DEVELOPMENT AND TEST RESULTS FOR LINERS FOR TIGHTENING OF LARGE SCALE WATER STORAGES

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Abstract – "Liners are leaking" is one of the first rules to learn when working with large scale water storages. Thus liners is a vulnerable part of large scale storages. To solve this problem and at the samt time to have an economically cheap solution with a minimum of moisture passing through the liner, several liner tests has been made by Danish Technological Institute. The latest test has taken place from December 2014 till Spring 2015. The test is carried out as an accelerated test using high temperatures (110 ºC) developed by Danish Technological Institute.
One PP-liner and 5 HDPE-liners have been tested in this way. The objective is to develop liners, that can last in 20 years at 90 ºC. The HDPE-liners are performing still better, but until now the objective has not been met.
PlanEnergi has therefore also investigated the possibilities for using metal liners (aluminium and stainless steel) since aluminium liners have been used as tightening of water storages in Sweden and Germany. This work has been elaborated in a project funded by Danish District Heating Association in Co operation with Marstal Fjernvarme.

1. INTRODUCTION

Pit heat Thermal sensible water Energy Storages (PTES) has been developed in Denmark by Danish Technical University (DTU) from 1980 and from 1990 til now in connection to demonstrations projects in Ottrupgård, Marstal and Dronninglund, where long team storages were needed to extend the solar fraction beyond 30 % in district heating systems.

The result is a simple construction in the ground covered with a water tight liner. The storage is filled with water and covered by a floating insulated cover.

The storage can be designed with different shapes, but the simplest is an excavation with soil balance and shaped as a truncated pyramid placed upside down in the ground as shown in Figure 1.

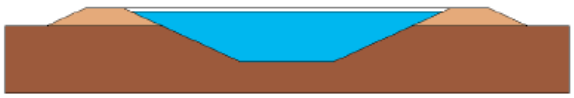

Figure 1. Principle sketch of a pit heat water storage [Jensen 2014]

The service life of a pit heat storage is very much depending on the liner. Water sealing with clay was tested in the storage in Ottrupgård (1995) with poor results. Therefore other solutions including different types of polymer liners (PP, PE), elastomer liners (EPDM) and different kinds of metal liners (stainless steel, aluminium) has been tested. This paper includes and comments the test results as also described in a development project financed by Danish District Heating Association (Jensen et. Al 2015).

Important for development of liner solutions has been:

- Price for materials and installation
- Resistance against vapour diffusion
- Ability to stand temperature variations between 10 and 95 ºC
- Service lifetime. 20 years with constant 95 ºC storage temperatures is preferable.

EPDM was used as liner in the storage in Ottrupgård, but in later projects the liners has been welded. Welding of EPDM is not possible and EPDM has not been used as liner material since Ottrupgård.

2. POLYMER LINERS

Polymer liners as PP and PE are relatively cheap and easy to install with well documented welding and testing techniques. The welding is shown in Figure 2.

Figure 2. Double welding of a HDPE liner and a welding maschine in action (Jensen et. al 2015)

PP was as the first polymer tested in 2000 (Pedersen and Nielsen, 2000) and a test methodology was developed where samples can be tested with up to 120 ºC water on one side and air on the other side in "test cells". The durability of the material was defined to when the

psysical property elongation at break is below 50 %. The test was accelerated by heating up the samples to 100, 107 and 115 °C.

The test of PP resulted in a calculated durability of 1.9 years at 80 °C. This was not satisfying for a pit heat storage liner and therefore two HDPE-liners were tested from 2003 til 2004. The test temperatures were also here 100, 107 and 115 °C.

For calculation of the duration period at lower temperatures Arrhenius equation is used and for calculation of expected service life in a pit heat storage, where the temperature varies during a year the formula for calculation of service life for preinsulated district heating pipes in EN253 is used.

The result for the two HDPE-liners can be seen in Table 1.

Temperature (°C)	Service life (years) Liner 1	Liner 2
90	2.5	3.2
80	6.1	7.2
70	15.9	17.0
60	43.7	42.4

Table 1. Service life for HDPE liner 1 and 2.

For both liners the service life for a pit heat storage calculated for storage temperatures if the storage was placed at Marstal Fjernvarme was more than 20 years. Liner 2 was implemented in a 10,000 m^3 pit heat storage in Marstal as part of the SUNSTORE 2 project (supported by EU 5th Framework).

In 2008 the SUNSTORE 3 project in Dronninglund started. In that project the intention was to extend the temperature range and thus the storage capacity up to 90 °C and down to 10 °C. Liner 1 and 2 could still be used, but would give limitations in use of the storage. During the design phase two new HDPE-liners were tested in 2010-11 and 2012-13 The test temperature was 110 °C. The results can be seen in Table 2.

Temperature (°C)	Service life (years) Liner 3	Liner 4
90	2.9	4.3
80	6.8	10.0
70	15.6	23.0
60	35.9	52.9

Table 2. Service life for HDPE-liners 3 and 4

A liner with same conditions as liner 2 was implemented in the SUNSTORE 4 project (supported by EU, 7th Framework program) in Marstal in a 75,000 m^3 pit heat storage. At that time liner 4 was not tested.

In the SUNSTORE 3 project (supported by the Danish EUDP program) was implemented a new developed HDPE-liner in 2013, because the supplier promised 20 years performance guarantee at 90 °C constantly.

In Figure 3 the cross section of the edge of the storage in Dronninglund is shown.

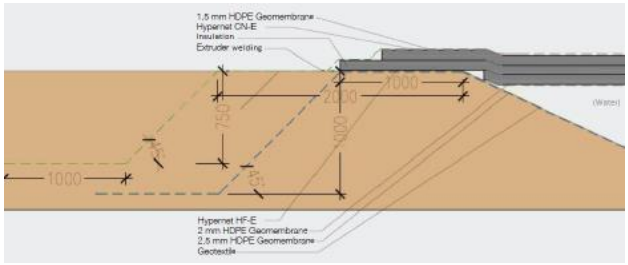

Figure 3. Cross section of the edge of the floating cover in SUNSTORE 3 illustrating also the liner solution (Jensen 2014)

A test of the new liner implemented in the SUNSTORE 3 pit heat storage of 60,000 m^3 has been carried out by Teknologisk Institut from December 2014. The expectation was that the duration of the test at 110 °C should be 4-5 years, but already after less than 1½ year the test showed physical property elongation at break below 50 %.

This is surprising and a new test will be made from September 2016. The theory is, that the storage water can break down the antioxidants in the liner material and oxygen then can differ trough the liner from outside and oxidate the liner.

The only difference between this test of liner 5 and the former liner tests is, that the first 4 liners were tested with tap water on the water side, while in the test of liner 5 the tap water was adjusted to pH=9 because this was the reality in Dronninglund. A part of the new test will be to use tap water to be able to compare to former results.

The reason why pH is high in Dronninglund is corrosion protection of the pipe system, but replacing metal with for instance PEX in in-and outlet it might be possible to lower pH in future projects.

The price for polymer liners is 9-12 €/m^2 incl. implementation.

3. ALUMINIUM LINERS

The polymer liners have two main problems. They are vulnerable to high water temperatures and there is vapour diffusion through the liner at high temperatures.

The permeability as a function of temperature can be seen in Figure 4.

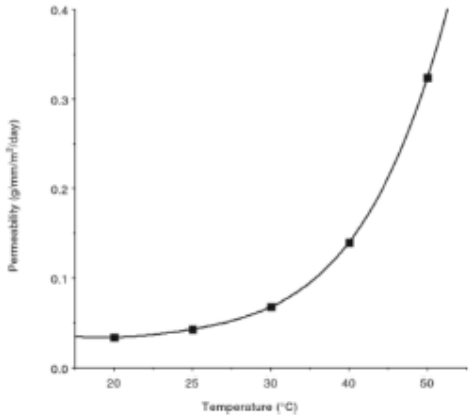

Figure 4. Water pavour permeability as a function of temperature for a typical HDPE liner (Scheirs 2009)

For a HDPE-liner the vapour permeability at 80 °C is app. 1 g/m^2/day. That means, that the insulated lid has to consist of vapour resistant insulation material or it has to be ventilated. The SUNSTORE 3 storage, shown in Figure 3 is ventilated.

Both these problems can be solved using metal liners. Hydro Aluminium in Hamburg recommends alloy 5251 with 3 or 4 mm thickness.

Maximum width is 1500 mm (for polymers it is 6,000 to 7,000 mm!) and elongiation at break is more than 8 %.

For a 3 mm liner the price is estimated to be 30-40 €/m^2 incl. installation and it has to be taken into account, that Ph of the water has to 6.5-8 to prevent corrosion and there is no experiences with implementation.

4. STAINLESS STEEL LINERS

Stainless steel liners has been used in tank storages in Sweden and in Germany, but none of the suppliers seem to exist any longer. Also stainless steel liners were tested at Danish Technical University (Heller et. al 2002). Figure 5 shows welding of the liner at DTU.

Figure 5. Induction welding of a stainless steel liner (Heller et. al 2002)

Stainless steel liners can resist corrosion at pH more than 9 as long as salts are removed from the water as it is in SUNSTORE 3 with reverse osmosis.

Suppliers of stainless steel liners can provide liners of 1450 mm width and 0.5-0.9 mm thickness.

ESAB has for PlanEnergi made welding tests with MIG (Metal Inert Gas) welding, TIG (Tungsten Inert Gas) welding and Induction welding. Induction welding seem to be the best methodology, but a mobile welding mashine will probably have to be developed as it seem not to be available on the market.

Also the quality of weldings has to be controlled carefully by tests before implementation of pit heat storages with stainless steel liners.

The price of stainless steel liners are expected to be between 35 and 50 €/m^2 incl. installation depending on liner thickness.

5. CONCLUSIONS

As can be seen none of the liner materials are ideal. Polymers are cheap and easy to handle, bud vulnerable to temperatures and vapour diffusion. Metals are expensive and difficult to handle.

So development is ongoing!.

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