INVESTIGATIONS OF ALTERNATIVE LANDFILL SURFACE SEALING SYSTEMS IN TEST FIELDS

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SUMMARY: The here discussed surface sealing systems are an alternative to plastic membranes. These alternative surface sealing systems for biologically stabilized landfill bodies offer ecological and economic advantages. They consist of a seal made of natural materials with a drain and a soil cover with high water storage capacity. The vegetation is part of the whole system. Three different alternative systems are investigated in test fields. The results so far are very promising.

1. INTRODUCTION

On test fields, three alternative surface sealing systems (alternative to plastic membranes), adjusted to the biologically stabilized landfill body of the old Kuhstedt landfill, are investigated with respect to their effectiveness on the long-term function reliability. The design of alternative site-adjusted surface sealing systems is significantly influenced by the premise not to cut back on environmental protection.

2. THE DESIGN OF SITE-ADJUSTED SURFACE SEALING SYSTEMS

The design of the surface sealing systems, installed in three test fields on the old Kuhstedt landfill (in the Rotenburg (Wümme) district, Germany; Heyer et al., 2003), is based on the following site-specific strategy:

- Guarantee of long-term operational reliability of the sealing system.
- Consideration of the emission and settling behavior of the landfill body.
- Design of the recultivation layer as a water storage and methane oxidation layer.
- Utilization of materials for the recultivation layers, for the drainage and the sealing elements which are of natural origin and preferable available in the proximity of the site.

On the basis of the findings obtained from the test fields, a surface sealing system shall be planned and installed, tailor-made for the biologically stabilized landfill body of the old Kuhstedt

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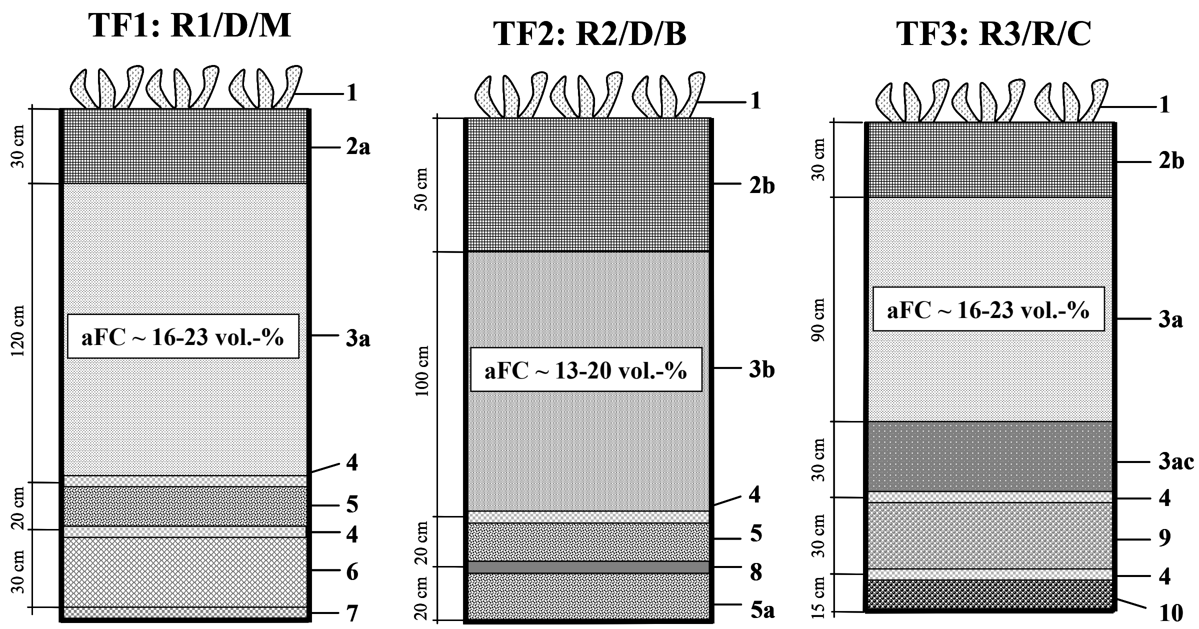
landfill. The test fields are to provide information about the following factors of influence on the water and gas balance:

- Varying thickness of the top-soil layers with different compost additions.
- Varying design of the subsoil layers with different materials, layer thicknesses and/or emplacement conditions.
- Varying sealing elements.
- Methane oxidation in the recultivation layer.

Due to the storage function of the top-soil and subsoil layers, the water uptake by the plants and evaporation via the surface, the water infiltration will be significantly reduced.

3. TEST FIELDS

Figure 1 and Table 1 show the profiles of the surface sealing systems installed in the three test fields (details are given in Hupe et al., 2001; Hupe et al., 2002).



1	**Grass and site-related planting**	**5**	**Drainage layer (sand)**
2a	**Top-soil: native soil with 30 vol-% compost**	**5a**	**Control drainage (sand)**
2b	**Top-soil: native soil with 20 vol-% compost**	**6**	**Mineral sealing (clayish silt)**
3a	**Subsoil: slightly compressed sandy loamy silt**	**7**	**Control drainage mat**
3ac	**Subsoil: highly compressed sandy loamy silt**	**8**	**Bentonite mat**
3b	**Subsoil: slightly compressed medium-silty sand**	**9**	**Capillary layer (sand)**
4	**Interlayer (fibrous web)**	**10**	**Capillary block (gravel)**
TF	**Test field**	**aFC**	**Available field capacity**

Figure 1. Design of the alternative surface sealing systems in the three test fields
Note: The mineral sealing was installed on the "dry part" of the Proctor curve (Horn, 2002)

Table 1. Surface sealing systems in the three test fields

Component / layer	Test field 1 R1/D/M	Test field 2 R2/D/B	Test field 3 R3/R/C
Vegetation	grass and site-related planting (succession)		
Top layer	30 cm: native soil with 30% compost addition	50 cm: native soil with 20% compost addition	30 cm: native soil with 20% compost addition
Subsoil	120 cm: slightly compressed sandy loamy silt	100 cm: slightly compressed medium-silty sand	sandy loamy silt: 90 cm: slightly compressed, and 30 cm: highly compressed
Drainage	20 cm: fine sand 0/1	20 cm: fine sand 0/1	30 cm: capillary layer of fine sand 0/1
Sealing	30 cm: clayish silt $k_f \leq 2 \times 10^{-10}$ m/s	Ca- bentonite mat $k_f \leq 5 \times 10^{-11}$ m/s	15 cm: capillary block of gravel 2/8, round-grain

TF 1 (R1/D/M): Structure of recultivation layer 1 as water storing and methane oxidizing layer on top of a mineral sealing layer (**R1/D/M**: **R**ecultivation layer **1** / **D**rainage layer / **M**ineral sealing)

TF 2 (R2/D/B): Structure of recultivation layer 2 with a bentonite mat as sealing material (**R2/D/B**: **R**ecultivation layer **2** / **D**rainage layer / **B**entonite mat)

TF 3 (R3/R/C): Structure of recultivation layer 3 with a retaining layer above a capillary barrier (**R3/R/C**: **R**ecultivation layer **3** / **R**etaining layer / **C**apillary barrier)

4. INVESTIGATIONS

4.1 Materials and methods

4.1.1 Water balance

In order to get site-related information about the effectiveness of the surface sealing systems, and to be able to make a balance of the water regime a monitoring system has been implemented. The measurement technique required and installed for this purpose can be subdivided into three categories (Figure 2):

- Meteorological measurement technique (meteorological station)
- Drainage measurement technique on each test field: tipping counters for water effluents from different layers, namely surface, drainage and leachate effluents (leachate effluents: water passing the sealing element)
- Soil-hydrological measurement techniques on each test field: soil water content and matrix potential using TDR probes (TDR: Time Domain Reflectometry is a method for in situ measurement of soil water content) and tensiometers (installed at different depths of the recultivation layer – soil water contents: 15 cm, 70 cm; soil-moisture tension: 15 cm, 40 cm, 70 cm, 100 cm, 135 cm)

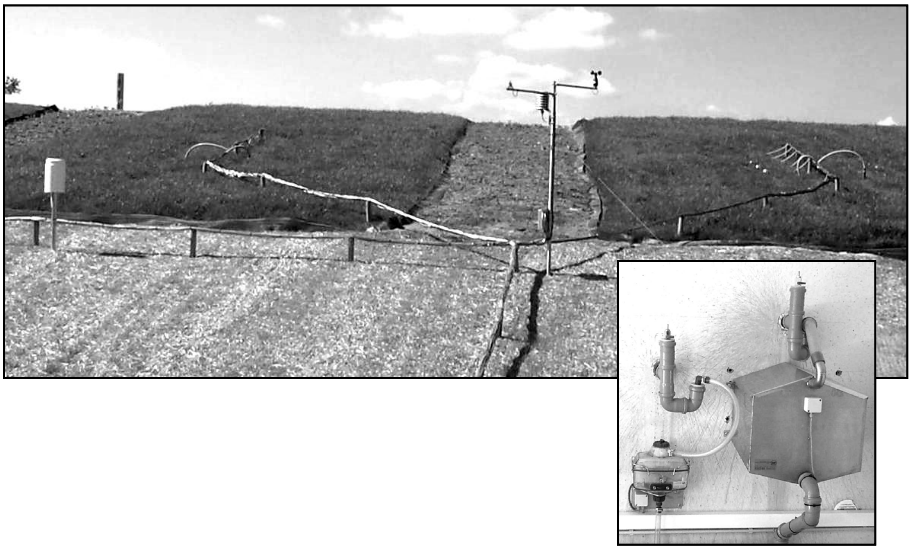


Figure 2: Monitoring system installed on the test fields at the old Kuhstedt landfill, Germany; *small picture*: used tipping counter unit

4.1.2 Methane oxidation

As already mentioned, the old Kuhstedt landfill is aerated in order to enhance the residual biological degradation processes in the landfill body (Heyer et al., 2003). Even after completion of the stabilization procedure of the landfill body according to the low-pressure aeration method, very small quantities of methane may still be produced. In order to avoid uncontrolled methane emissions via the landfill surface, the recultivation layers were, therefore, prepared for methane oxidation.

At present, investigations into the methane oxidation within the recultivation layer are carried out on the test fields. These investigations require artificial charging with landfill gas res. methane. The charging is effected via the drainage layers which, to a large extent, allow even distribution of the gas. The landfill gas is introduced, in a controlled way, into the respective test fields using a pump and distribution system. The gas supply rate is adjusted via the pump capacity. Gas probes were installed at different depths in the recultivation layers of the test fields in order to analyze the influence of methane addition res. the effectiveness of the respective recultivation layers, with regard to the methane oxidizing effect. For this purpose, the following parameters are measured at regular intervals:

- Soil temperature
- Gas volume flow and composition (particularly: methane, carbon dioxide, oxygen, hydrogen sulfide) of the introduced landfill gas
- Gas composition (as afore mentioned) and pressure at the different gas probes

4.2 Results and discussion

4.2.1 Water balance

The present findings of the effluent measurements must be considered as preliminary results after a period of 1.5 years. In order to enhance the validity of the results and for long-term forecasting, investigations over several years are required (≥ 5 years, if possible).

Figure 3 shows the results of the water balance investigations of the surface sealing systems on the three test fields.

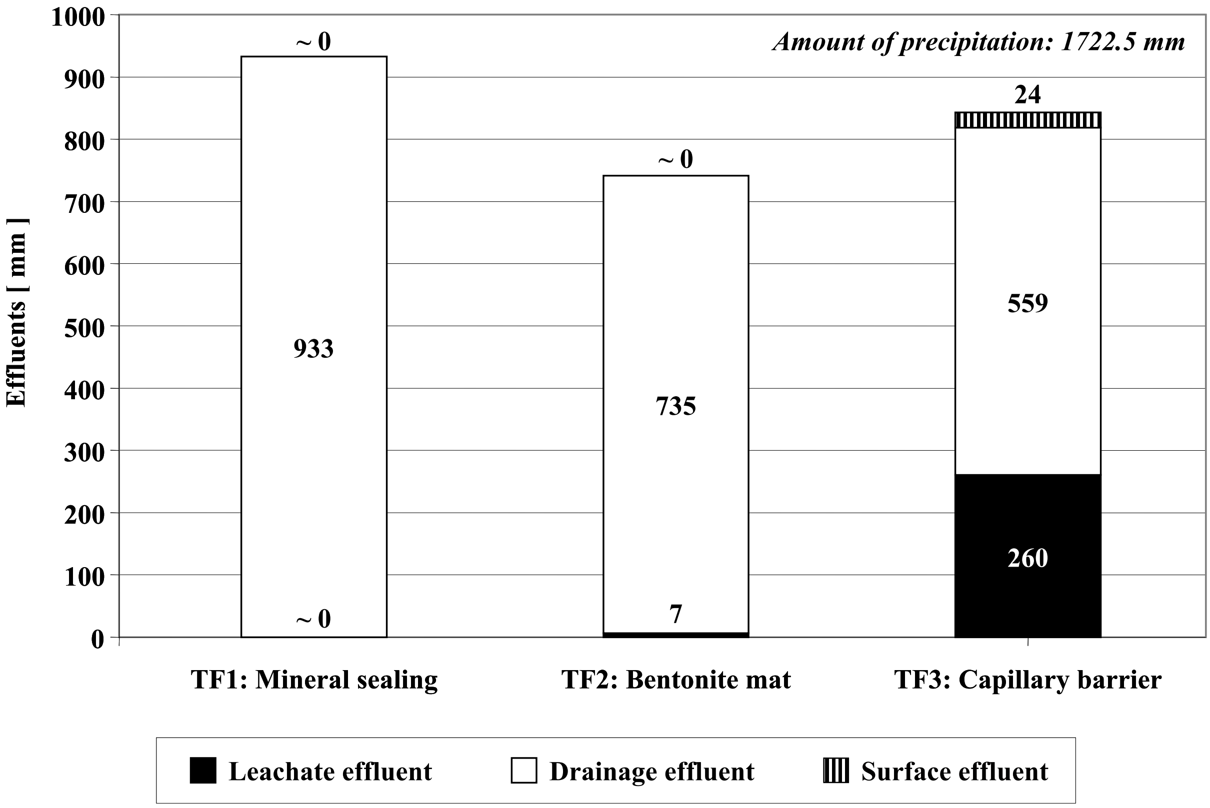


Figure 3. Effluents from the test fields – period: August 2001 – May 2003 (see also Table 1)

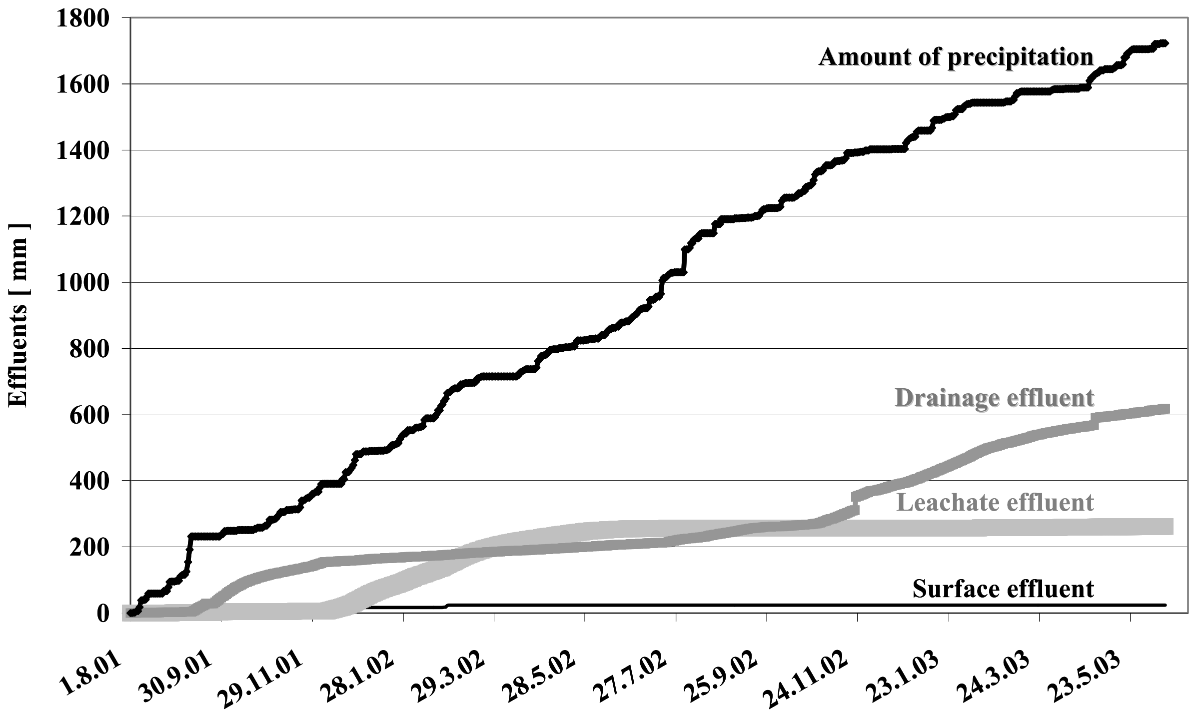


Figure 4. Exemplary representation of the water effluents from test field TF 3 with capillary barrier as sealing element (see also Table 1)

Despite the relatively short operation period of the test fields (operation started in August 2001), the results of the water balance obtained until now may be evaluated in summary as follows (see also Table 1):

- The different sums of effluents shown in Figure 3 can be explained due to the different water storage capacities and evaporation rates of the different surface sealing systems res. recultivation layers (see also Figure 1).
- *Mineral sealing (TF 1):* The mineral sealing was installed on the “dry part” of the Proctor curve, this causing several problems and delays during construction. As shown by the results obtained so far, the sealing is very effective. Until now, no water permeation through the mineral sealing could be observed.
- *Bentonite mat (TF 2):* The bentonite mat could be installed without any problems. The findings so far show water retention of almost 100%.
- *Capillary barrier (TF 3):* The capillary barrier system could also be installed without problems. However, in the course of the investigation phase, water break-through, limited in time, did occur (see Figures 3 and 4), meaning that, over a period of 5 months, water was passing the capillary block instead of being led off via the capillary layer. Under real conditions, this would cause leachate regeneration. Investigations by means of excavations indicate the following potential reasons:

  The amount of precipitation during the investigation period in question (from August 2001 to May 2002) was higher than average. Due to the short consolidation and plant growth phase (low evaporation rate) since the completion of the test fields, and to the insufficient slope of 1:8 (newest results show, the slope should be at least 1:6), the capillary barrier system was overloaded during the period of strong precipitation. Subsequently, the capillary barrier system reacquired full functional efficiency, and almost 100% of the water quantity is drained off via the capillary layer.
- *Recultivation layer:* The different recultivation layers show a good water storage capacity with a usable field capacity of approx. 20 vol.-%.

  Water content: Figure 5 shows the variations in the water content at different depths of the respective recultivation layers over a period of time (TDR probes – top-soil layer: 15 cm below the upper edge of the surface; subsoil layer: 70 cm below the upper edge of the surface).

  It could be observed that the addition of compost for the improvement of the top-soil quality increases the water storage capacity. Amongst other things, this is indicated by higher water contents with increasing compost addition. Whilst the seasonal fluctuations in temperature and precipitations in the top soils are clearly reflected in the variations of the water content, these variations are less significant in the subsoils. The highest variations could be observed in the subsoil of test field 2. This subsoil shows a less available field capacity than both of the other test fields (see Figure 1 and Table 1).

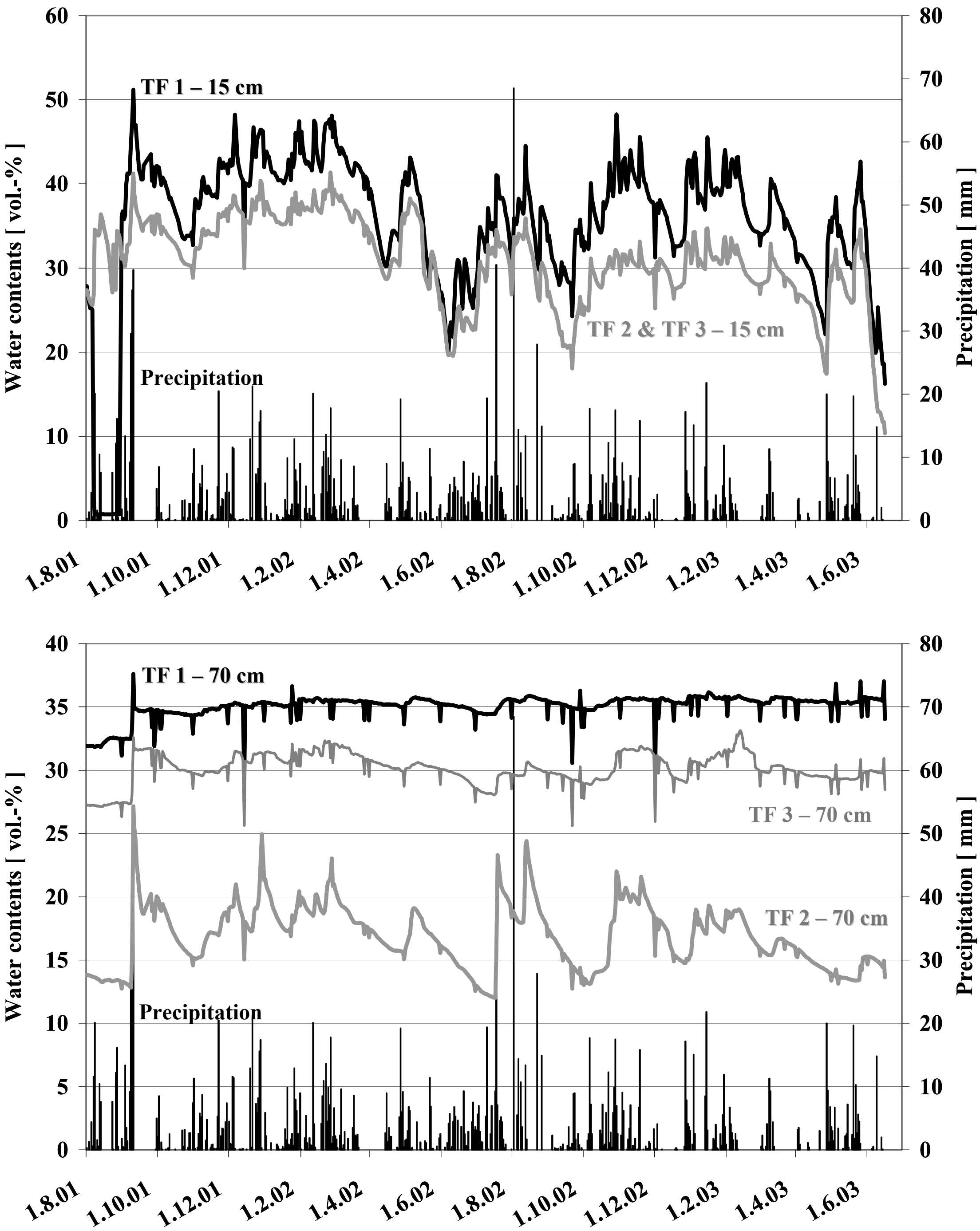


Figure 5. Presentation of the water contents in the top (15 cm) and subsoils (70 cm) of the three test fields (see also Table 1)

- *Soil-moisture tension*: It becomes obvious that, due to desiccation and remoistening, the highest variations with regard to the soil-moisture tensions may be ascertained in the area close to the surface of the recultivation layers. With increasing depth within the recultivation layer, the water movements are more even and both the variations of the soil-moisture tension as well as of the water contents are significantly lower. The measurements also confirm the functional efficiency of the recultivation layer as water storage layer and emphasize the usefulness of a sufficient size of the recultivation layer (see Figure 6). The sufficient size of the recultivation layer mainly depends on the available field capacity of the available res. used top-soil and the subsoil as well as on the precipitation rate at the specific landfill site.

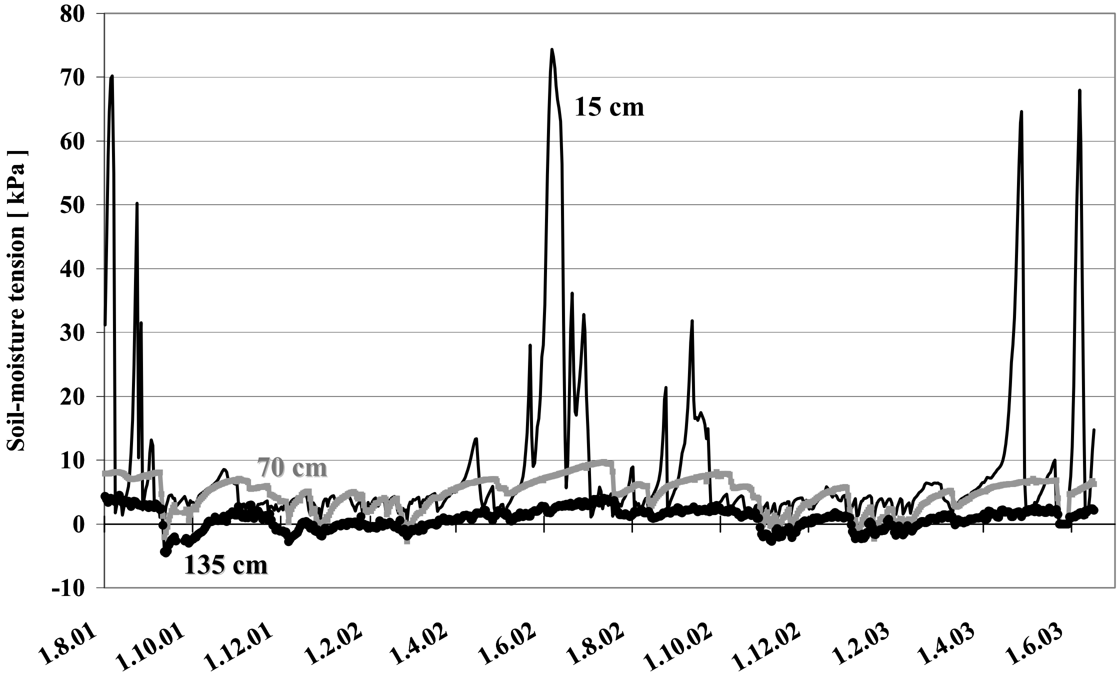


Figure 6. Precipitation and soil-moisture tension curves at a depth of 15 cm, 70 cm and 135 cm (serving as an example) in the recultivation layer from August 2001 to February 2003, test field TF 3 (capillary barrier), old deposit of Kuhstedt (see also Table 1)

The results obtained until now regarding the water balance of the test fields (taking into consideration the relatively short investigation period) show that:

- expectations are met to a large extent
- the design strategies so far proved to be target-oriented and useful.

4.2.2 Methane oxidation

The test fields were usually charged with approx. 0.5 $l_{\text{landfill gas}}/m^2$ h at an average methane content of approx. 30 vol.-% and an average carbon dioxide content of approx. 25 vol.-%. In general, no methane could be found any more during the investigations at a depth between 30 and 60 cm below the upper edge of the surface.

Exemplary results of test field TF 1: In test field 1, a significant decrease in the methane concentration could be measured over the whole profile of the recultivation layer after only one week. In December 2002, for example, the methane content decreased from 28.1 vol.-% at a depth of 120 cm below the upper edge of the surface to 0.7 at a depth of 30 cm below the upper edge of the surface. For six out of eight measurements, methane contents of only 0 – 0.3 vol.-% were measured at a depth of 30 cm below the upper edge of the surface whilst the original methane concentrations amounted to 28 – 40 vol.-%.

The observations so far show that methane conversion takes place particularly at depths between 120 and 90 cm below the upper edge of the surface. As is shown exemplarily by Figure 7, the methane content decreased from 36.3 vol.-% at a depth of 120 cm below the upper edge of the surface to

- 6.4 vol.-% at a depth of 90 cm below the upper edge of the surface,

- 6.2 vol.-% at a depth of 60 cm below the upper edge of the surface,
- 0.2 vol.-% at a depth of 30 cm below the upper edge of the surface.

The reason for the „suppressed“ degradation activity in the central area of the recultivation layer (90 – 60 cm below the upper edge of the surface) could not be explained until now, but turned out to be typical for this monitoring point.

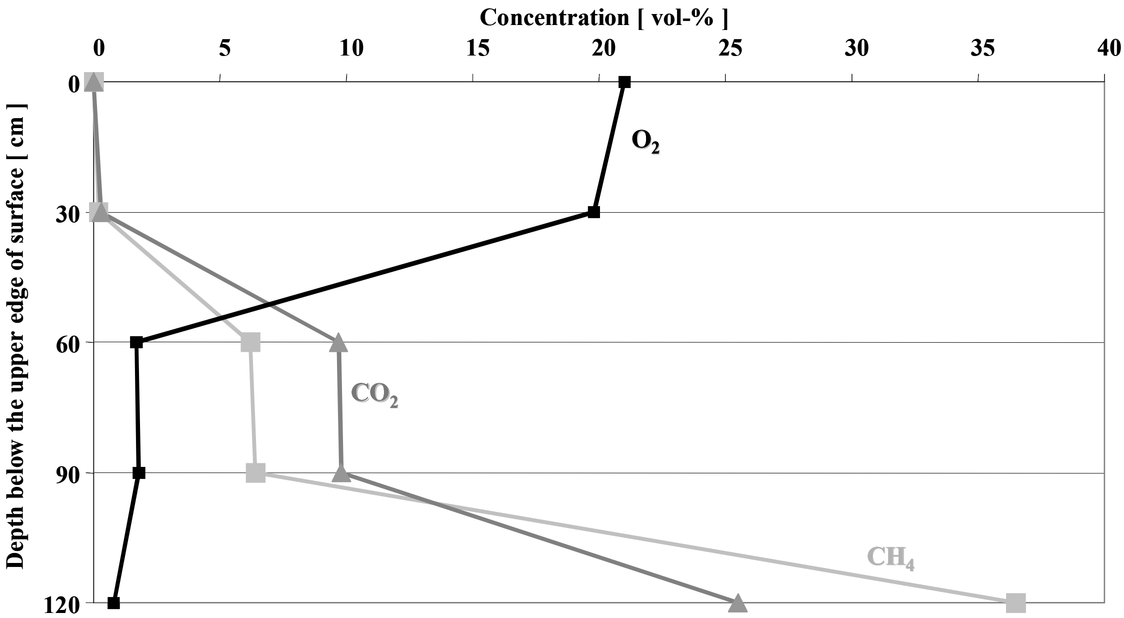


Figure 7. Exemplary presentation of the course of the gas composition over the depth of the recultivation layer of test field TF1 (December 2002; see also Table 1)

In general, the chosen structure of the layers and the installed soil materials in the recultivation layer of the test fields are suitable for methane oxidation to an extent which could be relevant subsequent to completion of the active aerobic stabilization process.

In further investigations regarding methane oxidation, the gas conditions (gas volume flow, gas composition) are varied during different seasonal climatic conditions. In addition, FID inspections will be undertaken. This procedure enables the identification of defects (preferential gas flow paths) and gas emissions via the surface.

5 OUTLOOK

The provisional results (approx. 22 months) of water budgets of the different top cover systems are very promising. However, the findings are not reliable enough for long-term forecasting. In general, for investigations of the water balance of surface sealing systems several years are necessary.

Based on the results so far gained further investigations are required:

- **Water balance**
  - For long-term forecasting: The influence of the water storage capacity of the recultivation layers and of the water removal via the drainage layers as well as the functional efficiency of the sealing systems should be further investigated.

  - In phases where plants on the surface grow very „intensely“, the influence of the water consumption via the plants should be investigated over several vegetation periods.
  - The performance of the mineral sealing, which was emplaced on the “dry part” of the Proctor curve (for the first time in a test field in Germany) should be further investigated. This is necessary to gain long-term experiences at varying climatic conditions. The results gained until now are very good.
  - The long-term „regeneration capacity“ of capillary barriers which, temporarily, have lost their functional efficiency, should be further investigated.
- **Methane oxidation:** Up to now, a landfill gas supply, monitoring and sampling system has been installed and tested over a period of 10 months. The preliminary results reveal that the investigated recultivation layers show a significant methane oxidation potential. The methane content thus decreased rapidly over the depth of the layer from the bottom to the top. For comparative investigations of the different systems with regard to their methane-oxidizing effect, long-term investigations are required. At the same time, the mechanisms of the methane contents decreasing over the depth of the layer should be further investigated - disappearance due to:
  - microbial conversion,
  - dilution effects,
  - preferred flow paths res. obvious problems in the test fields with regard to misdirected gas flows,
  - gas emission via the surface.

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