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INFLUENCE OF NITROGEN GAS AND OXYGEN SCAVENGERS ON FADING AND COLOR CHANGE IN DYED TEXTILES

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ABSTRACT—Unexpected and undesired color changes in paper materials following the use of anoxic treatments for killing insects that infest collections have been reported. This observation and attendant concerns prompted this research. This study examined the influence of a nitrogen gas purge and oxygen scavengers on color stability of dyed textiles in the presence and absence of light. Earlier studies showed that while most dyed textiles exhibit less fading and color change when oxygen is removed from the atmosphere via a nitrogen purge, a small number of dyes exhibit greater amounts of fading and color change in the presence of a reduced-oxygen atmosphere. However, it was unclear whether the earlier reports of increased fading observed in reduced-oxygen atmospheres were due to the presence of light or the absence of oxygen because none of the earlier studies included anoxic treatments conducted both in the presence and absence of light.

In recent years oxygen scavengers have been increasingly used for anoxic pest control measures. These scavengers are known to function through an exothermic reaction. Therefore, this study included a fabric colored with a temperature sensitive dye in an attempt to determine whether the heat generated by oxygen scavengers was responsible for observed color changes in some dyed materials rather than the low-oxygen atmosphere.

Selected fabrics dyed with natural dyes (turmeric and fustic on wool) and synthetic dyes (indigoid and acid dyes on wool, a disperse dye on polyester; and fluorescent dyes on cotton) were enclosed in transparent film packages, treated with one of three reduced-oxygen atmospheres (nitrogen purge, nitrogen purge plus oxygen scavenger, or oxygen scavenger alone), or ambient air (control), and exposed to continuous fluorescent light (320 lux) or total darkness for 90 days. Gas chromatography was used to verify that no measurable oxygen was present in the reduced-oxygen packages initially and that less than 2% oxygen was present in the reduced-oxygen packages after 90 days. At the end of the exposure period, color change was evaluated instrumentally using a spectrocolorimeter. If specimens exhibited significant color change according to instrumental color measurements, visual evaluations were completed to determine whether or not the changes were visually perceptible.

Results showed that oxygen scavengers did not affect the color of any of the dyes included in this study, including a temperature-sensitive disperse dye. This provides additional experimental findings in support of their safety for use in anoxic pest control treatments. Results also showed that the low-oxygen atmospheres examined in this study provided some level of protection against fading and color change for most, but not all, dyes. One fluorescent dye in the presence of continuous light exhibited significantly more color change in low-oxygen atmospheres than in ambient air. In the absence of light, the same fluorescent dye did not exhibit greater color change in the low-oxygen atmosphere than in ambient air. This suggests that the reaction is photochemical in nature and that the unwanted color change may be avoided during anoxic treatments by conducting anoxic pest control treatments in the dark.

TITULO—LA INFLUENCIA DEL GAS DE NITRÓGENO Y BARREDORES DE OXÍGENO EN LA DECOLORACIÓN Y CAMBIOS DE COLOR EN TEXTILES TEÑIDOS—RESUMEN. En ciertos museos se han reportado inesperados e indeseables cambios de color en materiales de papel, despues del uso de tratamientos anóxicos para matar insectos que a veces infectan las colecciones. Esta observación y los intereses relaciona-

dos inspiran esta investigación. Este estudio examinó la influencia de una purga de gas de nitrogeno y barredores de oxígeno, sobre la estabilidad del color de textiles tinturados en la presencia y ausencia de luz. Estudios anteriores muestran que mientras la mayoria de los textiles tenidos presentan menos decoloracion y cambios de color cuando el oxígeno es removido de la atmósfera vía purga de nitrogenos, un reducido número de tintes muestran cantidades mayores de decoloración y cambio de color en la presencia de una atmósfera con oxígeno reducido. Sin embargo, no fue claro si los reportes anteriores sobre el aumento de decoloración observado en atmósferas de oxígeno reducido, eran debido a la presencia de luz o a la ausencia de oxígeno porque ninguno de los estudios anteriores incluia tratamientos anóxicos, ambos conducidos en la presencia y ausencia de luz.

Adicionalmente, en años recientes el personal de museo ha aumentado el uso de barredores de oxígeno como medida de control de pestes anóxicas. Estos barredores son conocidos por funcionar a través de reacciones exotermicas. Por eso, este estudio incluyó una tela teñida con un tinte sensible al calor en un intento por determinar si el calor generado por los barredores de oxígeno era respon-sable por los cambios de color observados en algunos materiales teñidos, en lugar de la atmósfera baja en oxígeno.

Telas seleccionadas teñidas con tintes naturales (curcuma y fustete en lana) y tintes sintéticos (indigos, y colorantes ácidos sobre lana, un colorante disperse en polyester, y colorantes fluorescentes en algodón), fueron encerrados en paquetes de film transparentes y tratados con una de tres atmósferas de oxígeno reducido (purga de oxígeno, purga de nitrógeno más barredor de oxígeno, o barredor de oxígeno solo), o ambiente de aire controlado, y expuesto a luz fluorescente continua -320 lux- o a oscuridad total por 90 días. Se usó cromatogtaffa de gases para verificar que ningún oxígeno detectable estaba presente en los paquetes con oxígeno reducido después de 90 días. Al final del período de exposición, el cambio de color fue evaluado instrumentalmente usando un espectrofoto-colorímetro. Si los especímenes mostraban cambios de color significativos de acuerdo a las mediciones de color instrumentales, se completaban con evaluaciones visuales para determinar si los cambios eran o no visualmente perceptibles.

Los resultados demostraron que los barredores de oxígeno no afectaron el color de ninguno de los tintes incluidos en este estudio, incluyendo un tinte disperse sensible a la temperatura. Esto provee hal-lazgos experimentales adicionales en respaldo de la seguridad para su uso en tratamientos de control de pestes anóxicas. Los resultados también muestran que las atmósferas bajas en oxígeno exami-nadas en este estudio otorgaron algún nivel de protección contra la decoloración y el cambio de color para la mayoría, aunque no de todos los tintes. Un tinte fluorescente en presencia de luz continua mostró significativamente más cambios de color en atmósferas bajas en oxígeno que en aire ambiente. En la ausencia de luz, el mismo tinte fluorescente no exhibió mayor cambio de color en la atmósfera baja en oxígeno que en aire ambiente. Esto sugiere que la reacción es de naturaleza fotoquímica y que el cambio de color no deseado puede ser evitado durante los tratamientos anóxicos realizando los tratamientos de control de pestes anóxicas, en la oscuridad.

1. INTRODUCTION

During the 1990s reduced-oxygen atmospheres saw increased usage as an alternative to the use of broad spectrum chemicals for insect control. Anoxic treatments proved very effective in controlling insect pest infestations (Gilberg 1988;

Gilberg 1991; Valentin and Preusser 1990; Gilberg and Roach 1992; Daniel et al. 1993; Rust and Kennedy 1993; Selwitz and Maekawa 1998). In addition, low-oxygen atmospheres have been suggested as beneficial environments for storage of sensitive artifacts such as dyed textiles and water colors, because elimination or reduction of oxygen may slow or even arrest degradation processes including fiber degradation and unwanted color change or color loss (Amey et al. 1979; Daniel 1993; Giles et al. 1972; Giles 1965; Hansen 1998; Maekawa et al. 1992). Consequently, several researchers have recommended using low-oxygen atmospheres for long-term storage environments for selected museum objects such as textiles (Gilberg and Grattan 1994; Daniel 1993).

Low-oxygen atmospheres have been achieved by creating a vacuum then flushing an enclosure with an inert or low reactive gas. Nitrogen gas is often the inert gas used to achieve the low-oxygen atmospheres by gas flushing. An oxygen absorber may be inserted at the end of the nitrogen gas purge and before the container is sealed to extend the oxygen-free life span of a display or storage case or to insure maintenance of a reduced-oxygen level for a designated treatment period (Lambert et al.. 1992). Another method for achieving a reduced-oxygen atmosphere consists of using an oxygen absorber alone to achieve low-oxygen levels within a sealed container. The latter method is usually used when an institution does not have the necessary equipment for creating vacuums and performing gas purges.

While a number of studies have been conducted to verify the effectiveness of low-oxygen methods to kill insects and control infestations (Gilberg 1988; Gilberg 1991; Valentin and Preusser 1990; Gilberg and Roach 1992; Daniel et al. 1993; Rust and Kennedy 1993), none of the researchers examined the effects of anoxic pest control treatments on the colors of dyed and printed historic textiles. Similarly, while a number of researchers have examined the effects of a low-oxygen atmosphere on the lightfastness of dyes, none of them included the absence of light as a variable because the focus of their studies was lightfastness. Furthermore, the results of research focusing on the influence of low-oxygen atmospheres on the lightfastness of dyes have been mixed. Some researchers (Amey et al. 1979; Egerton and Morgan 1970; Padfield and Landi 1966) found that a low-oxygen atmosphere reduced fading of some dyes; some researchers (Egerton and Roach 1958; Schwen and Schmidt 1959; Giles and McKay 1963; Egerton and Morgan 1970; Amey et al. 1979) found low-oxygen atmospheres increased fading of selected dyes; and some researchers (Russell and Abney 1888; Giles and McKay 1963; Egerton and Morgan 1970) found that low-oxygen atmospheres neither reduced nor increased fading of dyes in comparison to light exposure in ambient air.

Vinod Daniel's (1993) chapter, entitled "Storage in Low-Oxygen Environments" in *Storage of Natural History Collections: A Preventive Conservation Approach*, includes observations by John Burke, Head Conservator of the Oakland Museum Conservation Center, Oakland, California, who noted "significant reduction in color fading for many colorants on paper in an environment with less than 0.1% oxygen." Because of the beneficial effect of a low-oxygen atmosphere in reducing fading of many dyes, Daniel (1993) recommended storing museum materials in reduced-oxygen environments. At the same time, he was aware of the sometimes negative effects of reduced-oxygen atmospheres because he also references the work of Japanese scientists who observed changes in certain artist colors subjected to reduced-oxygen atmospheres.

John Burke reported in a session at the 1996 American Association of Museums annual meeting his observations of accelerated fading of selected colorants on paper in reduced-oxygen atmospheres. In a subsequent conversation, Mr. Burke described especially pronounced fading of fluorescent colorants on self-adhesive paper labels when exposed to a low-oxygen environment created using oxygen scavengers, but not in ambient air (Burke 1997). The light levels were not controlled during his informal observations.

The acceptance of oxygen scavengers as appropriate for anoxic pest control treatments in historic collections has been rapid. Some conservation scientists, however, have recommended further study. For example, in his conservation text, which focuses on photochemical and thermal aspects of accelerated aging of materials, Robert Feller, director emeritus, Carnegie Mellon Research Institute, includes among his recommendations for future research, the need to study the effects of storing artifacts "under inert atmospheres or in the presence of oxygen scavengers" (Feller 1994, 168).

Conflicting reports regarding the effects of low-oxygen atmosphere on dyed textiles and papers, particularly the unexpected and undesired fading observed in some colored paper materials following the use of anoxic treatments for insect control in museums, prompted this study. No studies were found in which the effect of a low-oxygen atmosphere on the colors of dyed textiles was examined in both the presence and absence of light. By failing to include both the absence of light, as well as the presence of light in the experiments, several questions remained unresolved—whether the absence of oxygen alone would trigger adverse changes in color, whether the reaction was photochemical in nature and required light, and whether or not the heat generated by oxygen scavengers was the factor responsible for the rapid fading observed in some dyes. Specifically, the purpose of this research was 1) to investigate the influence of reduced-oxygen atmosphere on the color of selected dyed textiles stored both in continuous light and in total darkness and 2) to determine whether or not the accelerated fading observed in conjunction with low-oxygen atmospheres was due to the heat associated with the exothermic reactions of oxygen scavengers or due to the low-oxygen atmosphere.

2. EXPERIMENTAL METHODS AND MATERIALS

Dyed specimens were enclosed in transparent film packages, treated with three reduced-oxygen atmospheres (dry nitrogen gas, dry nitrogen gas plus oxygen scavenger, or oxygen scavenger alone), plus ambient air (control), and exposed to continuous light or held in darkness for 90 days. Eight dyes, applied to the appropriate textile substrate (cotton, wool or polyester), were chosen to provide a selection of natural and synthetic dyes with a range of lightfastness properties. The low-oxygen atmospheres selected and the methods used to achieve the atmospheres were all modeled after those used by conservators and other researchers in experiments designed to study the effectiveness of anoxic methods for killing insects that sometimes infest museum textiles.

2.1 DYES ON THE EXPERIMENTAL TEXTILES

Eight dyes were selected to provide a range of lightfastness properties and included mordant dyes, vat dyes, fluorescent dyes and one disperse dye. Two AATCC Blue Wool Lightfastness Standards-L2 and L6 (obtained from AATCC, Research Triangle Park, NC) were selected to represent dyes with known lightfastness qualities and fading rates. Blue Wool L6 has good lightfastness, whereas Blue Wool L2 has poor lightfastness. Color on

Blue Wool Lightfastness Standards is achieved by blending wool fibers that were fiber dyed using a fugitive dye (ErioChrome Azurole B-C.I. Mordant Blue 1) with wool fibers that were fiber dyed using lightfast dye (Indigosol Blue AGG-C.I. Solubilised Vat Blue 8). Blue Wool L2, the most light sensitive fabric in the AATCC set of lightfastness standards, is made from wool fiber dyed only with the fugitive chrome dye.

The dye used for AATCC Xenon Reference Fabric-1 is a temperature-sensitive disperse dye— [2,4 dinitro-6 bromo-2-amino-4-(N, N-diethy-lamino) azobenzene], which exhibits more rapid fading at elevated temperatures. The fabric substrate is polyester. According to the AATCC Technical Manual (1996), in the temperature range between 136-154°F an increase in temperature of 9°F results in an increase in total color change (Δ E*) of 4 CIELAB units for a given period of light exposure. Xenon Reference Fabric-1 was included because the chemical reaction that takes place when an oxygen scavenger absorbs oxygen is exothermic. Reasoning that if the heat generated by the oxygen scavengers was sufficiently high, the temperature sensitive dye used on Xenon Reference Fabric-1 might exhibit those effects.

Indigo (C.I. Vat Blue 8) was chosen because it is ubiquitous in both historic and contemporary textiles. Commercially available cotton denim fabric dyed with indigo was obtained from Lee Apparel Company (Shawnee Mission, KS).

Fustic and turmeric, yellow natural dyes, were included in the study because historic textiles containing these two natural dyes are represented in many museum textile collections. Fustic (C.I. Natural Yellow 8 and 11) was widely used prior to the 20th century and has better light-fastness properties than does turmeric (Crews 1987). Turmeric (C.I. Natural Yellow 3) is notable for its poor lightfastness properties and was included to provide a dye likely to show the influences of light and potentially of the low-oxygen atmospheres within the 90-day exposure period. At the University of Nebraska—Lincoln textile labs, wool flannel was mordanted with alum and subsequently dyed with fustic or turmeric according to 19th-century practices (Hummel 1888).

Fluorescent dyes, known to have poor lightfastness properties, were included because of noticeable color changes in fluorescent colorants on paper exposed to low-oxygen environments as reported by Burke (1997). Two commercially available cotton fabrics dyed with fluorescent dyes were purchased locally (So-Fro Fabrics, Lincoln, NE). The specific fluorescent dyes used on the purchased cotton fabrics are undetermined, but may be xanthenes, possibly highly substituted acid rhodamines which have been developed for fiber reactive dye applications on cotton (Wight 1998).

Fluorescent dyes and synthetic fibers are twentieth century developments that may not be found in great numbers in current museum collections, but they will become more prevalent as twentieth century textiles are added. Fluorescent dyes became important during World War n when used on signal flags and clothing. Dyes that fluoresce have been and continue to be popular for theater textiles such as carpets, costumes, and scenery. In addition, textiles for swim wear and children's clothing have been dyed with fluorescent dyes.

2.2. REDUCED OXYGEN ATMOSPHERES

The low-oxygen atmospheres achieved by three different methods, plus an ambient air atmosphere (serving as the control), were included in this study. The low-oxygen atmospheres were achieved by 1) using a nitrogen gas purge; 2) a nitrogen gas purge with an oxygen scavenger; and 3) an oxygen

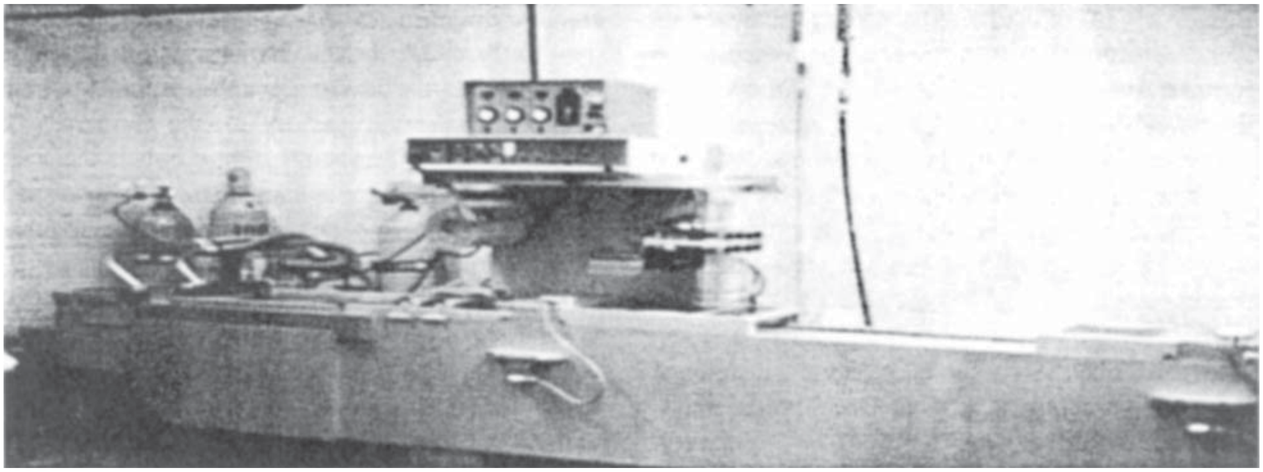

Figure 1. The commercial packaging machine with vacuum and nitrogen purging capacity, located in the Food Processing Center on the University of Nebraska–Lincoln campus, used to make the reduced-oxygen enclosures.

scavenger alone. All three methods for achieving low-oxygen atmospheres were used in an attempt to determine whether or not the absence of oxygen or the build up of heat or some other aspect of the oxygen scavenger packets was responsible for reported color changes. All three methods are used for anoxic pest control treatments.

Sealed enclosures for the textile specimens necessary to achieve the low-oxygen atmospheres were made from commercially available, transparent film, Curlon Grade 1262, Protective Packaging Film, distributed by Curwood (Oshkosh, WI). The film was a three-layer laminate with nylon providing strength for the outer layer; a copolymer middle layer of ethylene vinyl alcohol (EVOH), which is a polymer with very good oxygen barrier properties; and polyethylene, a chemically inert polymer with good heat sealing and adhesion properties for the inner layer. Charles Selwitz and Shin Maekawa describe EVOH in their book *Inert Gases in the Control of Museum Insect Pests* (1998) as having extremely low-oxygen permeability. They list it among the top three oxygen barrier films.

Three replications of each of the four atmospheres for each of the eight dyes for a total of 24 replicates per atmosphere was performed. Enclosures (6" x 8" x I") for the specimens in this research were made using a commercial packaging machine, Multivac M855 (Multivac, Kansas City, MO). The commercial packaging machine (fig. 1) was chosen to create our sealed enclosures, over buying ready-made film packages' .or using a hand sealing process such as a tacking iron, because the seals formed by the commercial packaging machine were more reproducible, uniform and secure.

The equipment possesses the capacity for creating a vacuum and gas flushing of packages as they move through the machine. Gas purging occurred just prior to thermal sealing of the packages. As packages reached the end of the line following thermal sealing, they were checked to make sure ^ oxygen scavenger sachets and specimens were not touching. The gas used for this research was dry nitrogen (99.9%). During the packaging process, film from the bottom roller was heat molded to a specified shape and size. The sealing temperature was 125°C. The packaging line could be started and stopped to insert dyed fabrics and oxygen

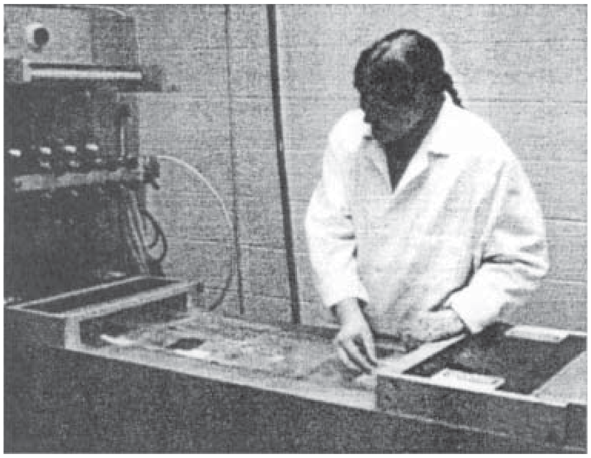

Figure 2. Dyed specimens being randomly placed onto the packaging machine's conveyor belt prior to entry into the machine's film molding and heat sealing chamber.

scavenger packets by hand according to a predetermined work plan. Ability to stop the machine during processing allowed for randomization of specimens (fig. 2).

Ageless ZPT (Mitsubishi Gas Chemical Company, New York) was the oxygen absorber selected for this research. As oxygen is absorbed, an exothermic chemical reaction takes place. Although the generated heat reportedly does not produce a harmful build-up within the enclosure (Grattan and Gilberg 1993), the heat generated makes the packets quite warm to the touch and for this reason, it is recommended that the oxygen absorber sachets not be placed in contact with objects to eliminate any coincidental effect (Gilberg and Grattan 1994). Calculations for determining the amount of oxygen absorber were carried out according to the method reported by Daniel (1993) for a "static system" and verified by a representative of Mitsubishi (Watanabe 1997). The Ageless ZPT sachets are designated ZPT-100, ZPT-200, ZPT-1000, etc., to indicate the milliliters of oxygen with which a single packet will react. An Ageless ZPT-200 sachet was placed in each package with the reduced-oxygen atmosphere created using a scavenger only. An Ageless ZPT-100 sachet was placed in each package with the reduced-oxygen atmosphere created using both a nitrogen gas purge and an oxygen scavenger.

2.3. VERIFICATION OF REDUCED OXYGEN ATMOSPHERES

To verify that a reduced-oxygen atmosphere was achieved initially, we used gas chromatography. A Perkin Elmer 880 Gas Chromatograph, Model 008-0686, hot wire thermal conductivity detector with Hayesep-D column for detecting nitrogen and oxygen, was used to verify that the desired nitrogen level (99-99.9%) and the reduced-oxygen level (less than 1%) was achieved. Gas was withdrawn from packages using a Hamilton Gas Tight #1725 syringe, 205 µl capacity.

Numerous trials on the packaging machine followed by chromatographic analyses were carried out to ensure that the desired low-oxygen atmospheres were achieved on the packaging equipment before the experimental packages were produced. Gas chromatographic analyses were completed on at least three randomly selected packages representing each atmosphere and each of the three replications initially. More than 36 randomly selected packages were analyzed on the first day of the exposure period to confirm that the level of oxygen was less than 1% and that the packages with ambient air contained 20% oxygen. Analyses confirmed that tested packages contained no measurable oxygen, except for those filled with air. Chromatographic analyses were completed on another set of randomly selected packages at the conclusion of the 90-day exposure period to confirm that the desired atmospheres were maintained throughout the exposure period. To provide additional verification that the desired low-oxygen levels were maintained throughout the exposure period, all of the packages from the scavenger-only atmosphere (replication one) were analyzed and all packages were found to contain 2% or less oxygen at the end of the 90-day exposure period. The sealed packages containing the scavenger only were thought to be the most likely to fail to maintain their low-oxygen atmosphere throughout the 90-day exposure period. For that reason, those packages were selected for additional verification. It appeared that there was some leakage, as might be expected because it is virtually impossible to create an oxygen-free container using a flexible barrier film; however, the oxygen level remained 2% or less after 90 days. So the reduced-oxygen level was maintained in the packages during the extended exposure period.

2.4. EXPOSURE CONDITIONS

Ninety days was selected as the time period for this experiment. While much longer than required for effective pest control treatments, 90 days reasonably approximates a common exhibition period for sensitive textiles. Two light conditions were chosen for this study—absence of light and presence of continuous light—to determine whether or not dyed textiles responded similarly to low-oxygen atmospheres in both darkness and light. The light level, 320 lux, was chosen in an effort to expose specimens to a sufficient amount of light to induce a color change during the 90-day exposure period for comparison to the specimens exposed to the various atmospheres in darkness. Additionally, 320 lux is a common light level found in workrooms where objects may be kept when being treated for pest infestations. The light source was overhead fluorescent lights in a windowless room. Absence of light simulated object storage in a closed container or cabinet where light is absent even if the storage room itself is lighted at any time. Absence of light was achieved by placing specimens in a cardboard box lined with black polyethylene and storing them in the same room as the other specimens.

2.5. COLOR EVALUATION

Instrumental color measurement was conducted according to guidelines in AATCC Evaluation Procedure 6, Instrumental Color Measurement, using a HunterLab LabScan® 6000 Spectrocolorimeter with 0°/45° optical sensor and a one-inch area of view. Specimens were presented to the colorimeter immediately as individual packages were opened. Specimens were backed with sufficient layers of the same material until light could no longer penetrate. The number of backing layers varied depending on the fabric— more layers were required for the cotton than for the wool specimens. Color difference was measured on all test specimens at the conclusion of the 90-day exposure period. Total color change (ΔE^*) was calculated, using the CIE 1976 $L^*a^*b^*$ equation for total color change, with illuminant D65 and 10° observer. Four repeated measurements were performed per specimen rotating 90° after each measurement. Since there were three replicate specimens, the mean colorimetric value for each dye and atmosphere is an average of 12 measurements.

When total color change, as measured instrumen-tally, was greater than 1 ΔE^* unit (the minimum amount of color difference regarded as visually perceptible), visual evaluations of color change were completed according to AATCC Evaluation Procedure 1, Gray Scale for Color Change. Visual ratings were assigned according to a scale from 1 to 5, with 5 corresponding to no visually perceptible change and 1 corresponding to the greatest overall amount of color change.

3. RESULTS AND DISCUSSION

The results of both the instrumental color measurements (Δ E*) and visual evaluations (Gray Scale Ratings) are presented in Table 1. Results showed that, among those specimens exposed to light, total color change (Δ E*) was lowest for those held in a reduced-oxygen atmosphere for all dyes, except the pink fluorescent dye. The pink fluorescent dye, in contrast, exhibited greater color change in a reduced-oxygen atmosphere than in air when held in the presence of light.

When the dyed specimens were held in total darkness, none of the dyes (including the pink fluorescent dye) exhibited visually perceptible color changes regardless of atmosphere. Consequently, further analysis of the data are focused on the effects of atmosphere (ambient air versus low-oxygen) in the presence of light on the selected dyes.

See Table 1 on following page.

Among the non-fluorescent synthetic dyes examined in this study, results show that all of these dyes exhibited almost no color change at the conclusion of the 90-day exposure period in either the light or the dark. Among this sub-group of dyes. Blue Wool Lightfastness Standard L2 and Xenon Reference Fabric exhibited the largest amounts of color change in ambient air. Both Blue Wool Lightfastness Standard L2 and Xenon Reference Fabric exhibited slightly less color change (lower Δ E* values) in a low-oxygen atmosphere than in ambient air. However, this difference in amount of total color change was not visually perceptible.

It is interesting to note that the Xenon Reference Fabric, known to be temperature sensitive, did not exhibit any visually perceptible color changes in the presence of Ageless oxygen absorbers (Δ E* = 0.1-Scavenger only and 0.2-Nitrogen + Scavenger). Therefore, it appears that the exothermic chemical reaction of the oxygen scavengers did not raise the temperature of the atmosphere surrounding the disperse-dyed polyester fabric sufficiently to induce a visually perceptible color change.

Among the natural dyes examined in this study, turmeric exhibited larger amounts of color change (larger Δ E*) in all atmospheres than did fustic. This is not surprising because the poor lightfastness of turmeric is well known (Crews 1987; Padfield and Landi 1966; Society of Dyers and Colourists 1971). The natural dyes, when exposed to continuous light, exhibited less fading in the low-oxygen atmospheres than in ambient air. This instrumentally measured color difference was just visually perceptible for the fustic exposed to air in the presence of light; the color changes were more noticeable in all turmeric specimens. Fustic: Gray Scale (GS) rating = 5 (no change) for all three reduced-oxygen atmospheres versus GS rating = 4.5 for air. Turmeric: GS rating = 4-4.5 for all three reduced-oxygen atmospheres versus 3.5 for air (see Table 1).

In contrast to all other dyes included in the study, the pink fluorescent dye exhibited larger amounts of fading or color change in a low-oxygen atmosphere in the presence of light than in ambient air. The accelerated fading observed in the reduced-oxygen atmospheres was quite noticeable with GS ratings for the reduced-oxygen atmosphere ranging from 1.5-2.5 whereas the GS rating for air = 4.5 (see Table 1). The yellow flourescent dye, on the other hand, exhibited about the same amount of color change in the reduced-oxygen atmospheres as it did in ambient air. The reduced-oxygen atmosphere neither reduced nor accelerated fading in the yellow flourescent dye.

Table 1: Mean Total Color Change (Δ E*) and Gray Scale Ratings for the Dyes Exposed to Low Oxygen Atmospheres and Ambient Air in Continuous Light and Darkness for 90 Days.

Mean Total Color Change and (Gray Scale Rating)

Dye	Light				Darkness			
	N_2 Only	N_2 +Scav	ScavOnly	Air	N_2 Only	N_2 +Scav	ScavOnly	Air
Synthetic Dye Group								
Blue Wool L6	0.3	0.3	0.3	0.4	0.1	0.2	0.2	0.1
Blue Wool L2	0.5	0.3	0.4	0.9	0.2	0.1	0.2	0.1
Xenon Ref. Fabric	0.6	0.2	0.1	1.6	0.1	0.1	0.1	0.1
Indigo	0.6	0.3	0.4	0.4	0.6	0.3	0.3	0.7
Standard Error = 0.1 -in light					Standard Error = 0.1-in dark			
Natural Dye Group								
Fustic	1.6(5)	1.2(5)	1.2(5)	2.9(4.5)	1.3	1.2	0.5	1.1
Turmeric	4.5(4)	3.7(4.5)	3.1(4.5)	8.3(3.5)	0.7	1.0	1.4	1.4
Standard Error = 0.8- in light					Standard Error = 0.3-in dark			
Fluorescent Dye Group								
Fluor. Pink	10.5(2.5)	14.0(2.5)	15.3(1.5)	3.6(4.5)	0.6	1.3	0.5	0.3
Fluor. Yellow	4.2(4.5)	3.3(4.5)	3.8(4.5)	4.1(4.5)	1.9	1.1	2.9	1.7
Standard Error = 0.9-in light					Standard Error = 0.4-in dark			

Note: Each mean total color change (Δ E* units) represents an average of 12 measurements—four measurements made on each of three replicate specimens. Gray Scale ratings (in parenthesis) are given for specimens exposed to light that exhibited 1 or more units of total color change.

4. CONCLUSIONS AND RECOMMENDATIONS

Results of this study showed that the presence of an oxygen scavenger in a sealed low-oxygen enclosure did not result in increased color changes for any of the selected dyes, including the temperature-sensitive disperse dye, when compared to the color changes observed in specimens stored in the nitrogen-only purged atmosphere. This provides additional experimental support for the relative safety of oxygen scavengers for use in anoxic pest control treatments.

On the other hand, this research demonstrates that a low-oxygen atmosphere, whether achieved with an oxygen scavenger or a nitrogen gas purge, does not necessarily slow fading in all dyes and may, in some instances, induce or accelerate unwanted color changes including fading in some dyes. The pink fluorescent dye, in the presence of light, exhibited significantly more color change in all three of the low-oxygen atmospheres than it did in ambient air. However, in the absence of light, the same pink fluorescent dye did not exhibit a visually perceptible increase in fading when held in a low-oxygen atmosphere rather than in ambient air. This suggests that the reaction is photochemical in nature and that the unwanted color change may be avoided during anoxic treatments by conducting the anoxic pest control treatments in the dark. Acknowledging that a very limited number of dyes, particularly fluorescent dyes, were included in this study, further research is needed to determine which fluorescent dyes are more photochem-ically sensitive in the absence ‘of oxygen. Nevertheless, it appears advisable for conservators and collection managers responsible for anoxic pest control treatments to devise ways to store objects in the dark while conducting these treatments since these findings showed that increased fading and other color changes induced by a low-oxygen atmosphere may be avoided by holding objects in total darkness when conducting anoxic treatments. By modifying treatment protocol in this manner, it appears that it would not be necessary to identify all dyes present in an object prior to treatment, thereby saving a great deal of time and expense.

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SOURCES OF MATERIALS

Curlon® Grade 1262 Protective Packaging Film
Curwood
2200 Badger Avenue, P.O. Box 2968
Oshkosh, Wisconsin 54903-2968.

Ageless ZPT
Mitsubishi Gas Chemical Company, Inc.
520 Madison Avenue, 25th Floor New
York, New York 10022.

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