DETERIORATION OF MATERIALS BY MICROORGANISMS

Dear students welcome for the lecture series on Industrial microbiology, the topic for today's discussion is Deterioration of Materials by Microorganisms.

Biodeterioration can be defined as the breakdown of food by agents of microbiological origin, either directly or from products of their metabolism. Microbiological sources can be present in foods prior to packaging or on the surfaces of packaging materials. The shelf life and safety of the food will depend on the type and quantity of microorganism, as well as the hurdles to their growth offered by various preservation techniques.

The topic is divided into following modules,

- **BIODETERIORATION OF WOOD**
- **BIODETERIORATION OF PAPER-PULP**
- **BIO DETERIORATION OF TEXTILE**
- **BIODETERIORATION PAINTED SURFACES, RUBBER AND LEATHER**
- **BIODETERIORATION OF ORGANIC MATERIALS AND ITS EVALUATION**

I. BIODETERIORATION OF WOOD

Wood is by far, the most versatile and beautiful building material available to man. It has been with us since man first started to build his own shelter. And yet, it is also the only building material that is subject to destruction by biological agencies, such as fungi and insects. This is one of the inherent disadvantages of using wood as a building material.

Wood is a natural plant material, and as such, is made up of a host of organic compounds, many of which represent a food source for the attacking agents. Wood is made up of cells, which are in turn, made from cellulose (and often strengthened with lignin deposits). Cellulose is a rich source of carbohydrate

Agents That Attack Wood

Wood is actually a very inert material, i.e., it does not go into chemical reactions that will actually destroy the material. It is surprisingly immune to acids, alkalis, and strong detergents. This, in fact makes paper making a tough proposition as wood is not easily converted to pulp by chemical means.

Bacteria and viruses also do not have any significant effect on wood, although it has beenrecorded that certain bacteria do destroy wood in the end. However, it must be noted that these attacks are mostly secondary in nature, i.e., something else did the first bite for both fungi and insects. They have evolved elaborate mechanisms forthe digestion of cellulose. The cellsalso contain other compounds, suchas starch, which is also a source ofcarbohydrate for these attackingagents. In other words, when an insect attacks a piece of wood, it is merely having a meal.

Pulp-wood represents the wood which is used to manufacture paper. It has been estimated that almost about 10% of all the paper-wood cut is deteriorated by the action of microorganisms, particularly fungi.

Temperature and moisture together with an appropriate availability of oxygen play an important role in growing the fungi to deteriorate pulp-wood. Basidiomycetous fungi are responsible for “white rots” and “brown rots” of pulp-wood. This classification of rots is based mainly upon the constituent of the wood that is attacked.

If one finds white rotten patches on the pulp-wood surface, it characterizes the degradation of brownish lignin leaving a white spongy cellulosic mass in the wood. Contrary to it, if there are brown rotten patches, they are the result of preferential microbial deterioration of the cellulose leaving behind a brown pinky mass predominantly of lignin.

When the moist pulp-wood is stored, its surface is attacked and degraded by some ascomycctous and deuteromycetous fungi. This degradation is characteristically called “soft rots”.

II. BIODETERIORATION OF PAPER-PULP:

As we know, the raw material, e.g., wood, cotton, linen rags, etc. are treated physically or chemically for the purpose of separating and purifying cellulose fibrous in the form of fibrous pulp. This pulp is generally called “paper-pulp”.

Those paper-pulps which are prepared by chemical treatments generally possess less nutrients for microorganisms and hence are less susceptible to microbial attack than the physically (mechanically) prepared paper-pulps.

However, microbial degradation of the paper-pulp may be encountered in the form of “paper-pulp slime” spots on the finished paper sheet. Paper-pulp slime is produced by the deposition of microorganisms and the subsequent enlargement of fibre, fines, and other debris from the water and compounds of the paper-making medium.

Bacteria, yeasts, moulds, algae, and protozoa have been isolated from pulp slimes. Bacteria, particularly capsulated bacilli such as Enterobacteraerogenes and Bacillus

spp. represent the most important group of pulp slime producers. Sphaerotilusnatans, the filamentous iron bacteria, can be found as part of the slime mass on those paper machines operating above pH 5.5.

The bacterium Alcaligenesviscosus var. dissimilis has been obtained from pink pulp slime. Species of Mucor, Penicillium, Trichoderma, Fusarium, and yeasts (Torula, Rhodotorula) are the fungi that have been isolated from pulp slimes in various paper-making industries.

Finished Paper:

Finished paper, i.e., the paper-sheet which is prepared by the refinement and fabrication of paper-pulp is also attacked by microorganisms. Various fungi (Penicillium spp., Aspergillus spp., Chaetomium, etc.) and bacteria are the main attackers as cellulose, the main constituent of the paper, is susceptible to them.

They may cause black, brown or yellow discoloration and spotting through “mildewing”. Glue or casein, the other constituents of the paper, also serves as substrate for certain microorganisms. This is the reason why some chemicals are generally added to the surface of the paper-sheet to avoid microbial attack.

However, the microorganisms produce certain chemicals during their metabolism and these chemicals cause staining or decolouration of the paper-sheet. Growth of cellulolytic microorganisms may result in either weakening of fibres, perforations and/or even complete destruction of the finished paper.

III. BIO DETERIORATION OF TEXTILE

Fabrics, that comprise the largest group of textile products, differ from one another in their composition, which varies according to their use. Many factors that define the fabric composition, e.g. thread thickness, product thickness, linear density, etc., affect the rate of deterioration. These factors determine the area that is attacked by microorganisms. Moreover, some additive substances added to fabrics during the process, such as adhesives, finishes and dyes, can affect the biodeterioration, i.e. they either accelerate or delay it. The most important factors are, however, the composition and origination of the textile raw materials. It is known that natural fibres and fibres based on natural raw materials are more easily and rapidly affected by biodeteriogens than synthetic fibres, this depending on the accessibility to deteriogens of essential nutrients in the material.

The external conditions under which at first raw material, then processed product and finally finished product are stored are equally important for biodeterioration, determining whether microorganisms can grow on a fabric or not. Microbial growth naturally

depends on their physiological and biochemical characteristics, as well as the availability of nutritive substances and appropriate physical conditions. The rate of deterioration and the degree and kind of damage depend on a combination of important factors, each of which has an effect on biodeterioration, viz. the temperature, the environmental relative humidity and the moisture content of the material, light intensity, and the reactivity and nature of the material.

The progressive changes occurring during natural ageing of material are also important. They are affected by external factors as well as the structure and kind of material. The ageing process leads to irreversible changes of a destructive character, which are the result of oxidation, hydrolysis and fission of polymer chains. It results in degradation of the material, manifest as decreased molecular weight and strength, increased solubility and altered crystallinity. After such changes, the fabric becomes more susceptible to biodeterioration; this factor is especially relevant in the case of historically important fabrics.

Biodeterioration of fabrics and other textile products becomes evident as surface changes, most often discolouration, and associated unpleasant odours. The chemical changes occurring with the growth of microorganisms result in decreased fabric strength and lead to partial or total destruction of the material. Methods of limiting the attendant economic losses and protection of both raw material and final product are therefore required. Biodeterioration of different types of fibres, both natural and synthetic, from which textiles are produced, and methods of controlling such biodeterioration, are now considered.

Textiles and cordages are susceptible to spoilage by certain microorganisms in raw, processing and finished stages. Loss of millions of rupees is estimated annually due to attack of microorganisms on these materials. The microorganisms involved in these deteriorations include both bacteria and fungi.

Moulds are the principal microorganisms responsible for the deterioration of cellulose fibres resulting in discolouration and weakening of fibre strength. The most important among bacteria are the aerobic Bacillus spp., Proteus vulgaris, and some actinomycctes, whereas the most important among fungi are Myrotheciumverrucaria, Penicillium, Aspergillus, Alternaria, Hormodendrum, Cladosporium, Fusarium, etc.

Moulds are essentially more important deteriorants of cotton textiles and their growth is favoured by high humidity, moderate temperature and diminished light. The bacteria caused damage by their proteolytic enzymes in woollen material which represents a protein, namely, keratin.

The nature of spoilage of textiles and cordages can be categorized as follows:

(i) Discolouration of fabric strain caused by pigment-producing (chromogenic bacteria) or coloured spore-forming (dematiaceous fungi) microorganisms.

(ii) Loss of strength due to attack by microbial enzymes (Moulds on cotton fabrics and bacteria on wool).

(iii) Change in the pH of the fibre resulting in change in shade of the dye.

IV. BIODETERIORATION PAINTED SURFACES, RUBBER AND LEATHER

Growth of microorganisms on paintings may cause aesthetic and structural damage. As aesthetic damage one must consider pigment discoloration, stains, and formation of a biofilm on the painted surface, whereas as structural damage one must consider cracking and disintegration of paint layers, formation of paint blisters, and degradation of support polymers or of glues and binders resulting in detachment of the paint layer from the support. Of course, the two types of damage are strongly linked, and in the long run, structural damage profoundly affects the aesthetic quality of a painting. Conversely, aesthetic damage may precede serious injuries to the materials. For instance, in fungal colonization of mural paintings, Saiz-Jimenez and Samson have shown that, at the beginning, growth of fungi on a mural's surface caused only aesthetic damage since there was little or no alteration of the painted surface. Later on, fungal growth in depth occurred. Hyphae penetrated the painted layer, degrading some of its components (especially glues and binders), which resulted in a decrease in the cohesion of the painted layers, thus giving rise to exfoliations, cracking, and loss of the paint. To these damages one should add those inflicted by metabolites, often acidic in nature, and by extracellular enzymes excreted by microorganisms. These compounds may modify the colors as well as the stability of the painted layer and of the substrate.

Similarly, cyanobacteria and algae growing on paintings exposed to light, such as frescoes on the facades of buildings, may cause considerable damage. Besides the aesthetic damage caused by a green, black, brown, or yellow algal patina covering the painted portions, these organisms may cause weathering of the surface layers, accelerating detachment of portions of the painted layer as well as the underlying plaster. The presence in a number of Italian frescoes of species of nitrogen-fixing Nostoc indicates that cyanobacteria may colonize frescoes in which combined nitrogen may be absent. Indeed, in this investigation, determination of acetylene reduction in situ demonstrated that nitrogen fixation occurred, albeit at a reduced rate, in the microbial biofilm covering the frescoes. In addition, cyanobacteria and algae can provide an important source of organic material on which heterotrophic bacteria and fungi may thrive, thus causing further aesthetic and structural damage to the paintings.

Painted surfaces of the material are also subject to attack by microorganisms unless the paints contain effective fungicidal ingredients. Painted surfaces exhibit evidence of mould-spotting or discolouration under certain environmental conditions. This discolouration is due to products of microbial metabolism of organic constituents of the paint.

Many moulds such as Aspergillus, Penicillium, Pullularia, Phomuglomerata, Alternaria, and Cladosporium and a bacterium called Flavobacteriummarinum have been isolated from “mildewed” or “mouldy” painted surfaces. Pullularia spp. are considered to be the most common cause of mould-spots on painted surfaces.

Rubber:

Rubber is subject to microbial deterioration, particularly natural rubbers rather than the synthetic ones like neoprene. The deterioration is serious in electrical insulation of buried cables and in the sealing rings of underground sewage pipes where the seals can decay long before the concrete pipes themselves need replacing.

The organisms responsible are various fungi and actinomycetes. Some of the accelerators used in the polymerization of rubber, such as dehydroabietyl ammonium pentachlorophenate, can help to prevent decay because they have biocidal properties. To prevent this degradation some biocides may be added during manufacture.

Leather:

We all know that several microorganisms harbor the living animals. When the animals die and their skin is removed, the microorganisms continue to be present on the hides. When the hides are taken for processing, several changes take place in the micro-flora.

If the leather or hide is preserved by drying and salting, most microorganisms are killed. Contrary to it, if they are soaked in water to keep them soft, the microorganisms multiply rapidly. Sometimes, undesirable microorganisms multiply and spoil the leather.

Besides, bacteria, some species of Aspergillus, Penicillium, Cladosporium, etc. are known to attack the leather and cause hardening of it. The spoilage of leather goods is very common under warm humid condition. On account of microbial attack, various types of leather goods are deformed and spoiled.

Metal Corrosion:

Growth of several microbial species plays an important role in corrosion of metal pipes and result in serious problem particularly in oil and gas delivery systems. Bacteria such

as Gallionella, Crenothrix, and Leptothrix species cause metal corrosion in aerobic conditions by oxidizing metal and forming metallic oxides as corrosion products.

Thiobacillus species, the sulphur-oxidizing bacteria, produce high concentrations of sulphuric acid in acrobic condition that causes corrosion. But, aerobic corrosion is not as serious as anaerobic corrosion. Desulfovibriodesulfuricans, the sulphur-reducing bacterium, is especially important in the corrosion of metals in anaerobic conditions by causing graphitization.

Graphitization is a process in which a metal-pipe losses much of its metal, becomes soft and brittle, and easily broken. Anaerobic microbial corrosion of steel results in more localized pitting which, sometimes, cause perforation of the pipe.

Wood Deterioration:

Forests are among the most valuable of all our resources as they provide us wood which is used for various purposes.

The microorganisms cause decay of wood and there are two types of wood decay:

(i) destruction of lignin (or infrequently cellulose) resulting in white or spongy rotten wood. This type of instruction is mainly caused by Trametspini and Ganodermaapplanatum, and

(ii) destruction of cellulose resulting in brown, soft and easily powdered wood. This destruction is caused by Pliaeolus sp., Letinuslepideus, Serpulalacrymans, and Poriaincrassata.

Food Spoilage:

Air-borne microorganisms are often troublesome in our home and in industries where food and food-products are manufactured.

V. BIODETERIORATION OF ORGANIC MATERIALS AND ITS EVALUATION

Biodeterioration is an important factor impairing aesthetic, functional and other properties of leather and other biopolymers or organic materials and the products made from them. It takes place particularly under conditions of high relative humidity that enable bacteria, actinomycetes or fungi to grow. Since both those processing and those using these materials wish to prevent avoidable damage, considerable effort has been expended in developing objective methods of evaluating their biodegradability. These methods and procedures are based on the ability of microorganisms to utilize these substrates as sources of nutrition.

Micromycetes, or moulds, belong to the most dominant group of microorganisms responsible for the degradation of biopolymers and other organic materials. The methods used for the evaluation of biodeterioration caused by micromycetes have many variations, but we have used three basic methods:

(a) Naturally contaminated or artificially inoculated samples are incubated in a temperature-controlled chamber maintained at 28–37°C and 90–100% relative humidity (RH). After a period of time, usually 4–8 weeks, the degree of growth is evaluated, its intensity characterizing the degree of resistance or susceptibility to the microorganisms being tested. Subsequently, the degree of deterioration is evaluated by assessing physical or chemical properties, e.g. for changes in tensile strength, elongation, electric conductivity and chemical composition;

(b) Samples are buried in soil, where they are exposed to a complex biocoenosis of soil and climatic factors such as rain, temperature change, etc. Again biodeterioration is assessed in terms of changes of physical and mechanical properties; and

(c) samples are placed on agar medium lacking a carbon source and incubated under optimum conditions for 28–56 days. The mineral requirements of the test organisms can be met by using Czapek–Dox agar (CDA) minus its carbohydrate component. Antimicrobial treatment in the form of biocides can be applied to test samples prior to incubation on the agar medium.

In the above test methods, it is advisable to use those microscopic fungi which are regularly encountered under natural circumstances. The choice of strains employed is of primary importance for these tests, since different species and strains attack the materials to different degrees, depending not only on the specific composition of the substrate but also the specific physiological attributes of the given strain involved. Until now, mixed conidial suspensions of several fungal strains have been used as inoculum in tests for the evaluation of biodeterioration of leather and that occurring during the process of its manufacture (Fig. 1). Less frequently the conidia of one strain have been used. Since the advantages of using the one approach rather than another have not yet been objectively and unambiguously demonstrated, in our laboratory we carried out a series of experiments in order to find out how various mould strains behaved when in mixed inocula or when used alone.