by Heijo Scharff

Sustainable landfills

Keeping in balance with the environment

There is currently no internationally accepted definition for sustainable landfills. What should be some of the criteria, what do they mean in practice, and how can they be achieved? A Dutch study delves into these issues for different types of landfills.

Modern waste management is based on a hierarchy of treatment and disposal strategies. The Dutch Sustainable Landfill Foundation (DSLF), whose research forms the basis of this article, acknowledges this hierarchy. Prevention, reuse and recycling should be favoured over disposal, and materials should not be landfilled if an alternative use is available that is practically, economically and ecologically more sensible.

But no matter how much prevention, reuse and recycling a society manages to realize, there will always be a role for landfills in an integrated waste management system. Primarily this will be in cases where prevention, reuse and recycling are not possible – that is, as a last resort. But landfills can be the best waste management option for particular types of waste such as materials contaminated with asbestos, soil treatment residues and inorganic sludge.

Landfills offer a 'safety net' for other waste management operations. In the event of temporary insufficient capacity, landfills can prevent waste materials remaining exposed to society. Landfills continue to perform this role as they have done in the past.

This means that landfills are a valuable and essential element of an integrated waste management system and should be recognized as such. Therefore, members of DSLF believe that a society striving for sustainable development needs sustainable methods for landfill.

Current landfill practice

In general, legislators consider landfill bodies to be 'black boxes' where various undesirable emissions occur. During operation, leachate and landfill gas (the two main types of landfill emissions) are collected and cleaned or utilized.

The 'black box thinking' has resulted in the practice of enclosing a landfill with an impermeable membrane as a precautionary measure. Emissions to outside the landfill will not occur if the landfill membrane remains intact. From this perspective, landfill containment seems to be an environmentally safe option – but this is not the full picture.

Landfills require a large investment and long-term commitment (especially in the maintenance and replacement of the landfill cap), and the potential for harmful emissions continues even when a containment strategy has been adopted. Contaminants may be released at some indeterminate point in the future.

Furthermore, according to the 'black box' approach, the characteristics of each batch of waste entering a landfill are evaluated individually. However, there is no evaluation of how *mixtures* of wastes behave in the landfill. This is a serious limitation when designing new landfill concepts that focus on minimizing emissions in the long term.

What is a sustainable landfill?

Sustainability has many aspects; these are not only environmental, but also economic and social. A development could be considered sustainable from an environmental point of view, but could be too expensive for a particular society and thus unsustainable in the long term. It is generally agreed that 'sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs' (UN Brundtland Committee). From this definition, it follows that each generation should solve its own problems. One generation is often considered to take a maximum of 30 years.

DSLF aims to develop sustainable methods for landfills so that they will achieve equilibrium with the environment as soon as possible, preferably within 30 years after the end of landfilling. This equilibrium means that the emissions from the landfill to the air, surface water or groundwater do not exceed acceptable levels. The term 'acceptable levels' means that the emissions no longer pose a threat to human health and the environment in any way. The emissions from such sites can be considered so marginal that an upper/cover liner is no longer essential. When in balance with its environment, the landfill's long-term risks are considered negligible and thus the landfill can be 'handed back to nature' safely. This would be the time to formally end aftercare. Further involvement with the site would depend on its ultimate use, but this could be minimized in a way comparable to park maintenance.

DSLF's research

From 2000 to 2005, DSLF investigated the processes that have a major impact on emissions and emission reduction. With a budget of €2.5 million, DSLF carried out laboratory experiments and field-based experiments using lysimeters, which bridge the gap between laboratory and full-scale field experiments. The results were interpreted in the context of the fundamental hydrological, biological and geochemical processes that occur in landfills and which are largely governed by the composition of the waste.

The research identified three types of landfills:

- landfills containing predominantly organic waste – biodegradation governs the pollution potential
- landfills containing hazardous waste: immobilization is an important mechanism to retain hazardous pollutants within the waste matrix
- landfills containing predominantly inorganic waste – solubility control and leaching govern the pollution potential.

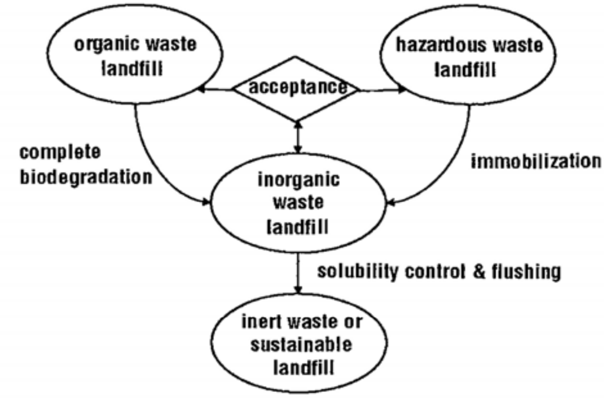


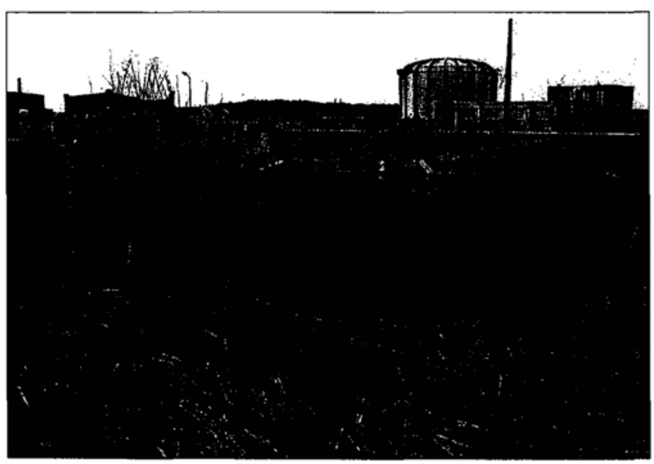
FIGURE 1. Towards a sustainable landfill

Each type has a specific kind of reactive behaviour and each type requires different measures to control or manipulate its biochemical and geochemical processes.

DSLF hypothesizes that, through control of processes, emissions from both the predominantly organic waste landfills and the hazardous waste landfills can be transformed into those of a landfill containing predominantly inorganic waste landfill (Figure 1). Furthermore, by solubility control and flushing of contaminants, an inorganic waste landfill can be transformed into a sustainable landfill with negligible emissions.

The EU Landfill Directive specifies that landfills for inert waste do not require isolation or aftercare. This implies that

Field-based experiments using lysimeters are carried out to investigate the impact of biogeochemical processes on emissions



the emissions from such landfills are considered acceptable. As a starting point, the European waste acceptance criteria (Annex II of the European Landfill Directive) adopted the position that a landfill must have no unacceptable impact on a hypothetical source of drinking-water nearby. Adopting the same approach for the entire landfill, DSLF assessed the future risks for all three types of landfills investigated here.

Results and future work

Organic waste landfill (bioreactor)

The speed and completeness of biodegradation can be increased through recirculation of leachate, addition of heat, or injection of oxygen, thus enabling aerobic conversion. An effective system of leachate recirculation can result in full biological stabilization within a few years. Methane emissions can be controlled, and so this should not limit the application of sustainable landfill methods. However, there is still no complete understanding of how leachate recirculation affects biological degradation.

Leachate infiltration increases the moisture content of the waste. Since all reactions take place in the water phase, leachate infiltration might increase the speed of biodegradation. Another potentially effective mechanism is the stirring effect of leachate infiltration. This improves the local conditions for biodegradation. Nonetheless, the high rate of biogas production and its rapid decline after a few years suggest that biological processes are enhanced in a much larger part of the waste body.

The main issue is not how to increase the rate of biodegradation, but how to flush out the large quantities of pollutants

A surprising result is that in none of the cases is biodegradation of organic material the rate-limiting step that determines leachate quality in the long term. For bioreactors, the main issue is not how to increase the rate of biodegradation, but how to flush out the large quantities of pollutants and how to deal with nitrogen. The largest uncertainty in landfill management is in how to achieve and guarantee sufficient homogeneous moisture movement in such a way that biological processes are stimulated throughout the whole landfill. This requires an improved understanding of the impact that initial waste composition, pre-treatment (such as shredding), landfill management (such as compaction) and biodegradation have on hydraulic permeability over time.

Immobilized hazardous waste landfill

At the moment it is difficult to draw conclusions about the long-term stability of stabilized waste. This is because

ABOVE LEFT Bioreactor pilot cell at Wijster landfill just before it was covered with topsoil. Mitigation measures for organic waste landfills should focus on flushing out pollutants **RIGHT** Stabilized hazardous waste pilot cells at Maasvlakte landfill. It has been difficult to quantify the long-term stability of stabilized hazardous waste

aspects on long-term stability have only been addressed qualitatively under 'worst case' scenarios.

DSLF's research showed that cementation and pore sealing through precipitation of calcium carbonate reduced emissions of all contaminants, and that bromide, chloride, sulphate, molybdenum and possibly selenium could be critical contaminants. Exposed material tended to deteriorate and showed signs of swelling, effects which did not seem to occur on material that was not exposed to the atmosphere.

Future work will focus on describing the change in emissions from stabilized waste over a longer timeframe. This includes the effect of carbonation, wet/dry cycles, pore sealing, and the soil layer with respect to its binding properties. The potential to perform such an assessment has been increased significantly by this research programme.

Although this approach is complex and will still be based on a number of assumptions, it is expected that the assessment of the environmental effects from stabilized waste will be properly addressed.

Inorganic waste landfill

Release of all contaminants can be reduced to below current practice levels by learning how the negative effects of different types of waste can neutralize each other and by acting on this knowledge. It is possible to achieve acceptable emission levels comparable to European waste acceptance criteria for inert waste landfills. Chloride and sulphate emissions do not currently meet those criteria; however, 30 years of flushing will wash out a major part of the chloride. This implies that sulphate may be the only remaining critical component. However, this is related to gypsum solubility control and cannot be influenced easily. Removal of all gypsum from the incoming waste is not an option – gypsum content can be lowered, but not eliminated. For sulphate, the only control measure is dilution in groundwater, and this is a common aspect in all landfills. For some countries, site selection close to the sea and a site-specific risk assessment could offer a solution. It is not considered useful to limit sulphate release in sulphate-rich groundwater.

Inorganic waste pilot cell (12,000 m^3) at Nauerna landfill receiving the first batch of waste. Emissions from inorganic waste landfills can be reduced to levels of inert waste landfills

Future prospects

Data from all the different scales and types of experiments show relatively consistent pH-dependent leaching behaviour. Closer examination reveals that leaching of these contaminants is controlled by the same chemical processes, including solubility control by mineral phases, sorption to hydrous ferric oxide (rust) and complexation to organic matter. Knowledge of these processes allows the design of technological measures for controlling the processes that cause the emissions.

The inert waste criteria can be defined as conditions to be reached when the active period of leachate treatment has expired

At present, it is unlikely that a significant number of landfill operators will apply these measures in the near future due to the additional costs involved. Implementation of sustainable landfill methods requires economic incentives to encourage a reduced period of aftercare. Such incentives can only be realized through dedicated regulations.

The requirements defined for inert waste landfills in the European Landfill Directive and its acceptance criteria provide a good basis for a first evaluation of sustainable principles in landfills. The inert waste criteria do not necessarily have to be met from the start of the landfill activities. They may be defined as conditions to be reached when the active period of leachate treatment has expired. This implies that management in the operational period and/or during a limited period of aftercare can ensure the reaching of the desired end condition.

Combining characteristics of waste materials enables us to create beneficial conditions for the leaching behaviour of contaminants. The current European regulatory framework provides a start, but further development is needed to understand the impact of mixing different waste types. The modelling and prediction of the long-term release of contaminants based on the characteristics and amounts of waste entering a landfill is now within reach. This also implies the possibility of developing an assessment framework on when and how to end aftercare.

DSLF intends to contribute to the further development of sustainable landfill methods and regulations enabling its application. To this end, DSLF seeks co-operation with scientists, regulators and operators.

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