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## Introduction

### DEFINITIONS

What *is* biodeterioration? The word has only been in use for about 40 years, but describes processes which have affected humankind ever since we began to possess and use materials. Many branches of science and technology either do not need or do not have an accepted definition in common use. We are all happy to think we know what physics is, but we have yet to agree what exactly constitutes biotechnology. Within biodeterioration we are fortunate to have a definition which was quickly accepted when first proposed by H. J. Hueck.

Hueck (1965, 1968) defined biodeterioration as '*any undesirable change in the properties of a material caused by the vital activities of organisms*'. Another term in common use is that of biodegradation. Although no formal definition has general acceptance, it may be useful to think of biodegradation as being '*the harnessing, by man, of the decay abilities of organisms to render a waste material more useful or acceptable*'. Both definitions involve humankind, in a negative or harmful way in the case of biodeterioration and in a positive or useful way in the case of biodegradation as defined here. Both definitions also involve materials. Materials are any form of matter, with the exception of living organisms, which are used by humankind. All materials (and processes) will have an intrinsic value and thus there is an important economic dimension to biodeterioration. This book seeks to introduce some of the interactions between living organisms and humankind's materials through the disciplines of environmental biology, materials science, and ecology.

The interaction among people, their materials, and living organisms has been recognized, if not fully understood, for a very long time. Some of the interactions are intimate, as in the case of gut parasites, body lice, or fungal

infections of the skin, hair, and nails. Others are not so close, as in the case of commensal pests, such as rats, thriving as a result of human activities. The relationships can be complex; a commensal rat may pass on more intimate insect parasites or bacterial and viral pathogens to a human population. In the case of pathogens there is usually a clear reaction from the living tissue affected, involving an attempt to limit or remove the pathogen, whereas in the case of detriogens of materials there is no such reaction. This is one of the fundamental differences which separates biodeterioration of materials from plant or animal pathology. In both biodeterioration and pathology, damage is caused in some way, and it is this damaging involvement of organisms which is considered here.

Many of early humankind's materials were derived from plants and animals, with minimum processing. Such materials were particularly vulnerable to attack by organisms, and biodeterioration may have played an important role in the ways in which early civilizations were able to develop and spread. What we now know as the Middle East is regarded by many as the 'cradle of civilization'. The climate is suited to the easy storage of grain, and such an advantage may have speeded human development in this region. Early control of biodeterioration utilized the basic principles which still hold good today. Food was either eaten fresh before any form of deterioration could occur, dried to minimize the growth of microorganisms, or physically protected from insects and rodents by use of sealed jars and bins. Salt and spices were used as preservatives. In the non-food area, early examples of control included the use of burning sulfur as a general fumigant and the use of copper sheeting on ships' hulls to provide a physical barrier to boring organisms.

In the world today, there is a bewildering range of materials. Many are complex and much changed from the original raw materials from which they were derived. New environments are, for good or bad, being exploited; roads and cities are being built in rain forests, structures are erected in seas and oceans for oil exploration and extraction, and high-rise office and apartment blocks take advantage of new building techniques. These new materials, their uses, and environments present biological problems, and together with the enormous range of organisms in the environment it is useful to classify the basic types of biodeterioration which can occur. It should be noted, however, that any such classification scheme is artificial, and one organism may cause more than one type of biodeterioration (see Figure 1.1)

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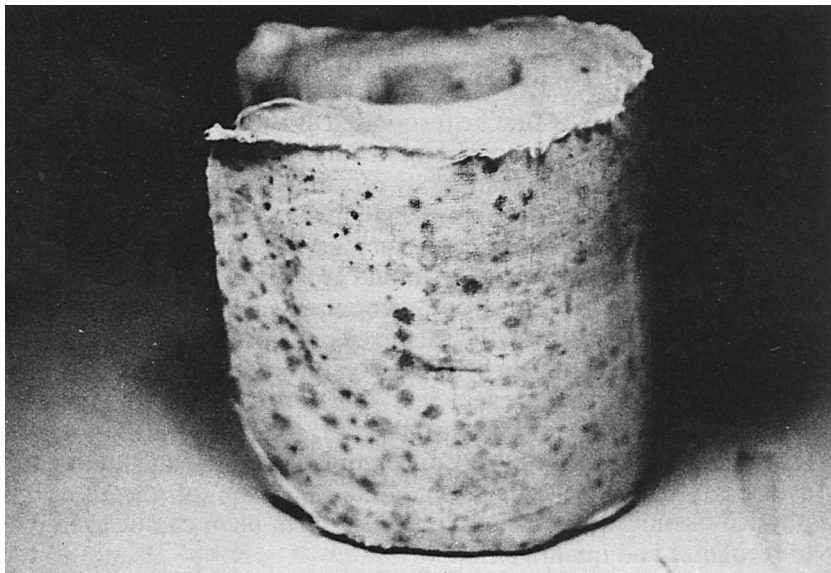
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**Figure 1.1.** Mould growth and staining on cotton wrapping of glass-fibre pipe insulation from a UK hospital. The mould is not only breaking down the cellulose of the cotton, but also causing disfigurement. Spores released into the air may also cause problems in a hospital environment. Photo: Dr K. J. Seal

**PHYSICAL OR MECHANICAL BIODETERIORATION**

In this instance, the organism quite simply disrupts or distorts the material by growth or movement and does not use it as a food source. There are few, if any, serious examples of such damage caused by microorganisms, but one which might be quoted is the expansion of microbial masses between rock layers, leading to spalling of the surface. Examples caused by higher organisms include the cracking of underground pipes by tree roots, the gnawing of electrical cables, cinder blocks, plasterboard, and wood by rodents, and bird strikes on aircraft. This latter example illustrates the point that biodeterioration is not necessarily caused by any 'conscious' process of the organism.

**FOULING OR SOILING (AESTHETIC BIODETERIORATION)**

Here, the objection is simply to the presence of an organism or its dead body, excreta, or metabolic products. Dead insects, moult cases, or

**Table 1.1.** Some problems associated with the presence of biofilms on materials

Biofilm location	Effects
Teeth	Tooth decay, caries
Medical implants	Antibiotic-resistant infection, weakening of implant material
Heat-exchanger tubes	Reduced heat transfer
Pipes carrying water or other liquids	Reduced flow, increased resistance to flow
Cooling towers	Reduced performance, degradation of material, provision of reservoir for pathogens (e.g., <i>Legionella</i> )
Drinking water distribution systems	Decreased water quality, increased treatment costs, health risks
Probes and sensors	Reduced efficiency
Ships' hulls	Increased fuel costs
Building materials	Reduced durability, discolouration
Food-processing equipment	Source of contamination, degradation of material, increased cleaning costs
Screens and filters	Loss of efficiency
Oil industry pipelines	Blockage and corrosion

droppings, even if in some cases not particularly harmful in themselves, can render foodstuffs unsaleable, especially in packages in developed countries. Microorganisms, especially fungi and algae, can be found growing on otherwise undamaged materials, utilizing surface dirt and detritus, but nevertheless detracting from the value or acceptability of the material. The classic example here is the dark fungal colonies growing on damp soap and skin residues on plastic shower curtains. The performance of the material is not affected, but the growth creates a generally unacceptable appearance. Many fungi may also release soluble or insoluble pigments and also a range of other metabolites which discolour on ageing.

Fouling can be more serious and transcend the category of purely aesthetic damage, in that a physical function can be impaired. The extra drag on ships caused by accumulations of weed and invertebrates on the hull can increase fuel consumption dramatically, and extra tidal stresses on marine structures such as oil rigs can be considerable.

In many cases, aesthetic biodeterioration is simply the presence of a surface layer of microorganisms and their products. These microbial

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layers are known as biofilms and are defined as surface accumulations of the organic products of biological activity. Generally, but not always, they include living microbial cells and, in this case, their presence may lead to the production of other classes of biodeterioration. Where the cells are in such close contact with the material, rather than merely dispersed in the surrounding environment, destructive cell activities are localized and concentrated and the resulting effects far more damaging. The best studied biofilms are those on the teeth, and the results of bacterial activities in these biofilms are well recognized by the layperson. Other damaging effects of biofilm presence are, however, less well understood. Some of these are shown in Table 1.1.

**(BIO)CHEMICAL ASSIMILATORY BIODETERIORATION**

This is probably the most easily understood form of biodeterioration. Quite simply, the organism is using the material as a food or energy source. Microbial enzymes breaking down cellulose, rats and insects eating stored grain, and insect larvae consuming stored fruit are all examples of this type of biodeterioration.

The consumption of human foodstuffs by detriogenic organisms is in the main recognized and understood by most people, it is the variety of the microbial diet which can cause problems. The fact that materials such as hydrocarbon fuels, cutting oils, adhesives, sealants, textiles, and other 'non-food' items can be utilized by microorganisms is often not realized and can lead to delays in establishing the cause of problems.

**(BIO)CHEMICAL DISSIMILATORY BIODETERIORATION**

In this instance, a material suffers chemical damage, but not as a direct result of the intake of nutrients by the organism. Many organisms excrete waste products, including pigmented or acidic compounds, which can disfigure or damage materials. This type of biodeterioration often goes hand-in-hand with chemical assimilatory biodeterioration and biofilm development, and the effects may be difficult to differentiate.

**THE RANGE OF DETERIOGENS**

No special criteria exist which debar any organism from being an actual or potential detriogen, except obligate parasites, which gain their nutrients

from the living tissue of their host (living tissue is not a 'material'). Such parasites, however, may well be associated with deteriogens (e.g., the rat flea). The range of potential deteriogens is therefore huge, although with many organisms the deteriogenic effects are a minor incidental part of their activities as a whole.

### CYCLING OF ELEMENTS

Within the biosphere, elements are constantly recycled. The reader will be familiar with the carbon and nitrogen cycles, and it is possible to propose cycles for other elements, although some (e.g., sodium) are present in the environment in such huge quantities as to make the effects of living organisms insignificant. Figure 1.2 shows a simplified carbon cycle with both biodeterioration and biodegradation taken into account. The carbon cycle is strongly biological, and its main feedstock is the carbon tied up in the cellulosic components of higher plants. The ultimate fate of all cellulosic materials used by humans is to be either burnt or broken down by organisms, and the prevention of biodeterioration is thus delaying the natural decay processes which would normally affect the materials if they had not been abstracted from the environment by people for their use. The biodegradation of wastes can be regarded as the opposite process: a hastening of breakdown of materials complementary to natural processes in the environment.

### RECOGNITION AND COSTING OF BIODETERIORATION PROBLEMS

Cases of biodeterioration must first be recognized as such before any economic costs can be attributed to them. Some cases of damage to materials are obviously of biological origin. Holes gnawed by rats in woodwork, drains blocked by weed growth, and pigeon droppings disfiguring ledges of buildings are all obvious examples. Less certain are cases such as the appearance of fruiting bodies of fungi on rotten woodwork and mould growth on foodstuffs. There is obviously a problem, but not everyone recognizes such 'growths' as living organisms. Cases of microbial growth well mixed or dispersed in materials, such as bacteria in cutting fluids, fungi in hydrocarbon fuels, and the spotting of paint films by microfungi and algae, are less easy still to recognize and appreciate, owing to the small size of the organisms involved, their unfamiliarity, and the fact that the substrate is chemically very different from animal and human foodstuffs.



Instances such as microbially induced corrosion of metals, in which separate physicochemical mechanisms may also be in play, can be even more difficult to recognize and quantify.

Even if damage to materials is recognized as being biological in origin, it may not be listed as such in routine reports, being simply classed with other types of losses as 'spoilage' or 'wastage'. Evidence of the true cost of biodeterioration is therefore often hidden or disguised. Recognized biodeterioration may be costed in a variety of ways.

### **Cost of prevention**

Where materials are known to be at risk, preventative measures can be taken from the outset. These measures may be physical, such as drying or cooling, or chemical, such as the addition of a biocide or preservative. The costs of such measures can be assessed for individual products by a producer or user, and, on a more general level, the turnover of a 'prevention' industry or firm such as a biocide manufacturer can be used as an indicator of the cost of biodeterioration in a particular field.

### **Cost of replacement**

The number of materials, especially in the more developed countries, which can be classed as 'cheap' is dwindling rapidly, but where low-cost materials are used, the replacement cost can be used as a guide to the cost of biodeterioration. All other considerations being equal, if the cost of replacement exceeds the cost of prevention, the wrong strategy is being employed.

### **Cost of remedial measures**

Any decision to apply remedial measures to restore a material to near its original condition hinges on the cost and practicality of such work as opposed to that of replacement, always assuming that a replacement is available.

The best examples of true remedial work are those carried out on costly or unique items such as museum specimens and archival items, for which prevention or replacement is not possible. Such work is usually very costly, and true remedial work is uncommon on everyday materials.

### Cost of litigation

Occasionally, the biodeterioration of a material will be due to neglect on behalf of one or more parties in the chain of production/supply leading to another party's seeking recompense through the law for loss of value. This can result in the employment of expert witnesses, analytical laboratories, and lawyers to find the cause of the problem, apportion blame, and decide on the level of compensation which may go far beyond the value of the lost goods.

In the life of some materials the costs of biodeterioration may come from all these basic areas, initial preventative measures, remedial measures during the use of the material, and eventual replacement. Anyone with wooden window frames will appreciate this. There is no single universal scheme for the costing of biodeterioration. However, there are certain exercises which can be carried out to reach very approximate global figures and at least show that biodeterioration can cost significant sums of money.

### A broad calculation

1. Select types of materials with known susceptibility to biodeterioration. These would include timber, paints, adhesives, natural-fibre textiles, paper and packaging materials, and stored foodstuffs.
2. Estimate a percentage of loss which would be assumed to be reasonably attributable to biodeterioration. Some stored or in-transit foodstuffs in the tropics may have losses of around 90% of the crop. To arrive at a figure which is beyond argument, decide on 1% (faced with this problem, most people decide on 5%–20%). Is it not reasonable to say 1% of all timber used fails prematurely because of biological attack?
3. Find the annual value of goods produced, whether locally, nationally, or on a world scale.
4. Take 1% of this figure. However approximate this calculation is argued to be, a large sum of money is involved.

This figure gives an indication of the importance of prevention of biodeterioration.

In the following chapters, biodeterioration is divided into sections on materials in which relevant organisms and control measures are described.

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Principles of control are covered in a separate chapter, as are recent developments in detection and research methods.

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