ABSTRACT

One of the most persistent causes of loss of cultural property and museum collections is damage done by insects, fungi and bacteria. Recently considerable research has been conducted with the use of modified atmospheres to manage insect pests, as a direct replacement for fumigation with toxic fumigants. Until relatively recently, the idea of putting a museum artifact in a low oxygen or anoxic atmospheres was not taken very seriously, mostly because of the difficulty of creating and maintaining such an environment. Today, creating an anoxic microenvironment is very simple and safe because of its lack of toxicity to people and collections, consequently anoxia is becoming the method of choice for treating infested objects in museums. A new R&D area could be the designing of an integrated system, which works both as a fixed fire-extinguishing system and as a sanitation one.

Keywords: insects, museum, library, sanitation, anoxic treatment, inert gas

1. INTRODUCTION

One of the most persistent causes of loss of cultural property and museum collections is damage done by insects, fungi and bacteria.
Main targets are manuscripts on paper and parchment, natural history collections and herbaria, but massive wooden objects also are often attacked and, occasionally, seriously harmed. Fungal and bacterial attacks on historic objects can result in unsightly blotches ranging from whitish through green or reddish brown to black, as well as actual destruction of the fine structures of their surfaces [1].

In the early 1980s, a number of trends emerged in museum pest management and the concept of *Integrated Pest Management* (IPM) was introduced. In fact, while there was concern about the damage that insects, fungi or bacteria were doing to different kinds of collections, there was equally concern about the damage that pesticides might do to the same collections and to the operators.

An IPM plan include monitoring and identification of the pest, inspection, habitat modification, good sanitation, treatment action and evaluation. IPM aims to prevent pest problems from occurring, reducing the use of toxic materials that may adversely affect the environment and protecting materials from pests [2].

## 2. TREATMENTS

### 2.1 FUMIGANTS

In the past, fumigation was seen as the sole means of ensuring elimination of pest infestations. The use of fumigants involves exposing infected material to a lethal gas; fumigants are among the most toxic of pesticides. Fumigant gases remain in the air and can easily spread over a wide area. In general, fumigants and other pesticides can cause long- and short-term health problems, ranging from nausea and headaches to respiratory problems or cancer. Many chemical treatments might not be harmful at the time of exposure, however they might be absorbed from the body causing health problems years later. It’s also known that many of the chemicals damage the treated materials and no chemical treatment provide a residual effect that will prevent re-infestation [3].

*Ethylene oxide*, a gaseous fumigant, was commonly used in libraries and archives until the 1980s, being effective against insect adults and larvae
but not in killing eggs unless used in vacuum. Unfortunately, it poses serious health hazards to workers and can change the physical and chemical properties of library and museum objects, such as paper, parchment and especially those materials with a high fat content (e.g. leather).

Governments have lowered acceptable limits on ethylene oxide exposure (OSHA -Occupational Safety and Health Administration - Permissible Exposure Limit is 1 ppm as an 8-hour time-weighted average over an 8-hour day and a Short-term Exposure Limit of 10 ppm averaged over a 15 minute period) and most existing ethylene oxide chambers in libraries cannot meet these restrictions.

Sometimes methyl bromide is used instead of ethylene oxide, but even a little quantity is highly toxic. Methyl bromide is a highly effective fumigant used to control insects, nematodes, weeds and pathogens.

The sulphuryl fluoride (the commercial name is Vikane) is used to fumigate wood and timber structures. It penetrates deeply into the woods and often thoroughly eliminates the pests. Research has been undertaken to assess the potential damage of Vikane to modern and traditional resins and waxes pigments, as well as metal and the potential interaction with proteins and dyes. Little to no visible damage to materials was noted when Vikane was properly applied [3,4].

2.2 FREEZING

Insect pests in museums may be eradicated by freezing as an alternative to the use of fumigants and pesticides. Freezing kills insects by rapid temperature change.

Controlled freezing has been applied in various institutions over the past 15 years and its effectiveness has been considered largely favourable. Freezing is attractive because it involves no chemicals and poses no hazard to library staff and environment. It can be used on most library materials and does not appear to damage collections, but research into this question is not yet complete (very fragile objects should probably not be frozen). Items have to be bagged and sealed to prevent insects from escaping. Bagging protects objects from changes in moisture content.
during defrost cycles and from condensation on cold books, when they are removed from the freezer.

It’s essential to guard against freeze resistance: some insects can acclimate to cold temperatures, if they are kept in a cool area before freezing or if freezing happens too slowly.

To avoid damage from the freezing process, specimens must be sealed in polyethylene bags at room temperature, cooled steadily to –20°C and held at this temperature for at least 48 hours. The bag must not be opened until the contents have thawed to room temperature (at least 24 hours). Repeated freeze-thaw cycles are recommended to assure insect eradication [3,5].

2.3 HEATING

Heat can effectively exterminate insects and may be efficacious in killing some moulds, but it should not be used for the sanification of paper collections because of accelerated oxidation and ageing. Heat causes other problems, such as softening of waxes, synthetic adhesive and surface coating, direct expansion of brittle material such as glass, shrinkage of animal skins in leather-bound books [3,5].

2.4 GAMMA RADIATION

Gamma radiation can be effective against insects, but the minimum lethal dose for various species is still unknown and is affected by variables such as climate conditions and the nature of the infested material. Most important, research has shown that gamma radiation may initiate oxidation and cause scission of cellulose molecules and has the potential to damage seriously paper-based materials [3].

2.5 MICROWAVES

Microwaves have been used for rapid treatment of books, papers and herbarium specimens, but there can be undesirable side effects as the heating may be uneven and localized overheating may occur. In addition, unnoticed metallic objects such as paperclips may cause sparking and
ignition of specimens and paper. This technique is not considered safe for use with museum collections [5].

2.6 MODIFIED ATMOSPHERE

Recently considerable research has been conducted with the use of modified atmospheres to manage insect pests, as a direct replacement for fumigation with toxic fumigants. Until relatively recently, the idea of putting a museum artifact in a low oxygen or anoxic atmospheres was not taken very seriously, above all because of the difficulty of creating and maintaining such an environment. Today, creating an anoxic microenvironment is remarkably simple and therefore, anoxia is becoming the method of choice for treating infested objects in museums mainly because of its lack of toxicity to people and collections [5,6,7].

Mechanisms of insect mortality

A number of mechanisms have been proposed to show how anoxia causes increased mortality, but desiccation seems to offer the best explanation; in fact:

?? insect physiology provides a well defined respiratory system that leads to accelerated desiccation in the absence of oxygen or in the presence of modest amounts of carbon dioxide;

?? death rates generally increase with dehydration; increasing temperature or decreasing humidity tipically makes anoxia a more effective killing procedure;

?? mortality rates are positively associated with weight loss, which under anoxic conditions can occur only by loss of water.

Insects are able to control both the exchange of oxygen and carbon dioxide and the conservation of water by a series of orifices known as spiracles. The spiracles are normally kept closed to minimize water loss and are opened just enough for the insect to take in needed oxygen. When oxygen is scarce, they are forced to open more frequently and widely, thus causing dehydration. An insect must get rid of carbon dioxide as well
and high concentrations of this gas in modified atmospheres, quickly sensed when the spiracles are opened, will also lead to sustained opening and, consequently, dehydration. These two conditions, that is very low oxygen levels and high concentrations of carbon dioxide, force the spiracles to open and remain open. This unnatural condition leads to high rates of water loss, as much as seven to ten times higher than when the spiracles are closed. Rising temperatures increase insect respiration, resulting in a greater production and loss of water and this is demonstrated by the research work of Valentin (1993) (see Fig. 1 and 2).

![Effect of temperature on the minimum exposure time to argon](image)

Fig. 1: Effect of temperature on the minimum exposure time to argon required to achieve complete insect mortality at 40% RH and 300 ppm oxygen (Valentin, 1993).
Fig. 2: Effect of temperature on the minimum exposure time to nitrogen required to achieve complete insect mortality at 40% RH and 300 ppm oxygen (Valentin, 1993).

As you can observe from Figgs. 1-2, for each carrier an increase in temperature from 20 to 30°C decreases the exposure time approximately 30% and an increase from 20 to 40°C shortens the exposure time about 90%. Furthermore, under comparable conditions (in the specific case, 40% RH, 300 ppm oxygen at 20°C, 30°C and 40°C), it generally took 50% longer with nitrogen than with argon to reach 100% mortality. Ali Niazee (1972) observed that helium also provides a much faster kill than nitrogen; the researcher found that helium generally took only half as long as nitrogen to achieve 97% mortality with red flour beetles and confused flour beetles (see Table 1).
Table 1: Effect of temperature and inert gas type on the exposure time required to produce 97% insect mortality at 38% RH and 0.05% oxygen concentration (AliNiazee, 1972).

<table>
<thead>
<tr>
<th>Temperature</th>
<th>15.6°C</th>
<th>21.1°C</th>
<th>26.7°C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Confused flour beetle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helium</td>
<td>12 h</td>
<td>9 h</td>
<td>5 h</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>30 h</td>
<td>15 h</td>
<td>12 h</td>
</tr>
<tr>
<td><strong>Red flour beetle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helium</td>
<td>12 h</td>
<td>9 h</td>
<td>6 h</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>24 h</td>
<td>13.5 h</td>
<td>12 h</td>
</tr>
</tbody>
</table>

Jay, Arbogast and Pearman, instead, studied the relationship between mortality and RH, by examining the death rate of red flour beetles and confused flour beetles in nitrogen atmosphere, containing between 8000 ppm and 10000 ppm oxygen after 24 hours at relative humidities of 9%, 33%, 54% and 68%. As shown in Fig. 3, both species showed a marked increase in mortality as the RH decreased.

Fig. 3: Mortality of red and confused flour beetles exposed 24 hours at 26°C to 1% oxygen in nitrogen at different relative humidities (Jay, Arbogast and Pearman, 1971).
Under anoxic conditions, any decrease in weight is due almost entirely to loss of water; when total body-water loss approaches 30%, most insects die.

Donahaye’s research was concerned about the developing of resistance of insect species to modified atmosphere. For this purpose, he subjected some red flour beetles to two modified atmospheres, that is 0.5% oxygen in nitrogen and 20% oxygen and 15% nitrogen in carbon dioxide, at 95% RH until 30-50% remained alive (the extremely high humidity was employed to suppress the desiccation mechanism). He repeated the treatment with the offspring of the survivors for over forty generations and he observed that two resistant strains of beetle developed, each resistant only to the specific atmosphere to which it had been subjected. The type of compensations that enabled the red flour beetles to survive included a decrease in respiration rate, an increase in stored oxygen reserves, physiological changes to prevent water loss and other biochemical adaptations.

Anyway, different studies suggested that evolution toward resistant species occurred when desiccation was overwhelmed by a supply of water. [8].
*Common museum pests*

Some common museum pests are enumerated in Table 2 [1,8,9].

Table 2: Common museum pests

<table>
<thead>
<tr>
<th>Pests</th>
<th>USA</th>
<th>Colombia</th>
<th>Cuba</th>
<th>Spain</th>
<th>Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anobium punctatum</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Anthrenus museorum</td>
<td></td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Attagenus piceus</td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Blattella germanica</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Catorama sp.</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Cryptotermes brevis</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Cryptotermes cevifroms</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Dermestes lardarius</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Drosophila melanogaster</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hylotrupes bajulus</td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Kalotermes flavicollis</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Lasioderma serricorne</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Lepisma saccharina</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Liposceli divinatorios</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Lyctus brunneus</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Lyctus linearis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Lyctus pubescens</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Neogastrallus sp.</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nicobium castaneum</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Periplaneta americana</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Periplaneta brunnea</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Reticulitermes sp.</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Reticulitermes lucifugus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Stegobium paniceum</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Tintola sp.</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Xestobium rufuvillosum</td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
Proteinaceous material, such as parchment, leather and mummified tissues, are highly susceptible to aerobic fungal and bacterial growth. Aerobic bacteria can damage both the surfaces and the layers of these materials, as do fungi with their blotches of white, green or dark-coloured colonies. Anaerobic bacteria, instead, produce proteolytic enzymes, which cause collagen depolymerization and thus the loss of an object’s strength and even its integrity.

Some common aerobic microorganisms are *Aspergillus niger*, *Aspergillus flavus*, *Penicillium commune*, *Actinomyces sp.*, *Bacillus sp.*, *Streptomyces sp.*

Anaerobic fungi are very infrequent in organic objects [1].

**The present-day sanitation technologies using anoxic conditions**

An anoxic environment suitable for treatment of infested objects can be achieved through two different basic approaches: static and dynamic. With the *static procedure*, which is the more common approach, objects are held under high-purity nitrogen or argon in a tightly sealed container with as little transmission of gas as possible. The oxygen concentration is brought down to anoxic levels by one of the three following methods:

- the container is purged with many exchanges of high purity nitrogen;
- the oxygen is removed using large quantities of an oxygen absorber;
- combination of purging and adsorption.

This procedure is used for small objects.

With the *dynamic approach*, an inert gas is continuously passed through the system during the treatment. Oxygen free nitrogen or argon is used to flush all the air out of the container by initially using a high purge rate; then, when an oxygen concentration of less than 1000 ppm is reached, the flow is reduced to that needed to maintain the low oxygen level for the duration of treatment. This procedure is suitable also for bigger objects [1].

At the present, the two following modified atmosphere treatments are used:

- the *BOOK SAVER* Process, which has been developed by the Spanish CSC (Conservaciòn de Sustratos Celulòsic S.L., Barcelon) center,
uses a machine, into which the bound books and documents are introduced, together with eptafluoropropane (HFC227) containing a reagent that neutralizes the acidity without attacking the ink. The amount of reagent to be used and the contact time between the material and the reagent depend on the state of the material to be treated.

?? the $\text{VELOXY}^2$ (VErY LOw OXYgen) Process was developed, patented and commercialized in Italy and Europe by R.G.I. (Resource Group Integrator srl); it’s a machinery, which uses the method of anoxia to control the parasites.

3. LIBRARY AND MUSEUMS SANITATION AND FIRE SAFETY INTERACTION

Considering that gas fire-fighting total flooding systems can be used to protect cultural institutions, a new R&D area could be the designing of an integrated system, which enables fire protection and pests control at the same time; there can be no doubt that it might represents a concrete possibility of increasing anoxic techniques utilization in the control of library, archive and museum pests. Besides, both from performance and from a technological point of view, the most advanced solution should be the installation of a gas system, which extinguishes flames when a fire breaks out and supplies inert gas when a sanification is necessary [10].

In order to realize an integrated system, it is necessary to solve some problems related to:

?? **microclimate conditioning and oxygen concentration control**: as you have seen, the success of an inert gas sanification process is strictly correlated with microclimate (temperature and relative humidity) and oxygen concentration control; consequently it’s very important monitoring and controlling these parameters by appropriate instruments, having the right resolution [1,11];

?? **designing of an integrated system with bivalent technical specifications**, that is capability of working both as a fixed fire-fighting system and as a sanitation system; it’s necessary to define the technical specifications of the integrated system and to optimize its performances, finding a
right compromise among costs, time of exposure and effectiveness of the treatment;

?? sealing of the space which needs sanification: the effectiveness of the sanitation treatment depends on the capability of maintenance of both anoxic conditions and optimum temperature and relative humidity values, therefore it is necessary the identification of the best sealing procedures, which guarantee both an easy application and removal of the sealant and a minimum damage to the structures;

?? monitoring and evaluation of the effectiveness of the treatment, through specific bio-assays, evaluating pest mortality rate.

4. REFERENCES