MiSAC matters
MICROBIOLOGY IN SCHOOLS ADVISORY COMMITTEE
50th Anniversary Articles

Landfill disposal of domestic refuse: what a load of rubbish!

John Grainger

Some 30 million tonnes of domestic solid refuse and waste from commerce and industry are generated each year in the UK. The material is dealt with by disposal to landfill and by composting, incineration and recycling of which landfill is the mostly widely used. Landfill sites are constructed either as heaps on open land or by filling exhausted gravel and sand pits with the long-term aim of beneficial re-use for building, agriculture or recreational purposes.

The components of refuse differ markedly from country to country and also change over time with new developments such as the use of plastics and synthetic textiles, introduction of electronic devices, increased attention to glass and metal recycling, and separate treatment of garden and food waste. An example of the composition of domestic refuse in the UK is given in **Figure 1**.

Component	Weight (%)
Paper, card and wood	22.7
Food	17.8
Garden	14.2
Plastics	10.0
Glass	6.4
Metal	4.3
Textiles	2.8
Non-combustibles	2.8
Combustibles	2.5
Other	16.5

Figure 1. Example of the composition of UK domestic refuse

The major biological activity in landfill takes place in its depths through the digestion of biodegradable components by microbes that grow anaerobically, *i.e.* in the absence of oxygen, though a contribution is also made in the surface layers by aerobes, *i.e.* those that require O_2.

The various components of refuse differ in their susceptibility to microbial degradation. For example, putrescible food is more readily degraded than are paper, card and wood which contain cellulose and lignin. In the UK the large majority of all the plastic material manufactured is eventually disposed to landfill but only some types are degradable and then only very slowly. Estimates of the time taken for plastic bags and bottles to be degraded in landfill range from 10 to 500-1,000 years depending on their composition. Government actions to discourage landfill and address the overall environmental problem caused by used plastic containers are now being accompanied by merchandiser initiatives such as using starch-based biodegradable plastics as wrapping materials. In addition, there is an increased interest in research on microbial degradation of plastics (see Article: *Time for the plastic eating fungus?* – G Robson & D Moore).

Landfill sites as bioreactors

Micro-organisms are grown on an industrial scale in large vessels called bioreactors. The purpose might be, for example, sewage treatment or for making such products as beer, mycoprotein or antibiotics in the more carefully controlled conditions provided by fermenters. Although different from these examples in many ways, a landfill site is a form of bioreactor controlled by the same basic principles that govern microbial growth and activities.

The major factors which affect microbial activity in landfill are aeration, moisture, temperature, pH value, nutrient supply, extent of mixing, the types of microbes naturally present on the refuse and time. Anaerobic conditions are achieved by mechanical compaction of each day's layer of refuse, supplemented by removal of remaining oxygen by growth of moulds and other oxygen-

requiring organisms. Moisture levels are dependent on rainfall, draining of which through the site also influences migration of micro-organisms and products of their metabolism and collects at the base of the site. Temperature is controlled by environmental conditions and is elevated by energy released from microbial activity. Time-scales are measured in years.

A mixed community of anaerobic microbes is responsible for a process that consists of three physiologically different sequential stages, *i.e. fermentation*, *acetogenesis* and *methanogenesis* (**Figure 2**). The end products which attract particular attention are biogas, *i.e.* methane (CH_4) + carbon dioxide (CO_2), and 'leachate' which is the term given to the liquid, containing volatile fatty acids (VFAs), *e.g.* butyric acid, and other products of microbial metabolism, that accumulates at the base of a landfill. The design of a landfill site includes incorporating wells and pipes for the controlled evacuation of biogas and sealing the base with compacted clay or other Impermeable material to prevent leakage of leachate into surrounding land and watercourses. However, there are many old, closed sites which were established before these design features were required.

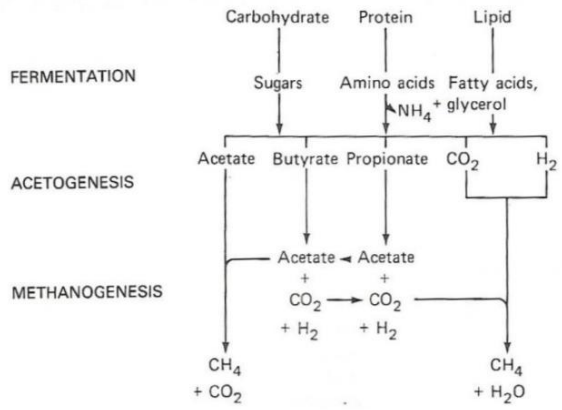

Figure 2. Pathways of methane generation

Landfill microbiology

During *fermentation*, *Clostridium* spp. and other anaerobic bacteria convert carbohydrates, proteins and lipids to sugars, amino acids and fatty acids, and then to acetate, butyrate, propionate, hydrogen (H_2) and CO_2. Naturally-occurring mixed microbial populations often interact with each other in ways which would not occur in monoculture. For example, H_2-utilising bacteria remove H_2 produced by other bacteria which would otherwise reach inhibitory levels. Similarly, end product inhibition of cellulose degradation caused by accumulation of cellobiose, a di-saccharide intermediate in the conversion of cellulose to glucose, may be relieved by another organism which produces a β-glucosidase enzyme.

In the *acetogenesis* stage specific groups of bacteria convert VFAs, principally butyrate and propionate, to acetate, CO_2 and H_2. This is followed by *methanogenesis*, the slowest of the stages, in which acetate is converted to CH_4 and CO_2, and H_2 is combined with CO_2 to form CH_4 and H_2O. Methanogenesis is accomplished by a group of morphologically diverse organisms known as methanogens, *e.g*. *Methanobacterium*, which are members of the *Archaea* (archaebacteria).

A similar series of stages that produce CH_4 also occurs in lake mud, the first stomach of ruminants, *e.g.* cattle and sheep, where products are crucial components in animal nutrition, and sewage treatment works where biogas produced by anaerobic digestion of sludge separated after aerobic treatment is used to generate electricity. In agriculture, anaerobic digestion of slurry is now being actively developed as a possibly significant contributor to improving sustainable farming.

The large capacity, high solids content, absence of mixing and consequent uneven distribution of moisture that characterise landfill sites contribute to slower microbial activity than in the fluid, mixed contents of the rumen and anaerobic digesters at sewage treatment works. Effects on microbial activity of differences in moisture content resulting from lack of mixing can be demonstrated by studying samples taken from layers of a landfill core. For example, Grainger *et al*., (1984) showed that the higher levels of amylolytic, proteolytic and cellulolytic enzyme activity were recorded in the surface layers, where moisture levels were maintained by rainfall, but decreased progress-ively as moisture levels decreased with depth. Marked increases in activity were observed again in samples taken at levels near to and within the

residual fluid, *i.e.* the leachate, at 7-10 m core depth. Parallel increases were observed in VFAs produced from products of these and other enzymatic activities and in the subsequent yields of biogas. Molecular methods that are now used in ecological research enable the amounts and identities of microbes in landfills and their locations and interactions to be studied more precisely.

Environmental concerns

Biogas extraction from landfills on a commercial scale began in the UK in the 1970s with gas being piped to local factories for firing kilns and furnaces, heating steam boilers or generating electricity. However, 20 years later the debate on combating global warming drew attention to the consequences of uncontrolled release of biogas from landfill sites because as a greenhouse gas CH_4 is some 30 times more potent than CO_2 and also presents a fire hazard. These concerns together with a decrease in availability of suitable locations for new sites led to European Union and national legislation aimed at reducing the use of landfill sites and increasing other means of disposal and recycling.

Although the amount of refuse disposal to landfill is being reduced, a responsibility remains for the management of existing closed and active sites. After closure, sites are capped with a cover such as clay and an impervious membrane overlain by a layer of soil for a period of restoration during which release of biogas can be controlled through a series of wells and pipes. Restoration may last for decades during which time microbial activity continues until it has decreased sufficiently for permission for re-use to be granted. Monitoring of stability, biogas release and quality of nearby ground water is maintained throughout restoration. The standards required and therefore the length of the restoration period depend on the nature of the intended development, *e.g.* more stringent limitations are applied for building purposes than for recreational use. Concern is also being expressed about the possibility of contamination of soil and water with small particles released during the long, slow degradation of plastic materials.

Further reading

Kuntin D (2018) How to reduce your lab's plastic waste. *The Biologist* **65** (6) 28-31.

Reference

Grainger J M, Jones K L, Hotten P M & Rees J F (1984) Estimation and control of microbial activity in landfill. In *Microbiological Methods for Environmental Biotechnology* eds Grainger J M & Lynch J M, pp 259-273. London: Academic Press.

AUTHOR PROFILE

John Grainger gained a BSc in Bacteriology at the University of Birmingham and a PhD in Microbiology at the University of Reading where he made his academic career becoming Head of the Department of Microbiology and then a Visiting Research Fellow. Alongside research interests in environmental microbiology he developed a parallel career promoting microbiology and biotechnology in schools, mainly through MiSAC of which he is Chairman and as Founder and former Director of the National Centre for Biotechnology Education. Work overseas included membership of the management board of the European Initiative for Biotechnology Education. He is a Chartered Biologist, a Fellow of the Royal Society of Biology (RSB) and has awards from the RSB and the Microbiology Society.