BIODETERIORATION
OF
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I. INTRODUCTION

Museum collections comprise of natural, organic, or mineral artifacts. The problem of conservation and protection is one of the most important issues in the field of cultural heritage. The degradation of museum objects, such as organic and inorganic materials, is a significant concern. Many factors contribute to the deterioration of these objects, including physical, chemical, and biological processes. In general, the degradation of organic materials is more complex than that of inorganic materials. The conservation of organic objects requires a multidisciplinary approach, involving experts in chemistry, biology, and other related fields.

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Fungi in Deterioration of Museum Objects

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Abstract

The problem of control of fungal infection is very important specially for those museum objects of organic origin. However, with proper care and maintenance it is easy to reduce its threat. In cases where the infection is quite severe and it is decided to make use of fungicide, it is necessary to study the likely effect of fungicide beforehand. Although a large number of chemicals have been used by various workers, the experience shows that the chemicals like \textit{o}-phenyl phenol, sodium salt of \textit{o}-phenyl phenol, para-chloro-m-cresol, salicylanilide and dichloro- phene give good results.

1. INTRODUCTION

Museum collections comprise of materials of cultural, artistic or historic significance. The protection of these valuable objects from deterioration is one of the basic functions of a museum. Depending upon their nature, the museum objects can be classified into two major categories, \textit{viz.} inorganic, e.g. metals, stone, ceramics and glass, and organic, e.g. objects of wood, paper, leather, textile etc.

A variety of factors, broadly classified as physical, chemical and biological are responsible for the decay of these objects (Garg \textit{et al.}, 1993; Rose, 1981). In principle, the objects of inorganic nature are less susceptible to deterioration than organic objects. The organic objects are particularly susceptible to biodeterioration, specially in countries of Southeast Asia where the climate is hot and humid for most part of the year. The decay and destruction of materials caused by biological agencies is termed as biodeterioration and the agencies causing this type of decay are termed as biodeteriogens. The various biodeteriogens may be classified into the following categories:
A. Lower Plants  B. Higher Plants  C. Animals
1. Bacteria  1. Ferns  1. Nematodes
2. Fungi  2. Gymnosperms  2. Ants
4. Algae
5. Lichens
6. Bryophytes (Liverworts and Mosses)

Out of all the deleterious plant growths commonly noticed over the museum objects, the occurrence of fungi is most common and quite destructive, specially for organic objects and as such has always been a cause of concern for the keepers and conservators of museums. The present paper describes in brief the various types of damages caused by fungi and the conservation treatment required in such cases.

2. FUNGI AS AGENTS OF DECAY OF MUSEUM OBJECTS

Fungi form an important part of the plant kingdom and differ fundamentally from the green plants in their lack of chlorophyll and are either saprophytes or parasites. Since these are heterotrophic in nature, they utilize the carbon source present in the substrate in order to continue their life cycle, consisting of vegetative and reproductive phases. The vegetative phase of fungal body (thallus), originates through the germination of a spore. The vast majority of the fungi have filamentous thalli. The long, fine filaments are called the hyphae, collectively known as mycelium. The hypha, being branched or unbranched, is a structural unit of the mycelium.

The hyphae in some species are variously coloured either due to nature of reserve food materials or some kinds of pigments. They may be with or without septa. The mycelium spreads its root-like structures (rhizoids) on or through the host material, the surface growth having the fruiting bodies or spore bearing structures i.e. sporangia or conidia. These spores which are always present in the environment can settle on the object and start growing whenever they get proper humidity above 65% and temperature between 25-35°C.

Damage caused by fungi: The most common and visible type of damage caused by fungi is the discoloration of the material and formation of different coloured stains e.g. black, green, grey, brown, pink, yellow etc. on the museum objects. Besides this, the fungal growth is also responsible for loss of strength
of the material either by the action of acids like oxalic, succinic, fumaric, citric etc. or different kinds of enzymes produced by the fungi. With the help of these enzymes produced by the fungi, the insoluble organic substances such as starch, cellulose, lignin and proteins of the substrate are dissolved and absorbed. This ability of fungi makes them capable of damaging a large variety of museum materials like wood, paintings, textiles, and leather. We shall now discuss the damage caused by fungi to specific types of materials.

**Wooden objects:** In the case of wooden objects, decay may be either by staining or by the decay of wood constituents (Garg and Mukerji, 1993). The fungi may develop either on the surface of the wood or within rays, parenchyma cells, tracheids etc. and can partially or wholly destroy the cell walls, breaking down their components into simpler ones. Of the various types of fungi found growing over wood, the white rot fungi are capable of destroying the cellulose and lignin of the wood, leaving it whitish in colour and light in weight. The dry rot fungi (brown rot) attack only cellulose and short-chain polysaccharides and leave a brown residue over the surface. In this case, the wood appears darker in colour and on drying, develops a typical cuboidal cracking along and across the grains of the wood (Plate 1). In the case of wood which is wet or continuously damp, the surface becomes soft and typically cracks on drying (soft rot).

**Archival materials:** In case of paper materials, the formation of different coloured stains as well as the loss of strength of the paper is mainly the result of fungal activity (Dhawan and Garg, 1993). The fungi growing on paper usually produce black, brown, yellow, or orange spots (Plate 2). In some cases the growth may even be colourless. Since these fungi have a remarkable cellulose-dissolving capacity, it results in the loss of strength. In case of books, the bindings are usually the first to be affected by fungal growth followed by its spread on the pages. In many cases, the fungi are responsible for the alteration of inks through the formation of an enzyme, tannase, that catalyses the hydrolysis of gallotannate. One particular and very common chromatic alteration of paper is the appearance of rust-coloured spots (foxing) believed by many workers to be associated with fungal growth (Dhawan and Garg, 1992).

**Leather and parchment:** Fungal growth on leather objects is a very common phenomenon under highly humid conditions (Caneva et al., 1991; Kowalik, 1980). As a result of fungal deterioration, the surface of the object becomes unpleasant to look at, looses its suppleness and becomes hard and brittle. Vegetable-tanned leather is most susceptible to fungal decay the chrome-tanned leather is almost completely resistant because of the presence of chromium compounds.

**Textiles:** The growth of fungi on textiles (Plate 3) results either in the
formation of stains or in the loss of strength of the material (Caneva et al., 1991; Kowalik, 1980; Montegut et al., 1991). Cellulosic fibres are more susceptible to fungal attack than protein fibres. **Paintings:** Almost all kinds of paintings whether on paper (Plate 4), wood, textile or wall are susceptible to fungal decay (Agrawal et al., 1989; Garg et al., 1994; Strzelczyk, 1981). In paintings on canvas, the fungal attack usually starts from the reverse as the natural susceptibility of the textiles is increased by the glue sizing. As they penetrate inside the textiles, fungi often reach the back side of the pigment layer, causing cracks and detachment of pigment particles. The hydrolysis of cellulose creates differences of adhesion between the pigment layer and the canvas. In many cases the filaments spread over the pigment layer, masking the colour and the design. In the case of wall paintings, the growth of hyphae and the fruiting bodies of the fungi causes stains, fissures and the loss of the paint layer.

Although a wide variety of fungal species has been found growing over the museum materials, the most common ones are - *Alternaria, Aspergillus, Aureobasidium, Chaetomium, Cladosporium, Curvularia, Fusarium, Mucor, Penicillium, Rhizopus, Scopulariopsis, Stachybotrys, Stemphylium, Trichoderma.*

3. **DEGRADATORY FUNGI**

More than 320 fungal species are known to attack paper and paper articles. Of these about 20 belong to Zygomycetes, 60 to Ascomycetes, 230 to Deuteromycetes and 10 to Basidiomycetes. Maximum degradation is done by Ascomycetes, particularly species of *Chaetomium* and *Myxotrichum* (Jong and Birmingham, 1992; Mucerji et al., 1980). Textile deterioration is mostly due to cellulose decomposing fungi like Chaetomiaceae. Wooden articles are mostly deformed by members of Chaetomiaceae and Moniliales. Leather articles are generally degraded by Deuteromycetes - Moniliales by species of genera *Penicillium, Aspergillus, Scopulariopsis* and *Cladosporium* etc.

4. **CONTROL OF FUNGI ON MUSEUM OBJECTS**

The control of fungal growth is an important step in the care and preservation of museum objects. This can be achieved by employing both preventive as well as remedial measures (Allsopp and Allsopp, 1983; Rose, 1981). However, before undertaking a fungal control measure an objective assessment of the problem based on the flow sheet (Plate 5) may prove useful.
A. Preventive Measures: The aim of all preventive measures is to forestall the possibilities of fungal attack on objects and includes good housekeeping and proper sanitation. Since certain climatic conditions are conductive to the germination of fungal spores, the modification of environmental conditions in such a way that the parameters like relative humidity and temperature either inhibit or slow down the growth of fungi, is probably the best possible way to check the fungal growth. All these parameters could be modified with simple routine maintenance procedures or by using sophisticated methods like air-conditioning. In general, the relative humidity should be as low as possible without falling to such levels that it adversely affects the material. On the other hand, the relative humidity should not be allowed to rise above 65% in the areas containing organic materials and the temperature should be kept within 16-20°C or at least under 20°C. In places where the relative humidity is high, any attempt to lower the temperature may result in condensation over the surface of the objects requiring proper remedial measures to avoid this situation. Proper ventilation and air circulation may help in avoiding condensation. Similarly, steps should be taken to ensure that the objects do not come in direct contact with moisture penetrating through the wall or the ground. The use of hygroscopic chemicals like, silica gel and calcium chloride in showcases also helps in lowering the relative humidity. The lowering of temperature may be achieved either by air conditioning, an expensive proposition for developing countries, or by using simple means like thick walls and roofs, use of curtains etc. outside the galleries and doors. However, in order to keep an eye on the climatic parameters, it is essential to install thermohygrographs and to take corrective measures as and when needed.

Regular dusting of objects and timely cleaning also helps in getting rid of fungal spores, thus reducing the threat posed by the fungi to a great extent. When on display or in storage the use of repellents like thymol, naphthalene, camphor, or para-dichlorobenzene also reduces the fungal growth. Before cleaning and dusting, objects should be fumigated with thymol/ethylene oxide/formalin in a special type of fumigation chamber.

As soon as the fungal attack is detected the material should be treated immediately in the laboratory or in situ.

Use of Fungicidal Paper: During transit, thymol crystals in muslin cloth may be placed in packing. Where the material is delicate, fungicidal paper can be used for wrapping and keeping in between the layers of costumes, flags, paper materials and textile objects. It can be prepared by dipping white blotting
sheets or tissue paper in 10% alcoholic solution of thymol or ortho-phenyl phenol.

**B. Remedial Measures:** The various remedial measures employed for the control of fungi can be classified as mechanical, physical, and chemical.

**Mechanical methods:** Traditional methods of removing fungi mechanically, consist of either hand picking or by making use of tools such as scalpels, spatulas, scrapers, swabs or vacuum cleaners. The mechanical methods have certain advantages as these do not add anything to the object that might cause further alteration.

**Physical methods:** The use of ultraviolet rays, gamma rays, heat etc. are included in this method. The part of the UV spectrum with fungicidal activity lies between 300-200 nm with a maximum of activity between 275-230 nm. In case of irradiation by gamma rays generally a dose of 10 kilo Grays is considered sufficient. In many cases heat is used in the disinfection of organic materials. The application of moist heat for disinfecting books is still one of the most widely used techniques where a temperature of 95°C with an R.H. of 40% for a period of 4 hours is recommended. Other methods involve exposure to deep freeze temperatures or reduction in pressure which causes the cells to burst thereby killing all the fungi.

**Chemical methods:** Biocides are chemicals used for destroying considerable biological growth. These chemicals have a biocidal action with a specific toxicity for the species of fungi to be eliminated. In selecting a fungicide the following characteristics should be taken into account:

a. The selected fungicide should posses a high toxicity against the fungi to be eradicated.

b. It should have a low toxicity for the operator.

c. The fungicide used should not affect or alter the properties of the object.

d. It should not cause environmental pollution.

The mode of application of fungicides varies depending upon the composition of the art object, its state of preservation, the organism to be eliminated, the density and diffusion of fungal infection as well as the product chosen. The common methods of treatment are spraying, brushing, by application of poultices, injection or fumigation.

i) Spraying and Brushing: Spraying and brushing of diluted fungicidal solutions is one of the most common methods of treatment. The spray method is preferred in case of objects having a badly deteriorated surface.

ii) Poultice method: This method is carried out particularly in cases of hard encrustations so as to increase the contact time between the fungicide and
the surface. The poultries are usually made of paper pulp or carboxymethyl cellulose. Often the poultries are covered with polythene to reduce the evaporation of the solvent.

iii) Injection method: This method is particularly useful for the treatment of wooden objects and wall paintings.

iv) Fumigation: This method is also widely applied. The treatment consists of distributing the fumigant in the air and thus through the materials. This method has some advantages such as the rapid efficacy of the treatment and deep penetration of the fungicide. Since generally the fungicides are toxic to human beings, these must be applied in air tight chambers or perfectly sealed spaces. Fumigation with thymol could be done in the chamber where the lower shelf has heating arrangement with a 60 Watt bulb. The dish used to hold thymol crystals should be of heat resistant material such as Pyrex glass or Ceramic. Thymol should be heated for 30 minutes daily for 7-10 days. Fumigation with formalin is also very effective, but where protein-based material is present formalin should not be used. Para-dichlorobenzene crystals may also be used as a fumigant. The crystals should be wrapped in muslin cloth and placed in a store box. There is a variety of fungicides available (Allsop and Allsop, 1983; Rose, 1981; Strzelczyk, 1981) today but not all of them are suitable for museum objects. Table 1 lists some of the most common fungicides. For treatment by spraying, brushing or the poultice method, the fungicides are usually diluted in organic solvents or water at required concentration of 0.1 to 3%. For treatment by the injection method higher concentrations up to 10% may be used.

5. PRECAUTIONS IN THE USE OF FUNGICIDES

It should always be remembered that all fungicides, whether liquid, powder or vapour are toxic in nature and may affect living beings. Therefore, all necessary precautions must be taken in their handling. Some of the precautions to be taken are as follows:

a. All the fungicides should be stored with proper labels and the containers should be checked regularly for leakage.

b. As the fungicides may result in the contamination of food or drinking water, one should not store these next to food, and should not drink, eat or smoke in that area.

c. Since certain fungicides may be absorbed through the skin, any contact with skin should be prevented by putting on gloves, goggles and protective clothes.

d. The chances of inhaling are much higher when the fungicides are used as vapour or spray. Therefore, gas masks or respirators should be used during
their application.
e. After completing the work, hands and face should be washed thoroughly with medicated soap.

6. SUGGESTIONS FOR CURATORS AND CONSERVATORS

i) All the objects of organic origin should be fumigated before display in galleries and it should be a regular practice to check for the presence of any biological agents.
ii) The relative humidity and temperature inside the galleries and the storage area should be recorded regularly and maintained at the desired levels.
iii) There should be use of repellents within displays.
iv) Cleaning and dusting of the materials should be carried out in separate rooms, away from the display or storage areas.
v) Before carrying out the fungicidal treatment the effect of fungicide should be investigated on some obscure corner of the object.

REFERENCES


### Table 1. Some common fungicides used for the control of fungi.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Chemical Name</th>
<th>Trade name</th>
<th>Object type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Tri-n-butyl tin oxide</td>
<td>Thaltox</td>
<td>Wood, Textile, Leather, Murals</td>
</tr>
<tr>
<td>2.</td>
<td>Tri-n-butyl tin naphthenate (2-4%)</td>
<td>Metatin IV-58-10</td>
<td>Wood</td>
</tr>
<tr>
<td>4.</td>
<td>Zinc dimethyl dithiocarbamate (below 1%)</td>
<td>Ziram</td>
<td>Textile</td>
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<tr>
<td>5.</td>
<td>Zinc 8-quinolinolate (0.1-2%)</td>
<td>-</td>
<td>Textile, Paper, Leather</td>
</tr>
<tr>
<td>6.</td>
<td>Copper naphthenate</td>
<td>Nuodex-Copper-Naphthenate</td>
<td>Wood, Textile</td>
</tr>
<tr>
<td>7.</td>
<td>Copper 8-quinolinolate (0.1-2%)</td>
<td>-</td>
<td>Wood, Textile</td>
</tr>
<tr>
<td>8.</td>
<td>Copper 8-hydroxyquinolinolate (0.5%) (1.7-6.7%)</td>
<td>Mystox P8</td>
<td>Paper</td>
</tr>
<tr>
<td>9.</td>
<td>Pentachlorophenol (0.1-3%)</td>
<td>Mystox 8</td>
<td>Textile</td>
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<tr>
<td></td>
<td>Sodium salt of Pentachlorophenol (0.1-1%)</td>
<td>-</td>
<td>Wood, Textile, Paper, Paintings, Leather</td>
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<tr>
<td></td>
<td>Pentachloro phenyl laurate (1-3.5%)</td>
<td>Mystox LPL</td>
<td>Paper, Textile, Leather, Paintings</td>
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<td>10.</td>
<td>O-phenyl phenol (0.05-2%)</td>
<td>Preventol O</td>
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<td>11.</td>
<td>Sodium salt of O-phenyl phenol</td>
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<td>Para-chloro-m-cresol (0.1-2%)</td>
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<td>S.No.</td>
<td>Chemical Name</td>
<td>Trade name</td>
<td>Object type</td>
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<td>12.</td>
<td>Thymol</td>
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<td>Paper</td>
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<td>13.</td>
<td>Dichlorophene</td>
<td>Panacide</td>
<td>Textile</td>
</tr>
<tr>
<td>14.</td>
<td>Salicylanilide (1%)</td>
<td>Shirlan</td>
<td>Textile, Paper</td>
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<td>15.</td>
<td>Quarternary Ammonium compounds</td>
<td>Preventol R50 R80, R90</td>
<td>Textile, Paper, Paintings</td>
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<tr>
<td></td>
<td>Benzalkonium chloride</td>
<td>Bradophen</td>
<td>Organic material</td>
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<td></td>
<td>Dodecyl dioxyethyl benzylammonium chloride</td>
<td>Metatin 101</td>
<td>Organic material</td>
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<td></td>
<td>Lauryl dimethyl benzyl ammonium bromide</td>
<td>Hyamine 1622</td>
<td>Organic material</td>
</tr>
<tr>
<td></td>
<td>Benzethonium chloride</td>
<td>Gloquat C</td>
<td>Organic material</td>
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<tr>
<td>16.</td>
<td>Fumigants</td>
<td>Ethylene oxide &amp; CO₂ (9:1)</td>
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<td></td>
<td>Formaldehyde</td>
<td>-</td>
<td>Library and archival materials</td>
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<tr>
<td></td>
<td>Para-dichlorobenzene</td>
<td>Paracide</td>
<td>Textile, Wood</td>
</tr>
<tr>
<td></td>
<td>Thymol</td>
<td>-</td>
<td>Paper</td>
</tr>
</tbody>
</table>
late 1. A wooden Bhuta image, Crafts Museum, New Delhi showing fungal rot.
Plate 2. Black fungal spots on archival material.

(a) A close-up of the infected area.
(b) A close up of the infected area.

Plate 3: A textile affected by fungal growth.
Plate 4. Discoloration of a miniature painting due to fungi.
Figure 1. Flow sheet for deciding upon the fungal control measures.

1. Do you think there is ______ No
   a fungal problem? _______ Yes _______ Isolate and classify the fungi and evaluate the damage

2. Is treatment necessary? ______ No _______ Do not perform any type of control treatment
   ______ Yes _______ Study the physical and chemical condition of the object

3. Can the object tolerate ______ No
   the treatment? ______ Yes _______ Select the best method and the period of treatment

4. Can preventive methods ______ No
   be applied? ______ Yes _______ Plan the treatment Plan for routine and periodic maintenance