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Detecting and Controlling Insect Infestation in Fine Art

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Introduction

The problem of insect and microbial infestation of fine art is centuries old. Techniques to control it have included such things as herbal treatments, fire smoke, and, most recently, chemicals. All have provided some degree of effectiveness if not complete control of the pests. But too often the treatment, while meant to save the art, has created damage of its own. In an effort to eliminate the side effects of controlling insect or microbial attack on art objects, parallel research efforts in a number of laboratories worldwide, including ours, have focused on nonchemical means using oxygen-free environments. This approach has proven very successful for insect control and is currently the only method we use at the MMA to treat infested art objects. This approach does also seem to work for fungal control, although when used for this purpose it is much more time-consuming than when it is used to control insects.

Detection of life in art

Before any treatment is undertaken, it is essential to know that an object is in fact infested. How is this determined? Generally, by the time an infestation is apparent to the unaided eye, it is severe, and significant damage has already occurred. Visual detection

of insect activity is difficult in all but the most severe levels of infestation and virtually impossible in the early stages of an attack. How can we improve the situation?

Many attempts have been made to adapt techniques from the field of microbiology for detection of vital activities of insects and microbes in materials, including fine art. Some of the techniques are as sophisticated as those used on the Viking probe to Mars; others are more prosaic, such as listening for movement. Additional techniques have included X-rays, chemical indicator reagents, and microwaves. Unfortunately, most of these techniques, with the possible exception of sound, would generally be impracticable or even dangerous for use on many art objects.

A promising technique pioneered at the MMA for nondestructive testing of insect (and any biological) presence is to test for gaseous byproducts. This could include detection of methane (for termites or wood microbes) or carbon dioxide (for insects or microbes). A prototype system for measurement of insect respiration byproducts was constructed using a Fourier transform infrared spectrometer (FTIR) system to measure the CO_2 produced by insects (Koestler, 1993). The prototype system proved capable of measuring a change in carbon dioxide that was 0.3-0.4 ppm/hr, but required days to reliably determine this level.

Using this system, measurements have been collected from insects both free in jars and in hidden in objects, before and after treatment of infested paintings, panels, and other art objects. The technique has also been useful in measuring CO_2 generated by fungal cultures. Further work is in progress to attempt to differentiate between insect- and fungus-derived byproducts.

A second, more sensitive, FTIR system has been used to improve the sensitivity limits of the prototype. This second instrument can detect changes as low as 0.09 ppm/hr and can provide results in only 4 hours. Representative results from insects important to museum collections are given in Table 1. A detailed discussion of the system and results is published elsewhere (Koestler et al., 2000).

Using this FTIR-respiration system, it is possible to detect the presence of respiration activity in art objects suspected of being infested. Further, it is possible to measure the effectiveness of any treatment to eradicate the infestation.

Methods of eradicating insects

Once an object has been shown to be infested, either by direct visual evidence or by instrumental detection of respiration byproducts, it is necessary to treat it to eradicate the infestation.

The requirements for treating fine art safely are much more stringent than those for treating any other type of material. Selection of a treatment that is safe for the object is of paramount importance. In the past, the application of a biocide (fumigant or microbiocide) would have been the course of action whenever an insect or microbial problem was suspected. (A biocide is any chemical that reacts with one or more life processes of living organisms and inhibits that process, resulting in the death of the organisms.) Unfortunately, biocides tend to react with more than the target organisms—they also, too often, react with some component of the art. Sometimes the reaction is very apparent—e.g., when the color or gloss is altered in a painting; at other times it is hidden—e.g., adsorption of the fumigant into the material.

The history of fumigation treatment for insect control in the museum conservation field is a story of the use of one inappropriate chemical after another. A fumigant is a biocide that is a volatile material, forming vapors that destroy insect pathogens and other pests. All fumigants are therefore reactive. They actively interfere with some aspect of the pests' life processes. The interference may be specific to one life process, such as respiration or digestion, or nonspecific, affecting many aspects of the insect. But the reactive ability of the fumigant to kill the pest has a detrimental side, in that the fumigant also reacts with the art object, and, if they are not careful, with the personnel handling the art. Fumigants can be harmful, or even lethal, to humans in the amounts used to control insects. They can be harmful to the environment as well.

Over the past 30 years a succession of fumigants have been used on art objects. Some of these are methyl bromide, ethylene oxide, and sulfuryl fluoride. All have been found to damage art objects, and their use has been curtailed for the most part.

Methyl bromide, for example, breaks sulfur bonds; it may weaken materials and produce noxious odors and it is not used for sulfur-containing materials anymore. This product has other serious side effects: It attacks the atmospheric ozone layer three times more effectively than fluorocarbons do. As a result, a worldwide ban on methyl bromide is imminent. Its use is now banned in Switzerland and its production is supposed to be banned in the U.S. this year.

Ethylene oxide is very effective in killing insects and fungi; it is still used extensively in hospitals. Unfortunately for art objects, though, it may be trapped in lipid-containing components of the art, e.g., parchment and leather. Ethylene oxide is also highly toxic to humans. The U.S. Environmental Protection Agency recommends no

more than a time-weighted average (TWA) of 1 ppm/day. (This is a TWA over an 8-hour work day. For comparison, consider that the TWAs for methyl bromide and sulfuryl fluoride are both 5 ppm.) Ethylene oxide is further classed as a suspected human carcinogen. The U.S. Library of Congress has recently determined that it takes at least 14 cycles of outgassing before ethylene oxide residues reach low enough values to permit handling of fumigated library materials (Dr. C. Shahani, personal communications).

Sulfuryl fluoride, the fumigant most recently used by museums in the U.S., has been found to actually melt the surface of some pigment systems in tests conducted by my laboratory at the Metropolitan Museum of Art. In the study, 10 out of 11 pigment systems were altered by this fumigant. We have since banned the use of this product for any art object in our collection (Koestler et al., 1993).

Alternatives to fumigants

Research undertaken by myself and others over the past 10 years has shown that the use of anoxic gases is effective in eradicating insect infestations in museum objects. An anoxic gas is one that is essentially inert; examples are helium, nitrogen, and argon. Such gases are nontoxic, nonflammable, and nonreactive. Nitrogen gas has been used for decades by agricultural services and government agencies around the world to control insects in granary silos. Helium gas has been used for some 45 years to protect one of the most important historical documents in U.S., the Declaration of Independence. Argon gas has been employed in museums around the world to control insect attack in fine art--with no damage to the art.

Since the early 1990s, argon gas has been the technique of choice at the Metropolitan Museum of Art, it is also used at the museums of the Smithsonian Institution, the Museu d'Arte in Sao Paulo, Brazil, the Singapore Art Museum, and the Restoration Center of the Republic of Slovenia, among other art collections.

Other techniques that have been under consideration and in use at some museums are: the use of CO_2, heating, freezing, and radiation treatment. However, all of these techniques are considered by us to subject the objects to a higher degree of risk than anoxic treatments do.

Humidified carbon dioxide has the potential to produce moisture droplets containing carbonic acid (which would be at a pH in the range of 4 to 5). If these droplets were to condense on an art object, unacceptable damage might occur. Further, in the U.S., carbon dioxide is classified as a fumigant, and therefore requires specially licensed personnel in order for it to be used in the museum context.

Heating, cooling, and various wavelengths of radiation all stress the physical material to a greater or lesser extent. Art is often composed of a wide mixture of materials, each of which may respond differently to the energy changes it would be subjected to. For example, if the coefficient of expansion is significantly different for the different materials in an art object, if the object is frozen or heated the component materials will expand and contract at different rates. This can lead to cracking in some kinds of objects. Gamma radiation testing on old and new parchments has shown that radiation damage effects are cumulative and that older parchments are more susceptible to damage than new ones (Dr. J. Petushkova, Laboratory of Biodiagnostic and Conservation of Cultural Property, Moscow, personal communication).

Considering all factors, we feel that the safest insect eradication technique to use for fine art is anoxic treatment with argon gas. This is the only technique we currently employ at the MMA. Over the past 10 years we have treated more than 2000 fine art objects using argon suffocation procedures, with no discernible alteration in the art.

The anoxic gas method for insect control

The concept of anoxic treatment is simple, and is the same for any anoxic gas used. It consists, essentially, of the following three steps:

1) Isolate the object from the oxygen-rich environment;

2) replace the oxygen-rich air with an anoxic (oxygen-less) air; and

3) wait until the insects die and then remove the object from its anoxic environment.

While simple in concept, each step requires an understanding of environmental, physical, and biological factors that may affect the procedure. An overview of these steps is given in Koestler (1992).

Perhaps the most important of the three steps is isolation of objects. Isolating an object requires construction of a suitable barrier around the object. The anoxic environment necessary to kill all stages of insects in a reasonable amount of time (i.e., 3-4 weeks) requires an oxygen environment of less than about 500 ppm (0.05%) of O_2. This

means any enclosure system must successfully maintain such a low level of oxygen for extended periods of time, ideally with a minimum of intervention and cost.

There are basically two methods of doing this: build either a solid-walled container system or a soft-walled one.

A solid-walled container system may be cost-effective if a large number of objects have to be treated, keeping the chamber in operation continuously for many years. In such a system all connections--humidity control system, oxygen monitoring system, temperature control system, gas flow system, or oxygen scrubber system--are "hard-wired" into the sides of the chamber. Each must be leak-proof, as must the door seams into the chamber. In the U.S., such chambers are expensive, on the order of $100,000-200,000, and tend to leak, making oxygen levels below 0.3% difficult to maintain without constant input of new gas or constant "scrubbing" of oxygen from the air. A chamber may also require a service contract and a full-time technician, adding to the overall expense of operations.

A soft-walled enclosure system can be constructed from heat-sealable plastics, which can be made to low-oxygen leakage rate specifications that make it easy to achieve and maintain the required low-oxygen environment. In such a system, all of the control systems for temperature, humidity, and oxygen level are connected on a temporary basis, as needed. Once the internal conditions in the enclosure are set, there is usually no need to alter or readjust them. Monitoring of the bags becomes a matter of rapid visual inspection and occasional instrumental monitoring.

A soft-walled enclosure system can be easily transported to the site of the infested objects and built around those objects. This reduces the cost of treatment, since

packaging and transporting the object become unnecessary. In addition, treatment on site reduces the risk of breakage during transport and the risk of infesting other objects during packaging, transit, and treatment.

A hard-walled enclosure system can only be started up six to seven times a year due to the long treatment times necessary to ensure insect death, and once the operation commences it cannot be interrupted to place new objects into the chamber. A separate soft-walled enclosure system, however, can be built quickly and easily around each and every object infested without interfering with objects already undergoing treatment.

Another advantage of a soft-walled system is that it can be built to conform to the shape of the infested object(s), thus reducing the volume of gas needed. A chamber system, by contrast, requires the same volume of treatment gas whether it has one or many objects within it.

Other drawbacks of a hard-walled system are that the door seam requires maintenance or replacement with some frequency, and loading and unloading of the chamber can be time-consuming and potentially more dangerous for the objects than with a soft-walled system.

The initial cost of a soft-walled bagging system is on the order of $20,000 to $40,000, depending upon quantities of bagging material ordered. A hard-walled chamber system requires $100,000-$200,000.

Choice of inert gas. The inert gases that have been used in the museum field for restricting or eradicating insects are helium, nitrogen, and argon. Each has certain advantages and disadvantages. The gas with the most advantages and least disadvantages is argon. A summary of the reasons is given below:

Helium. Helium has been used for about 45 years to preserve one of the most important historical documents in the U.S., the Declaration of Independence. The enclosure for this document was something of a minor engineering feat since helium diffuses so easily through most materials. Helium is considered to be a totally inert gas. What this means is that it does not react with anything else. Helium is the most expensive of the three gases mentioned here, but considering the valuable document it protects, cost was an insignificant factor. It was more important that the gas not be able to react with anything in the document, and that the gas not encourage or support anaerobic life (that is, life that grows in the absence of oxygen). Despite the advantages of this gas, the helium cases are now being replaced by argon-filled cases; one reason is that there is less gas leakage with argon.

Nitrogen. Nitrogen has been used for insect control in food storage silos for decades. A superficial understanding of its use there can lead one to conclude that it will be useful in the art field, but there are some potential drawbacks that restrict its utility for art. For one thing, nitrogen is not really inert. Although at normal room conditions it is not believed to be reactive, nitrogen gas is an essential requirement for anaerobic microbes—microbes that can survive when oxygen levels are low and when humidity levels in the material is conducive to their growth. In fact, this is the kind of microbe responsible for recycling most of the world's organic matter. So, due to the ability of some microorganisms to utilize humidified nitrogen, it is not recommended as the gas of choice, especially for long-term storage.

Argon. Argon is the gas of choice for many collections and museums, including the Metropolitan Museum of Art, which has pioneered the use of this gas in the museum

community. Argon shares the inertness of helium, but it costs less. It is also easier to keep in an enclosure than is helium, since it is a larger molecule. Argon does not share any of the disadvantages of nitrogen; it is not used as a nutrient by any organism and it cannot be converted into any other product. In addition, argon is heavier than oxygen, and therefore will sink to the bottom of an enclosure, pushing any remaining oxygen to the top of that enclosure. This has the effect of producing a lower oxygen environment at the bottom of an enclosure, where an object usually rests. Another important feature of argon is that it causes insects to die faster than nitrogen does. According to Valentin et al. (1992), argon is 25-50 percent faster at killing insects than is nitrogen. This difference, I suspect, is due to the ability of argon to push the lighter oxygen molecules out of the object, producing a lower-oxygen environment than occurs with nitrogen.

Length of treatment. The length of treatment (LOT) for an object is dependent upon the insect species involved, the type of infested material, and the material density and moisture content. Numerous laboratory studies of insects isolated in glass vessels have been published. These studies report LOT times ranging from one to four weeks for nitrogen, depending upon temperature and humidity. Comparison studies of LOT for insects in argon versus nitrogen environments have shown that argon gas is 25-50 percent faster than nitrogen at the same temperature and humidity conditions.

LOT data from the literature to date are based either upon insects isolated in laboratory containers or from newly, intentionally, infested pieces of wood. While it may seem reasonable to project LOT results from these studies to actual infested objects, there are problems with this approach. Insects in objects are well-acclimated to their niche and may be physically isolated from the environment (e.g., insect frass may be packed around

them) in addition to being in quite a few different physiological states (i.e., egg stage, larval stage with one to twelve distinct instars, pupal stage, or adult). Studies by Navarro (1991) and others have shown that different insect life cycle stages respond differently to inert gas treatment. It should be noted that, in practice, it is not always easy to identify the life cycle stage of the insect in an object.

At the MMA, I have determined actual LOT values using the above mentioned FTIR respiration systems. Using this equipment, I can measure an object before and after treatment. As a result of these direct measurements of real art objects, I've found that the literature has in some cases drastically underestimated the amount of time necessary to kill the insects. I have seen that treatment with argon requires a 3-to-4-week period. If nitrogen had been used, the treatment time would have had to be 5-6 weeks, 25-50 percent longer, to ensure the demise of all the insects at all their life stages.

Summary

Recent research studies at the Metropolitan Museum of Art have demonstrated the effectiveness of an FTIR respiration system for the detection of life in art and for determining the effectiveness of insect control treatments. A safe and effective insect treatment procedure, based upon anoxic gas treatment with argon, was discussed.

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Table 1

Respiration Rate of Selected Insects

Ground Worker Termites *Reticulitermes* sp.	0.1 – 0.2 ppm/termite/hr
Carpet Beetle Adult *Anthrenus* sp.	0.09 ppm/adult carpet beetle/hr
Carpet Beetle Larva *Anthrenus* sp.	0.65 ppm/larva/hr
Odd Beetle Larva *Thylodrias* sp.	0.35 ppm/larva/hr
Silverfish Adult *Lepisma* sp.	0.07 ppm/adult silverfish/hr (below instrument detection limits)

Table taken from Koestler et al. (2000).

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