AN APPROACH TO THE ASSESSMENT OF COVER LINING SYSTEMS

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SUMMARY: Within a research project the authors are working on a concept to assess different kinds of cover lining systems used in the district Thuringia, Germany (cf. Figure 1). This paper presents the latest results to qualified cover lining systems based on a comparison of different systems (and components), the geological and climatic conditions of Thuringia and numerical simulations to the balance of water. The second part shows new developments and approaches to monitoring processes. A master conception to a monitoring program of test fields for cover lining systems will be introduced additionally.

1. INTRODUCTION

These days alternative cover lining systems are planned and realised in most landfills due to the expensive and partially technical superannuated cover lining systems of the German general administrative provisions (TA-Siedlungsabfall, 1993; TA-Abfall,1991). An equivalent-verification must be provided to get an administrative planning permission for these systems.

The verification of the equivalence can be conducted by analytic and numerical calculations of the components (e.g. sealing layer, drainage layer etc.) and of the whole cover lining system. Furthermore laboratory tests have to be conducted to the different materials too. All results have to correspond to the limits of the DIBt (1995). The regional conditions (e.g. climate, size, side) of the analysed landfill represent the specific values of the calculations.

The installation of test fields is the other possibility to verify an equivalence. First the cover lining system is built in as a temporary system. If the operativeness of the system would be provided by the measurement results of the test fields, then the system will be homologated for appropriate. The interest concentrates on the balance of water in the cover lining system, especially the storage capacity of the restoration layer and the leakage through the sealing layer(s) respectively the capillary barrier. As consequence a well developed monitoring system is required for controlling the test fields (e.g. matric potential, water content).

Figure 1. Map of Germany

2. COVER LINING SYSTEMS

2.1 A comparison of cover lining systems

2.1.1 Components and systems

In Germany the landfills are divided into three classes: Landfill class 1 includes inert and relative unperilous waste (material), landfill class 2 a normal sanitary waste and class 3 deposites of hazardous waste. As consequence the base lining system, the waste and the cover lining system must perform each type under different conditions (see TA-Siedlungsabfall, 1993; TA-Abfall,1991).

A cover lining system consists of following components: A restoration layer covered by vegetation, a drainage layer, a sealing (different possibilities) and a compensation layer. The compensation layer often takes over the function of a gas drain too. Table 1 presents the values according to the German standards for cover lining systems. Landfill class 3 differs to class 2 in a lower coefficient of permeability ($k_f = 5 \cdot 10^{-10}$ m/s). Furthermore the sandwich sealing should be controllable and reperable.

In the following paragraph the particular components are specified (cf. Zeh and Witt, 1999, 2000). Recent recommendations (LAGA-AG, 2000, GDA, 2000) present the state-of-the-art.

The importance of a well designed restoration layer (RL) has been proved by test fields results and simulations of the balance of water the last years. The RL has not only to resist the sealing of frost and bioturbation respectively to give a vegetation substructure but also a high water reserve to minimise the infiltration. A sufficient water regime can only be obtained by a well graded layer (thickness = 1,5 - 3,0 m, subdivided into: a upper ‘vegetation’ part with a high content of humus; a mid water storage part with $\rho \leq 1{,}45$ g/cm³ and available field capacity FC ≥ 200 mm; a lower part with a higher soil density to stop respectively minimise roots).

The drainage layer (DL) must drain and collect the infiltrated water. In general, gravel or chemical and mechanical resistant residue is built in (grain size 16/32 mm). Alternatives are geosynthetic filter layers like woven fabrics or combinations of mineral grains in geosynthetic coats. All drainage systems are endangered by clogging (filter criteria, chemical impacts).

There are several types of sealing components. They (or their combinations) should prevent the waste body of infiltration water, the leakage of landfill gas and of harmful to the environment elements by evaporating water.

The most appropriated sealing element is the common mineral sealing (MS). It consists of fine- or mixed-grained soils like clay and silt respectively silty, loamy or high-clay sand, sometimes improved with bentonite. A big problem of MSs is the loss of the high imperviousness by cracks and micro pores. This is often caused by desiccation (summer dry-period), defomation and bioturbation (roots, animals). For an example, chapter 2.1.2. presents results of in-situ tests of mineral sealings.

Table 1 - Requirements of the components / systems of cover lining systems in Germany (TA-Siedlungsabfall, 1993)

Components	Landfill class 1		Landfill class 2	
	d_{min} [m]	requirements	d_{min} [m]	requirements
Restoration layer	1,00	arable soils	1,00	arable soils
Drainage layer	0,30	$k \geq 1 \cdot 10^{-3}$ m/s inclination ≥ 5 %	0,30	$k \geq 1 \cdot 10^{-3}$ m/s inclination ≥ 5 %
Flexible membrane liner	-	-	0,0025	special approval
Mineral sealing	0,50	$k \leq 1 \cdot 10^{-9}$ m/s two-part	0,50	$k \leq 1 \cdot 10^{-9}$ m/s two-part
Compensation layer	0,50	-	0,50	-

Alternatives are improved mineral sealings (IMS) and geosynthetic clay liners (GCL). IMS is a mixture of sand and bentonite enriched by polymers, sodium etc. (cf. Boels and Van der Wal, 1999, Favaretti and Moraci, 1997). Such an improvement leads to lower rates of permeability, a higher capability to assimilate deformations, higher shear strength and higher resistances to outer impacts (bioturbation, desiccation). Unknown is long-term behaviour (chemical, biological) of the additives and consequently the long-term durability of IMS in detail. Geosynthetic clay liners consist of a thin layer of clay (bentonite) sandwiched between two PE-HD geotextiles (total thickness 7 - 15 mm) which are mostly needlepunched or sewed together (Daniel, 1993). They feature a low permeability rate, high capability to assimilate deformations and relative low costs. Research demands exist to impacts of bioturbation, desiccation and to long-term durability of internal shear strength above all.

Another traditional sealing component is flexible membrane liner (FML). FML is often used as a component of sandwich sealing systems (e.g. FML + MS). It should have a minimum thickness of 2,5 mm and PE-HD as synthetic material. FMLs are almost technical dense but the regime oxidative ageing is partial contentious (Pierson et al., 1999, Kalbe et al., 1999). A further proposal is the combination of FML with a leakage monitoring system. Recommendations are presented in BAM (2000).

A further upcoming system to reduce infiltration is a capillary barrier (CB). The components are a capillary block (coarse sand / fine gravel) overlained by a capillary layer (fine sand). It seems to be a very effective system with a good long-term durability (e.g. Kämpf and Montenegro, 1999). CBs are not dense against landfill gas and need a minimum slope of about 8°.

Table 2 lists the most important impacts and resistances of the different components to cover lining systems. They are partially correlated in space and time.

The different cases and the corresponding limits are determined by DIBt (1995).

Table 2 - Impacts and resistances of components

Components	Impacts	Resistances
Restoration layer	infiltration (amount, intensity) climate (temperature, UV) erosion installation bioturbation (roots, animals)	balance of water vegetation grading (special installation procedure) root barrier (dense soil layer, geosynthetics)
Drainage layer	clogging bioturbation forced deformations	filter criteria drain capacity minimum inclination (≥ 5 %)
Sealing	infiltration moisture / temperature gradient bioturbation forced deformations thermal expositions chemical exposition ageing installation	permeability rates (materials) capability of deformation self-healing capability (MS, IMS, GCL) durability (materials) retention ability (pollutants) drain capacity, length of slope (CB)
Gas drain	clogging chemical exposition forced deformations	filter criteria shear strength (material)
Compensation layer	(clogging) forced deformations	filter criteria shear strength (material)

2.1.2 Relevant results of test fields in Germany

A number of publications refer to the results of test fields (lysimeters) and excavations. A detailed conclusion contains Zeh and Witt (2000). The main purpose of all examinations is to control the long-term behaviour and the applicability of different cover lining systems (chapter 3). Within this paper, the authors present the most important results depending on the components of the cover lining systems.

Melchior (1993, 1997) reports of heavily increasing flow rates through ‘normal’ mineral (clay) sealings after a few years. The influence of summer dry-periods to the temperature and moisture gradients ensures a fast and stable dry out in the clay liner, also micro pores (cracks). Additionally, plants root in the clay layer because of scanty water storage (welting point).

Several investigations were performed to get a better understanding of capillary barrier (among others Kämpf and Montenegro, 1999, Breh and Hötzl, 1999, Melchior, 1997). High efficiency and the best results are reached by a simple CB, as a bare ‘sealing’, combined with a well designed RL (buffer effect). Combinations of a CB with MDs or as so-called Double-CB show worse results.

A validation to the efficiency of GCLs presents Siegmund et al. (2001) and Egloffstein (2000). Both present compendious a stable permeability rate (partially after Ion-Exchange) and a high self-healing potential. Desiccating appearance only results in by reduced or worse designed RLs (Melchior, 1997). A so-called moisture layer (0,10 m fine sand) overlaining the GCL conducts to good results till now (Siegmund et al., 2001, Mühlfriedel, 2001).

2.2 Boundary conditions

Thuringia is embossed by four geological units (Seidel, 1995) - the Thüringer Schiefergebirge (‘Thuringian Schist-Mountain’), the Thüringer Wald (‘Thuringian Forest’), Thüringer Becken (‘Basin of Thuringia’) and the Südwestthüringisches Triasgebiet (‘Thuringian South-West Triassic’). The subsoil consists of 95 % rock, covered by small layers of sediments. The sequence of strata was deeply deformed by strengths interior of the earth. First the strata was folded and broken, displaced and tipped over later. Consequently, the result is a complex geological regional splitting. In behalf of our considerations the Thüringen Becken and the Thüringer Wald are especially important. They lead to very different climatic conditions in Thuringia as follows.

Table 3 - Climatic specific values of the annual average(after Müller-Westermeier et al., 2000, Veit et al., 1987)

	Temperature [°C]	Precipitation [mm]	Sunshine-Duration [h]
Germany (total)	8,8	797	1532
Erfurt	7,9	528	1601
Leinefelde	7,5	641	1528
Sonneberg	6,2	917	1534
Schmücke	4,2	1112	1413

Table 4 - Spectrum of climatic specific values of Thuringia annual average (after Müller-Westermeier et al., 1999)

	Temperature [°C]	Precipitation [mm]	Sunshine-Duration [h]
Minimum	4,0 - 4,5	~ 450	1300 - 1400
Maximum	9,5 – 10,0	1400 - 1500	1600 - 1700

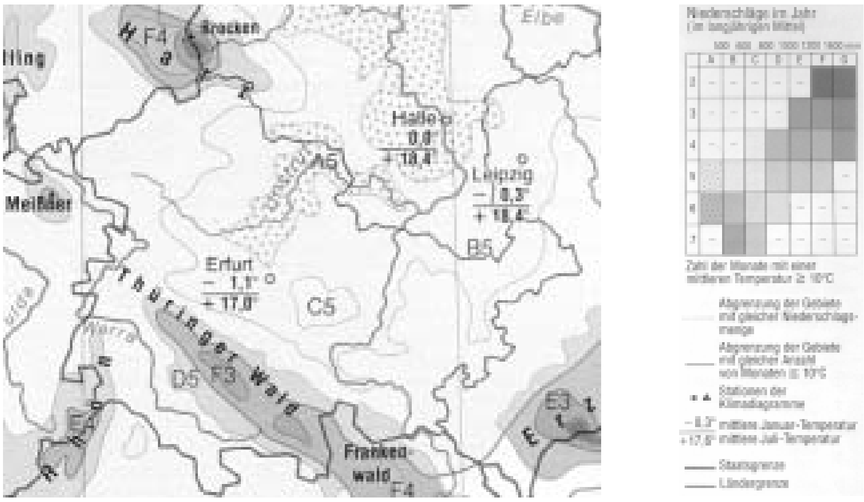

Figure 2. Precipitation and temperature regimes of Thuringia (Diercke Weltatlas, 1996)

The territory of Germany belongs to the moderate-warm rain-climate of the medial latitudes (Müller-Westermeier et al., 1999). Humid air-bulks of the Atlantic are fed by preponderant western winds which bring rainfalls all over the year. As a rule, the influence of the ocean ensures relative mild winters and summers not too hot.

The climate of Germany is deeply structured by the topographic configurations of the highlands and paled platter landscapes. That means the lowlands often have a warm, dry and sunny climate and the higher sites a cool, rich in precipitation and cloudy climate during the year. The eastern parts of Germany (including Thuringia) are relatively dry (Thuringian average annual precipitation: 693 mm/a) and a little cooler because of the longer distance to the Atlantic.

Table 3 shows the climatic specific values to Germany and some selected locations of Thuringia. Erfurt and Leinefeld are locations of the Thüringer Becken and the other two locations of the Thüringer Wald. The wide range of the climatic specific values of Thuringia annual average is shown in Table 4 and Figure 2, too. This spatial change in climatic impacts should be considered in the design of the lining system.

2.3 Numerical simulations to the balance of water

At time several tests are conducted to calculations to the balance of water. Hereby, two useable programs HELP D-3.50 (Schroeder et al., 2001) and BOWAHALD-2D (Dunger, 1997) are compared by climate values of a dry (Erfurt) and a wet (Sonneberg) location in Thuringia. Different cover lining systems are varied by the kind of construction, the thickness of layers and the soils / materials.

The fundamental objective is to compare first the programs regarding to possible results and the friendly utilization and second to develop recommending cover lining systems dependent on the very varying climate conditions in Thuringia above all.

First results yield naturally some different, but mostly similar at the values solutions (e.g. evapotranspiration, leakage, ...) of both programs. For the beginning three cover linings systems are tested; a normal cover (only restoration layer, d = 1,5 m), a qualified cover (d = 1,5 m) and cover lining system based of landfill class 2 with qualified restoration layer (d = 1,5 m). BOWAHALD achieves higher evapotranspiration values and smaller leakage than HELP. In particular the results of the dry location differ very strong (leakage). The results of the wet location are very similar to the regime (evapotranspiration, leakage) of both programs. Hereby, HELP always yields a higher leakage.

The examinations are continued by varying the different components of the programs and the cover lining systems (soils, thickness, components, etc.).

2.4 Regional recommendations

The following points show a short resume to chapter 2 and first regional recommendations to cover lining systems and theoretical and practical examinations.

- The operativeness of single components and total cover lining systems can be easily controlled by test fields and subsidiary excavations. Future test fields should be designed as described in chapter 4 to prevent a part of the different influences indeed. Furthermore results of test fields only reflect selective values. They do not automatically valid for the total area.
- The calculation programs to the balance of water are useful to design and compare different systems depending on the landfill conditions (site, size ,climate) but they simplify or neglect important physical equations. A decision to a special cover lining system should not only come by using calculation programs.
- Sandwich sealings (FML+MS, after TA-Siedlungsabfall) are very effective (but mostly expensive).
- MSs and GCLs are sensitive against strong alteration to water content (desiccation, bioturbation). Solutions are a root / pet barrier (in the RL), a moisture layer above the sealing or modified installation of the MSs (‘dry part’ of Proctor curve). The IMSs could be alternatives but especially the long-term behaviour is not verified until yet.
- The simple CB combined with a mighty and well graded RL is a recommending alternative if it is not necessary to have a total impermeable sealing and the surface of the landfill has a minimum slope.

3. MONITORING METHODS

The installation of test fields / lysimeters and operating for years is the most practicable method to verify the operativeness of cover lining systems and their single components. Normally, a impermeable FML-tub bounds the test field. As a rule, the measurements to the lateral and vertical flow of the components and to the physical specific values (moisture / water content, temperature, matric potential) are performed in the same test field (Benson et al., 1994, Melchior, 1993, Kämpf and Montenegro, 1999). Additionally, excavations are executed there steadily.

As a part of the basic concept, the authors submit a partition of the different evaluations in separated fields (cf. Figure 3); a ‘discharge measuring field’ (DMF) and a ‘moisture measuring field’ (MMF) for all cover lining systems which have to be analysed. The test section have to place at the waste body, not outside the landfill. The dimension of the test fields should have proportions of length / wide ≥ 2,5 (wide ≥ 8 m) to get adequate results regarding the lateral flows. Due to the partition following advantages result in:

- In the MMF, specific values (moisture, matric potential, temperature, etc.) are measured by real In-situ conditions. No disturbances by the FML-tub because of the direct contact to the waste body (temperature, moisture transport, contamination transport).
- No measurement instruments or installations disturb the vertical and lateral flows in the DMF.

The DMF gauges the discharges of the surface (lateral flow), of the drainage layer (indirect the vertical flow of the restoration layer) and of the sealing (vertical flow) with a second drainage layer sandwiched by the sealing and the FML-tub (cf. Figure 4). A external discharge monitoring station should be preferred. Minimum one measurement configurations should be integrated to compare the results of DMF and MMF.

The measurement configurations have to analyse the different physical specific values in the MMF, particularly developments in the restoration layer and in the sealing. In the most cases direct or indirect moisture measuring methods are used, additionally temperature and matric potential. They have minimum 2 profiles each with 3 or more measure points (because of redundancy). Also, the MMF should have at least two configurations (cf. Figure 4).

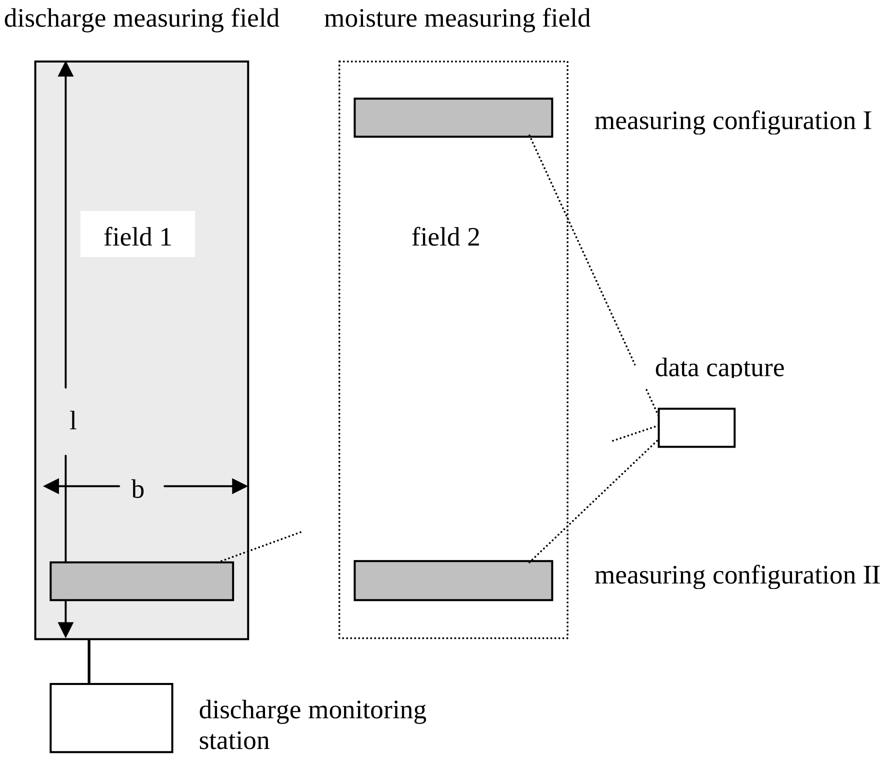

Figure 3. Schematic structure of a test section

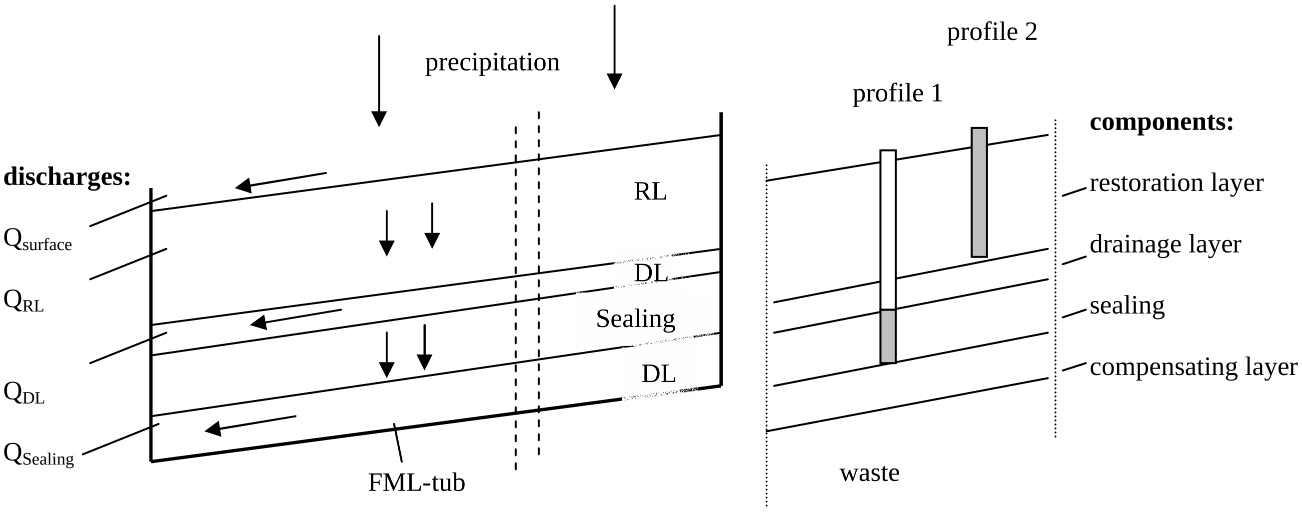

Figure 4. Schematic structure of DMF (left) and MMF (measuring configuration)

Table 5 – Recommended moisture measure methods

Components	Methods	Aspects
RL	FDR-lance (frequency domain reflectometry)	measurements in different levels relatively cheap
	TRIME-TDR (time domain reflectometry)	single point measurements (fast, simple) good handling
	Tensiometer	single point measurements damageable (too high potentials, frost)
	GPR (ground penetrating radar)	non-destructive demand of development (e.g. dissolution)
MS / IMS	FDR-lance (frequency domain reflectometry)	measurements in different levels relatively cheap
	TRIME-TDR (time domain reflectometry)	single point measurements (fast, simple) good handling
	Tensiometer	single point measurements damageable (too high potentials, frost)
	moisture sensor (TAUPE)	large area
CGL	moisture sensor (FORMI)	large area
FML	leachate control system	large area

The moisture methods depend on the technical requirements (accuracy, application limits, validations to the specific soils) and often the costs. Furthermore the different sealings need variably equipment (cf. Zeh and Witt, 2000). All measurements must have a high temporal resolution, high accuracy and the results have to collect digitally at the data capture. A selection of recommended moisture measure methods is presented in Table 5 (Zeh and Witt, 2000). The disadvantage of all methods is the deeply interference into the structures (not GPR) of the components.

A further control of the test section (or total landfill) by selective excavations should be made every 3 years. Hereby, it is recommended to conduct in-situ infiltrometer tests at the sealing (not at FML or CB) in addition to the examination of soil samples in a laboratory.

4. CONCLUSION

The design of functional alternative cover lining systems bases on the thorough inspection to the special conditions of the landfill. Hereby, the climate conditions and the temporal status of the landfill (contamination discharge, deformation) are the most important items. Deepening examinations to the different specific values of the different landfills and hereon resulting optimisations as well as considerations of the global conditions of impact and resistance should become the standard to the design of a cover lining system. The overall criterion is the allowed amount of leakage and their compatibility to the deposit in the end.

Test fields and numerical simulations to the balance of water are important tools to design location-optimized cover lining systems. However the computer programs (simulations to the balance of water) have to refine and the calculations should be performed not only by using historical climate values but also with forecast values. The partition of the test fields and the specific selection of the measuring instruments is a further step for a better understanding of the material movements between components of the cover lining system (and the deposit).

All these indicate that the design and assessment of a cover lining system can only base on the specific conditions to the respective landfill.

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