A Case History on a Challenging Encapsulated Geomembrane Containment System for a Lime Sludge Pond Facility

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ABSTRACT
In 2007 Statoil acquired North American Oil Sands Corporation with over 1,100 square kilometres of oil sands leases in northern Alberta. An important component of Statoil's oil sands strategy was the building of an experimental Steam Assisted Gravity Drainage (SAGD) facility near Conklin, AB. The Leismer Commercial Demonstration Plant was built to test technology leading to reductions in the use of water and CO_2 emissions over conventional SAGD technology. Part of the Leismer project required the building of a 15,000 square metre lime sludge pond and other site containment systems. The lime sludge pond is a double-lined system protected by a concrete cover. This paper covers some of the unique aspects of the installation of containments in the tank farm, the storm water pond, and the lime sludge pond.

RÉSUMÉ
En 2007, Statoil acquiert North American Oil Sands Corporation, soit plus de 1 100 km^2 de concessions de sables pétrolifères dans le Nord de l'Alberta. Statoil cherche alors à construire une installation expérimentale de drainage par gravité au moyen de vapeur (DGMV) près de Conklin, en Alberta. L'usine de démonstration commerciale Leismer sert à tester la technologie visant à améliorer la technologie DGMV en réduisant sa consommation d'eau et ses émissions de CO_2. Le projet Leismer exige également la création de plusieurs systèmes de confinement, dont un bassin de boues résiduaire de chaux à double paroi de 15 000 m^2, recouvert de béton. Le présent article s'attarde à certaines caractéristiques uniques de l'installation de systèmes de confinement dans le parc de réservoirs, le bassin d'eaux pluviales et le bassin de boues résiduaire de chaux.

1 INTRODUCTION

The Statoil Leismer containment project involved the construction of four containment areas over a year of construction. This project was interesting due to the complexity of the containments and because the liner installation company acted as general contractor. The installation of containments is usually subcontracted work and liner performance can often take second place to earthwork contracts and project schedules. By assigning the liner installer as the general contractor containment performance was given precedence over other site activities. This case history outlines the design, construction, and testing of the containments on the Leismer project.

2 PROJECT OVERVIEW

As the liner installation contractor our original involvement on this project was the installation of the containments in the tank farm and storm pond areas. Once on site the project managers identified significant scheduling problems with the containment projects and there was considerable doubt that the project could be completed before freeze-up in 2009. Working closely with the project managers we were able to expand the scope of our work to accommodate additional containment construction and move the project time line ahead.

The containments at the Leismer Commercial Demonstration Plant were constructed between September 2008 and August 2009. There were four containments constructed during this period, the tank farm area, the storm water pond, the lime sludge pond and the warm lime softener tank spill containment.

Figure 1: Liner installed under/behind Supernatant Sump. Note backfill protection under concrete structure.

The first project was the tank farm area. When building large tanks the normal practice is to line the area below the tanks, backfill and protect those lined areas, and then turn the site over to the tank builders who weld the tanks together on site. Once the tanks are built the berms are constructed and the liners underneath the tanks are exhumed and extended to the berms.

The second project was the storm water pond. This single-lined pond involved excavation, compaction, and lining.

The most complex part of the Leismer containment project was the lime sludge pond. This double lined pond involved a unique design with the liners being placed underneath all concrete structures in the pond. This project involved excavation, installation of double lining systems under concrete structures, completion of the liner system after structure completion, leak location testing, roller compacted concrete base protection, and concrete filled fabric forms for slope protection, and finally, a water test. The timing of this pond had the potential to delay the start up of the entire project.

The warm lime softener tank is supported on a network of piles with a 2m air space below the tank. A spill containment liner was needed under this tank however the number and proximity of the piles precluded use of a standard liner material. A sprayed in place polyurea liner was used under this tank.

Figure 2: Support structure underneath the warm lime softener tank. With this type of detail only a spray-on liner will be effective.

There were a number of unusual aspects on this project. The first was the assignment of the liner installation company as the general contactor with responsibility for the effectiveness of the containments. This led to the use of a leak location survey on the completed lime sludge pond and a detailed water test. The effectiveness of this arrangement was demonstrated conclusively when the liner was damaged at the completion of concrete operations by a sub trade.

Of particular note was the design of the containment system in the lime sludge pond. The principle behind this design was to place the liner system underneath all structures to eliminate penetrations of the liner system and to connect the leak location system throughout the pond.

Finally there were a number of interesting products that were incorporated into these containments that provided additional useful features or helped to advance the construction schedule.

3 DESIGN

3.1 Lime sludge pond liner

The most interesting aspect of the containment design on the Leismer project was the placement of the lining system underneath the concrete structures in the lime sludge pond. The idea to put the liners underneath the concrete structures was excellent but was difficult to put into practice mostly because that part of the project took place in the winter months.

From bottom to top the lining system consisted of a 340 g/m2 geotextile, a 1.5 mm smooth HDPE secondary geomembrane, a 5 mm thick geonet leak detection layer, a 1.5 mm single-side textured HDPE primary geomembrane, a single-sided geocomposite geonet with nonwoven geotextile bonded to the top, 300 mm of select fill, and 150 mm of roller compacted concrete. The side slopes excluded the 300 mm of fill and used fabric forms to place 100 mm of concrete.

The placement of both layers of liner below all the concrete structures in the pond had three purposes. The first purpose was to eliminate penetrations of the lining system. Making a permanent connection to pipes or concrete structures in a pond adds significant complexity which becomes more difficult the larger the structure. Since concrete, steel batten bar, and geomembrane all have different expansion and contraction coefficients the larger the penetration the more difficult they are to seal together. Since the largest concrete structure, the Supernatant Sump, was the size of a 2-car garage it would have been very difficult to create a permanent batten connection that would last the design life of the containment. Placing the entire liner system underneath the foundation of these large concrete structures eliminated the need to make batten connections.

The second important aspect of eliminating penetrations is that it allows an electrical leak location test to take place with much more accuracy. Concrete and steel batten penetrations of the liner create a conductive path to ground which show up as a large leak in the leak location test. This large false reading masks smaller leaks in the area. By eliminating the penetration entirely leak location testing could take place right up to the edge of the concrete structure. In fact the accuracy of the leak location method would extend underneath the concrete structure as well. The leak location method would be able to see underneath the structure and show if there were any leak signals.

The third advantage of building the concrete structures on top of the liner system is that the leak detection system can be extended underneath the concrete structures. This allows any leakage that might occur in the system beneath the structures to be dealt with. Since concrete structures can crack over time leakage could occur through the bottom of concrete sumps. By placing the entire concrete sump above the liner system leakage from sumps is entirely confined to the double lined area of the pond.

There were five concrete structures which were to be within the confines of the liner system itself, four of the structures were supports for pipe racking. The fifth structure was the pump house. As each of these penetrations could have been possible leak points, it was decided that the geomembrane liners would be placed before the concrete structures were poured in order to remove them as possible leaks.

The complexity with this design was in the excavation of wedges in the pond slopes under the structures. These wedges needed to be cut, the liner installed, the concrete structure poured, and then the slope rebuilt to match the grade of the rest of the pond. Although the slopes of the pond were designed at a comfortable 3:1 (H:V), the slopes of the wedge excavations were 1:1 and included many angles and corners which greatly complicated the installation of the liner.

Figure 3: Installation of concrete filled fabric forms. Note that the pond is being water tested during this part of the installation.

3.2 Lime sludge pond concrete lining

The purpose of the concrete lining in the lime sludge pond was twofold. First it allowed significant protection for cleaning that is anticipated over the life of the pond. Since this pond is projected to collect a large volume of sludge frequent cleanings will be required. Adding a concrete inner layer provides a working surface for cleaning equipment while protecting the lining system from damage. The second reason for the concrete lining was to protect the lining system from possible heat damage from a nearby flare. In an upset condition the heat from the flare could produce enough heat to melt the geomembrane materials so the concrete protection was extended to the top.

Placing roller compacted concrete on the base of the pond was relatively straightforward. Placing a thin layer of concrete on a side slope is more difficult. On this project 100 mm thick fabric forms for concrete were used. These forms consist of two layers of fabric tied together with threads to create a uniform section. Sections of fabric forms are sewn together to cover the area required and then filled with a pumped structural grout. Once the grout hardens a solid layer of concrete is in place. On this project the fabric forms were prefabricated into large panels prior to delivery and the sewn together on site. Because of the weight of concrete over the length of the slope fabric bulkheads needed to be placed inside the forms to limit the amount poured at any one time. In this project the forms were filled 1/3 of the way up the slope and then allowed to cure before the next section was filled.

3.3 Steel containment berms

The original design for the containment berms in the tank farm was for concrete berms supported by driven piles. In the original tender for this project steel containment berms were proposed with ground plates that would support the dykes without piles. The steel berms with ground plates were cheaper and were ultimately selected.

Steel containment berms are made from sections of corrugated steel supported with posts or other structural sections. In this project the steel walls were 1.4 m high. A special ground plate that works with this system is placed on the ground and extends into the dyked area. Backfill on this ground plate and any spilled liquid from the tanks prevents tipping of the wall during a spill event. The ground plates are known as a zero ground disturbance system since they do not need piles.

Figure 4: Steel containment berms showing external support posts and liner attachment to the bottom of the berm inside the wall.

4 CONSTRUCTION

Initial construction started on the tank pads and liners and the storm water pond in September 2008. With the liner installation company acting as general contractor the tasks included excavation, compaction, and lining of both of these areas. Moving from one area to the other allowed completion of enough of the tank pads to begin assembly of the largest steel tank in the winter months. While most of the tanks were prefabricated the largest steel tank needed to be built in place so that pad had to be mostly complete before winter. About ½ of the tank pads were completed before freeze up in 2008.

The storm water pond was excavated in the fall and was days from being completed when poor weather shut down compaction activities. This pond then had to be set aside until spring.

During the winter of 2009 construction continued on the tank pads. Using scaffolding and hoarding to protect areas the tank pad construction continued throughout the winter months and into the spring.

Review of the lime sludge pond construction schedule showed that it would be difficult to complete the pond if construction was delayed until spring. In order to accelerate the schedule excavations of the areas beneath the pond structures were started in November of 2008. Since these areas were cut into undisturbed in-place soils compaction was not required. The excavations and linings in these areas were completed in March and the construction of the concrete structures started immediately afterwards. To protect the double liner system placed under each concrete structure a layer of plywood was placed and then buried with backfill. This allowed the concrete work to take place without risk to the lining system. Shortly after the concrete work began the excavation of the remainder of the lime sludge pond got started.

In May the weather permitted the completion of the earthworks on the storm pond. As soon as the first portion of the pond was completed lining began and the liner was completed by June.

In June the lining system in the lime sludge pond got started. First the liner under each concrete structure was exhumed. Then the double lined system was completed. Construction of the lime sludge pond liners took from June until mid-August.

Figure 5: Installation of roller compacted concrete.

Once the lime sludge pond lining system was completed a leak location survey was done on the entire pond. The leak detection system between the two liners was flooded with water and a quantity of water was placed in the pond. The water survey leak location method located a small number of pinholes in the primary liner. These were repaired and then the first water test performed. Once the water test was done the liner system was backfilled.

A single sided geocomposite was placed over the base of liner system for protection before backfilling the base with 300 mm of select fill. The combination of the geocomposite and backfill was needed to protect the liner in the base of the pond during concrete placement.

Fabric forms 100mm thick were used to place concrete on the slopes of the pond while 150mm of roller compacted concrete was placed on the base. A road way and turning pad was constructed with rig matting to provide a route for the dump trucks to get into the bottom of the pond. Once in the pond the trucks backed up in a straight line to the concrete placement machine without making any turns on the backfilled liner.

During the removal of the rig mats a forklift inadvertently put its forks through the backfill and damaged the liner system. The liner installer's site superintendent noticed the damage. The backfill was exhumed for 15 m on all sides of this damaged area and the liner layers were opened up to inspect each layer. Repairs were completed and then the backfill was replaced and then covered with concrete.

Figure 6: Damage to liner caused by forklift removal of the rig mats.

After the concrete was placed a final water test was performed near the end of September. This water test was monitored and compared with the required action leakage rate. The water detected in the sump was well below the action leakage rate for this size of pond and the leakage rate was trending downward suggesting that it was mostly residual construction water in the leak detection system.

Construction of the project wrapped up in September with the completion of the water test and the spray-on liner under the warm lime softener tank.

5 TESTING

One of the key challenges on this project was to develop a testing plan that would ensure that the lime sludge pond would be installed without leakage. With a concrete cover over the entire lining system there repairs after installation would be prohibitively expensive. The liner installer initiated a testing plan to make sure that the liner met expectations at each step during installation.

The first issue that had to be resolved was how much leakage is acceptable in a pond this size. It is very important to discuss this criterion at the beginning of the project. From there a testing plan was prepared that balanced cost with performance testing of the liner system. The final plan included complete quality control testing of all aspects of liner installation. In addition the plan included an electrical leak location test and two monitored water tests.

5.1 Electrical leak location testing

The electrical leak location method has been in use for over 20 years but is still not common practice in geomembrane installations. This is unfortunate because this is the one method that accurately determines the number of defects in a completed pond. Construction quality assurance and third party geomembrane testing services concentrate primarily on seams and seam integrity. Leak location tests the entire wetted area of the pond under test and can be adapted to exposed slopes and backfilled liners.

The electrical leak location method impresses an electrical voltage between the contents of the pond and the earth surrounding the pond. The plastic geomembrane acts as a dielectric insulator between these two media. A leak shows up as a flow of current from the pond contents to the earth and is detected by a mobile probe. This method shows discontinuities in the geomembrane which could potentially be leaks. Not all discontinuities detected are leak paths (a carbon agglomeration in the sheet could create a non-leaking electrical path) but all discontinuities found are repaired.

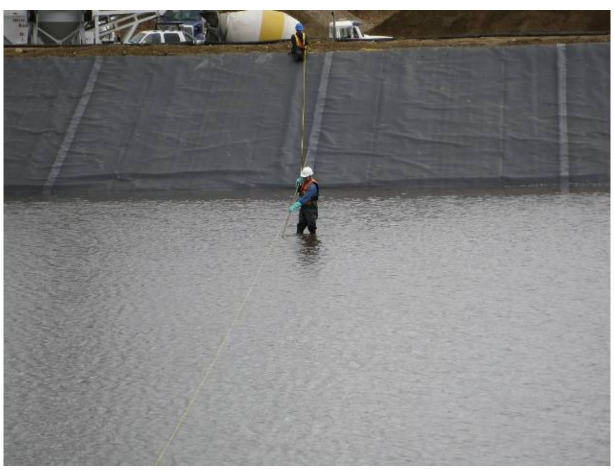

Figure 7: Leak Location Survey using the water survey method. Yellow rope is marking the path across the pond so that the surveyor can accurately locate his survey.

One of the limitations of this test method is that connections to ground such as pipe penetrations and structures show as large leaks. Careful design of a pond is required to eliminate or limit these leak signals. Usually this includes using plastic pipe, capping steel batten bars with geomembrane, and completely covering concrete structures with geomembrane where they contact the pond contents. In this project the designers did an excellent job in isolating the concrete structures by placing the liner underneath the structure and eliminating all potential leaks. This pond was ideally suited to leak location testing.

It is important to determine the optimum project stage to perform a leak survey. In single-lined exposed ponds a survey at pond completion is satisfactory. When backfilling a single-lined pond leak location surveying is often done after the backfill is complete to detect any damage. In double lined ponds it is possible to test one or both geomembrane layers. Usually only one layer is tested due to cost. Adding 1 m of water to a pond can sometimes add significant cost and is usually only done once. In some cases testing the secondary liner is done followed by a water test of the primary liner. In other cases the leak detection zone is flooded and only the primary liner is tested. That was what was done on the lime sludge pond. Five small leaks were found during the leak survey and were marked and repaired.

5.2 Water Testing

While terms like “impermeable” and “impervious” are commonly used for most containment systems, whether clay or geosynthetic, there is always some amount of leakage that occurs. Adding a volume of water to a dual-lined pond and monitoring the sump can provide performance information but this often requires interpretation. Occasionally the criteria for leakage in a geomembrane system is stated as “zero leakage” however this is neither a reasonable nor a practical goal. Alberta Environmental Protection has the Action Leakage Rate Guideline (Alberta Environment 1996) available

Action Leakage Rate Calculation

$$Q = C_b\ a\ (2gh_w)^{1/2}$$

Q = Leakage Rate (m^3/s)
a = Hole Area (m^2)
C_b = Dimensionless coefficient (0.6)
h_w = Liquid Depth (m)
g = Gravity (m/s^2)

$Q = 0.6\ (3.14 \times .0001^2)\ (2 \times 9.81 \times 1)^{½}$
$= .0000008346$ m3/s x 2600000
$= 21.7\ m^3$ / month

ALR = Q x Pond Area x Holes
= $21.7\ m^3$ /month x 1.35 ha x 2 holes
= $58.6\ m^3$ / month
= ($58.6\ m^3$/month) / (30.42 days/month)
= ($1.926\ m^3$/day) / (24 hours/day)
= ($0.802\ m^3$ /hour) x (1,000 l/m^3)

= 80 l/hour

The ALR for the sludge pond is 80 litres per hour

Figure 8: Calculation of Action Leakage Rate.

which provides direction on leakage and water testing.

The Alberta Action Leakage Rate Guideline is a detailed study of the current state of practice in the definition of leakage in double-lined liner systems. This guideline takes into account the size of the containment and the leakage rates identified by research as being typical and reasonable. The accepted rate is equivalent to two pinholes (2 mm each) per hectare. By calculating the action leakage rate for a particular impoundment a measure of performance is established. If the leakage from the containment is below this level no action is required. Leakage above this level requires action to mitigate leakage. Calculation of the action leakage rate for this pond is shown in Figure 8 and was found to be 80 litres an hour.

Two water tests were performed on the lime sludge pond. The first water test was done at the completion of the electrical leak survey and after the small pinholes identified were repaired. The pond was filled with water and left to sit for 5 days. Then water leakage was monitored for 2 days. This water test showed a leakage rate below 30 litres per hour. While this appears to be a significant fraction of the action leakage rate it is important to note that the leak detection layer had been flooded with water during the electrical leak survey and this “construction water” takes a long time to drain. The large surface area and small cross sectional area of a geonet drainage layer tends to retain water and seepage of this construction water can continue for a long time. Leak detection layers can also be flooded during construction with rain or other water and interpreting leakage immediately after construction usually will require the calculation of and action leakage rate for interpretation.

Once the first water test was passed the backfill, geocomposite, and concrete protection layers were added. A second water test was done at the completion of all work to verify the performance of the pond.

The final water test was completed over a three day period after all liner installation operations were

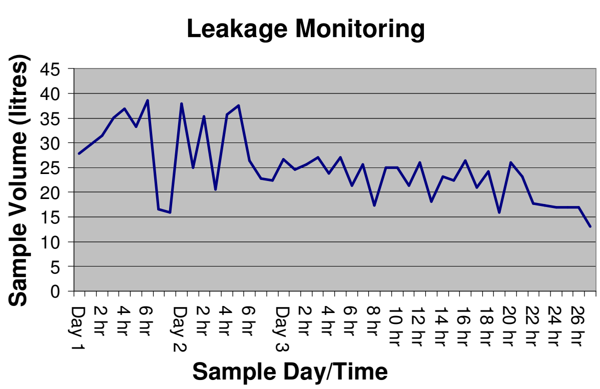

Figure 9: Leakage monitoring over 3 days including a 24 hour period of monitoring on day 3. Leakage is well below the ALR and trending downward.

complete. The first two days of monitoring took place during the day. The last day’s monitoring was for 24 hours with leakage being measured hourly. The leakage measured in this last water test is shown in Figure 9.

It is clear from Figure 9 that leakage measurements are not as straightforward as expected. It is clear however that the rates were well below the action leakage rate of 80litres/hour. It is also evident that the measured leakage is trending downward. This is evidence that the water measured is most likely construction water and not leakage. At the conclusion of the third day of monitoring the leakage rate had fallen to 13 litres per hour.

6 CONCLUSIONS

The containments at the Statoil Leismer project were a challenge for a liner installation company to tackle as a general contractor; however, having the liner contractor running the project focussed operations on successful pond performance. This was shown clearly in the response to the forklift damage and in the conduct of the electrical leak location and water testing.

Working closely with the engineer and the project managers solutions were brought forward that kept the project on time and budget. Here is a quote received from the project managers at the completion of the project:

> *The LS Pond was an extremely challenging project from the point of view of scheduling. It was anticipated that StatOil operation would be in the midst of Commissioning and Start Up in the spring & early summer of 2010. The LS Pond would therefore have to be completed prior to freeze up in the fall of 2009. The summer weather windows in the Leismer area are very unpredictable and can be quite unforgiving. Some key decisions that were made to enhance schedule opportunities were:*
>
> *i) complete rough excavation of the pond in the fall of 2008*
>
> *ii) Construct the Silencer support foundation, the Supernatant Sump, and the Discharge support foundations during the winter season 2008/09. These structures were designed to be “within the liner envelope”. The liner was placed under each foundation and protected with sand and plywood until the embedded sections could be spliced into the over all liner*

The Statoil Leismer containments were complex and challenging. By working as a cooperative team with the engineer and the project managers the job was completed successfully.

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