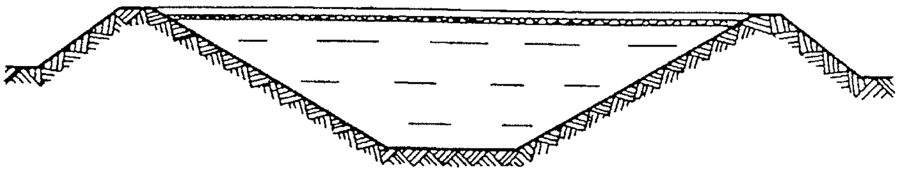
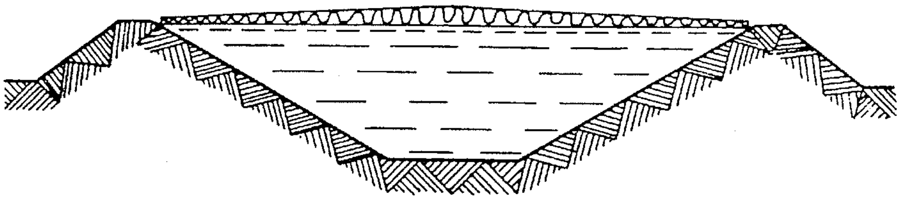
FLOATING LID CONSTRUCTIONS FOR PIT WATER STORAGE - A SURVEY

ALFRED HELLER





REPORT

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Preface

This report is part of a series of two reports, representing the conclusion of the research project, "Floating Lid Construction for Pit Water Storage - Phase I" (in Danish: "Lågkonstruktioner til damvarmelagre, Fase I"), journal no. 51181/95-0030, financed by "Energistyrelsen", Danish Energy Agency through the renewable energy development program, UVE. The other report of the series, "Investigation Floating Lid Construction, Pit Water Storage Ottrupgaard, Denmark", gives a detailed report of the investigations made at the newest lid design in Denmark.

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1. Introduction

The application of hot water storage to district heating systems makes exploitation of waste heat from e.g. electricity production and industries possible and enables the employment of solar heating. Storage is expensive and is therefore applied to special purposes only. Hence, development of low cost storage is required for the propagation of waste heat storage and solar heating systems.

Storage is categorized into short time and seasonal storage, dependent on the storage cycle - the time between two chargings. Although the current work is concentrating on seasonal storage, the results can be applied to other storage types.

In the current storage type water is applied as a storage medium due to the advantageous properties of the material. Water is mostly available, is cheap, is not poisonous and has good physical properties, like the ability of thermal stratification, high heat capacity and high heat transfer rate.

Water storage can be designed in many ways as cave-storage, steel-tank storage and so on. Steel tanks are rather expensive but a common known and accepted concept. Hence such tanks are dominating. On the other hand pit water storage is simple to build and cheap, but a rather unknown concept which is to be developed. In Denmark pit water storage is seen as the most promising candidate of seasonal hot water storage with high expected reliability and low installation cost.

Basically, there are two types of lid constructions which can be applied to pit water storage; bearing and floating lids. Bearing lids are part of the static construction of the pit, similar to the roof construction of a house. Such constructions are rather expensive and therefore alternatives are required. Floating lid constructions are basically designed to float on the pit water surface without any static structure. In some cases the lid is supported by a simple steel construction or a wire net for critical periods with no water in the pit.

Although floating lid constructions are noticeably cheaper than bearing lids, the construction accounts for over 50% of the total cost for a hot water pit which proves the necessity of developing more economical designs. In the past the lid designs have turned out to be a technically difficult construction. The most dominating difficulty lies in the fact that the lid insulation is to be kept dry. The first lid construction, tested at the Department of Buildings and Energy, was found unreliable [Duer, 1995b]. Experiences from this investigation will be summarized below. Based on these experiences a redesigned lid construction is tested and applied to the Ottrupgaard pit water storage.

The pit water storage concept is based on an artificial ditch, tightened by a hybrid clay layer liner at the pit and a floating lid at the top. The concept was, among others, presented at Workshops of the CSHPSS Working Group in 1994 by Sørensen, 1994 and Wesenberg, 1994. The clay layer construction was presented at the ISES Solar World Congress in 1993 by Duer and Svendsen and will not be treated in this work.

A pilot hot water pit is built in Ottrupgaard, Jutland, Denmark in 1993. The first results from this system are presented e.g. at a workshop in Stuttgart in 1995 by Wesenberg, 1995a and a final report is given by Wesenberg, 1995b.

The objective of the current project is to investigate the Ottrupgaard design, to give a status of floating lid construction designs and to sketch future design developments.

The objective of the current report is to give an overview of the floating lid designs for hot-water pit storage and to describe the advantages and disadvantages of the technique and its designs. At last some ideas for future development are presented.

2. Floating Lid Constructions for Hot Water Storage - Basics

Lid constructions for hot water storage have the following functions:

- Heat barrier.
- Steam barrier.
- Rain draining.
- Bearing construction for snow and traversing persons.

Above these primary functions the following secondary functions are to be met:

- Protection against light to avoid growth of algae.
- Possibility of emptying the pit.
- Flexibility, sectioning, low weight, easy handling and reparations.
- Possibility of secondary application of the ground area.
- Aesthetic aspects.
- Safety aspects and safety against wanton destruction of property.

Above bearing constructions, it is possible to choose light-weight bearing constructions, like cable carrying, tent, suspension bridge or air-filled bubble constructions. These solutions came up under a brainstorm on the subject which is presented in [LfV-Meddelelse 91], chapter 6 (in Danish). A short summary is given in the following. The overview presents three floating lid construction types: pontoons with insulation, floating insulation with top membrane and submerged insulation with top membrane. As we will see in the following, these construction types seem to cover most constructions applied during the last years. The brainstorm came up with the following border designs.

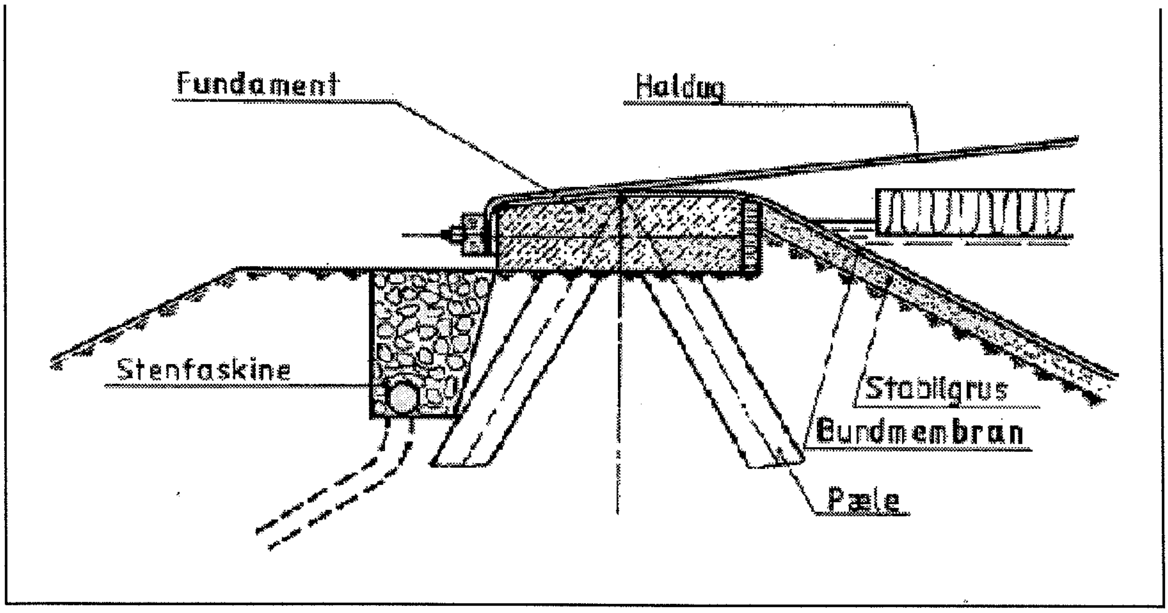

Figure 1 Principal sketch of floating lid border design. Pontoon with insulation. Source: [LfV-Meddelelse 91]

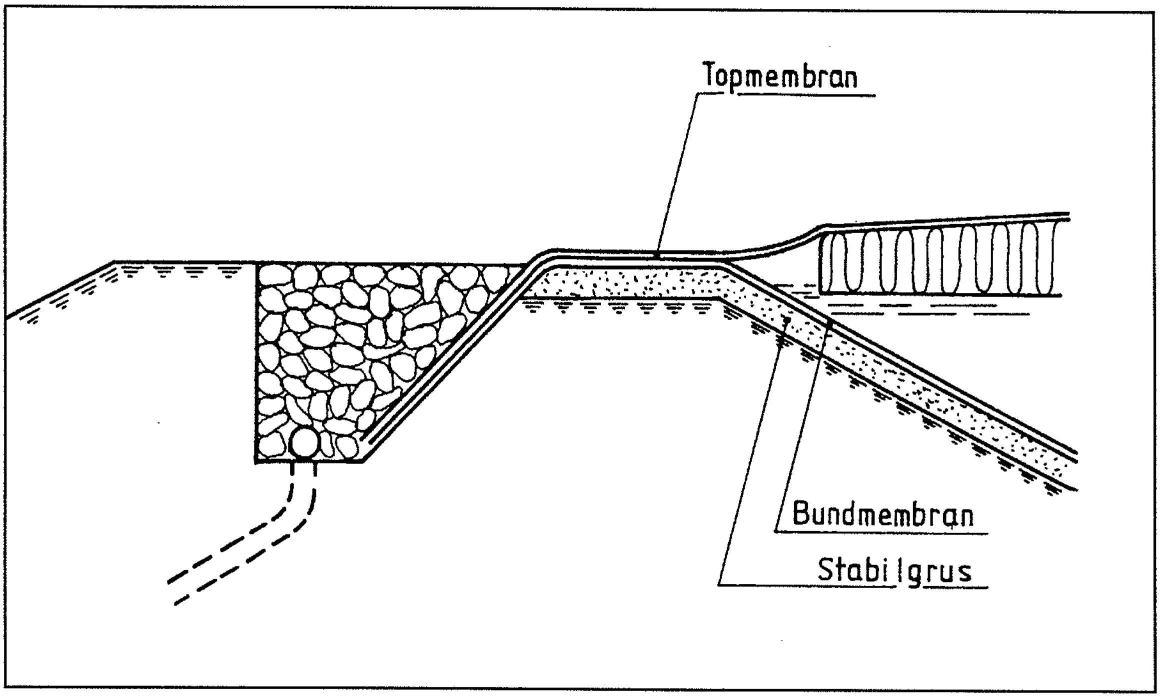

Figure 2 Principal sketch of floating lid border design. Floating insulation with top membrane. Source: [LfV-Meddelelse 91]

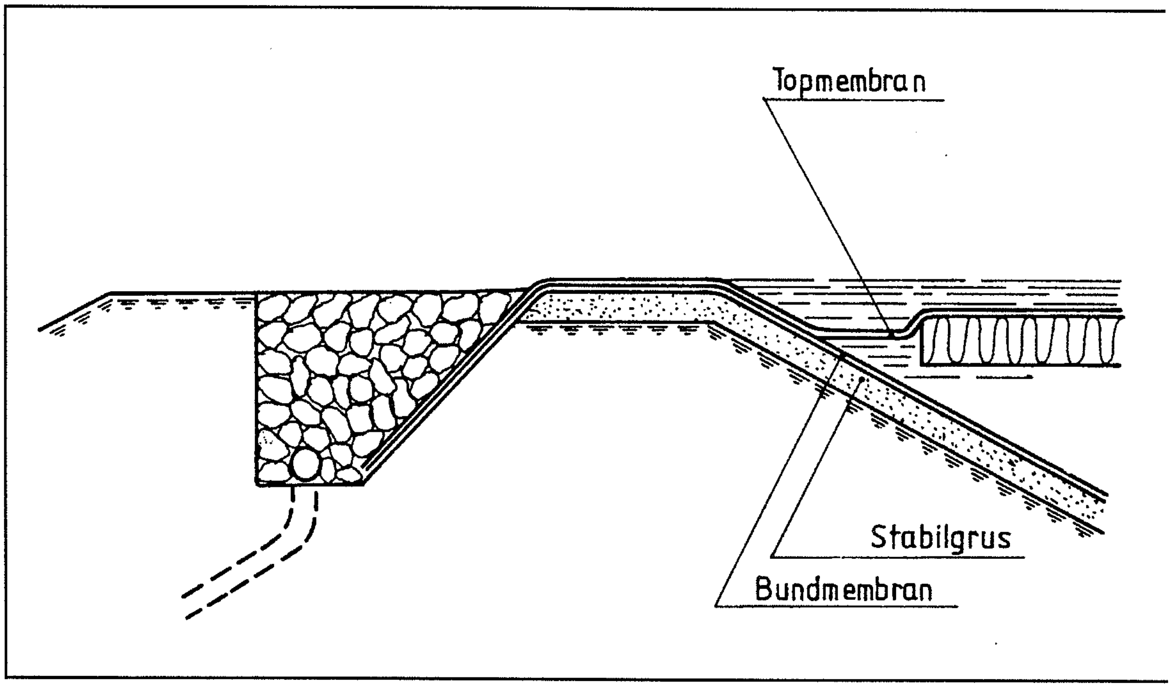

Figure 3 Principal sketch of floating lid border design. Submerged insulation with top membrane. Source: [LfV-Meddelelse 91]

It may be mentioned that submerged design makes it possible to apply the lid area as a solar collector as known from salt gradient pit storage.

Floating lids are in general composed by three parts; Insulation, top and bottom cover. The insulation layer acts as a heat barrier. Unfortunately, most insulation materials must be kept dry to survive in the harsh conditions of the hot water and steam atmosphere. The challenge is therefore to tighten the construction at the top and bottom covers in one way or another. Most constructions serve this purpose by covering the insulation with metallic or plastic liners. Metallic liners are, if worked out properly, 100% water and vapour tight, but expensive [Duer, 1995a]. Plastic liners are cheap, but are often open for diffusion and have a life length that is shorter than the life of the storage [Nielsen, 1994]. Combinations of metallic and plastic liners are also applied as we will see.

3. Experience on Floating Lid Constructions

Floating lids for hot-water storage are applicable in countries with low prices of land like Denmark and Sweden. In other countries, like Germany, the prices of land are too high. Hence the storage ground area is to be used for a secondary purpose which requires a static, bearing lid construction. Based on this fact, most examples presented in this survey are taken from Sweden and Denmark. The Swedish examples are based on a paper by Heino Zinko, ZW-Energiteknik, Sweden, the Danish examples are partly based on a paper by Carsten Wesenberg, Nellemann A/S. Copies of the papers can be found in the appendices. Further references can also be found there.

In this section the basics of the floating lid concept are given. Then the individual designs are described and discussed.

3.1 Lyngby, DTU-1982, Denmark

The first floating lid construction in Denmark was developed in 1982 at the Technical University of Denmark (DTU) in Lyngby for a 500 m^3 seasonal water storage pit [Hansen, 1983]. The storage is used for research purpose only. The 16 times 16 metres lid was designed as follows:

Bottom lining	1.0 mm butyl rubber liner
Insulation material / design	0.5 m polystyrene with an inclination of 0.2m.
Top lining	2.5 mm polyethylene plastic liner ("gasket"), connected to the concrete walls, to make rain running off the lid. See Figure 4.
Lid-wall gap sealing	Top liner placed across the 2 cm gap between lid and pit wall.

To ensure proper construction, the lid was gathered under a dry dock, afterwards dragged into position and sealed by dragging the top liner onto the pit wall construction.

On the top of the pit a 0.30 m thick reinforced concrete wall is built and a drain pipe placed in gravel to lead off the surface water. See Figure 4 for details.

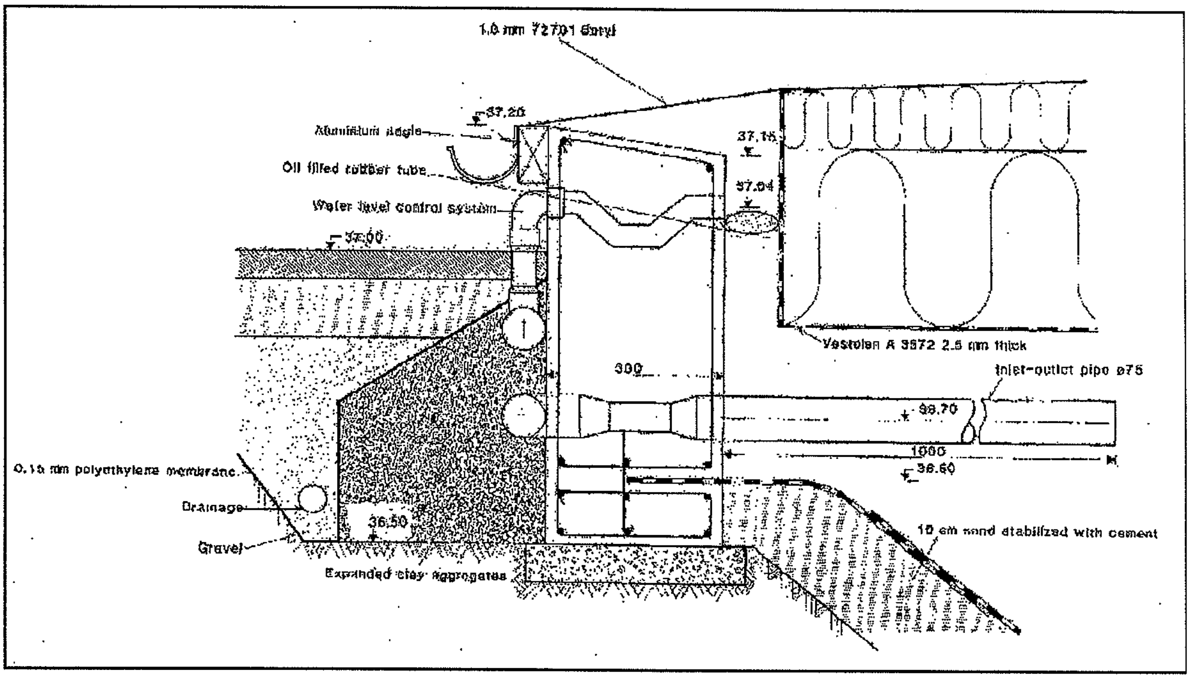

Figure 4 Detail of border design.

An unexpected heat loss at the edges was found which was caused by evaporation losses. This loss led to an estimated efficiency drop for the storage from an expected level of 74% to 58% really a serious fault. To avoid this drop a redesign is recommended where the "gasket" is fastened to the pit wall ensuring a closed system.

The pit was used for about 3 years, first as a pit water storage, then as a combination of a gravel and an artificial aquifer. The latest construction is still existing but not in use any more. The construction price is unknown. The lid worked as expected. The sealing method on the gap between lid and pit wall was problematic and led to unexpected heat losses there. Better sealing methods were recommended. Still today the lid materials seem to be in a good shape.

3.2 Studsvik, Sweden

The Studsvik system was a solar heated pond for district heating with a volume of 640 m^3. Drawings of the system, lid construction details and procedure of placing the insulation, can be found at the end of the current section and also in Appendix A. The circular formed lid of 15 metres was rotatable for solar tracking and designed to carry solar collectors as shown in Figure 5.

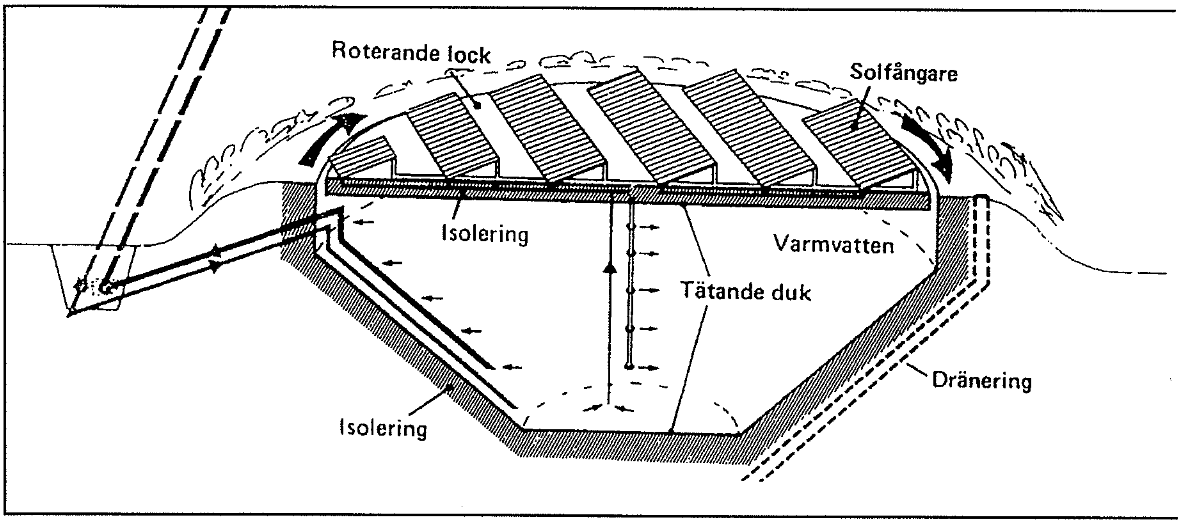

Figure 5 Studsvik rotatable lid design.

The construction was as follows:

Bottom lining	butyl rubber
Insulation material / design	PU-blocks, 1x2x0.2 metres
Top lining	2 mm butyl rubber and 1.5 mm polyester net for stress distribution.
Lid-wall gap sealing	Top liner placed across the 2 cm gap between lid and pit wall. Special rubber on top of wall to ensure proper rotation of the lid.

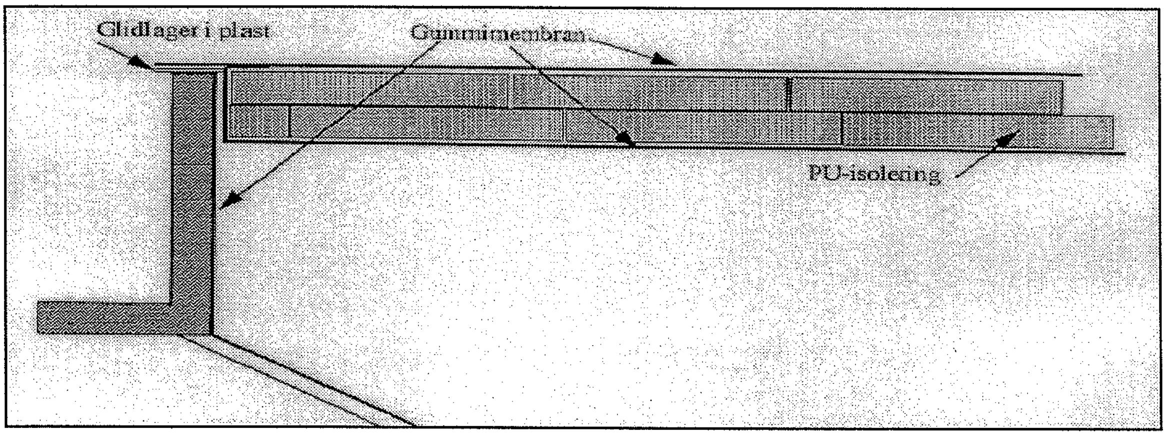

Figure 6 Studsvik lid border design.

The bottom liner was placed directly on the water surface. Then the insulation blocks were placed in two layers with displaced assembly. Thereafter the two top liners were placed, then the bottom liner hitched up and assembled with the top lining system to ensure a tight construction.

The lid was functioning for an observation period of 6 years with expected economic results. A rather large damp loss through the gap between lid and pit wall was observed. Due to the pressure of the solar collectors on the top of the lid, holes were pressed into the top liner, resulting in rainwater entering the construction. This water ran into the centre of the bottom liner and could be drained by a pump added for this purpose afterwards. The conductive heat transfer coefficient for the PU-blocks had fallen to 0.24 W/(m^2 K) after humification.

Due to the humification of the insulation, the heat bridges around the piping and the gap between lid and pit wall, a larger heat loss of 30% was estimated for the whole construction compared to the ideal case. After six years of operation the lid was demounted and examined. The PU-plates were in such a good shape that they could be used for something else than lid construction.

3.3 Lambohov, Sweden

The Lambohov system design is based on the experience from Studsvik and built in 1980. The solar heated pond for district heating has a volume of 10,000 m^3, insulated to the ground with Leca-nuts. The 32.5 metres lid is designed as in Studsvik, but with fixed position, to ensure proper sealing between lid and pit wall. An inspection opening is established, mounted on a stand placed on the pit ground. Installation for pumping is placed through this opening. A diffuser system was established to ensure proper thermal stratification.

The pit wall and the lid constructions were not tight at any time. Hence ground-, rain- and pit water penetrated into the wall and lid. After taking down the lid in 1989 (possibly 1992), the PU-blocks were affected by the high water temperatures of 60-70 degrees to a stage where the insulation effect was diminished decisively. The overall heat loss was estimated at 250 MWh/a which was 3 times the expected loss. Hence the project was stopped.

3.4 Ottrupgaard, Jutland, Denmark

The Ottrupgaard system is a solar heated pond for district heating with a volume of 1,500 m^3 and a square lid of 700 m^2, in operation since the autumn of 1995.

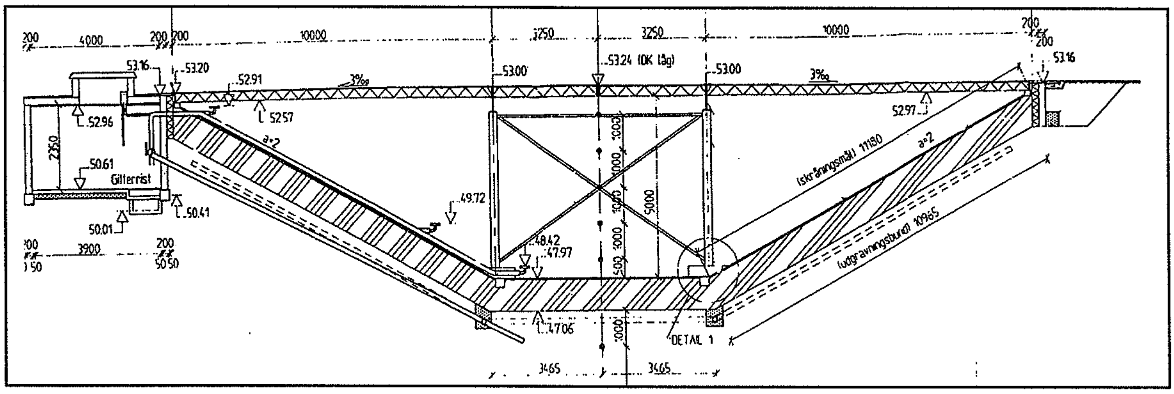

Figure 7 The Ottrupgaard lid design. Industrially produced sandwich elements with PUR-foam are applied.

One of the basic goals was to adopt industrial products on pit water constructions to attain a low prise. Standard sandwich construction elements, known e.g. from refrigerator vans and containers, are applied. The overall data for the lid design are as follows:

Bottom lining	0.5 mm stainless steel plates
Insulation material / design	230 mm PUR foam, 3 $^{0}/_{00}$ slope
Top lining	0.63 mm plastic protected steel sheet
Lid-wall gap sealing	Welded stainless steel edges and border, EPDM plastic liner across the gap, covered by a stainless steel sheet and held in place by flagstones.

Construction procedure: A static stand is placed into the pit, bearing the lid in case of an empty pit. The sandwich elements are placed onto a stand. Plate profiles are assembled by pop-rivets. The gap insulated by injection of PUR foam. Two step sealing of silicone and tape. The price was carried away by the difficulties of tightening the construction and ended at 1,163 Dkr per m^2 lid. The price of the lid for a 100,000 m^3 storage pit is estimated at 1,140 Dkr/m^2 [Wesenberg, 1996].

Figure 8 gives an idea of the composition of sandwich elements applied to the Ottrupgaard lid.

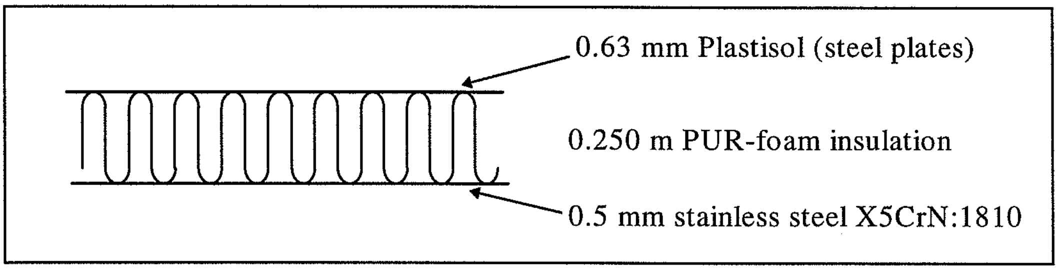

Figure 8 Sandwich element applied to the Ottrupgaard lid. The element is basically two plates filled with PUR foam as insulating material. This composition is rather stiff and stable without any additional stabilising constructions.

A picture taken from the top of the lid is given in Figure 9

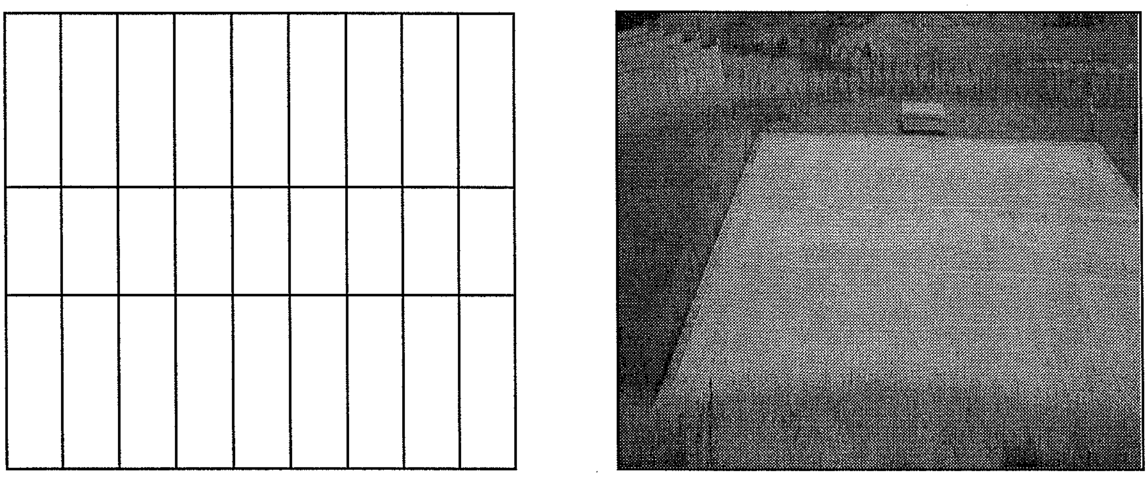

Figure 9 A sketch and a picture of the lid taken from the top. There are three rows with elements jointed as shown in Figure 10. The rows are connected by joints as shown in Figure 11.

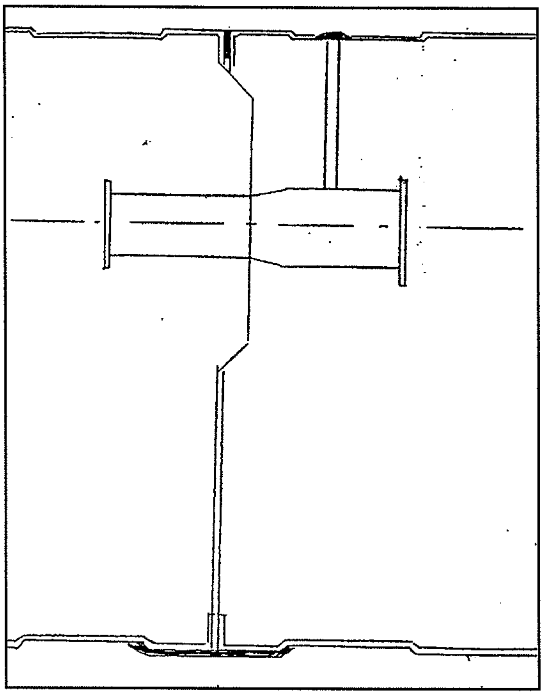

Figure 10 The assembly details for the sandwich elements. The two elements are fixed by a plastic bolt and the joints sealed by silicone mass and ID-tape.

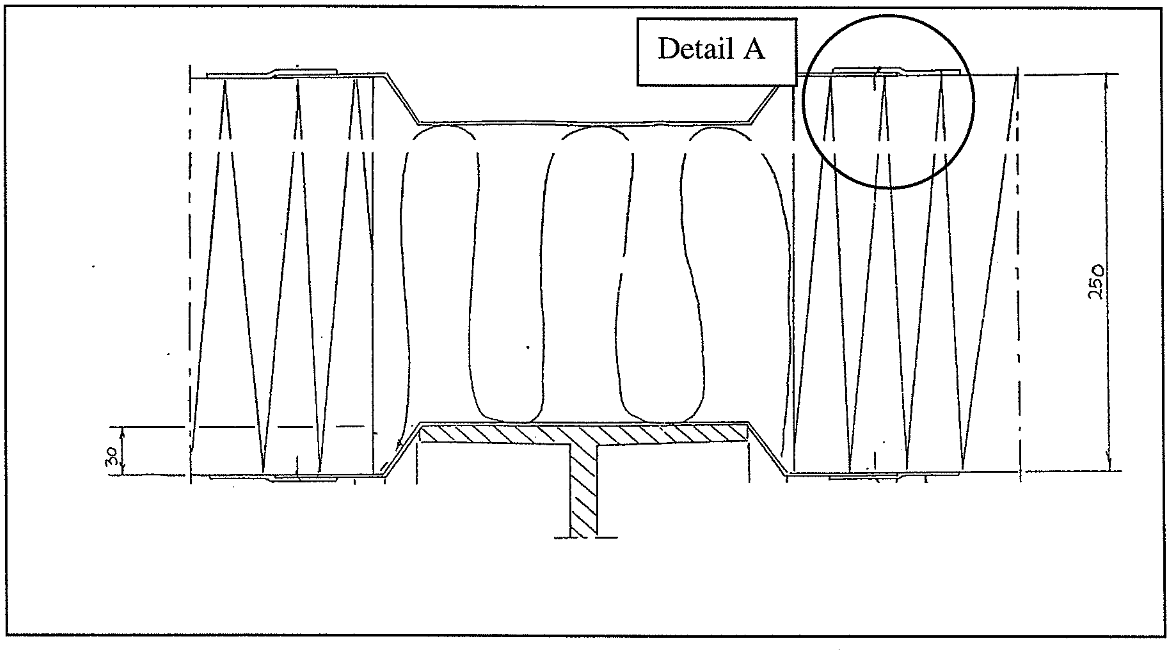

Figure 11 The assembly details for the sandwich elements. A special joint steel profile is fixed with pop-rivets onto the top- and bottom plate of the two sandwich elements. The joints are tightened by a two-step-sealing, shown in Figure 12. The gap between the elements is then filled with PUR-foam in situ. Note: The I-beam is in contact with the lid only if there is no water in the pit. Otherwise the lid is floating above the steel construction.

To decrease heat losses due to evaporation, the gap between lid and pit wall is tightened by a steel profile.

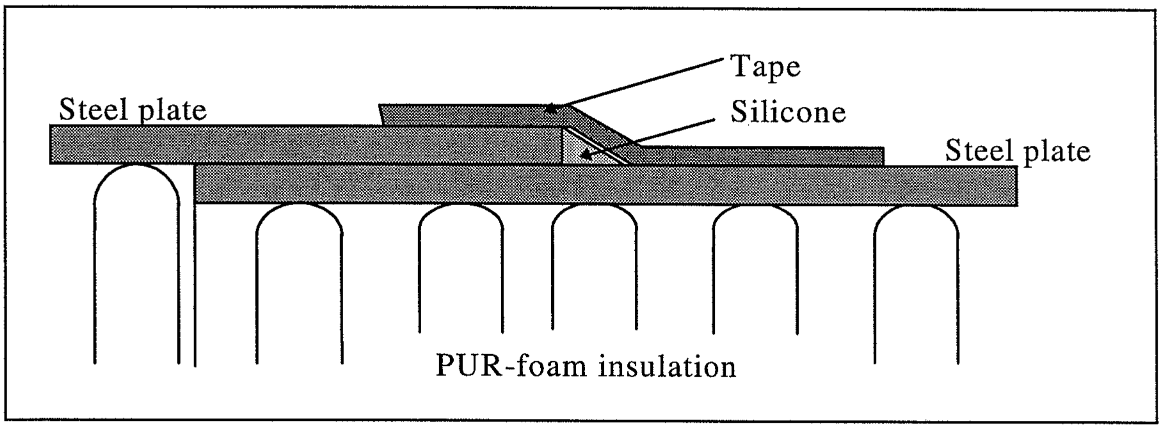

Figure 12 Detail A from Figure 11. The two-step-sealing; a primary sealing of silicone paste and a secondary sealing of a rubber tape which will be discussed in the following sections.

The edge elements are tightened by stainless steel profile jointed to the elements with pop-rivets and sealed by silicone mass and ID-tape. The border gap (ca. 5 cm) between pit-wall and lid is covered by a steel plate and an EPDM-liner.

In the case of an empty storage, the sandwich elements are held in position by a supporting steel construction as sketched in Figure 13.

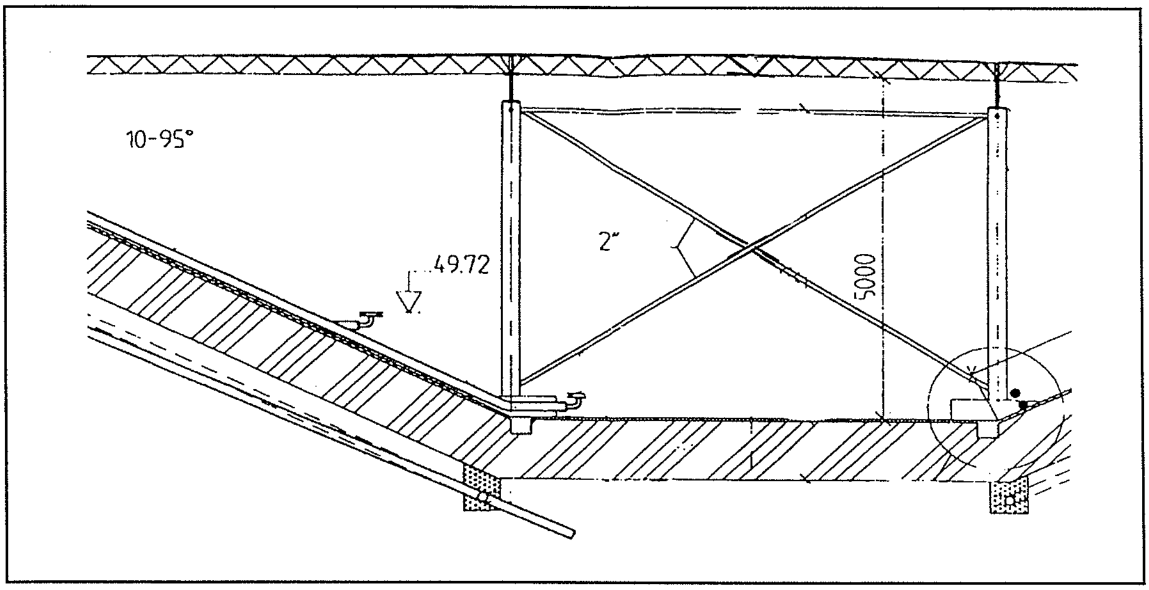

Figure 13 The steel construction supporting the floating lid for the case where no water is in the pit.

The lid was designed to enable rainwater to run to the side which was disturbed by unexpected friction between lid and pit wall, resulting in small water pools along the lid edges. Even so, no problems with pressure, freezing etc. were observed due to these water pools.

A rather worrying dislocation is observed at the Ottrupgaard lid which showed no sign of higher heat loss at this position. Hence the dislocation seems not to lead to any problems with leakage e.g.

Two-step sealing by silicone and butyl rubber-bitumen tape [Duer, 1995b] or bitumen only tape (IDL 0314 Tape from General Electric Plastics) is found to be much too complicated, work extensive, expensive and cause water entering the insulation. It is not clear if the water is entering from the top or the bottom. By destructive investigation by the author on a test lid exposed to 50 and 70 degrees for several months, penetrated water was found at the inside of the top cover sheet. There was water underneath all tape primary sealing which unfortunately works out to be a channel through which water is transported freely along all sealing joints affecting the whole construction.

Although water was found in the construction, no affection on the PUR-foam was found. Further experimental investigations on the effect of this water on the insulation is carried out and showed penetrating water in the insulation. In a few weeks the water line was moved about 0.5 cm into the foam insulation. The experiments could not prove if the insulation cell walls were destroyed and thereby the resistance of the insulation material affected. Further investigations are to be made on this subject.

Thermographic photos of the Ottrupgaard-lid showed some minor heat bridges at the joints between the sandwich elements with no serious influence on the heat transfer.

Thermophotos also showed serious heat losses at the pit border. An alternative solution is presented in Appendix B. In the redesign the lid is prolonged above the pit wall and laid on a draught strip. Hence no heat bridges will lead to heat losses. At the outermost corner a final list ensures tightness against evaporation. The solution seems to do its job. No experience is made on the solution.

Due to the fact that the water in Ottrupgaard is normal tap water, the metallic lid edges are affected by chloride steams which may lead to corrosion. Anyway, no corrosion is observed on the stainless steel sheets (X5 Cr Ni 18 10, German standard). Even so it is advised to employ better quality stainless steel of type W.nr 1.4401 or W.nr.1.4539 (German standard).

From the given experience it is advised to find alternative sealing techniques which are easier to handle and do not involve such a number of different materials. Assemblies underneath the water line should be avoided. The application of higher steel qualities are recommended. A construction has to make sure that no substantial amount of water is assembled at the top of the lid to avoid damage of the lid.

The experience on the Ottrupgaard lid design is reported in detail in the other publication of the current project [Heller, 1997].

3.5 Other Experience

In **Hoerby, Denmark**, [Cenergia, 1992], [Wesenberg, 1993] a partly buried concrete tank with concrete bearing lid gave some interesting experience with relevant material that could be applied to floating lids. Inside the tank, a membrane is floated on the hot water. The space between this membrane and the bearing lid is then filled up with inactive air. On the bearing lid a LECA-nuts layer of 0.5-1.2 m thickness is laid on a roof membrane

(Phønix PF 2000) for evaporation tightening. The rest of the construction is irrelevant for the current conclusion. The temperatures at the top was at a temperature level of 75-95°C swinging with a daily cycle.

After the first year a number of problems were observed. Evaporating water led to shrinkage of floating membrane as well as roof membrane. Condensed water was found in LECA-nuts and the rest of the construction. Insulation of the pit walls by polystyrene insulation was destroyed. Heat losses were very large. The storage was taken out of operation, then the construction tightened again and the whole inside of the storage wrapped into an EPDM-liner. Hereafter the storage was working well.

The relevant conclusion from this storage in Hoerby is:

- Multilayer constructions may lead to uncontrolled problems.
- Element constructions need to be tightened by total covering and reliable materials.
- Movements due to stress and temperatures are to be taken very seriously. Tightening has to be able to deal with deformations due to stress.

At a seasonal storage in **Tupperupvaenge, Denmark**, [KAB, 1996], similar experiences are made. The storage is made by sheet piling which is another element storage type. This element construction led to serious tightening problems. Polystyrene insulation was destroyed as in Hoerby. An EPDM-liner led to serious leakage. The construction had to be redesigned after two years in operation. The construction is now tightened by a 0.5 mm stainless steel liner (254 SMO) and techniques known from Rottenweil, Germany and Malung, Sweden. The reconstruction of Tupperupvaenge in 1996-97 has improved experience with handling and welding techniques for stainless steel liners. The techniques can now be applied in the coming designs.

4. Future for Floating Lid Constructions

At the moment three project groups known to the author are working on floating lid designs; the group behind the current project (DKG), the Fachhochschule Aachen, Solar-Institut Jülich, Germany (DG) and a Swedish design group (SG).

As we will see the ideas are straightforward consequences of the experience from the past. Overall, there are only a few different design paradigms. The author finds the following

- Taking insulation that cannot survive under the harsh conditions of the storage and cover it with liner and/or inactive gas. All design groups are working with this design paradigm in one or another way. There are two basic concepts for such designs; single section concept and sectioning. The basic idea behind sectioning is that an unwanted leakage cannot affect the whole lid construction. The drawback is the introduction of heat bridges in the design leading to larger heat losses. SG is working with an enhanced single section concept as DG is working with sectioning.
- Applying insulation materials which can survive in the harsh environment. DKG will work on this paradigms.
- To redefine the problems that are to be met and their interconnections. The solution to the single and interconnected problems can then be solved one by one or in groups. For almost all known solutions all the problems were met in one single boundary, the liner between hot water and the insulation. It is advised to work in the mentioned direction.

DKG will work with at least two different design paradigms; an element concept as in Ottrupgaard and a concept with insulation material directly floating on water. DG is working on a pontoon design and the SG with an element design which lies between the Ottrupgaard design and the pontoon design of DG.

In the following, the SG and DG concepts are introduced.

4.1 German lid design

Fachhochschule Aachen, Solar-Institut Jüllich is working on a storage design with floating lid [Liegl, 1996]. It would be the second floating lid applied in Germany known to the author. The first floating lid design was built in Berlin [Voigt, 1988] applying vacuum super-insulation which was much too expensive.

The 2500 m^3 seasonal storage is planned to be tightened by a polypropylene-liner from the firm of GSE-Lining. Based on investigations by Prof. Grosskurth, TU Braunschweig, this lining material gives a better life-length of the lining material than the lining material of other competitors, such as PEHD or EPDM.

The lid is basically built up by pontoons of stainless steel and insulation material. A sketch of a pontoon element is shown in Figure 14.

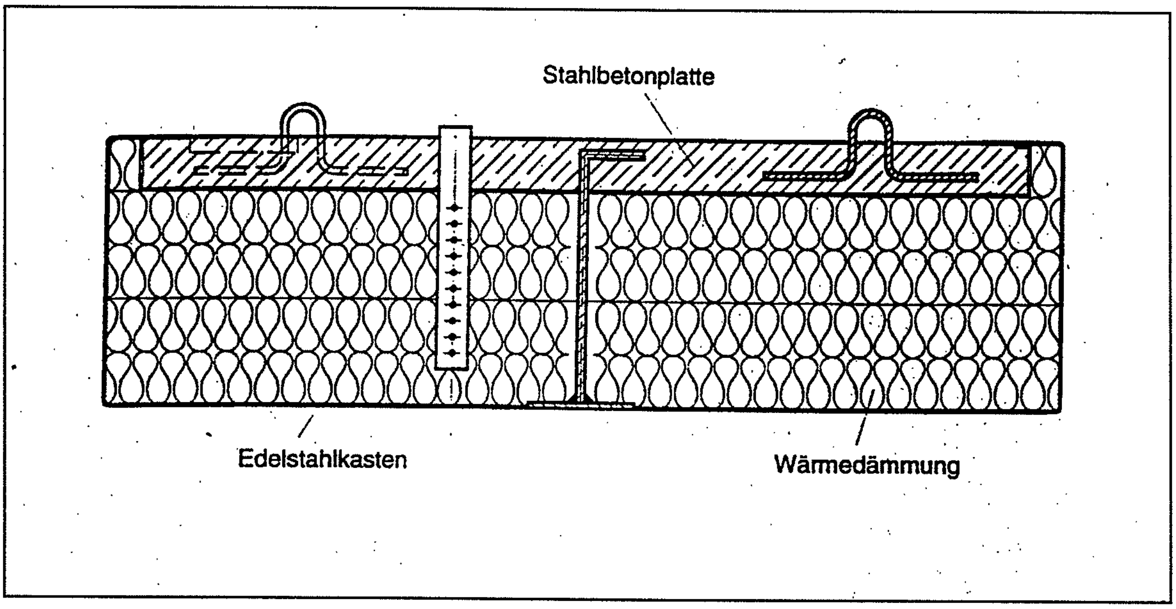

Figure 14 Cut through a pontoon element of the German lid design.

A pontoon element (0.9 x 0.9 x 0.25 m) is built up as a case of 1.5 mm stainless steel (V4A, Werkst. Nr. 1.4571, German standard) filled by two types of insulation material. The first insulation material ensures a proper thermal resistance, the second gives the construction a static stability. The case is then closed by a plastic membrane and covered by concrete plates to ensure stability and distribution of weight. For transportation four hooks are poured into the concrete plates. Through a 30 mm stainless steel pipe the insulation material is aired to avoid accumulation of moisture.

The pontoons are tightened by plastic profiles glued to the top covers as shown in Figure 15.

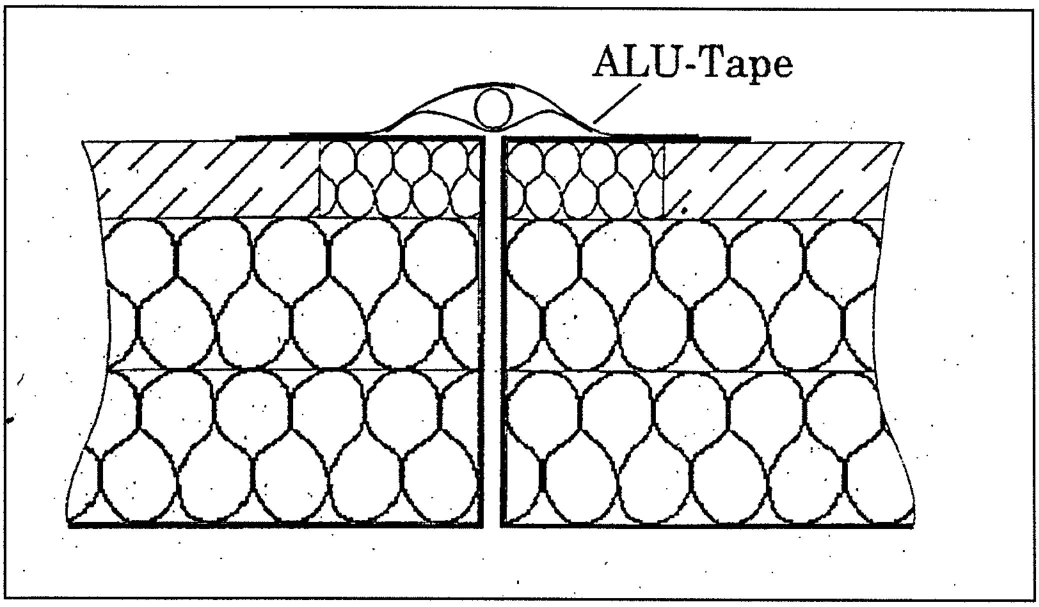

Figure 15 Detail on tightening between pontoons.

The detail on tightening the corners is investigated with a number of solutions. It is not yet chosen which one to apply in a possible construction. In Appendix C these details are shown.

In Appendix B, the original description is given in German.

4.2 Swedish lid design

Heino Zinko, Energiteknik, Sweden recommends the following floating lid construction for the next pit water storage. The lid is made up of a single stainless steel liner at the bottom and the top of the insulating lid. The bottom liner is U-formed as shown in Figure 16

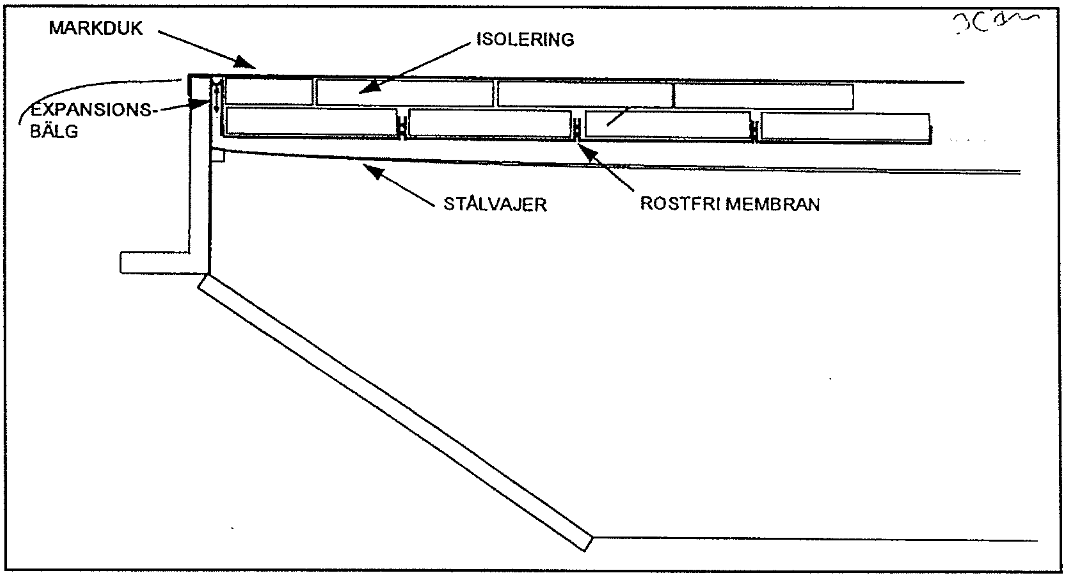

Figure 16 Floating lid construction with U-formed bottom liner.

The overall design is given as:

The overall design is given as:

Bottom lining	Prefabricated stainless steel sheets of 1.2 m with raised borders (U-formed).
Insulation material / design	PU-blocks, undefined
Top lining	Waterproof geo-textile (undefined type).
Lid-wall gap sealing	Special expansion design that ensures tightness for up to 30 cm water pile. The top liner is prolonged over the wide walls of the pit to tighten the construction against rain. See Appendix A.

The U-formed elements build sections where water can collect without affecting the other insulation sections. To avoid heat bridges the raised borders are not hitched up to the top cover.

A supporting wire net is fastened to the pit walls for the case of absence of water in the pit. The bottom liner elements are placed by crane onto the water, then welded together with two seams from a pontoon from the water side, then tested for tightness.

The gap between lid and pit wall is designed as shown in Figure 17.

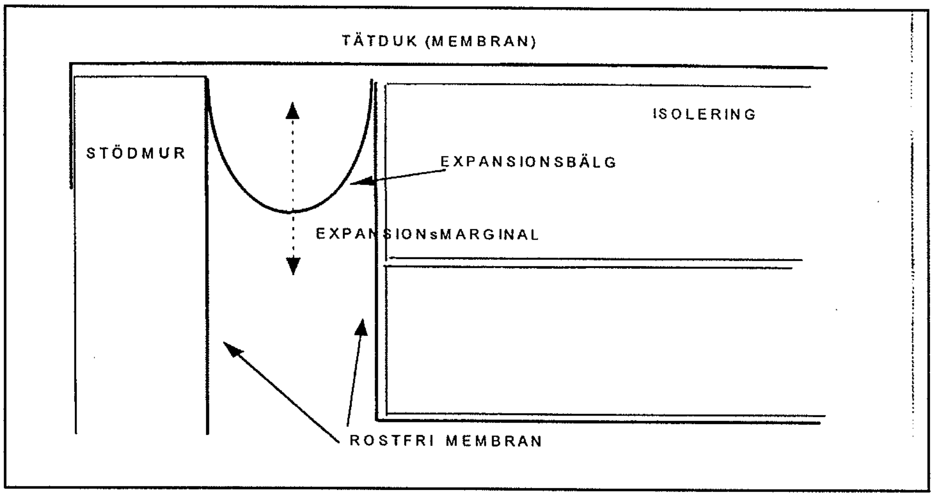

Figure 17 Border design for the Swedish floating lid design.

As we see from Figure 17, the boundary design is including an expansion construction to ensure the water level to change and at the same time to ensure tightness against evaporation.

The estimated price for the lid construction of a 3,600 m^2 lid in Swedish kroner is:

Stainless steel including welding	500 SKr./m^2
PUR insulation	700 SKr./m^2
Steel wire net and holders	133 SKr./m^2
Geo-textile	80 SKr./m^2
Special gap system	56 SKr./m^2
Total cost	**1469 SKr./m^2**

As mentioned before, the Swedish lid design is a natural consequence of the experience of known lid designs which have the bad characteristics that entering water will destroy the insulation of the whole lid. To enhance the security of lid construction the lid can be built up by a number of self-contained sections. If one section is affected by penetrating water, the others are still working properly. The disadvantage of such constructions is the increased heat loss due to heat bridges on the section borders. To avoid such heat losses the Swedish design breaks these borders before meeting the top cover.

Taught by the experience from the Ottrupgaard lid the author warn to rethink the construction. Penetrating water seems easily to be able to diffuse through the PU-foam. The consequences will be that entering water will be distributed through the whole construction. Hereby the sectioning is evaded.

In Appendix A the original description is given in Swedish.

4.3 Air-borne lid system

A simple idea of getting a lid sectioning can be achieved by applying smaller sections/pontoons like steel cans, plastic balls, rubber tubes, pre-insulated district heating pipes and so on. Although industry is producing parts like the mentioned in large quantities, it was not possible to find an economical alternative in the project which could work reliable for a long period. Anyway the idea seems convincing and should be kept in mind.

The idea could also be applied to constructions where the different functions of the lid constructions are distributed to a number of layers or sections.

4.4 Danish lid design

Based on introductory experiments the Danish designers have hoped to be able to create floating lids with no or very cheap bottom liners. This can be achieved by applying insulation material which can survive in hot water and damp, or by using a floating layer which has also an insulating effect. At the moment it is too early to conclude on these ideas. Such constructions could be carried out for under half of the price of known designs. Such price reductions would lead to storage concepts that can meet the energy prices of the day.

5. Conclusion and Recommendations

Based on the current survey of floating lids the following statements and recommendations can be made:

5.1 Applicability of floating lids

- There is no doubt about the economic advantages of floating lids, compared to static, bearing lids for seasonal pit water storage.
- Floating lids can, above pit water storage, also be applied to steel tanks.
- Floating lids cannot be applied at locations with heavy traffic or the like.
- Floating lids are to be made secure for traversing and against unwanted traffic.
- If the storage area has to be applied for a secondary purpose, floating lids are often too unstable. Anyway, solar collectors e.g. can be placed on top of a floating lid. (See Studsvik project)
- Applying floating lids, one has to consider the case of an empty pit. This means that the construction has to be hold up by a secondary construction.

5.2 Top Lining

- The top layer of the lid construction has to be UV resistant.
- The lid insulation must cover the border and side constructions to avoid heat bridges.
- The top liner must be more open for diffusion than the lower liner. Hence entering water can exit the construction.
- It is recommended to design lids in such a manner that rainwater can be drained off the lid.

5.3 Bottom Lining, Construction and Handling

- The water quality is a factor that has to be taken into account when designing a lid construction and choosing materials.
- The storage temperature is the dominating factor for the choice of material. Plastic materials are very sensitive to temperatures.
- Do not joint any material underneath the water line.
- Sectioning would make the construction more secure and reparation could be made possible.
- It is necessary to have good trained staff to carry out the work to be done. In such ways many errors can be eliminated.

5.4 General Findings, Methods and Project Management

In general the following partial details need to be investigated and to be solved:

- Material for insulation.
- Material for lining.
- Tightening details for the gap between lid and pit and also between sections.

Above these, the following overall investigations are necessary for successful design of lid constructions and others:

- Material testing under hot conditions and the presence of water has to be performed, experience collected and possible new methods for the testing of the material under the given conditions defined.
- Methods for the estimation of the life length of materials have to be defined. Experiences are to be collected. The time consumption of such tests is one of the critical factors.
- There are two types of errors; The first class will show up after short time such as leakage due to bad joining. The other class will show up after many years such as wrong chosen liner material. Scale tests (1.5 x 1.5 metres lid involving all details) executed under real conditions as shown in [Heller, 1997] and applied to the German design will exhibit the first class of problems. A number of errors on pit and lid constructions are detected during the first year in operation. Most of these errors can be found by such tests. The second class can only be found by long-time monitoring of the systems. There is a need of economical help for long-time monitoring and also a need for monitoring facilities that can show problems with e.g. sub-surface storage where nothing is visual from the top.
- Product development tools should be applied in projects like this lid project. In such ways problems with communication of ideas, tasks and so on could be avoided. Small models could be applied to give better understanding and hereby errors could be avoided.

Based on all these experiences one can conclude that lid design (also storage design) needs a long investigation time to ensure proper solutions. It is normally not possible to find such solutions in the time frame of a project. Therefore solutions are to be found in development projects that are not stressed in time. Hence financing are to be found in fields of development and not by carrying out installation projects. A consequence hereof is that public funding has to carry most of such projects which are normally very expensive.

Another subject is the fact that end-users are to be made aware of the riscs that can arise from development projects.

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Note: It can seem confusing for outsiders that the following Institutes have old and new names:

	Danish	**English**
Old	Laboratoriet for Varmeisolering	Thermal Insulation Laboratory
New	Institut for Bygninger og Energi	Department of Buildings and Energy
Old	Danmarks Tekniske Højskole	Technical University of Denmark
New	Danmarks Tekniske Universitet	Technical University of Denmark

Appendix A

Swedish Lid Construction Designs

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PM96-06-21

Lockkonstruktioner för gropvärmelager

1. Inledning

I Sverige har under sjuttio- och åttiotalet byggts tre stycken gropvärmelager. Två av dessa har haft flytande isolerande lock: Studsvik och Lambohov, för det tredje värme-lager (Malung) togs två konstruktionslösningar fram, en med flytande lock och en med fast lock. Av kostnadsskäl valdes sedan lösningen med fast lock. Nedan ges en teknisk beskrivning och erfarenhetsredovisning från lockkonstruktionen av de äldre värmelagren från Studsvik och Lambohov. Locket i värmelagret Malung är beskrivet i en tidigare utarbetad rapport ZW-96/05 (Ref 1).

2. Locket på värmelagret i Studsvik (Ref 2, 3)

Konstruktion

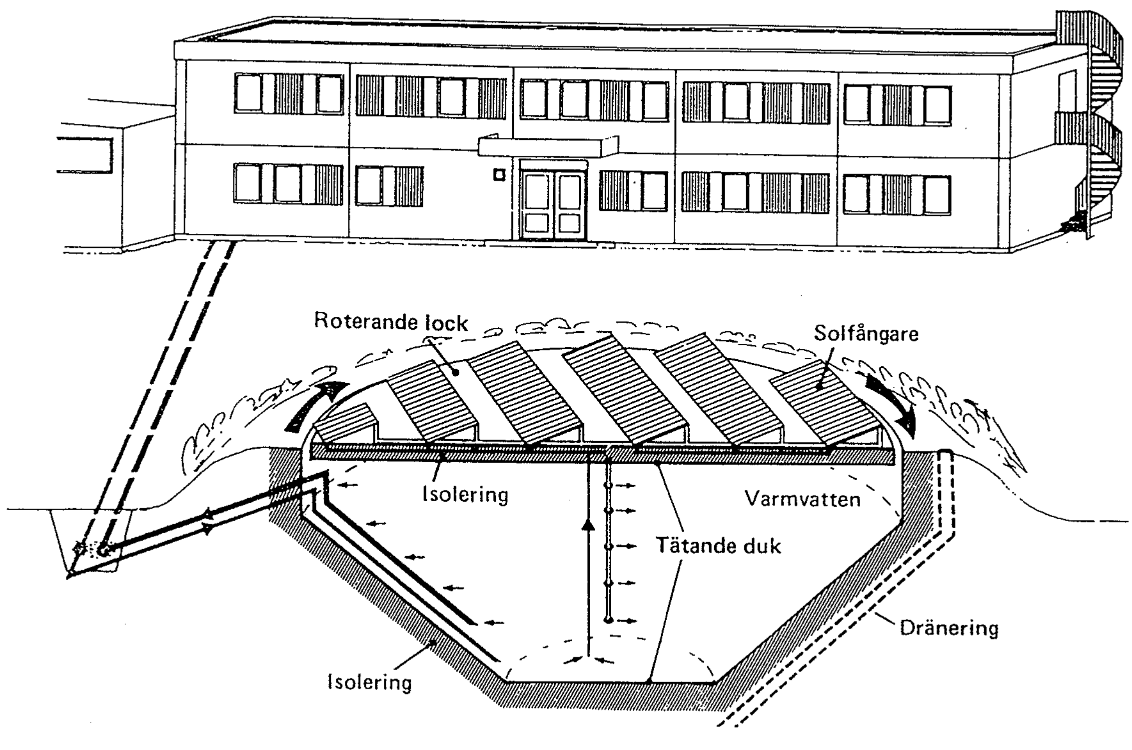
Principuppbyggnad av värmelagret med solfångaranläggningen framgår av Figur 2.1. Värmelagrets volym var 640 m³ och lockets diameter 15 m. Lagret har cylindrisk geometri och lagerväggens övre del består av prefabricerade L-profiler som utgör en vertikal vägg. Materialet i tätskiktet var butylgummi. Locket var konstruerat så att det kunde även bära solfångarfältet och rotera med solens rörelse för att utnyttja solstrålningen på bästa sättet. Lockets principuppbyggnad framgår av Figur 2.2. Locket består av två lager polyuretanblock (1m × 2m × 0.2 m) som var skyddade mot vatteninträng med en gummiduk, såväl mot vatten som mot inträngande regnvatten. Locket monterades direkt på vattenytan av den vattenfyllda gropen (se Figur 2.3). Först monterades den undre duken så att den hängde från sidoväggarnas överkant ner till vattenytan. Sedan monteras PU-blocken med förskjutna spalter såsom det visas i Figur 1.3. Utanpå isoleringen lades sedan två olika typer av duk. Först en 1,5 mm tjock polyesterväv för tryckavlastning (skydd mot solfångarstativen), därefter en 2 mm tjock gummiduk som sträcker sig över spalten mellan lock och vägg.

Spalttätningen visas i Figur 1.2. Väggens överkant var belagd med en 1,5 mm tjock polytenplatta. Denna utgjorde ett glidlager för lockets övre gummiduk. Den nedre gummiduken var uppdragen längs isoleringens sidokant och infäst mot isolerblockens ovansida. Pga av lockrotationen var det viktigt med en relativ stor spaltbredd av ca 2 cm. Gummiduken var således den ända ångspärr i spalten och konstruktionen medförde en del förångsningsförluster. Pga den relativt låga topptemperaturen i lagret (< 70 °C) blev förlusterna dock måttliga.

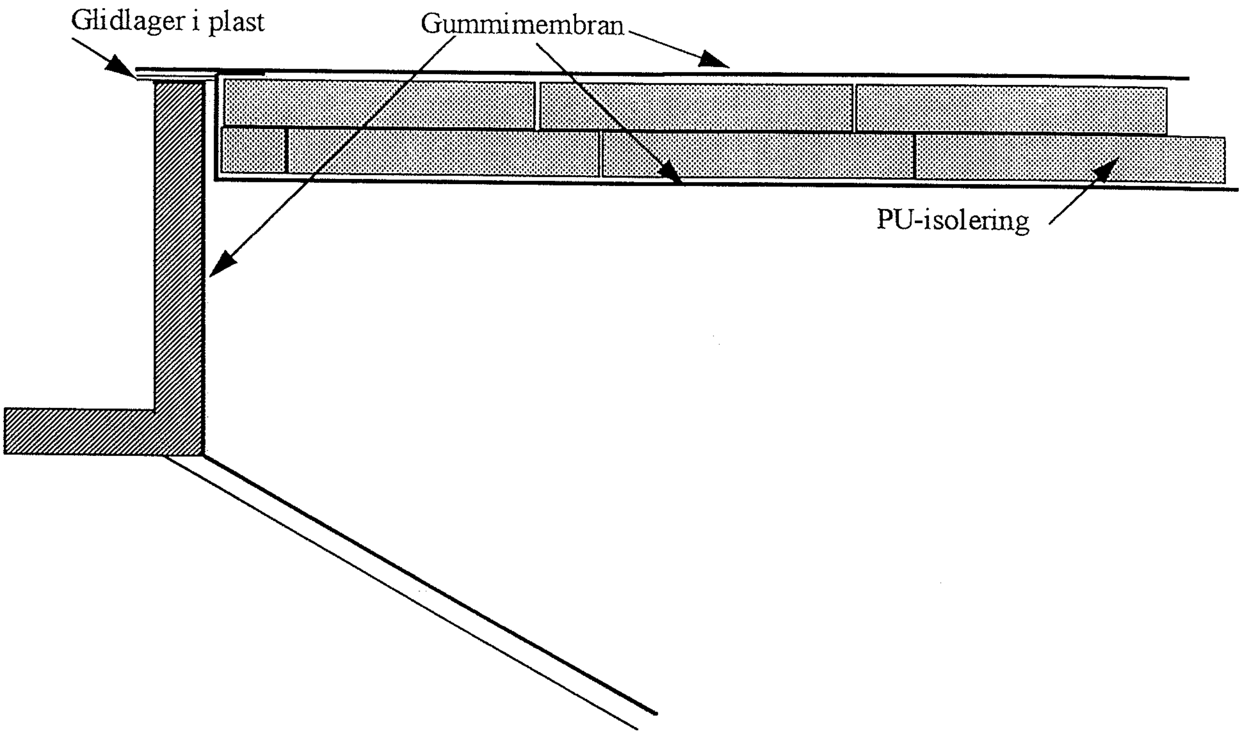
Drifterfarenheter

Locket fungerade tillfredsställande under de 6 år anläggningen var i drift. Det konstaterades att man inte lyckades hålla locket helt tät mot inträngande regn- och smältvatten. Orsaken var att stativen till solfångarna gjorde på vissa ställen hål i gummiduken så att ytvatten kunde tränga in till isoleringen. Det mesta av det inträngande vattnet rann när i spalterna mellan isoleringsblocken och samlades ovanför den undre gummiduken, där det bildades en vattenbubbla i lockets mitt. Det monterades en dräneringspump i mitten och på så sätt kunde lockets funktion upprätthållas. Kontinuerlig mätning av värmeledningsförmågan i en PU-block visade, att själva PU-materialet inte förändrades under tiden utan att det höll en värmeledningskoefficient av $\lambda = 0.024$ W/(m² K). Däremot uppmättes en total värmeförlust från lagret som var 30% större än beräknad. Huvudanledning till det var dels värmeförlusterna genom sidospalten mellan lock och vägg och dels värmeförluster i samband med det utpumpade uppvärmda regnvattnet.

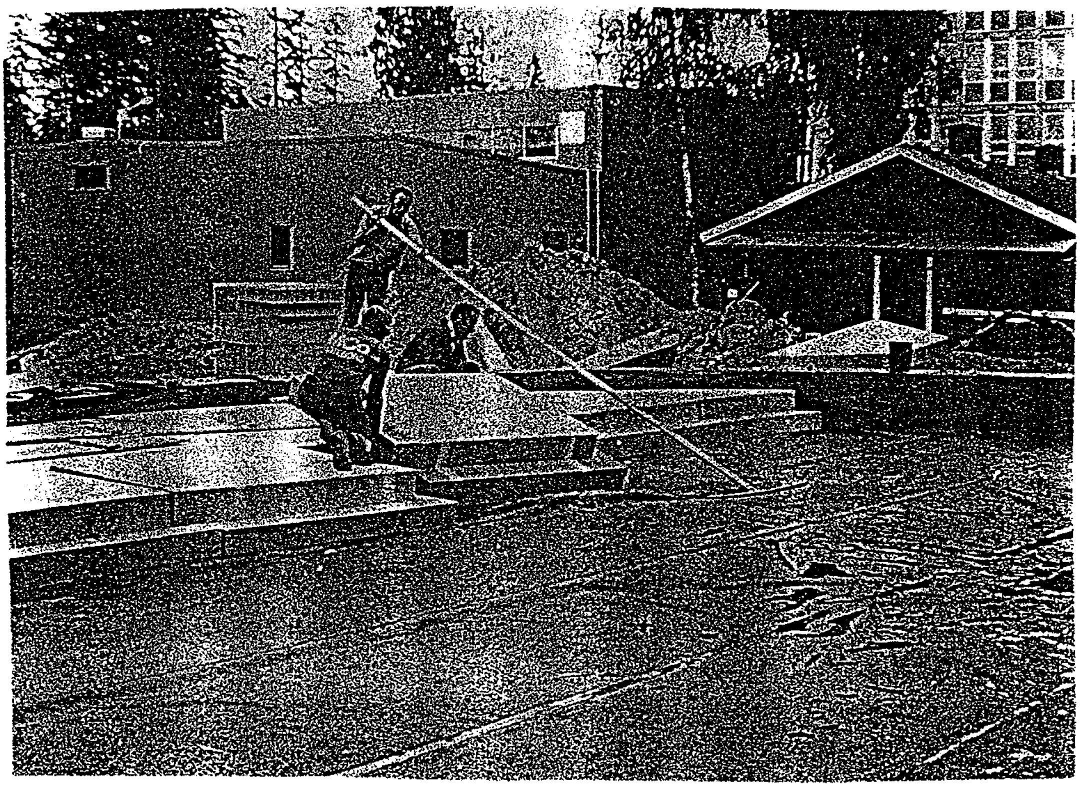
Hela anläggningen var i drift under 6 år och lades sedan ner av ekonomiska skäl. Lockmaterialet (PU-blocken) var i så pass gott skick att de sedan kom till återanvändning på taket i värmelagret av Malung.



Figur 2.1: Principskiss av solvärmecentralen i Studsvik



Figur 2.2: Principskiss över lockkonstruktion av värmelagret i Studsvik



Figur 2.3: Montering av lock

3. Locket på värmelagret i Lambohov (Ref 4)

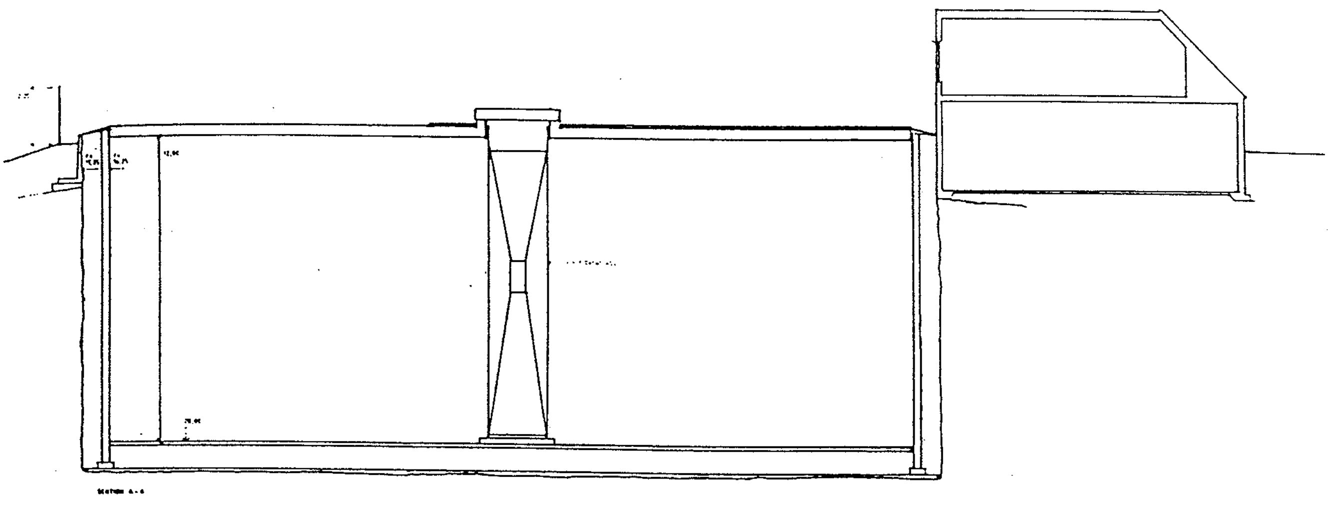
Konstruktion

Värmelagret i Lambohov baserades på de erfarenheter från Studsvik. Lagret var dock betydligt större, volymen var 10 000 m³ och lockets diameter 32,5 m. Gropen var nedsprängd i berg med sidoisolering av Leca. Konstruktionen av locket i Lambohov var av samma konstruktion som locket i Studsvik. Dvs två lager PU-block med överlappsskarvar (1.2 m × 2 m × 0.2 m) mellan två dukar. Den lägre duken var en helsvetsad gummiduk (butylgummi), den övre duken var en helsvetsad plastduk. Polyestervävnaden utgick eftersom lockets toppsida var obelastad. Eftersom locket inte roterade, så kunde lockets isolering utföras utan större sidospalt. Man övervägde olika lösningar för en särskild sidospalttätning, men dessa utfördes aldrig. Locket hade en kvadratiskt inspektionslucka i mitten som i sin tur isolerades med en PU-block (se Figur 3.1). Luckan placerades ovanpå ett stativ för en skiktfördelare placerade i lagrets mitt och stående på lagrets botten. Det rörde sig om ett diffusorsystem med uppgiften att leda det solvärmda vattnet till rätt nivå i lagret. Via denna inspektionslucka kunde man även länspumpa vatten som trängde in i locket.

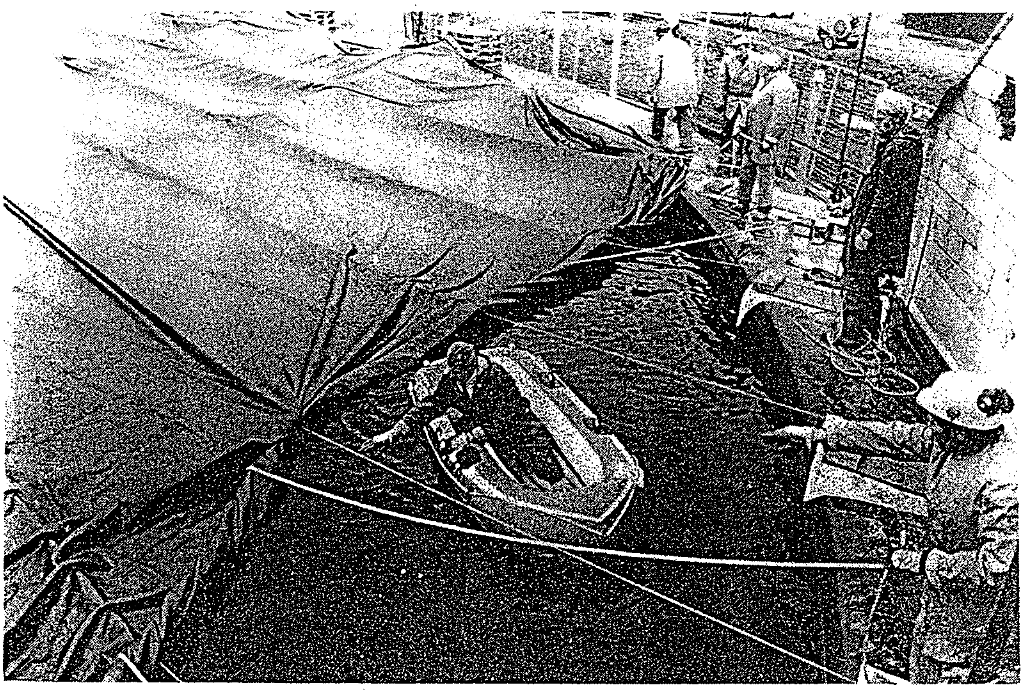
Utläggningen av gummiduken framgår av Figur 3.2. Duken rullades ut vilande på hjälplinor med hjälp av två kranar och livbåt. Det konstaterades att hantering av en så stor sammanhängande duk är komplicerad, särskilt vid otjänlig väderlek. Det finns många moment, där risken är stor att duken kan skadas. Däremot gick utplacering av isoleringsblocken och topptätduken i plast smidig.

Drifterfarenheter

Det ansågs att lagret aldrig var riktigt tät, utan att det förekom hål såväl i toppens tätduk som i sidoväggarnas tätduk. De vertikala sidoväggarna var byggda i Leca stabiliserad med betong (s k lättklinker). Materialet var poröst och kunde vattenfyllas såväl från utläckande lagervatten som från inläckande grundvatten. I början försökte man hålla sidoväggarna torra med hjälp av länspumpning, men efter ett år beslöt man att acceptera en vattendränkt isolering. Man konstaterade att vatten även trängde in i locket mellan de två tätduken. Länspumpning skedde inte kontinuerligt utan endast vid enstaka tillfällen. Man konstaderade i samband med rivning av lagret 1992 att PU-isoleringen skadades genom att ligga en längre tid i varmt vatten (lagrets toppskikt var 60 - 70 °C). Lagrets totala värmeförlust uppskattades till ca 250 MWh/år, vilket var minst 3 ggr högre än projekterat värde.



Figur 3.1: Tvärsnitt lager Lambohov: Botten, sidovägg lock och inspektionslucka.

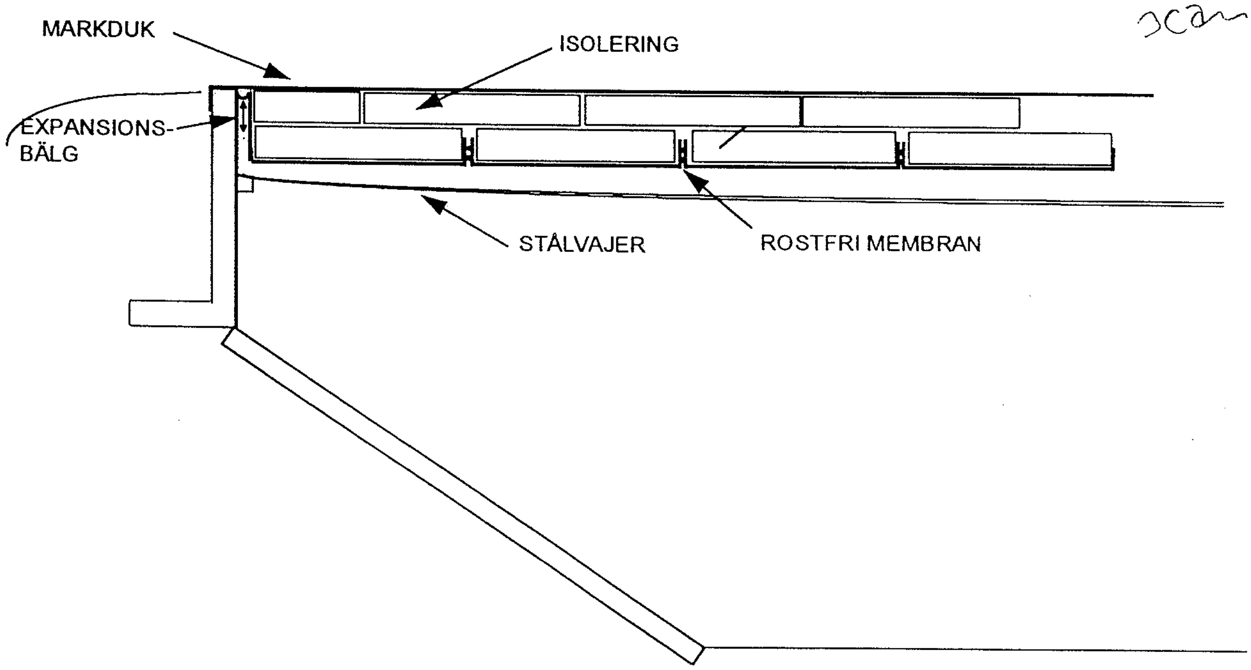


Figur 3.2: Montage av tätduk på lagret (med påfyllt vatten).

4. Förslag på ny design för ett flytande lock

Konstruktion

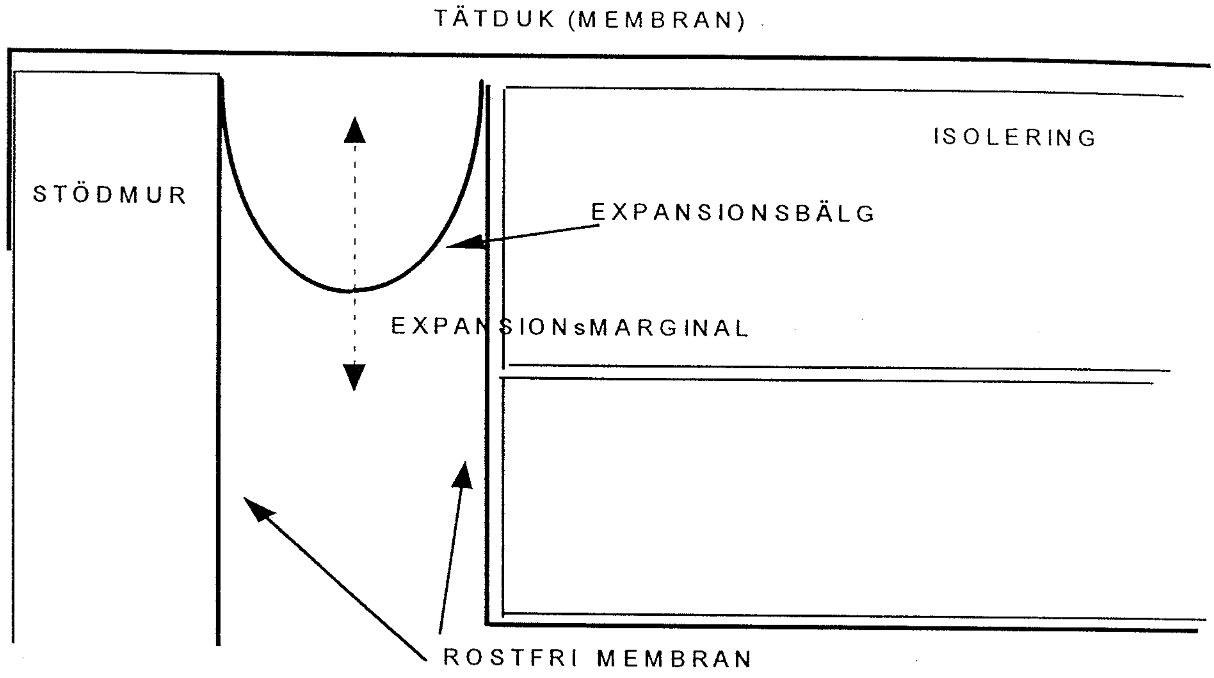
De erfarenheterna från Studsvik, Lambohov och Malung visar att det finns fördelar med en membran som även kan fungera som ångspärr för att förhindra förångningsförluster och vatteninträng i isoleringen. Vidare visade sig att antalet spalter måste hållas lågt eftersom dessa fungerar som värmebryggor i isoleringen. Det uppstår stora värmeförluster, om vattenånga tillåts att kommer i kontakt med lockets ovansida. Av den anledning föreslås här ett flytande lock som er baserad på de konstruktionselement som vi samlade goda erfarenheter med: Genomgående tätmembran mot vattenytan och isolering bestående av PU-block. Principuppbyggnad av locket visas i Figur 4.1



Figur 4.1: Flytande lock baserad på rostfri membran och PU-block isolering.

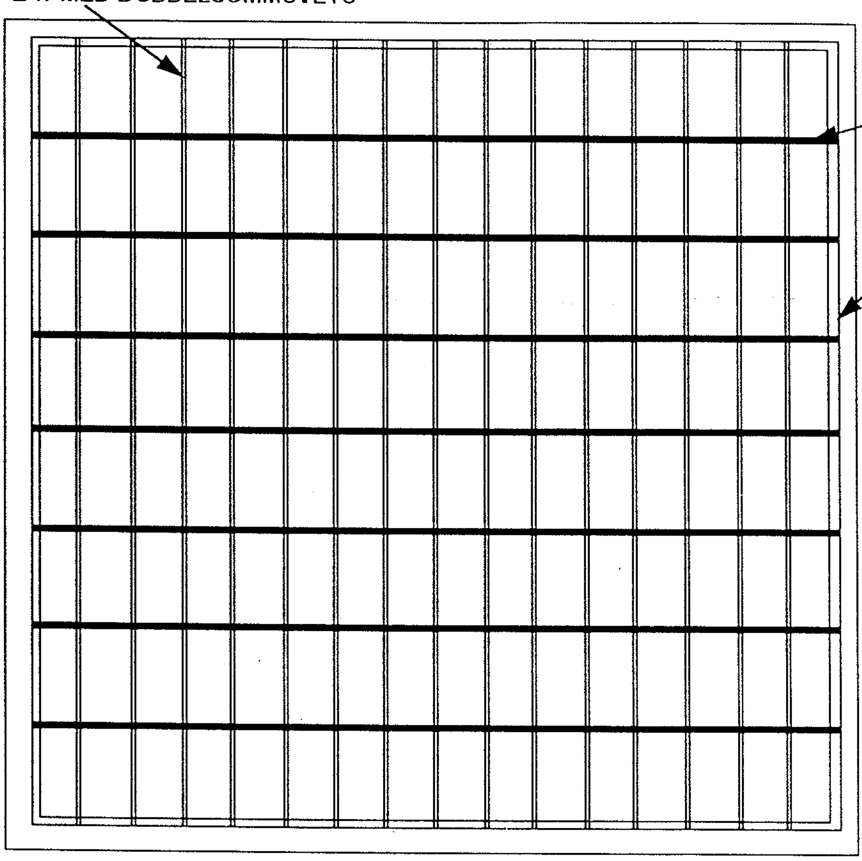
Locket består av en hel tät elementbyggd membran baserad på dubbelsömsvets. Membranet sätts ihop av vinkelplåtprofiler som lyfts med kran på den färdiga, med vatten fyllda gropen. Plåtelementen är 1,2 m bredda och längden motsvarar gropens bredd. Membranen ansluts via en expansionsbälg till gropen sidoväggarna så att hela inneslutningen av vattnet blir ångtät. Via en bälgkonstruktion tillåts att vattennivå kan ändra sig, ca ± 20 cm. Se detalj Figur 4.2. De enstaka plåtelementen svetsas tät med varandra med hjälp av dubbelsömsvets som utförs från vattensida medels ponton. Konstruktionen tål ett övertryck av ca 30 cm vattenpelare. Ett rör med säkerhetsventil som byggs in i locket öppnar vid större övertryck.

På tätmembranen läggs isoleringen i form av polyuretanblock, en metod som fungerade bra i Studsvik och Lambohov. En tätmembran läggs även ovanpå gropen. Av tekniska skäl vill vi föredra rostfritt även där, av kostnadsskäl är det dock också intressant med en markduk som inte är genomsläppligt för vatten, men diffusionsöppen för vattenånga.



Figur 4.2 Detalj ur randtätning av värmelagrets lock

Erfarenheterna från Studsvik visar att locket bör skyddas mot att falla ner vid vattenförlust. Membranen säkras därför med stålvajrar som är spända vinkelrätt mot svetsriktningen. Se Figur 4.3. Vajrarna, även de i rostfritt, fästas på lämplig lägsta nivå för locket i ett fyrkantrör som utgör en inre ram runt stödmuren.



Figur 4.3 Locket på gropmagasinet sett nerifrån med sömsvetsar och stålvajer

Kostnaderna

Kostnaderna för lockkonstruktionen utgörs i första hand av membranen och isolering. Vidare tillkommer kostnader för markduken och vajerkonstruktionen.

För en större lockyta (3600 m²) räknar vi med följande kostnader:

		SEK
Rostfri membran. (svetsad)	(500 SEK/ m²)	1 800 000
Isolering (PU)	(700 SEK/ m²)	2 520 000
VKR + Stålvajer		480 000
Markduk	(80 SEK/ m²	288 000
Bälg och övrigt		200 000
Summa		5 288 000

För en grop på 25 000 m³ med 60 m lockdiameter blir de specifika lockkostnaderna således 211 SEK/ m³.

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Appendix B

Danish Lid Construction Designs

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Denmark

Carsten Wesenberg, Nellemann, Nielsen & Rauschenberger

28. januar 1997

Lågkonstruktioner for damvarmelagre i Danmark

1 Indledning

Siden begyndelsen af 80-erne er i Danmark bygget tre nedgravede damvarmelagre tilsluttet fjernvarmeanlæg eller blokvarmecentraler. To af damvarmelagrene har fast låg og et har flydende låg:

* Hørby Varmeværk A.m.b.a., 1989, (fast låg) 500 m^3
* Tubberupvænge, 1990 (fast låg) 3.000 m^3
* Ottrupgård, 1995 (flydende låg) 1.500 m^3

2 HØRBY-tanken

Varmelagertanken i Hørby blev idriftsat i efteråret 1989 som en delvis nedgravet modificeret gylletank af betonelementer med DENSIT-belægning, som er en speciel kemisk modstandsdygtig og temperaturbestandig beton. Lagertanken er opført i totalentreprise som en varmeakkumuleringstank (max 95°C) og isoleret i top og sider med et 0,5 - 1,2 m tykt lag af løse LECA-nødder. Indv. mål: diameter 13,3 m og højde 4,0 m.

Tanken er opført som prøvetank for et nyudviklet damvarmelagerkoncept baseret på 3.000 - 10.000 m^3 standard betonelementtanke/1/ og fungerer som døgnvarmelager og reservelasttank for det 1,6 MW store halmfyrede varmeværk, som forsyner ca. 180 huse i Hørby ved Sæby med fjernvarme.

Temperaturen i toppen af tanken ligger konstant på 75-95°C og temperaturen i bunden varierer dagligt fra 45°C til 88°C (døgnvarmelagring). *Hørby-tanken udsættes derfor i løbet af blot én måned for lige så mange temperaturvariationer som et sæsonvarmelager udsættes for i løbet af 20 år.*

Den oprindelige lågkonstruktion

Låget er opbygget af standard betondækelementer med 1 centersøjle. Herover blev udført en damptæt tagmembran (PHØNIX PF 2000) og ca. 1,2 m løse LECA-nødder afdækket med en alm. plast-tagfolie og græstørv. Mineraluld kunne ikke bruges ved de aktuelle fugtforhold /1/; LECA-isolering mister ikke - i modsætning til mineraluld - isoleringsevnen ved vandfyldning.

Hulrummet mellem låg og vand udluftes til det fri gennem en selvdrænende vandlås, og for at mindske fordampningen fra og iltoptagelsen i vandet, blev udlagt en flydende topmembran af en speciel temperaturfast polystyrenisolering (ECOPRIME 933, T_{max} = 115°C) flydende direkte på vandoverfladen i tanken.

Driftserfaringer og konstruktionsændringer
I foråret 1990 konstateredes fugt og kondens i lågets LECA-isolering, som nu var op til 70°C varm på oversiden. Endvidere var græsset visnet. Undersøgelser viste, at der ikke var fuget mellem betondækelementerne og at dampmembranen af bitumenpap var krympet og utæt, så vanddamp fra tanken kunne diffundere direkte op i isoleringen og kondensere under tagfolien.

Inden problemerne med fugt i topisoleringen blev løst, sprang tanken læk (juli 1990) og tanken blev tømt for vand. En nærmere undersøgelse viste, at fugerne imellem vægbetonelementerne godt nok var udført i en speciel temperaturfast kvalitet (PCI Silicoform UW, T_{max} = 165°C), men da bagstopningen af alm. skumplast ikke var egnet til høje temperaturer og derfor svandt ind, sprang fugerne læk p.g.a. manglende understøtning. Fugeprimeren af epoxy var tilmed blød og alle fugerne kunne let trækkes ud.

Det kunne endvidere konstateres, at der var lodrette revner i den nederste trediedel af vægelementerne og at den flydende topmembran af temperaturfast polystyrenisolering var ødelagt af det varme vand.

Fugerne imellem betonelementerne blev fuget om med massive fuger og der blev tilsvarende fuget imellem dækelementerne. Den ødelagte polystyrenisolering blev fjernet
I september 1990 blev tanken igen fyldt med vand og idriftsat.

Da vandtabet herefter stadig var for stort (1,8-2,0 m^3/dag), bekostede leverandøren i 1992 ilægning af en tæt EPDM-membran i bund, sider og top, og samtidig etableredes en flydemembran af EPDM med flydelegemer.

Herefter har tanken (inkl. LECA-topisoleringen) fungeret tilfredsstillende. Iøvrigt henvises til rapporterne /2/ og /3/.

Priser
Hørby-tanken kostede i 1989 732.000 kr eller 1.479 kr/m^3 incl. en 5-års tæthedsgaranti, som i 1992 dækkede udgifterne til ilægning af en EPDM-membran i bund, sider og top (ca. 200.000 kr).

Konklusion
Driften af Hørby-tanken har vist, at damvarmelagre af standard betonelementtanke kræver indvendig membrantætning.

Benyttes en alm. gylletank uden DENSIT-belægning, alm. fuger og en indvendig beklædning med en speciel temperaturbestandig EPDM-membran eller en rustfri tyndpladeliner, skønnes en 500 m^3 lagertank at kunne opføres for ca. samme pris som prøve-tanken i Hørby (1.500 kr/m^3 incl. projektering, excl. moms og grund). Da levetiden for en EPDM-membran i 95°C varmt vand ikke kendes, vil en indvendig beklædning med en rustfri tyndpladeliner i bund, sider og top - tilsvarende tankene i Malung (1991), Rottweil (1995) og Tupperupvænge (1996/97) - i givet fald være at foretrække; Se efterfølgende afsnit om Tubberupvænge-tanken.

Forslag til nye tiltag
Hørby Varmeværk A.m.b.a. og NNR foreslog i maj 1990 tanken tilkoblet et 1.700 m^2 solvarmeanlæg til sommerstop af halmfyr. Overslag: 2,7 mio kr /5/.

3 TUBBERUPVÆNGE-tanken

I 1990 opførtes i Herlev en 3.000 m^3 nedgravet varmelagertank med spunsvægge som sider og et fast betondæk som låg.

Den indvendige isolering bestod af:
- Loft: 60 mm PU-isolering og 125-500 mm EPS-(polystyren)isolering.
- Vægge: 60 mm PU-isolering og 120-445 mm EPS-isolering.
- Bund: 20 mm EPS-isolering (30 kg/m^2) og (under beton) 300 mm løs LECA.

På indvendig side af isoleringen i bund, vægge og loft blev tanken tætnet med 1,5 mm EPDM-gummidug med limede samlinger.

Dækket over tanken blev tætnet med en tagmembran og grus - se tegning. Indv. mål: 14,5 x 43,0 x 5,5 m.

Tanken er udført i totalentreprise af Rasmussen & Schiøtz A/S og skal fungere som korttidsvarmelager for et 1.000 m^2 solvarmeanlæg m.v.

Driftserfaringer og rekonstruktion (1996)
Efter idriftssætningen i juni 1990 konstateredes vandtab og tanken blev tømt og EPDM-liner repareret - primært ved overgang gulv/væg - og idriftsat i august. I juni 1991 konstateredes igen et stort vandtab og efter at den oplagrede varme var brugt, blev tanken i febuar 1992 tømt for vand og undersøgt, uden at man dog kunne finde utætheder(ne).

En voldgiftssag blev igangsat og en lang række undersøgelser, indhentning af tilbud på reparation m.v. blev igangsat. Simple forsøg med udtagne prøver af den anvendte EPS-isolering viste, at isoleringen med tiden skulle forventes at falde sammen, hvorefter en indvendig tætning med en ny EPDM-membran blev opgivet.

Byggeskadefonden gik ind i sagen og i slutningen af 1996 blev tanken påbegyndt tætnet ved ilægning af en flexibel 0,5 mm rustfri tyndpladeliner i bund, sider og loft. Arbejdet forventes færdig i foråret 1997, hvorefter solvarmeanlægget vil blive startet op igen.

Reparationen med en rustfri tyndpladeliner af syrefast, søvandsbestandig rustfri stål (254 SMO) - med samme svejseteknik som i tankene i Malung (1990) og Rottweil (1995) - blev valgt ud fra ønsket om at udvikle den i Danmark hidtil ukendte teknik som kommer fra AVESTA i Sverige; Tyndpladelinere samles hovedsagelig med en selvkørende svejserobot og dobbelte svejsesømme, som kan tæthedkontrolleres og repareres før tanken fyldes med vand. Iøvrigt henvises til rapport/4/.

Priser
Tubberupvænge-tanken kostede ved opførelsen ca. 3,1 mio inkl. moms (827 kr/m^3 excl. moms). Reparationen forventes at løbe op i ca. 3 mio kr, hvilket dog tildels skyldes ekstraordinære krav til stålkvalitet, isolering, svejsekontrol og fugtkontrolfunktioner m.v.

Konklusion
En tyndpladeliner er en meget fleksibel tætningsmulighed, som også vil kunne bruges ved tætning af betontanke samt flydende og faste lågkonstruktioner. Teknikken anses i både Sverige og Tyskland som den mest lovende og perspektivrige tætningsmulighed for store sæsonvarmelagre, idet levetiden forventes at være over 50 år i varmt vand (95°C).

Vandets clorid-indhold er dog afgørende for levetiden, og undersøgelserne i f.m. Tubberupvænge-tanken har vist, at der i danske tanke bør vælges en speciel søvandsbestandig rustfri stål: Fordampningen af vand med selv små koncentrationer af clorid - ved mindre utætheder etc. - vil kunne give anledning til cloridkoncentrationer over den kritiske værdi.

En tyndpladeliner til en ny tank vil ifølge den svenske entreprenør, CONSWEDE AB, koste ca. 600 kr/m^2 (excl. moms).

Forslag til nye tiltag
Når tanken er rekonstrueret og solvarmeanlægget idriftsat, vil en evaluering af konceptet fordre en ny målekampagne.

4 OTTRUPGÅRD-tanken

Ottrupgård-tanken er opført som pilotprojekt for lertætnede damvarmelagre med flydende lågkonstruktioner og tilkoblet et 562,5 m^2 solvarmeanlæg, som forsyner 21 huse med lavtemperatur fjernvarme. Idriftsat i september 1995.

Geometrien er fastlagt ud fra et koncept for 100.000 m^3 damvarmelagre /6/; Lermembranen udføres med samme tykkelse (ca. 0,85 m) og anlæg (1:2) og lågkonstruktionen tilsvarende med samme isoleringstykkelse og udformning som i et 100.000 m^3 damvarmelager. Sidelængden (26,5 m) er 1/4 af sidelængden i et 100.000 m^3 damvarmelager (110 m). Dybden (5 m) er 1/3 af dybden i et 100.000 m^3 bassin (15 m). Tanken er fuldt nedgravet.

Den valgte udformning er ikke optimal for et 1.500 m^3 damvarmelager, idet varmetabet vil være uforholdsmæssig stort. Overfladen pr. m^3 (og dermed varmetabet pr m^3) er over fire gange så stor som i et 100.000 m^3 lager.

Lermembranen

Lermembranen består af ca. 85 cm moræneler komprimeret til 96 % Standard Proctor og opbygget oven på en relativ tæt membran af 0,75 mm EPDM udlagt med overlæg (ikke-vandtætte samlinger). Undersidemembranen har til formål, at forhindre udtørring af lermembranens bagside, som skal forblive vandmættet for at gøre leren vandtæt.

På overfladen er lermembranen afdækket med geotextil og 6 cm SF-sten for at undgå opslemning af lerpartikler i bassinvandet og overfladeerosion fra regnvand/befærdelse i byggeperioden.

Lermembranen er afsluttet tæt imod en 1,2 m høj og 0,2 m tyk støttevæg af vandtæt jernbeton, isoleret ind mod bassinet med 200 mm PU-skum, tætnet med en 1,2 mm højtemperaturbestandig EPDM-membran med varmvulkaniserede samlinger. Manøvrerum er indrettet i en vandtæt kælderkonstruktion af jernbeton integreret i støttevæggen.

Lermembranens udformning, tykkelse, hældning og komprimering er bestemt ud fra ønsket om at begrænse udsivningen af det op til 95°C varme vand til 10 $l/m^2 \cdot år$ (≈ 1% af tankens volumen/år) og sikre skåningernes stabilitet i vandmættet tilstand. Iøvrigt henvises til GI-Rapport 1 /7/.

2.3 ***Lågkonstruktion***

Lågkonstruktionen er udformet som en 230-250 mm flydende skive af sammenspændte sandwich-paneler, isoleret med varme- og fugtbestandig PU-skum (praktisk varmeledningstal 0,020 W/m°K) som i fjernvarmerør.

Oversiden er 0,6 mm plastisolbelagte ståltagplader med fald, så regnvand ledes ud til siderne af lågkonstruktionen. Undersiden er 0,5 mm rustfri stålplader med svag profilering.

Kanter og midtersamlinger er udført i 1 mm rustfri stålprofiler popnittet til sandwichelementerne, fuget og udskummet (med PU-skum) på stedet. Fugerne er lukket med silicone-fugemasse og afdækningsbånd med dampspærre (ID-bånd) med henblik på at opnå en damptæt og regntæt lågkonstruktion, der kan befærdes (og belastes) som et tag. Levetiden påregnedes at være mindst 20 år.

En søjle/bjælke-stålkonstruktion bærer låget, når der er for lidt vand i tanken.

Den flydende lågkonstruktion reducerer fordampningen og iltningen af vandet i tanken, og påregnes at kunne bygges billigere end et fast låg /1/.

Spalten mellem støttevægen og lågkanten er afdækket med en 1,2 mm højtemperaturbestandig EPDM-gummi, 0,5 mm rustfri stålplader og betonfliser. Kantafdækningen er udført flexibel, så lågets lodrette bevægelser som følge af vandets udvidelse og lågets belastning kan følges. Luftspalten er udluftet til det fri gennem et specielt tryk/vacuum-arrangement.

Lågkonceptet er udformet af leverandøren af lågkonstruktionen i totalentreprise, HERCULES A/S, som har fabrikeret sandwichelementerne, kantprofiler, samlingsdetaljer m.v. Nødvendige modificeringer under byggeriet (efter april 1995, hvor det videre samarbejde med HERCULES A/S måtte opgives) er anvist af bygherrens tilsyn fra NNR i samarbejde med Plastconsult, underleverandører (DANA LIM A/S og DAFA A/S) og bygherrens medhjælpere fra AR-CON og i samråd med HERCULES A/S, som har stillet en 2-års garanti for lågets funktion.

Niveaukontrol

I manøvrerummet er anbragt en overløbstank, hvori vandstanden i damvarmelageret kan registreres. En niveaukontrol åbner ved vandmangel for spædevandspåfyldningen til lagerkredsen i varmecentralen. Damvarmelageret virker således som højdebeholder for vandet i lagerkredsen.

Stiger vandstanden hurtigt over overløbet eller udvider vandet i lagertanken sig hurtigere end overløbet kan følge med, vil overskydende vand kunne sive ud over bassinstøtteværggens kanter imellem gummimembranerne, som ikke er samlet tæt.

Når lageret opvarmes, vil låget bevæge sig op svarende til vandets udvidelse, som ved en opvarmning på 50°C vil være 2% eller 30 m^3, svarende til en hævning af låget på 48 mm. Udsivningen gennem lermembranen (anslået til 15 m^3/år) vil dog modvirke lågets hævning ved opvarmning af vandet.

Driftserfaringer og forslag til ændring af låg- og kantkonstruktionen.
Sandwichelementerne var nemme at montere og gav uden anden afstivning end ved enderne en god og stabil arbejdsplads. Samlingsmetoden med fugemasse gav dog store problemer med afhængighed af vejrlig etc, hvilket forsinkede og fordyrede byggeriet. Fugning under lågelementerne gav store omkostninger til stillads, udtørring og besværlig arbejdsgang og kontrol. Senere kan der blive problemer med fugernes tæthed og måske korrosion.

Sammensvejsning af bundpladen bør i fremtidige projekter prioriteres højt og alle samlinger bør kunne udføres uafhængig af vejrlig fra oversiden af låget. Iøvrigt henvises til slutrapporten /10/.

Konceptet for låg- og kantkonstruktionen er i 1996 optimeret yderligere /11/ (lågets tykkelse reduceret til 180 mm, taghældning og støttemur udeladt) i forbindelse med en justering af konceptet for store lertætnede damvarmelagre - som vist på figuren herunder;

(se vedlagt)

Priser (excl. moms)
Det oprindelige anlægsbudget for pilotlageret i Ottrupgård (aug 1993) var ifølge /10/ 1,6 mio kr (1.048 kr/m^3) - heraf låget ca. 600.000 kr (854 kr/m^2). Ved afslutningen af byggeriet (dec 1995) kunne anlægsudgiften (excl. grund, forbindelsesledninger, projektering og ekstraordinære udgifter) opgøres til ca. 1,8 mio kr (1.200 kr/m^3) - incl. låg (810.000 kr ≈ 1.163 kr/m^2).

Ifølge "STORE LAGRE 4" /11/, kan et 113x113 m flydende låg til et 100.000 m^3 lertætnet damvarmelager (nyt koncept, apr 1996) udføres for 14,2 mio kr (1.130 kr/m^2) - eller 57% af den totale lagerpris (25,1 mio kr ≈ 249 kr/m^3).

Referencer

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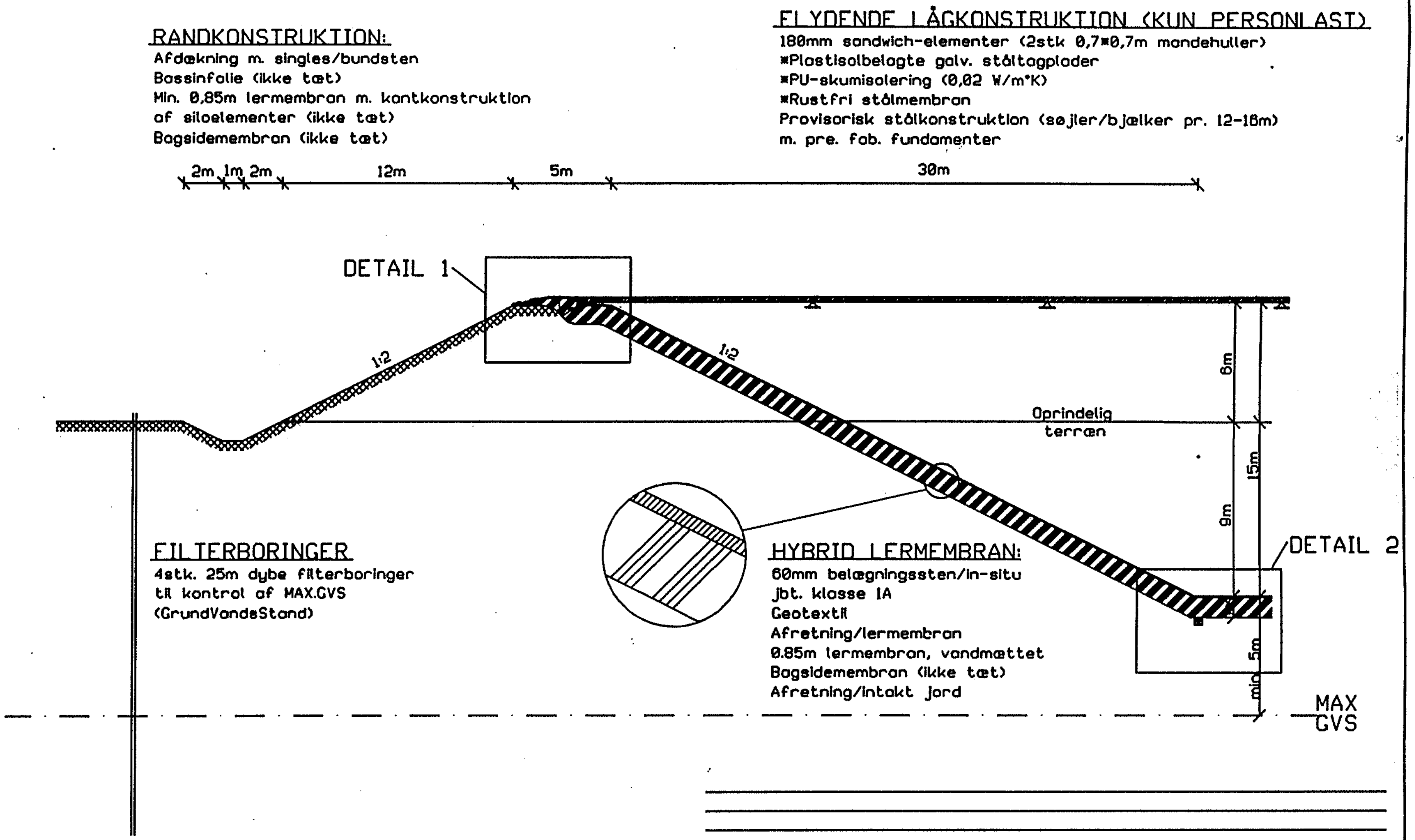

SNIT A-A, 1:200

		22.05.96	CAW/HPK		
Udgave	Betegnelse/Revision	Dato	Udført	Kontrol	Godkendt
Sag	SOL/SÆSONVARMELAGRE, STATUSRAPPORT	Sag nr.	07.354.00		
Emne	100.000 M3 LERTÆTNET DAMVARMELAGER SNIT A-A	Tegn nr. Udgave			1A
Målestok	1:200	Cad nr.	MORTEN		

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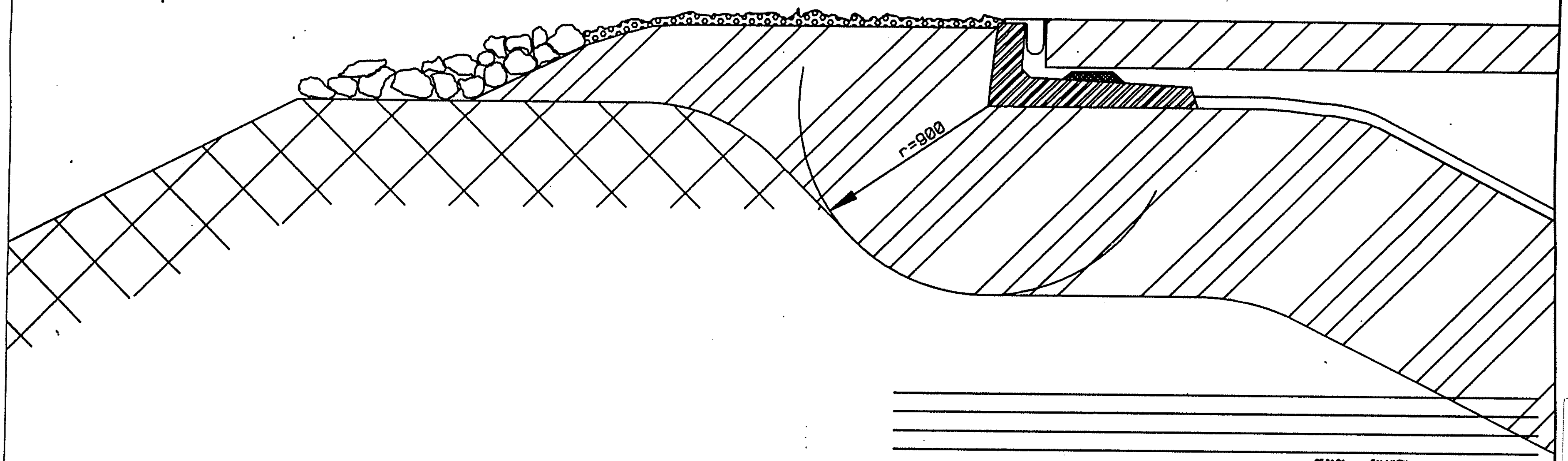

		25.06.96	CAW/MPK	
Udgave	Betegnelse/Revision	Dato	Udført	Kontrol	Godkendt

Sag

SOL/SÆSONVARMELAGRE, STATUSRAPPORT

Sag nr. 07.354.00

Emne

100.000 M3 LERTÆTNET DAMVARMELAGER
DETAIL 1

Tegn nr. Udgave

Detail 1

Målestok

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