Geotechnique and Resources
Edmonton, Alberta
1998
Géotechnique et Ressources

51st CANADIAN GEOTECHNICAL CONFERENCE

51ième CONFÉRENCE CANADIENNE DE GÉOTECHNIQUE

Preprint Volume 2

The Canadian Geotechnical Society
La Société Canadienne de Géotechnique

CANADA

PERFORMANCE OF AN EXPOSED HDPE PULP MILL POND LINER AFTER TEN YEARS

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ABSTRACT: In 1987 the Millar Western Pulp Mill was constructed in Whitecourt, Alberta. This mill used a new technology called the bleached chemithermomechanical pulp (BCTMP) process that required a unique water treatment system. Part of the water treatment system was an effluent pond that was lined with a 1.5 mm (60 mil) High Density Polyethylene (HDPE) geomembrane. Layfield Plastics reviewed the performance of this geomembrane ten years after performing the installation.

On September 24th, 1997 Layfield Plastics inspected the bio-basin and removed HDPE material and seam samples for testing. The samples were tested for mechanical properties and seam strengths, while the original resin manufacturer compared a number of polymer properties with the original resin. Performance of the HDPE lining material was found to be within the original performance specifications except for yield strain in one sample and the consumption of the primary anti-oxidant additive in both samples. Problems observed in the inspection are discussed and recommendations for the continued service of the pond are outlined.

ABSTRAIT: En 1997 l'enterprise Millar Western a construite une usine de pâte à papier située à Whitecourt en Alberta. Cette usine utilisait une novelle technologie qui avant besoin d'un système de traitement de eaux spécifique. Une partie de ce système de traitement était un bassin biologique à effluent bordé d'une géomembrane de polyéthylène de haute densité (HDPE) et ayant une épaisseur de 1,5 mm. Layfield Plastics a réexaminé la performance de cette membrane dix ans après l'installation.

Le 24 Septembre 1997, Layfield Plastics inspecte le bassin biologique et enlève quelques échantillons de membrane HDPE incluant les joints pour en faire l'analyse. Les propriétés physiques de échantillons sont analysées ainsi que la résistance à la traction de joint. Le manufacturier de la résine, lui, compare les propriétés chimiques des échantillons face a la résine originale. Les résultats indiques que la membrane HDPE conforme aux spécifications originales de projet excepté celles de la traction (yield strain) dans un cas et la consomption de l'additif primare anti-oxyde dans duex cas. Les problèmes observés durant l'inspection seront révélés et les recommandations pour le service maintenu du bassin biologique seront résumées dans ce papier.

1. INTRODUCTION

In 1987 the Millar Western Pulp Mill was constructed in Whitecourt, Alberta. This mill used a new technology called the bleached chemithermomechanical pulp (BCTMP) process that required a unique water treatment system. Part of the water treatment system was an effluent pond that was lined with a 1.5 mm (60 mil) High Density Polyethylene (HDPE) geomembrane. Layfield Plastics reviewed the performance of this geomembrane ten years after performing the installation. This paper outlines the installation in 1987, and the inspection in 1997 including the results of the tests of material samples removed during the inspection.

2. INSTALLATION OF THE LINING SYSTEM

On July 9th, 1987, Layfield Plastics was awarded the contract to supply and install a 60 mil HDPE exposed pond liner for the Millar Western Pulp Mill in Whitecourt Alberta, Canada.

This project was one of the first to use automatic wedge welding equipment on HDPE in Alberta. In order to ensure that weld quality was maintained using this new equipment, a third party testing firm was retained by Layfield Plastics to provide full time Quality Assurance personnel and testing.

The Millar Western Pulp bio-basin lining system consists of approximately 36,000 m^2 of single-lined, 1.5 mm (60 mil), High Density Polyethylene (HDPE). The pond is constructed entirely in fill using a river cobble that was available locally. The cobble was covered by a bedding layer of sand approximately 200 mm thick. The base of the liner is backfilled to a thickness of 1 metre while the 3H:1V side slopes remain exposed. There is an access road to the base of the pond from the north west corner. Aeration piping is stabilised by concrete pads that sit on top of the liner (in the base backfill) in order to limit liner penetrations. Seven large fibreglass pipes connect the aeration structures to the pond with a 3H:1V flush penetration into the liner. There is an outlet structure in the east end of the pond and a simple inlet pipe in the west slope.

Plastalene Ltd of Granby, Quebec, manufactured the material used for this project starting on August 20th, 1987. The HDPE material was manufactured from Chevron Chemicals HiD 9642 resin. This resin was manufactured at Chevron's Orange Texas facility utilising Phillip Particle Form reactor technology. The HDPE sheet was manufactured on a flat die extruder 2.27 m wide. These narrow rolls were welded together into rolls 6.70 m wide for shipment to site. Tests were

Figure 1. Installation of the lining system.

performed on the sheet material and factory seams before shipment. There were two unique aspects of the sheet goods available from Plastalene. First of all the thickness control on the material was very accurate. The flat die extrusion method yielded sheet that varied from project thickness by only a few percentage points. The second unique aspect of this sheet was that all rolls were sized to the project. Each roll was exactly the length required to cover the area intended without waste. The north slope panels were 27 m long each while the south slope panels varied from 54 to 122 m long.

Site construction began on September 14th, 1987. There was still significant construction activity taking place in the pond as we began. The south west berm of the pond was still being constructed and formworks for most of the aeration structures on the south berm were still under construction. An on-site qualification of our welding equipment took place on our first day on site. Some additional labour was also required to prepare the subgrade prior to starting. On September 18th the first liner panels were placed and seamed together. The seaming was started on the north slope at approximately the location of seam # 19 (the seam tested in this case history) and progressed to the west until the access road was covered. Seaming then moved to the east until the north slope was covered.

Construction of other structures in the pond was not completed yet and sheet welding progressed in sections around the other construction. We bypassed the structures on the south slope and placed panels in between each of them. This led to wasted material later during the tie-in seams, however it was important in the late season to keep all aspects of construction moving to completion before winter. After the aeration structures were completed the remaining sheet was installed and the mechanical attachment to the structures started. The large fibreglass pipes had a flush cut flange that was used to attach the liner to the pipe at the 3H:1V angle of the slope. This connection proved to be very effective and relatively easy to construct. While the mechanical attachments were being completed the base of the liner was being backfilled. The liner backfill consisted of 300 mm of sand, followed by 700 mm of gravel. The backfilling process was monitored by Layfield Plastics' staff.

Construction of the aeration piping system took place in the winter months. A concrete pad was poured directly on the liner and then held in place with backfill. The pipes were anchored to these concrete pads. Baffle walls were installed in much the same way. A floating curtain was installed on the top of the timber frame baffle walls to help prevent shortcutting of the wastewater.

The Quality Assurance program was a uniquely co-operative effort between Layfield Plastics and the Engineer. A full time site QC representative was paid for equally by Layfield Plastics and the Engineer. The site QC representative measured the change in thickness of weld tracks, peak temperatures during welding, and took samples of qualification welds and forwarded them to Alberta Research Council (ARC) for destructive tests. The QC representative performed the record keeping for the project and prepared the as-built drawings. As a co-operative QC venture, the cost was reduced because QC testing was not duplicated by Layfield and the QC representative.

3. TEN YEAR INSPECTION

An inspection of the lining system was performed on September 24th, 1997. Since the Pulp Mill was undergoing a planned shutdown the water level of the bio-basin was lowered to a level 3 m below operating levels. This was the first time the water level had been lowered since start-up in 1988. A careful inspection was made of the entire perimeter of the liner and a history of the operation of the liner was obtained from the operators.

3.1 Interview with the Environmental Co-ordinator

Layfield Plastics visited the site to inspect the liner system and to interview the operators of the facility. An interview was held with the Environmental Co-ordinator at Millar Western. She had been the Co-ordinator since the start up of the bio-basin and was familiar with all aspects of the operation.

3.1.1 System Operation History

The operation of the bio-basin has changed considerably over the years in order to improve the environmental performance of the system. Millar Western Pulp was the first North American pulp mill to receive certification to British Standard 7750 in 1995, and ISO 14001 in 1996 for Environmental Management.

The Millar Western Mill produces 280,000 tonnes per year of pulp using the BCMTP process. The mill uses approximately 10,000 litres of water per minute, with all water being recycled about 15 times before going to the waste water system. A trench system in the mill directs all collected water to a wastewater processing system. Screens separate the solids from the wastewater before it is directed to the primary clarifier. From the primary clarifier the water is sent to the bio-basin.

In 1988 the facility opened using the Bio Basin as an Aerated Stabilisation Basin (10-day lagoon). "After the initial few months of mill operation, while only one line was producing, all discharges were well below our licence requirements. Once line two started up in December 1988, the limitations of the system became painfully obvious. Toxicity, BOD, and TSS (due to biosolids generation) all became a problem. In order to stay in compliance with its licence the mill voluntarily curtailed production" (Nielsen and Lyka, 1996).

An immediate short-term solution was to shut down one cell in the bio-basin to create a settling zone. The existing air header was used to remove accumulated sludge from this zone and send it to the primary clarifier where it could be removed by a sludge press. Although this idea was successful, a permanent solution was required.

In December 1989 a secondary clarifier was added to the system and the treatment process converted to an activated sludge system. Problems occurred in trying to convert the settling zone in the bio-basin back to an aeration zone. "Inspection by divers showed an estimated 200 tonnes of sludge at the bottom of the settling zone. This was brought up by intermittently turning the air on in this zone" (Nielsen and Lyka, 1996).

Continuous improvements to the system since 1989 have resulted in discharges well below that required for current operating licenses. Just prior to the inspection of the liner in 1997 the final steps in converting to an Extended Aeration Activated Sludge System were completed.

Biological Oxygen Demand (BOD) has always been in compliance however Total Suspended Solids (TSS) has caused some problems. The initial start-up TSS was 20,400 kg/day. At the completion of the change to the activated sludge system the TSS has been lowered to 3,400 kg/day. All wastewater treatment is now in compliance.

3.1.2 Operational Issues

A number of operational issues have occurred in the bio-basin in the past ten years. Initially there were wooden walls with floating curtains on the top of each wall to control shortcutting. The fabric curtains were badly damaged and sections of the wooden walls were displaced early in the operation of the pond.

A pumping strategy has been taken that minimises the loss of these barriers in the system. Recently the aeration piping has been modified to a subsurface jet aeration system. In the future they may look at increasing the aeration in the basin, perhaps even to the level of supersaturation.

Recently divers have discovered that the 1 metre of backfill on the bottom of the pond has been displaced by the aeration jets and that the liner is exposed in a number of areas. Visibility is zero for the divers and they have to feel their way around the bottom of the pond so no inspection of the exposed liner has been possible.

Around the bio-basin are a number of monitoring wells to detect any leakage. None of the monitoring wells have shown any evidence of leakage from the bio-basin in the past ten years.

3.2 Pond Visual Inspection

On September the 24th, 1997 a visual inspection of the perimeter of the pond was carried out. Prior to our arrival the liner had been washed down with water to enhance visual inspection. Approximately 10 m of exposed liner was visible on all slopes. A number of problem areas were discovered and some repairs were made to immediate problems.

In 1990, after an accident, a safety net was added to the entire perimeter of the pond at the water level. The safety net was anchored to the top the slope with metal

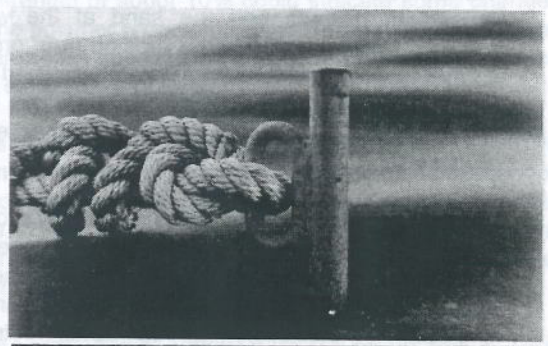

Figure 2 Stake through liner.

stakes. In a number of cases the stakes penetrate the liner (above the water level). It appeared that a round hole had been cut in the liner prior to placing the stake. A few stakes were placing stresses on the liner, however most stakes did not appear to be causing any problems.

The most important problem occurred in the south slope. A modification to the electrical system in the aeration structures created an opening in the liner at the rear of each building. Water run-off from the roadway on top of the berm was flowing towards the bio-basin and eroding an area under the liner beside the aeration structures. There were a number of problems related to this erosion. On three aeration structures the erosion of the subgrade had caused settlement of the liner around the structure causing corner tears in the liner. These tears were immediately repaired prior to returning the bio-basin to service.

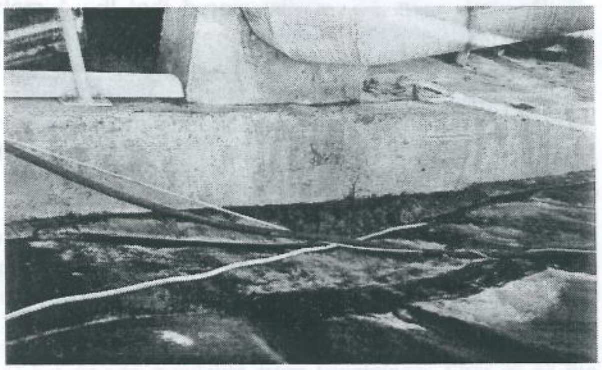

Figure 3 Erosion under the liner.

There were four areas where erosion to the subgrade on the slope was evident. An area of liner appeared "loose," with an area underneath that location (at the water line) where there was a bulge in the subgrade. It appeared that the water seeping in from the road had washed the sand subgrade off the slope and that it had been deposited at the water level as the sand could not flow freely below this point. Although underneath the "loose" area of liner there appeared to be less cushioning sand, the bulk of the subgrade sand appeared to have been deposited at the operating water line. The eroded areas did not appear to be in immediate distress and the sand at the water line seemed to be preventing the erosion from progressing further down the slope. The erosion that had occurred did not appear to be endangering the liner, however, steps should be taken to prevent further erosion in these areas.

In order to correct the problems caused by erosion from the roadway along the south pond slope Layfield Plastics recommends that the road be graded to slope water away from the pond. We also recommend that the openings in liner behind each aeration structure be filled in a way that moves water away from these openings. The restricted access where these openings are located prevents a liner repair in this area. Correcting the drainage would present the easiest solution to the problem.

There were a number of areas of damage to the liner, all of which appeared to have a clear cause. The primary cause appeared to be mechanical damage from hoses or pipes being dragged or dropped on the liner. On the west slope a series of holes corresponded to the location where the vacuum trucks would dump into the pond. A clever arrangement of a permanent rigid pipe for the vacuum trucks to drain their hoses was built by the mill and removed the source of damage. Two other damage areas at the north east, and south east corner appeared to be caused by an item being dropped on the liner (likely a hose again). All of these areas of damage were above the operating water line but were repaired immediately.

The last area of damage was rather unusual. An animal hole was discovered on the southwest corner of the pond at the point where the liner entered the anchor trench. The liner formed a small "hood" about 150 mm wide, which was not buried in the anchor trench. This small area not in the anchor trench appeared to be caused by a section of the liner having been removed for testing. The resulting small opening was exploited by some small animal, perhaps a fox. Interestingly there was no evidence at the entrance or anywhere near the opening of the liner having been gnawed, or damaged in any way. The existing hole had been used as an entry point under the liner. This animal hole did not appear to endanger the liner in any way but should be removed as part of regular maintenance.

Figure 4 Run-off entry point that led to erosion.

3.3 Sample Removal

As part of the inspection of the liner system samples were removed for laboratory testing. Since the water level was below the operating level for the first time since commissioning, there was a unique opportunity to remove a sample from below the water level. This sample would have had 9 years of continuous exposure to pulp mill effluent. A matching sample taken from the exposed liner above the operating water level would give us an indication of the liner after 10 years of UV exposure The exposed liner sample was taken from the north side of the pond, from a 3H:1V southfacing slope from an area that would have been fully exposed (not subjected to cover by foam from the pond).

We were concerned that welding a patch to the existing liner could present a problem. The concern was that the new patch material may not weld the same as the 10 year old material. As a precaution, the exposed material sample was removed from well above the operating water level. A full set of qualification welds were performed on this sample including peel and shear testing to determine bond strength and quality. Only after the exposed sample was welded successfully and all testing completed was a sample removed from below the operating water level.

Each sample was approximately 1 metre square with a field seam on one edge of the sample. This was to enable testing of both parent material and seam. The samples were removed from seam number 19 which joined panel number 103 to panel number 106. The upper sample (UV exposed, identified as Sample 1) contained seam 19 and a portion of panel 103, the lower sample (Immersed, identified as Sample 2) contained seam 19 and a portion of panel 106.

With the samples removed the subgrade was inspected under the liner. The sand cushion was still in place on top of the cobbles that were used for berm construction. Even at the operating water level, where wave action was expected to cause the sand to settle, the sand cushion was in place. This observation was reinforced by our visual inspection of the liner where we could "feel" the soft sand cushion in place under the liner as we walked the perimeter. Only in the eroded areas (mentioned previously) did we encounter an area where sand did not appear to be in place under the liner.

3.4 Sample Testing

The samples were cut into two pieces and sent to two different laboratories for testing. Physical tests on the parent material and seams were performed by the Alberta Research Council (ARC) in Edmonton where the QC testing for the original installation had been performed. Advanced polymer testing was performed by the Chevron Chemical Company in Orange, Texas (Chevron) who was the resin manufacturer.

The results of the physical testing are shown on Table 1. There were two historical sets of test results available for comparison to parent material strengths on this project. These were the mill test certificates and the results of the QC testing program. The closest mill certificates to the samples removed were from panel 103. Missing entries in the numbering of the QC test samples did not permit panel identification so the overall average of the QC tests was used (based on 15 material samples).

Seam test results could be identified by the day tests were performed but not by seam number. Seam number 19 was performed on September 18th, 1987. It was one of 5 seams produced that day. There were two sets of qualification welds tested that day and the average of these results is presented in the table. The QC tests performed in 1987 were actually sent to the same lab at ARC as the physical test samples from this case history.

The advanced polymer testing was performed by Chevron Chemical Technology Center in Orange Texas. This testing included Density, Melt Index (MI), High Load Melt Index (HLMI), Thermal Stability Temperature, Oxidative Induction Time (OIT), Notched Tensile Constant Load Stress Cracking test (NTCL), and a Gel Permeation Chromatography (GPC) investigation of the Molecular Weight Distribution. Chevron was able to compare the samples from the pond to the original resin specifications taken from their records. The results are shown in Table 2.

3.5 Testing Results

The physical test results compared very well to the original material values. Both the UV exposed, and the Immersed sample met most of the original project specifications. Only the yield strain on the UV exposed sample was less than project specifications. Strength values appeared to be decreasing slightly in breaking strength. The reduction in breaking strength was between 7 and 15% (compared to the QC test results from 1987).

The only property not meeting the original project specifications was the yield strain of the UV exposed sample. The yield strains of 9.8 and 9.6 are slightly lower than the required 10% strain of the specification. The QC tests from 1987 showed the elongation of the material to be 10.7 to 10.8% while the mill certificates showed values as high as 15%. This is likely due to variations in testing technique. Current elongations in HDPE materials vary depending on the test method used. The best comparison in this case is between the same laboratory from 1987 to 1997. The reduction in yield strain from 10.8% to 9.8% along with a reduction of strength of about 10% could indicate some changes in the polymer properties. All values were, however well over project specifications, except the yield strain of the UV exposed sample.

The physical property testing showed that the HDPE lining material met most of the project specifications in place at the beginning of the project after ten years of use. The advanced testing by the material manufacturer was intended to determine if any polymer damage had occurred.

The Chevron was able to track the lot number of resin from the project mill certificates. Historical data existed for Density, Melt Index (MI) and High Load Melt Index (HLMI). Information on the resin additives package was available for that lot number. A new sample was created from current resin, blended according to the 1987 recipe, for comparison testing with the case history samples. The first tests, Density, Melt Index, and High Load Melt Index showed that there had been no change in material properties in 10 years. Thermal Stability Temperature also showed no change. The Oxidative Induction Time (OIT) test showed that the primary antioxidant in the polymer was now mostly consumed after 10 years of use. A Notched Constant Tensile Load Stress Cracking test (a test not available at the time of the installation) showed the immersed sample passing a 422 hour test, while the UV exposed sample was still intact after 1080 hours. A Gel Permeation Chromatography (GPC) test was done to determine the molecular weight distribution of the samples. The molecular weight of the case history samples was compared to the molecular weight of a modern resin of the same grade.

TABLE 1 Material Physical Properties

	Project Spec	Mill Certs Panel 103	QC tests A	Sample 1 UV Exposed	Sample 2 Immersed
Parent Material Tests					
MD Yield Stress mPa	13.8	17.91	20.2	20.7	19.2
Strain %	10	15	10.8	9.8	11
Break Stress mPa	20.7	33.25	33.2	30.8	28.3
Strain %	500	852	820	777	759
TD Yield Stress mPa	13.8	18.2	20.8	20.6	19.6
Strain %	10	14.8	10.7	9.6	10
Break Stress mPa	20.7	33.74	34.1	29.8	30.3
Strain %	500	937	883	828	834
Seam Shear Tests					
TD Yield Stress mPa				20.1	19.6
Strain %				17	16.5
Break Stress mPa	13.8		18.3 B	14.9	15.2
Strain %			401	326	366
Seam Peel Tests					
TD Yield Stress N/mm	13.7		21.0 B	21.9	23.3
Strain %				26.5	25.5

A. Average of all QC tests on material, 15 samples.
B. Average for qualification welds on Sept 18th, 1987.

TABLE 2 Advanced Polymer Testing

	Unit	HiD9642 Base Material	Sample 1 UV Exposed	Sample 2 Immersed
Density	gm/cc		0.953	0.952
Melt Index A	gm/10 min	0.13	0.13	0.13
High Load Melt index A	gm/10 min	14	14	14
Thermal Stability Temperature B	Degrees C	245	245	250
Oxidative Induction Time B	Min	12.2	6.4	7.4
Antioxidant Change	%		-48%	-40%
Primary Antioxidant Change	%		-95%	-90%
Stress Crack Resistance by NTCL B	Hours	> 780	> 1080	422

A. Compared to historical records.
B. Compared to modern resin compounded according to historical formula.

3.6 Discussion of Test Results

The advanced testing showed that, with the exception of the Oxidative Induction Time (OIT) test, very little had changed in the makeup of the polymer. In each test, it was apparent that no significant polymer changes were detectable after ten years of service. The only significant change was the reduction of the primary antioxidant additive, as measured by the OIT test.

The Oxidative Induction Temperature test is a method for measuring the primary antioxidant in a Polyolefin polymer. Antioxidants are added to the polymer to protect it from the high heat of extrusion and welding and to prevent cross linking and chain scission due to thermal and UV breakdown in service. As long as the antioxidant remains in place in the polymer the strength of the polymer should remain mostly unchanged. Once the primary antioxidant is consumed the effects of UV, oxygen, and thermal stresses may begin to degrade the polymer.

In the case of the Millar Western bio-basin liner an OIT of 12.2 minutes was standard at the time of manufacture. This standard has been raised since 1987 with a 100 minute OIT now being. Consumption of antioxidant takes place "exponentially with incubation time at all incubation temperatures" (Hsuan, Guan, 1998). Therefore it takes longer to consume the last fraction of antioxidant than the first.

Recent tests have found that an unstabilised polymer has a standard OIT of 0.5 minutes (Hsuan, 1998). The OIT values of our tested samples were 6.4 and 7.4 minutes (the UV exposed sample having the lower OIT value). This represents a 95 and 90 percent reduction in antioxidant (respectively) from the original formulation. We begin to see that the last 5% of the antioxidant remaining is responsible for over half of the OIT results. Our samples are still well above the 0.5 minute OIT value of an unprotected polymer.

Once the primary antioxidant in the polymer is depleted, chain scission and cross-linking can occur. Chain scission reduces the molecular weight of the polymer and increases the Melt Index results and strength properties for the sample. Cross-linking has an opposite effect. Only after the primary antioxidant is consumed does significant physical changes occur to the polymer.

Knowing that the primary antioxidant is close to being depleted our next clues as to the remaining longevity of the liner are the physical properties. In all of the physical properties measured the changes, if any, were small. This indicates that the antioxidant is still performing its job. Two specific tests give us reason to believe that the liner is still in excellent condition.

The Notched Tensile Constant Load Tensile Stress Cracking Test (NTCL) is a very sensitive test of the surface properties of the polymer. Since HDPE is a surface-active polymer, changes in the polymer are more readily detected by changes in surface properties. Environmental Stress Cracking is the most sensitive surface property of HDPE. The NTCL test results for the samples removed showed excellent results. The Immersed sample turned in a time of 422 hours, while the UV exposed samples had not failed after 1080 hours. Current standards for NTCL testing are 200 hours and both samples easily meet these requirements. The Immersed sample has been effected the most by surface chemical action due to the action of the wastewater on the liner. A significant change in material strength caused by chemical attack, or depletion of antioxidant would immediately show up in the NTCL test. Although there is some difference between the UV exposed sample and the Immersed sample, these are likely caused by absorption of trace organics in the wastewater. The robust test result of 422 hours for the Immersed sample indicates that little change in physical properties has occurred.

The final indication that the liner is in excellent condition is the result of the GPC testing performed by Chevron. The GPC tests determine the molecular weight distribution of the polymer and accurately shows any changes in polymer structure. The two case history samples were compared to a sample of modern resin that was compounded to match the historical formula for the resin used in the pond.

Every lot number of resin has a slightly different molecular weight distribution curve. What is significant about the GPC testing is that both the Immersed sample and the UV exposed sample followed exactly the same curve. If significant polymer damage had occurred then the two samples, exposed to different environments, should develop a different pattern of damage. In the GPC results there is no damage evident to the polymer.

4. RECOMMENDATIONS

The Millar Western Whitecourt Pulp Mill pond liner has provided good service for ten years, and with care and maintenance should last many more years. The following items are recommendations to ensure the maximum life of the lining system.

4.1 Maintenance and Repairs to Liner

The damage to the liner that was discovered during the inspection has been repaired. It is important that an exposed liner system be inspected on a regular basis to detect and problems and repair them. In the spring of 1998 additional damage was found to the liner that appeared to be caused by ice accumulations falling from overhanging structures. This damage has also been repaired. An annual inspection by the operators should be a minimum requirement and repairs taken as needed. The animal burrow in the southwest corner should be dealt with as part of this maintenance program.

The holes from the stakes supporting the safety net are well above the water line and should not create any problems. Monitor the liner material around these holes for any signs if cracking. If cracking occurs seek repairs immediately. Plastic deformation around the holes as a result of thermal movement of the liner should be relieved by enlarging the hole. The idea is to prevent the creation of a stress concentration point that could initiate stress cracking.

4.2 Change Drainage on South Slope

In order to prevent further erosion along the south slope the drainage pattern of the south berm needs to be changed to drain away from the pond. Regrade the roadway on the berm top and place a curb, small berm, or other impediment to water drainage to prevent water flow into the pond. Monitor the existing erosion under the liner by regular inspection (annual) and repair if the conditions worsen.

4.4 Expected Service Life

The expected service life of the lining system is dependent on a number of factors. Regular inspection and maintenance is a prerequisite for any long-lived lining system. The Millar Western Pulp bio-basin lining system has performed for the first ten years with no significant loss in mechanical properties. The remaining longevity of the liner will be dependent on the consumption of the remaining antioxidant-oxidant, and the speed at which the physical properties of the liner change after the antioxidant is consumed.

There are three stages of HDPE geomembrane ageing. The first is antioxidant depletion, the second is induction time to the onset of polymer degradation, and the third is the time to reach 50% degradation of a particular property. For antioxidant depletion to take place at 25C, it could take between 40 and 120 years. The total antioxidant depletion is only the first step in the geomembrane lifetime. After antioxidant depletion, the mechanical properties of the HDPE geomembrane still remain essentially unchanged until the onset of polymer degradation (Hsuan, 1995).

How long will the bio-basin liner last? An accurate estimate can be made by looking at HDPE longevity in other applications, such as wire and cable. In these applications, using much the same formulations as the HDPE liner in the bio-basin, 30-year useful lifetime is estimated. Local site conditions can modify these predictions, however a 30-year life is typical. The remaining antioxidant in the liner may take five to ten years to be completely consumed based on the experience of the resin manufacturer. Only by monitoring the antioxidant can a prediction be made as to the eventual longevity of the liner.

The HDPE pond liner in the bio-basin is approaching the end of the first stage of the polymer degradation cycle. A regular monitoring program should be implemented that will monitor the remaining antioxidant levels and the onset of stage two and three. A testing program that will measure OIT and physical strengths of the HDPE material at regular intervals will help the operators predict the useful life of the system. An OIT (ASTM D3985) and Stress at Break (ASTM D638) test should be performed at an interval of every two to five years. This will confirm the expected life of the lining system and allow the operators to co-ordinate liner replacement with other major plant upgrading activities.

Sampling for OIT testing should take place from the same panel as this case history; from UV exposed material. Panel 103 is easily accessed on the north slope of the pond and the sampling point is well above the water line. Sample removal and repair can be incorporated into a regular maintenance program without affecting the service of the pond. Local testing facilities at ARC can perform both OIT and tensile testing.

5. CONCLUSIONS

The HDPE lining system in the Millar Western Pulp bio-basin was inspected at the end of the first ten years of operation. During this time significant changes were made in operation of the bio-basin. The HDPE lining material showed few changes in material properties as it is still in the first stage of the polymer degradation process. Consumption of the primary antioxidant is an exponential process and monitoring of this property over the next ten years will permit the operators to make accurate longevity predictions. Problems with the liner revealed by the inspection were not of a serious nature and regular maintenance and inspection should keep the liner in operating condition.

At the end of ten years of service the Millar Western Pulp bio-basin liner is performing well and with care should provide good service for many years to come.

REFERENCES

Neilsen G. and Lyka W. 1996 The Use of Extended Aeration Activated Sludge to Treat Alkaline Peroxide Pulp (APP) Effluent. Unpublished

Ransom R.R. 1987 Final Report - Quality Monitoring Program Millar Western Pulp Mill Aeration Pond. CQA Report.

Hsuan G. 1995. Long term Durability of HDPE Geomembranes, Part I - Depletion of Antioxidants. GRI Report #16.

Hsuan G. and Guan Z. 1998. Antioxidant Depletion During Thermal Oxidation of High Density Polyethylene Geomembranes. 6th International Conference on Geosynthetics.