EDO UNIVERSITY IYAMHO

Department of Microbiology

MCB 314 Biodeterioration

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Description: biodeterioration highlights the process of chemical and physical alterations of products of economic value mostly in an undesirable/unpleasant manner by the action of microorganisms or their enzymes. The course describes the different aspects of biodeterioration from physical/mechanical, soiling and fouling, assimilatory and dissimilatory biodeterioration which covers a bewildering range of all materials that can be attacked by biodeteriogens. Also, the biodetrioration of different materials will be discussed highlighting the microorganisims involved in each case. Other topics of significance that will taught in this course include the factors that favour biodeterioration, effects of micro and macro organisms on biodeterioration and biodeterioration control.

Prerequisites: Students are expected to have an exhaustive knowledge on the concept of biodeterioration with respect to types, organisms involved and the materials involve in biodeterioration. Also students should be accustomed with the factors that encourage biodeterioration of materials, the macro and microorganisms involved as well as the best approach to properly manage or control biodeterioration to ensure longevity of materials.

Learning outcomes: At the completion of this course student are expected to :

1. Understand the concept of biodeterioration
2. To know the materials involved in each type of biodeterioration
3. To differentiate between all types of biodeteriorationa and their mechanisms of action
4. To enumerate and the different micro and macro organisms involved in biodeterioration
5. To gain requisite knowledge in controlling biodeterioration of different materials

Assignments: Three (3) individual homework, one group seminar presentation and a mid-term test will be administered to students for continuous assessment (C.A.) in this course while a final exam will be written at the end of the semester. The group seminar, a power point presentation (ppt) is designed to encourage students work as a team and also master the skills of ppt. The C.A.

is organized to prepare students for the final exam and also to ascertain how well they have understood the course.

Grading: Students will be graded 100% for both C. A. and final exam. 30% of the total score will be allotted to C.A. while the remaining 70% to final exam. C.A. comprises of Group Assignment, individual assignment, quiz and power point presentations.

Textbook: The recommended textbooks for this course are:

Title: Introduction to biodeterioration
Authors: Dennis Allsop, Kenneth J Seal and Christine C. Gaylarde
Publisher: Cambridge University Press
ISBN: 0-521-821-35-5
Year: 2004

Title: Handbook of Material Biodegradation, Biodeteriorationa nd Biostabilization
Authors: Michalina Falkiewicz-Dulik; Katarzyna Janda and George Wypych
Publisher: CRC PressChemTec Publishing
ISBN: 978-1895198447
Year: 2010
Other relevant peer reviewed journal articles will also be used as reference materials.

PRINCIPLES OF BIODETERIORATION

Biodeterioration is simply defined as any undesirable change in the property of the material caused by the vital activities of organisms in that material e.g. bacteria fungi as well as pests are constantly causing problems in the conservation of our cultural heritage as well as other materials (food, lethaer, cosmetics, woods, plastics) because of their biodeteriorating potential.

TYPES OF BIODETERIORATION

In recent times, many materials are complex and much changed from the original raw materials from which they were derived. New environments are being explored or exploited and technology advanced. These new materials and their uses presents biological and environmental problems due to the enormous range of organisms in the environment that deteriorate them. However, it becomes useful to classify the different types of biodeterioration which can occur :

a)Physical and mechanical biodeterioration

In this case the organism quite simply disrupts the material by growth or movement and does not use it as a source of food. There are few if any serious examples of such damages caused by microorganisms but an example is the expansion of microbial mass between rock layers leading to spalling of the rock surface. Other examples caused by microorganisms include cracking of underground pipes by roots, gnawing on electrical cables, cinderblocks, plasterboards and wood by rodents and bird strikes on aircraft. This latter point shows that biodeterioration is not necessarily caused by any conscious process by the organisms.

b)Soiling or Fouling (aesthetic) Biodeterioration

This type of biodeterioration is characterized by either the presence of dead insects or droppings, excreta or metabolic products on food stuffs or materials which renders it unsaleable. Microorganisms especially fungi and algae can be found growing on the surface of materials, utilizing surface dirts, reducing its economic value or acceptability. A classic example is dark fungal colonies growing on damp soap and skin residues on plastic shower curtains.

Many fungi also release metabolites, soluble or insoluble pigments which discolour the surface of materials. Fouling can be more serious and transcend the category of purely aesthetic damage in that a physical function can be impaired e.g. the extra drags on ship caused by accumulation of weeds and invertebrates on the hull can increase fuel consumption dramatically.

Biochemical Assimilatory Biodeterioration

The organism utilizes the material as food or energy source. Examples are: microbial enzymes breaking down cellulose. Rats and insects eating stored grain and in layer consuming stored food.

Biochemical Dissimilatory Biodeterioration

In this case, a material suffers chemical damage but not as a result of direct intake of nutrients by the organism. Many organisms excrete waste products including pigmented or acidic compounds which can disfigure or damage materials.

BIODETERIORATION OF DIFFERENT MATERIALS

a) Biodeterioration of stored food materials

Stored (unorocessed) plant materials (fruit or seeds) are uasually decayed due to post harvest attack of bacteria and fungi. The microbes can damage the plants partially as well as completely. A large number of bacteria such as *Erwinia* spp., *Corynebacterium* spp. And fungi such as *Phytopthora* spp., *Curvularia* spp., *Aspergillus* spp., are commonly found to be associated with food materials. The most affected products are soft fruits and salad vegetables whereas grains, oil seeds and legumes are durable products.

b) Biodeterioration of Leather

Leather is a product of animal hides. Besides its wool and animal glues, there are other animal products which are attacked my microorganisms since leather contains keratin, animal fats and proteins. Therefore, these are rapidly deteriorated by lipolytic and proteolytic microorganisms which screte lipases and proteases. Leather production from animal hides involved soaking process which is carried in water where Several *Bacillus* (*B. subtilis*, *B. megaterium* and *B. Pumilis*) are present. They secrete several extracellular enzymes that may attack the leather and remain active long after the death of the produced organism. During leather deterioration, microbial activities cause loss of tensile strength and colouration. Since finished leather is quite acidic, fungi such as *Rhizopus, Mucor, Cunninghamella* and *Aspergillus* deteriorate quite fairly whereas bacteria are secondary colonizers. The damage on leather causde by biodeteriogens include: colour change, odour, loss of tensile strength.

c) Biodeterioration of Stone and Building Materials

Old/ancient monuments, natural rocks, building materials are attacked by various microorganisms such as *Cyanobacteria, Pleurococcus, Oscillatoria* etc, Lichens, while fungi include *Botrytis Penicillum* and *Trichoderma* spp. The use concrete, bricks and mortar of building materials as nutrients. Microbes colonize these materials which may cause excessive expansion and contraction. Entrapment of water within the colonises and cracks can lead to enhanced damage. In addition, hyphal penetration into surface layers of these materials can result in crack formation which may be promoted by excretion of corrosive metabolites. Several organic acids solubilize calcium carbonate while oxalic and citric acids solubilize silicates. Desulfovibrio desulfuricans reduce sulphur compounds and produces H_2S which is then oxidized to sulphuric acid by *Thiobacillus thioxidans*. Various niyrifying bacteria such as *Nitrobacter*, *Nitrosomonas* also solubilize calcium associated with building materials. Additionally, a large number of Pseudomonas corrode steeled iron structures used in building construction.

d) Biodeterioration of Paper and other Cellulosic Materials

Plant cells are composed of cellulose, hemicellulose, lignin and pectic substances. Therefore, paper and cards are derived from plants. Although a large number of factors are responsible for the microbial spoilage of paper. Deterioration of paper occurs by several cellulolytic fungi such as *Trichoderma chaetomium* and *Aspergillu*s and bacteria such as *Cellulomonas.* These microorganisms secrete cellulose (endo-β-glucanases, exo-β-glucanases and β-glucosidase) convert cellulose into glucose. Besides, more microorganisms also secret enzyme xylanases that deteriorate hemicellulose present in paper. However, many other microbial activities have major effects on paper material strength.

e) Biodeterioration of Metals

Microorganisms are jnown to corrode metals. They make biofilm by colonization of cells which release corrosive metabolic productsresulting in the removal of hydrogen by sulphate reducing bacteria (SRB). Microbial concentration of cells appear from an oxygen gradient that develops as a microbial colonyin contact with the metal and utilizing the available oxygen. These colonies have both oxygen limited zone (centre) which are having negative and positive charges respectively. These leads to metal ion formation by producing insoluble hydroxides

Iron corrosion occurs mainly due to a bacterium *Gallionella* (chemolihotrouph) that oxidizes ferrous ion to ferric acid and form insoluble ferric hydroxide deposits at the site of microbial attack. Biological activities that stimulate corrosion include:

- Anodic reactions by acidic metabolism
- Cathodic reactions by microbial production of cathodic reactants such as H_2S
- Breakdown of protective films
- Increase in conductivity of the liquid in the environment.

f) Biodeterioration of Plastics

Plastics are polymeric materials e.g. polyethylene, polystyrene, polyvinyl chloride (PVC) and polyesters. Plastics are resistant to microbial attack but addition of various other materials makes the plastics prone to microbial attack. Streptomyces *rubireticuli* and *Penicillum* spp are reported to deteriorate PVC and polyamides (nylon). Polyesters, polycaprolactone and polybutylene adipate are degraded by bacteria and fungi.

g) Biodeterioration of Pharmaceuticals and Cosmetics

Cosmetics and pharmaceuticals are manufactured in the form of lotion, cream, drugs and powder forms. They consist of large quantity of water, animal, plant and mineral oils, natural gums, thickening agents, carbohydrate, aroma and flavouring agents in addition to protein hydrolysates, milk, beer, egg, plant extracts etc. These product formulations are good sources of nutrients for microbes. Although preservations are added but due to the complex nature of the formulations. becomes less effective. Sometimes, creams and lotions are contaminated with Pseudomonas, although with low levels of these groups of organisms, the individual is not harmed but when applied to a damaged skin, situation may become worse. Some of the deteriorated cosmetics impart foul odour due to the production of organic acids, fatty acids, amines, ammonia, H_2S or acids which alters the pH changing the consistency and colour of the product. Sometimes, gas bubbles are generated. Such products may later become unstable and form separate oil and water phases.

Assignment

Write exhaustively on Biodeterioration of fuels as a global challenge.

FACTORS FAVOURING DETERIORATION OF MATERIALS

The process on biodeterioration is supported on supported on sveveral factors which is a complex interplay of the effect of climate or meterological factors, biological process and chemical processes. The major environmental factors involved in the deterioration of materials include:

- Moisture
- Temperature
- Solar radiation
- Air movement and pressure
- Precipitation
- Chemical and biochemical attack
- Intrusion of macro-microorganism

Moisture:

Moisture and temperature affect the chemical, biological, and mechanical processes of decay. The formation of a moisture layer on the material surface is dependent upon precipitation. It may also be generated as a result of the reaction of adsorbed water with the material surface, deposited particles with the material surface, and deposited particles with reactive gases.

Relative humidity:

Among climatic factors, humidity plays the most important role in outdoor metal corrosion. In the absence of atmospheric moisture, there will be very limited non pollutant-induced and pollutant-induced corrosion. The rate and nature of the corrosion is a function of relative humidity, sunlight radiation, surface contaminants, the properties of the film of electrolytes formed on the metal surface, and the duration of the effect on the metallic surface

Temperature:

Temperature affects the processes of deterioration of a material gradually and in a variety of ways. Changes in temperature induce a thermal gradient between the surface layer and the inner layer of materials (particularly in materials with lower thermal conductivity), which may result in the degradation of the Mechanical properties of the material land can lead to the formation of fine cracks. The formation of cracks is accompanied by a loss of strength and by an increase in material porosity, which may lower the chemical resistance of the material.

Solar Radiation:

Solar radiation causes temperature changes in materials and may induce volume changes of material in the pores due to expansion of water which is heated by solar radiation. Solar radiation plays an important role in photochemical reactions since it supplies the energy for the excitation or splitting of bonds in the reacting molecules. Adequate intensity of solar radiation at suitable wavelengths is an essential condition for photochemical reactions that influence the deterioration of different construction materials.

These natural factors continuously promote weathering and material decay including metal corrosion. There are four mechanisms involved in the deterioration of different materials and structures. An understanding of these would aid in evaluating the influence of the above listed environmental factors. They are:

1. Erosion
2. Volume change of the material
3. Dissolution of material and the associated chemical changes
4. Biological processes.

Erosion:

Can be described as continuous recession of a surface because of localized impact in an outdoor environment, suspended abrasive particles usally cause erosion of materials mostly by fine solid particles moving against the material surface by flowing fluids.

Changes in volume of the material:

This is a function of temperature, solar radiation and humidity. The contraction and expansion of a material caused by heat is influenced by temperature difference which is in the open environment and depends largely on time and degree of exposure to sun rays (solar radiation) and the direction the material surface faces. Volume variation occurs due to uneven distribution of moisture content on a material surface can be caused by rainfall, fog or wind, an attack of the material can be caused by differential moisture content through the layer of a homogenous material since the side with a lower moisture content will expand less than that with a higher moisture content.

Dissolution of material and the associated chemical changes:

Chemically induced damage involves dissolution, oxidation and hydrolysis. The damage will occur as a result of the interaction between the material and natural constituents, chemicals and amount of water present. The interactions will vary depending on the reactivity of the material, the character of the intercepting surface, the exposure time and the nature of the contaminants. The chemical changes are enhanced by heat (most chemical reactions proceed more rapidly as the temperature increases). Therefore chemical changes occur more in one climate.

The dissolution of building materials especially structures with carbonate is most frequently caused by the action of acidic solution such as rain which contains carbonic acids or both carbonic acids and sulphuric acids. The effects of these acids is weathering of a surface. Oxidation of a material by atmosphere oxygen results in the chemical changes in the formation or composition of the material (especially surface) e.g. reaction of metal ions with oxygen to form oxides or hydroxides. Hydrolysis can cause the dissolution of a material or cause a chemical change in its composition simply by a reaction between a material and water.

Biological processes:

Biological factors cause deteroiation through biochemical effects and intrusion of organisms. The former is a crucial or essential factor in biodeterioration of building structures as the metabolites (enzymes, excrements or feaces) of micro and macro organisms, plant and animals living in a material can cause chemical damage of the material. Fungi hyphae, lichens and plant root systems which spread through structures can induce a mechanical damage. Also, boring insects may destroy structure cohesion which can encourage water penetration more quickly and deeply facilitating other deteriorating processes

BIODETERIORATION OF MATERIALS: EFFECTS OF MICRO & MACRO ORGANISMS

Myriads of micro and macro organism cause chemicals, physical changes as well as mechanical damage to materials. Relative humidity, temperature levels and other parameters determine whether these organisms flourish or exist at all. Microorganisms can cause damage through a range of processes.

1. Enzymes secreted by these organisms can be catalysers of chemical reactions that stimulate an attack on the material
2. Microorganisms may utilize products of this reaction e.g. (corrosion products) or use certain product of the materials as source of carbon and energy.
3. Chemical damage which is also important may arise by excretion of acids. These acids are capable of chelating metal ions
4. Stone and wood may be damaged when they serve as substrate for some higher animals
5. Bushes and trees are observed on buildings. They can cause mechanical and chemical deterioration on constructions. During growth, plants and roots generate high pressure which may damage buildings
6. The humic acid present in roots systems attack carbonate compounds.

The bacterial chemical action constitutes the major risk for the deterioration of stone. Especially harmful are those bacteria that obtain carbon from carbondioxide or energy from light or by chemical redox reaction. Some are capable of utilizing inorganic compounds e.g. sulphur and nitrogen to produce sulphuric and nitric acids. These acids influence the pH of the environment where they live and cause damage to various stone structures. Example of a bacterium that uses the oxidation of hydrogen sulphide and sulphur as an energy source and converts this form of sulphur to sulphuric acid are the species in the genus Thiobacillus.

Sulphate reducing bacteria having the unique ability to convert sulphate to produce sulphites as metabolites are well known for the damage they cause to metals. *Desulfovibro vulgaris* and *Desulfotomaculum nigrificans* produce H_2S that induce this corrosion on different systems. Examples of systems that can experience corrosion include oil and gas pipelines, gas distribution systems and sewage systems. Sulphate reducing bacteria use sulphate ions from the surrounding micro environment as an oxygen source for the oxidation of metals. The catalysers of this process are the enzymes of the bacteria. The product of redox reactions in these processes is sulphide which is released. Microorganisms will support the corrosion of metals using corrosion products.

Bacteria may lead to a change in the physical characteristics of the wood e.g. permeability and absorptibility which can lead to loss of strength. Some bacteria such as those belonging to the genus cytophaga are highly specialised in the only substrate they can use as a carbon and energy source is cellulose. They can completely destroy the structure of cellulose fibres. These bacteria are highly distributed in soil, continental waters and seawaters.

Assignment: As a microbiologist discuss bio deterioration as a societal menace.

The genus Clostridium is involved in anaerobic decomposition of cycles. Likewise Actinomycetes play an important role in the decomposition of organic materials. This group of bacteria usually a unicellular mycelium with long branching hyphae that attack substances such as cellulose, hemicellulose, chitin, certain and decompose lignin. They occur in both freshwater and salt water and soil.

Algae are another group of microorganisms that grow in the water film, on the stone surface and deteriorate it. They are also found in buildings. They have also been found on limestone and sandstone as well as historical objects. Algae also attack stones by exhaled CO_2 which in the presence of water supports the dissolution of the carbonated components of stone. Again, mechanical deterioration of stone occurs if algae develops to an extent that the multicellular colonies generated increases the pressure on the walls of the pores thereby damaging the stones. Some algae living within the stone may contribute to this aggregation of the stone.

FUNGI:

Most fungi are organisms with mycelium as their vegetative structure. Fungi can destroy the structural integrity of a material mechanically and chemically. Mechanical damage to stone, concrete and other building materials is caused by the intrusion of the hyphae into the structure and by the contraction and expansion of the mycelium with changing humidity. Mechanically, the hyphae grow into the structure. The fungi can colonise and form a film over the surface of the stone which blocks the pores. Any moisture that does penetrate through the stone will dry out more slowly which makes the material stay wetter for a long period which enables dissolved salt to penetrate more deeply. Wood destroying fungi induce several types of decay ranging from the formation of mycelia on the wood surface to destruction of wood and rot. Notably each species of fungus may attack different parts within the wood. Examples of the class fungi that can cause biodeterioration include

- Basidiomycetes
- Ascomycetes and
- Deuteromycetes

LICHENS:

Excrete organic acids that attack materials and produce compounds such as salts of salicylic acid and tartaric acid which also degrade carbonates in an alkaline medium. Lichens have hyphae that can grow through the pores in stones. After absorbing water, they enlarge considerably in volume and affect the wall of pores by applying pressure on them. Lichens are extremely sensitive to gaseous sulphur compounds which account for their rare occurrence in polluted areas.

MOSSES:

Often grow on the surface of stones that are covered by humus. They have the ability to absorb large quantity of water and they also produce organic acids.

Pests attack wood in the soil, water and also in the ambient air. Here are different types of insect such as ants, termites, beetles and insects that frequently cause great damage to materials. Insects cause a loss of wood strength and in some extreme cases they result in the collapse of structures.

BIODETERIORATION CONTROL

Biodeterioration is a worldwide challenge, several control measures have been applied to prevent biodeterioration. These include:

- The use of fungicides
- Biological control
- Prevention of biodeterioration by control of environmental conditions
- Periodic cleaning of dirt, dusts and spores
- The use of radiation

All of these issues are related to understanding the risk-benefit relationship of each treatment, relative to the materials or object in question.

In general, one needs to use extreme care in altering the environment conditions surrounding an object, restrict the use of any active chemical toxins and text how or whenever possible, the treatment on similar materials before applying a treatment reported allegedly to be safe.

For insect control, the use of Anoxil treatment represent the safest method currently available to control insect on wood, museum objects and food.

Fungal infection of materials can be controlled by drying proper cleaning and storage at 50 – 60% relative humidity. In the museum at constant temperature, there is little chance for most fungal spores to germinate. This seems to be due to the fact that the spores will not enter dormancy. If spores are frozen and dried, they may enter a dormant state and thus will be potentially viable years later.

Microbes can persist in dry environment. Active metabolism, however requires appropriate levels of relative humidity and temperature. A combination of low humidity and low temperature is the simplest way to control microbial growth but this treatment may be less effective for control of fungi and it is impractical in outdoor situations. Regular cleaning may be the most effective treatment for preventing biofilm formation and subsequent biodeterioration of materials such as historic buildings, monument and other materials.

BIOCIDES:

The application of biocides has become a routine, a practice in the conservation of materials. Biocides are chemical substances designed to inhibit or prevent the growth of microbes when applied or surfaces. However environmental issues have severely limited the number of available infective biocides or subsidal biocides used in the conservation of materials. Biofilm bacterial respond differently to biocide and are generally more resistant than unattached cells. Because microbes are capable of rapidly acquiring chemical resistance, no single chemical can be relied on for long term use. Frequently or most times, several chemicals need to be combine in order to achieve effective eradication of biofilm population. Biocides are very difficult tools for preservation because many are too caustic for environmental use. They are not strong enough to discourage microbial growth or the microbe ultimately develop resistance.

CONSOLIDANTS

They have been used over time to conserve archaeological stones, rocks or building surfaces from biological and chemical weathering consolidation is a means of generating structural strength in disintegrating materials and it is an artificial means of repairing the damage caused by natural processes.

The efficacy of consolidants on outdoor stones is controversial because they can distort or upset the natural saturation and evaporation of moisture from within the stone often resulting in exfoliation and cracking of stone surfaces.

Some consolidants may also discolour as they degrade because of aging, photochemical processed and oxidation. However, the addition of biocides to consolidants would help to prevent microbial deterioration, increasing the longevity of the treatments. More preferably, environmentally acceptable biocides should be used as additives in consolidants.

Some scientists have divided the control of biodeterogens into two methods, which are direct and indirect methods: the indirect methods involves modification of the climatic parameters of the surrounding environment which include; humidity, light, temperature and nutrient sources. These can be relatively possible for indoor sites or indoor materials while it is only partially applicable for outdoor materials e.g. (by avoiding the direct rainfall, wall surfaces, roofs and surfaces).

The most widely used direct method consists of:

- Biomass removal (mechanical method)
- Use of lamps with wavelengths that are non-compliable with the photosynthetic activities of biodeterogens (physical method)
- The application of compounds with biocide activity or consolidants (chemical method)

DRYING AS A MEANS OF CONTROLLING FOOD BIODETERIORATION

Drying is one of the oldest methods of food preservation against microbiological spoilage as well as bio-deterioration. Drying helps to maintain the edible status of food and also extend their shelf life (life span). The required level of moisture content to prevent spoilage achieved in a drying process depends on the microbes prevent. Sometimes pre-drying operations such as osmotic dehydration, evaporation are employed to reduce water concentration to the desired level. Drying usually refers to the process of liquid water being evaporated from the surface of the product or from the pores within the product. Sometimes additional heat is usually required to accelerate the drying process. The heat can be supplied in many ways:

- Solar energy
- Microwave or
- Hot gas strain

  They are two different types of drying processes which are in-air or in-vacuum drying.

For the vacuum drying, they are useful to remove water vapour when the products are best treated in the absence of air and where relatively low temperatures are preferred.

AIR DRYING

No matter the mechanism of heat - supply, e.g. microwave, radiation or conduction. Air is frequently used as the medium to remove water vapour from the moist material. It is slow process although air flows with a high velocity relative to the food product being dried are employed to increase mass and heat transfer. Hot air drying is the most common method used in the industries.

FREEZING

Freezing is an effective preservation technology because of the role of temperature in bio-system stability and the reduction of moisture levels within foods after freezing and during frozen storage. Both factors combine to significantly slow down the chemical, physical and biological reaction that governs deterioration of food. The process of freezing involves the removal of heat from a food material accompanied by physical change as liquid water becomes solid ice.