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Flexible landfill covers and barrier liners

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ABSTRACT: In the use of geomembranes for the protection of groundwater, needs arise which require performance away from the ability of materials used today for these applications. For the various applications high performance capabilities are required. This is both during installation where flexibility is of importance as well as in use where elongational properties are required. In this paper the evolution in Polyethylenes manufacturing is discussed which led to the development of C8-VLDPE. Some of the mechanical and performance properties of C8-VLDPE based geomembranes are highlighted. In addition the development of a flexible barrier liner is presented.

1 INTRODUCTION

In order to protect and preserve the march of civilisation, it is necessary to use our natural resources in a responsible way, and to reduce environmental pollution as a result of civilisation to a very minimum. An example is the isolation and monitoring of specially designed depots for e.g. municipal waste. It is this application where geomembranes have being used for over a decade as a barrier in order to prevent the migration of polluted water.

The recent developments in polymer production and processing made it possible to produce geomembranes with welding, bi-axial elongation and barrier properties.

2 THE DEVELOPMENT OF HDPE GEOMEMBRANES

2.1 *High Pressure Process*

In 1933, it was accidentally discovered in the ICI laboratories in the UK that ethylene, in the presence of adventitious oxygen, could be polymerised to a branched structure. This discovery, a by product of the study of chemical reactions at high pressure created the basis of the wide range of Low Density Polyethylenes (LDPE) now being made by free-radical polymerisation at high pressures i.e. 1.000 - 3.000 bar and high temperatures 170-300 °C.

This process provides only limited control of densities (915-930 kg/m^3). The products are branched, not linear, Polyethylenes.

It took another decade to commercialise this development and produce LDPE at large scale.

2.2 *Slurry Process*

In the early 1950's Phillips Petroleum scientists patented a process and catalyst for producing Polyethylenes of a higher density (935-965 kg/m^3) than those produced in the conventional high pressure process.

This slurry technique process converts raw material to product. Monomer, diluent, co-monomer and catalyst are fed to the reactor having a 30-35 bar pressure and a temperature of 80-100 °C. In contradiction to the High Pressure Process the Polyethylene molecules have a linear structure.

In order to differentiate these Polyethylenes from those produced by the High Pressure Process they were called High Density Polyethylenes (HDPE)

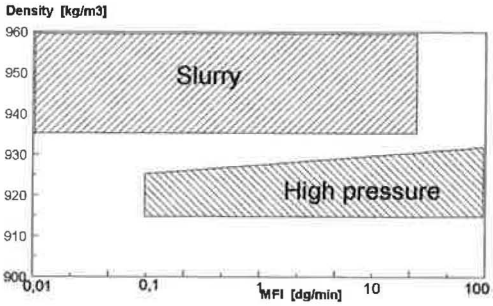

Fig. 1: PE Processes; Melt Flow Index vs density

The world was separated into Low Density PE (LDPE) and High Density PE (HDPE).

In Figure 1 the capabilities of both processes are depicted. The main characteristics are density and melt flow index (a measure of polymer melt flow).

2.3 *HDPE Geomembranes*

In the late seventies when the need for geomembranes was identified, only two types of Polyethylenes were available being LDPE and HDPE. Because the mechanical properties and chemical resistance of HDPE are significant better in comparison with LDPE it was obvious that HDPE geomembranes were developed.

In order not to loose to much flexibility and toughness on one side and chemical resistance on the other the optimum density was found to be 935-940 kg/m^3 (excluding carbon black). It must be emphasised that the initial HDPE product-data for geomembranes was derived from the pipe industry where similar materials had been in use for several decades.

3 POLYETHYLENES TODAY

3.1 *Gasphase process*

The Polyethylenes situation changed dramatically in 1977, when Union Carbide announced the development of a low pressure, Gasphase process for the production of linear Polyethylenes with a similar density as LDPE, the so called Linear - LDPE (LLDPE).

The co-monomer used in these LLDPE was 1-butene (C4), because it was the least expensive co-monomer which could yield a product with toughness clearly superior to LDPE.

This Gasphase process is capable to produce linear Polyethylenes in a density range from 915-965 kg/m^3.

3.2 *Solution process*

Also in the late seventies DSM developed the solution process. This process was able to produce Linear Polyethylenes (DSM's trade name Stamylex™) in a wide range of melt index and densities 900 - 965 kg/m^3. The lowest density is labelled Very Low Density PE (VLDPE)

The density was regulated by the amount of co-monomer 1-octene (C8). The choice of C8 was obvious since this brings out the best in LLDPE.

The capabilities of both processes are illustrated in Figure 2.

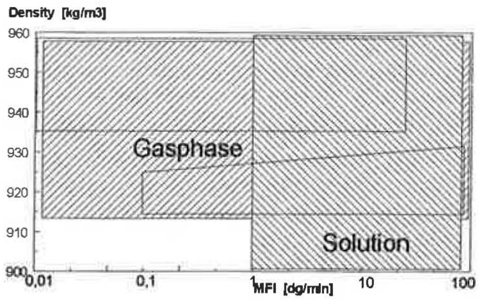

Fig. 2: PE Processes; Melt index vs density

That (V)LLDPE has taken it's share of the Polyethylene market is with pictured in Figure 3.

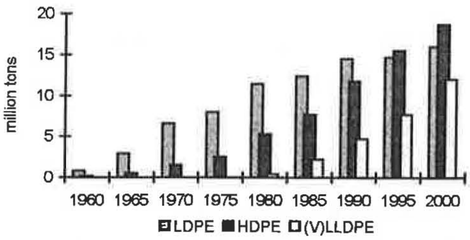

Fig. 3: World PE demand development 1960-2000

3.3 *Terminology*

It is evident that the introduction of both the Gasphase process and the Solution process brought confusion in the categorisation of Polyethylenes. A commonly used subdivision today is:

Branched Polyethylenes
- LDPE 915-930 kg/m^3

Linear Polyethylenes
- HDPE 946-960 kg/m^3
- MDPE 931-945 kg/m^3
- LLDPE 916-930 kg/m^3
- VLDPE 900-915 kg/m^3

In this respect it would thus be more appropriate to rename HDPE geomembranes into MDPE geomembranes.

3.4 *C8-VLDPE Geomembranes*

The unique requirements of geomembranes applications are becoming increasingly evident and are resulting in the development of advanced resins such as C8-VLDPE specially tailored for geomembranes.

By lowering the density and using the higher alpha olefin co-monomer C8 the improvement of many properties is achieved, such as:
- flexibility,
- sealability,
- seal integrity,
- low temperature behaviour,
- toughness.

Due to these properties C8-VLDPE grades have been developed for landfill covers and barrier liners.

4 FLEXIBLE LANDFILL COVERS

The primary function of a landfill closure system is to prevent percolation of rain water or surface water into the landfill causing the creation of leachetes.

Hence, a desire exists to close landfill sites as soon as possible in order to reduce the forming of leachate, and to diminish the free emission of gases.

However, differential waste settlements are common in municpal landfills, causing undue stress upon cap liner components. Differential settlements can cause bi-axial strains in geomembranes upto 10-15%. Because this can cause the liner to tear, landfill sites can only be closed if the remainder of the settlement is less than the geomembrane can deal with. For HPDE geomembranes this is <5%.

4.1 *Installation*

Important for installation of the geomembrane are the flexibility of the geomembrane and the welding characteristics.

4.1.1 Flexibility

In order to be rolled, packaged and installed geomembranes must be flexible. If the flexibility can be maintained at low temperatures it is even possible to continue installation over a broad period of time during the year.

Also with regard to the behaviour during settling, and the promotion of a good bond to mineral lining (e.g. bentonite) a material of very high flexibility and elasticity is desirable. Such a material has the advantage of readily following the settling which occurs beneath the geomembrane.

A material with very low density must than be used (Figure 4). The flexibility which is thus critical to the geomembrane comes directly from the C8-VLDPE resin, without the use of e.g. plasticizers.

Although a properly installed liner will not experience very low temperatures, C8-VLDPE will provide the greatest safety factor in this regard.

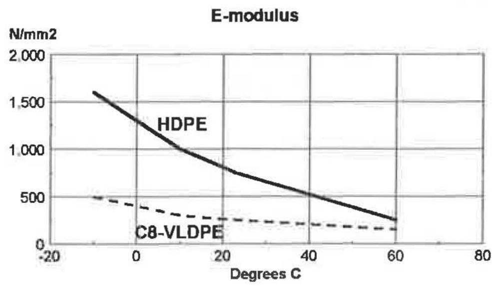

Fig. 4: E-modules vs. temperature

4.1.2 Flex-crack

During installation the geomembranes are often exposed to frequent bending. In more rigid products like HDPE this could result in initial so called flex-cracks. Repairs are than necessary.

C8-VLDPE due to it's flexibility and elongational properties has a high resistance to these flex-cracks.

Bending experiments have shown that C8-VLDPE based geomembranes have a 3-5 times higher resistance to these crack forming.

4.1.3 Welding

For the installation of geomembranes in large areas welding is unavoidable. This implies that geomembranes should have good weldability properties. Like HDPE C8-VLDPE geomembranes can be welded by the following techniques:

- hot wedge welding,
- extrusion welding,
- hot-air welding.

Next to the possibility to weld via different techniques the welding window is very important. The window is characterised by the following parameters:

- welding speed,
- welding pressure,
- welding temperature.

In Figure 5 the welding window of HDPE and C8-VLDPE is given. The welding pressure was kept constant 20 N/mm.

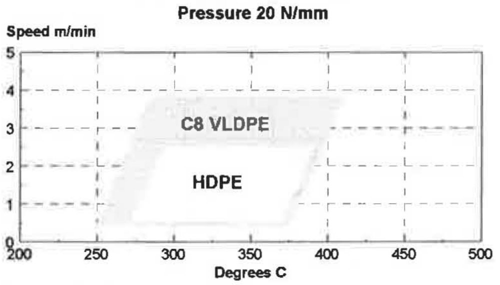

Fig. 5: Welding window

HDPE has a seaming temperature range between 275-375 °C, whereas C8-VLDPE will seam between 250-400 °C.

This can be explained by the melting behaviour of both polymers caused by the difference in crystallinity HDPE has a higher crystallinity and therefor more of a melting point whereas C8-VLDPE has a low crystallinity and a melting range that already starts at a low temperature.

The wider welding window of C8-VLDPE based geomembranes improves the seam's integrity, and reduces the risk of failures.

4.2 *In use*

When a geomembrane is in use different properties are of importance then during installation, such as notch sensitivity, environmental stress-crack resistance, puncture resistance, chemical resistance and bi-axial elongation.

4.2.1 Notch sensitivity

During installation notches can occur in the geomembrane. Notch sensitivity relates to the susceptibility of the geomembrane to stress crack under constant load condition.

In Figure 6 the elongation at break is reflected of HDPE and C8-VLDPE of a notched specimen. It clearly shows the low notch sensitivity of C8-VLDPE.

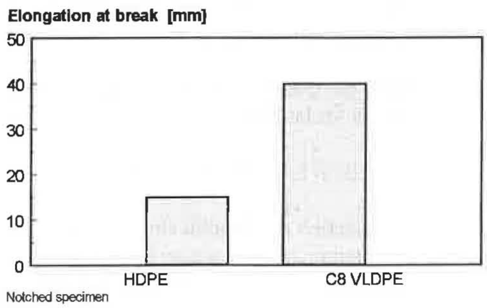

Fig. 6: Notch sensitivity

4.2.2 Environmental stress-crack resistance

The method measures the time to failure of notched specimen in an aggressive media and at sub yield stresses at elevated temperatures.

The stress crack resistance of Polyethylenes is strongly dependent on density and co-monomer used.

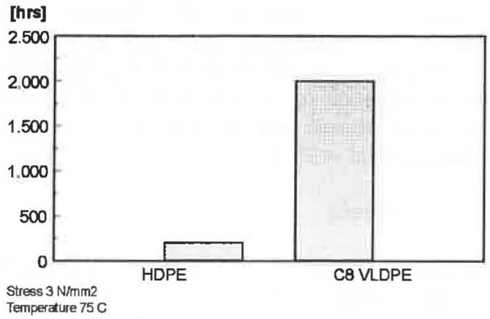

Fig. 7: ESCR values

As can be seen in Figure 7 C8-VLDPE shows no cracking until 2.000 hrs. HDPE fails at less than 200 hrs.

4.2.3 Puncture resistance

It might be expected that since HDPE has a higher modules and tensile strength that it would also have a better puncture resistance. However, C8-VLDPE has a higher puncture resistance, due to the puncture elongation.

The difference is thus the ability of the liner to conform to an irregular surface, such as stones in a mineral layer.

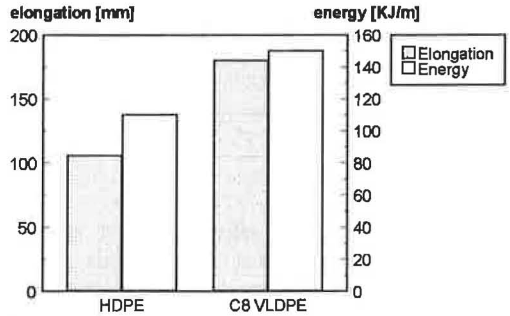

Fig. 8: Puncture resistance

4.2.4 Chemical resistance

One of the reasons Polyethylene has become very important in the geomembrane market, is because of its chemical resistance. This is a result of the absence of functional groups in the polymer chain and the absence of easily attacked additives.

The chemical resistance of HDPE and C8-VLDPE geomembranes was tested against various saturated solvents such as:

- gasoline and aromatics (Group 1),
- aliphatic esters and ketones (Group 2).

In Table 1 the change in mechanical poperties of both products is given after exposure for 2 months at 30 °C.

Table 1: Chemical resistance of geomembranes; change in mechanical properties

	HDPE [%]	C8-VLDPE [%]
Group 1		
• yield stress	18	9
• elongation at break	9	13
Group 2		
• yield stress	5	4
• elongation at break	10	5

The data indicates no significant detrimental effect on the C8-VLDPE based geomembrane and no difference in comparison with HDPE.

4.2.5 Bi-axial elongation

Total and differential waste settlements are common in municipal landfills, causing immoderate strains upon cap liners. This may cause the liner to tear or fail, also in the seam areas.

An important development in testing geomembranes is the determination of multiaxial elongation performance. This procedure is basically a large burst test which delivers a circumferencial elongation to a geomembrane sample, instead of a monoaxial tension .

This test shows to be more advantageous over conventional stress-strain relationship developed by tensile tests. The multiaxial test more closely nears situations which can develop in the field due to irregularities in landfills.

Figure 9 shows clearly the high ability of C8-VLDPE to stretch out bi-axialy.

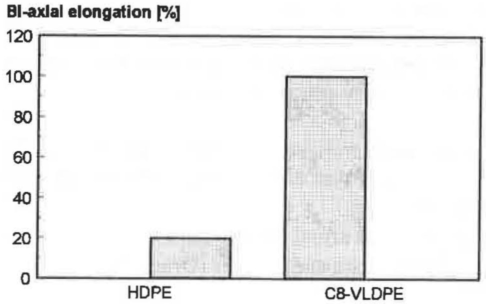

Fig. 9: Bi-axialelongation values of geomembranes

Similar to the "stress - time to failure" diagrams as developed for pressure pipes, diagrams will be developed for "bi-axial elongation - time to failure". Figure 10 shows how a diagram will look like for HDPE and C8-VLDPE. This will be a very viable tool for design engineers.

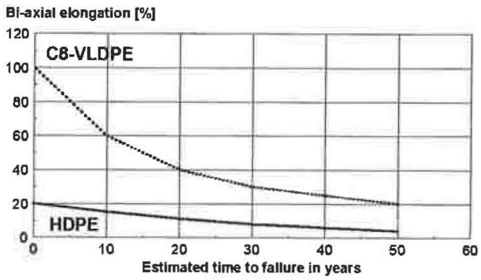

Fig. 10: Bi-axial elongation vs. estimated time to failure

5 FLEXIBLE BARRIER LINERS

A polyolefine based geomembrane such as polyethylene has very good barrier properties for a-polar media as ammonium compounds. However for polar media, such as polycyclic aromatic hydrocarbons and 1,2 dichlorobezene (DCB) the permeation rate is very high. These media are found in e.g. spoil (dredge silt).

A HDPE based geomembrane in combination with aluminium foil is a possibility. Yet, this rather rigid product has all the disadvantages a HDPE geomembrane has including the limited multiaxial elongational properties.

It was therefor obvious that a C8-VLDPE based barrier liner was looked for.

5.1 *Testmethods*

The C8-VLDPE based barrier liner concept was extensively tested on mechanical properties and barrier properties i.c. 1,2 DCB.

The barrier properties were determined via permeation measurements. The barrier liner separated 2 compartments, one with an aqueous solution of 1,2 DCB, the other with distilled water. The concentration of the 1,2 DCB in the distilled water compartment was monitored in time. The system was kept at 23 °C.

5.2 *Testresults*

The mechanical properties of the barrier liner are of the same magnitude as C8-VLDPE.

The bi-axial elongation values are given in Table 2. It shows that the bi-axial elongation is not negatively influenced.
The barrier properties are summarised in Table 3. The differences between HDPE and C8-VLDPE can be neglected in comparison with the barrier liner concept.

Table 2: Bi-axial elongation of geomembranes

Geomembrane	Bi-axial elongation [%]
HDPE	20
HDPE/alufoil/HDPE	15
C8-VLDPE	>100
Barrier liner	100

Table 3: Barrier properties of geomembranes

Geomembrane	1,2 DCB permeation $[kg/m^2/year]$ at 15 °C	at 23 °C
HDPE	15.10^{-3}	100.10^{-3}
C8-VLDPE	20.10^{-3}	130.10^{-3}
Barrier liner	30.10^{-9}	210.10^{-9}

6 CONCLUSIONS

Geomembrane material selection is not simply a matter of comparing cost on the basis that all geomembranes do the same thing: function as a barrier. It requires a careful assessment of the service conditions and desired performance of the geomembrane.

The recent developments in very low density Polyethylene (C8-VLDPE) make it possible to manufacture a new class of high performance geomembranes that are flexible and tough. The outstanding low temperature properties, stress crack resistance and elongational characteristics ease geomembrane installation and substantially improve system durability.

C8-VLDPE forms also the basis of a flexible barrier liner. This new concept reveals outstanding barrier properties for polar media as e.g. 1,2 DCB without losing the typical C8-VLDPE properties such as bi-axial elongation.

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