

# **DURABILITY OF HDPE GEOMEMBRANES IN BASAL LINING SYSTEMS OF LANDFILLS: SPECIFICATION AND SELECTION OF THE GEOSYNTHETIC BARRIER UNDER CONSIDERATION OF ELEVATED SERVICE TEMPERATURES**

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**SUMMARY: Nowadays the decisive criterion for the acceptance of the primary sealing system is durability. However, life time depends among others on temperature conditions. We will show that HDPE-geomembranes provide sufficient durability thus ensuring long-lasting service life.**

## **1. INTRODUCTION**

HDPE geomembranes have become the most commonly used sealing element for environmental protection applications. HDPE offers excellent resistance against chemical and biological attack. Apart from this the raw material, is now available worldwide at favourable price levels compared to other plastic materials. These prices and the wide-spread availability boost the consumption of this material. Certain grades of HDPE have been developed to overcome an until recently still inherent HDPE-problem (stress cracking) and as a result the material, when converted into wide-width sheets of 1.5 – 3.0 mm thickness now governs the application as primary sealing layer in landfill basal linings.

The operation phase of an engineered landfill in many cases is set at a period of 30 years. The after-care period has been set at another 30 years. As a result the industry, engineers and the scientists talk about life time for HDPE liners well in excess of 100 years. But there are some questions to be answered, like:

- can such service life be forecasted for materials when exposed to higher temperatures?
- can constructive measures cure the possibly anticipated temperature impacts?
- And: how should the geomembrane be installed and protected?

With the author's background and experience in material quality control in production and on-site it is obvious that this paper will rather focus on the lessons learned in practice than on the scientific approach issues. However, at the beginning a few excursions into legislation, into manufacturing process of HDPE, into aging mechanisms and resistance, and the state of scientific research need to be made.

## **2. SERVICE LIFE AND AFTER CARE PERIOD - THE LEGISLATIVE BACKGROUND**

The construction of landfills in Europe and in the United States is to a great extent regulated by authorities. In 1999 the European Union issued a directive (Council Directive 1999-31 on the Landfill of Waste) which has been transformed into national laws in all European countries (in Germany the Technical Directions on Municipal Waste issued in the early 1990's have been transformed into the Landfill Regulation DEPv of 14.07.2002 that is now effective). The US authorities through the U.S: Environmental

Protection Agency (EPA) has revised their landfill regulation in 2002. Here are some statements on the after-care period of the landfills:

EPA Guidance & Regulations, Chapter 1, USA (EPA, 2002):

“Generally, leachate generated by a landfill will need to be collected for the active life of the landfill plus a 30-year post-closure period. However, the 30-year period has yet to be reached for any landfill constructed under current EPA regulations. Longer periods of leachate removal may be required for at least some sites, while for many modern sites, leachate generation should essentially cease prior to the end of the 30-year period.”

EU - directive Article 10, Europe (Council directive 1999/31/EC)

..”the estimated costs of the closure and after-care period of the site for a period of at least 30 years shall be covered by....”

Both EPA and DEPV specify composite barriers for landfills with leachate production. In this the primary barrier in a landfill (the HDPE liner) is to prevent migration of leachate into the underground. Therefore, this material needs to have an outstanding performance for the operational phase and the after-care period. In engineered landfill structures the operational phase can last for as long as 30 years, depending on the method chosen for leachate treatment. The after-care period is generally to be considered to last another 30 years, thus providing for at least 60 years of life time of the primary barrier.

When properly chosen, manufactured and installed and when proper quality assurance systems have been applied from the time of selection throughout construction, the life time of the geomembrane is estimated to be well in excess of 100 years. But, as for any other construction material, ageing has an impact on the service life time expectancy.

### **3. OVERVIEW OF MANUFACTURING PROCESS**

Before we describe how ageing works let us take a closer look at the manufacturing process of polyethylene materials. Polyethylene is produced by way of polymerisation of ethylene molecules. Depending on physical conditions, the type of polymerisation procedure and the chemical environment, different molecular structures of polyethylene molecules are produced as a result of this process. This leads to materials with various differences in morphology and density providing a great variety of different material properties. The oldest technology that goes back to the 1930's is the high-pressure polymerisation at high temperatures which produces a highly branched molecule – the low density polyethylene - LDPE. Using transition metal catalysts (Ziegler-Natta type), ethylene can be polymerized at lower pressures and temperatures in a so called low pressure polymerisation forming high density Polyethylene - HDPE.

We can distinguish between different manufacturing processes depending on the characteristics of the catalyst, the chemical environment and physical conditions. For example the Unipol process, a gas phase polymerisation, is a process that provides linear polyethylene polymers almost completely free of any branching structure.

Figure 1 illustrates the molecular structure of Polyethylene types.

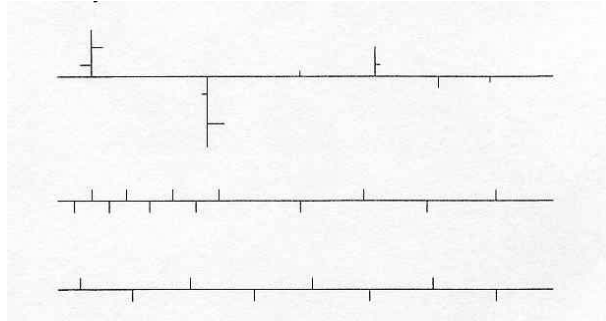


Figure 1 Schematic illustration of polyethylene molecular structures of various density ranges, Top to bottom: LDPE; HDPE; LLDPE (Müller, 2007)

Polymers of ethylene and  $\alpha$ -olefins (butene, hexene, octene) have been produced since late 1970's. These so-called  $\alpha$ -Olefin co-monomers have many advantages similar to HDPE (resistance to chemicals) but do not show the disadvantage of stress cracking. Therefore, the problems with LDPE, which is due to its structure that is less resistant to chemicals, and the stress cracking problem with HDPE have been resolved in another single type of material – LLDPE. Such LLDPE materials provide geomembranes suitable for engineering purposes. The density of the pure resin is below  $0.94 \text{ g/m}^3$ . Since the density of geomembranes coloured with carbon black made of such LLDPE resins is above  $0.94 \text{ g/m}^3$ , they are called HDPE by the geomembrane industry based on the ASTM D 4976 classification and ASTM D 883 – “HDPE - those linear polyethylene plastics – having a standard density of  $0.94 \text{ g/cm}^3$  or greater”.

Thus custom-designed properties can be provided through the manufacturing of polymers which nevertheless hardly differ in density. At the same time the copolymers allow to optimize material properties with regard to flexibility while also providing mechanical strength and high resistance to stress cracking.

Further material properties result from antioxidants and light stabilizers which are mixed into the polymer and are important for an appropriate ageing resistance.

#### 4. AGEING RESISTANCE

In the following we will give a short description of the relevant ageing mechanisms on the one hand and on the other hand of the relevant geomembrane properties determining service life time.

##### 4.1 Resistance to thermo-oxidative and photo-oxidative ageing

Oxidative ageing takes place in the amorphous phase of the polyethylene. The fundamental process of oxidative ageing of polymeric materials is a free radical chain reaction. The so called auto oxidation including complex radical reaction chains is leading to decomposition and cross-linking of polymer chains and the creation of low-molecular reaction products and at the end to embrittlement of the polyolefin. The process is accelerated by the influence of UV-radiation and high temperatures.

A well known test procedure to determine the ageing resistance is the evaluation of Oxidative induction time (OIT) as well as the evaluation of high pressure-OIT (HP-OIT) and the initial properties as well as the evaluation of properties after accelerated artificial ageing (oven ageing and UV-weathering). Since the availability of oxygen is diffusion controlled beneath the polymer morphology and the addition of a stabilisation package

sufficient thickness is determining resistance.

## 4.2 Resistance to stress cracking

Based on a simple model, the long-term effect of stress causes a gradual deanchoring and distanglement of the tie-molecule chains that connect the crystalline regions (Müller, 2007). Crack formation in the geomembrane, which finally causes the material to break, is caused by tensile stress that is less strong than the yield strength. When stress cracking occurs, an apparently smooth fracture surface grows slowly into the cross section of the material until local tensile stress, having increased accordingly because of the decreasing cross section, exceeds yield strength and the material cracks along the margin of the fracture surface. The break is characterised by a smooth and even fracture surface. Thus a brittle failure of the material has occurred. This process is accelerated by chemicals.

HDPE-geomembranes produced from such LLDPE materials can be classified as very resistant, and their resistance mainly differs acc. to the content and molecular mass of the co-monomers. The manufacturing condition and the resulting morphology have also an influence on the resistance feature of the material.

State of art today is the single-point NCTL test (notched constant tensile load) acc. to ASTM 5397. Apart from this index test, in some European countries the test concept for HDPE pipes is also applied for geomembranes. Pipes are extruded using the raw material for geomembrane production. Pressuring the pipe section causes a three-axial state of stress in the pipe wall. The time to failure under this internal stress in a water bath at elevated temperature is measured. This leads to the classification of PE types based on their long-term hydrostatic resistance. PE 80 is the type to be used for geomembranes acc. to KIWA BRL-K538 (Dutch certification procedure for the use of geosynthetic barriers) as well as BAM-requirements (German Certification Guidelines for plastic geomembranes used for landfill lining). The classification is derived from the minimum required strength after 50 years at 20°C service life the material can exhibit – here 8.0 MPa. Details of the methods for the forecasting of the long-term hydrostatic strength are given in ISO 9080 and DIN 16887. This test for evaluating stress cracking is also an implicit test of oxidation stability.

## 4.3 Resistance to chemicals

“A chain is as resistant as the weakest link“. Polyethylene consists of repetitive, simple molecular links. This explains its high chemical resistance. However, chemicals penetrate the geomembrane in 3 ways:

- Diffusion and enrichment in the polymer structure leading to swelling forces
- Chemical reactions -in case of polyolefins – oxidation process
- Extraction and modification of additives

Chemical resistance is tested in immersion tests. The properties which give indication of chemical damage are appearance, changing in mass, mechanical parameters and stress crack resistance. The EPA method 9090 with an immersion at 2 temperatures over 120 days using landfill leachate is an approach to resistance testing. German regulations require the exposure to highly concentrated chemicals since functional reserves can only be evaluated by this way. Only a few special plastic materials, especially HDPE-geomembranes, will pass this stringent 3 month test acc. to BAM certification procedure.

HDPE-geomembranes are not entirely inert, but they are extraordinarily resistant to a

wide spectrum of highly concentrated chemicals over a long period of time without any serious damage. Comparable resistance is not evaluated for such other geomembrane products as for instance EPDM, bituminous membranes, ECB and PVC or recycled polymer materials and this should always be taken into account especially when specifying the sealing layer for a landfill basis.

## **5. SERVICE LIFE TIME - SCIENTIFIC RESEARCH - PRACTICAL EXPERIENCE**

### **5.1 Scientific research findings**

A well-known model is the elevated temperature incubation with Arrhenius modelling and extrapolation to lower site-specific temperatures carried out by the Geosynthetic Research Institute (GRI) in the United States. This has resulted in an estimated service lifetime of 550 years at normal conditions for a particular HDPE-geomembrane. Three stages of ageing are described here (stage A - antioxidant depletion time – 200 years, stage B – induction time – 30 years, stage C, the actual change of the molecular structure accompanied by a deterioration of the decisive mechanical properties – 320 years). However, temperatures higher than 20°C will cause lifetime to decrease exponentially. At, 40°C, the predicted lifetime of the same 1.5 mm geomembrane is approximately 90 years (Koerner, 2005).

A different approach was taken in Germany (Müller & Jacob, 2003). HDPE- geomembranes with a thickness of 2.5 mm were stored both in air and water at 80°C over a time period of more than 13 years (air) and 6 years (water) respectively. The changes of elongation at break as well as the antioxidant depletion were tested. In this context, it was found that ageing in water obviously takes place more rapidly than in air. In hot water migration/leaching of antioxidants dominates, which has a major effect on the ageing process and therefore on the service life time of HDPE-geomembranes. Oxidative ageing in air takes place rather slowly and plays only an insignificant role compared with migration/leaching. In water, some samples, having lost all of their antioxidants, showed a rapid decrease of elongation at break. The conservatively estimated lower limit of service life time of the HDPE-geomembranes tested was calculated to be at least 300 years (at a usage temperature of 20°C). This calculation was based on very low activation energy.

### **5.2 Practical experience - test results on field exposed HDPE-geomembranes**

GSE has data available on HDPE-geomembranes exposed of up to 30 years. These indicate that further ageing resistance is provided by the weathered geomembrane. In 1974, at the location in Galing/Germany a jarosite sludge deposit was built (Galing I) with a composite liner system using 2.5 mm thick geomembranes. Jarosite sludge is the waste arising from the production process of zinc and lead. The sludge has a pH-value of ca. 2-4. The lined area was about 11 ha.

In 1984, the second pond (12 ha) was built at the same location (Galing II). On the slopes, the HDPE-geomembranes are permanently exposed to weathering (annual solar energy ~ 90 kLy). The landfill is pictured in figure 2.



Figure 2 Jarosite sludge landfill Galing/Germany

For Galing II a comprehensive test program for the assessment of long-term behaviour was carried out by the Süddeutsches Kunststoffzentrum (SKZ), Würzburg/Germany as early as in 1984. The evaluation of properties was conducted 6 times in 26 years (SKZ, private communication).

Even 26 years of exposure show that the tensile properties do not change significantly. The environmental stress crack resistance (ESCR) was originally measured according to ASTM D 1693, now superseded by the NCTL-test (ASTM D 5397). The initial value of 2000 hours acc. to the older test is still preserved. Evaluating the stress crack resistance acc. to ASTM D 5397 (SP-NCTL), it was found that 60% of the initial value (52 hours) is still preserved.

A significant reduction of the oxidative induction time (OIT) was noted, a value which indicates the amount/depletion of antioxidants. In order to determine the remaining antioxidant content more precisely, in 2000/2005 the OIT measurements were taken at lower temperatures. The OIT-value decreased continuously over the years, which indicates that there is a slow consumption of antioxidants. The remaining antioxidants provide continued ageing resistance. Figure 3 shows the OIT results (full cross section of sample tested).

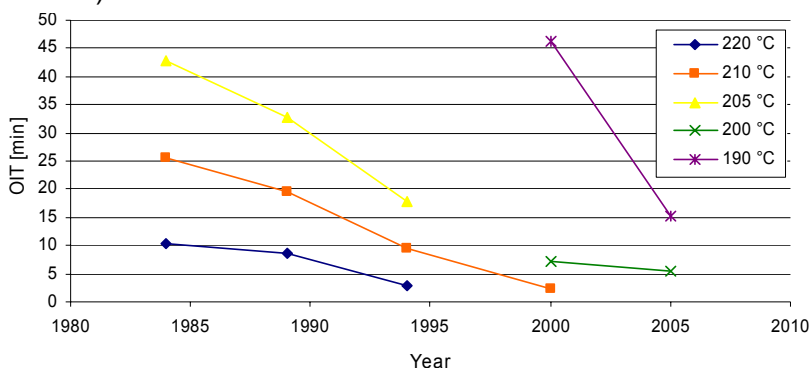


Figure 3 Galing II, OIT acc. to DIN EN 728 – Depletion of antioxidants

For Galing I, after 31 years of exposure, the tensile test results show that the tensile stress, the elongation at yield, and the tensile stress at break have not changed significantly whereas only 30 % of the original elongation at break is retained (only transverse direction was tested). Time to failure in SP-NCTL-testing amounted only to five hours. A significant reduction of the OIT-value (5 min) was determined, but still small amounts of antioxidants are there.

For a better understanding of the antioxidant depletion process, the OIT-testing was conducted separately on the top surface and the middle layer of the geomembrane. Table 1 provides a survey of the results.

Table 1 Antioxidant content in different layers 1995/2005 – Galing I / 2005 – Galing II

Project	Galing I (31 y)				Galing II (21 y)	
Year of test	1995		2005		2005	
Layer tested ~ 0.9 mm	Top	Middle	Top	Middle	Top	Middle
OIT [min] at 200 °C	7,1	8,8	0	4	5	65
OIT [min] at 190 °C	13,8	20,9	0	8,5	10,5	148

In the top layer of the geomembrane weathered over the period of 31 years no antioxidants could be detected. In the middle layer, however, antioxidants are still present. Also in the top layer of the 21 year old geomembrane of Galing II a significant reduction of OIT could be detected, whereas in the middle layer no reduction is found. Due to the carbon black stabilization, the UV-radiation penetrates only the upper layer. The top layer is penetrated by oxygen faster, since its availability in the geomembrane is essentially diffusion controlled. Therefore we can conclude that the thickness of the liner has a major influence on the antioxidant depletion and subsequently on the preservation of the barrier function. It has been shown that the outward migration of antioxidants is slower on thick geomembranes (Rowe et al, 2002).

### 5.3 Results of temperature measurements in landfills

The impact of (permanently elevated) temperatures on the service life of geomembranes became recently the major focus of discussion.

Since normally more than 50% of solid municipal waste consists of organic matter, they offer a huge capacity for heat production. Heat will cause accelerated antioxidant depletion in the geomembrane and desiccation of the clay liner. In addition to the height of temperature the duration of high temperatures on the lining system are determining factors of service life. In the last 15 years several temperature measurements in landfills have been carried out to assess the long-term decomposition process of wastes and heat energy potential to determine the length of the after-care period and to evaluate to what extent the sealing system is affected. Some measurements are presented in this paper:

Case 1: Hazardous Landfill Rondeshagen, (Lhotzky & Partner)

This is a landfill in which incineration ashes are disposed of, it is lined with a composite liner system using 2.5 mm thick geomembranes. For these measurements a system from the company Phytex/Braunschweig has been employed. The measuring probes had been placed in different levels of the lining system as well as below the geomembrane as shown in figure 4.

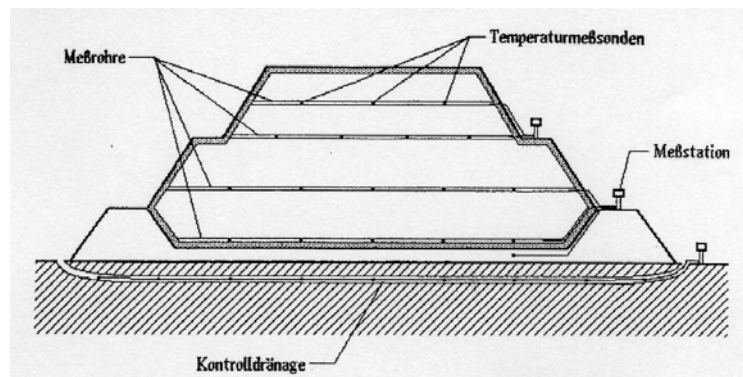


Figure 4 Arrangement of measuring probes (Lhotzky, 1997)  
 Figures 5 and 6 show the measured temperature profiles in different cells of the landfill.

Obviously, the temperature is decreasing from the hot inner zone to the bottom and to the top. In different measuring segments parallel temperature profiles had been detected, though altogether there are significantly lower temperatures in the cell with a thin layer of the ashes. By installing thin layers, the energy released in the chemical processes can easily be emitted to the environment.

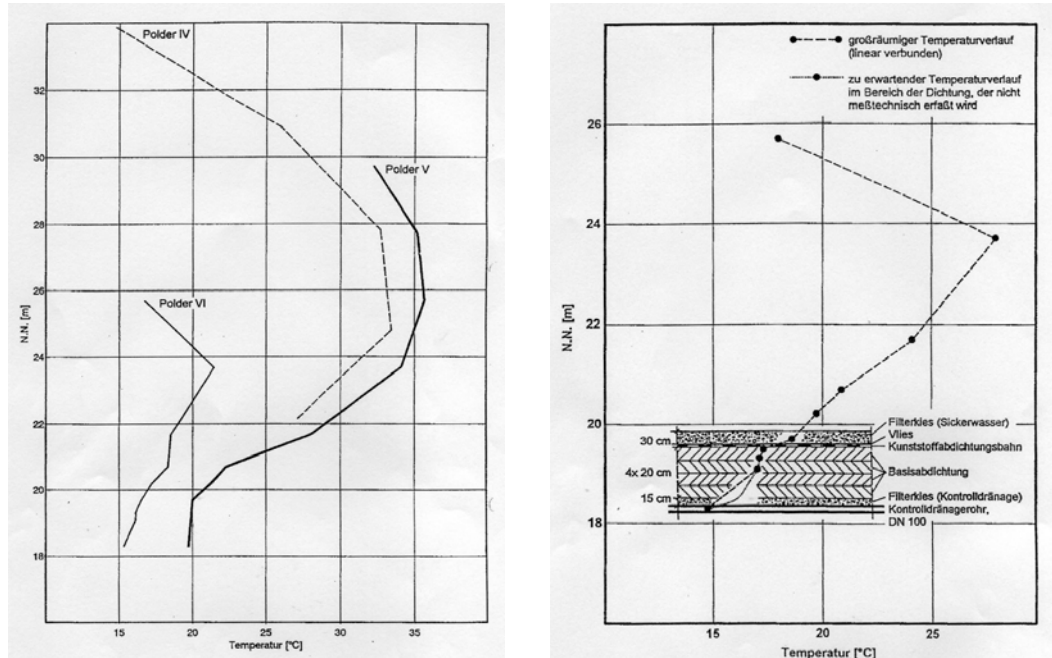


Figure 5 + 6 Temperature profiles in different cells / Rondeshagen (Lhotzky, 1997)

#### Case 2: MSW Landfill Hannover, Germany (Collins, 1993)

This is a landfill that was erected in 1938 and was operated until 1980. Here in a partial area the marl layer was used as barrier, the other part was built on a peaty soil. The waste measures a height of 60 m. The temperature in the waste was measured in bore holes with special preparation. It was not expected to find temperatures of up to 65°C. The temperature was decreasing going to the bottom of the landfill. But in the case of the marl layer 54°C were measured on the marl layer whereas only 30°C on the peaty soil. If the leachate is not drained off (in this case it is the leachate that does not seep away), the temperature rises in the area above the sealing layer.

#### Case 3: MSW landfill near Philadelphia, USA (Koerner G.R. & Koerner R.M., 2005)

Here a dry and a wet landfill cell have been monitored. The wet landfill cell is a so-called bioreactor landfill. The landfill is lined with a double composite liner system using 1.5 mm HDPE-geomembranes. After 10.5 years of monitoring the geomembrane beneath the dry cell, the average temperature was measured at 20 °C for 5.5 years but then abruptly increased to an average of about 30°C and has been slightly rising since then. For the wet cell, the temperature has started at 25°C and has gradually risen to 45°C over ~ 4 years' monitoring time.

#### Case 4 : MSW landfill Ihlenberg, Germany (Lhotzky, 1997)

Here temperature measurements were taken during the construction phase. In the uncovered composite liner system temperatures between -16°C and up to 53°C were measured. When covered with a thick geotextile, the temperature range was -5°C to 43°C. Covered with mineral drainage material the temperature range was again lower. Further measurements are taken when monitoring drainage pipes. Acc. to the legislative



regulation in Germany, landfills have to be monitored during the operation phase and then during the after-care period. This applies also to the landfill base and in most cases is limited to the examining/camera monitoring of the leachate pipes. This often includes temperature measurement. Temperatures of 30°C going up to 40°C are evaluated. The temperature curves inside of a gas pipe and a drain pipe are shown in figure 7.

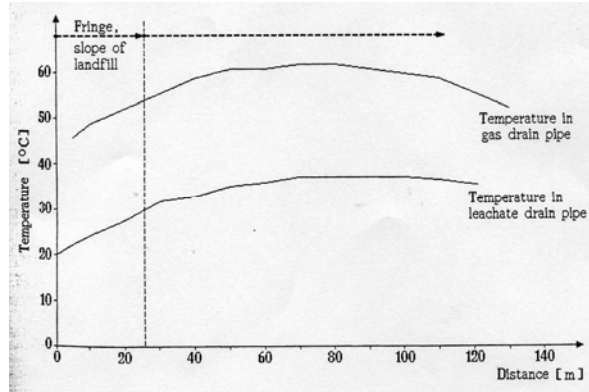


Figure 7 Measured temperatures in leachate pipe and gas pipe (Collins, 1993)

The temperature in the leachate pipe is in the range of 30°C. The temperature inside the gas pipe measured up to 60°C increases with the distance to the outside.

## 6. BARRIER CONCEPTS AND SERVICE LIFE TIME

### 6.1 Layer systems

The engineered landfill can certainly meet all demands in order to provide a secure place for disposing and storing of waste for several hundred years.

The ideal concept from the geotechnical point of view using numerous geosynthetic layers is shown in figure 8.

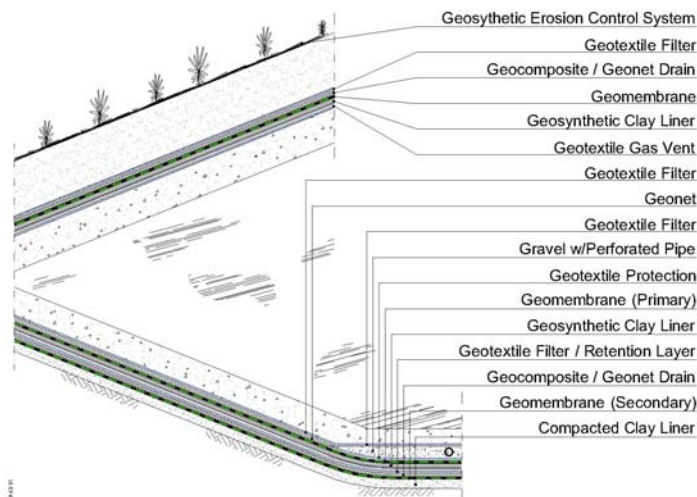


Figure 8 The ideal layer system from geosynthetic point of view (EPA, 2002)

For Germany the sealing system for MSW landfills acc. to the Landfill Regulation ("De-

ponieverordnung”) based on the Council-Directive is shown in figure 9. The German concept is based on fewer but thicker layers.

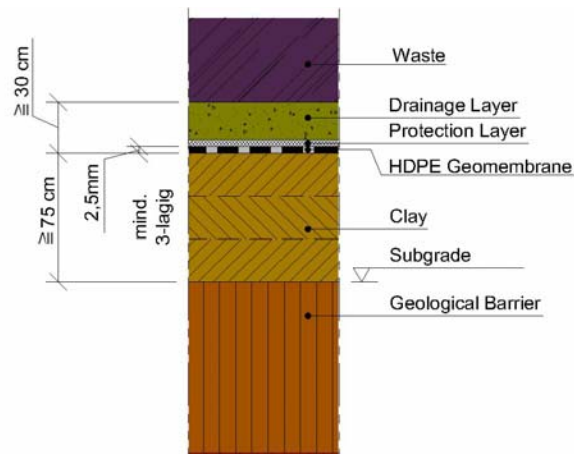


Figure 9 MSW landfill layer system acc. to German Regulations

The operation of a landfill with its way of disposing of waste should also contribute to this for instance by prior separation of organic waste in order to avoid temperature rises, fire etc. in the landfill. The basal sealing as a system to retain the contaminant should always meet state-of-the-art standards of technology. In most municipal waste landfills this is today – and probably will remain for quite a number of years to come – a composite liner consisting of primary sealing with geomembranes and secondary mineral layer.

## 6.2 Constructive measures supporting service life of the sealing system

Based on the experimental results mentioned above and on the experience in constructing landfills, we can conclude that a variety of constructive measures can be taken to support service life and that a variety of negative factors that have an impact on the service life of a lining system can be avoided thus ensuring an effective protection for the ground water for decades, even for centuries.

The basal lining of a landfill today should be a composite liner system. The choice of construction materials offering sufficient ageing resistance under harsh conditions is the next step. A well proven high-quality HDPE-geomembrane is one construction product offering such life time. In this context we would like to point out that the HDPE-geomembranes should be chosen in sufficient thickness ( $\geq 2.0$  mm).

The laying of the geomembrane shall immediately follow the installation of the compacted clay liner.

The installation process of the sealing layer has an impact on service life. With regard to the geomembrane, the installation works shall be performed in such a way as to prevent stresses in the geomembrane, Continuous stress upon a certain value results in a premature failure - stress cracking - of the geomembrane. Based on theoretical considerations, different research results and the hydrostatic pressure creep test (pipe testing procedure) on geomembranes Müller has found that 3% has to be regarded as the long-term strain limit (Müller, 2007). Conversely, stress crack formation is impossible when deformation stays below this limiting strain. This limiting strain value is independent over a wide range of temperatures and should be considered in regard to laying, the problems around subsidence and the pressure applied by drainage covers and wastes. The geotextile protection layer should be amply dimensioned to protect the geomem-

brane against localised stresses due to the gravel size of the drainage material. So called load plate tests simulating the landfill system and loads can be used to determine proper dimensioning. Standards describing these procedures are available.

The geomembranes should be installed with a minimum of weld seams and even better – with a small content of extrusion welds. Seams connecting liners that had been installed the day before as well as the seams connecting slope liners with the basal geomembranes should not be welded, if possible, before the next day in order to allow the liner to relax and to avoid fixing the tension and thus achieving a full area contact with the clay liner. For the connection to pipe penetrations or in other disruptions bevelling should ensure flat transitions between such elements and the geomembrane.

Apart from the construction material, the welding works determine the life time. Welded joints are part of the system of the basal lining and therefore need to be critically observed as well. Apart from the short-term peeling tests (on-site QC testing), long-term peeling tests in laboratories can also be carried out. Weld specimens are stored in an aqueous solution of a surfactant at 80°C under 6N/mm of stress. The existing results show for extrusion welds ~ 50 hours and for double hot wedge welds ~ 300 hours to failure. These tests demonstrate one more time that, just like the material properties, the quality of welding should never be left out of consideration. One can derive from these tests under stress how important the free-of-stress installation is for the length of life time of the sealing system.

The installed segment should upon examination immediately be covered at least by thick geotextiles. Open segments should in any case be covered with a weight for instance sand bags. Covering the geomembrane with a geotextile immediately after welding works will protect the barrier against wrinkling that can possibly result in stress.

The laying of the drainage layer shall be done in such way as to achieve full contact of the geomembrane with the clay layer – without any fixation of wrinkles. A good practice is the laying of drainage material with a long-arm excavator from mineral layer ramps.

In order to provide for the highest quality of the lining systems and a sufficient service life, we recommend to carry out the inspection and testing beginning with the product and later to carry on during the installation and in addition during the service life as well.

Temperature measuring in landfills is one way to evaluate risk for further landfill construction and operation. The temperature measurement presented herein show that high temperatures are generally to be expected within the waste body above the sealing system. In case of proper working sewage water collection elevated temperatures of max. 40°C have to be expected. This is a familiar calculation factor with regard to service life expectancy under the precondition that the geomembranes are installed without stress.

Further measures to protect the sealing system – the clay layer as well as the HDPE-sealing – are absolutely necessary in case of expected temperatures of more than 60°C to ensure sufficient service life. Since temperature measurements lead to the result that the sealing system is strongly influenced during the construction phase already tipping of wastes should begin directly after construction. The filling with thin layers of waste will even enhance the protection of the sealing system against high temperatures.

## 7. CONCLUSIONS

Based on the scientific research findings and the practical experiences obviously a sealing layer using HDPE-geomembranes produced from modern  $\alpha$ -olefin co-monomers is offering more than 100 year service life under conditions normally to be expected in a landfill. Proper specification based on GRI GM 13 and further test procedures as described above allow choosing such a high-quality product. Sufficient thickness of the geomembrane -  $\geq 2.0$  mm - is an eminent factor to withstand ageing and therewith the key to sufficient service life.

Besides, third party quality controlled installation works as well as the well managed operational phase aid on service life. The filling with wastes directly upon completion of the barrier supports service life as well as filling in thin layers.

Mineral layer and the geomembrane are affected by elevated temperatures. Several measurements show that the sewage water generally reaches temperatures between 30°C and 40°C which is a known factor on service life time. Higher temperatures directly on top of the barrier were measured beneath the sewage water build-up. This leads to the conclusion that a sewage water collection system has to be maintained throughout service life.

In case higher temperatures (above 60°C) are expected, further measures should be taken to support service life of the barrier system.

Along with monitoring the material we positively assess the method of conducting relevant monitoring of the construction work by experienced independent auditors.

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