3 was significantly greater than those associated with the other treatments, except for #4 (see Table 20). No significant differences were observed among the ΔE means for treatments #1, #2, and #5-7. As previously discussed, the least amount of fading occurred in the untreated controls (#7) and specimens treated with antimicrobial finish #6; hence, they had the lowest mean ΔE values overall and after 80, 160, and 320 AFU's of exposure (see Table 19).

Antimicrobial finishes #2, #3, and #4 significantly increased the amount of fading in C.I. Acid Blue 277 and 324, resulting in the highest mean Δ E values at each exposure level. Antimicrobial finish #4 also caused substantial yellowing in the undyed specimens during light exposure and significantly increased the color change in C.I. Acid Yellow 49.

Similiar results were obtained for the antimicrobial finish #4 after 80 AFU's of xenon light exposure in that it significantly increased fading in C.I. Acid Yellow 49 and yellowing in the undyed specimens.

Antimicrobial finishes #3 and #4 also had the highest mean color difference values after 320 AFU's of xenon exposure; whereas finish #6 (an organo-tin compound) and the untreated controls had the lowest means which correspond to the results obtained with visual assessment. The mean ΔE for antimicrobial finish #6 at this exposure level was less than the mean for the untreated controls, indicating that it had a protective effect (see Table 19). These findings support previous research (57) which has shown that metallic compounds may increase the lightfastness of dyes, while quaternary ammonium compounds often increase fading during light exposure.

Dye Type

The mean color difference values for the seven dye types (six acid dyes and the undyed) on nylon 6 for each xenon exposure level are given in Table 15. All the dye types had mean ΔE's of less than 2.0 after 40 AFU's, except for C.I. Acid Blue 277 and 324. These two dyes also had the highest Δ E's after 80 and 160 AFU's. However, C.I. Acid Yellow 49, followed by C.I. Acid Blue 277 had the highest color difference values after the fourth xenon exposure. Hence, the overall mean ΔE for C.I. Acid Yellow 49, averaged over all treatments and exposure levels, was significantly higher than those associated with the other dyes, followed by C.I. Acid Blue 277 and 324 (see Table 21). These findings

differ from those obtained from visual assessment. Based on the Gray Scale ratings, C.I. Acid Red 299 exhibited the greatest amount of fade.

C.I. Acid Yellow 219 and the undyed nylon had mean color difference values that were significantly lower than the other dye types (Δ E = 1.20 and 1.70, respectively), indicating minimal fading (see Table 22). These dye types also had the highest Gray Scale values, indicating the least amount of color change.

Second and Third Order Interactions

The mean color difference values for the seven dye types within each treatment after 40, 80, 160, and 320 AFU's are presented in Tables 23-26. The corresponding data for each replication are found in Tables B1-B6, Appendix B.

The amount of color change associated with the treatments as well as their rank order was influenced by exposure level and dye type. Minimal discoloration was observed in the undyed specimens at each of the four exposure levels, except for those specimens treated with the phenolic compounds (finishes #4 and #5) where yellowing occurred. Only treatment #4 caused substantial yellowing after 40 and 80 AFU's, compared to the higher exposure levels in which both finishes (#4 and #5) caused appreciable yellowing. The ΔE values for all of the other undyed specimens untreated and treated with antimicrobial agents #1-3 and #6 were less

Table 21. Mean △E for Dye Types within Each Xenon Exposure Level

Dye Type	Mean △E Light Exposure (AFU's) 40	80	160	320
C.I. Acid Yellow 49	1.8	3.6	9.9	25.5
C.I. Acid Yellow 219	0.6	1.1	1.1	2.0
C.I. Acid Red 299	1.5	2.6	4.9	11.7
C.I. Acid Red 361	1.1	2.0	5.1	14.7
C.I. Acid Blue 277	3.4	5.9	9.9	17.1
C.I. Acid Blue 324	2.2	4.1	7.7	13.2
Undyed	1.7	1.8	1.7	1.7

Table 22. Duncan's Multiple Range Test on Mean △E Values for Dye Types

Dye Type	Mean △E	Grouping
C.I. Acid Yellow 49	10.2	A
C.I. Acid Blue 277	9.1	B
C.I. Acid Blue 324	6.8	C
C.I. Acid Red 361	5.7	D
C.I. Acid Red 299	5.2	D
Undyed	1.7	E
C.I. Acid Yellow 219	1.2	E

Table 23. Mean △E Values for Dye Types within Treatments after 40 AFU's of Xenon Light Exposure

	Mean △E Treatment						
Dye Type	1	2	3	4	5	6	7
1	1.7	1.9	1.6	3.7	0.8	1.2	2.1
2	0.8	0.4	0.5	0.2	1.3	0.5	0.7
3	1.2	1.5	2.3	0.7	1.9	1.6	1.5
4	0.9	1.3	1.4	1.0	0.5	1.1	1.3
5	2.3	3.4	5.0	5.5	2.6	2.7	2.5
6	1.8	1.8	5.7	2.8	1.2	1.2	0.7
Undyed	1.0	1.1	0.6	7.1	0.7	1.1	0.7

Table 24. Mean △E Values for Dye Types within Treatments after 80 AFU's of Xenon Light Exposure

	Mean △E Treatment						
Dye Type	1	2	3	4	5	6	7
1	3.8	3.5	3.0	6.9	2.0	1.6	3.8
2	0.4	0.6	1.6	1.5	0.7	1.8	0.8
3	2.3	2.4	3.6	1.7	3.1	2.6	2.5
4	2.2	1.9	2.7	1.5	1.8	1.5	2.1
5	4.7	6.0	8.0	6.6	5.5	5.2	4.9
6	4.1	3.8	8.9	3.7	3.5	2.6	2.4
Undyed	0.9	1.1	0.7	7.3	0.6	1.1	0.7

Table 25. Mean △E Values for Dye Types within Treatments after 160 AFU's of Xenon Light Exposure

	Mean △E Treatment						
Dye Type	1	2	3	4	5	6	7
1	9.3	9.1	9.8	20.1	7.2	5.7	7.9
2	0.9	1.2	1.9	1.3	1.0	0.7	0.9
3	4.7	4.5	7.1	3.3	6.1	4.5	4.4
4	4.1	4.5	7.7	4.6	5.5	4.6	4.7
5	8.8	10.2	12.6	10.1	9.8	9.4	8.7
6	7.6	7.5	13.6	6.5	6.8	6.0	6.0
Undyed	0.7	0.7	0.6	7.7	0.8	0.9	0.5

Table 26. Mean △E Values for Dye Types within Treatments after 320 AFU's of Xenon Light Exposure

	Mean △E Treatment						
Dye Type	1	2	3	4	5	6	7
1	24.3	22.9	28.6	44.6	21.5	16.0	20.6
2	1.1	2.2	3.8	1.6	1.8	1.4	1.9
3	11.8	10.1	16.3	10.2	13.3	10.0	10.0
4	13.6	12.3	21.5	17.1	13.2	12.3	12.6
5	16.5	18.8	20.0	16.0	17.7	16.9	15.0
6	14.3	12.8	22.6	10.8	11.6	10.9	9.4
Undyed	1.1	0.7	0.6	6.5	0.9	1.0	0.7

than 1.2 after 40, 80, 160, and 320 AFU's of xenon exposure.

Except for antimicrobial finishes #3 and #4, the majority of the treatments caused no appreciable increase in fading in the dyed specimens after 40 and 80 AFU's. Among the six dyes, antimicrobial finish #3 caused a substantial increase in fading in both acid blue dyes, whereas #4 increased fading in C.I. Acid Yellow 49 and C. I. Acid Blue 277. Only those specimens dyed with the red and blue acid dyes and treated with antimicrobial finish #3 exhibited more than a two Δ E unit increase in fading, compared to the untreated dyed specimens exposed to the same test conditions. After 320 AFU's, all the dyed specimens treated with antimicrobial finish #3 exhibited color difference values that were two Δ E units or greater than the untreated dyed controls. The majority of the treatments caused minimal increases in fading after 320 AFU's, compared to the untreated exposed controls (see Figure 4). Those treatments that resulted in more than a two ΔE unit increase in fading were antimicrobial finish #1 on C.I. Acid Blue 324, antimicrobial finish #2 on both acid blue dyes, antimicrobial finish #4 on C.I. Acid Yellow 49 and C.I. Acid Red 361, and antimicrobial finish #5 on C.I. Acid Red 299 and C.I. Acid Blue 324. Hence, the treatments only had a significant effect on the fading of selective dye types, and the amount of fading was influenced by exposure level. Hence, the

exposure level x dye type, exposure level x treatment, dye type x treatment, and exposure level x treatment x dye type interactions were significant.

Overall, C.I. Acid Yellow 219 exhibited the least amount of fading with ΔE values after each exposure level less than 4.0 for specific treatments, whereas, C.I. Acid Yellow 49 exhibited the greatest amount of fading with and without the antimicrobial treatments. Both the untreated and treated specimens dyed with C.I. Acid Red 361 and exposed to 320 AFU's faded more than C.I. Acid Red 299. C.I. Acid Blue 324 had better lightfastness on the untreated nylon after each exposure level, compared to C.I. Acid Blue 277, but C.I. Acid Blue 324 was more sensitive to the antimicrobial finishes.

A slightly significant interaction occurred between replication and treatment. This interaction may have been caused by the lamp breaking in the Xenon Weather-Ometer during the second replicate. The mean ΔE for the first replicate was approximately 0.5 greater than the mean ΔE for second replicate. Inconsistant values occurred randomly for specimens dyed with C.I. Acid Yellow 219 and the undyed specimen. However, the ΔE's for these dyes are extremely low overall, indicating little color change in the specimens. For finish #4 on the undyed specimen, considerable variablity existed between replications 1 and 2. However, the same trends occured in each replication with a large color

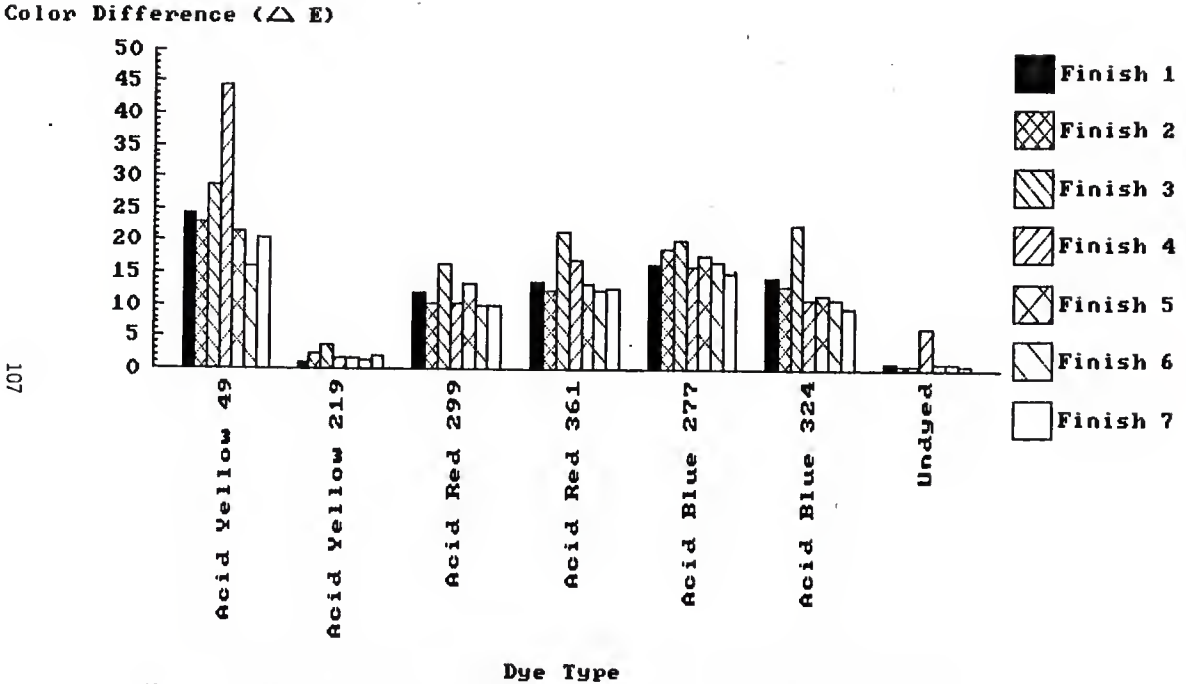


Figure 4. Mean / E Values for J Dye Types within Treatment After 320 AFU's of Xenon Light Exposure

difference after 40 AFU's of xenon exposure. This color difference decreased after 320 AFU's of exposure. These results are common to phenolics which cause yellowing in fabrics which decreases with continued light exposure (19). In addition, more variation was noted between replications for finishes #3 and #5. This variablility probably occurred due to difficulty in finish application (i.e., application of 1 gram of each compound).

In both the visual and instrumental evaluation, considerable interaction was noted between finishes and dyes. Overall, finish #3 (quaternary ammonium/organo-tin compound) and finish #4 (phenolic compound) caused the greatest amount of color change in the dyed specimens. The acid red dyes demonstrated the greatest amount of color change when evaluated visually while the acid blue dyes, and C.I. Acid Yellow 49 demonstrated the greatest amount of color change when evaluated instrumentally.

Susceptiblility of Antimicrobial Finishes to Light Degradation

In order to evaluate the susceptiblity of the antimicrobial agents to light degradation, undyed nylon 6 specimens were treated with seven finishes and exposed in the Xenon Weather-Ometer for 20, 40, and 80 AFU's. After exposure, the antimicrobial properties were evaluated by a modified agar plate method. Antimicrobial activity was

assessed by 1) designating growth or no growth and 2) measuring the diameter of the zone of no growth or inhibition. The test organisms were Staphylococcus aureus and Escherichia coli, and the agar plates were evaluated after 24 and 48 hours of incubation.

ANOVA and Duncan's Multiple Range Tests were conducted on the diameter (cm) of the zone of no growth, and Chi-square tests were applied to the growth/no growth data. Because of the limited number of observations, Chi-square analyses for growth/no growth were only used to support visual observations and the results from the zone diameter measurements.

Controls

Preliminary tests were conducted on nylon 6 control specimens (2.54 cm in diameter) treated with 0.5, 1.0, 2.0, and 4.0 g of the antimicrobial finishes. Presented in Tables 27 and 28 are the diameter measurements of the no growth zones for E. coli and S. aureus that were recorded for the controls treated with six finishes at four application rates. In general, differences among the treated specimens were more easily detected using S. aureus as the test organism, compared to E. coli which exhibited greater resistance (i.e., smaller zones of no growth) to the antimicrobial finishes using the modified agar plate method (Table 27). This may have been attributed to the greater

Table 27. Effect of Application Rate on the Performance of the Antimicrobial Finishes with E. coli

Finish	Zone of no growth (diameter, cm) Application rate (g/specimen)				
	0	0.5	1.0	2.0	4.0
#1	0.0	1.5	1.6	3.2	0.0
#2	0.0	0.0	0.0	1.0	0.0
#3	0.0	0.0	0.0	0.0	0.0
#4	0.0	4.7	5.9	4.4	5.1
#5	0.0	3.5	3.8	4.9	4.7
#6	0.0	2.4	1.3	1.3	3.3

Table 28. Effect of Application Rate on the Performance of the Antimicrobial Finishes with S. aureus

Finish	Zone of no growth (diameter, cm) Application rate (g/specimen)				
	0	0.5	1.0	2.0	4.0
#1	0.3	3.3	3.3	3.3	3.6
#2	0.3	3.5	3.5	3.3	3.7
#3	0.3	4.4	4.1	2.6	5.3
#4	0.3	6.0	6.1	6.4	6.3
#5	0.3	4.9	5.9	5.7	5.7
#6	0.3	4.4	4.4	4.8	4.7

resistance of E. coli to antimicrobials, the procedures used for testing, or the selective activity of the finishes. Because of the greater sensitivity of S. aureus to the antimicrobial agents, it was better able to discriminate among the treatments as well as detect the degrading influence of light. Considerable variability was observed for the antimicrobial finishes when applied to the control specimens at the four application rates and evaluated with E. coli.

The ANOVA for the no growth zone diameter measurements confirmed that the main effects (finish, organism, and application rate) had a significant effect on bacterial growth (Table 29). The majority of the second and third order interactions also were significant. Hence, the size of the no growth zone was influenced by antimicrobial agent, organism, and replication.

The Duncan's Multiple Range test results on the no growth diameter means obtained for the untreated controls and the six antimicrobial finishes for both organisms are given in Table 30. The corresponding data based on percent no growth are in Table 31. Differences in the no growth percentages for the treated specimens were statistically significant at $p < 0.001$, based on the chi-square test. Finishes #4 and 5 which were unbound antimicrobials produced significantly larger zones of no growth with mean diameters

Table 29. Analysis of Variance Test on No Growth Zone Diameters. Pretest

Source of Variation	Degrees of Freedom	Sum of Squares	F-value
Replication	1	16.97	3.88
Organism	1	113.29	25.92
Finish	6	251.27	9.60
Organisms*Finish	6	44.48	1.70
Replication*Organism	1	20.55	4.70
Replication*Finish	6	12.45	0.47
Replication*Organism* Finish	6	26.22	17.48
Application Rate	4	58.35	58.35
Application Rate* Organism	4	21.44	21.45
Application Rate* Organism*Finish	28	0.00	0.00
Exposure*Dye*Finish	108	567.90	6.87

Table 30. Duncan's Multiple Range Test on Mean No Growth Zones for Treatments for Both Organisms

Finish	Mean Zone Diameter (cm)	Grouping
#4	5.6	A
#5	4.9	A
#6	3.3	B
#1	2.5	BC
#3	2.0	C
#2	1.9	C
#7 (control)	1.7	D

Table 31. Percentage No Growth Based on Treatment (Chi-Square Analysis)

Finish	Percent No Growth
#4	100.00
#5	100.00
#6	81.25
#1	75.00
#2	56.25
#3	43.75
#7 (control)	0.00

of 5.6 and 4.9, respectively, compared to the bonded antimicrobial finishes (#1 and #2). At each of the four application rates using S. aureus, the bonded antimicrobial finishes produced zones of no growth which were the same size as the specimen (2.5 cm in diameter), thus indicating no leaching abilities. Overall, finishes #1-3 and #6 appeared to be less effective against E. coli than finishes #4 and #5.

At a 2 g application rate, all of the finishes appeared to be effective against E. coli, except finish #2 and #3. However, finish #1 had no bactericidal effects against E. coli when applied at the highest application rate (4 g). In the light exposure study, finish #1 demonstrates no effect against E. coli. Therefore, the bactericidal effects demonstrated in the pre-test may be due to variable growth of E. coli or to the weight of the fabric on the agar surface. Table 32 presents the frequency of no growth for each finish over application rates. As stated previously, finishes #1-3 and #6 had less of an effect on E. coli.

It should be noted that finish #7 had a mean zone diameter of 1.67 cm due to the variable growth of a few petri dishes caused by the weight of the fabric on the agar or variable growth of the organisms. For this reason, variable growth was classified as growth since it could not be attributed to the finishes applied to the fabric specimens. Overall, the no growth zones were not visually different for

Table 32. Effect of Application Rate on the Performance of Antimicrobial Finishes (Frequency of no growth)

Finish	Number of specimens with no growth Application Rate (g)				
	0	0.5	1.0	2.0	4.0
#1	2/2	2/1	2/1	2/2	2/0
#2	2/2	2/0	2/0	2/1	2/0
#3	2/2	2/0	2/0	1/0	2/0
#4	2/2	2/2	2/2	2/2	2/2
#5	2/2	2/2	2/2	2/2	2/2
#6	2/2	2/1	2/1	2/1	2/2

Note: Finish 7 = untreated
Total possible frequency for each treatment = 4
Data displayed as:

$$\frac{\text{specimens with no growth, S. aureus}}{\text{specimens with no growth, E. coli}}$$

Therefore the total frequency possible = 2/2

the 24-hour to the 48-hour incubation periods. Small differences may have occurred due to death/growth rate of the organisms and variations in measurement.

From these preliminary experiments, it was determined that the modified agar plate method could be used to evaluate the effect of light on the antimicrobial finishes. Leachable antimicrobial agents will inherently have larger zone diameters, compared to bonded antimicrobials. Therefore, effectiveness of the antimicrobial agents should be based on both growth versus no growth and the no growth zone diameters.

Significant differences were observed between the mean zone diameters for the different application rates. These differences were probably due to the leachable finishes, since no growth zone diameters for the bonded antimicrobial agents using S. aureus were the same size as the specimen or slightly larger. Finishes #4 and #5 demonstrated the largest mean zone diameters of all the treatments (see Table 30). Since both of these finishes function by leaching, these results were expected. Finishes #1 and #6 demonstrated variable growth when exposed to E. coli.

Light Exposure

The resistance of the antimicrobial finshes to light degradation was evaluated using both E. coli and S. aureus. Based on the results of the ANOVA test on the diameter of the

zones of no growth, treatment (six antimicrobial finishes plus the untreated controls), xenon exposure level, and organism had a significant effect on the antimicrobial properties of the treated and untreated specimens (Table 33).

The mean diameters of the zones of inhibition or no growth for S. aureus and E. coli after 0, 20, 40, and 80 AFU's of xenon light show a progressive decrease in the bacteriacidal properties of the finishes with each successive exposure (see Table 34). The mean diameters for the unexposed specimens were 5.2 cm (S. aureus) and 1.2 cm (E. coli), whereas the corresponding mean diameters after 80 AFU's were 0.7 and 0.6 cm which indicated that light reduced the effectiveness of the antimicrobial finishes. As previously discussed, the growth of S. aureus was inhibited to a greater extent by the finishes, resulting in larger zones of no growth, compared to E. coli. S. aureus also was considered more sensitive to changes in the finishes during light exposure. These findings are similiar to those observed in the application rate experiments in which finishes #1, #2, and #3 appeared not to inhibit the growth of E. coli.

Table 35 presents the mean diameters of no growth for the seven treatments within each exposure level. The corresponding data for the individual organisms are in Tables 36 (E. coli) and 37 (S. aureus). Prior to exposure, finishes

Table 33. Analysis of Variance Test on No Growth Zone Diameters

Source of Variation	Degrees of Freedom	Sum of Squares	F-value
Replication	1	63.70	81.15
Organism	1	859.75	1095.22
Incubation	1	2.27	2.89
Finish	6	1729.99	367.30
Organism*Finish	6	172.35	36.59
Replication*Finish	6	7.95	1.69
Replication*Incubation	1	0.09	1.15
Replication*Organism	1	37.95	48.34
Replication*Organism *Finish	6	4.71	0.78
Exposure	3	622.39	257.56
Exposure*Organism	3	321.73	133.14
Exposure*Finish	18	271.63	18.73
Exposure*Organism *Finish	18	101.18	6.98

Table 34. Mean No Growth Zones for the Test Organisms within Xenon Light Exposure Levels

Organism	Mean Zone Diameter (cm) Light Exposure (AFU's) 0	20	40	80
S. aureus	5.2	4.3	3.1	0.7
E. coli	1.2	1.4	0.8	0.6

Table 35. Mean No Growth Zones For Treatments within Xenon Light Exposure Levels

Finish	Mean Zone Diameter (cm) Light Exposure (AFU's) 0	20	40	80
#1	1.8	1.6	0.8	0.0
#2	1.7	1.2	1.3	0.0
#3	3.0	3.1	2.0	0.6
#4	6.6	5.7	5.4	3.8
#5	5.7	4.8	2.9	0.0
#6	3.2	3.2	1.3	0.3
#7 (control)	0.0	0.4	0.2	0.0

Table 36. Mean No Growth Zones for Treatments within Xenon Light Exposure Levels for E. coli

	Exposure (AFU's)						
	0	20		40		80	
Finish	*D(cm)	D(cm)	*R(%)	D(cm)	R(%)	D(cm)	R(%)
#1	0.0	0.0	-	0.0	-	0.0	-
#2	0.0	0.0	-	0.0	-	0.0	-
#3	0.0	1.2	-	0.0	-	0.0	-
#4	4.9	4.8	3	4.7	5	3.8	23
#5	3.5	3.5	0	1.8	49	0.0	100
#6	0.0	1.0	-	0.0	-	0.7	-
#7 (control)	0.0	0.0	-	0.0	-	0.0	-

*D = diameter of zone of no growth
*R = percentages reduction

Table 37. Mean No Growth Zones for Treatments within Xenon Light Exposure Levels for S. aureus

	Zone of no growth (diameter, cm) Exposure (AFU's)						
	0	20		40		80	
Finish	*D(cm)	D(cm)	*R(%)	D(cm)	R(%)	D(cm)	R(%)
#1	3.6	3.3	8	1.7	53	0.0	100
#2	3.3	2.4	28	2.6	22	0.0	100
#3	5.9	4.9	17	3.9	34	1.3	78
#4	8.1	6.9	15	5.9	28	3.8	54
#5	7.9	6.1	23	4.6	42	0.0	100
#6	6.4	5.5	14	2.6	59	0.0	100
#7 (control)	0.0	0.9	-	0.5	-	0.0	-

*D = diameter of zone of no growth
*R = percentage reductions

#4 and #5, which were nonbonded antimicrobials, had the largest mean zones of no growth for both S. aureus and E. coli (6.6 and 5.7 cm), followed by finishes #6, #3, #1, and #2 (smallest zone diameter of 3.3 cm) (see Table 36). The mean zone diameters for finishes #4 and #5 using S. aureus were 8.1 and 8.0 cm. When evaluated using E. coli, only finishes #4 and #5 had measureable zones of no growth (see Table 36). As previously discussed in the results for the pretest on application rates, finishes #4 and #5 had the highest mean zone diameters because of leachability from the fabric specimens to the agar medium.

After 20 AFU's of light exposure, all of the antimicrobial treatments exhibited a decrease in their ability to inhibit the growth of S. aureus as evidenced by the smaller zones of inhibition (Table 37). In particular, finish #2, an organo-silane, had the largest decrease (28% reduction) in zone size, followed by finishes #5 (23% reduction) and #3 (17% reduction) which were phenolic compound/organo-tin compound and quaternary ammonium compound/organo-tin compound, respectively. Conversely, finish #1, an organo-silane, was affected the least by 20 AFU's of light.

Initially, the untreated nylon 6 specimens had no zones of inhibition which was expected since the fiber is not inherently germicidal. However, a small zone of no growth in

S. aureus was observed for untreated specimens after 20 and 40 AFU's of light exposure. Perhaps this increase was attributed to volatiles given off by the other finishes during light exposure, the decomposition of contaminants on the surface of the fabric, or to growth spurts in the S. aureus. None of the xenon exposures resulted in zones of no growth around the untreated specimens when evaluated using E. coli.

After 40 AFU's of xenon exposure antimicrobial finishes #6 (an organo-tin compound) and #1 (an organo-silane) exhibited more than a 50% reduction in the zone of no growth for S. aureus. Finishes #3, #4, and #5 also exhibited an appreciable reduction in their no growth zones, compared to those recorded for 20 AFU's; however no additional decrease was observed for finish #2.

The ability of the finishes to inhibit the growth of S. aureus was decreased appreciably after 80 AFU's of light exposure. Finishes #3 and #4 exhibited a 79.1% and 53.3% reduction in the zone of no growth, and the other finishes had no measureable zones of no growth (see Table 37). Figure 7 presents data for all treatments over exposure levels.

The no growth zone data for E coli provided minimal information concerning the deleterious effects of light on the finishes because of the greater resistance of the organisms to all of the antimicrobials. None of the

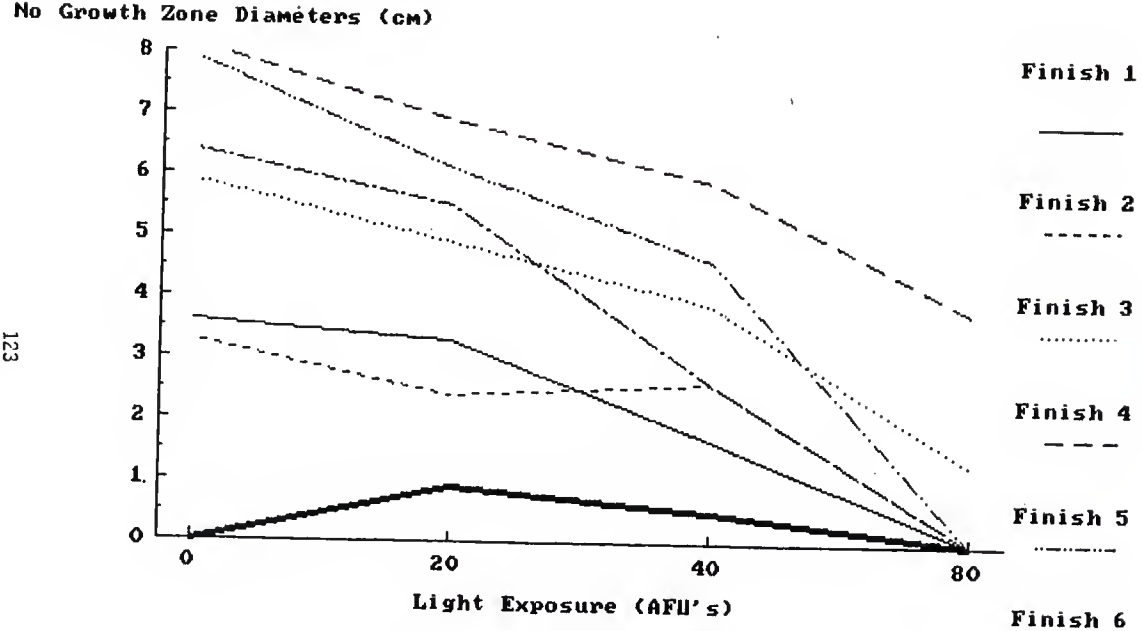


Figure 5. Effect of Xenon Light Exposure on Treatment Using S. aureus

specimens treated with antimicrobial agents #1-3 and #6 had measurable zones of no growth prior to exposure. After 20, 40 and 80 AFU's, the majority of the specimens treated with these finishes also had no measurable zones of inhibition, indicating that leachable degradation products were not produced (see Figure 8). However, finishes #4 and #5 which are leachable antimicrobial agents did exhibit a reduction in the zone of no growth with each subsequent exposure to xenon light (Table 36). After 80 AFU's of exposure, finish #5, a phenolic compound/organo-tin compound, had a 100% reduction in zone diameter, indicating that it was no longer effective against E. coli. Finish #4, also a phenolic compound, maintained its antimicrobial properties to a greater extent after the fourth exposure period, compared to finish #5. None of the untreated control specimens inhibited the growth of E. coli.

The chi-square analyses supported the conclusions made from visual evaluation and the ANOVA test for the diameter measurements of no growth zones (see Tables 38-40). Table 38 presents the frequency of no growth for each treatment after each exposure level. Differences among the percentages were significant at $p < 0.001$ when using a chi-square test. Finish #4 was effective against both organisms over all exposures. Finishes #1, #2, and #5 had no effect on the organisms after 80 AFU's exposure. Finishes #1-3 and #6

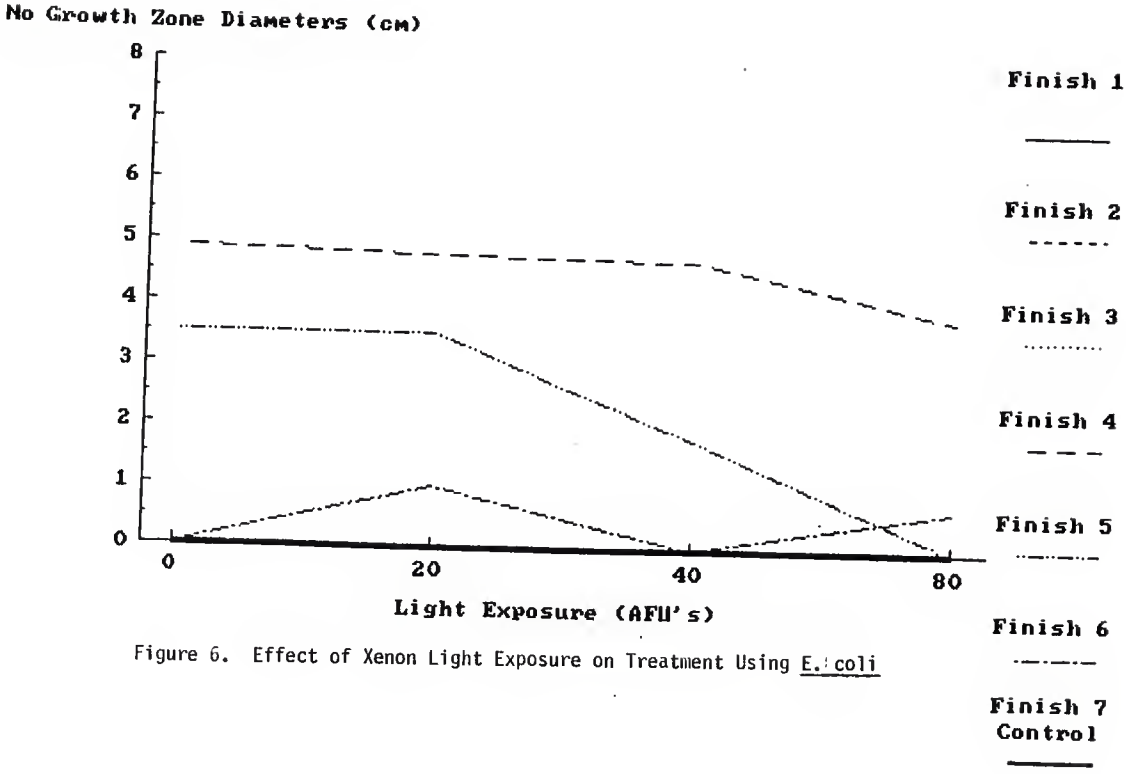


Figure 6. Effect of Xenon Light Exposure on Treatment Using E. coli

Table 38. Percentages of No Growth For Xenon Exposure Level

Exposure Period (AFU's)	Percentage of no growth
0	54.43
20	61.90
40	44.05
80	18.95

Table 39. Percentage of No Growth for Treatments

Finish	Percentage of no growth
#4	100.0
#5	62.5
#3	45.8
#6	39.6
#2	30.2
#1	29.0
#7 (control)	6.4

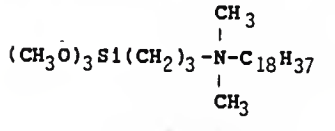
Table 40. Frequency of No Growth
for Treatments with Xenon Exposure Levels
Exposed to both *E. coli* and *S. aureus*

Finish	Frequency of No Growth Xenon Light Exposure (AFU's			
	0	20	40	80
#1	12	12	6	0
#2	12	9	8	0
#3	12	16	11	4
#4	24	24	24	24
#5	20	22	17	0
#6	12	17	6	3
#7	0	4	2	0

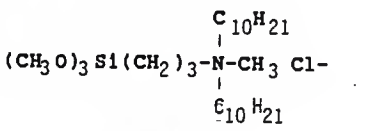
Note: Total possible frequency = 24
(12 for *S. aureus* and 12 for *E. coli*.

demonstrated litte effect against E. coli.

Overall, the phenolic finish #4 and the quaternary ammonium/organo-tin finish #3 retain their effectiveness longer when exposed to light than did the organo-silanes, organo-tins, and phenolic compound/organo-tin compounds. Finish #2 (organo-silane) maintained its effectiveness longer than did finish #1 (organo-silane) when exposed to light. The structures for these compounds are shown below.



Finish #1



Finish #2

These compounds were similiar in structure, except for the carbon groups attached to the nitrogen. The reduction in effectiveness of the organo-silanes could be due to increased polymerization of the finish, since organo-silane compounds have greater polymerization at higher temperatures. The greater light resistance of finish #3 was probably due to the benzene ring attached to the nitrogen on the quaternary ammonium structure rather than the organo-tin compound, since finish #6, also an organo-tin, had no antimicrobial properties after 80 AFU's of exposure. Finish #5 was a trichloro-phenol applied with an organo tin compound, while finish #4 was a mixture of halogenated phenolic compounds. Finish #5 may have lost its effectiveness due to the organo-

tin component of the finish rather than the phenolic component, considering the performance of finish #4.

SUMMARY AND CONCLUSION

Evaluated herein were the influence of antimicrobial finishes on the fading of acid dyes and the susceptibility of these finishes to light degradation. In order to assess the effects of antimicrobials on dye fading, nylon 6 specimens were dyed with six acid dyes treated with the finishes, and then exposed to 40, 80, 160, and 320 AFU's in a Xenon Weather-Ometer. Color change in the specimens after light exposure was evaluated visually by using the AATCC Gray Scale for Color Change and instrumentally with a Hunter colorimeter. Results showed that the extent of fading was influenced by antimicrobial treatment, dye type, and xenon exposure level. Fading increased with exposure time (AFU's), however, minimal discoloration was observed in the dyed and finished specimens after only 40 and 80 AFU's. This was not unexpected since most carpet dyes have good fastness to light.

The acid dyes varied in their inherent lightfastness properties and in the extent to which they were adversely affected by the antimicrobial finishes. Similarly, differences were observed in the extent to which the six antimicrobial agents increased the fading rate of the acid dyes within each exposure level, resulting in significant second and third order interactions among the independent variables. Antimicrobial finishes #3 and 4 caused the most

color change in all the dyed specimens; whereas finish #6 caused no significant color change in the specimens and reduced color change in some of the dyes. Conner et al (32) reported that zirconium compounds increased the lightfastness of outdoor fabrics providing some evidence that organo-metallic compounds, in general, may prevent color loss. Finish #3 was a quaternary ammonium compound/organo-tin compound. Quaternary ammonium compounds have been noted to increase color change in dyes (57). Finish #4 was a phenolic compound which are noted for yellowing of textile products (19). The organo-silane compounds seem to have some effect on color change, but the adverse effects were not as great as those observed for finishes #3 and #4.

The susceptibility of the antimicrobial finishes to light was evaluated on undyed nylon specimens using a modified agar plate method and two organisms. S. aureus was more sensitive to differences among the changes within the antimicrobial finishes during light exposure, compared to E. coli which appeared to be more resistant to the finishes. The quaternary ammonium compound/organo-tin compound (finish #3) and the phenolic compound (finish #4) were the least affected by light exposure, compared to the other finishes evaluated. All other finishes, demonstrated no antimicrobial properties after 80 AFU's of light. The effectiveness of finishes #1 (organo-silane) and #6 (organo-tin) was

drastically reduced after 40 AFU's of light exposure while finish #5 (phenolic/organo-tin) steadily decreased with each exposure levels. Finish #2 (organo-silane) did not significantly decrease in effectiveness until after 80 AFU's of exposure, unlike finish #1 which also was an organo-silane. This was probably due to the different pendant groups on the nitrogen in the compounds.

Leachable antimicrobial agents, specifically the quaternary ammonium and phenolic compounds, caused more color change in dyed textiles, but retained their antimicrobial properties longer than did the bonded antimicrobials when exposed to light. The organo-tin compounds did not increase color change of the dyed textiles and maintained their antimicrobial properties up to 40 AFU's of xenon light exposure. The organo-silane compounds had a significant effect on the lightfastness of the dyes, but to a lesser extent than the quaternary ammonium and phenolic compounds. The susceptibility to light degradation of the organo-silanes seemed to depend on the side groups attached to the nitrogen of the pendant quaternary ammonium compound.

Further research on the susceptibility of antimicrobial agents to light degradation needs to be conducted, using other, more quantitative test methods. Developoment of a quantitative test method that is simplier to use and which provides less variable results is definitely needed. In

addition, research using pure finishes (not mixtures as finishes #3 and #5) and using the same concentration rather than the manufacturer's suggested concentration might provide useful information.

Bibliography

1. AATCC Technical Manual, Vol 62, American Association of Textile Chemists and Colorists, Research Park, N.C. (1987).

2. Ahluwalia, V. K., Arora, K. K., and Kaur, G., "Synthesis of Thiazolyldithiocarbamates and their metal complexes as Potential Antifungal and Antibacterial Agents," Synthesis and Reactivity in Inorganic and Metal Organic Chemistry, 16(1):127-136 (1986)

3. Anso IV Guide to Commercial Carpet, Allied Fibers and Plasitics Company, New York, N.Y., 24 p.

4. Arnold, L. B., "Antimicrobial Finishes for Textiles: Some Practical Aspects," American Dyestuff Reporter, 52(3):31-34 (1963).

5. Arnold, L. B., "Antimicrobial Activity on Carpet," Carpet and Rug Industry, 12(4):22,24-27 (1984).

6. Annual Book of ASTM Standards, Vol. 07.01, Textiles - Yarns, Fabrics, General Test Methods and Vol. 07.02, Textiles - Fibers, Zippers, American Society for Testing and Materials, Philadelphia, PA (1986).

7. Bakkar, P. G. H., Influence of Carpets on Hospital Hygiene, Wool Research Organization, New Zealand, Report #29, pp. 1-20 (1975).

8. Baldry, P., The Battle Against Bacteria: A Fresh Look, Cambridge University Press, New York, 179 p. (1976).

9. Banville, R. R. and McNeil, E., "Microbiology of Drycleaning," Applied Microbiology, 14(1):1-7 (1966).

10. Barnes, C. and Warden, J., "Microbial Degradation - Fiber Damage from Staphylococcus Aureaus," Textile Chemist and Colorist, 3(3):29-33 (1971).

11. Brumbelow, J. B., "The Effectivenss and Cleanability of Antimicrobial Finishes on Carpet Tiles," AATCC Book of Papers, pp. 70-75 (1986)

12. Burgress, R., "Micro-Organisms and Textiles," Symposium on Microbial Spoilage on Industrial Materials: Paper V, pp. 230-245 (January 1954).

13. Cano, R. J., and J. S. Colome, Microbiology, West Publishing Company, New York, pp 311-329 (1986).

14. Carpenter, P. L., Microbiology, W. B. Saunders Co., Philadelphia, 432 p. (1961).

15. Chamberly, C., and T. A. Perenich, "TLC Detection of Benzoyl Peroxide on Textiles," Textile Chemist and Colorist, 16(8):37-40 (1984)

16. Collins, R. J., and Purkess, B. E., "The Application of Dichlorophene in The Textile Industry," The Textile Colorist and Finisher: The Textile Manufacturer, 87:239-245 (1960).

17. Connor, C. J., Isaacson, B. L., Dana, G. S., and Cooper, A. S., "Microbiological Protection of Cotton with Copper and Silver Fungicides," Textile Research Journal, 36(4):367-371 (1966).

18. Connor, C. J., Cooper, A. S., and Reeves, W. A., "Zirconium Salts: Algaecides for Cotton," American Dyestuff Reporter, 55(8):21-24 (1966).

19. Cooper, H. R., "Yellowing of Textiles due to Atmospheric Pollutants," Textile Progress. Update on Yellowing, 15(4):1-6 (1987).

20. Danna, G. F., Vigo, T. L., and Welch, C. M., "Permox-A Hydrogen Peroxide-Zinc Acetate Antibacterial Finish for Cotton," Textile Research Journal, 48(3):173-177 (1978).

21. Dorset, B. C. M., "Pollution and Fading in Fabrics," Textile Colorist and Finisher: Textile Manufacturer, 99:27-31 (October 1972).

22. Dow Corning Corporate Test Method, Antimicrobial Activity - Dynamic Test of Surfaces, Dow Corning Corporation, Midland, Micigan, 7 p. (1979).

23. El-Kashef, H. S., Abd-Alla, M. A., Bayoumi, B. E., and El-Timawy, A. A. M., "Synthesis and Antibacterial Activity of Some New Prazolone Dyes," Journal of Chemical Technology and Biotechnology, 33A:294-298 (1983).

24. Fung, D. Y. C. and Miller, R. D., "Effect of Dyes on Bacterial Growth," Applied Microbiology, 25 (5):793-799 (1973).

25. Gagliardi, D. D., "Antibacterial Finishes," American Dyestuff Reporter, 51(2):50-58 (1962).

26. Gagliardi, D. D., and Kenney, V. S., "Microbial Deterioration of Textile Resin Systems," Developments in Industry Microbiology, 9:189-200 (1968).

27. Getting, R. L., Dow Corning, Midland, Michigan, personal communication, Fall 1988.

28. Getting, R. L., and Triplett, B. L., "A New Durable Antimicrobial Finish for Textiles," AATCC Book of Papers, pp. 259-261 (1978).

29. Gonzales, E. J., Welch, C. M., and Guthrie, J. D., "The Bonding of Phenols to Cotton with Zirconium Acetate," Textile Research Journal, 33(8):600-608 (1963).

30. Hale, M. G., Sorkin, M. E., and White, W. C., "Antimicrobial Treatments. Part I. What They Are and Why They Are Used," Reprint from Cleaning and Restoration Magazine, Vol 24 (March 1986).

31. Hale, M. G., Sorkin, M. E., and White, W. C., "Antimicrobial Treatments. Part II. Types and Considerations for Use," Reprint from Cleaning and Restoration Magazine, Vol 24 (April 1986).

32. Hale, M. G. and White, W. C., "Antimicrobial Treatments. Part III. Methods for Determining Their Effectiveness," Reprint from Cleaning and Restoration Magazine, Vol 24 (May 1986).

33. Hardy, E., "Fungi, Molds and Mildews in Textiles," Rayon Textile Monthly, 24:68-70 (March 1943).

34. Hawker, L. E., and Linton, A. H., Microorganisms, Function, Form, and Environment, Edward Arnold LTD., London, 727 p. (1971).

35. Hawker, L. E., Linton, A. H., Folkes, B. F., and Carlile, M. J., An Introduction to the Biology of Microorganisms, St. Martins's Press, New York 452 p. (1960).

36. Hollen, N., Saddler, J., and Langford, A.L., Textiles, 5th ed., Macmillan Publishing Co., Inc., New York, 326 p. (1979).

37. Hsieh, Y. L., Timm, D. A., and Merry, J., "Bacterial Adherence on Fabrics by a Radioisotope Labeling Method," Textile Research Journal, 57(1)120-128 (1987).

38. Intili, H., "Inherently Antimicrobial Non-Woven Fabrics," Journal of Industrial Fabrics, 3(1):4-8 (1984).

39. Isoard, P., and Crance, J. M., "Study of Particle and Microorganism Retention in Textiles," Proceedings of the International Symposium on Contamination, pp. 98-101 (1978).

40. Isquith, A. J., Abbot, E. A., and Walters, P. A., "Surface-Bonded Antimicrobial Activity of an Organosilicon Quaternary Ammonium Chloride," Applied Microbiology, 21(4):771-773 (1971).

41. Joseph, M. L., Introductory Textile Science, 4th ed. Holt, Tinehart, and Winston, Newyork, 406 p. (1981).

42. Kamaeth, Y. K., Ruetsch, S. B., and Weigman, H. D., "Microspectra Photometric Study of Ozone Fading of Disperse Dyes in Nylon," Journal of Textile Research, 53(7):391-402 (1983).

43. Kaswell, E. R., Textile Fibers, Yarns, and Fabrics, Reinhold Publishing Co., New York, pp. 140-171 (1953).

44. Lashen, E. S., "New Method for Evaluating Antibacterial Activity Directily on Fabric," Applied Microbiology, 21(4):771-773 (1971).

45. Latlief, M. A., Goldsmith, M. T., Friedl, B. S., and Stuart, L. S., "Bacteriostatic, Germicidal, and Sanitizing Action of Quaternary Ammonium Compounds on Textiles," The Journal of Pediatrics, 40:324-329 (1952).

46. Lightfastness to Dyes on Nylon Carpet Fibers, A Research Monogram, Allied Signal Fibers, Petersburg, Virginia, 27 p. (March 1984).

47. Mahomed, R. S., "Antibacterial and Antifungal Finishes," Chemical Aftertreatments of Textiles, H. Mark, N. S. Wooding, and S. M. Atlas, Eds., Wiley-Interscience, a Division of John Wiley and Sons, Inc., New York, pp. 507-552 (1971).

48. Malek, J. R., and Speier, J. L., "Development of an Organosilicone Antimicrobial Agent for the Treatment of Surfaces," Journal of Coated Fabrics, 12:38-45 (July 1982).

49. Mandels, M. and Reese, E. T., "Fungal Cellulases and the Microbial Decomposition of Cellulosic Fabric," Developments in Industrial Microbiology, 5:5-20 (1964).

50. Margolis, A., "Quality Fabric Finishing Combats Mildew," Industrial Fabrics Products Review, 60:42-44 (January 1983).

51. McGee, J. B. and Gettings, R. L., "Method for Evaluation of Immobilized Antimicrobial Agents," AATCC Book of Papers, pp. 219-220 (1986).

52. McGee, J. B., Malek, J. R., and White, W. C., "New Antimicrobial Treatment for Carpet Applications," American Dyestuff Reporter, 72(6):24-28 (1983).

53. McNeil, E., "Detection and Evaluation of Antibacterial Activity of Treated Fabrics," American Dyestuff Reporter, 51 (4):26-29 (1962).

54. McNeil, E., "Dissemination of Microorganisms by Fabrics and Leathers," Developments in Industrial Microbiology, 5:30-35 (1964).

55. Mebes, B., "Evaluation of Antimicrobial Finishes Under Conditions of Everyday Use," Melliand Textilbertichte (English Edition), 73:965-966 (November 1973).

56. Moore, R. A. F. , Ruetsch, S. B., and Weigman, H.D., "The Role of Dye Diffusion and Ozone Fading of Acid and Disperse Dyes in Polyamides," Textile Chemist and Colorist, 16(12):250-254 (1984).

57. Morris, C. E. and Welch, C. M., "Use of Aluminum or Titanium Compounds to Bind Antibacterial Agents to Cotton Fabric," Textile Research Journal, 53(3):143-147 (1983).

58. Morris, C. E., Vigo, T. L., and Welch, C. M., "Binding of Organic Antimicrobial Agents to Cotton Fabrics and Zirconium Complexes," Textile Research Journal, 51(2):90-95 (1981).

59. Nahta, R., "Textile Softeners," American Dyestuff Reporter, 70(10):22, 24, 26, 38 (1981)

60. O'Neill, F., "Antimicrobials: Here to Stay or Just Another Fad?," Carpet and Rug Industry, 12(2):8,11-12,14 (1984).

61. Platt, M. W., Hadar, Y., and Chet, I., "The Decolorization of the Polymeric Dye Poly-Blue (Polyvinalamine Sulfonate-Anthroquinone) by Lignin Degrading Fungi," Applied Microbiology and Biotechnology, 21:394-396 (1985).

62. Pourboghrat-Afiat, J., The Effect of Commercial Insecticide Products on Acid and Disperse Dyes on Nylon Fabrics, Master's Thesis, Kansas State University, Manhattan, Kansas, 127 p. (1976).

63. Quinn, H., "A Method for the Determination of the Antimicrobial Properties of Treated Fabrics," Applied Microbiology, 10:74-78 (1962).

64. Radford, P. J., "Application and Evaluation of Antimicrobial Finishes," American Dyestuff Reporter, 62(11):48-55 (1973).

65. Reagan, B. M., Rolow, A. M., and Urban, J. E., "Microwave Sanitization of Polyester and Cotton," Textile Research Journal, 52(3):186-192 (1982).

66. Robinson, G., Carpets and Other Textile Floorcoverings, Textile Book Service, London, pp. 165-201 (1972).

67. Shakara, S., and Ghettas, A. A. G., "Effect of Hydrogen Bonds on Azo Dye Lightfastness," American Dyestuff Reporter, 69(3):36,66-67 (1980).

68. Straley, J. M., "A Review of Disperse Dyes," Textile Chemist and Colorist, 9(12):276-278 (1977).

69. Textile Fibers Identification Act. Code of Federal Regulations, Section 16, Part 303, pp 157-180 (1988).

70. Trotman, E. R., Dyeing and Chemical Technology of Textile Fibers, 6th ed., John Wiley and Sons, New York, (1984).

71. Thimmaiah, K., Symptoms and lesions, in dog and Rats Following Parenternal Admisistration of Furacin, Master's Thesis, Kansas State University, Manhattan, Kansas, 57 p. (1962).

72. United States Code. Title 7. Agriculture. Chapter 6 - Insecticides and Environmental Pesticide Control, pp. 103-140 (1982).

73. Vigo, T. L., "Antibacterial Finishing of Textiles - Potential, Problems, Progress, and Prospects," Chemtech, 6(7):455-458 (1976).

74. Vigo, T. L., and Benjaminson, M. A., "Antibacterial Fiber Treatments and Disinfection," Textile Research Journal, 51(7):454-465 (1981).

75. Vigo, T. L., Danna, G. F., and Welch, C. M., "Antibacterial Cotton Fabrics Containing Peroxide Complexes of Zirconyl Acetate," Textile Chemist and Colorist, 9(4):28-31 (1977).

76. Walters, P. A., Triplett, B. L. and Smith, L. M., "A New Durable Antimicrobial Treatment for Carpets," In Dow Corning 5700 Antimicrobial Agent, Dow Corning Corporation, Midland Michigan.

77. White, W. C., and Gettings, R. L., Evaluating the Properties of Silane Modified Surfaces, Dow Corning Corporation, Midland Michigan.

78. Wilkoff, L. J., Westbrook, L., and Dixon, G. J., "Factors Affecting the Persistence of Staphylococcus aureus on Fabrics," Applied Microbiology, 17(2):268-274 (1969).

79. Wilkoff, L. J., Dixon, G. J., Westbrook, L., and Happich, W. F., "Potentially Infectious Agents Associated with Shearing Bedpads: Effect of Laundering with Detergent-Disinfectant Combinations on staphylococcus aureaus and Pseudomonas aeruginosa," Applied Microbiology, 21(4):647-652 (1971).

80. Wiksell, J. C., Pickett, M. S., and Hartman, P. A., "Survival of Microorganisms in Laundered Polyester-Cotton Sheeting," Applied Microbiology, 25(3):431-435 (1973).

APPENDIX A

Table A1. Gray Scale Rating after 40 AFU's of Xenon Light Exposure

Dye Type/ Finsih	Gray Scale Rating							
	Replication 1				Replication 2			
	Observation				Observation			
	a	b	c	Mean	a	b	c	Mean
Acid Yellow 49								
1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
2	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4	3.5	5.0	5.0	4.5	4.0	5.0	5.0	4.7
5	5.0	4.5	5.0	4.8	5.0	5.0	5.0	5.0
6	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
7	4.5	5.0	5.0	4.8	4.5	5.0	5.0	4.8
Acid Yellow 219								
1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
2	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4	4.5	5.0	5.0	4.8	5.0	5.0	4.5	4.8
5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
6	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
7	4.5	5.0	5.0	4.8	5.0	5.0	5.0	5.0
Acid Red 299								
1	5.0	3.5	5.0	4.6	5.0	5.0	5.0	5.0
2	4.0	5.0	5.0	4.6	5.0	5.0	5.0	5.0
3	5.0	4.5	5.0	4.7	4.5	4.0	5.0	4.5
4	3.5	5.0	4.5	4.3	5.0	5.0	4.5	4.8
5	5.0	3.5	5.0	4.5	5.0	4.5	4.5	4.7
6	4.5	5.0	5.0	4.8	5.0	5.0	4.5	4.8
7	4.5	5.0	5.0	4.8	5.0	5.0	5.0	5.0
Acid Red 361								
1	4.5	4.5	5.0	5.0	5.0	5.0	5.0	5.0
2	4.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4	5.0	5.0	5.0	5.0	4.5	5.0	5.0	4.7
5	4.5	5.0	5.0	4.8	5.0	5.0	5.0	5.0
6	5.0	5.0	5.0	5.0	5.0	4.5	5.0	4.8
7	4.5	5.0	5.0	4.8	5.0	5.0	5.0	5.0
Acid Blue 277								
1	5.0	5.0	5.0	5.0	4.5	5.0	5.0	4.8
2	5.0	5.0	5.0	5.0	5.0	5.0	4.5	4.8
3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
5	4.5	5.0	5.0	4.8	4.5	5.0	5.0	4.8
6	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
7	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Table A1. Gray Scale Rating after 40 AFU's of Xenon Light Exposure (cont)

Finish/ Dye Type	Gray Scale Rating							
	Replication 1				Replication 2			
	Observation				Observation			
	a	b	c	Mean	a	b	c	Mean
Acid Blue 324								
1	5.0	5.0	5.0	5.0	4.5	5.0	5.0	4.8
2	5.0	5.0	5.0	5.0	4.5	4.5	5.0	4.7
3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
6	4.5	5.0	5.0	4.8	5.0	5.0	5.0	5.0
7	4.0	5.0	5.0	4.7	5.0	5.0	5.0	5.0
Undyed								
1	4.5	5.0	5.0	4.7	3.0	5.0	5.0	4.3
2	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4	3.5	3.0	4.0	3.5	3.5	3.0	4.0	3.5
5	4.0	5.0	5.0	4.7	3.0	5.0	5.0	4.3
6	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
7	4.5	5.0	5.0	4.8	5.0	5.0	5.0	5.0

Table A2. Gray Scale Rating after 80 AFU's of Xenon Light Exposure

Dye Type/ Finsih	Gray Scale Rating							
	Replication 1 Observation				Replication 2 Observation			
	a	b	c	Mean	a	b	c	Mean
Acid Yellow 49								
1	4.0	4.5	5.0	4.5	4.5	5.0	4.5	4.7
2	3.5	4.5	5.0	4.3	4.0	5.0	5.0	4.7
3	4.5	5.0	5.0	4.8	3.0	5.0	5.0	4.3
4	4.0	5.0	5.0	4.7	4.5	5.0	5.0	4.8
5	5.0	5.0	5.0	5.0	4.0	4.5	5.0	4.5
6	4.0	5.0	5.0	4.7	4.5	5.0	5.0	4.8
7	4.0	4.5	5.0	4.5	4.5	5.0	5.0	4.7
Acid Yellow 219								
1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
2	4.5	5.0	5.0	4.8	4.0	5.0	5.0	4.7
3	4.5	4.5	5.0	4.6	5.0	5.0	5.0	5.0
4	4.5	5.0	5.0	4.8	4.0	5.0	5.0	4.7
5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
6	4.0	5.0	5.0	4.7	5.0	5.0	5.0	5.0
7	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Acid Red 299								
1	5.0	4.0	4.5	4.5	5.0	4.0	4.5	4.8
2	4.0	4.0	5.0	4.3	4.5	3.5	4.5	4.2
3	3.5	4.0	4.5	4.0	4.5	4.0	4.0	4.2
4	4.5	5.0	5.0	4.8	5.0	5.0	4.5	4.8
5	4.0	4.0	5.0	4.3	4.0	3.5	4.0	4.3
6	4.0	4.5	4.5	4.3	4.0	4.0	4.0	4.0
7	3.5	4.5	5.0	4.3	4.0	3.5	4.5	4.0
Acid Red 361								
1	4.0	5.0	5.0	4.7	4.5	5.0	5.0	4.7
2	3.5	4.5	4.5	4.3	4.5	5.0	5.0	4.8
3	3.5	4.0	4.5	4.0	2.5	5.0	5.0	4.2
4	4.5	5.0	5.0	4.8	4.0	5.0	5.0	4.7
5	4.0	4.5	4.5	4.3	5.0	5.0	5.0	5.0
6	3.5	4.5	5.0	4.3	3.5	5.0	5.0	4.8
7	4.0	4.5	5.0	4.5	4.5	5.0	4.5	4.8
Acid Blue 277								
1	4.5	5.0	5.0	4.8	4.0	5.0	5.0	4.7
2	4.0	4.5	5.0	4.5	5.0	5.0	4.5	4.7
3	4.0	4.0	4.5	4.2	3.5	4.5	4.5	4.2
4	3.0	4.5	4.5	4.7	5.0	5.0	4.5	4.8
5	4.5	5.0	5.0	4.7	3.5	5.0	4.5	4.2
6	3.5	4.5	5.0	4.3	3.5	5.0	4.5	4.2
7	4.0	5.0	5.0	4.7	4.0	5.0	5.0	4.7

Table A2. Gray Scale Rating after 80 AFU's of Xenon Light Exposure (cont)

Finish/ Dye Type	Gray Scale Rating							
	Replication 1				Replication 2			
	Observation				Observation			
	a	b	c	Mean	a	b	c	Mean
Acid Blue 324								
1	4.0	5.0	5.0	4.3	4.0	5.0	5.0	4.7
2	4.5	4.5	5.0	4.3	3.5	5.0	5.0	4.5
3	3.0	4.5	5.0	4.2	3.5	4.5	5.0	4.3
4	4.0	5.0	5.0	4.7	4.0	5.0	5.0	4.7
5	4.5	5.0	5.0	4.8	5.0	5.0	4.5	4.8
6	4.0	5.0	5.0	4.7	5.0	5.0	5.0	5.0
7	4.5	5.0	5.0	4.5	5.0	5.0	5.0	5.0
Undyed								
1	5.0	5.0	5.0	5.0	3.5	5.0	5.0	4.5
2	4.5	5.0	5.0	4.8	4.0	5.0	5.0	4.7
3	3.5	5.0	5.0	4.5	3.0	5.0	5.0	4.3
4	2.5	4.0	3.0	3.2	2.5	2.0	4.0	2.8
5	4.0	5.0	5.0	4.7	3.5	5.0	5.0	4.5
6	3.5	5.0	5.0	4.5	4.0	5.0	5.0	4.7
7	3.5	5.0	5.0	4.3	4.0	5.0	5.0	4.7

Table A3. Gray Scale Rating after 160 AFU's of Xenon Light Exposure

Dye Type/ Finsih	Gray Scale Rating							
	Replication 1 Observation				Replication 2 Observation			
	a	b	c	Mean	a	b	c	Mean
Acid Yellow 49								
1	2.5	4.0	4.5	3.7	3.0	3.0	4.0	3.3
2	3.0	3.5	4.5	3.5	4.0	5.0	4.5	4.5
3	3.5	4.0	4.5	4.0	3.0	5.0	4.5	4.2
4	2.0	2.5	3.5	2.7	3.0	5.0	4.0	4.0
5	3.0	4.5	4.5	4.0	3.0	2.5	4.5	3.3
6	3.5	5.0	5.0	4.5	4.0	5.0	4.5	4.5
7	3.0	4.0	4.5	3.8	3.5	5.0	5.0	4.5
Acid Yellow 219								
1	4.0	5.0	5.0	4.7	5.0	5.0	5.0	5.0
2	4.0	4.5	5.0	4.5	5.0	5.0	5.0	5.0
3	3.0	4.0	5.0	4.0	5.0	5.0	5.0	5.0
4	3.5	5.0	5.0	4.5	5.0	5.0	5.0	5.0
5	5.0	5.0	5.0	5.0	4.5	5.0	5.0	4.8
6	4.0	5.0	5.0	4.7	5.0	5.0	4.0	4.7
7	4.0	5.0	5.0	4.7	5.0	5.0	5.0	5.0
Acid Red 299								
1	2.5	3.0	3.0	2.8	3.5	2.5	3.0	3.0
2	2.5	3.0	4.0	3.1	3.0	3.0	3.5	3.2
3	2.0	2.0	3.0	2.3	3.0	2.0	3.0	2.7
4	3.5	4.0	4.5	4.0	5.0	4.5	4.0	4.5
5	2.5	3.5	4.0	3.0	2.5	1.5	2.5	2.1
6	3.0	3.5	4.5	3.5	3.0	2.0	4.0	3.0
7	2.5	3.0	4.0	3.2	3.5	2.0	3.5	3.0
Acid Red 361								
1	2.5	3.0	4.0	3.2	3.0	4.0	4.0	3.5
2	3.0	3.0	4.5	3.5	3.5	5.0	4.5	4.3
3	2.0	3.0	3.0	2.3	3.0	2.5	4.0	3.2
4	3.0	4.0	4.5	3.6	3.0	3.5	4.0	3.5
5	3.0	3.5	3.5	3.3	3.0	3.0	4.0	3.3
6	3.0	3.5	4.0	3.5	3.0	3.0	4.0	3.3
7	3.5	1.5	4.0	3.0	3.5	3.0	4.0	3.6
Acid Blue 277								
1	3.0	3.0	4.5	3.5	3.0	3.5	4.5	3.6
2	3.5	4.0	4.5	4.0	5.0	3.5	4.5	4.3
3	2.5	3.0	3.5	3.0	3.0	3.5	3.5	3.3
4	3.0	4.0	4.5	3.6	4.5	5.0	4.5	4.7
5	3.0	3.5	4.5	3.5	3.0	2.0	4.5	3.2
6	3.0	4.0	4.5	3.6	4.5	4.0	4.5	4.3
7	4.5	4.5	4.5	4.5	4.5	4.0	4.5	4.3

Table A3. Gray Scale Rating after 160 AFU's of Xenon Light Exposure (cont)

Finish/ Dye Type	Gray Scale Rating							
	Replication 1				Replication 2			
	Observation				Observation			
	a	b	c	Mean	a	b	c	Mean
Acid Blue 324								
1	4.0	4.0	4.5	4.2	3.0	5.0	4.5	4.2
2	3.5	4.0	4.5	4.0	5.0	5.0	4.5	4.8
3	3.0	1.5	4.0	2.8	3.5	3.0	4.5	3.5
4	4.0	4.5	5.0	4.5	5.0	4.5	5.0	4.8
5	4.0	4.5	4.5	4.3	4.0	5.0	5.0	4.7
6	3.5	4.5	5.0	4.3	5.0	5.0	4.5	4.8
7	4.0	5.0	4.5	4.5	5.0	5.0	5.0	5.0
Undyed								
1	3.5	5.0	5.0	4.5	4.0	5.0	5.0	4.3
2	3.0	4.5	5.0	4.2	3.0	5.0	5.0	4.3
3	4.0	4.5	5.0	4.5	4.0	5.0	5.0	4.7
4	3.0	2.0	4.0	3.0	2.5	2.5	3.0	2.7
5	4.0	5.0	5.0	4.7	3.0	5.0	5.0	4.3
6	3.5	5.0	5.0	4.5	3.0	5.0	5.0	4.3
7	4.0	5.0	5.0	4.7	5.0	5.0	5.0	5.0

Table A4. Gray Scale Rating after 320 AFU's of Xenon Light Exposure

Dye Type/ Finsih	Gray Scale Rating							
	Replication 1 Observation				Replication 2 Observation			
	a	b	c	Mean	a	b	c	Mean
Acid Yellow 49								
1	2.5	2.0	3.0	2.5	1.5	1.5	3.5	2.2
2	2.5	2.5	3.5	2.8	2.0	1.5	4.5	2.7
3	3.0	2.0	3.0	2.6	1.5	2.0	2.5	2.0
4	1.0	1.0	1.0	1.0	1.0	1.5	1.0	1.2
5	2.5	2.5	4.0	3.0	2.5	2.0	3.0	2.5
6	3.0	4.0	4.5	3.8	3.0	3.0	4.5	3.5
7	2.5	3.0	3.5	3.0	2.5	2.5	4.5	3.2
Acid Yellow 219								
1	4.5	5.0	4.5	4.6	5.0	5.0	5.0	5.0
2	4.5	5.0	5.0	4.8	5.0	1.0	5.0	2.2
3	4.0	4.0	5.0	4.3	5.0	5.0	5.0	5.0
4	4.0	5.0	5.0	4.3	5.0	5.0	5.0	5.0
5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
6	4.0	5.0	5.0	4.7	5.0	5.0	5.0	5.0
7	4.0	5.0	5.0	4.3	5.0	5.0	5.0	5.0
Acid Red 299								
1	2.0	1.5	1.0	1.7	2.5	2.5	2.5	2.5
2	2.5	2.0	3.0	2.5	2.5	5.0	3.0	3.5
3	1.5	1.0	1.0	1.2	2.0	1.0	1.0	1.3
4	2.0	3.0	2.0	2.3	3.0	1.0	2.5	2.2
5	2.5	1.0	3.0	2.2	1.0	1.0	1.0	1.7
6	3.0	2.5	3.0	2.8	2.5	1.5	2.5	2.2
7	3.0	2.0	3.0	2.7	3.0	1.5	3.0	2.5
Acid Red 361								
1	1.5	2.0	2.0	1.5	2.0	1.5	2.5	2.0
2	3.0	3.0	3.5	3.2	3.0	1.5	2.5	2.3
3	2.0	1.0	1.0	1.2	1.5	1.0	2.0	1.5
4	2.0	2.0	2.0	2.0	2.0	1.0	2.0	1.7
5	2.5	1.5	2.0	2.0	2.5	2.5	3.0	2.7
6	2.0	3.0	2.5	2.5	2.5	1.5	3.0	2.3
7	2.5	2.5	3.0	2.6	2.5	1.0	3.0	2.2
Acid Blue 277								
1	3.0	2.5	3.5	3.0	2.5	3.0	3.5	3.0
2	3.0	2.5	3.5	3.0	2.5	3.5	4.5	3.5
3	2.5	1.0	2.0	1.8	2.5	1.5	4.0	2.7
4	3.5	3.0	4.0	3.5	3.5	3.0	4.5	3.5
5	2.5	2.0	3.0	2.5	2.5	2.5	3.0	2.7
6	2.5	2.5	3.0	2.7	2.5	2.0	4.0	2.8
7	3.5	3.5	4.0	3.7	3.5	2.5	4.5	3.5

Table A4. Gray Scale Rating after 320 AFU's of Xenon Light Exposure (cont)

Finish/ Dye Type	Gray Scale Rating							
	Replication 1				Replication 2			
	Observation				Observation			
	a	b	c	Mean	a	b	c	Mean
Acid Blue 324								
1	2.5	3.0	3.5	3.0	2.5	3.0	4.5	3.3
2	3.5	3.0	4.5	3.7	3.0	3.5	4.5	3.7
3	2.5	1.0	4.5	4.7	2.5	2.0	3.5	2.7
4	4.0	4.0	4.5	4.2	3.5	5.0	4.5	4.3
5	3.5	3.5	4.0	3.7	3.0	3.5	4.5	3.5
6	4.0	3.5	4.5	4.0	3.5	3.5	4.5	3.8
7	3.5	4.0	4.5	4.0	3.5	3.5	4.5	3.8
Undyed								
1	5.0	5.0	5.0	5.0	4.0	5.0	5.0	4.7
2	4.5	5.0	5.0	4.8	4.5	5.0	5.0	4.8
3	4.0	5.0	5.0	4.7	3.0	5.0	5.0	4.3
4	3.0	3.5	4.5	3.7	2.5	3.0	4.5	3.3
5	4.0	5.0	5.0	4.7	3.0	5.0	5.0	4.3
6	4.0	5.0	5.0	4.7	3.0	5.0	5.0	4.3
7	4.5	5.0	5.0	4.8	4.5	5.0	5.0	4.8

Table A5. Mean Gray Scale Ratings for each Replication

Dye Type	Light Exposure (AFU's)	Rep	Gray Scale Rating Finish 1	2	3	4	5	6	7
Acid Yellow 49	40	1	5.0	5.0	5.0	4.5	4.8	5.0	4.8
	40	2	5.0	5.0	5.0	4.7	5.0	5.0	4.8
	80	1	4.5	4.3	4.8	4.7	5.0	4.7	4.5
	80	2	4.7	4.7	4.3	4.8	4.5	4.8	4.7
	160	1	3.7	3.5	4.0	2.7	4.0	4.5	3.8
	160	2	3.3	4.5	4.2	4.0	3.3	4.5	4.5
	320	1	2.5	2.8	2.6	1.0	3.0	3.8	3.0
	320	2	2.2	2.7	2.0	1.2	2.5	3.5	3.2
Acid Yellow 219	40	1	5.0	5.0	5.0	4.8	5.0	5.0	4.8
	40	2	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	80	1	5.0	4.8	4.6	4.8	5.0	4.8	5.0
	80	2	5.0	4.7	5.0	4.7	5.0	5.0	5.0
	160	1	4.7	4.5	4.0	4.5	5.0	4.7	4.7
	160	2	5.0	5.0	5.0	5.0	4.8	4.7	5.0
	320	1	4.6	4.8	4.3	4.3	5.0	4.7	4.3
	320	2	5.0	2.2	5.0	5.0	5.0	5.0	5.0
Acid Red 299	40	1	4.6	4.6	4.7	4.3	4.5	4.8	4.8
	40	2	5.0	5.0	4.5	4.8	4.7	4.8	5.0
	80	1	4.5	4.3	4.0	4.8	4.3	4.3	4.3
	80	2	4.8	4.2	4.2	4.8	4.3	4.0	4.0
	160	1	2.8	3.1	2.3	4.0	3.0	3.5	3.2
	160	2	3.0	3.2	2.7	4.5	2.1	3.0	3.0
	320	1	1.7	2.5	1.2	2.3	2.2	2.8	2.7
	320	2	2.5	3.5	1.3	2.2	1.7	2.2	2.5
Acid Red 361	40	1	5.0	5.0	5.0	5.0	4.8	5.0	4.8
	40	2	5.0	4.7	5.0	4.7	5.0	4.8	5.0
	80	1	4.7	4.3	4.0	4.8	4.3	4.3	4.5
	80	2	4.7	4.8	4.2	4.7	5.0	4.8	4.8
	160	1	3.2	3.5	2.3	3.6	3.3	3.5	3.0
	160	2	3.5	4.3	3.2	3.5	3.3	3.3	3.6
	320	1	1.5	3.2	1.2	2.0	2.0	2.5	2.6
	320	2	2.0	2.3	1.5	1.7	2.7	2.3	2.2
Acid Blue 277	40	1	5.0	5.0	5.0	5.0	4.8	5.0	5.0
	40	2	4.8	4.5	5.0	4.8	4.8	5.0	5.0
	80	1	4.8	4.5	4.2	4.7	4.7	4.3	4.7
	80	2	4.7	4.7	4.2	4.3	4.2	4.2	4.7
	160	1	3.5	4.0	3.0	3.6	3.5	3.6	4.5
	160	2	3.6	4.3	3.3	4.7	3.2	4.3	4.3
	320	1	3.0	3.0	1.8	3.5	2.5	2.7	3.7
	320	2	3.0	3.5	2.7	3.5	2.7	2.8	3.5

Table A5. Mean Gray Scale Ratinis for each Replication

Dye Type	Light Exposure (AFU's)	Rep	Gray Scale Rating Finish 1	2	3	4	5	6	7
Acid Blue 324	40	1	5.0	5.0	5.0	5.0	5.0	4.8	4.7
	40	2	4.8	4.7	5.0	5.0	5.0	5.0	5.0
	80	1	4.3	4.3	4.2	4.7	4.8	4.7	4.5
	80	2	4.7	4.5	4.3	4.7	4.0	5.0	5.0
	160	1	4.2	4.0	2.8	4.5	4.3	4.3	4.5
	160	2	4.2	4.8	3.5	4.8	4.7	4.8	5.0
	320	1	3.0	3.7	4.7	4.2	3.7	4.0	4.0
	320	2	3.3	3.7	2.7	4.3	3.5	3.8	3.8
Undyed	40	1	4.8	5.0	5.0	3.5	4.7	5.0	4.8
	40	2	4.3	5.0	5.0	3.5	4.3	5.0	5.0
	80	1	5.0	4.8	4.5	3.2	4.7	4.5	4.3
	80	2	4.5	4.7	4.3	2.8	4.5	4.7	4.7
	160	1	4.5	4.2	4.5	3.0	4.7	4.5	4.7
	160	2	4.3	4.3	4.7	2.7	4.3	4.3	5.0
	320	1	5.0	4.8	4.7	3.7	4.7	4.7	4.8
	320	2	4.7	4.8	4.3	3.3	4.3	4.3	4.8

Table A6. Mean Gray Scale Ratings for Finishes

Finish	Replicate	Gray Scale Rating Light Exposure (AFU's) 40	80	160	320
#1	1	4.9	4.7	3.7	3.4
	2	4.8	4.7	3.8	3.2
#2	1	4.5	4.5	3.8	3.5
	2	4.9	4.6	4.1	3.6
#3	1	5.0	4.2	3.2	2.9
	2	4.7	4.4	3.8	2.8
#4	1	4.6	4.5	3.8	3.1
	2	4.7	4.6	4.2	3.4
#5	1	4.8	4.7	4.0	3.7
	2	4.9	4.7	3.7	3.5
#6	1	4.9	4.5	4.1	3.6
	2	4.9	4.8	4.2	3.4
#7	1	4.8	4.6	4.1	3.6
	2	5.0	4.7	4.0	3.6

Table A7. Mean Gray Scale Ratings for Dyes

Dyes	Replicate	Gray Scale Rating Light Exposure (AFU's) 40	80	160	320
1	1	4.8	4.6	3.7	2.7
	2	4.9	4.7	4.0	2.5
2	1	4.9	4.8	4.4	4.5
	2	5.0	4.9	4.9	4.6
3	1	4.6	4.4	3.2	2.2
	2	4.8	4.3	3.2	2.3
4	1	3.6	4.4	3.3	2.3
	2	4.9	4.7	3.3	2.1
5	1	4.9	4.6	3.9	2.9
	2	4.9	4.6	4.0	3.1
6	1	4.9	4.5	4.1	3.9
	2	4.9	4.7	4.6	3.6
7	1	4.7	4.5	4.3	4.6
	2	4.6	4.3	4.2	4.4

APPENDIX B

Table B1. Mean L*, a*, b*, and Delta E after 0 AFU's of Xenon Light Exposure

Dye Type/ Finish	Replication 1			ΔE Value	Replication 2			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
Acid Yellow 49								
1	83.3	-5.9	103.1	---	83.7	-5.9	104.9	---
2	83.5	-6.7	102.0	---	84.0	-6.3	105.5	---
3	83.8	-7.3	103.7	---	83.4	-6.9	102.2	---
4	83.5	-6.6	102.6	---	84.2	-7.6	105.3	---
5	84.0	-7.7	103.7	---	83.7	-7.5	105.1	---
6	83.7	-6.4	105.1	---	84.5	-7.7	104.2	---
7	83.8	-7.1	102.6	---	84.6	-6.9	105.7	---
Acid Yellow 219								
1	63.8	28.4	76.9	---	62.0	32.4	77.3	---
2	63.1	29.4	76.6	---	63.2	30.5	78.4	---
3	63.9	27.6	76.9	---	62.8	30.5	76.3	---
4	61.6	32.1	76.1	---	62.1	32.3	76.1	---
5	63.5	29.5	78.3	---	63.3	30.0	77.6	---
6	63.1	29.9	77.6	---	61.7	32.6	76.0	---
7	63.5	29.4	77.8	---	63.1	30.4	77.3	---
Acid Red 299								
1	21.7	33.9	-8.6	---	19.6	30.9	-5.7	---
2	21.2	34.0	-8.8	---	19.5	31.8	-6.4	---
3	19.9	32.5	-7.6	---	21.1	31.1	-5.7	---
4	19.8	31.9	-7.0	---	19.7	30.2	-6.0	---
5	19.7	31.5	-7.3	---	22.3	33.6	-7.6	---
6	20.9	34.3	-8.5	---	20.2	30.7	-6.3	---
7	21.5	35.1	-9.1	---	21.7	31.9	-6.7	---
Acid Red 361								
1	35.2	54.9	8.0	---	35.0	55.2	8.4	---
2	35.2	55.2	8.4	---	34.7	55.4	9.8	---
3	35.9	54.9	6.9	---	34.2	54.4	9.4	---
4	34.5	54.9	9.3	---	35.8	55.7	9.4	---
5	35.3	54.6	9.2	---	33.7	54.6	10.4	---
6	35.7	55.0	9.1	---	35.5	55.1	8.3	---
7	36.4	55.8	8.3	---	35.8	55.0	7.5	---
Acid Blue 277								
1	28.6	21.9	-49.1	---	28.2	22.7	-49.4	---
2	29.4	21.9	-49.3	---	28.3	24.2	-51.1	---
3	30.6	20.9	-49.3	---	29.6	16.0	-46.3	---
4	31.6	20.0	-49.3	---	27.4	24.4	-50.8	---
5	30.1	19.5	-49.0	---	27.2	24.1	-50.3	---
6	30.7	20.6	-49.3	---	28.9	21.7	-49.0	---
7	28.3	23.8	-50.9	---	29.1	22.2	-50.2	---

Table B1. Mean L*, a*, b*, and Delta E after 0 AFU's of Xenon Light Exposure (cont.)

Dye Type/ Finish	ΔE Value							
	Replication 1				Replication 2			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
Acid Blue 324								
1	30.3	21.2	-49.5	---	27.9	17.4	-46.0	---
2	30.6	15.6	-46.1	---	30.1	16.1	-46.7	---
3	30.0	20.7	-48.5	---	28.0	22.9	-49.5	---
4	29.4	15.9	-45.4	---	28.0	17.9	-47.0	---
5	20.4	16.9	-45.9	---	25.8	19.2	-56.5	---
6	28.4	17.2	-46.7	---	27.9	18.0	-47.2	---
7	27.2	18.6	-47.5	---	27.7	18.6	-46.5	---
Undyed								
1	91.8	-1.4	3.7	---	91.2	-1.1	3.3	---
2	91.7	-1.3	4.2	---	91.4	-1.4	2.9	---
3	91.2	-1.6	3.7	---	91.5	-1.4	3.1	---
4	91.3	-2.3	5.5	---	91.1	-1.6	3.9	---
5	91.3	-1.7	3.5	---	90.8	-1.3	3.4	---
6	91.6	-1.7	3.6	---	91.7	-1.4	3.3	---
7	92.1	-1.2	3.7	---	91.3	-1.1	2.9	---

Table B2. Mean L*, a*, b*, and Delta E after 40 AFU's of Xenon Light Exposure

Dye Type/ Finish	ΔE Value							
	Replication 1				Replication 2			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
Acid Yellow 49								
1	84.0	-7.5	102.9	1.6	83.8	-6.3	103.3	1.7
2	83.8	-6.9	99.7	2.4	84.1	-6.6	104.2	1.4
3	84.2	-6.9	102.4	1.5	83.8	-7.1	100.6	1.7
4	82.8	-5.9	98.7	4.0	83.2	-6.8	102.3	3.3
5	84.2	-7.7	103.8	0.2	83.9	-7.6	103.6	1.5
6	84.0	-6.7	103.5	1.7	84.5	-7.7	103.5	0.7
7	84.0	-7.5	99.5	3.2	84.6	-6.8	104.6	1.1
Acid Yellow 219								
1	64.2	28.6	78.1	1.3	61.7	32.6	77.1	0.4
2	63.1	29.7	76.6	0.3	63.2	30.6	77.8	0.6
3	64.2	27.6	76.5	0.5	62.9	30.1	76.4	0.4
4	61.1	32.0	76.1	0.2	62.0	32.0	76.2	0.3
5	63.6	29.9	79.9	1.7	63.1	29.9	75.9	0.8
6	63.3	29.9	77.4	0.3	61.6	32.8	76.7	0.7
7	63.4	29.5	74.7	1.1	62.9	30.4	77.6	0.4
Acid Red 299								
1	22.7	34.7	-8.0	1.3	20.2	31.6	-6.1	1.0
2	22.6	33.7	-8.2	1.5	21.0	32.4	-6.4	1.6
3	22.2	32.9	-6.9	2.5	21.6	33.0	-6.3	2.1
4	20.4	32.2	-7.1	0.7	20.1	30.9	-5.8	0.8
5	20.0	32.8	-6.1	1.8	24.3	33.7	-7.6	1.9
6	22.1	34.3	-8.0	1.3	21.1	32.3	-6.5	1.9
7	22.6	34.5	-8.3	1.5	22.3	33.3	-7.0	1.6
Acid Red 361								
1	35.3	54.4	7.5	0.6	35.2	54.4	7.5	1.2
2	35.9	54.2	7.7	1.4	35.3	54.8	9.1	1.1
3	37.2	53.4	6.1	2.1	34.7	54.0	9.1	0.7
4	35.0	53.8	9.5	1.3	36.0	55.1	9.8	0.7
5	35.2	54.5	8.9	0.3	34.1	54.1	10.0	0.8
6	36.1	54.5	7.9	1.3	35.9	54.4	7.9	0.8
7	36.0	54.5	7.3	1.7	36.3	54.4	7.3	0.8
Acid Blue 277								
1	28.8	20.5	-47.6	2.0	28.8	21.0	-47.5	2.7
2	30.2	19.5	-47.0	3.5	28.8	21.9	-48.7	3.4
3	32.4	16.5	-45.1	6.3	30.8	18.3	-44.1	3.6
4	32.5	15.5	-45.3	6.1	27.6	20.7	-47.5	5.0
5	29.5	19.9	-47.6	1.6	27.9	21.4	-47.8	3.7
6	31.5	18.6	-47.4	2.9	29.4	20.0	-47.3	2.4
7	28.8	22.1	-49.4	2.4	29.6	20.4	-48.2	2.7

Table B2. Mean L*, a*, b*, and Delta E after 40 AFU's of Xenon Light Exposure (cont.)

Dye Type/ Finish	ΔE Value							
	Replication 1				Replication 2			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
Acid Blue 324								
1	30.4	19.5	-47.8	2.4	27.9	16.7	-44.9	1.3
2	31.2	14.5	-45.0	1.7	31.1	14.0	-45.6	2.0
3	31.8	16.4	-44.5	6.2	29.0	19.2	-46.1	5.2
4	29.4	13.9	-44.0	2.4	28.1	15.5	-45.0	3.1
5	27.5	16.4	-45.9	0.6	26.4	17.9	-47.8	1.8
6	29.2	16.1	-46.0	1.5	28.2	17.4	-46.8	0.8
7	27.7	17.8	-47.0	1.1	27.7	17.3	-46.1	0.5
Undyed								
1	91.6	-1.1	2.9	0.9	91.4	-0.7	2.4	1.1
2	92.1	-0.9	3.0	1.3	92.0	-1.0	2.5	0.8
3	91.5	-1.2	3.3	0.6	91.8	-1.0	3.0	0.5
4	89.9	-2.9	11.4	6.1	89.9	-2.9	11.8	8.1
5	91.0	-1.4	4.4	0.9	91.0	-1.1	3.9	0.5
6	91.9	-0.9	2.7	1.2	92.0	-0.9	2.5	0.9
7	92.0	-1.1	2.8	0.9	91.6	-0.9	2.7	0.4

Table B3. Mean L*, a*, b*, and Delta E after 80 AFU's of Xenon Light Exposure

Dye Type/ Finish	ΔE Value							
	Replication 1				Replication 2			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
Acid Yellow 49								
1	84.3	-8.0	100.4	3.5	83.8	-7.0	101.0	4.1
2	83.9	-7.5	96.7	5.3	84.2	-7.1	104.0	1.6
3	84.1	-7.3	100.5	3.1	83.8	-7.7	99.6	2.7
4	82.5	-5.8	94.4	8.3	83.1	-6.9	100.2	5.3
5	84.5	-8.0	101.2	2.6	83.8	-8.0	102.0	3.1
6	83.9	-6.9	102.5	2.6	84.6	-8.1	103.7	0.6
7	84.1	-7.9	97.6	5.1	84.6	-7.0	103.2	2.5
Acid Yellow 219								
1	64.2	28.5	76.9	0.4	61.8	32.2	77.0	0.4
2	63.0	29.6	76.4	0.3	62.6	30.8	78.9	0.9
3	64.1	27.3	75.9	1.1	62.8	30.0	78.2	2.0
4	61.8	31.4	76.1	0.7	61.8	31.8	78.3	2.2
5	63.7	30.0	78.2	0.5	63.1	29.8	76.7	0.9
6	63.2	29.6	77.3	0.4	61.6	32.5	79.3	3.2
7	63.5	29.3	76.7	1.1	62.7	30.4	77.1	0.4
Acid Red 299								
1	24.1	34.3	-7.8	2.5	21.3	32.1	-6.0	2.2
2	23.3	33.5	-7.6	2.5	21.3	33.3	-6.0	2.3
3	23.9	32.6	-6.4	4.2	22.5	33.8	-5.7	3.1
4	20.8	32.5	-6.5	1.3	20.3	31.9	-5.1	2.1
5	21.5	32.8	-6.3	2.4	26.0	33.5	-7.2	3.7
6	23.0	34.2	-7.5	2.3	21.2	33.3	-6.0	2.8
7	23.7	34.3	-7.7	2.7	23.4	33.4	-7.0	2.3
Acid Red 361								
1	36.2	53.3	6.6	2.4	35.8	53.8	7.1	2.0
2	36.5	53.5	7.1	2.5	35.5	54.7	9.1	1.2
3	38.4	51.6	5.4	4.4	34.8	53.7	9.3	0.9
4	35.2	53.4	9.1	1.8	36.0	54.8	10.1	1.2
5	36.2	53.7	7.9	1.9	34.6	53.6	9.3	1.8
6	36.5	54.0	7.5	2.0	36.1	54.2	8.0	1.1
7	37.3	53.8	6.9	2.6	36.6	53.7	7.1	1.6
Acid Blue 277								
1	29.6	19.0	-46.1	4.3	29.5	19.3	-45.7	5.2
2	30.9	17.7	-45.1	6.2	29.0	20.1	-47.1	5.8
3	33.7	14.3	-42.5	10.1	31.2	11.6	-42.4	6.1
4	32.4	15.2	-44.5	6.8	27.4	19.6	-46.5	6.4
5	30.5	17.5	-45.5	4.1	29.0	19.2	-45.7	6.9
6	32.3	17.0	-45.5	5.4	29.6	18.2	-45.7	4.9
7	29.3	20.8	-47.9	4.4	30.2	18.6	-46.3	5.5

Table B3. Mean L*, a*, b*, and Delta E after 80 AFU's of Xenon Light Exposure (cont.)

Dye Type/ Finish	ΔE Value							
	Replication 1				Replication 2			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
Acid Blue 324								
1	31.2	17.9	-46.2	4.8	28.9	15.2	-43.5	3.5
2	31.6	13.3	-43.5	3.6	31.3	13.4	-44.1	3.9
3	32.9	14.3	-42.1	9.5	29.4	17.0	-44.0	8.2
4	29.5	13.2	-43.1	3.6	27.7	14.9	-44.4	3.9
5	28.6	14.9	-44.4	2.8	27.0	16.2	-43.8	4.3
6	29.3	15.2	-44.8	2.9	28.0	16.2	-45.7	2.4
7	28.1	17.1	-46.1	2.2	28.0	15.8	-44.6	2.6
Undyed								
1	91.9	-1.1	3.0	0.8	91.8	-0.8	2.5	1.1
2	91.9	-0.8	2.9	1.4	92.1	-1.0	2.5	0.8
3	91.5	-1.0	3.0	0.9	91.8	-1.0	3.1	0.5
4	89.8	-3.1	11.4	6.1	90.2	-3.4	12.1	8.4
5	91.5	-1.4	4.0	0.6	91.2	-1.0	3.7	0.5
6	91.9	-0.9	2.7	1.3	92.1	-1.1	2.5	0.9
7	92.1	-0.9	2.7	1.0	91.6	-0.8	2.7	0.5

Table B4. Mean L*, a*, b*, and Delta E after 160 AFU's of Xenon Light Exposure

Dye Type/ Finish	ΔE Value							
	Replication 1				Replication 2			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
Acid Yellow 49								
1	84.5	-8.6	95.2	8.4	84.2	-7.6	94.9	10.2
2	84.4	-8.5	90.4	11.8	84.5	-7.4	99.1	6.4
3	84.6	-8.3	95.1	8.7	84.3	-8.0	91.4	10.9
4	83.0	-5.1	80.0	22.7	82.9	-6.4	87.9	17.5
5	84.7	-8.7	96.7	7.1	84.2	-8.6	97.9	7.2
6	84.6	-7.9	99.1	6.2	84.7	-8.4	99.0	5.2
7	84.7	-8.8	92.5	10.3	84.9	-7.6	100.2	5.6
Acid Yellow 219								
1	63.9	28.3	75.8	1.1	61.8	32.2	76.6	0.0
2	63.2	29.2	75.7	0.9	62.7	30.4	76.9	1.6
3	64.5	26.7	75.4	1.9	62.9	29.2	74.7	1.9
4	62.2	31.1	76.2	1.2	61.9	31.3	75.2	1.3
5	63.8	29.3	77.7	0.7	63.4	29.2	76.6	1.3
6	63.6	29.3	77.1	0.9	61.8	32.0	75.8	0.6
7	64.7	29.2	76.8	1.0	62.7	30.3	76.7	0.7
Acid Red 299								
1	26.5	33.4	-7.0	5.1	23.7	32.3	-5.4	4.4
2	25.7	33.1	-7.3	4.8	23.5	32.7	-6.2	4.1
3	28.5	31.2	-5.7	8.9	26.2	32.3	-5.8	5.3
4	22.7	32.9	-5.8	3.4	22.5	30.9	-4.7	3.2
5	23.8	32.7	-6.0	4.5	29.9	32.6	-6.3	7.7
6	25.3	34.0	-7.3	4.6	24.3	32.5	-6.4	4.5
7	26.0	34.3	-7.3	4.9	25.2	33.4	-6.7	3.8
Acid Red 361								
1	37.8	51.1	5.6	5.2	35.9	52.2	8.1	3.1
2	38.1	51.4	6.2	5.2	37.0	53.0	7.9	3.9
3	41.6	47.2	4.6	9.9	37.3	50.2	7.7	5.5
4	36.7	51.1	8.1	4.7	37.7	51.6	8.8	4.6
5	37.9	51.6	6.7	4.8	37.4	52.0	6.1	1.2
6	38.1	51.9	6.4	4.7	37.9	51.5	6.6	4.6
7	38.5	51.2	6.2	5.4	37.8	51.9	6.4	3.9
Acid Blue 277								
1	31.0	16.6	-43.6	8.0	31.1	16.4	-42.9	9.5
2	33.0	14.2	-42.1	11.2	30.4	17.9	-44.7	9.2
3	36.3	10.8	-38.7	15.7	32.8	9.7	-39.9	19.5
4	34.1	12.2	-41.9	10.9	28.6	17.7	-44.5	9.3
5	32.2	14.7	-42.5	8.4	30.3	16.2	-42.9	11.3
6	34.0	13.8	-42.7	10.1	31.2	15.9	-43.0	8.7
7	30.6	17.2	-45.1	9.2	31.2	16.8	-44.3	8.3

Table B4. Mean L*, a*, b*, and Delta E after 160 AFU's of Xenon Light Exposure (cont.)

Dye Type/ Finish	ΔE Value							
	Replication 1				Replication 2			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
Acid Blue 324								
1	32.9	15.4	-43.4	8.8	29.6	13.2	-41.4	6.4
2	33.4	9.9	-40.7	8.3	32.1	11.8	-41.9	6.8
3	35.4	11.1	-38.6	14.8	31.4	14.4	-41.1	12.5
4	30.3	10.8	-41.2	6.7	28.6	13.3	-42.5	6.4
5	29.6	12.7	-42.1	6.1	27.9	13.9	-41.7	7.5
6	30.6	12.3	-42.6	6.7	29.3	14.3	-43.6	5.3
7	29.2	13.3	-42.6	7.5	28.6	14.5	-43.2	4.5
Undyed								
1	91.9	-1.5	3.6	0.2	91.8	-0.8	2.4	1.1
2	91.1	-1.4	4.5	0.7	91.8	-1.0	2.6	0.7
3	91.6	-1.2	3.1	0.8	91.6	-1.1	3.2	0.3
4	90.8	-3.5	11.5	6.2	90.1	-3.7	12.8	9.2
5	91.6	-1.5	4.0	0.7	91.6	-1.0	3.1	0.9
6	92.1	-1.0	3.1	0.9	92.0	-1.1	2.7	0.5
7	92.2	-1.0	3.0	0.7	91.4	-0.8	2.7	0.3

Table B5. Mean L*, a*, b*, and Delta E after 320 AFU's of Xenon Light Exposure

Dye Type/ Finish	Δ E Value							
	Replication 1				Replication 2			
	L*	a*	b*	Δ E	L*	a*	b*	Δ E
Acid Yellow 49								
1	85.1	-8.6	81.3	21.9	84.7	-7.3	78.5	26.5
2	85.0	-8.3	77.0	25.1	84.8	-7.6	84.3	20.7
3	84.8	-7.9	78.0	25.8	84.7	-7.3	70.8	31.4
4	83.7	-2.9	56.7	46.2	83.5	-4.1	62.5	42.9
5	85.3	-8.6	83.3	20.4	84.7	-8.6	82.5	22.6
6	84.8	-7.7	89.0	16.2	85.2	-8.7	88.5	15.8
7	84.8	-8.5	81.3	21.3	85.2	-8.1	85.9	19.8
Acid Yellow 219								
1	63.9	28.0	75.5	1.5	61.9	31.7	76.9	0.8
2	63.3	28.8	74.5	2.1	63.1	30.1	76.1	2.3
3	64.6	26.1	73.3	4.0	63.0	28.8	73.1	3.6
4	62.2	30.7	75.6	1.6	62.2	31.0	75.1	1.6
5	63.9	28.6	76.6	1.9	63.5	28.9	76.4	1.6
6	63.4	29.0	76.3	1.6	61.4	32.1	75.1	1.1
7	63.5	28.9	75.6	2.2	62.7	30.0	75.9	1.5
Acid Red 299								
1	33.2	30.1	-4.5	12.8	29.9	30.4	-2.9	10.7
2	31.2	30.1	-5.4	11.3	28.1	31.5	-4.6	8.8
3	36.8	25.4	-2.9	19.0	34.0	28.1	-3.0	13.5
4	28.8	29.8	-1.2	10.9	27.5	29.2	-1.0	9.3
5	29.2	30.7	-4.4	9.9	37.5	28.1	-3.5	16.7
6	30.8	31.3	-5.2	10.9	29.2	30.8	-4.6	9.2
7	31.4	31.2	-5.3	11.3	30.3	31.6	-4.9	8.8
Acid Red 361								
1	42.9	44.3	4.5	13.6	42.9	44.7	4.9	13.6
2	42.5	45.2	4.4	13.0	40.9	46.4	6.0	11.6
3	49.0	36.2	3.9	23.0	45.3	38.1	6.3	19.9
4	42.9	41.0	7.3	16.5	44.6	40.4	8.1	17.7
5	43.3	43.9	4.7	14.2	40.7	45.5	6.1	12.3
6	42.2	46.4	4.8	11.6	42.6	44.5	5.1	13.1
7	42.9	45.1	4.6	13.1	42.5	45.3	4.9	12.1
Acid Blue 277								
1	34.2	12.4	-38.7	15.1	34.8	11.5	-37.1	17.9
2	36.8	10.4	-36.7	18.7	34.0	13.0	-39.7	16.9
3	41.6	7.0	-31.9	24.8	35.5	6.8	-36.1	14.9
4	36.5	8.9	-37.0	17.3	30.1	14.0	-40.7	14.8
5	35.8	10.6	-37.4	15.8	34.0	11.1	-37.3	19.6
6	37.7	9.8	-37.0	17.8	34.7	11.5	-38.1	16.0
7	33.2	13.4	-40.8	15.4	34.0	12.8	-40.1	14.6

Table B5. Mean L*, a*, b*, and Delta E after 320 AFU's of Xenon Light Exposure (cont.)

Dye Type/ Finish	ΔE Value							
	Replication 1				Replication 2			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
Acid Blue 324								
1	36.6	11.1	-38.0	16.5	31.9	9.7	-37.6	12.1
2	36.0	7.5	-36.9	13.4	34.6	8.6	-38.3	12.1
3	40.9	7.1	-31.4	24.5	35.8	9.8	-35.3	20.8
4	31.5	8.3	-37.9	10.9	29.7	10.3	-39.4	10.8
5	31.8	9.8	-39.1	10.8	29.5	10.6	-38.5	12.4
6	32.7	9.4	-39.2	11.6	31.0	11.1	-40.5	10.1
7	29.9	11.9	-41.0	9.7	30.2	11.5	-40.3	9.0
Undyed								
1	91.9	-1.0	2.6	1.2	91.7	-0.9	2.6	0.9
2	91.4	-1.3	4.6	0.5	92.0	-0.9	2.4	0.9
3	91.5	-1.3	4.1	0.6	92.0	-1.0	3.0	0.7
4	91.0	-3.3	9.9	4.6	90.7	-3.9	12.0	8.4
5	91.9	-1.1	3.1	0.9	91.6	-1.0	3.1	0.9
6	91.9	-1.0	2.8	1.1	92.1	-1.0	2.7	0.9
7	92.1	-1.0	2.7	1.1	91.6	-0.9	2.7	0.4

Table B6. Color Difference Values (ΔE) for Replication

Dye	Light Exposure (AFU's)	Rep	ΔE Value Finish 1	2	3	4	5	6	7
Acid Yellow 49	40	1	1.6	2.4	1.5	3.9	0.2	1.7	3.2
	40	2	1.7	1.4	1.7	3.3	1.5	0.7	1.1
	80	1	3.5	5.3	3.1	8.3	2.6	2.6	5.1
	80	2	4.1	1.6	2.7	5.3	3.1	0.6	2.5
	160	1	8.4	11.8	8.5	22.6	7.2	6.2	10.3
	160	2	10.2	6.4	10.9	17.5	7.2	5.2	5.5
	320	1	21.9	25.2	24.9	46.1	20.5	16.2	21.7
	320	2	26.5	20.7	31.2	42.9	22.7	15.8	19.4
Acid Yellow 219	40	1	1.3	0.3	0.5	0.2	1.7	0.3	1.1
	40	2	0.4	0.6	0.4	0.3	0.8	0.7	0.4
	80	1	0.4	0.3	1.1	0.7	0.5	0.4	1.1
	80	2	0.4	0.9	2.0	2.3	0.9	3.2	0.4
	160	1	1.1	0.8	1.9	1.2	0.4	0.9	1.1
	160	2	0.8	1.6	1.9	1.3	1.3	0.6	0.7
	320	1	1.5	2.2	4.1	1.6	1.5	1.6	2.2
	320	2	0.8	2.3	3.6	1.6	1.6	1.1	1.5
Acid Red 299	40	1	1.3	1.5	2.5	0.7	1.8	1.3	1.5
	40	2	1.0	1.6	2.1	0.8	1.9	1.9	1.6
	80	1	2.5	2.5	4.2	1.3	2.4	2.3	2.7
	80	2	2.2	2.3	3.1	2.1	3.7	2.8	2.3
	160	1	5.2	4.8	8.8	3.4	4.5	4.6	4.9
	160	2	4.4	4.1	5.3	3.2	7.7	4.5	3.8
	320	1	12.5	11.3	19.3	10.9	9.9	10.9	11.2
	320	2	10.7	8.8	13.2	9.3	16.5	9.2	8.8
Acid Red 361	40	1	0.6	1.4	2.1	1.3	0.3	1.3	1.7
	40	2	1.2	1.1	0.7	0.7	0.8	0.8	0.8
	80	1	2.4	2.5	4.4	1.8	1.9	2.0	2.6
	80	2	2.0	1.2	0.7	1.2	1.7	1.1	1.6
	160	1	5.2	5.2	9.9	4.7	4.8	4.7	5.4
	160	2	3.1	3.9	5.5	4.6	6.2	4.6	3.9
	320	1	13.8	13.0	23.1	16.5	14.1	11.6	13.1
	320	2	13.6	11.7	19.8	17.8	12.3	13.1	12.1
Acid Blue 277	40	1	2.0	3.5	6.3	6.1	1.6	2.9	2.4
	40	2	2.7	3.4	3.6	5.0	3.7	2.4	2.7
	80	1	4.3	6.2	10.0	6.8	4.1	5.4	4.4
	80	2	5.2	5.8	6.1	6.4	6.8	4.9	5.5
	160	1	8.0	11.1	15.6	10.9	8.4	10.1	9.2
	160	2	9.5	9.2	9.5	9.3	11.2	8.7	8.2
	320	1	15.1	18.7	24.9	17.3	15.8	17.9	15.4
	320	2	17.9	16.9	14.9	14.7	19.6	16.1	14.5

Table B6. Color Difference (△E) for Replications

Dye	Light Exposure (AFU's)	Rep	△E Value Finish 1	2	3	4	5	6	7
Acid Blue 324	40	1	2.4	1.7	6.2	2.4	0.6	1.5	1.1
	40	2	1.3	2.0	5.2	3.1	1.8	0.9	0.5
	80	1	4.8	3.6	9.5	3.6	2.7	2.9	2.2
	80	2	3.4	3.9	8.2	3.9	4.3	2.4	2.6
	160	1	8.8	8.3	14.8	6.6	6.1	6.8	7.4
	160	2	6.4	6.8	12.5	6.4	7.5	5.3	4.5
	320	1	16.5	13.5	24.5	10.9	10.8	11.7	9.7
	320	2	12.1	12.1	20.8	10.8	12.4	10.2	8.9
Undyed	40	1	0.9	1.3	0.6	6.1	0.9	1.2	0.9
	40	2	1.1	0.8	0.5	8.1	0.5	0.9	0.4
	80	1	0.8	1.3	0.9	6.1	0.6	1.3	1.0
	80	2	1.1	0.8	0.5	8.3	0.5	0.9	0.4
	160	1	0.2	0.7	0.7	6.2	0.7	0.9	0.7
	160	2	1.2	0.6	0.3	9.1	0.9	0.8	0.3
	320	1	1.2	0.6	0.5	4.6	0.9	1.1	1.1
	320	2	0.9	0.9	0.7	8.4	0.9	0.9	0.4

Table B7. Mean △E values for Finishes

Finish	Replicate	△E Value Light Exposure (AFU's) 40	80	160	320
#1	1	1.5	2.6	5.3	11.8
	2	1.4	2.6	5.1	11.8
#2	1	1.7	3.1	6.1	12.1
	2	1.5	2.4	4.6	10.5
#3	1	2.8	4.8	8.2	17.3
	2	2.0	3.4	5.8	14.9
#4	1	2.9	4.1	7.9	15.4
	2	3.1	4.2	7.3	15.1
#5	1	1.1	2.1	4.6	10.5
	2	1.6	3.0	6.0	12.3
#6	1	1.4	2.4	4.9	10.1
	2	1.2	2.8	4.2	9.5
#7	1	2.1	2.6	5.6	10.6
	2	1.0	2.2	3.9	9.4

Table B8. Mean △E values for Dyes

Dyes	Replicate	△E Value Light Exposure (AFU's) 40	80	160	320
1	1	2.1	4.4	10.7	25.2
	2	1.6	2.8	8.9	25.6
2	1	0.8	0.5	1.1	2.1
	2	0.5	1.5	1.2	1.8
3	1	1.5	2.6	5.2	12.3
	2	1.5	2.6	4.7	10.9
4	1	1.5	2.5	5.7	15.0
	2	0.9	1.4	4.6	14.3
5	1	3.5	5.9	10.5	13.9
	2	3.4	5.8	9.4	16.4
6	1	2.3	4.2	8.4	13.9
	2	2.1	4.1	7.1	13.2
7	1	1.7	1.7	1.5	1.4
	2	1.8	1.8	1.9	1.9

Table B9. Mean △E for each Finish over Exposures

Replicate	Mean △E Value Finish 1	2	3	4	5	6	7
1	5.6	5.5	8.4	7.6	4.6	4.5	5.2
2	5.2	4.8	6.7	7.1	5.7	4.3	4.1

Table B10. Mean Color Difference Values (△E's)

Dye Type	Finish	Light Exposure (AFU's) 40	80	160	320
Acid Yellow 49	#1	1.7	3.8	8.4	22.0
	#2	1.9	3.5	9.1	22.9
	#3	1.6	3.0	9.8	28.6
	#4	3.7	6.9	20.1	44.6
	#5	0.8	2.8	7.2	21.5
	#6	1.2	1.6	5.7	16.0
	#7	2.1	3.8	7.9	20.6
Acid Yellow 219	#1	0.8	0.4	0.9	1.1
	#2	0.4	0.6	1.2	2.2
	#3	0.5	1.6	1.9	3.8
	#4	0.2	1.5	1.3	1.6
	#5	1.3	0.7	1.0	1.8
	#6	0.5	1.8	0.7	1.4
	#7	0.7	0.8	0.9	1.9
Acid Red 299	#1	1.2	2.3	4.7	11.8
	#2	1.5	2.4	4.5	10.1
	#3	2.3	3.6	7.1	16.3
	#4	0.7	1.7	3.3	10.2
	#5	1.9	3.1	6.1	13.3
	#6	1.6	2.6	4.5	10.0
	#7	1.5	2.5	4.4	10.0
Acid Red 361	#1	0.9	2.2	4.1	13.6
	#2	1.3	1.9	4.5	12.3
	#3	1.4	2.7	7.7	21.5
	#4	1.0	1.5	4.6	17.1
	#5	0.5	1.8	5.5	13.2
	#6	1.1	1.5	4.6	12.3
	#7	1.3	2.1	4.7	12.6
Acid Blue 277	#1	2.3	4.7	8.8	16.5
	#2	3.4	6.0	10.2	18.8
	#3	5.0	8.0	12.6	20.0
	#4	5.5	6.6	10.1	16.0
	#5	2.6	5.5	9.8	17.7
	#6	2.7	5.2	9.4	16.9
	#7	2.5	4.9	8.7	15.0

Table B10. Mean Color Difference Values (△E's)

Dye Type	Finish	Light Exposure (AFU's) 40	80	160	320
Acid Blue 324	#1	1.8	4.1	7.6	14.3
	#2	1.8	3.8	7.5	12.8
	#3	5.7	8.9	13.6	22.6
	#4	2.8	3.7	6.5	10.8
	#5	1.2	3.5	6.8	11.6
	#6	1.2	2.6	6.0	10.9
	#7	0.7	2.4	6.0	9.4
Undyed	#1	1.0	0.9	0.7	1.0
	#2	1.1	1.1	0.7	0.7
	#3	0.6	0.7	0.6	0.6
	#4	7.1	7.3	7.7	6.5
	#5	0.7	0.6	0.8	0.9
	#6	1.1	1.1	0.9	1.0
	#7	0.7	0.7	0.5	0.7

Table B11. Color Difference (△E's) After Xenon Light Exposure: C.I. Acid Yellow 49

Finish	Replication	Light Exposure (AFU's) 40	80	160	320
1	1	1.7	3.5	8.4	22.0
	2	1.7	4.1	10.2	26.5
	Avg.	1.7	3.8	9.3	24.3
2	1	2.4	5.3	11.8	25.1
	2	1.3	1.6	6.4	20.7
	Avg.	1.9	3.5	9.1	22.9
3	1	1.5	3.3	8.7	25.8
	2	1.7	2.7	10.9	31.4
	Avg.	1.6	3.0	9.8	28.6
4	1	4.0	8.3	22.7	46.2
	2	3.3	5.3	17.5	43.0
	Avg.	3.7	6.9	20.1	44.6
5	1	0.2	2.6	7.1	20.4
	2	1.5	3.1	7.2	22.6
	Avg.	0.8	2.8	7.2	21.5
6	1	1.7	2.6	6.2	16.2
	2	0.7	0.6	5.2	15.8
	Avg.	1.2	1.6	5.7	16.0
7	1	3.2	5.1	10.3	21.3
	2	1.1	2.5	5.6	19.9
	Avg.	2.1	3.8	7.9	20.6

Table B12. Color Difference (△E's) After Xenon Light Exposure: C.I. Acid Yellow 219

Finish	Replication	Light Exposure (AFU's) 40	80	160	320
1	1	1.3	0.5	1.1	1.5
	2	0.4	0.4	0.7	0.7
	Avg.	0.8	0.4	0.9	1.1
2	1	0.3	0.3	0.9	2.1
	2	0.5	0.9	1.6	2.3
	Avg.	0.4	0.6	1.2	2.2
3	1	0.5	1.1	1.9	4.0
	2	0.4	2.0	1.9	3.6
	Avg.	0.5	1.6	1.9	3.8
4	1	0.1	0.7	1.2	1.6
	2	0.3	2.3	1.4	1.6
	Avg.	0.2	1.5	1.3	1.6
5	1	1.7	0.5	0.7	1.9
	2	0.7	0.9	1.3	1.6
	Avg.	1.3	0.7	1.0	1.8
6	1	0.3	0.4	0.8	1.6
	2	0.7	3.2	0.6	1.1
	Avg.	0.5	1.8	0.7	1.4
7	1	1.1	1.1	1.0	2.2
	2	0.4	0.4	0.7	1.5
	Avg.	0.7	0.8	0.9	1.9

Table B13. Color Difference (ΔE's) After Xenon Light Exposure: C.I. Acid Red 299

Finish	Replication	Light Exposure (AFU's) 40	80	160	320
1	1	1.3	2.5	5.0	12.8
	2	1.0	2.2	4.4	10.7
	Avg.	1.2	2.3	4.7	11.8
2	1	1.5	2.5	4.8	11.3
	2	1.6	2.3	4.1	8.8
	Avg.	1.5	2.4	4.5	10.1
3	1	2.5	4.2	8.9	19.0
	2	2.1	3.1	5.3	13.5
	Avg.	2.3	3.6	7.1	16.3
4	1	0.7	1.3	3.4	10.9
	2	0.8	2.0	3.2	9.3
	Avg.	0.7	1.7	3.3	10.2
5	1	1.8	2.4	4.5	9.9
	2	1.9	3.7	7.7	16.6
	Avg.	1.9	3.1	6.1	13.3
6	1	1.3	2.3	4.6	10.9
	2	1.8	2.8	4.5	9.2
	Avg.	1.6	2.6	4.5	10.0
7	1	1.5	2.7	4.9	11.3
	2	1.5	2.3	3.8	8.8
	Avg.	1.5	2.5	4.4	10.0

Table B14. Color Difference (△E's) After Xenon Light Exposure: C.I. Acid Yellow 361

Finish	Replication	Light Exposure (AFU's) 40	80	160	320
1	1	0.7	2.4	5.2	13.6
	2	1.2	2.0	3.1	13.6
	Avg.	0.9	2.2	4.1	13.6
2	1	1.4	2.5	5.2	13.0
	2	1.1	1.2	3.9	11.6
	Avg.	1.3	1.9	4.5	12.3
3	1	2.1	4.4	9.9	23.0
	2	0.7	1.0	5.5	19.9
	Avg.	1.4	2.7	7.7	21.5
4	1	1.3	1.8	4.7	16.5
	2	0.7	1.2	4.6	17.7
	Avg.	1.0	1.5	4.6	17.1
5	1	0.3	1.9	4.8	14.2
	2	0.7	1.7	6.2	12.3
	Avg.	0.5	1.8	5.5	13.2
6	1	1.3	2.0	4.7	11.6
	2	0.8	1.1	4.6	13.1
	Avg.	1.1	1.5	4.6	12.3
7	1	1.7	2.6	5.4	13.1
	2	0.8	1.6	3.9	12.1
	Avg.	1.3	2.1	4.7	12.6

Table B15. Color Difference (△E's) After Xenon Light Exposure: C.I. Acid Blue 277

Finish	Replication	Light Exposure (AFU's) 40	80	160	320
1	1	2.0	4.3	8.0	15.1
	2	2.6	5.2	9.5	17.9
	Avg.	2.3	4.7	8.8	16.5
2	1	3.5	6.2	11.2	18.7
	2	3.4	5.8	9.2	16.9
	Avg.	3.4	6.0	10.2	18.8
3	1	6.3	10.0	15.7	24.9
	2	3.6	6.1	9.5	14.9
	Avg.	5.0	8.0	12.6	20.0
4	1	6.0	6.8	10.9	17.3
	2	5.0	6.4	9.3	14.8
	Avg.	5.5	6.6	10.1	16.0
5	1	1.6	4.0	8.4	15.8
	2	3.7	6.9	11.3	19.6
	Avg.	2.6	5.5	9.8	17.7
6	1	2.9	5.4	10.1	17.8
	2	2.4	4.9	8.7	16.0
	Avg.	2.7	5.2	9.4	16.9
7	1	2.4	4.4	9.2	15.4
	2	2.7	5.5	8.3	14.6
	Avg.	2.5	4.9	8.7	15.0

Table B16. Color Difference (Δ E's) After Xenon Light Exposure: C.I. Acid Blue 324

Finish	Replication	Light Exposure (AFU's) 40	80	160	320
1	1	2.4	4.8	8.8	16.5
	2	1.3	3.4	6.4	12.1
	Avg.	1.8	4.1	7.6	14.3
2	1	1.7	3.6	8.3	13.4
	2	2.0	4.0	6.8	12.1
	Avg.	1.8	3.8	7.5	12.8
3	1	6.2	9.5	14.8	24.5
	2	5.2	8.2	12.5	20.8
	Avg.	5.7	8.9	13.6	22.6
4	1	2.4	3.6	6.7	10.9
	2	3.1	3.9	6.4	10.8
	Avg.	2.8	3.7	6.5	10.8
5	1	0.6	2.7	6.1	10.8
	2	1.8	4.3	7.5	12.4
	Avg.	1.2	3.5	6.8	11.6
6	1	1.5	2.9	6.7	11.6
	2	0.8	2.4	5.3	10.1
	Avg.	1.2	2.6	6.0	10.9
7	1	1.1	2.2	7.5	9.7
	2	0.5	2.6	4.5	8.9
	Avg.	0.7	2.4	6.0	9.4

Table B17. Color Difference (△E's) After Xenon Light Exposure: Undyed

Finish	Replication	Light Exposure (AFU's) 40	80	160	320
1	1	0.9	0.8	0.2	1.2
	2	1.1	1.1	0.9	1.3
	Avg.	1.0	0.9	0.7	1.0
2	1	1.3	1.4	0.7	0.5
	2	0.8	0.8	0.7	0.9
	Avg.	1.1	1.1	0.7	0.7
3	1	0.6	0.9	0.8	0.6
	2	0.5	0.5	0.3	0.7
	Avg.	0.6	0.7	0.6	0.6
4	1	6.1	6.2	6.2	4.6
	2	8.1	8.4	9.2	8.4
	Avg.	7.1	7.3	7.7	6.5
5	1	0.9	0.6	0.7	0.9
	2	0.5	0.5	0.9	0.9
	Avg.	0.7	0.6	0.8	0.9
6	1	1.2	1.2	0.9	1.1
	2	0.9	0.9	0.6	0.8
	Avg.	1.1	1.1	0.9	1.0
7	1	0.9	1.0	0.7	1.1
	2	0.4	0.4	0.3	0.4
	Avg.	0.7	0.7	0.5	0.7

THE SUSCEPTIBILITY OF ANTIMICROBIAL AGENTS TO LIGHT DEGRADATION AND THEIR INFLUENCE ON DYE FADING

by

Diana Gail Johnson

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ABSTRACT

Antimicrobial agents are applied to textiles for a variety of reasons, including aesthetic, hygenic, health, and medical. These finishes retard the growth of bacteria and fungi which can damage fibers or contribute to the spread of diseases. The increased use of carpeting in hospitals, schools, and other institutions has created a greater need for durable, effective, antimicrobial finishes for carpeting.

Six antimicrobial finishes were evaluated in this study for their influence the lightfastness of acid dyes and susceptibility to photodegradation. To evaluate the effects of the antimicrobial agents on the lightfastness and appearance of the dyed and undyed nylon, treated and untreated specimens were exposed to 0, 40, 80, 160, and 320 AFU's in a Xenon Weather-Ometer, and then evaluated visually with the Gray Scale for Color Change and instrumentally with a Hunter Colorimeter. A modified agar plate method was used to determine if xenon light exposure reduced the effectiveness of the antimicrobial agents.

Overall, the leachable antimicrobial agents (quaternary ammonium compounds and phenolic compounds) caused more color change in the dyed textiles, but they retain their antimicrobial properties longer than did the organo-silane and organo-tin compounds when exposed to light. Organo-tin compounds seem to reduced the amount of color change in some select dyes. Organo-silane compounds have a significant

effect on the colorfastness of acid dyes but to a lesser extent than quaternary ammonium and phenolic compounds. The organo-silanes varied in their resistance to light degradation.