Composite Liner Systems

Experience with the Classic Barrier System (HDPE-Liner over CCL-Liner) and Alternative Geosynthetic Solutions

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ABSTRACT
A composite barrier should preferably be a standard in any basal containment system where leachate is generated or harmful substances for the environment are to be contained for indefinite periods such as landfills, tailing dams or leach pads. In this paper the necessity of a composite liner in containment systems is highlighted and some alternative liner components introduced. Besides the requirements on the liner components itself, the installation works of the full barrier system influence the long-term functionality which is discussed into detail herein. Even at times of financial and economic crisis one should not allow lowering of this technical standard, for landfills (or other containment facilities). Technology for the environment needs to be sustainable.

1. INTRODUCTION

Composite liner systems for environmental protection applications should be, ideally, constructed with a thick HDPE-geomembrane primary layer as the hydraulic barrier. The secondary layer can alternatively be a compacted clay liner or a geosynthetic clay liner, in the following referred to as CCL or respectively GCL. The combination of the hydrophobic geomembrane barrier with the hydrophilic clay barrier functions properly even under long-term impact of organic liquids. Both liners in a composite barrier system must be constructed with intimate contact between the two.

This paper refers mainly to solid waste landfill liners from HDPE but conclusions herein are valid for HDPE-liners in other environmental protection applications like tailings dams or leach pads as well. Some may argue why do not use liners that have better layflat characteristics (just to name a point often used to criticize HDPE). In the following it is shown why HDPE-liners are chosen and how to install them laying flat.

HDPE-liners demonstrated an unprecedented track record for environmental protection applications, but around the world with different requirements on quality (long-term properties) and on thickness.

Why 2.5 mm thick certified HDPE-liners in Germany where chosen amongst the alternatives for primary liners and the necessity of a composite liner system as basal barrier in a landfill is described by Müller (2007) in detail. The use of a thick HDPE-geomembrane and the necessity of a composite liner system is a real German point of view one could argue here – especially when looking to costs it seems obvious that money could be saved by reducing layers or using thinner components. In Germany landfills are considered as final storage systems from which no environmental burden shall arise over a period of centuries. Therefore it is necessary to get a clear view on the durability of the HDPE-liner and on installation procedures as well as assuring long-term function of the entire barrier system. Proper raw material selection, manufacturing process and thickness specification and thorough quality control are imminent factors on service life. Redundancy of the barrier components is another relevant factor as well as protection of the barriers during service life – this explains the “German” view.

Several steps determine the quality of any barrier system:

Detail design and technical specification - right selection of high quality geosynthetics avoids risk of premature failures. Consideration by the consultant should be given to launch a separate tender for just the geomembrane and to nominate products and installers unless certified products are specified.

A description how installer and contractor have to achieve laying and welding without geomembrane overfolding is necessary. Proper design of cover layer is critical as well.

Tender - evaluation of tenders should more focus on technical functionality rather than on price and nomination of prequalified products should be considered beforehand.

Construction - construction shall be under third party control and supervision, a proper quality plan established prior to begin of installation works. Protection or other cover layers shall be handled with same care.

The paper wishes to refer to geosynthetic liner components, especially in respect to HDPE-liners and to its leak free construction. The following paragraphs focus on the classic composite barrier system, state of the art installation highlighting a special installation concept – "Riegelbauweise" = "lock bar" installation. A short excurse on alternatives to the classic barrier concept is included.

2. CLASSIC COMPOSITE LINER SYSTEMS

In Germany a composite landfill barrier system consists of a 2.5 mm certified flat-die HDPE-geomembrane and a CCL liner constructed in 3 layers with an overall thickness of 0.75 m with a permeability of < 5×10^{-10} m/s for conventional municipal wastes and 1.8 m height for hazardous wastes supplemented by a protection layer. The protection layer can either be a mineral layer fine grained, a sand-mat, a heavy weight geotextile or a geosynthetic drainage and protection geocomposite in case of a capping system. This liner system installed acc. to the state of the art is to be regarded as impervious.

Acc. to European regulations- EU-Directive on landfills (1999) the basal liner system for hazardous wastes and non-hazardous wastes shall be a composite barrier, comprising a mineral layer with a thickness of 5m and a hydraulic conductivity of $k \leq 10^{-9}$ m/s for hazardous wastes and for non-hazardous wastes with a thickness of ≥ 1m and a hydraulic conductivity of $k \leq 10^{-9}$ m/s and of an artificial sealing layer and a drainage layer. EU member states set specific requirements based on this general rules; HDPE-geomembranes became therein the primary barrier principally. In the United States the HDPE-liner has to be 1.5 mm thick for municipal solid waste, the compacted clay liner 0.6 m thick with a permeability of 1×10^{-9} m/s, for hazardous wastes double liner systems are required. The South African requirements foresee a 1.5 mm HDPE-liner above a GCL if a composite barrier is needed.

For any proper working composite barrier system in an environmental protection application the surface of the compacted clay layer must be smooth, without cracks (installed with a water content higher than proctor optimum) to achieve the low hydraulic conductivity. In a composite liner system it is assumed that the pore space of the mineral liner accessible to diffusion is water saturated, therewith VOCs which can diffuse in small quantities through the geomembrane cannot be transported in the mineral layer (no gas transport takes place). These quantities which can diffuse develop in the interface mineral layer and geomembrane on a thin water film.

The geomembrane above the clay liner must be installed without waviness so that the overburden loads assure an intimate contact of the geomembrane to the CCL. The development to use HDPE-geomembranes in basal landfill barrier systems began first due to their excellent chemical resistance. Safe and reliable jointing technology on large area products needing less seams were a second factor to the track record of HDPE liners. The knowledge that VOCs can diffuse through the geomembrane led to the requirement on 2.5 mm thick products and to the requirement on composite barrier systems. Diffusion is decreasing disproportional with increasing thickness and therefore mass transport of hydrophilic hydrocarbon components already highly suppressed by the thick HDPE-geomembrane itself (Tatzky-Gerth, 1988). Besides the optimised tightness by this thickness requirement an extraordinary service life time of the HDPE-geomembrane (>= 100 years) can be achieved (in the initial state of the development of HDPE-geomembranes for landfill lining the service life was expected with ~ 30 years only and after that period the clay liner and the geological barrier regarded to take the long-term barrier function).

A perfectly installed, faultless composite liner is therefore extremely impermeable for enduring periods. Not every liner leaks necessarily. The combination of a hydrophobic liner material with a hydrophilic mineral layer – comprising the composite liner, operates properly also under the impact of liquid organic materials.

To assure the proper function the geomembrane in the liner system has to be protected against damage by coarse objects in a coarse sized mineral drainage layer. Under dynamic load during construction period and under static load in use these objects can cause indentations, holes and tears. The geomembrane is protected by a protective layer for two reasons - to prevent perforations by sharp-edged objects and to ensure that indentations or imprints do not exceed the maximum permissible limiting strain which is in the range of 3% (conservatively) – 5%. The protection layer is necessary to avoid permanent stress and thus stress propagation resulting into stress cracking.

The type and design of the protective layer depends on the loading conditions. “Plate load tests” simulating the on-site conditions are available to evaluate the protection efficiency. Since the protection layer is an essential element of the liner system the long-term durability should be taken into consideration for any protection layer. The extraordinary service life required for geomembranes cannot be ensured without a suitable protection layer providing same service life.

3. INSTALLATION WORKS AND THIRD PARTY CONTROL

3.1 PREFACE

Collaboration between installer, main contractor and third party inspection improve functionality of the liner system. Third Party Inspection should be regarded as a dialogue partner ensuring quality and assistance in specific topics.

3.2 CONSTRUCTION OF THE SECONDARY BARRIER

Before the geomembrane installation can start, the subgrade must be prepared. The construction shall be carried out in that way that the surface of any supporting mineral layer is even and compacted. It shall have a closed structure in case of a clay liner. Imprints or protrusions should be minimised, in case of a CCL they should not be larger than 2cm (figure 2a). Desiccation of the clay layer must be avoided (figure 2b) – excessive wetting on the other hand a swell. The installation works of soils are commonly carried out by the main contractor and should be coordinated to the installation of the primary barrier. Whatever CCL area got prepared in a day shall be covered by the HDPE geomembrane on the same or next day. (This is also the case when using GCLs.)

a) Optimum surface b) Insufficient surface, desiccation

Figure 1. Clay liners.

If the secondary barrier is a GCL is has to be installed in dry condition (or prehydrated under load). Particular attention must be paid to the overlaps here. The GCL liner must be installed without wrinkles (which is not too complicated). Of importance is that swelling takes place only under load to assure the required barrier properties. Sufficient lapping and sometimes additional treatment of the overlaps depending on product type is necessary. Correct treatment of overlaps is all the more necessary since seam tightness cannot be tested afterwards – one must rely on visual appearance only. Any adjacent soil layer has to be chosen to minimize cation exchange.

3.3 CONSTRUCTION OF THE PRIMARY BARRIER

The primary barrier should be a ≥ 2.0 mm thick HDPE-geomembrane in case of a basal barrier system in any environmental protection application where leachate generation is to be expected or harmful fluids have to be stored.

3.3.1 LAYING AND SEAMING OF THE HDPE-LINER

Besides the quality of the HDPE-geomembrane the installation without wrinkles and only small waviness is of imminent importance. Waviness seams to increase when the long-geomembrane panels lie uncovered for longer periods especially on slopes. Therefore they should be covered or ballasted immediately. Besides, geomembranes manufactured with less “frozen” tension - -i.e. those that provide good dimensional stability, will also provide better layflat characteristics. Installers know the difference of products.

Any welding works have to be carried out to avoid stresses in the seam or liner system. Arrangement of the geomembrane panels can be done to keep welds as few as possible and machine welded double hot wedge weld can be used to the largest extend. Also special care must be taken to connect the geomembrane to other constructions.

Waves and wrinkles inhibit the intimate contact and the proper function of any composite barrier system, and they lead to peak stresses into the geomembrane and therefore shorten the service life time due to unacceptable stress and possible cracking. Waviness can be reduced by proper laying and even more by joining sequence taking the development of temperatures during day period into consideration. The seam to be welded last in a working day or the next morning only is the seam between the section installed the previous day and the section of the current working day. The seaming area ballasted with sandbags in the front of figure 2 is the seam to be welded last, welding of the other panels (in the back) takes place in sequence.

Figure 2. Welding sequence.

Seams between the bottom liner and the slope liners should also preferably be carried out in the next morning to avoid trampoline effect during cooler day times.

Extrusion welding shall be kept to a minimum – since the seam area must be treated mechanically and thermically. Experience of welding technicians is of importance here. Any installer shall be experienced, even better certified, to assure reliable laying and welding works.

Waves and wrinkles can fully be avoided also at hot ambient temperature conditions which will be shown in a later paragraph on "Riegelbauweise".

3.3.2 QUALITY CONTROL

Sufficient tools are available to test the seam quality of HDPE-liner systems. Seam quality is described in a lot of standards or guidelines, and there is no other liner material known where weld performance is known and described in such a detail. Not only the short-term performance is known also the long-term. HDPE-geomembranes can be installed with reliable seam quality. The double hot wedge welds can easily be tested by air pressure channel test. Ultrasonic testing if applied gives information on seam thickness over full length. Extrusion welds are tested in vacuum box test or by spark testing.

The installers have the tool to check their own welding works in shear and peel tests, on trial welds as well as on on-site seams taken for example at the end of a seam. The samples for destructive tests should be taken in distances of approximately 150 m seam length, however please avoid to apply this rule too strictly - better place the point of taking samples for destructive tests at the beginning or the end of the continuous seam so as not to unnecessarily increase the need of patching works in sensitive areas. In regard to quality once again sufficient thickness of the geomembrane is highlighted. With sufficient thickness it is guaranteed that not the full cross section of the material is stressed by the welding heat. This is even more important looking to extrusion welding where in addition mechanical treatment is needed. Not only the results on peel strength and/or shear strength give indications on quality of welding works also the visual appearance and cross section measurements can be used to indicate good or poor seam quality. Scrub marks and notches along the seam - they need to be avoided. Looking to wedge weld geometry the "squeeze-out" should be just right to get rid of the oxide film, and cross section measurements give good indications.

3.4 SPECIAL INSTALLATION PRINCIPLES

3.4.1 RIEGELBAUWEISE

This special construction method uses the temperature gradient over the day to assure complete intimate contact of the geomembrane to the clay liner or subgrade. Figure 3 shows the smooth lying geomembrane and the fixation principle.

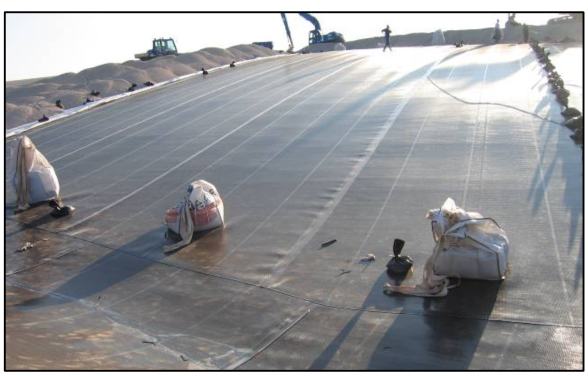

Figure 3: Lock bar installation, "Riegelbauweise"

The steps are as follows: Early in the morning surface verification of the clay liner installed the previous day is necessary. The geomembrane is unrolled, positioned exactly right from the beginning. The geomembrane is allowed to warm up. After getting adapted to the ambient temperatures panels shall be pulled even to the maximum possible extent. Smoothing and aligning is repeated on each roll to be welded. After placing the welding can begin. After testing of the welds the geotextile roll is placed. Then placement of the "Riegel" (lock bars), which are the core of the "Riegelbauweise", begins. The geomembrane (protected by a geotextile) is loaded by heaps of soil using a long-arm excavator. Lock bars are constructed at center-to center distances of approximately 50 m. The weight of the bars fixes the geomembrane. One lock bar is needed along the toe of slope to avoid trampoline effects. Furthermore the geomembrane is fixed in an anchor trench by backfilling soil. The geomembrane contracts with the gradually decreasing evening temperature. Now the system can fully be covered with the protection layer and the gravel layer. The full installation is accompanied by third party control the complete day.

3.4.2 MODIFICATION OF "RIEGELBAUWEISE"

Construction progress may not permit to apply "Riegelbauweise" at all times. In that case immediate but temporary ballasting of the geomembrane is recommended. Whenever lock bar construction technology is prohibited the HDPE-geomembrane liner system must first (after welding) receive only provisional ballast using a heavy weight geotextile and or sand bags for instance, this temporary ballast to be spread over the installed geomembrane area, preferably along the welds. As before, backfilling of the mineral layer after a longer installation period is done during lower temperatures or even at nights or early morning. The seam between the section welded the current working day and the previous day shall be performed only at last on the current working day or the next morning, seams between the bottom liner and the slope liners should also preferably be carried out the next morning.

3.5 INSTALLATION OF PROTECTION AND DRAINAGE LAYERS

3.5.1 GEOSYNTHETICS

The barrier installation does not just end after welding. One main part to assure long-service life is the installation of the protection layer and the drainage layer or other earthen materials on top of the HDPE-liner. If the protection layer is a geotextile it has to be installed with sufficient overlap ensuring that no earthen material can enter the gap between geomembrane and geotextile. The same is relevant when the protection layer is a geocomposite. Thermal fixing of the overlaps is one tool to assure this. The geomembrane below shall lay flat.

3.5.2 MINERAL LAYERS

A protection layer can be fine grained sand or gravel as well. Mineral drainage layers can use gravel between 8-16 mm to 16-32 mm or even higher. As already mentioned in chapter 2 above, the protection layer has to be dimensioned such that the tolerable permanent load is exposing the HDPE geomembrane to less than (3% conservatively) 5% strain. For the mineral protection layer or the mineral drainage layer to be installed on top of the geomembrane the same installation principles apply. Flatness of the geomembrane liner can be achieved by distributing the earthen materials from ramps with long-arm excavators, which are installed at first (figure 3).

Figure 4. Installation of mineral layer with long-arm excavator from a ramp

The height of the mineral ramps to be driven on to assure that the geomembrane below cannot be damaged depends on the earthen material itself, the quality of subgrade below the geomembrane and the construction vehicle used. Height can be evaluated in test fields.

The intimate contact of the geomembrane to the subsoil without waviness is the goal to be achieved with installation of earthen material. As already described this can be achieved with the "Riegelbauweise" and in comparable amount when the geomembrane has been ballasted after installation and in addition by taking care of the construction of the earthen layers. Backfilling of mineral layers during cooler day periods eases these works. Here a good networking between main contractor, installer and third party control is helpful.

4. ALTERNATIVES TO THE CLASSIC COMPOSITE BARRIER

4.1 COEXTRUDED WHITE GEOMEMBRANES AS PRIMARY BARRIER

Instead of using a classic black HDPE-geomembrane a white surfaced HDPE-geomembrane can offer advantages. The white layer of a coextruded white geomembrane is thin HDPE-white coextruded with the thick black HDPE geomembrane. The white and the black layer form a monolithic panel.

The white surface can improve installation works and provides two primary advantages. First, it reflects sunlight which minimizes radiant heat absorption and heat built-up to effectively minimize liner temperature. This results in less expansion of the liner – therewith wrinkles are minimized. Installation works can be carried out faster. Another benefit of the lower liner temperature can be the decreased moisture evaporation from the underlying secondary (CCL) barrier.

The second function is to improve visual inspection. In case the thin white surface is damaged, the black portion of the geomembrane shows clearly. Post-installation damage is much more likely to be observed and repaired as well as damages along the seams. Thereby construction quality control is improved.

4.2 GCL'S AS SECONDARY BARRIER

Since their introduction in the 1980's as barrier system for waste containment sites, GCLs have been installed in a wide variety of applications. Often the standard question to be answered is only that they must show same performance (which is often reduced to hydraulic conductivity) as the specified CCL.

For comparison purposes question on permeability, toughness and chemical resistance have to be answered. Even though CCL thickness cannot be compared with GCL thickness, the hydraulic conductivity can be considered equivalent given the proper installation and manufacturing assurance and construction quality assurance. The categories for equivalent judgement should be hydraulic issues, physical/mechanical issues and construction issues. In Germany equivalence judgements for the use of GCLs as a system component in multiple barrier capping were carried out lately.
Equivalency to a CCL cannot be demonstrated with regard to chemical absorption capacity and diffusion. However, this question is solved if the GCL is used in a composite barrier system.

There are some advantages of a GCL compared to a CCL. At first they save installation time and costs. Less transport emissions and therefore protection of the environment are a second factor. They can be installed with relatively ease on slopes. A geosynthetic product, controlled in the lab, offers consistent properties. In a capping where a CCL is susceptible to desiccation a GCL would perform even better provided that the top soil layer is adequate and thick enough.

5. SUMMARY AND CONCLUSIONS

Classic composite barriers- as well as alternative composite barrier solutions – are a proven tool to achieve environmental protection. The composite barrier system was developed due to the fact that the polymeric barrier is highly chemical resistant, but not absolutely tight to VOCs. Redundancy of the liner components was a second factor.

It was shown that the flat-lying of the HDPE-liner can be achieved by special construction. This is not only necessary for the composite barrier working principle but also for service life time. Intimate contact of the both liner components is needed to assure the working principle. Therefore construction and installation works must target thereon.

The German concept on landfills is a concept strongly focussing on service-life of the entire barrier system – not only on the liner components itself but on state of the art construction.

To achieve long-service periods the HDPE-liner has to be protected sufficiently and therefore protection layers have to be designed carefully.

One could ask: "Why do all these time and money – consuming steps?" Any barrier component has to survive installation and operation phase. Steps are necessary to overcome the story that every liner leaks and to protect the environment for decades or even better centuries.

The networking between the geosynthetic manufacturers, designers, main contractors, installers accompanied by third party control can assure reliable environmental protection.

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