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Chapter 2.3

Mineral Liners for Bottom Barrier Systems

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1 Introduction

Mineral bottom liners must have a very low hydraulic conductivity and maintain this characteristic long term under the chemical, biological, temperature and moisture conditions at the base of the waste body. They should have the capability of adsorbing contaminants, and their shear strength must be sufficient to provide for adequate slope stability of the deposited waste pile under short and long term conditions. Many natural clayey soils, such as clays of high, medium or low plasticity, silty clays or clayey silts meet these requirements. Their characteristics with respect to sealing function and to shear strength depend on their composition, in particular on the amount and type of clay minerals present. Subsequently, the term “compacted clay liner (CCL)” is used for all mineral liners which predominantly consist of the fine grained soils mentioned: clays, silty clays and clayey silts.

Well graded coarse grained soils may also serve as mineral liners, provided they are homogeneous, well compacted and contain a sufficient amount of fines (silt- and clay size particles) to achieve the required very low hydraulic conductivity. In general, for engineered coarse grained mineral liners it is necessary to add the required fraction of fines and to mix the sealing material in place or in plant. Since the required quality and homogeneity of the mineral liner can be achieved reliably by mixing in plant rather than by mixing in place, only mixed in plant coarse grained well graded mineral liner material (CGL) is treated in detail in the following sections.

2 Mineral Bottom Liners

For the placement of mineral bottom liners and for their compaction with heavy equipment, the subsoil surface must be well prepared: removal of trees, roots and any other deleterious material, grading, compaction and/or ground improvement. The surface of the subsoil has to be modelled according to the requirements of the leachate collection system (Chapter 3.2).

2.1 Compacted Clay Liners (CCL)

The clayey soil to be used for a bottom liner has to be submitted to suitability testing well in advance of the construction execution (section 3.1). The requirements have to be specified according to the needs of the particular project and/or pertinent regulations. The following criteria given as an example for the constructed mineral bottom liner have been applied successfully at many landfill construction sites in Europe and in North America (Canada):

Requirements for compacted clay bottom liners (CCL), example:

- Hydraulic conductivity $k \leq 1 \cdot 10^{-9}$ m/s, preferably $< 5 \cdot 10^{-10}$ m/s
- Compatibility with leachate (no shrinkage under exposure to leachate)
- Grain size distribution: clay fraction (< 2 µm) ≥ 20 % by weight)
- Clay minerals: ≥ 20 % by weight of clay fraction < 2 µm shall consist of clay minerals (alternatively minimum cation exchange capacity of about 10 milli-equivalents (meq) per 100 g of soil, to provide for contaminants-adsorption capacity)

Requirements for execution of compacted clay liners (CCL):

- Thorough kneading compaction by pad-foot or club-foot rollers
- Clods of clay must be destroyed, no inter-clod voids are permitted
- Degree of compaction: ≥ 95 % of Standard Proctor density
- Placement water content: ≥ 2 % above Standard Proctor optimum water content, (slightly above plastic limit w_p)
- Free of natural or compaction induced fractures
- Homogeneous, uniform distribution of minimum hydraulic conductivity values (k)
- Liners should be immediately covered to prevent shrinkage.
- Desiccated liner sections have to be removed, pulverized, rewetted and re-compacted.
- Liner sections must be protected from frost.
- Maximum thickness of compacted lifts: 0.25 m (Thickness of lifts must be kept small to achieve thorough homogenisation and adequate compaction of clay)

Examples of construction equipment used for the placement of CCL are shown on Photos 1 to 4 in the annex.

The minimum thickness of mineral bottom liners is often prescribed by national regulations. The European Landfill Directive requests a minimum thickness of 0.5 m with or without a geomembrane, depending on the type of waste to be disposed of. German practice requested:

- 0.50 m mineral liner for inert waste landfills (without geomembrane)
- 0.75 m mineral liner for domestic waste landfills with geomembrane
- 1.50 m mineral liner for hazardous waste landfills with geomembrane

2.2 Compacted, Mixed In-plant, Coarse Grained Mineral Liners (CGL)

Mixed in plant coarse grained well graded mineral liner material with a small amount of clay (CGL) has the following advantages over compacted clay liners:

- Higher dry density ρ_d [g/cm^3]
- Lower porosity n
- Higher shear strength S [kN/m²]
- Lower hydraulic conductivity k [m/s]
- Lower diffusion coefficient D [cm²/s]
- Properties can be controlled by selecting components, mixing ratio and processing
- Placement at frost temperatures is possible
- Not vulnerable to desiccation cracking

If suitable clayey soils are not available at a site or if one or more of the above mentioned advantages over clayey soils are given, mixed in-plant coarse grained well graded mineral liner material (CGL) may be used.

The components and the mixed, coarse grained sealing material to be used for a bottom liner have to be submitted to suitability testing well in advance of construction execution (section 3.2). The requirements have to be specified according to the needs of the particular project and/or pertinent regulations. The following criteria are given as an example for the constructed mineral bottom liner (CGL):

Requirements for mixed in-plant, coarse grained well graded mineral liners, example:

- Hydraulic conductivity $k \leq 1 \cdot 10^{-10}$ m/s
- Compatibility with leachate (no deterioration of mineral grains under exposure to leachate, no increase in permeability due to cation exchange of clay minerals)
- Grain size distribution: Gradation curve follows the Fuller-parabola

- Clay fraction (< 2 μm) ≥ 3 % by weight (typically 3 to 10 %), consisting of ≥ 80 % by weight of clay minerals (one or more clay minerals may be chosen)

Requirements for execution of mixed in-plant, coarse grained well graded mineral liners (CGL):

- Mixed in plant
- Thorough compaction by vibratory rollers
- Degree of compaction: ≥ 100 % of Standard Proctor density
- Placement water content: near or slightly above Standard Proctor optimum water content (to be determined in suitability tests)
- Homogeneous, uniform distribution of minimum hydraulic conductivity values (k)
- Liners should be covered to protect them from adverse weather conditions

Examples of construction equipment used for the placement of CGL are shown on Photos 5 to 7 in the annex.

Minimum thickness of bottom liners, example:

- 0.25 m liners for domestic waste landfills with or without geomembranes
- 0.50 m composite liners for hazardous waste landfills with or without geomembranes

There are methods to improve the sealing properties of in-plant processed mineral liners by using chemical additives such as special silanes and/or waterglass (sodium silicate). If additives are used their effect on the mineral sealing material (function and compaction properties) has to be investigated by suitability tests (LAUF & MÜLLNER, 1993).

3 Suitability Testing

3.1 Compacted Clay Liners (CCL)

The suitability of clayey soils which serve as bottom barrier material has to be determined by testing. The parameters to describe soil type and composition, placement - compaction criteria and performance properties have to be established by soil mechanic laboratory tests. In addition, the adequacy of the placement and compaction technology and equipment should be examined in a test field (section 4). Test results obtained on undisturbed samples from the test field can be used as the basis for production quality criteria.

For the description of soil type and composition, the tests given in Table 1 are to be carried out and parameters determined accordingly. Sampling at the borrow pit has to account for variations in soil properties at the site. A sufficient number of samples have to be obtained and tested.

Table 1: Identification tests

Test / determined parameter	Symbol	German standard*
Grain size distribution		DIN 18123
Water intake	w_b	DIN 18132
Consistency limits liquid limit plastic limit shrinkage limit	 w_l w_p w_s	 DIN 18122-1 DIN 18122-1 DIN 18122-2
Plasticity index $I_p = w_l - w_p$	I_p	DIN 18122-1
Activity (I_p / % by weight finer than 2 μm)	I_A	DIN 18122-1
Organic content		DIN 18128
Density of soil particles	ρ_s	DIN 18124
Calcium carbonate content		DIN 18129
Natural water content	w	DIN 18121-1
Density	ρ	DIN 18125-1

* Transitionally German standards are noted in Tables 1 to 3 until European / International CEN ISO standards are finally available.

The hydraulic conductivity, the shear strength and the compressibility of a soil depend on the composition and state of the soil. The state of a soil is primarily expressed by its density, porosity and water content. For material to be used in barriers, the relationship between density and water content (Figure 1) has to be determined by compaction testing, using either the Standard Proctor Test or the Modified Proctor Test (DIN 18127). The methods differ in the amount of compaction energy applied to the soil sample. It must be stated in the test report, whether Standard or Modified Proctor energy was applied. On the basis of the compaction test results the recommended placement water content w and the minimum dry density ρ_d to be achieved in the production of the barrier can be specified. Experience has shown, that the placement water content w should be near or slightly above the plastic limit w_p, in order to facilitate efficient kneading compaction and avoid macro-pores due to crumbling and cracking of the soil which is likely to occur when the soil reaches a semi-solid state during compaction. For this reason the placement water content should lie about 2 to 4 % above the Standard Proctor optimum water content w_{Pr} (recommendations on construction see chapter 2.5).

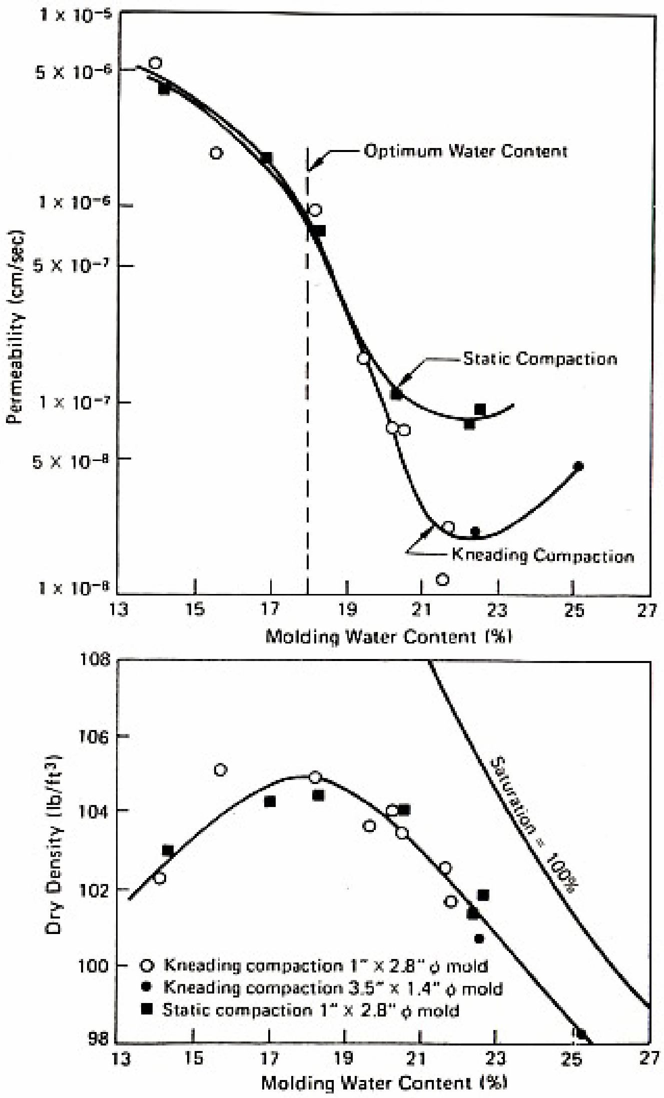

Figure 1: Influence of compaction method and molding water content on the hydraulic conductivity of silty clay. Constant compactive effort was used for all samples (from MITCHELL & SOGA, 2005).

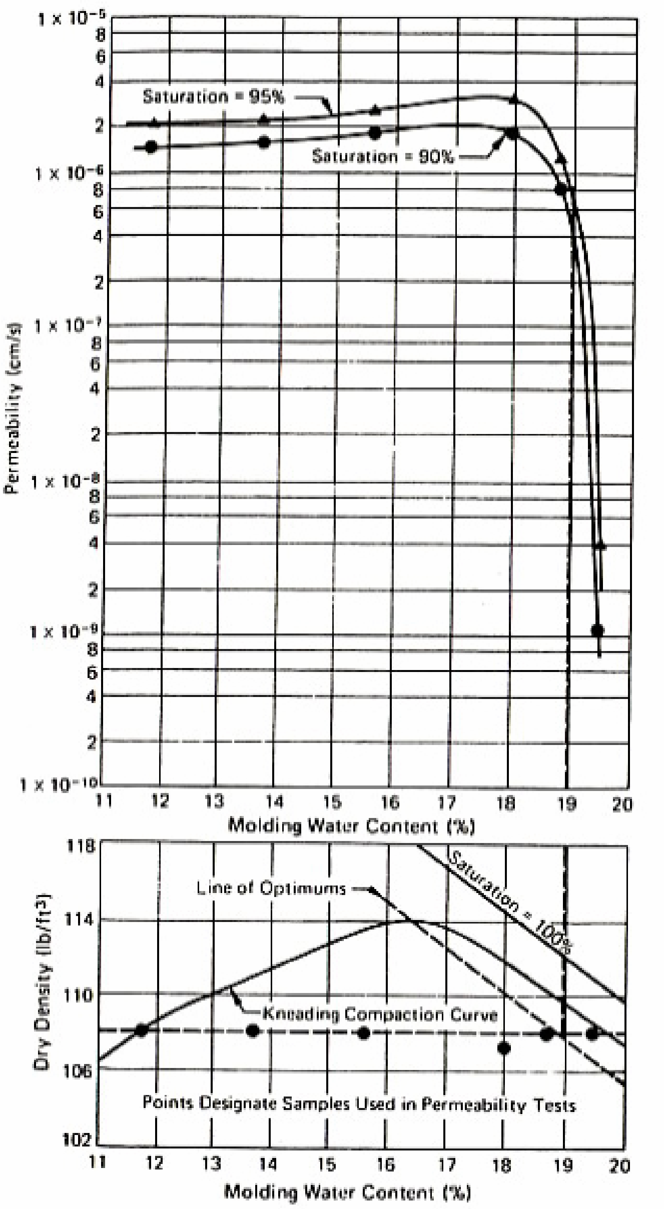

Figure 2: Hydraulic conductivity as a function of compaction water content for samples of silty clay prepared to constant density by kneading compaction (from MITCHELL & SOGA 2005)

For the design of the landfill structure the performance properties of the barrier soil have to be known. They are determined on soil samples compacted to the recommended dry density at the recommended placement water content. It is advisable, to carry out the tests according to Table 2 not only for the specified compaction criteria, but also for a set of water content – density values below specification, in order to be able to judge the importance of probable deviations from specification with respect to hydraulic conductivity and shear strength.

Table 2: Performance tests

Test	Parameter	German standard*
Oedometer test	Compression parameters for settlement prediction	DIN 18135 (in progress)
Swelling test	Swelling parameters	DIN 18135 (in progress)
Triaxial or direct shear test	Drained shear strength parameters φ'; c'	DIN 18137-1, -2, -3
Uniaxial compression test	Undrained shear strength c_u	DIN 18137-1, -2, -3
Permeability tests	Hydraulic conductivity k	DIN 18130-1

* Transitionally German standards are noted in Tables 1 to 3 until European / International CEN ISO standards are finally available.

Since the chemistry of the liquid may have an influence on the hydraulic conductivity, the quality of the water used for testing has to be known and, unless experience with the clayey soil in question and the properties of the anticipated leachate exist, the sensitivity of the clay with respect to chemicals representative of critical components of the leachate should be determined. Experience has shown that leachate from domestic waste does not adversely affect the hydraulic conductivity of inactive clays ($I_A < 0.75$); it rather leads to a decrease of the hydraulic conductivity k with time. However, some active clays ($I_A > 1.25$), tend to shrinking at the presence of certain cations or water soluble organics. If such conditions cannot be excluded, special attention has to be paid to the clay mineralogy and the chemistry of the anticipated leachate. It may be necessary in such cases to perform additional permeability tests using special test liquids instead of water for the determination of the hydraulic conductivity. The advice of an expert in clay mineralogy may be needed in such cases.

Hydraulic conductivity tests on inactive clays ($I_A < 0.75$) and probably on clays with normal activity ($0.75 < I_A < 1.25$) can be carried out with flexible walls in triaxial cells or with fixed walls in oedometer-type cells. If active clays ($I_A > 1.25$) are tested, fixed wall cells should be used to detect any tendency for to shrinkage of the clay. In this case, the soil samples should not be too thick, to facilitate an exchange of the sample pore fluid volume at least twice during the test. The tests should be run as constant head permeability tests on samples with a high degree of saturation. The degree of saturation achieved during the test has to be determined and recorded. The hydraulic gradient i has to be recorded. It is recommended to execute constant head tests at $i = 30$.

The determination of soil-water characteristic curves SWCC (water retention curve) and hydraulic conductivity functions for unsaturated soils are beyond the scope of common suitability testing. Since clayey soils for bottom barriers in landfill applications are usually placed at high water content, saturated conditions are assumed for stability analyses, seepage and contaminant transport estimates (Chapter 2.2).

The determination of apparent porous media diffusion coefficients D_P for particular molecules or ions is also beyond the scope of common suitability testing for clayey soils which are used as mineral bottom seals.

3.2 Compacted Mixed In-plant Coarse Grained Mineral Liners (CGL)

The principles given in section 3.1 for suitability testing of material for compacted clay liners (CCL) apply to compacted mixed in-plant coarse grained mineral liners (CGL) as well. So this section supplements the previous section only in those details which are particular to CGLs.

The suitability of the components and of the mixture before placement has to be demonstrated by laboratory testing. Since the coarse gravel fraction imposes limitations on small scale tests in the laboratory, especially for performance tests emphasis is placed on field trials (section 4). The following suitability tests should be carried out (Table 3):

Table 3: Identification tests

Test / determined parameter	Symbol	German standard*
Coarse fractions (gravel, sand, silt):		
Grain size distribution of components		DIN 18123
Grain shape and –strength		DIN 4022
Density of soil particles	ρ_s	DIN 18124
Clay fraction:		
Water intake	w_b	DIN 18132
Consistency limits:		
liquid limit	w_l	DIN 18122-1
plastic limit	w_p	DIN 18122-1
shrinkage limit	w_s	DIN 18122-2
Plasticity index $I_p = w_l - w_p$	I_p	DIN 18122-1
Activity (I_p / % by weight finer than 2 μm)	I_A	DIN 18122-1
Organic content		DIN 18128
Density of soil particles	ρ_s	DIN 18124
Calcium carbonate content		DIN 18129
Natural water content	w	DIN 18121-1
Mixture: Grain size distribution (band width)		DIN 18123
Density	ρ	DIN 18125

* Transitionally German standards are noted in Tables 1 to 3 until European / International CEN ISO standards are finally available.

For the optimization of the sealing material, mixtures may have to be tested with different amounts of dry clay powder to be added (e. g. 3 %, 6 %, 9 %) and with clays from different sources with different dominating clay minerals (e. g. kaolinite, illite, montmorillonite, in special cases chemical additives may be added, see section 2.2).

Example of a CGL (Compacted mixed in plant coarse grained mineral liner)

Grain Size Distribution of **CGL "Chemoton"** andCCL

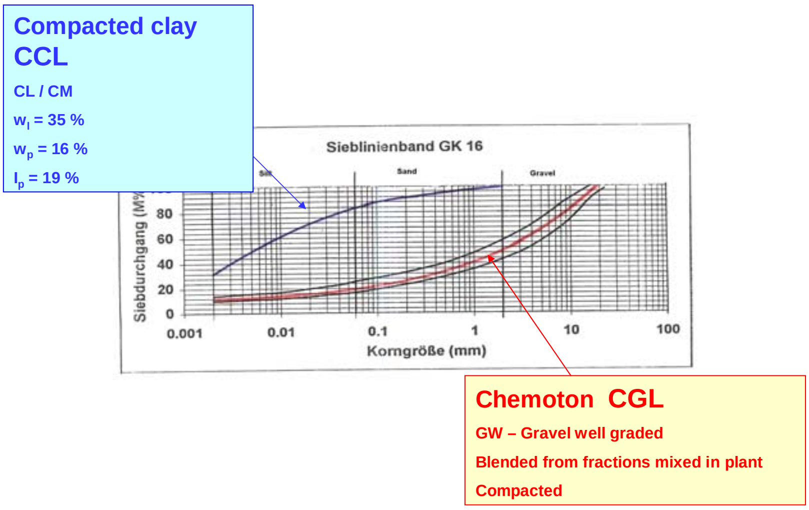

Figure 3: Grain size distribution of a CGL

As mentioned in section 3.1, the hydraulic conductivity, the shear strength and the compressibility of a soil depend on the composition and the state of the soil. In case of the coarse grained sealing material the compressibility is commonly of no concern and the shear strength has to be tested only, if the liner is placed on a steep slope. The hydraulic conductivity may be tested on large compacted samples in the laboratory for reference purposes. However, because it is impossible to obtain undisturbed samples from coarse grained liners in the field, permeability field trials are more important than laboratory tests, and the quality control tests have to be carried out as field tests (GDA E 5-9).

4 Field Trials

Preparation of a field trial for a mineral barrier has to be regarded as a large scale suitability test to demonstrate the following:

- Suitability of the mineral sealing material under site conditions (clayey soil or well graded coarse grained mixed in plant material)
- Suitability of the methods of extraction of clayey soils at the borrow pit, treatment and preparation
- Suitability of mixing process in case of mixed in plant material
- Suitability of the methods of placement and compaction
- Adherence to the requirements for permeability, water content and density of the mineral sealing material on a large scale basis
- Adherence to the requirements for surface finishing, especially for composite liners
- Establishment of reference parameters for quality assurance

The dimensions of the field trial have to relate to the design of the barrier, the earthworks equipment used and the requirements of the proposed field tests, sampling, measurements and observations. The gradient of the subgrade on which the field trial is placed must correspond to that of the actual structure. An example is given in Figure 4.

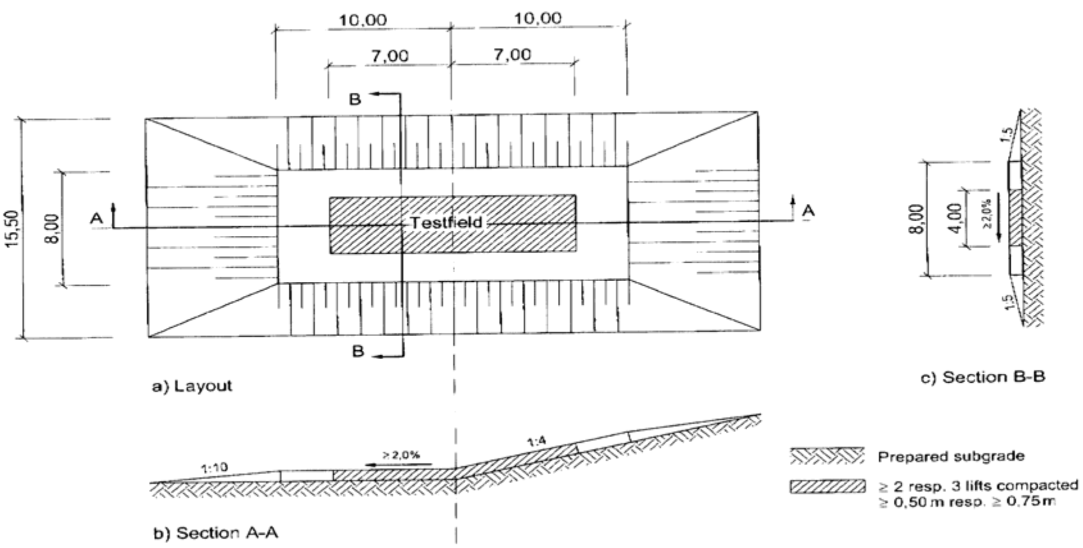

Figure 4: Example of field trial with test field sections horizontal and gradient 1:4

The subgrade on which the field trial is placed has to be prepared according to the specifications of the final landfill structure and it has to be surveyed geodetically. Placement of the barrier material including treatment for remolding and homogenization, wetting or drying and compaction is to be executed with the equipment and technology to be used in production. If variations in the equipment and technology are tested in the field trial, this has to be done systematically, and the observations have to be recorded. All measured data, conditions and methods used in the preparation of the subgrade and in placement and compaction of the liner have to be documented. The following items should be recorded:

- Geometry, encountered soil type, methods of treatment and conditions of subgrade before placement of liner material
- Origin, type and condition of the mineral sealing material
- Geologic features of the borrow pit of the clayey mineral sealing material
- Methods used for extraction, transport, treatment and placement of clayey sealing material
- Details of mixing plant and mixing process used in case of well graded coarse grained sealing material
- Type, operating principle, weight and major dimensions of the compaction equipment used
- Diameter and length of the roller, operating weight with and without ballast, operating speed of the compaction equipment, frequency and energy of vibrating rollers, length, cross sectional area and arrangements of studs used to achieve a kneading effect in the case of pad-foot rollers
- Number of passes with the roller, indicated separately for each type where various types of roller are used
- Type, dimensions and characteristic values of any soil conditioning equipment used
- Number of rotations and operating speed of conditioning machine
- Methods used for breaking up clods of soil, maximum permissible clod size and degree of breaking up achieved
- Method of checking and, if necessary, correcting the moisture content of the soil to be placed, origin of the water, period elapsing between distribution of the water and the commencement of compaction
- Period of time elapsing between mixing process and placement and compaction of well graded coarse grained sealing material
- Thickness of the lift before and after compaction
- If necessary, quantity and type of additives, e. g. powdered clay, calcium bentonite or others, method of batching, number of rotations or duration of mixing in the pressure mixer
- Methods used for surface finishing
- Daily weather data of the site at the time of execution of the field trial (temperature, precipitation, wind direction and velocity, degree of cloudiness or sunshine, relative humidity)

Soil samples should be taken from at least 3 locations after completion of each layer and also after completion of the whole field trial for density, moisture content and in case of clayey soils hydraulic conductivity determination. In addition, in case of clayey soils, samples also have to be taken from each interface between the lifts for permeability tests. In-situ infiltrometer tests shall be carried out in case of well graded coarse-grained sealing material for hydraulic conductivity measurement (GDA E 5-9). Grain size distribution, water intake or consistency limits tests shall be carried out on samples and results compared to those of the initial suitability tests on samples from the borrow pit to verify conformance (section 3). If substantial deviations are observed, it may be necessary to obtain additional samples from the test field for compression tests and shear strength tests in case of clayey soils. The homogeneity of the liner has to be assessed on the basis of sampling and testing, if necessary supplemented by additional excavations and visual inspection. The field trial also offers an opportunity for supplementary in-situ testing.

5 Quality Assurance

Quality assurance as part of quality management (Chapter 1.8) is directed towards the elimination of mistakes in production and at achieving the required quality criteria. The quality achieved can depend on the weather conditions during production. It may not be possible to construct mineral liners under extreme climatic conditions (for limiting conditions see Chapter 2.5).

The bottom barrier system comprises all functional layers from the base up to the surface of the leachate collection system. This section deals with the subgrade and the mineral sealing layers only. Quality assurance relating to geomembranes and to the elements of the leachate collection system are treated in the pertinent sections 2.4 and 3.3.

The general suitability of the ground at the site to support the landfill at an accepted degree of safety, with respect to bearing capacity failure and predicted settlements, has to be assessed on the basis of ground exploration and design calculations. Once the site has been stripped, the following shall be demonstrated by means of in-house and third party testing (see Chapter 1.8):

- Quality characteristics of the subsoil as a stabilising element for the site in accordance with the site licence or permit
- Adequate bearing capacity of the subsoil surface
- Adherence to the allowable tolerances in respect to the design geometry and in respect to evenness in particular

Prerequisites for the construction of the mineral liner are completed suitability testing and field trials in agreement with sections 3 and 4 as well as acceptance of the subgrade. Random samples of the mineral seal material have to be taken at the borrow pit, on delivery at the site and again on placement, the samples should be tested for identification, to demonstrate conformance with the material tested in suitability tests and field trials.

To ensure that the specified quality is achieved in the field, the following range of quality tests will normally be required:

- Characteristics of the materials used: grain size distribution (every 1000 m²), consistency limits or water-intake and moisture content (every 5000 m²)
- Moisture content on placement, visual inspection of homogeneity of the material placed, number of passes with the roller, quantity of water added if any (every 1000 m²)
- Minimum clod size, cutting depth and quantity of additives if any (every 1000 m²)
- Thickness of the individual lifts, evenness of the lift surfaces and adherence to proposed levels and dimensions (every 500 m²)

- Degree of compaction and homogeneity achieved in the sealing layer on each lift by the determination of density, moisture content, grain-size distribution and plasticity, if appropriate, and by survey (every 1000 m^2)
- Determination of the permeability of the sealing layer for each lift (every 2000 m^2)

Permeability should be determined on undisturbed samples in the laboratory in accordance with section 3 for clayey sealing material and by field tests in case of well graded coarse grained sealing material. The hydraulic conductivity values should be compared with target values. The permeability test results may not be required prior to acceptance, provided other test results relating to quality assurance – in particular grain size distribution, moisture content and dry density correspond to data from the suitability tests. Permeability tests are then undertaken for record purposes only.

Holes in the sealing layer caused by soil sampling for quality testing or by field testing must be carefully closed and re-compacted. Successful closure of test holes should be assessed and recorded.

6 Design Analyses

In practice, the design of bottom barriers is commonly based on minimum requirements imposed by national regulations. When national regulations specify detailed requirements for the properties and minimum thickness of the mineral liner (typical criteria are presented in section 2 as an example), then design analyses may be needed only to assess slope stability of the waste body (including spreading failure modes) as far as potential slip surfaces are passing through the bottom liner, and for the prediction of settlement associated with the compression of the mineral liner under waste overburden. The shear strength parameters and the compression parameters obtained by suitability testing apply to such analyses. All relevant situations that have to be anticipated during the life time of the landfill have to be taken into account in the structural analyses. For these analyses compacted clay liners (CCL) can be regarded as fully saturated. Drainage conditions during loading (undrained / drained) are time dependent and have to be considered accordingly.

The design of the barrier-dimensions by functional analysis in respect of permissible migration of contaminants is complicated by the fact that comprehensive mathematical modelling of the contaminants-transport through the liner is a very complex problem. For the comparison of the efficiency of different mineral liner systems it is however possible to estimate the contaminant flux (advection and diffusion) through the liner under simplifying assumptions (details are treated in Chapter 2.2).

7 Bibliography

DEUTSCHE GESELLSCHAFT FÜR GEOTECHNIK E. V., 1997: GDA Empfehlungen Geotechnik der Deponien und Altlasten, 3. Auflage. Ernst & Sohn

DEUTSCHE GESELLSCHAFT FÜR GEOTECHNIK E. V., 1993: Geotechnics of Landfill Design and Remedial Works, 2nd Edition. Ernst & Sohn

European Landfill Directive, 1999: The Council of the European Community.

LAUF G. & MUELLNER B., 1993: A new barrier material with high chemical resistance. Proceedings Sardinia 1993, 4th International Landfill Symposium, 499-505.

MADSEN, F., MITCHELL, J. K., 1989: Chemical effects on clay hydraulic conductivity and their determination. Nr. 135 Mitteilungen des Institutes für Grundbau und Bodenmechanik – Eidgenössische Technische Hochschule Zürich

MITCHELL, J. K. & SOGA, K., 2005: Fundamentals of Soil Behavior. 3rd edition. John Wiley & Sons, Inc.

Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste-Treatment Facilities, 2001 (Abfall-Ablagerungs-Verordnung AbfAblV)

Ordinance on Landfills and Long-Term Storage Facilities and Amending the Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste-Treatment, 2002 (Deponie-Verordnung DepV).

ROWE, R. K, QUIGLEY, R. M., BOOKER, J. R., 1997: Clay barrier systems for waste disposal facilities. E & FN SPON – An Imprint of Chapman & Hall

Technical Instructions on Waste, 1991: Federal Ministry for Environment, Protection of Nature and Safety of Reactors (TA Abfall: Technische Anleitung zur Lagerung, chemisch / physikalischen, biologischen Behandlung, Verbrennung und Ablagerung von besonders überwachungsbedürftigen Abfällen)

Technical Instructions on Waste from Human Settlements, 1993: Federal Ministry for Environment, Protection of Nature and Safety of Reactors (TA Siedlungsabfall: Technische Anleitung zur Verwertung, Behandlung und sonstigen Entsorgung von Siedlungsabfällen)

Photo Annex

Photo 1:
Placement of CCL, conditioning of clay material

Photo: E. Gartung, Altdorf, Germany

Photo 2:
Compaction of CCL

Photo: E. Gartung, Altdorf, Germany

Photo 3:
Homogenization of clay for compaction

Photo: E. Gartung, Altdorf, Germany

Photo 4:
Kneading compaction by pad-foot roller

Photo: E. Gartung, Altdorf, Germany

Photo 5:
Mixing plant for mixed in-plant coarse grained well graded mineral liners

Photo: E. Gartung, Altdorf, Germany

Photo 6:
Mixed in-plant coarse grained well graded mineral liners

Photo: E. Gartung, Altdorf, Germany

Photo: E. Gartung, Altdorf, Germany

Photo 7:
Infiltrometer for in-situ permeability testing