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# Materials for construction of top cover in landfills

Experience in the Nordic countries

TemaNord 2009:549

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# Content

# Foreword

This document is the final report on the project entitled: "*Materials for construction of top cover in landfills* - *Experience in the Nordic countries"* financed by Nordiska ministerrådet, PA-Landfill group. The project was initiated in October 2006 and was finished in June 2008.

The main objective of the project was to collect information on common practices and experiences of top cover materials as well as to raise interest in and national discussion on the use of waste materials in the top cover of landfills. This background report can then be used for preparation of national guidelines on requirements for waste materials in top cover.

The project group consisted of the following persons:

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# Summary

The aim of this project was to compile existing information about materals used for designing a top cover construction pursuant to Landfill Directive 1999/31/EC. The report will be used to spread and develop knowledge of the material used for construction of the top cover among agencies, County Administrations, courts and other parties whom might be concerned. The report includes a short review of existing requirements on top liners, especially in the Nordic countries.

Accepting waste materials in top cover requires reliable information of both the technical and environmental properties. Important properties of waste material are listed, and factors to be considered in evaluating the functionality of the whole top cover construction are discussed. Key points in the evaluation of the suitability of waste materials in top cover are:

- the waste material fulfils the quality requirements and functions of the whole construction
- the quality variations of key properties are known and acceptable
- the long-term behaviour of the waste material is evaluated through pilot studies and proved reliable.

This report describes the characteristics of the most typical waste materials used for designing top cover constructions. Moreover, a summary of Nordic studies on potential waste materials for top cover has been collated.

# Definitions

| | |
|---|---|
| Artificial sealing liner | A synthetic protective layer that is placed on top of the impermeable mineral layer. It controls both the generation of leachate by minimising the infiltration of water and uncontrolled release of landfill gases/perched leachate. |
| Capping | The sealing of a landfill to prevent the entry of precipitation and the escape of gas, odour and other fugitive emissions. Permanent capping is part of the final restoration following completion of landfilling/tipping. |
| Daily cover | The material used to cover the working face of a landfill at the close of each day. |
| Drainage layer | The objective of the layer is to facilitate the drainage of rainwater and surface water that percolate through the top soil cover in order to keep as much moisture away from the impermeable mineral layer below as possible. |
| Final cover | The final cover on a landfill is meant to seal the landfill and reduce the amount of water entering the landfill after it is closed. It usually consists of various layers of material including the top soil cover. |
| Gas drainage layer | A permeable layer that allows landfill gases to be collected directly beneath the artificial sealing or mineral layer. |
| Grading layer | The grading layer consists of material which is put on top of the waste to make the surface uniform and level. |
| Impermeable mineral layer | A mineral layer which reduces the generation of leachate by minimising the infiltration of water. The impermeable mineral layer is put in place to keep as much water out of the landfill as possible. |
| Landfill cap | An engineered cap on top of the landfill which consists of different layers. Synonyms: Landfill cover, Surface cover, Surface sealing. |
| Regulating layer | The regulating layer consists of material which is put on top of the waste to make the surface uniform and level. Synonyms: Grading layer |
| Top soil cover | The top soil cover protects the layers underneath from cracking, and freezing and thawing during cold months. It will also allow roots from vegetation to grow. A layer of nutrient-rich soil usually comprises the topmost part of the top soil cover. Vegetation (grass etc.) can be planted on top soil. |
| MSWI | municipal solid waste incinerator |

# 1. Introduction

## 1.1 Background

The main environmental concerns related to landfilling of waste are the emissions of landfill gases and the release of harmful constituents into the landfill leachate. The amount and type of emissions and releases depend on the disposed waste, the age of the landfill, landfill operation system as well as on climate conditions.

The landfill directive sets requirements for the use of liners and leachate and gas collection systems to reduce emissions into the environment. However, leachate collection and the use of bottom sealing are often missing in old landfill systems and therefore many landfills have been, or will be closed down in the near future. A top cover is generally required for the final closure of an old landfill. A general function of the top cover is to reduce the rainwater entering the waste body and to enable the collection and/or oxidation of landfill gases in case of disposal of biodegradable wastes.

The landfill directive does not include specific requirements for the top cover of the landfill. In the Nordic countries, the legislation and policies for landfill covers are different. Significant amounts of materials are needed for the top covering of landfills. The final construction and required material amounts depend on the desired function of the top cover at the specific landfill (type of landfill, disposed waste, new or old landfill, site specific conditions such as geological barrier, etc.). Interest in using industrial waste, e.g. foundry sands, fly ash and paper sludge, in the mineral top layer at landfills is increasing among both waste producers and landfill owners. The use of waste materials is an economically attractive alternative to natural materials, and many of them have also shown suitable geotechnical properties. However, the acceptance of wastes in the top cover layer at landfills requires reliable knowledge of the technical and environmental properties, especially biodegradability and the leaching behaviour and contents of harmful compounds.

The assessment of the applicability of potential waste materials to be used in top cover constructions is demanding because of the variety of waste materials with different characteristics in addition to the requirements for the whole top cover construction. The practices and knowledge about material used for constructions of top covers on landfills also vary between the Nordic countries. Therefore, it is important to compile existing information about today's practices and experience concerning the construction of surface covers on landfills throughout the Nordic countries as well as study what materials are currently used in order to provide a more comprehensive knowledgebase.

## 1.2 Objective

The aim of the project was to:

- raise specific questions to pose in the decision-making on the use of waste materials
- highlight potential materials and influences on functionality (experience, “lacking info”, references).

The target group for this report includes all the stakeholders involved such as the authorities, regulators, waste producers, consultants, and testing laboratories.

The report does not address the aspects relating to human risk (e.g. occupational health in the waste handling and the construction of the top cover).

# 2. Boundaries of work

## 2.1 Landfill directive

The EU Landfill Directive 1999/31/EC was accepted in 1999. Three types of landfill were set out in the directive; landfills for “Inert waste”, for “Non-hazardous waste”, and for “Hazardous waste” were distinguished in the directive.

There are no specific requirements for surface sealing in the Landfill Directive. Only recommendations for the structure of the surface sealing in non-hazardous waste landfill and hazardous waste landfill are given (see Table 1). If the competent authority after consideration of the potential hazards to the environment finds that the prevention of leachate formation is necessary, a surface sealing may be prescribed. The requirements for landfill surface sealing construction and leachate collection can also be reduced on the basis of an assessment of environmental risks. It has then to be shown that the landfill poses no unacceptable risk to soil, groundwater or surface water.

**Table 1. Recommendations in EU Landfill Directive for surface sealing in landfills.**

| Layer | Landfill category | |
|---|---|---|
| | *Non-hazardous waste* | *Hazardous waste* |
| Top soil cover ≥ 1 m | Required | Required |
| Drainage layer ≥ 0.5 m | Required | Required |
| Artificial sealing liner | Not required | Required |
| Impermeable mineral layer ≥ 0.5 m | Required | Required |
| Gas drainage layer | Required | Not required *) |

*) need depends on earlier history of landfill; i.e. type of waste landfilled

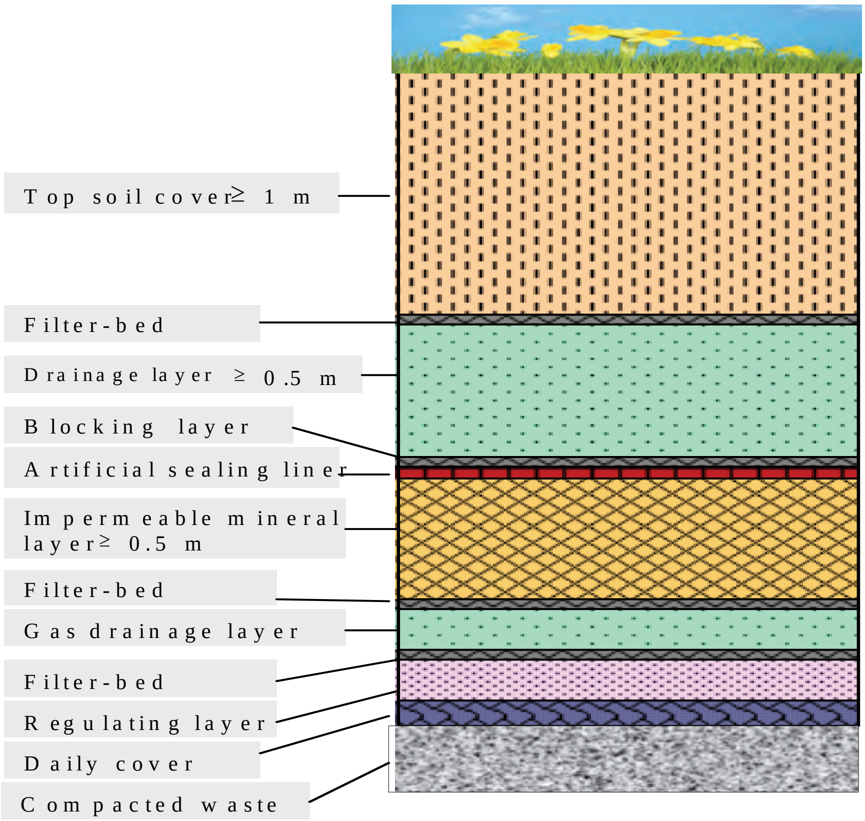


*Figure 1. Principle of construction layers in surface cover of landfill.*

## 2.2 National implementation and policy

A short overview of existing requirements on top cover systems in the Nordic countries is presented in Table 2. More specific information on existing requirements on top cover systems in the Nordic countries is collated in Appendix 1/1.

The national situations are reflected in the regulation and in the national policy in the implementation of the EU regulation. For example, country-specific features concern geological conditions (e.g. level of groundwater table, discharge of leachate to sea), the type of produced waste materials (e.g. industry), and waste management policy, e.g. regarding treatment of municipal solid waste.

The policy for use of top covers differs in Denmark from other Nordic countries. In Denmark, landfills are covered with soil directly after closure of the landfill, and since the overall Danish policy regarding landfills is that a landfill should be transformed to the passive phase as soon as possible after closure of the landfill, an impermeable final top cover is not accepted on any category of landfills with active environmental protection systems.

**Table 2. National requirements for top cover systems.**

| Country | General policy | Remarks |
|---|---|---|
| Denmark | An impermeable final cover is not accepted on landfills with active environmental protection systems.<br>Landfills not compliant with the Landfill Directive have to be closed by 16 July 2009 | Final covering shall ensure that the landfill passes from the active phase to the passive phase as soon as possible<br>The type and thickness of final cover must be chosen in accordance with the desired effect |
| Faroes *) | Requirements for top sealing.<br>Household waste and organic waste cannot be landfilled | - Monitoring of landfill leachate quality and the soil around the landfill required |
| Finland | A tight surface sealing is required. Specific requirements given for the mineral layer.<br>Old landfills (in operation in November 1999) must comply with the Landfill Directive by 1 November 2007 if still in use | - Requirements in top cover system can be reduced if it is shown that the landfill does not cause any health or ecological risks or soil/groundwater contamination |
| Iceland | A tight surface sealing is required.<br>Landfills not compliant with the Landfill Directive have to be closed by 16 July 2009 | |
| Norway | A tight surface sealing is required. Impermeable mineral layer can be replaced by artificial sealing.<br>Landfills not compliant with the landfill directive have to be closed by 16 July 2009 | - If waste contains organic material, top cover should be permeable enough to keep the water content of the waste at a sufficient level to maintain biological activity (decomposition)<br>- It should also enable oxidation of methane |
| Sweden | Requirements for a tight surface sealing set for the whole construction: The amount of water that passes through the top cover construction should not exceed 50 litres per square meter per year for landfill with non-hazardous waste and 5 litres per square meter per year for landfills with hazardous waste.<br>Organic and combustible waste cannot be landfilled (unless an exemption has been granted.<br>Landfills not compliant with the Landfill Directive have to be closed as soon as possible and latest by 31 December 2008. | A normal top cover system has regulating layer, impermeable mineral layer, or , artificial sealing liner, drainage layer and top soil cover. |

*) The Faroes are not a member of EU and therefore not bound to implement all EU regulations

For comparison, the national requirements and guidelines developed to support the implementation of directives in Germany and the Netherlands were also checked. Both countries have also worked in favour of the use of waste materials in landfill structures. An overview of existing requirements and instructions is presented in Appendix 1/2.

# 3. Important aspects in evaluation of suitability of waste materials in the top cover

In this section, general aspects of importance for the evaluation of the functionality are discussed. Material/related properties and related test methods are discussed further in Section 4. The key points in evaluation of suitability of waste materials in the top cover are:

- the waste material fulfils the quality requirements and the functions of the constructions;
- the long term behaviour of the material is evaluated through pilot studies and proved reliable;
- the quality variations of key properties in the waste are known and acceptable.

## 3.1 General requirements on waste and constructions

### *3.1.1 Baseline for use of waste in top cover constructions*

The main focus in utilisation of waste materials in landfill construction has been on the use of waste materials in top covers of non-hazardous landfills. The baseline for use of waste materials in top cover construction is that waste material is fit for the purpose and fulfils the functions of different top cover layers. Typical purposes and properties of layers in top covers are collected in Table 3.

Both in Sweden and in Finland, there are recommendations on the use of waste materials in top cover constructions. In Finland the starting point in the acceptance of waste materials is that waste materials must always meet the criteria given for the landfill class of interest (i.e. waste containing biodegradable organic materials can only be used on landfills accepting organic waste). General recommendations given in Sweden on the use of waste materials in top cover constructions relates to:

- documented results from a field test needed for approval
- waste material under the sealing should fulfil the waste acceptance criteria (WAC) for the relevant landfill class

- neither waste nor natural material should have a negative impact on the function of the top cover or should influence the quality of water on the surface or in the drainage layer
- the use of waste should not cause danger to human health and the environment. The waste should be tested for pollutants and leaching properties
- biodegradable organic matter should not be used in the mineral layer
- a stabilisation time of at least 6 months is recommended for biodegradable compost material and 3 months for matured sewage sludge, whereafter the compost should be stored for another 6 months before use
- the share of waste that includes soluble amounts of nutrient salt, metal or organic compounds should not exceed 40 % of waste in the top layer. (Note: the total amount of waste should not be a risk to human health and environment.)

The functionality of the top cover cannot be assessed solely based on material studies. A general conclusion from a review of existing knowledge and requirements for top covers is that the decision on the use of waste material is usually made on a case-by-case evaluation taking into account the whole functionality of the top cover. The properties of the material are not necessarily the same as the properties of the structure and parts of the structure in use. The technical performance (e.g. compaction mode) influences the final properties of the material in a layer. The technical characteristics of a layer (e.g. water permeability) are also highly influenced by external conditions (e.g. weather).

Often the waste properties need to be upgraded in order to meet both technical and environmental requirements. For example, treating the material with compounds (additives) that bind harmful components, or sufficient protection of the structure can reduce the amount of harmful components that are transported into the environment. Also ageing of materials influences the chemical and physical properties (e.g. carbonisation, puzzolanic reactions). The degradation of materials in top covers is discussed especially for potential waste material containing biodegradable organic matter. The main concern relates to the long-term stability (see Section 4.4).

**Table 3. Purpose and properties of top cover layers in a non-hazardous landfill constructed of traditional materials.**

| Layer | Purpose | Material (traditional) | Thickness | Remark on Nordic requirements regarding material properties |
|---|---|---|---|---|
| Top soil cover | Frost protection of mineral layer, protects mineral layer from drying<br>Secures water supply for vegetation<br>Protects lower layers from roots<br>Biological oxidation of methane and odorous gases<br>Reduces rainwater infiltration into the waste fill<br>Aesthetic factors<br>Prevents spreading of infections<br>Prevents fire risk<br>Prevents spreading of dust and litter<br>Promotes reclamation of the area<br>Prevents water and wind erosion | Humus soil | Over 1 m | Finland:<br>Surface erosion resistant<br>Sufficient protection against frost action<br><br>Sweden*):<br>Requirements for total water permeability in the top cover system:<br>non-hazardous waste landfills: max 50 $l/m^2$/year<br>hazardous waste landfills: max 5 $l/m^2$/year |
| Filter-bed | Prevents the clogging of drainage layer | Sand, gravel, geotextile | | Filter criteria, strength |
| Drainage layer | Reduces hydraulic gradient towards mineral layer<br>Conducts infiltrated water out of the structure | | Over 0.5 m | Water permeability, $k > 10^{-4}$ m/s Minimum slope gradient 5 %<br>Fine-grained material content <5% Slope stability |
| Blocking layer | Prevents the mixing of drainage layer materials with mineral layer material | Sand, geosynthetic materials | | Grain size distribution and grain shape<br>Bursting strength |
| Artificial sealing liner | Prevents the infiltration of rain water into the waste fill<br>Improves gas collection | Geomembrane | | Resistant to strain caused by differential settlements<br>Compatibility with landfill gases to be checked |
| Impermeable mineral layer | Reduces rainwater infiltration into the landfill.<br>Improves gas conduction into the gas collection system | Clay, silt, moraine, sand-bentonite | Over 0.5 m | Finland:<br>Water permeability, $k < 10^{-9}$ m/s (infiltration rate 5 %), exception: $k < 10^{-8}$ m/s (infiltration rate 20-25 %)<br>Risk of cracking caused by drying and chemical changes of the material and settlement of the fill<br>Dissolution of carbonate minerals and other substances<br>Biodegradation<br>Functionality with artificial sealing |
| Filter-bed | Prevents the mixing of mineral layer and gas collection layer | Sand, gravel, Geotextiles | > 0.10 m | Filter criteria |
| Gas drainage layer | To collect landfill gas<br>To conduct gas into collection system<br>Increases load-carrying capacity of the structure | Coarse-grained, sorted material, geosynthetic material | Over 0.3 m | Gas permeability<br>Resistant to different components of gas<br>Resistant to incrustation caused by gases |
| Filter fabric | | | | When needed |
| Primary cover | Prevents the mixing of top layer with other layers and waste<br>Levels compression<br>Balances the pressure towards other layers when compacting top layer<br>Assists gas transfer into gas collection layer | Natural soil | Over 0.3 m | |

*) Sweden recommends a minimum of 1.5 meter of cover for protection for roots, frost protection of sealing layer (mineral) above artificial sealing (site specific).

### *3.1.2 Construction and performance*

Requirements have been especially set for the mineral layer. The most important aspects to be considered during the planning of landfill structures are presented in Table 4.

**Table 4. Examples of important technical properties of concern for different layers in landfill structures.**

| Property | Regulating layer | Artificial sealing liner | Gas drainage layer | Impermeable mineral layer (surface) | Drainage layer (surface) | Top soil cover |
|---|---|---|---|---|---|---|
| Stability | X | X | X | X | X | X |
| Deformations | X | X | | X | | |
| Bearing capacity | X | | X | X | | |
| Frost protection | | X | | X | X | |
| Prevention of drying | | | | X | | |
| Erosion protection | | | | | | X |
| Water permeability | | X | | X | | |
| Hydraulic conductivity | | | X | | X | |

Performance of top cover is influenced, e.g. by the following factors:

- the design of the construction (e.g. slopes, which depend on material properties, material thickness, landscaping);
- working methods (e.g. mode of compaction);
- disposed waste and prevailing landfill conditions (i.e. leachates and gas). In the case of non-hazardous landfills accepting organic waste, attention is needed on settling caused by the biological degradation of organic content;
- landfill operation. In the case of recycling of leachate, e.g. with high organic load, the influence of leachate on construction layers needs to be evaluated (may influence water permeability, stability).

In practice, the following problems may arise during the construction of the mineral layer:

- permeability studies problematic (field conditions different from laboratory tests, time limitations for results)
- weather conditions (e.g. rain, frost)
- mixing material
- quality variations
- technical problems (e.g. packing, machinery can damage the material)
- storage of material
- working environment.

In particular, the use of the landfill area after closure needs to be taken into account when waste materials are planned for use in the top layers. Those factors which should be taken into consideration are, for example, climate, long-term changes in the environmental conditions (e.g. pH changes), exposed objects in the location of the structure (groundwater, organisms in the soil, plants) and transfer through them into the food chain (people).

Waste materials are recommended to be used mainly in large or medium-sized constructions because it is difficult to control the use in smaller constructions. Landfill covering offers in this respect a good opportunity, as the construction of a top cover requires large volumes of materials. For example, in Finland it is estimated that for the covering of one landfill square meter, 4.2 $m^3$ of material is needed. In Sweden a material need for up to about 2.5 $m^3$ has been reported for the covering of one landfill square meter (see one example in Table 5). Local variations in natural material resources may cause longer transport distances leading to higher transport costs and, e.g. air emissions. The use of waste materials can also have other positive effects, such as reduced consumption of energy or emissions compared to natural materials.

There are also many other material-specific and structure-specific factors which simultaneously affect the functionality of the top cover, and there is not always enough information about their combined effects. Furthermore, for many waste materials, experiences in their use have been acquired only over a relatively short period of time. Therefore, the general requirements have to be directed first to the level which ensures the technical functionality of the materials and their safe use with respect to human health and the environment. The waste material user has to show that, on the basis of material-specific or site-specific risk assessment, or the functional properties and structural requirements, the materials are applicable in certain structures or types of structures. Adequate guarantees about the applicability of materials also improve the prerequisites for the productive use of waste material because one can then avoid negative experiences resulting from inappropriate use.

Attention should also be paid to quality control so that the properties can be guaranteed to remain within the compliance limits. In order to show functionality in practice, sufficient experience of building sites and preferably works and design instructions are needed.

An example of the normal operational stages of top cover earth construction and use, and their possible environmental hazards is shown in Table 6.

**Table 5. Example of a material need for top cover materials at Lilla Nybo landfill in Sweden (33 ha). (Máscik *et al.* 2007)**

| Layer | Height of construction layer (m) | Total material volume (m3) |
|---|---|---|
| Regulating layer | 0.5 (0.3-1) | (165 000) |
| Impermeable mineral layer | 0.6 | 198 000 |
| Drainage layer | 0.2 | 66 000 |
| Top cover, protective layer | > 1.1 | 330 000 |
| Top cover vegetation layer | 0.2 | 66 000 |
| TOTAL | 2.5 | 825 000 |

**Table 6. Stages of the use of waste materials in top cover construction and related exposure for humans and animals.**

| | Dispersal route | Exposure route, object of exposure, and probable manifestation |
|---|---|---|
| Transport of waste material | Raising dust, if a fine-grained waste material is transported on an open platform and if the material has been slightly moistened. | Dust may lead to exposure to lungs, skin, or mouth, or the leaching of components into the soil with dust. The effects depend on the amount and location of dust. The possible dust is random and local. |
| Intermediate storage (in a pile) | There can be a lot dust if the fine-grained waste material is stored uncovered. Harmful components are also transported with water if, under the pile, there is no isolating material such as plastic or asphalt. If the pile has been covered or has been watered, there is less dust. | Workers and local residents may be exposed through the lungs or skin. The effects are short-term. |
| Pre-processing of waste materials | Pre-processing stages that cause a dust effect can be, for example crushing and mixing. Crushing stations need their own environmental licence. Release of gas, e.g. ammonium from mixing of sewage sludge with fly ash. | |
| Construction | Raising dust, if the surface layer of the fine-grained waste material dries. If the material remains uncovered for a long time, rainwater can dissolve harmful components. Release of gas, e.g. ammonium from mixing of sewage sludge with fly ash. | |
| Use of construction | Leaching into rainwater which gets into the construction and transfers into surface- and groundwater or leaching into groundwater which rises into the construction. Harmful components may also be transported into the environment through diffusion. With use of the road, the asphalt cracks more and its water leakage increases. | Concentrations in the area may rise and affect the vegetation in the environment and organisms in the soil. Contamination of ground- and/or surface water can effect humans as well as aquatic organisms. |
| Maintenance and repairs of structure | Leaching and transport of harmful components into the environment will increase if more water gets into the construction. Raising dust when structural layers are dug. | |
| Accident risks | In transport one must take into account the risk of an accident. When an accident occurs harmful components can leach into the soil from materials, or lead to the raising of dust. | Those moving around in the accident area are exposed to dust. The effect is usually very local. Exposure through skin or mouth is possible |

## 3.2 Aspects of importance for evaluation of long-term behaviour

### *3.2.1 Effect of organic matter*

Organic matter affects the top cover construction in many ways. In the growth layer, organic matter is needed especially for cultivation and for reducing water infiltration into the waste body. Organic matter in the landfill cover also has a positive effect on methane oxidation of landfill gas. In Denmark a project is currently running on the use of engineered biocovers in the top cover, in which the aim is to reduce emissions of methane from landfills by improving conditions for biological oxidation (Fredenslund *et al.* 2007).

On the other hand, organic matter may lead to the formation of dissolved organic carbon (DOC) capable of mobilising metals and organic pollutants. Moreover, leached organic carbon increases the leachate oxygen demand. Biodegradation of organic matter may also lead to the loss of materials and settling. It may also cause a decrease in the water permeability owing to the formation of small particles clogging the open channels in the waste layer.

Organic matter appears as a natural constituent in humic soils, which are also used in the growth layer of the top cover. In soil, the natural organic matter (NOM) is essential for the growth of plants. NOM consists of weak organic acids, e.g. fulvic acids, humic acids and humane, and constitutes a proton source enhancing the mineral weathering processes. Generally, organic anions wash base cations down into the soil profile or out into the surface waters leading to soil acidification. Furthermore, fluxes of macro-nutrients, such us nitrogen and phosphorous, from the material to the water is to a large extent controlled by that of NOM as these elements are bound to organic matter. Changes in the quantity or properties of NOM will therefore result in changes in aquatic flora and fauna. It also binds heavy metals and absorbs organic pollutants. The ability of humic matter to influence both the transport and bio-availability of contaminants is strongly dependent on the quality of the NOM. For example, fulvic acids are very reactive and humine less reactive with regard to heavy metal binding. (Nordtest 2003)

Some waste materials also contain organic matter. Organic matter in waste is currently less well defined than natural organic matter (NOM) in soils and sediments. Usually, organic matter does appear as stable as in soils. Typical examples are municipal solid waste (MSW) and waste streams from the forest industry. The organic content in ashes from incineration processes (e.g. coal ash, MSWI ash) are usually less than 10 %.
Some important remarks on sewage sludge and tyres related to the scope of the Landfill Directive (1999/31/EC):

- Use of waste, e.g. sewage sludge on the soil for the purpose of fertilisation is excluded from the scope of the Landfill Directive (Article 3).
- The ban on landfilling whole and shredded tyres (Article X) was inserted into the Directive because the landfilling of tyres poses risks for the environment, in particular the risk of fires and the risks for the stability of the landfill (this clarification was given in a letter from the Commission dated 10.1.2006). These risks also have to be considered when deciding whether used shredded tyres can be used as engineering materials.

### *3.2.2 Chemical stability of layer*

Some waste materials may contain a significant amount of reactive compounds which cause physical changes in the material layer with time. As a consequence, this might cause instability in the landfill layer, which needs to be taken into account in the design of the cover. Examples of reactive compounds in wastes:

- leachable fractions (e.g. salts). Typical waste materials are ashes from flue gas cleaning, containing over 10 % easily leachable salts.
- easily degradable organic matter. However, in this case also formation of degradation compounds may also have a positive influence on the waste layer, e.g. causing a decrease in permeability owing to clogging of channels.

### *3.2.3 Interaction with other layers*

Interaction with other layers might appear in the following cases:

- in the case of alkaline waste materials, a leachate of high pH is produced which may influence the behaviour of surrounding materials (especially layers beneath the alkaline waste). A typical example is fly ash with a pH value over 12. If a construction layer (e.g. daily cover) is covered with a mineral layer construction with fly ash, the influence of alkaline conditions needs to be evaluated. The leaching of some constituents is significantly pH-dependent (e.g. Cr, Pb, DOC).
- an ion-exchange reaction might occur in direct contact between some materials (e.g. bottom slag covered with bentonite). This might cause a decrease in the functionality of bentonite with time.
- leaching of DOC might have an influence on the leachability of some constituents (e.g. copper, organic contaminants). A typical example is the influence of DOC on metal leaching from MSWI bottom ashes. In several countries (e.g. the Netherlands) there are restrictions on disposal of bottom ashes together with materials with organic content.

- reducing conditions appearing owing to some slags (blast furnace slag). Some constituents have different leaching behaviour in reducing conditions.
- gas from landfill with organic waste can cause holes in thin geosynthetic clay liner.

## 3.3 Quality control

There is a wide variety of different types of materials produced in industrial processes which are potentially suitable for use in top covers both from an environmental and geotechnical point of view. If the same types of waste materials are in continuous use it is not usually necessary to repeat the extensive basic characterisation. It is, however, very important to control the quality of the produced material regularly to ensure that its properties meet the requirements defined. A quality control system for the assurance of conformity of the materials with environmental and technical specifications should be established in connection with the characterisation. Only where there are significant changes in the quality of the material, such as changes in the production process or raw materials, might it be necessary to renew the characterisation tests or a part of them.

The quality control system is material-specific. The technical characteristics that are significant to the application and the most critical environmental characteristics are selected for periodic checking. Less monitoring is required for homogeneous materials with well-known characteristics than for more complicated and less investigated materials. In addition to the properties to be monitored and the monitoring methods, sampling methods, sampling and control frequencies, limit values and acceptable errors as well as reporting methods should be presented in the quality control programme.

Both in Finland and Sweden so-called instruction manuals have been prepared, usually on the initiative of waste material producers in order to promote use of the waste in landfill constructions (see Table 11). The specific manual often contains a description of the geotechnical and environmental requirements to be met, which includes the following: manufacturing, storing, installation and follow-up/monitoring. This instruction manual is aimed at those who are planning closures of a landfill with specific waste material and who need guidance to plan, carry out and control the liner construction.

The producer is responsible for ensuring that the material complies with the defined quality control criteria and that quality control is carried out according to the requirements. The user’s responsibility is to use the material in defined applications according to the appropriate instructions for use. Therefore, the producer has to ensure that satisfactory user guidelines have been prepared and that they are available to customers, when needed.

Development of an accepted earth construction product from industrial waste materials is a long-term project. The main stages of the process include:

- Preliminary definition of the uses and applications of the material
- Collection and assessment of existing data about the application
- Characterisation studies (environmental and technical characterisation)
- Pilot constructions
- Development of a quality control programme
- Preparation of a design manual, user guidelines and product information sheet
- Development of a production control system.
- Certification of material for use as construction product for top cover.

The quality of a product (e.g. waste material) can be proved through certification. In Finland a system for certification of materials in landfill constructions has been developed. The certification system is based on the following criteria:

- Technical properties (e.g. water permeability)
- Durability (during construction)
- Long-term durability against chemical, physical and biological stresses
- Long-term functionality
- Long-term stability of the properties
- Structural safety
- Compactibility and functionality with other materials and layers in the top cover
- Processibility
- Feasibility and reliability of quality control measures
- Environmental properties

The properties and functionality of a certain material and/or structure are assessed against general demands and values presented by the authorities and/or against site-specific demands.

# 4. Evaluation of material properties for top cover utilisation

Key issues in the evaluation of suitable solutions for top cover systems including waste materials are the following:

- characteristics of harmful compounds regarding both total content and leaching behaviour (and also influence on the behaviour of surrounding materials). Environmental risks from the sealing layers containing wastes are primarily caused by the release of harmful substances to water flows in the landfills.
- long-term behaviour of waste materials and its influence on technical properties (e.g. stability). Especially degradation of organic materials and changes of properties must be examined.

Technical properties are usually linked to recipes for materials and the design of the construction (including compaction). The recipes are normally developed case by case. Materials containing waste materials need to fulfil the same requirements as traditional materials used for top cover. The test methods used for technical properties are only briefly discussed in Section 4.2.

## 4.1 Testing of material characteristics

Tests to characterise the waste material can generally be divided into three categories (van der Sloot, 2007):

1. Basic characterisation constitutes a full characterisation of the waste by gathering all the necessary information for safe management of the waste in the short and long term (disposal or reuse). Basic characterisation should provide information on the waste (type and origin, composition, consistency, leachability, etc.) as well as information for understanding the behaviour of waste in the considered management (utilisation) scenario. The basic characterisation should also include a comparison of waste properties against specific acceptance values given or proposed for disposal

and utilisation of waste as well as detection of key variables for compliance testing and options for simplification of compliance testing.

2. Compliance/conformity testing is used to determine if the considered waste stream complies with the result of the basic characterisation and, optionally, with the relevant limit values (when the relationship with the basic characterisation has been established). The function of compliance testing is to periodically check regularly arising waste streams. The relevant parameters to be tested are determined in the basic characterisation. Parameters should be related to basic characterisation information: only a check on critical parameters (key variables) as determined in the basic characterisation, is necessary. The tests used for compliance testing shall be one or more of those used in the basic characterisation.

   The frequency of testing can be increased or reduced depending on the results (statistics). It can also be related to the degree of agreement with the previously collected characterisation test data.
3. On-site verification/quality control tests have the purpose of determining quickly (within a short time) if a product (or condition) complies with earlier determined or expected behaviour in its practical application. In general, visual inspection, and simple properties such as pH, electrical conductivity and redox control may suffice.

A summary of appropriate test methods for basic characterisation has been compiled in Appendix 2. When testing, it is important to evaluate the applicability of the method for the specific test material and the questions to be answered.

## 4.2 Technical characteristics

The technical characteristics of the mineral layer are of major concern. One key parameter to be tested is the water permeability of the mineral layer. Examples of the main technical properties to be tested are presented in Table 6.

**Table 6. Examples of technical properties to be tested. Requirements and test methods presented in Finnish recommendations.**

| Property | Requirement | Method | Layer |
|---|---|---|---|
| Amount of carbonate minerals | < 20 m-% | Acid titration | Drainage layers, top soil cover |
| Amount of other dissolving minerals | < 5 m-% | Water-solubility test, pH = 4 | Mineral layers, drainage layers |
| Biodegradability | Case-specific | | Mineral layers |
| Chemical stability | Should not cause increase of k-value (hydraulic conductivity) | Water permeability test using leachate | Mineral layer (bottom) |
| Strength | Loss ≤ 50 % | Los Angeles -test, ASTM* C 131 | Drainage layers |
| Shrinkage (volume) | ≤ 5 % | ASTM* D 427-39 or comparable | Mneral layer (surface) |
| Compressibility<br>Shear strength and friction angle | Case-specific<br>Case-specific | Compression test<br>Ttriaxial compression test or box shear test | Mineral layers<br>Mineral layer (bottom), top cover layers |
| Water permeability | Case-specific | ASTM* D 5084, ASTM D 2434 or comparable | Mineral layers, drainage layers |
| Compactibility vs. water content | Required k-value obtained by compaction index 90-95 % | Proctor -test<br>ICT -test | Mineral layers |
| Gas permeability | Case-specific | | Mineral layer (surface) |

*ASTM = international standards organization (former American Society for Testing and Materials)

## 4.3 Environmental characteristics

### *4.3.1 Composition*

Information on material composition including both the major and minor constituents is important for material characterization. The total content of harmful constituents shows the maximum release and exposure of contaminants that is possible.

For organic contaminants, the material acceptance is usually based only on total content. Organic contaminants are usually strongly bound to the waste matrix, but they can be transported to the environment, e.g. through the formation of colloids. There are several research studies on the leaching behaviour of organic contaminants, but there is still a need for fundamental studies before standard test methods for waste and guidelines for interpretation of test results can be developed.

The total content (not only leachable fractions) is important for wastes in surface layers (e.g. use of lightly contaminated soils). The acceptability of soil used in the surface growth layer is evaluated primarily on the basis of total concentrations of harmful inorganic and organic compounds.

Potential risks have to be evaluated case by case, because the risks are compound-specific. Characteristics such as leachability and biological accessibility are also of importance. Target values and limit values given for the assessment of soil pollution can also be used, e.g. for identification of critical constituents.

The basic composition studies need to include the following:

- major inorganic constituents
- harmful metals
- organic pollutants
- organic matter and loss of ignition

Generally, there are two approaches for the determination of total content of harmful compounds: either total digestion or only an extraction. In environmental analysis, aqua regia is often used, but (contrary to what is often attributed) this is an extraction and not a digestion. Although aqua regia is a very strong acid, it is not able to digest silicates and therefore all elements that are bound to that matrix are not digested and will consequently not be analysed. Appropriate standards for aqua regia extraction are EN 13657, Horizontal 6 18, and ISO 11466.

The digestion of silicates requires hydrofluoric acid, which is used for total digestion methods – EN 13656 and ISO 14869-1. Alternatively, alkaline fusion methods (CEN/TR 15018 and ISO 14869-2) can be used for a total digestion. However, this technique is applied to major components only and not to trace elements.

X-Ray-Fluorescence (XRF) is a different technique. No digestion is required for the analysis. The sample is either fused with borate or mixed with wax to obtain a tablet for further analysis. Consequently this method also gives the total content of elements in the sample. A suitable method is prEN 15309 (draft).

There are only a few testing methods that are standardised for organic contaminants (hydrocarbons, PAH, PCB) in waste materials. Standardised methods developed for soil are often applicable for waste as well.

### *4.3.2 Leaching behaviour*

#### Water contact and release

An evaluation of the water flows in a construction work is the basis for the impact evaluation of waste materials. The release of substances (direct leaching) to surrounding construction materials, disposed waste, soil beneath the landfill site, groundwater or surface water is always mediated through water contact. Without water contact there will be no release and no need for environmental assessment.

The transport of leached compounds to the surface water and groundwater is especially of concern. The mode of contact with the mineral layer is largely dependent on the water permeability. Compounds are leached out from the surface by washing or diffusion if the hydraulic conductivity is less than $10^{-9}$ m/s. In the case of “sandwich-constructions”, where the mineral layer is covered by an artificial tight sealing, the leaching of substances is negligible as long as no cracks appear in the artificial sealing and the rising of the capillary water is hindered. Practically, this means that the requirements for water permeability can be met, even if the mineral layer beneath the artificial sealing has higher water permeability.

The leachability also depends on the material properties and on the landfill conditions. Examples of critical properties or conditions are:

- ageing of the material (drying)
- density of the material
- influence of other sealing materials
- influence of landfill leachate
- impact of landfill gas (thermal effect?)
- biodegradability of the material
- stability of the material (amount of soluble salts and minerals)
- ion exchange.

Table 8 shows the water flows in contact with the construction layer including important aspects to be taken into account in the impact evaluation.

**Table 8. Water flows in top cover layers and other environmental conditions in impact evaluation.**

| Layer | Water flows and nature of water in contact with layer | Type of suitable methods | Environmental conditions of concern |
|---|---|---|---|
| Top soil cover | Rainwater percolates the layer | Percolation test, batch tests, pH-dependence test | Influence of biological activity in growth layer on availability |
| Drainage layer | The rainwater percolating this layer contains nutrients (e.g. nitrogen, TOC) from the upper layer | Percolation test, batch tests, pH-dependence test | Sulphidic and iron-rich materials may cause reducing conditions in the lower material layers.<br>Ion exchange may appear in adjacent material layers in contact with the waste material (see Section 3.2.3) |
| Impermeable mineral layer | Water from the upper layers forms run-off water which washes the surface of the mineral layer (surface dissolution). | Diffusion test (surface dependent release) or percolation test, batch tests, pH-dependence test | The water washes out harmful compounds from the mineral layer to the run-off water from the landfill<br>Basically anaerobic conditions<br>Information on total content of organic pollutants is important<br>Information on total content of inorganic compounds is important for waste classification and might consequently be of concern for approval |
| Gas drainage layer | The landfill gas (mostly methane) influences primaryly the properties of the mineral layer (drying of the layer) | Percolation test, batch tests, pH-dependence test | |
| Primary cover of disposed waste | Conditions similar to landfilled waste | Percolation test, batch tests, pH-dependence test | |

Test methods

There are two types of standard test methods for materials used in earth constructions, based on the leaching mechanism of the material. The leaching mechanism depends on the material properties and on the environmental conditions. Typically, the materials are divided into granular materials and monolithic materials with the following contact with water:

- granular materials in which water percolates through the material layer. The leaching behaviour is dictated by the solubility of the compounds. The leaching behaviour is studied by using a so-called percolation test.
- stabilised and solidified materials (monolithic materials) that typically have a small hydraulic conductivity and maintain their shape in water contact, and in which water only can be in contact with the surface and not percolate through it . The leaching behaviour is surface-dependent, often dictated by diffusion and studied by a so-called diffusion test. Note: monolithic waste to be disposed at landfills in several Nordic countries is recommended to be tested by percolation tests or leaching tests for equilibrium conditions because the leaching is in this case dictated by solubility control of compounds. In a landfill top cover layer, the height of the waste materials is much thinner and here the leaching is most often surface dependent.

The new CEN method called dynamic monolithic leaching test DMLT under preparation (similar to the Dutch standard diffusion test NEN 7345) is not, without modifications, applicable for mineral layer materials that have small hydraulic conductivity but, on the other hand, lose their shape in water contact. The surface dissolution and leaching through diffusion in mineral sealing materials can be studied with a modified diffusion test NVN7347 that was developed for determining leaching through diffusion specifically in materials (e.g. clay) that do not keep their form in water contact. The method is standardised in the Netherlands. The principle is that the material to be studied is compacted in a test vessel that is then submerged in water. Substances dissolving from the surface of the test material are determined. From the results, the amounts of substances ($mg/m^2$) are calculated per time unit. The modified diffusion test has been used in Finland for leaching studies of potential mineral liner materials.

If the hydraulic conductivity of the sealing material is higher than $10^{-9}$ m/s, the amount of dissolved substances has to be determined with other methods. Suitable tests for this case are the percolation test prCEN/TS14405 (Nordtest ENVIR 002), or the so-called cell test ENVIR 007 (modified column test). Equipment designed for measurement of water permeability is used in the cell test. The sample is packed at optimal water addition in a cell permeameter. Water is percolated through the sample at a specified flow rate up to a fixed liquid-to-solid ratio (L/S ratio). The L/S ratio describes the relationship between the sample solid (S) and the amount of water (L) passed through the sample. Eluates are collected and analysed. The amounts of cumulatively leached component are calculated (mg/kg). The test results are evaluated on the basis of the L/S ratio. Furthermore, it is possible to roughly convert the L/S ratio to a time scale at a disposal site and to describe the quality of leachate in time frames of interest.

The influence of leachate quality (e.g. leachate containing humus or salts due to the composition of the upper sealing layers), landfill gas and reducing conditions must be evaluated on a case by case basis and might sometimes require further testing. Examples of additional tests are batch shaking tests performed with artificial water as a leachant. The influence of reducing test conditions can be assessed by mixing the material with a slag with reducing properties (e.g. blast furnace slag). The effect of landfill gas can be studied by storing the test material in a chamber filled with landfill gas before testing.  The influence of environmental conditions is usually tested by using so-called parameter tests (e.g. pH-dependence test, prCEN/TS14429 & prCEN/TS 14997).

## 4.4 Degradability

The degradability of organic content in waste depends on the origin of the waste. Most information is available on degradation of organic content in typical municipal solid waste. Very little information is available on how to interpret impacts in the long term.

Existing criteria for degradability:

The EU has defined limit values for inert waste and for stable biowaste (Table 9). The limit values are given for total organic concentration (TOC), for dissolved organic carbon (DOC) in an eluate from the waste, ignition loss and respirator index. These values can be used in assessing the biodegradability of the waste.

The rationale for the EU criteria for dissolved organic carbon (DOC) leached from inert waste is the DOC´s ability to increase the solubility of some harmful metals (copper, nickel). In addition, DOC in run-off water from the landfill increases the oxygen consumption in the surface water, which may cause reducing conditions and potentially increase the solubility of salts. The limit values for DOC are given for inert waste (class A), non-hazardous waste (B1b) and hazardous waste (C) landfills. No EU criteria have been given for mixed organic and inorganic non-hazardous waste. The acceptance criteria for landfill for organic waste are to be defined on a national basis.

If the waste cannot be proven stable based on these EU criteria for TOC and leachable DOC, so-called biotests can be used. Alternatively, the stability can also be proven with field tests simulating landfill conditions in the long term.

**Table 9. Parameters and limit values for assessment of biodegradability and stability in EU legislation.**

| Regulation | Object | Parameter of concern |
|---|---|---|
| Council decision on waste acceptance criteria and procedures (33/2003/EC) | Classification of waste as inert | - Total content of carbon (TOC) under 3 %<br>- Leached DOC value determined by leaching test at L/S 10 below 500 mg/kg<br>- |
| German regulation: "Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste-Treatment Facilities", 20.2.2001 | Landfill criteria given for waste from thermal treatment (slag, ashes) | - Loss of ignition under 5 %<br>- TOC under 3 %<br>- DOC value determined by leaching test at L/S 10 below 1000 mg/kg |
| Second proposal made by a working group under Commission "Biological treatment of biowaste, 2nd draft" (2001) | Biodegradation | - Quality requirement for residual municipal waste after a mechanical/biological treatment prior to landfilling: the achievement of either a Respiration Activity after four days ($AT_4$) below 10 mg $O_2$/g dry matter or a Dynamic Respiration Index below 1000 mg $O_2$/kg VS/h<br>- Above suggestions also given for surface growth layer<br>- Quality criteria for residual municipal waste after incineration: Total Organic Carbon (TOC) under 5 % |

Biotests for measurement of degradability

Table 10 comprises the potential parameters for the evaluation of biodegradability of organic content in waste. Ignition loss and total organic carbon (TOC) are usually not regarded as a suitable parameter to describe the potential biological reactivity of waste, because

- Ignition loss comprises also the biologically undegradable fraction of the organic matter. A part of the waste, which is biologically inert, cannot be degraded by microbial attacks, especially normal plastics, but also other heavily degradable material, such as wood. This part will mostly not contribute to the landfill reactions.
- Positive effects of the remaining or biologically converted organics, such as the high binding capacity of humus-like substances, are not considered.
- Ignition loss contains volatile inorganic compounds as well.
- TOC also contains the biologically undegradable organic carbon.

The stability and the reactivity of the waste can generally very easily be evaluated from the level of dissolved organic carbon (DOC) in a test eluate derived from the waste. The rationale is that degrading waste usually forms organic compounds (fatty acids, fulvin acids) measured as DOC. Lignine and other big organic molecules are not normally measured as DOC compounds (van de Sloot 2003).

**Table 10. Examples of potential indicators for degradability. (Binner & Zach 1999, Soyez 2001, Soyez & Plickert 2002).**

| Parameter | Information type | Remarks |
|---|---|---|
| *Biological* | | |
| Respiration activity/rate ($O_2$-consumption, $CO_2$- production) | Degradability in aerobic conditions | - Relative quick stability parameter for standard operation<br>- Momentary biological activity<br>- Shows the readily degradable material |
| Biogas ($CO_2$, $CH_4$) production | Degradability in anaerobic conditions | - Anaerobic conversion to biomass, $CO_2$ and $CH_4$ |
| Gas production (fermentation degree) | Degradability in anaerobic conditions | - Anaerobic conversion to biomass, $CO_2$, $CH_4$ and heat<br>- Possible degradation potential<br>- Control parameter / Stability parameter for standard operation |
| *Chemical* | | |
| TOC in eluate (DOC) | Bioactivity through reaction products of degradation, expected load in leachate | - Quick stability parameter for standard operation / compliance testing<br>- Good correlation with biotests |
| $HNO_3$ or $H_2SO_4/H_2O_2$ extraction | Non-water soluble, slowly degradable C | - Test: Selective dissolution test e.g. for identification of plastic of non biogenic origin |
| COD solution | Chemical oxygen demand | - Correlates quite well with DOC in large range of concentrations<br>- Oxidation with $K_2Cr_2O_7$ |
| Loss of ignition (LOI) at 550 °C | Combustion / chemical | - C is not degradable<br>- Reference parameter / poor indicator |
| Total organic carbon (TOC) | Chemical | - Most plastics and residual organic matter do not significantly contribute to biodegradability C is not degradable<br>- Reference parameter / moderate poor indicator |

The biodegradability of a material can be studied under anaerobic or aerobic conditions. There are many test methods available:

- The principles of the tests are that microbe inocculant from a water treatment plant or compost is added to a nutrient solution and that the organic content of the sample is the only carbon source for the microbes. The oxygen consumption or the formation of breakdown products, carbon dioxide and/or methane is measured in the tests. The degradability of the samples is generally greater under aerobic conditions than under anaerobic ones.

Problems with biotests:

- Tests for biodegradability are developed for assessing the degradability of chemicals and polymers. Therefore, it is important to confirm the applicability of the test and to avoid the risk that low degradability is due to the toxicity of the material. The applicability of the test is also checked by using a known control sample. The toxicity of the sample can slow down the degradability because it destroys microbes that break down the sample. The biodegradability of the sample can also be hindered by the type of carbon source. The organic compounds of the test sample might not, as such, be a suitable carbon source for the selected microbes, but in a richer microbe population environment a suitable microbe strain might appear able to degrade the sample.
- Under aerobic conditions, degradation may occur in several ways. Therefore, tests only indicate the degradation in a similar situation that has been studied.  The very slowly degradable compounds are not detected within the testing time.

# 5. Current practice of utilization

## 5.1 General

A literature survey on potential waste materials for top cover constructions has been carried out. General “environmental based” principles for the use of materials have recently been worked out in Finland. In Sweden, guidelines are under preparation. These guidelines will probably promote use and be of help in product development. Tools to make a product of wastes through certification are briefly discussed in Section 3.

Several reports on the properties of material potentially suitable for use have been published, especially in Sweden. The published reports give good background on potential use and material characteristics. Owing to the recent interest in the use of waste materials, there is limited information from field testing (e.g. for technical properties, “workability” of materials).

A survey on materials currently used in Finland has also been performed based on environmental permits for use. It seems evident that several types of waste materials have been used in construction layers, especially in the mineral layers of top cover. A general conclusion is that the decision for approval of material is usually made from case to case, taking into account the properties of waste materials available for use. However, the reports on material properties which have been the basis for the decision by the authorities have not yet been published. Experience of use is only presented in seminars and expert meetings.

## 5.2 Results from mapping

Potential materials to be used in different layers of top cover are presented in Tables 11 and 12 along with information about some reports focusing on potential waste materials for top cover. Most reports deal with laboratory studies on potential materials aimed to be used in the mineral layers. However,, only few reports dealing with experience and compliance of environmental test results obtained in laboratory testing to full scale applications were found.

The properties of waste have generally been improved by mixing waste with other materials. One of the key issues seems to be the quality variations in materials and the influence of weather conditions when the waste mixtures are compacted at the site. The most unclear issue relates to how to estimate long-term stability and degradation of organic material.

The most typical materials of interest are paper mill sludges alone or together with fly ashes from electrical power plants, and green liquor (Finland) and fly ash (e.g. coal, biomass, wood ashes) mixed with sewage sludge (Sweden). Other potential materials are

- foundry sands (containing bentonite)
- slightly contaminated soils alone or together with bitumen, fly ashes from electrical power plants (coal, peat, wood)
- sewage sludges together with fly ashes (e.g. Hydrostab, Dutch trademark for water glass plus hazardous waste components)
- MSWI slags (beneath the mineral layer)
- metallurgical slags (e.g. blast furnace slag, steel slags) are theoretically potential materials, but no real use as top cover material has been reported (owing to the use as an aggregate in civil engineering).

***Table 11. Overview of selected Nordic reports on potential waste materials for top cover.* Abbreviations for topics included in the reports: Env – environmental aspects, Tech – technical aspects, Lab – laboratory studies, Field – field studies, Gen – general aspects of concern, Leg – legal issues. *Värmeforsk reports can be downloaded from www.varmeforsk.se.***

| Top cover layer | Alternative materials | Examples of Nordic reports | Topic | Focus | Scale of material studies |
|---|---|---|---|---|---|
| All layers | General | Wahlström, M., Laine-Ylijoki, J., Eskola, P., Vahanne, P., Mäkelä, E., Vikman, M., Venelampi, O., Hämäläinen, J., Frilander, R. 2004. Environmental acceptability of industrial by-products in landfill construction. VTT Research Notes 2246. Espoo. 84 s. + liitt. 38 s. (in Finnish). available at: www.inf.vtt.fi/publications) | Env, Tech, Lab | - Study on applicability of standardised test methods for use of waste materials in top cover<br>- Rrecommendations for environmental acceptance of waste materials in top cover | - Laboratory studies on selected materials (some similar materials have been used in a full-scale application, but the results are not reported here) |
| | | Tham, G., Ifwer, K. 2006. Utilization of ashes as construction materials in landfills (Askanvändning i deponier). Värmeforskrapport 966. In Swedish | Tech, Field | - Review on experience from use of ashes in different construction layers. | - Review covers technical experience from pilot and full-scale applications (incl. some leachate analysis from site) |
| | Soil | Anon. 2006. Certification of soil for (agricultural and) civil engineering purposes by P-marking (Certifieringsregler för P-märkning av anläggningsjordar.)SP Sveriges Provnings- och forskningsinstitut. SPCR 148. (in Swedish) www.sp.se | Quality control | - A description of certification scheme (conditions for certification, technical requirements and requirements for continuous inspection of soil for civil engineering purposes) | |

**Table 11 Cont. Overview of selected Nordic reports on potential waste materials for top cover. Värmeforsk reports can be down loaded from *www.varmeforsk.se*.**

| Top cover layer | Alternative materials | Examples of Nordic reports | Topic | Focus | Scale of material studies |
|---|---|---|---|---|---|
| Top soil cover | Sewage sludge in top soil (growing zone) | Greger, M., Neuschütz & Isaksson, K.-E., 2006. Sealing layer of fly ashes and sewage sludge and vegetation establishment in treatment of mine tailings impoundments (Flygaska och rötslam som tätskikt vid efterbehandling av sandmagasin med vegetationsetablering). Värmeforsk rapport 959. In Swedish | Env, Tech, Lab, Field | - Study on applicability of sewage sludge together with fly ash as cover material in tailing deposits | - Laboratory study of 5 mixtures (with focus on technical properties water permeability, compression strength)<br>- Field tests performed at 3 test plots (size 0.3-1 ha)<br>- Monitoring of drainage water<br>- Follow up of plant growth (root penetration) |
| Top soil cover | Slightly contaminated soil | Nno public report available | | | |
| Mineral layer | Paper sludges are water-containing sludges from pulp and paper plants containing fibres and filling material | Finncao 2001. Finncao-fibreclays for mineral layers in landfill topcover constructions. Instructions for planning and design. (in Finnish) | Tech | - Technical guidance on use of paper sludge in landfill top cover construction.<br>- Classification of materials | |

**Table 11 Cont. Overview of selected Nordic reports on potential waste materials for top cover. Värmeforsk reports can be down loaded from *www.varmeforsk.se*.**

| Top cover layer | Alternative materials | Examples of Nordic reports | Topic | Focus | Scale of material studies |
|---|---|---|---|---|---|
| Mineral layer | Fly ashes and sewage sludge | Carling M., Håkansson K., Mácsik J., Mossakowska A., Rogbeck Y. 2007. Flygaskastabiliserat avloppsslam (FSA) som tätskiktsmaterial vid sluttäckning av deponier – en vägledning. Svenskt Vatten AB. Rapport 2007-10. (www.svensktvatten.se) | Tech<br>Env | - Instruction manual aimed for those who are planning closures of a landfill with a mixture of fly ash and sewage sludge and need guidance to plan, carry out and control the liner construction | - Report includes performance characteristics from 4 case studies (including examples of properties to be monitored) |
| | | Mácsik, J., Rogbeck, Y., Svedberg, B., Uhlander, O. & Mossakwska, A., 2003. Fly ash and sewage sludge as liner material – Preparations for a pilot test with fly-ash stabilised sewage sludge as landfill liner. (Linermaterial med aska och rötslam – Underlag för genomförande av pilotförsök med stabilierat avloppsslam som tätskiktsmaterial). Värmeforsk rapport 837. In Swedish. | Tech<br>Env | - Development of recipes for a liner material based on bio fly ash and sewage sludge<br>- Six mixtures have been tested in laboratory (un-drained shear strength, permeability, compression strength) | - Preparatory work for field study |
| | | Mácsik, J., Maurice, C., A., Mosskowska, A. & Eklung, C., 2005. Pilotförsök med flyg-askastabiliserat avloppslam (FSA) som tätskikt. Värmeforsk rapport 942. | Tech<br>Field | - Development of recipes based on mixtures of ash and sewage sludge<br>- Evaluation on suitability of ash stabilised sewage sludge | - Field test carried out on landfill (1500 t)<br>- Follow-up time: 6 months<br>- Sudies focussed on leachability, technical durability, water permeability and experience from construction and design |

**Table 11 Cont. Overview of selected Nordic reports on potential waste materials for top cover. Värmeforsk reports can be down loaded from *www.varmeforsk.se*.**

| Top cover layer | Alternative materials | Examples of Nordic reports | Topic | Focus | Scale of material studies |
|---|---|---|---|---|---|
| | Fly ashes and sewage sludge –cont. | Mácsik, J., Maurice, C., A., Mosskowska, A. & Eklung, C. & Erlandsson, Å. 2007. Follow-up – Installed liner construction at Dragmossen waste site (Uppföljning – Kontroll av tätskiktskonstruktionen på Dragmossens deponi). Värmeforsk rapport 1011. In Swedish | Tech Field | - Focus on technical performance, geotechnical parameters (e.g. permeability)<br>- Environmental monitoring of drainage water<br>- Aspects of concern in full-scale operation pointed out | - Follow-up of technical performance of pilot study started in 2004 |
| | | Carling, M., Ländell, M., Håkansson, K. & Myrhede, E. 2006. Covering of landfills with ash and sludge – experience from three field tests (Täckning av deponier med aska och slam – erfarenheter från tre fältförsök). Värmeforsk rapport 948. In Swedish. | Tech Field | - Field tests where working methods (mixing, spreading, packing, compaction) in use of ash-sludge mixtures have been evaluated | - Field tests with follow-up of technical and environmental performance (e.g. degradation of material, gas monitoring, quality of drainage water) |
| | | Carling, M., Håkansson, K., Mácsik, J., Mossakowska, A. & Rogbeck, Y. 2007. Instruction manual – Fly ash stabilised sludge (FSS) as liner material. (Vägledning: Flygaskastabiliserat avloppsslam (FSA) som tätskikt). Värmeforsk 1010. In Swedish | Gen | - General recommendations on use of fly ash stabilised sludge<br>- Overview of experience gained in projects | |
| | | Bäckström, M. & Karlsson, U. 2006. Ash and sludge covering of mine waste – Final report (Aska och rötslam som tät- och täckskikt för vittrat gruvavfall – Slutrapport). Värmeforsk 960. (in Swedish) | Env, Field | - Chemical characterization of materials used for covering of a mine deposit<br>- Monitoring of drainage from mine deposit | - Full-scale use of ash and sludge as top cover material of mine deposit |
| | | Bäckström, M., & Johansson, I. 2004., Ash and sludge covering of mine waste (Askor och rötslam som täckskikt för gruvavfall). Värmeforsk. Rapport 855. In Swedish | Env Field | - See above. | - See above (report includes an hydrological description of mine deposit area) |

**Table 11 Cont. Overview of selected Nordic reports on potential waste materials for top cover. Värmeforsk reports can be down loaded from *www.varmeforsk.se*.**

| Top cover layer | Alternative materials | Examples of Nordic reports | Topic | Focus | Scale of material studies |
|---|---|---|---|---|---|
| | Fly ashes and sewage sludge –cont. | Wikman, K.,.Berg, M., Andreas, L., Lagerkvist., A., Jannes, S., Tham, G. & Sjöblom, R. 2003. Grouting of fly ash in sanitary landfills (Injektering av flygaska i hushållsdeponi).Värmeforsk 830. In Swedish. | Field<br>Tech | - Technical performance in use of fly ash slurries for prevention of settlements<br>- Cost evaluation for method | - Pilot study: 100 tons of fly ash mixture have been injected |
| Mineral layer cont. | Paper sludges are water-containing sludges from pulp and paper plants containing fibres and filling material | Stenmarck, Å. & Sundqvist, L-O, 2006. Användning av täta oorganiska restprodukter som tätskikt i deponier. IVL rapport 1665. www.ivl.se | Field<br>Tech<br>Env | - Comparison of technical and environmental compatibility of 6 waste materials (ashes from paper industry, green liquor sludge | - Pilot test (5 m x 5m) carried out<br>- Follow-up time: 3 years<br>- Studies focused on technical properties (water permeability) and leachability |
| | | Wikman, K., Svensson, M., Ecke. H. & Berg, M., 2005. Nedbrytningshastigheten för tätskikt uppbyggda av slam och aska. Värmeforsk rapport 945. | Env<br>Lab | - Study on degradability of organic material in 2 mixtures of ash and sewage sludge and influence on water permeability | - Laboratory study (using permeater) on change of TOC in leached material and material before and test<br>- Test duration (permeater): 300 days<br>- Recommendations for field tests |
| | | Wikman, K. Svensson, M., Ecke, H. & Berg, M., 2005. Nedbrytningshastigheten för tätskikt uppbyggda av slam och aska. Värmeforsk rapport 943. | | - See above | - |
| | | Munde, H., Svedberg, B. Macsik, J., Maijala, A., Lahtinen, P., Ekdahl, P. & Néren, J., Handbok. Flygaska i mark- och vägbyggnad. Värmeforsk rapport 954. | ? (only summary available?) | - ? | - ? |

**Table 11 Cont. Overview of selected Nordic reports on potential waste materials for top cover. Värmeforsk reports can be down loaded from *www.varmeforsk.se*.**

| Top cover layer | Alternative materials | Examples of Nordic reports | Topic | Focus | Scale of material studies |
|---|---|---|---|---|---|
| Mineral layer cont | Foundry sands (especially bentonite containing sands) | Ekvall, A.,& von Bahr, B. 2004. Environmental assessment of foundry sand and bottom ash (Sammanställning av genomförda kemiska analyser och tester for gjuterisand, bottenaska och stenmjöl, samt jämförelser med olika bedömningsgrunder.) SP rapport 2004:12. Bygg och mekanik. Borås 2004. In Swedish. (to be ordered from www.sp.se ) | Env | - Chemical characterisation (incl. toxicity tests) of 7 foundry wastes, 2 quarry dusts, 1 bottom ash from wood, 1 mixture of mesagrus, grönslutsslam, ash<br>- Development of a model based on total content for assessment of environmental applicability | - Material study |
| | | Orkas J., Vehmas, M., Wahlström, M. & Laine-Ylijoki, J. (1999).Utilization and disposal of foundry sand – Part 1. TKK-VAL-1. Helsinki University of Technology, Espoo, Finland 1999. 40 p. + App.12 p. *(in Finnish)*<br><br>Orkas J., Vehmas, M., Wahlström, M. & Laine-Ylijoki, J. (2001).Utilization and disposal of foundry sand – Part 2. TKK-VAL-1. Helsinki University of Technology, Espoo, Finland 2001. 48 p. + App.14 p. *(in Finnish)* | Env<br>Tech | - Chemical characterisation, study on quality variations<br>- Recommendations for acceptance criteria for use of bentonite foundry waste in top cover<br>- Recommendation for quality programme for foundry waste | - Material study<br>- Field studies |
| | Steel slag | Herrmann, I, Andreas, L. ; Lidström-Larsson, M. , Ecke, H.,Lagerkvist, A. (2006).Reuse of Steel Industry Slag in a Landfill Top Cover. / In: Abstract proceedings of the 4th Intercontinental Landfill Research Symposium. Luleå : Luleå University of Technology / Civil and environmental engineering / Waste science and technology, 2006. p. 88-89 (Teknisk rapport / Luleå tekniska universitet; 2006:5). | Tech | - Hydraulic properties of mixtures of ladle slag (LS) and electric arc furnace slags (EAFS) | - |

**Table 11 Cont. Overview of selected Nordic reports on potential waste materials for top cover. Värmeforsk reports can be down loaded from *www.varmeforsk.se*.**

| Top cover layer | Alternative materials | Examples of Nordic reports | Topic | Focus | Scale of material studies |
|---|---|---|---|---|---|
| Gas drainage layer | eg. MSWI slag for certain landfills | Discussed in Finland, no public report available | | - | - |
| Primary cover of disposed waste | Lightly contaminated soil | No public report | | - | - Full-scale practice in Finland |
| Filling of mines | Oother application | Nordström, E., Holmström, M. & Sandström, T. 2004. Användning av askor från förbränning med returpap-persslam inom gruvindustrin. Värmeforsk rapport 862 | Env<br>Tech<br>Lab/Field | - Development of recipes for ash mixtures<br>- Evaluation on suitability of ashes as filling material for mines | - Laboratory tests on recipes (leaching test, compression strength measurements etc)<br>- Pilot test carried out for some technical parameters |

**Table 12. Overview of selected Nordic reports including characteristics or experiences of some waste materials supplementary to Table 11. (note the focus of listed reports is not specifically on use of materials in top cover.**

| Waste material | Type of usage | Examples of Nordic reports | Focus | Remark |
|---|---|---|---|---|
| Wood ash | Fertiliser for forest soil | Westling, O., Larsson, P.-E., 2006. Översättning av resultat från asklakningsförsök i laboratorium till fältförhållanden. IVL Rapport B 1660 (in Swedish) www.ivl.se | - Development of laboratory test for description of leaching of nutrients and acid neutralisation capacity in field conditions<br>- Study on 3 ashes and limestone | - Leaching of metals not included in study |
| | Fertiliser for forest soil | Zetterberg, T., Akselsson, C., Westling, O. 2006. Markvattenkemiska effecter vid spridning av aska på skogsmark. Slutrapport från ett 10-årigt dosförsök | - Optimisation of doses for use of ash as fertiliser of forest soil<br>- Follow-up of field tests (focus on acid neutralisation capacity (hydrogen ion) and nutrients (Ca, Mg, K, Al, Nitrates, Sulphate, Chloride, Sodium, Mangan) | - Leaching of metals not included in study |
| Ashes from energy production | General | Bendz, D., Wik, O.I, Elert, M, Håkansson, K., 2006. Environmental guidelines for re-use of ash in civil engineering applications. Värmeforsk rapport 979. | - Proposal for common environmental guidelines for reuse ash in civil engineering applications<br>- Project focused on a limited set of substances (naphthalene, bens(a)pyrene, antimony, selen , arsenic, lead, copper, chrome, mercury, nickel, zinc, fluoride, chloride and sulphate<br>- Development of models addressing health and environmental risks associated with spreading of particles and exposure of dust, oral intake, dermal contact and intake by vegetables or wild grown berries, health risk owing to consumption of groundwater, and health and environmental risks of the post-use phase.<br>- Proposal for evaluation of results | |
| | Oivil engineering | Wilhelmsson, A., & Paijkull, M., 2003. Using waste for construction purpose – Environmental legal aspects regarding recycling of waste. Värmeforsk rapport 839. | - Overview of steps in the procedures for environmental approval for use, important stakeholders to be involved and other aspects to be taken into account in reuse of materials<br>- Report includes case studies on use of waste (e.g. experience in use of sludge in top cover) | |

**Table 12 Cont. Overview of selected Nordic reports including characteristics or experiences of potential materials for top cover.**

| Waste material | Type of usage | Examples of Nordic reports | Focus | Remark |
|---|---|---|---|---|
| Fly ashes | Civil engineering | Mácsik, J., Svedberg, B., Lenströmer, S. & Nilsson, T. 2004. FACE. Fly ash in civil engineering stage 1: inventory/application. Värmeforsk report 870 (in Swedish) | - Study of geotechnical properties of nine different ashes from incineration of bio fuels<br>- Classification of materials based on geotechnical properties | |
| Bottom ash from municipal waste incineration | Civil engineering | Arm, M., 2006. Handbok. Slaggrus i väg- och anläggningsarbeten. SGI. Information 18:5. www.swedgeo.se | - Review of geotechnical and environmental characteristic of bottom ash for use of material in civil engineering<br>- Key issues of concern in use of material<br>- Rreport on experiences from cases where bottom ash has been used as a construction material | |
| | Civil engineering | Lind, B., Larsson, L., Gustafsson, J-P., Gustafsson, D., Ohlsson, S-Å, Norrman, J., Arvidson, O. & Arm, M., 2005. Energiaska som vägbyggnadsmaterial – utlakning och miljöbelastning från en provväg. SGI. Varia 557. In Swedish | - Development of methods for evaluation of long-term leaching of wastes in road constructions<br>- Study includes characterisation of waste material both in respect to inorganic and organic contaminants<br>- Field study (constructed in 2001)<br>- Geochemical modelling of transport of contaminants | |
| Iron sand | Ccivil engineering | Kvarnström, B. 2005. From waste to profitable product. Own control and product marking of iron sand at New Boliden Rönnskärsverken. Examensarbete 2005: 087 CIV. | - Proposal protocol scheme for quality control of iron sand for fulfilling quality demands<br>- Note: no specific information on suitability for use in top cover presented, information of general properties of iron sand | |
| Potential waste materials | Civil engineering | Wik, O., Lindeberg, J. Nilsson Påledal, S. 2003. Inventering av restprodukter som kan utgöra ersättningsmaterial för naturgrus och bergkross i anläggningsbyggnad | - Review of material characteristics (origin, amounts produced, potential use) | |
| | Civil engineering | Lahtinen, P., Kolisoja, P.,Kuula-Väisänen, P., Leppänen, M., Jyrävä, H., Maijala, A. & Ronkainen, M. 2005. Proposal for a UUMA development programme. Suomen ympäristö 805, Ympäristönsuojelu, s. 121. ISBN 951-731-354-3 (PDF). (report in Finnish) | - Review of material characteristics (origin, amounts produced, outlook, potential use) | State-of-the-art report for a Finnish development programme on waste materials in earth construction |
| | Use as top cover | Engström, H. & Ulwan, Å. 2005. Sluttäckning av avfallsdeponier ur ett nationellt perspektiv. Traditionella material eller restprodukter – miljömässiga och ekonomiska konsekvenser. Examensarbete. Uppsala universitet. (in Swedish) | - Review of material characteristics (origin, amounts produced, potential use as top cover material, costs) | |

## 5.3 Examples of typical materials

A summary of the typical properties of some materials and current experience from use is given in the following material cards. The data has been collected from:

- available reports, environmental permits for use
- contacts with material producers, landfill operators, authorities
- presentations at seminars.

**MATERIAL CARD -PAPER SLUDGE**

| | |
|---|---|
| Origin | Paper sludges are water-containing sludges from pulp and paper plants containing fibres and filling material. They are usually formed in process fault situations.<br>There are three types of paper sludges:<br>Group A: paper sludges from mechanical paper processing paper plants<br>Group B: paper sludges from pulp paper plants<br>Group C: sludges from de-inking process |
| Technical properties | Density: 360-600 kg/m$^2$<br>Water content 120-220 %<br>Optimal water content: 40-100 %<br>Water permeability: 5 x 10$^{-8}$ – 5 x 10$^{-9}$ m/s<br>Plasticity limit: 94-147 %<br>Flow limit: 218-285 %<br>Thermal conductivity: 0.6-0.7 W/mK<br>Compression index, $C_c$: 1.2-1.8<br>Consolidation factor, $C_v$: 4-16 m$^{2/}$/a<br>Undrained shear strength: 10-35 kPa<br>Cohesion, $C^{'}$: 13-16 kPa<br>Friction angle, Φ: 23-31° |
| Environmental properties | Low metal content<br>Leaching of DOC<br>Organic content: 55-80 %<br>Gas formation (Sulphur compounds) in anaerobic conditions |
| Applications in landfill construction | Top covers: mineral layer<br>Bottom layers |
| Processing needs | Homogenisation<br>Addition of additives (fly ash) |
| Experiences | High water retention capacity<br>Water permeability decreases as the organic matter content decreases (material becomes tighter)<br>Biological degradation is to be taken into account in the structure design<br>In mineral structures freezing is to be prevented<br>For demonstrations and usability evaluated case by case |

| MATERIAL CARD - FLY ASH FROM COAL, PEAT, WOOD COMBUSTION | |
|---|---|
| Origin | The composition of fly ashes from energy production varies significantly depending on boiler type and used fuels. Fly ash from coal plants is fine powdery material with a grain size of 0.002-0.1 mm corresponding therefore to loam. The properties of co-combustion (peat, wood etc.) fly ashes are in principal similar to coal fly ashes, but the quality variations are usually more severe. |
| Technical properties | Requires stabilisation<br>Powdery, low module self-hardening material<br>Frost-susceptible<br>Hydraulic when dry<br>High compressibility<br>Significant quality variation<br>Loose structure during rain or irrigation<br>Corrosive and dusty |
| Environmental properties | Contains metals and salts<br>Leaching of Mo, Cr, V, Se, As and salts<br>Dust |
| Applications in landfill construction | Embankments and filling<br>Blinding structure<br>As stabilised in mineral layers of top covers |
| Processing needs | Storage as dry in silos<br>Addition and mixing of additives (paper sludge, desulphurisation gypsum, other activators) |
| Experiences | Right water content during the construction important<br>High quality variations lead to case-by case<br>Water contact should be avoided during the storage<br>Repeating freezing-thawing cycles, salts, high humidity and load break up bonds<br>Low hardening temperature slows down consolidation and reduces compressibility<br>Too high load during the hardening breaks the structure and bonds<br>Construction possible only on dry conditions<br>The structure is to be covered during the same day |

| MATERIAL CARD - SURPLUS FOUNDRY SANDS | |
|---|---|
| Origin | Foundries use in their process 100 % quartz sand, which is recycled in the process several times before it is discharged from the process as surplus sand. The main types of foundry sands are green sand, furan sand, alkaline phenolic sand and sodium silicate sand. Green sand contains bentonite. Furan sand and alkaline phenolic sand contain residues of organic binders. |
| Technical properties | Green sand has low permeability |
| Environmental properties | Chromium content high, but Chromium is not usually in leachable form<br>PAH<br>Residues from organic binders (phenols and formaldehydes) |
| Applications in landfill construction | Embankments and filling<br>Blinding<br>Green sand also in mineral layers of top covers |
| Processing needs | Mixing with moraine |
| Experiences | Suitable for demonstrations<br>If the sand is not frost-susceptible it can be used in high embankment fillings |

| MATERIAL CARD - CONTAMINATED SOIL STABILISED WITH BITUMEN | |
|---|---|
| Origin | Soils contaminated with metals and a variety of organic compounds (excluding VOC's) |
| Technical properties | Significant quality variation (soil) |
| Environmental properties | Leaching tests have to be included in the initial test programme |
| Applications in landfill construction | Top cover: impermeable mineral layer |
| Processing needs | Soil is mixed in a mixing unit with a mixture of bitumen (temperature 150 °C) and cold water (cellular bitumen). Cold water added to hot bitumen creates bitumen foam whose volume is 20 times higher than the original volume. After water is evaporated, foam disappears and leaves the soil particles covered with bitumen. |
| Experiences | Soil material has to be homogenised before stabilisation<br>Water permeability $k < 1 \times 10^{-8}$ m/s can be reached if suitable soil material is available (measured max $k = 1 \times 10^{-10}$ m/s)<br>Can be compacted with sheep's-foot roller or smooth roller (10-15 cm layers)<br>Compaction index 90 % from the max compactness can be reached easily if water content is suitable<br>It is advisable to cover mineral layer with drainage layer material as soon as possible to prevent the drying of stabilised material |

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Engström, H. & Ulwan, Å. 2005. Sluttäckning av avfallsdeponier ur ett nationellt perspektiv. Traditionella material eller restprodukter – miljömässiga och ekonomiska konsekvenser. Examensarbete. Uppsala universitet.

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# Sammanfattning

*(Summary in Swedish)*

Syftet med detta projekt var att samla tillgänglig kunskap om avfallsmaterial som har använts i Norden som konstruktionsmaterial i sluttäckningen av deponier. Utgångspunkten vid planeringen av sluttäckningskonstruktionen är de allmänna rekommendationer för sluttäckningen ges i EU's Deponeringsdirektiv 1999/31 samt de specifika kraven som givits i det respektive nordiska landet. Målgruppen för denna rapport är prövnings- och tillsynsmyndigheter, avfallsproducenter, entreprenörer, konsulter samt andra berörda aktörer.

Förutsättningen för användning av avfall i sluttäckningen är att det finns tillförlitliga uppgifter både om de tekniska som miljömässiga egenskaperna hos avfallsmaterialet. I rapporten diskuteras kort kraven och betydelsen av olika materialegenskaper samt också andra aspekter som är viktiga vid bedömningen av funktionalitet hos hela sluttäckningskonstruktionen.

Viktiga aspekter vid bedömningen av tillämpbarheten av potentiella avfallsmaterial är:

- avfallsmaterialet uppfyller kvalitets- och funktionskraven
- kvalitetsvariationerna är kända och acceptabla
- avfallsmaterialets egenskaper på lång sikt är bedöms som tillförlitliga via pilot studier.

Denna rapport beskriver karakteristiska egenskaper hos de mest typiska avfallsmaterial som har använts i sluttäckningskonstruktioner i Norden. Därtill presenteras en förteckning om olika nordiska studier om materialegenskaper eller om erfarenheter i byggandet med avfallsmaterial.

# Appendix 1

An overview of existing requirements on top cover systems.

**Table 1. An overview of existing requirements on top cover systems in Nordic countries.**

| Country or area | National regulations | National policy | Recommendations and requirements | Remarks |
|---|---|---|---|---|
| Denmark | - Statutory Order on Landfills<br>- Aftercare of areas used for the landfill of waste and raw material extraction with a view to future exploitation in cultivation, Ministry of Agriculture | - Landfills not complying with the Landfill Directive have to be closed by 16. July 2009<br>- The competent authority may approve the continuation of a landfill after 15 July 2009 with reduced requirements for liner system and leachate collection<br>- Continuation is possible only if an assessment of environmental risks substantiates that reduced requirements do not give reason to potential hazards for soil, groundwater and, if relevant, surface water<br>- Final covering shall ensure that the landfill passes from the active phase to the passive phase as soon as possible<br>- The intention is that leachate from a landfill should be acceptable in the groundwater or surface water not later than 30 years after the closure of a landfill. | - Guidelines from the Danish Environmental Protection Agency No. 9/1997, Landfilling of Waste<br>- A tight, impermeable final cover is not accepted on landfills with active environmental protection systems<br>- The type and thickness of final cover must be chosen in accordance with the desired effect | - If cultivation layer is needed it should consist of an upper layer of 0.2 m of topsoil and a lower layer of 0.8 m of soil containing clay and silt<br>- The total thickness of the layers without root barriers should be ≥ 1.7 m |
| Faroes | | - Household waste and organic waste cannot be landfilled<br>- after the landfill is closed, the owner must take care of the maintenance, monitoring and control for at least 20 years<br>- New landfills or expansion of old landfills must comply with the landfill directive | - ≥1 m topsoil<br>- Grass must be used for landscaping | - Leachate water has to be monitored ( heavy metals, cond., pH)<br>- The soil around the landfill is monitored (heavy metals) |
| Finland | - Government Decision on Landfills (VNp 861/97) | - Old landfills (in operation in November 1999) must comply with the Landfill Directive by 1 November[t], 2007 if still in use<br>- The permitting authority may approve the continuation of a landfill after 1 November 2007 with reduced requirements for liner system and leachate collection<br>- Continuation is possible only if it is shown that reduced requirements do not cause any health or ecological risks or soil contamination | - Landfill sealing structures, Finnish Environment Institute, Environment Guide 36, 1998<br>- Guide for closing landfills, Finnish Environment Institute, Environment Guide 89, 2001<br>- Environmental acceptability of industrial by-products in landfill constructions, VTT Research Notes 2246/2004 | - Requirements can be reduced if it is shown that a landfill does not cause any health or ecological risks or soil/groundwater contamination |

**………………. continued**

| **Country or area** | **National regulations** | **National policy** | **Recommendations and requirements** | **Remarks** |
|---|---|---|---|---|
| Iceland | - | - New landfills can be constructed at the side of closed ones<br>- Old landfills will be monitored in a better way in connection with the monitoring scheme of new landfill<br>- Landfills not complying with the landfill directive have to be closed by 16 July 2009 | - No handbooks available<br>- ≥1 m topsoil; sand, stones, clay etc. or a combination<br>- Grass must be used for erosion protection and landscaping | - Contaminated soil has to be mixed with manure, leachate water has to be monitored (BTEX, oil, fat etc)<br>- Biofilter (woodchips) is allowed if smell is a problem |
| Norway | - - | - Landfills not complying with the landfill directive have to be closed by 16 July 2009<br>- During the passive phase the landfill owner shall take care of the maintenance, monitoring and control for at least 30 years. | - Standard recommendations to county governors with regard to requirements in permits for municipal landfills | - If waste contains organic material, top cover should be permeable enough to keep the water content of the waste at a sufficient level to maintain biological activity (decomposition)<br>- It should also enable oxidation of methane |
| Sweden | - Regulation 2001:512<br>- Sweden has implemented requirements that states the amount of water that may pass through the top cover (included the mineral layer) | - Landfills not complying with the landfill directive have to be closed as soon as possible and at the latest by the end of 2008. The competent authority may approve the continuation of a landfill after 1 January 2009 if the landfill has similar protection as the requirements in the directive and if there is no risk for human health or the environment.<br>- During the passive phase the landfill owner shall take care of the maintenance, monitoring and control for at least 30 years or for a longer time if the supervising authority finds that it is necessary. | - The water amount through the top cover system should not exceed 5 litres per square meter per year for landfills with hazardous waste and 50 litres per square meter and year for landfills with non-hazardous waste. The competent authority can give exceptions to the requirements of permeability if there is no risk for the environment and the human health | - Utilisation guidelines of waste is under preparation. Waste that contains more than 10% organic is not accepted at landfills since 2005, although some exceptions of waste have been made. |

**Table 2. An overview of existing requirements on top cover systems in Germany and the Netherlands.**

| Country/ Requirements | The Netherlands | Germany |
|---|---|---|
| National regulations | - EC Landfill Directive 1999/31/EC objectives are incorporated in the legislation | - German Federal Waste Disposal Ordinance<br>- Landfill Ordinance<br>- Ordinance on Landfills and Long Term Storages, 2002<br>- Ordinance pertaining to the recovery of waste at surface landfills and amending the Commercial Wastes Ordinance<br>- Ordinance on Environmental Compatible Storage of Waste from Human Settlements and on Biological Waste Treatment Facilities |
| National policy | - After closure of landfill, a system of eternal aftercare becomes effective<br>- Aftercare costs for operating landfills are covered by a fund created by the landfill operator and transferred to an aftercare organisation after closure | - Landfills not compliant with the Landfill Directive have to be closed by 2005 |
| Recommendations and requirements | - Manual for design and construction of caps for landfills, Ministry of Housing, Spatial Planning and Environment, Publikatiereeks Bodembescherming nr. 1991/4<br>- Guideline for landfill barrier construction, Ministry of Housing, Spatial Planning and Environment, Publikatiereeks Bodembescherming nr. 1993/2<br>- Guideline for the application of geomembrane to protect the environment, Ministry of Housing, Spatial Planning and Environment, Publikatiereeks Bodembescherming nr. 1991/5<br>- The construction of liners is subjected to a system of quality assurance<br>- The regulations do not describe specific liner materials, but provide a reference construction and specifications instead | - Technical Instructions on Waste Management, TA Abfall<br>- Waste Management Facts 11, Eignungsbeurteilung von unter Verwendung von Abfällen hergestellten mineralischen Deponieoberflächenabdichtungen, Staatliches Gewerbeaufsichtsamt Hildesheim, 2005<br>- Surface sealing system shall be constructed in accordance with presented standard structures or equivalent combination for different landfill classes |
| Remarks | - Natural clay in general does not meet the requirements of liner material<br>- Approved and applied alternatives are:<br>  - Mixtures of sand and bentonite<br>  - Mixtures of sand, bentonite and polymer (Trisoplast)<br>  - Geosynthetic clay (bentonite and geotextile)<br>  - Fine textured demolishing material, sludge, fly-ash and waterglass (HYDROSTAB)<br>- Two proposals for the environmental assessment framework for residuals:<br>  - Materials that are used above membrane must be assessed against Building Materials Decree and below membrane against Landfill Decree<br>  - Materials that are used in the supporting layer or under it must be assessed against Landfill Decree and above supporting layer against Building Materials Decree | - Alternatives for mineral sealing layer: asphalt, bentonite enhanced liner, geosynthetic clay liner, capillary barrier, polymer enhanced liner, water glass enhanced liner<br>- Alternatives for drainage layer: drainage mats<br>- Alternatives for flexible membrane liner: asphalt<br>- Waste material suitable for every component of a sealing system (except synthetic geoembranes) if neutral and permissible and fulfils needed engineering properties, primary use below sealing component<br>- Used waste materials in mineral seals: clay slag (ironworks/steelworks slag, clay flour, bentonite), DOM (loam, grate slag from incinerator, water glass, sewage sludge (sewage sludge prohibited nowadays)), HYDROSTAB, dredged material Gas collection layer/adjusting layer: recycled glass, processed demolition waste<br>- Recultivation layer: soil material mixed with waste (list of permitted values for the pollutant contents and eluate concentrations are given, exceptions are possible) |

# Appendix 2

## Standardised tests for evaluating environmental acceptability of sealing materials

| Construction layer | Property | Suitable methods | Test information |
|---|---|---|---|
| All layers | Total content | - EN 13656 Microwave assisted digestion with acids<br>- EN 13657 Digestion using aqua regia<br>- prEN 15309: X-ray fluorescence method<br>- prCEN/TR 15018: alkali-fusion techniques<br><br>Note! Important to ensure the applicability of chosen method | - Identification of harmful compounds to be further checked |
| All | Organic contaminants | - Methods developed for soil, sludge | - Identification of harmful compounds to be further checked |
| All | Dry matter | - PrEN 14346 Determination of dry matter at 105 °C. | - Basic parameter in calculations of release, part of basic characterisation study |
| All | Organic content | - EN13137 Determination of Total Organic Carbon<br>- prEN 15169 Determination of loss of ignition at 550 °C | - Part of basic characterisation, important in studies of biodegradability |
| Mineral layer at landfill bottom | Leaching behaviour | - Cell test (ENVIR 007) or percolation test prCEN/TC 14405 (NT ENVIR 002) | - Simulate leaching from a tight material in which water percolates through the material layer. Results can be used in assessment of applicability. |
| Surface sealing, drainage layer | Leaching behaviour | - percolation test prCEN/TS14405, (NEN 7343, Nordtest NT ENVIR 002)<br><br>Note ! CEN-method describes testing condition in more detail than NEN 7343 and ENVIR 002) | - Simulate leaching from material, in which the materials percolates through the material. Results used in assessment of applicability. |
| Mineral layer at the surface sealing | Leaching behaviour | - modified diffusion test NVN 7347, or percolation test prCEN/TS 14405 (NEN 7343, NT ENVIR 002) or cell test (ENVIR 007) | - Simulate leaching from surface through diffusion or dissolution (construction stable and water permeability less than $10^{-9}$ m/s) or percolation test or cell test (cracks in the constructions or water permeability over $10^{-9}$ m/s). Results used in assessment of applicability. |
| All | Leaching behaviour | - pH-dependence methods ANC-prCEN/TC14429 or pH-static test prCEN/TS 14997 | - Simulate the influence of pH on leaching behaviour |
| Mineral layer in the bottom sealing or surface sealing | Biodegradability | - OECD method 301 F<br>- ISO/DIS 14853 or ASTM method D5210<br><br>Note! Methods developed for determination of biodegradation of chemicals and polymers | - Degradation of organic fraction in aerobic or anaerobic testing conditions by use of microbes |