A COLLECTION OF GEOSYNTHETIC CHALLENGES

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ABSTRACT

Lining and cover are primary applications of geosynthetics in mining, landfill, wastewater management, and irrigation works. This paper demonstrates the use of various type of geosynthetics in lining and cover system. The strength, the weakness, and the caution are clearly discussed through example from many field trails and construction projects. This paper provides not only a technical detail but also an insight efficiency and cost comparison as a decision tool for many projects.

Keywords: Lining system, cover, geomembrane, efficiency/cost ratio

MINING

Mining has many applications for geosynthetics, especially geomembranes which are used for water and waste management as well as special applications many of which involve aggressive

Chemicals and Temperature

Hornsey, Scheirs and Gates put forward an excellent summary and performance analysis of the rigours imposed by various mining extraction processes. Sometimes these involve ponds with aggressive chemicals at elevated temperatures.

Whether the mineral extraction process uses leaching or other more mechanised and industrial processes there is always a need for storage of process liquors. These are often open ponds and the process liquor is often based on acids or other aggressive chemicals at elevated temperatures. These ponds have names such as PLS (pregnant liquor solution), raffinate and barren ponds.

One of the common difficulties with these ponds is pipes that discharge hot liquor directly onto a liner. Sometimes an additional protective layer is used and in other cases these incoming pipes are HDPE and they are floated on the liquor so that they discharge in the centre of the pond.

Hornsey, Scheirs and Gates identify a number of special polymers or formulations for geosynthetics that are better able to cope with these aggressive chemical exposures. Mining houses need to evaluate these special materials for both performance and cost because there is always the option of using more conventional geosynthetics with an acceptance that a shorter service life will need programming for a planned replacement.

Fig. 1 A PLS pond at a smaller mine

Fig. 2 A floating cover for a copper mine PLS pond being installed over two 900 mm diameter inlet HDPE pipes

The Environment

Mining operations are inevitably in locations where there are many different types of minerals exposed at the surface and in the general environment. Often these minerals are different to the ones being targeted by the mining operation.

At a copper mine in a desert environment (aren't they all) we observed unusually rapid deterioration of a HDPE liner in an acid solution storage pond. There were no particularly extreme conditions involved and yet the deterioration was unusually rapid with significant roughening apparent on the liner surface.

Samples were taken from the liner at various locations and were tested for Oxidation Induction Time (OIT) using the original OIT values from the MQC records as a basis for comparison. The results can be summarised as follows:

- Anchor trench (effectively unexposed) 98% retained
- Floor of pond (full exposure to solution) 60% retained
- Slope of pond (midway – below liquid level) 50% retained
- Crest of pond (above liquid level) less than 20% retained

Further examination indicated that the dust and grime on the crest sample liner surface contained manganese and ferric ions (as well as the targeted copper) and it also had a residual of low level gamma radiation. It was suspected but never proven that this combination of metallic ions and the low level radiation was leading to accelerated oxidation of the HDPE.

Fig. 3 An unusual inlet pipe and distribution arrangement

The Engineering

As well as aggressive chemicals with elevated temperatures there can be some unusual hydraulic or mechanical arrangements in the mining industry.

One of these is the rotational Counter Current Decantation (CCD) thickeners which for nickel extraction can often expose a liner to hot sulphuric acid based slurries with aggressive mechanical stirring of the slurries by raking devices.

Tailings

Mining operations and processing often result in waste streams that contain both solid and liquid components that are often handled as a sludge or slurry and placed in essentially impermeable containment facilities. The solid component often has some residual value that might lead to reprocessing in the future. This residual value, along with environmental concerns, will often lead to a choice of a geomembrane liner for the tailings storage facility.

Once the tailings are placed in storage the solid component tends to settle out leaving a decant liquid which is often allowed to evaporate or is pumped off and treated as required to allow its reuse or discharge to a stream.

Since tailings ponds tend to take a long time to fill the geomembrane liners used in tailings facilities face some very harsh conditions which include:

- Prolonged UV exposure
- Exposure to strong winds without the benefit of solids or water in the pond to provide ballast.
- Exposure to chemical and other elements in the waste stream or in the natural environment
- Exposure to long term thermal expansion and contraction that can result in 'thermal creep' with thinning of the membrane at the crest.
- Exposure to drag on the liner as the tailings dry and shrink

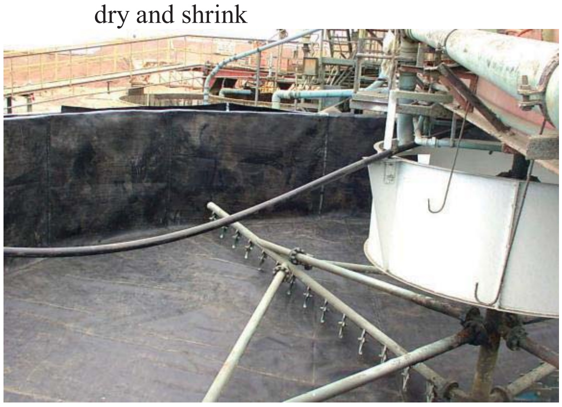

Fig. 4 A relatively small thickener with rotating arms and racks to draw the slurry towards the central outlet. This one is about 10 m in diameter.

Fig. 5 A large (70 m diameter) CCD thickener with a primary liner being installed over a geocomposite. The rake clearance is less than 200 mm to be effective.

Fig. 6 A tailings dam with ballasted geomembrane on the dam face

Fig. 7 A large tailings storage with various earthen structures on top of the liner. These structures can be for access or for ballasting of the liner against wind uplift and storm damage.

Fig. 8 A tailings pond with the tailings drying at the perimeter more than the centre which leaves the tailings tending to slide down the face of the liner imposing significant downdrag stresses.

WATER

Leakage Does Happen

Leakage does occur with most liners and we do have a good body of guidance for design and operations for waste applications where the hydraulic heads are in the order of 300-500 mm. Because the imposed hydraulic heads are much greater in water and waste water facilities we need to be cognisant of the potential for much higher leakage rates.

Fluet posed some questions about leakage rates in a paper titled “Impermeable liner systems: Myth or Reality” and proposed some formulas and criteria based on the earlier work by Giroud and others. Subsequently Sadlier, Frobel and Cowland looked at theoretical leakage rates for a variety of defects and partially welded systems under heads of 1000 mm.

Finlay and Sadlier in 2006 reported on a 220,000 m^3 water supply reservoir at Tamworth Hill in Western Australia.

Fig. 9 Tamworth Hill reservoir with 200 columns in the floor

The Tamworth Hill reservoir is 10 m deep and has some 200 columns on concrete stubs to support a steel deck roof. Leakage had caused subsidence and damage to the concrete liner which was reconstructed before installation of a LLDPE double liner system with a zoned leak collection system.

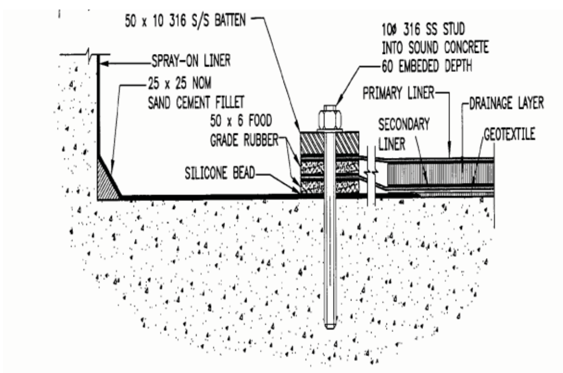

Fig. 10 Batten system used at each column

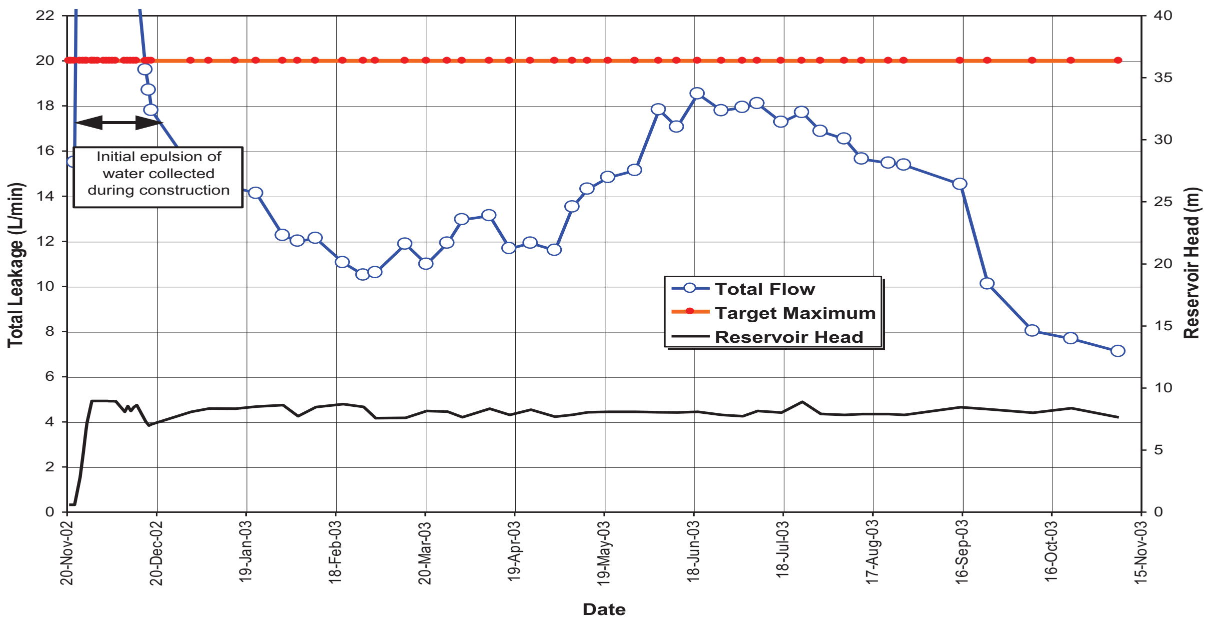

Fig. 11 Typical Leakage Results from Commissioning in December 2002 to October 2003

Each of the stub columns was treated with a spray applied polyurethane membrane and the double LLDPE liner system was connected to the polyurethane by a batten and compressible rubber connection. Various air and water pressure tests were conducted with this batten system to establish that a good seal could be achieved but it was recognised that this connection was a point of potential weakness.

Leakage via the collection system was monitored and yielded the curve set out below. There are a number of points to be noted.

(i) The initial rate of water collection/expulsion was quite high and exceeded the acceptable level. This was attributed largely to water which had accumulated during construction although the contractor did have divers enter the reservoir and apply sealants around a number of columns that were considered suspect.

(ii) The reduction of the leakage rates in early 2003 was attributed partly to the contractor's efforts but also partly to the effects of accumulated sludge causing some clogging of the leaks. This water supply uses an alum based purification process which generates some residual sludge after flocculation.

(iii) The increase in leakage rates in mid 2003 is attributed to the effects of using divers using suction equipment to remove sludge.

It can be seen that sludges from dust and other sources are able to effectively reduce leakage rates but usually only if the flow is effectively in one direction.

Embedded Liner Systems

These are systems that use mainly thick HDPE liners with studs or lugs on one side such that they can be cast into the face of concrete surfaces or grouted onto a floor. These systems can still have leaks and accommodation needs to be made for these leaks.

Whilst these liner systems are often used in the mining sector they are also often used in concrete tanks used to store water from reverse osmosis or microfiltration systems. This water often has very little mineral content and the water can aggressively attack concrete for its mineral content.

On a project with quite tall tanks and constant water level movement the liner had been cast into the concrete by one contractor and another contractor had the job of welding it all together. The cast in liner had been left some 50-100 mm short of the actual corners and the second contractor was having to weld cover strips of smooth liner over the corners.

Fig. 12 Corner cover strips subjected to external water pressure when tank is empty

With very small rates of leakage there was an accumulation of water in the void between the liner and the concrete and when the tanks were empty the external water pressure caused the coving strips to ‘pop’ inwards and fail some of the welds in shear.

This situation was avoidable with proper detail design and repairs were eventually effected by using more embedment liner grouted across the corners.

On another project embedment liner was used on the internal floor and walls of a large circular tank. The tank was designed with in internal peripheral collection drain and a fall from the domed centre of the floor to the perimeter. When the tank was filled the air in the void between the liner and concrete was forced to the centre which lead to the liner lifting from the floor grout.

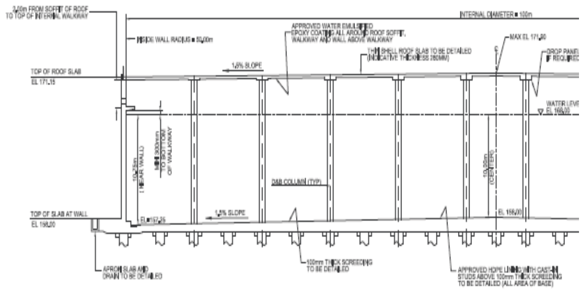

Fig. 13 Part section of tank with perimeter drain and domed floor

Fig. 14 Separation of liner from base as a result of air bubble at domed centre.

WATER CHANNELS

In many arid parts of the world agricultural activity relies on the transmission and distribution of water via open channel systems. Some of these channels are concrete lined and others depend on soil based liners or even natural compacted soil. Loss of water by seepage from these channels is a major concern, not only for the loss of a valuable water resource, but for the damage that leakage can cause as a result of rising levels of soil salinity.

Beginning in 2001 and carrying on until 2003 the Australian National Committee on Irrigation and Drainage (ANCID) sponsored field trial applications of numerous different types of geomembrane and other liners in open earthen channels in the Murray - Darling Basin area of South East Australia. This area presents hot and arid conditions with high UV radiation levels. The channels are unprotected so a successful liner must stand up to these conditions as well as the vagaries of wildlife and normal agricultural activity. They were generally installed in 200 m long trial sections of operating channel and were evaluated during installation for cost and installation ease.

Their performance was evaluated on the basis of initial channel ponding tests before the liner was installed and subsequent ponding tests to assess liner performance.

In evaluating what materials were to be trialed consideration was given to previous experiences including the work by the US Bureau of Reclamation at Deschutes Canal, the concrete channels guidance provided by the Department of Natural Resources in Queensland and the current array of established and new geomembrane and other liner materials.

The materials used were the well known HDPE in different thickness, polypropylene (PP) in different thickness and reinforced and unreinforced forms, a Geosynthetic Clay Liner (GCL) and other more unusual materials which are described.

Field Trials

The field trials were carried out at various channel sites operated by Goulburn Murray Irrigation Ltd, Murray Irrigation Ltd, Murrumbidgee Irrigation Ltd and Wimmera Mallee Water.

The materials were supplied and installed on what was essentially a commercial basis, although irrigation authority technical staff often acted as unskilled assistants in order to gain some appreciation of the installation requirements.

The channels were generally 6 to 10 m wide and 2 m deep. The installation plots were nominally 200 m long in order to provide a fairly representative indication of cost and performance. As far as possible sections without bends were chosen for simplicity.

The unlined channels were typically rough and unevenly shaped with ponded water, animal tracks and burrows and occasional tree roots. They were prepared for liner installation by removal of standing water, minimal reshaping and tree root removal by an excavator and excavation of anchor trenches as required.

The liners were field seamed and QC tested in accord with normal practice using thermal welding for the thermoplastic materials.

Fig. 15 Typical Unlined Channel

HDPE 0.75 mm with soil cover

This section of channel was approximately 20 m wide and 1200 m long and this was a much larger trial than the other installations. The liner was fully welded and QC tested as per normal practice. The soil cover was material previously overexcavated from the channel bed and stockpiled to each side. It was placed and spread by backblading with excavators.

Fig. 16 Soil Cover Installation over 0.75 mm HDPE

Geosynthetic Clay Liner (GCL) with soil cover

The GCL liner was installed at Tooloondo channel in 2002. Preparation for the GCL also required overexcavation to provide the final soil cover which was again placed and spread by excavators. It is to be noted that the soil cover must be placed before the GCL becomes wet as unconfined or premature hydration can permanently damage the GCL. The GCL seams are overlaps with supplementary bentonite.

Butyl rubber

It was intended to install a 2 mm Butyl Rubber liner at the Lakeview channel near Griffith but it was passed over in favour of the EPDM which appeared to provided better performance at reduced cost. Commercial quotations were obtained and these are included in the cost comparison.

Fig. 17 GCL Installation

EPDM rubber

Ethylene propylene diene monomer is a synthetic rubber material and arrangements were made to install 1.0 mm EPDM in prefabricated panels into the Lakeview channel near Griffith in 2001 but the installation did not proceed because of an earlier than usual requirement to use the channel for irrigation.

The prefabricated and folded panels were placed in covered storage for a year and the material was found to have bonded to itself ('blocked') such that it could not be used. The commercial costs are included in the cost comparison.

Reinforced PP 1.14 mm

The major advantages expected of reinforced PP are in the form of better thermal stability and hence less thermal expansion/contraction and the potential for better resistance to puncturing by hoofed animals. It was installed at the Finley Main Channel in 2001.

Fig. 18 Reinforced PP 1.1 mm

Fig. 19 Unreinforced PP 0.75 mm
(Note large crew size)

Unreinforced PP 0.75 mm

The major feature of 0.75 mm PP is that is able to be prefabricated into large panels such that the trial installation was entirely prefabricated. This does require good advance information on the channel size and profile. It was installed at the Finley Main Channel in 2001.

Unreinforced PP 1.0 mm

The unreinforced PP used in this trial was manufactured in 7 m wide rolls which made prefabrication less useful. It was installed at Dahwilly near Deneliquin in 2002.

Rubberised bitumen emulsion

The product used was a rubberized bitumen emulsion in a water based carrier. It was applied cold in multiple coatings over a geotextile carrier. Some UV deterioration is expected and a periodic overcoat is recommended for exposed portions every 2-3 years.

Fig. 20 Rubberised bitumen emulsion

HDPE 1.5 mm

HDPE 1.5 mm is the most common grade of HDPE and this was installed in the normal way with cross seams. One of the hazards for these installations is the local wildlife and this was well illustrated by the discovery of a dead kangaroo one morning when the installation was almost complete. The surface is extremely slippery and the animals cannot get out.

HDPE 2.0 mm

The HDPE 2.0 mm was installed at the Finley Channel in 2003 and a post installation pondage test is yet to be undertaken.

PE Co-extruded composite

The PE composite was based on co-extruded blends of LLDPE and the upper layer was a tan layer with additional UV stabilization. It is said to provide better puncture resistance and better control of thermal expansion than a black material.

Fig. 21 HDPE 1.5 mm (note dead kangaroo)

Field Trial Preliminary Results

The Field trial preliminary results are set out in Table 1.

Table 1 Field trial preliminary results

Material	Installed Cost A$/sqm	Seepage Rate L/m2/day	Apparent Efficiency %	Efficiency/ Cost Ratio
HDPE 0.75 mm with soil cover	$7.10	3.8	90%	1.268
GCL with soil cover	$11.91	11.1	87%	0.730
Butyl Rubber	$21.10	na	85%	0.403
EPDM Rubber	$20.14	na	85%	0.422
Reinforced PP 1.14 mm	$16.92	na	85%	0.502
Unreinforced PP 0.75 mm	$11.93	2	71%	0.595
Unreinforced PP 1.0 mm	$15.37	0.5	94%	0.612
Rubberised Bitumen Emulsion	$10.33	1.6	63%	0.610
HDPE 1.5 mm	$13.70	1.1	77%	0.562
HDPE 2.0 mm	$12.20	na	85%	0.697
PE Co-extrusion 1.5 mm	$16.54	0.5	94%	0.568

There are a number of points to be noted about these results:

(i) The apparent efficiency is the ratio of the leakage rate after installation to the leakage rate before installation.
(ii) Where a pondage test has not yet been conducted an apparent efficiency of 85% has been used in the comparison
(iii) There is some doubt about the efficiency of the end seals used in the HDPE 1.5 mm pondage test since a close inspection found no apparent defects.
(iv) There is obviously some variability in the cost data as the HDPE 2.0 mm would be expected to cost more than the HDPE 1.5 mm.
(v) The additional size of the HDPE 0.75 mm trial (24,000 sqm rather than 3000 sqm) means that the HDPE 0.75 mm enjoys a cost advantage of 30 to 50% in this comparison.

Observations

Since much of the ultimate interest is in longer term performance in the face of wildlife and other interventions it is too early to draw any conclusions and we really need to see results of second and third round pondage tests to see a pattern. It is apparent that protection from animal life is a substantial issue and that soil covered materials (HDPE 0.75 mm and GCL) seem to show a performance benefit from that protection.

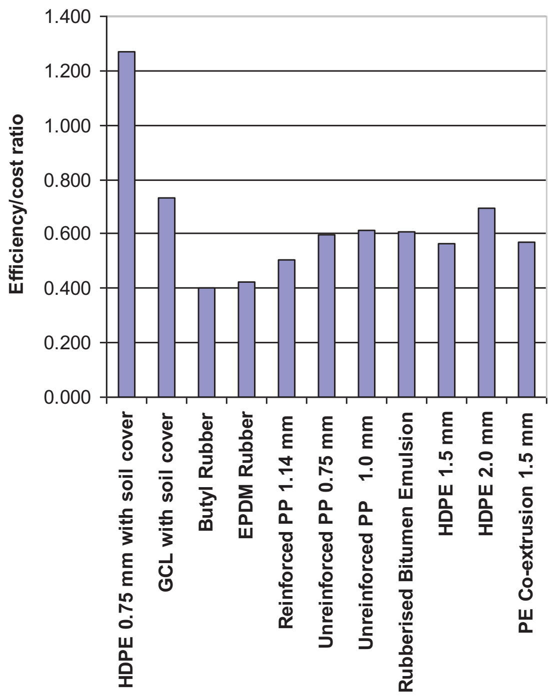

Fig. 22 Apparent efficiency/cost

Reference to the work of Sadlier et al,(2002). which examined potential leakage rates from un-seamed or partially seamed liner systems would indicate that there may be benefit from an examination of unseamed liners with large overlaps and soil cover for these irrigation channel systems. Such systems would be capable of installation without specialist welding skills and could well provide a suitable balance of cost and performance.

WASTEWATER STORAGE AND TREATMENT

Geosynthetics are used in various applications for waste water facilities. The most common use is in lagoons operating with anaerobic and aerobic lagoon processes. Other applications include enhanced evaporation of wastewater and sludge dewatering by permeable geotextile geotubes.

Anaerobic Lagoons With Covers

When wastewater with a reasonably high organic load is kept in a lagoon for several days an active anaerobic sludge accumulates at the bottom of the lagoon. In an uncovered lagoon the anaerobic digestion activity takes place at the base of the lagoon and the activity near the surface tends to be more aerobic. Lagoons left uncovered in this way are said to be facultative.

We can cover these lagoons with a geomembrane floating cover to:

- enhance the anaerobic digestion activity by the exclusion of air (oxygen)
- enable the harvesting of gas (especially methane) which can be used as a fuel
- reduce the effect of odour from the anaerobic activity

This anaerobic process is a very effective way of treating wastewater, especially wastewater with a strong organic content such as animal waster from piggeries or abattoirs or mixed municipal wastes.

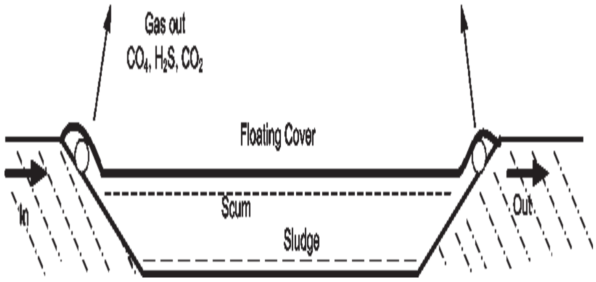

Fig. 23 Anaerobic lagoon with floating cover

Generally these lagoons will take wastewater with BOD of 400 to 5000 g/cum and the output effluent will have the BOD reduced by 90 to 95%. Detention time is normally 4 –7 days.

The progress also produces significant quantities of methane and other gasses which require careful and safe handling but can be very successfully harvested for fuel.

The anaerobic process is largely self propelled and the only mechanical input is that required to feed wastewater to the lagoon and force its ultimate exit at an overflow outlet.

There may be a need for systems to deal with excessive accumulations of sludge (base) and scum (surface under cover) but this will depend on the nature of the wastewater and the dynamics of the system.

Fig. 24 An anaerobic wastewater processing facility with floating cover and gas collection

Aerobic (Aerated) Lagoons

Aerated systems use either surface aerators or diffuser systems to introduce air into the wastewater and this results in consumption of the organic content of the wastewater which is mostly released as carbon dioxide.

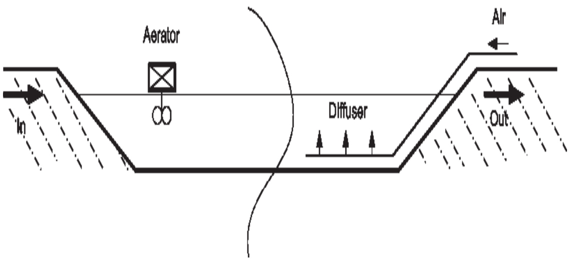

Fig. 25 Aerobic lagoon

Typically these systems take wastewater with BOD in the order of 500 to 1500 g/cum and the output effluent will have the BOD reduced by around 90%. Detention time is normally 4 –7 days.

These aerobic systems require considerable mechanical input to operate the aeration system and further work may be need to remove excess sludge from the base from time to time.

Combined Anaerobic and Aerobic Lagoons

Many wastewater plants make use of anaerobic and aerobic systems as a combined or two part process. This can be readily achieved in one lagoon using a specially designed geomembrane floating cover.

These combined systems have a capacity to take wastewater with BOD of 5000 g/cum and to achieve an output effluent less than 100 g/cum. Total detention times would be in the order of 10 days although some systems use final 'polishing' lagoons or grass filtration and irrigation.

Fig. 26 HDPE lined lagoon with floating surface aerators

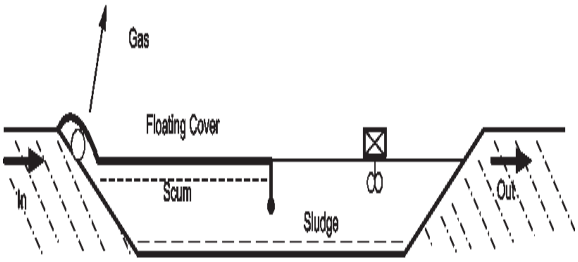

Fig. 27 Combined anaerobic and aerobic system

The combined systems also have the capability for the gas to be used on-site to provide power which can be used for the aeration energy input.

Fig. 28 A combined anaerobic and aerobic system as part of a much larger system

Greenhouse Gas

Under the umbrella of the Kyoto Protocol and the United Nations UNFCC a number of frameworks have developed that allow funding of greenhouse friendly projects under what are known as Clean Development Mechanisms (CDM). These arrangements allow small scale projects for harvesting and use of greenhouse gasses to be implemented in developing Asia with funding being provided as carbon credits under the CDM protocols.

Candidates for these opportunities include high organic waste water producing enterprises such as piggeries and abattoirs, breweries, palm oil, starch and other foodstuff producers.

A typical small pig farm with 900 breeding pigs will produce about 0.5 megalitres of high organic content wastewater per day. In a covered anaerobic lagoon this will produce gas at a rate of about 1000 cum per day with a carbon dioxide equivalent in excess of 3000 tonnes per annum.

The typical capital cost of a suitable covered anaerobic facility would be around $500,000 using existing lagoons and pipelines. The typical return period on investment based on power generation from the gas would be 7-10 years. With carbon credits from the gas emissions and the replaced power generation this return period can be reduced to 3-5 years.

Applications for Geosynthetics

The applications for geosynthetics in these lagoon systems are essentially associated with the liner system and with the floating cover system but there are many variations that may be chosen according to circumstances.

Liner systems

The liner systems may be a Geosynthetic Clay Liner with soil or concrete cover. However the soil or concrete surface is rather rough and in some cases it will be desirable to use a very smooth low friction HDPE upper liner as this can help to move the sludge to locations from which the excess can be removed.

Cover systems

The more durable and stable cover systems are based on polyethylene materials (PE) but cover applications that must accommodate rising and falling water levels can not use HDPE for the whole cover because it is too stiff. HDPE is often used for fixed level covers such as those on many anaerobic reactors.

One option is to construct the whole cover in a flexible reinforced geomembrane such as polypropylene or elvalloy. Another option is to use a hybrid of more flexible PE materials such as mPE-R or LLDPE which are placed in the flex zones of the cover. This hybrid cover gives the stiffness and security of the HDPE cover with the flexible zones where they are required.

Cover designs may also vary with factors such as the intended operation of the cover with respect to effluent levels, gas collection and associated factors, as well as the construction and launching restrictions which may limit the cover design options.

Many floating covers are built in the floor of the empty lagoon and floated into place. Others are built by 'launching' – pulling of the cover from one side of the lagoon and others are built over movable pontoon platforms. Each cover must be designed for the intended method of construction.

Fig. 29 A cover being built over a temporary pontoon platform.

Fig. 30 An inflated gas storage cover over an anaerobic lagoon

Controlling evaporation

A typical black geomembrane with shallow wastewater over it will see the wastewater temperature rise with solar radiation creating an enhanced capacity for evaporation. This is used in wastewater disposal and for salt and mineral extraction processes.

Fig. 31 Hybrid HDPE/mPE-R Covers. Note hinges same colour as main plates.

A variation of this process can be used in regions with seasonal rainfall and a pronounced dry season. A floating cover over the wastewater will prevent growth of waste volume in the wet season as well as enabling fresh water to be gathered from the cover. In the dry season wastewater can be pumped onto the cover for enhanced evaporation. This will require some management of cover residues at change of seasonal operations.

For more permanent water storage facilities there is a need to address several concerns:

- potential contamination of the stored water by wind blown contaminants or by animals
- For potable water degradation of chlorine disinfectant in the water when it is exposed to sunlight.
- Need to control loss by evaporation of valuable treated water. In arid areas evaporation losses can be 1-2 m per year

For these reasons covers are often placed over water storage basins. These covers may be fixed structural roofs or they may be floating membrane covers systems. Fixed roofs present concerns over the integrity of liner systems at supports whilst floating membrane covers do not need support and are significantly more cost effective.

Fig. 32 A floating membrane cover to a water storage facility

Fig. 33 Geomembrane bladder for water or gas Storage

A further possibility is the use of geomembrane materials to fabricate water storages that might be described as bladders which provide full enclosure of the stored water. These can be prefabricated and packaged for transportation to the intended location where it is merely a matter of limited site preparation and connection of inlet and outlet pipes

THE ECONOMICS OF COVERS FOR EVAPORATION CONTROL

Many projects, especially for mining and resource processing, are being developed in areas where water is scarce and there are high rates of evaporation and often quite low rainfall. Under these circumstances there is a great incentive to provide floating geomembrane covers over water storages and process ponds in order to control valuable water loss by evaporation.

This section will examine the economic costs and benefits of such a solution. It will use a typical but hypothetical project as the basis for an economic study. Although hypothetical this project will include many of the circumstances and parameters that apply to projects in the real world. Factors to be considered will include:

- Water storage requirements without a cover (with additional allowance for evaporation loss) compared to storage requirements with a cover.
- Reservoir construction costs for reservoir with and without a cover.
- Pipeline and headworks (e.g. pumping) construction costs with and without a cover.
- Operation costs with and without a cover.

Project and Parameters

These parameters are hypothetical but typical of those that are often found in the real world.

Consider a typical desert environment common to many projects in North and South America, Australia, Africa or China. Negligible rainfall at 200 mm per annum with evaporation at 1500 mm per annum. Typical temperature ranges from 10 – 20 °C in cool season and 15 – 30 °C in warm season.

Assume an operational water requirement of 480 ML (480,000 cum) on an annual basis with constant consumption all year. Minimum storage capacity to be one months supply in addition to pumping capacity from source capable of filling the reservoir in a month. This means a minimum storage volume of 40 ML (40,000 cum).

Assume water source to be 5 km away from an underground bore and water quality is such that no treatment is required. Water is pumped to site via an above ground or shallow trench pipeline with a pump station at source and no intermediate pump stations. This assumption is actually very optimistic as it is not uncommon for a water source to be 50 km or more away.

Without going into details of terrain and head losses etc let us assume that the base requirement of 40,000 cum/month can be achieved by one 500 mm diameter pipeline and that the evaporation allowance reservoir will require an increase to 650 mm diameter with a corresponding increase in wall thickness.

Reservoir Options

A reservoir 150 m long and 100 m wide with slopes at 1:2 and a depth of 5 m will yield a storage capacity of 44 ML (44,000 cum) which will meet our base requirement. In order to keep the evaluation simple we are using the full volume without consideration of any freeboard. With a surface area of 15000 sqm and an evaporation rate of 1500 mm per year the annual evaporation loss will be 22500 cum or about 50% of our net storage capacity. Therefore we need to provide 50% more storage and 50% more pumping capacity to overcome the evaporation losses.

A reservoir 150 m long and 100 m wide with slopes at 1:2 and a depth of 8 m will yield a storage capacity of 44 ML (44,000 cum) which will meet our requirement for the reservoir with additional evaporation allowance storage.

Some mining projects would use simple inlet and outlet arrangements with inlet pipes over the crest and floating pump stations for outlets. Others would utilise concrete structures for a combined outlet/scour, an overflow and an inlet structure and this is the basis we will use.

The reservoir will need a 1.5 mm HDPE geomembrane liner installed over a compacted and prepared subgrade.

The floating cover could be either reinforced polypropylene (PPR) or a polyethylene hybrid. It must have a ballast and float system to control cover shape through a full range of water level movement and it will require a concrete perimeter beam for fixing.

Costings

The costing data here is typical of many projects and is simplified in order to illustrate the key issues and the rates used are based on recent real project outcomes in US$.

The cut to fill earthworks for the base size of both reservoirs would be the same. The embankment dimensions would remain the same for the reservoir with evaporation allowance and the excavated material would be removed for possible use elsewhere.

A typical unit rate for excavate, place and compaction is $3.00 per cum for the base reservoir. For the evaporation allowance reservoir the

Table 2 Comparative costing data

Reservoir with Evaporation Allowance		**Reservoir with Floating Cover**	
Cut to fill earthworks 22000 cum @$3	$66,000.00	Cut to fill earthworks 22000 cum @$3	$66,000.00
Additional excavation for evaporation allowance. 22000 cum @ $5	$110,000.00		
Concrete structures	$12,000.00	Concrete structures	$12,000.00
		Concrete perimeter beam. 500 linm @$60	$30,000.00
HDPE Liner 1.5 mm 17000 sqm @$8	$136,000.00	HDPE Liner 1.5 mm 17000 sqm @$8	$136,000.00
		Floating Cover 17000 sqm @$18	$306,000.00
Pipeline 5 km @ $450	$2,250,000.00	Pipeline 5 km @ $300	$1,500,000.00
Pumps (2 plus 1 standby)	$80,000	Pumps (1 plus 1 standby)	$40,000.00
Total Capital Cost	**$2,654,000.00**	**Total Capital Cost**	**$2,090,000.00**

excavation will be deeper and probably in harder material and a rate of $5.00 per cum will be required to allow for this as well as the cost of cartage and disposal. Very often the additional depth will encounter very much harder material that my require ripping or even blasting to remove. This additional cost is therefore quite conservative.

A typical floating cover in 1.1 mm PPR with a Double – Y ballasting and float system would cost between $15 and $20 per sqm. The actual cost would vary with factors such as local labour rates and weather conditions. For this comparitive table we have used a rate of $18 per sqm

A 500 mm dia HDPE pipe will have a supply cost of around $200 per metre depending on delivery costs and a field welding and installation component will bring this up to around $300 per linear metre. A 650 mm dia pipe in HDPE will have close to double the unit mass and therefore a supply cost of around $400 per metre depending on delivery costs and a field welding and installation component will bring this up to $500 per linear metre

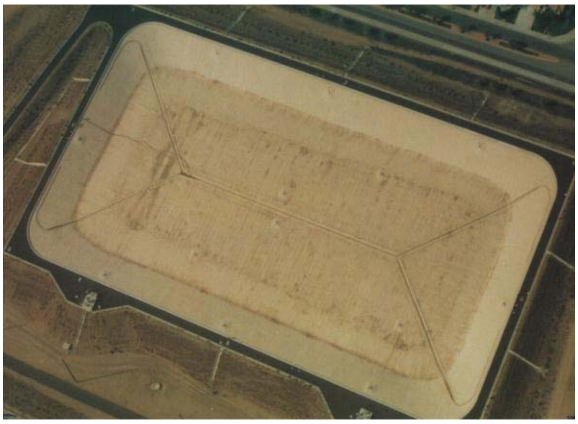

Fig. 34 A typical water reservoir floating cover

The operations and maintenance costs of the two reservoirs will be similar. There will be a need to remove wind and other debris from the floating cover and there will be a need to desludge the reservoir from time to time.

In addition to these capital cost differences because the evaporation allowance system is pumping 50% more water the operational energy costs for pumping will be 50% more than the floating cover solution.

It can be readily seen from this basic cost comparison that the cost of doing nothing and pumping extra water to make up for evaporation losses can be considerably more than the cost for utilisation of a floating cover for evaporation control.

Fig. 35 Completed floating cover for a copper mine PLS pond

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This potpourri of geosynthetic experiences represents over 30 years of geosynthetic field endeavours.

None of these projects could have been realised without the support of those brave and adventurous souls who were willing to take a chance and give these new materials a try. Similarly none of these project would have been realised without the support of manufacturers willing to risk their capital and reputations to make these new materials.

REFERENCES

Australian National Committee on Irrigation and Drainage (ANCID) (2004) Channel Seepage Management Tool website http://ancid.org.au/seepage/index.html

Finlay P.J. and Sadlier, M.A. (2004). Geosynthetic and technical aspects of a double LLDPE liner in a 200,000 m3 roofed, concrete lined reservoir, Proc. GeoAsia 2004, Seoul, Korea.

Frobel, R and Sadlier, M. (1997). Geomembrane properties - a Comparative perspective, Proc. GeoEnvironment 97 Conference, Melbourne, Australia.

Sadlier M., Russel J., and Harris M (1994). Innovative geosynthetic based waste water treatment systems. Proc. 5th International Conference on Geotextiles Geomembranes and Related Products, Singapore.

Sadlier, M, Sieracke, M and Taylor , R. (2001). Luggage point water re-use lagoons. Proc. Geosynthetics 2001 Conference IFAI, Portland, USA, :263-277.

Sadlier, M., and Taylor, R (2002). Recent developments in polye for use in floating covers. Proc. 7th International Conference on Geosynthetics, Nice, France.

Sadlier M.A., Frobel, R., and Cowland J.W. (2004) Liner systems - Appropriate technology and performance, Proc. GeoAsia 2004, Seoul, Korea.

Sadlier, M.A. (2005). Geosynthetics aspects of a methane gas storage bladder. Proc. GeoFrontiers, Austin, Texas, U.S.A.

Schader L and Taylor R.., (1993). Geomembrane floating covers: Technology for the nineties, Proc. Geosynthetics '93, IFAI, Vancouver, British Columbia, Canada, :1161-1172.

Stevenson, B.A. (1999). Repair and Replacement Options for Concrete Lined Irrigation Channels, Land and Water Resources Research and Development Corporation, Department of Natural Resources, Queensland, CD-Rom.

Swihart, J., Haynes, J., and Comer, A. (1994). Deschutes - Canal-Lining Demonstration Project Construction Report, Bureau of Reclamation, US Department of the Interior, Denver, U.S.A.