Geomembrane raincoat liners in the mining heap leach industry

By Allan J. Breitenbach and Mark E. Smith

Introduction

Raincoat liner (RCL) terminology is used in the mining heap leach industry in reference to a temporary exposed geomembrane cover (EGC) that minimizes rain stormwater infiltration into the ore heap fill and diverts cover surface storm runoff to the natural drainages (see Thiel and Smith, 2004, for a general description of heap leaching operations).

Raincoat liners were first used in the late 1980s on gold ore heap fills in Costa Rica (Smith, 1996) to allow continuous wet season heap leaching in a very high-rainfall climate. The RCL covers provided several wet season improvements including: 1) reduced surplus water balance management, 2) less dilution of process solutions for improved metal recovery, 3) reduced reagent consumption in recirculated barren solutions, and perhaps most importantly, 4) reduced the likelihood of accidental spills due to excessive storm pond water accumulation.

Heap leach RCL covers, unlike semi-permanent to permanent EGCs used in other industries, are generally for relatively

Photos 1-4 courtesy of Vector Engineering

Photo 1 | Raincoat liners applied at the Pierina gold mine heap leach project located north of Lima, Peru. Rainwater is routed to a lined holding pond for reuse in mining operations.

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Photo 2 | The Pierina gold mine main slope.

Photo 3 | Raincoat liner cover startup installation on bottom slopes of a gold heap leach pad in Costa Rica. Stormwater runoff is diverted to the lined pond shown in the foreground for water-quality testing and release to natural drainages.

short-term wet season use with on/off installation (removal from the top fill surface for continued ore lift placement), and often are placed on rugged and steep rock fill slope conditions requiring more frequent liner maintenance.

This article includes a review of raincoat liner systems in use or planned for use on heap leach pads in regions with high rainfall events or annual month-to-month wet seasons. The review includes a general discussion of raincoat liner selection and design parameters, based on the design experience and site observations by the authors, as well as discussions with clients, engineers, and raincoat liner installers in both the mining and landfill industries.

Selected raincoat liner photographs are included showing typical raincoat liner geomembrane covers on both leach pads **(Photos 1-4)** and landfills **(Photo 5)**.

Background

Most modern day heap leach mining projects involve the use of geomembrane-lined leach pads to contain process solutions in the recovery of precious and base metals from the ore for both economic and environmental reasons. In a heap leach operation, ore is stacked in piles (the "heap") and irrigated with either an alkaline cyanide solution (for gold and silver) or a sulfuric acid solution (for copper and nickel). The lined leach pad and pond system collects the solution for metal recovery in the process plant, and the barren water is then mixed with reagents and recycled back to the heap.

Rain and snow stormwater is also collected and stored in the lined leach pad/pond system. A surplus water balance may occur in high-rainfall climates, either as an accumulation during the wet season or during extreme short-duration storm events. This surplus water balance may also occur from spring snowmelt runoff in cold climate regions.

RCL covers have been used on several warm climate gold heap leach projects in Central and South America, Africa, and Asia (Philippines) to cover the ore and separate the rainfall fresh water from the heap solutions (Breitenbach and Smith, 2006), and several base metal RCL applications are planned for 2007.

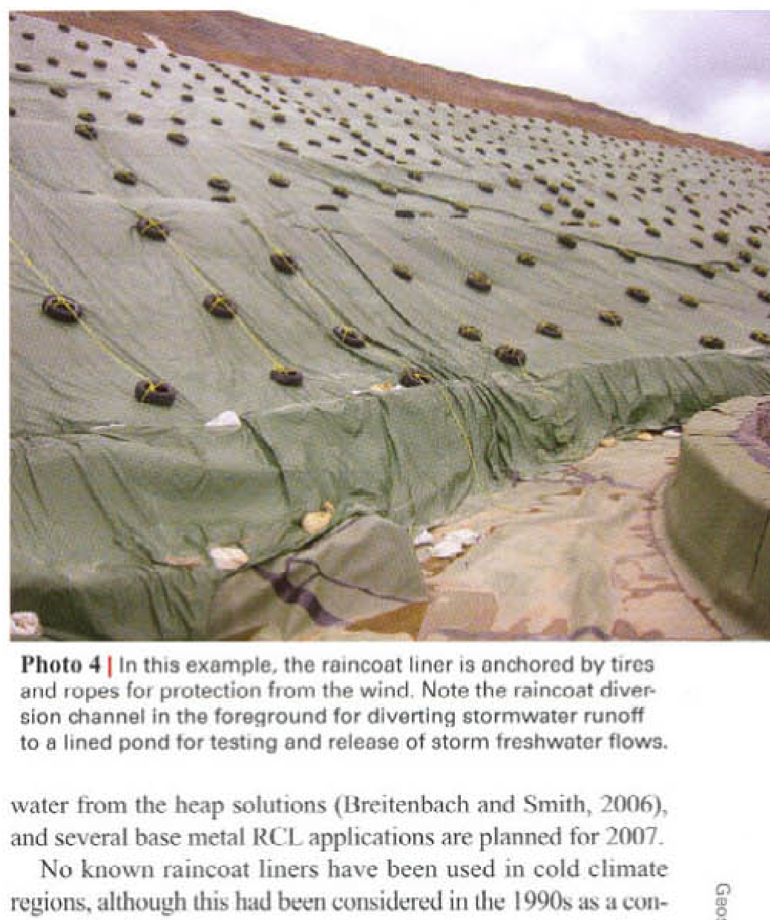

Photo 4 | In this example, the raincoat liner is anchored by tires and ropes for protection from the wind. Note the raincoat diversion channel in the foreground for diverting stormwater runoff to a lined pond for testing and release of storm freshwater flows.

No known raincoat liners have been used in cold climate regions, although this had been considered in the 1990s as a conceptual design option on several planned gold heap leach projects in Idaho and Montana, and more recently in the Chilean Andes for heat retention in bacterial copper leaching operations.

A summary of planned or constructed leach pad raincoat liner systems known by the authors, and located in high rainfall regions, are listed in **Table 1** (p. 34).

Raincoats

Table 1			
Dates	**Project, Location, Metals & Status**	**Owner & Raincoat Designer**	**General Comments and Information**
c. 1987 to 1990	Rio Chiquita gold, northwestern Costa Rica (now closed)	Rio Chiquita	Earliest known raincoats application, integral with interlift liners. Small facility. 0.5 & 0.75mm PVC. Also used floating covers. Covered 100% of heap including active drip areas.
c. 1989 to 1990	Marcacona gold, western Costa Rica (now closed)	Rio Heron	Small dynamic heap with a fixed roof for rain cover.
c. 1994 to 1997	MaquiMaqui mine, Yanacocha Complex, north-central Peru	Yanacocha Newmont Vector	1.0mm & 1.5mm HDPE raincoats. Used only on idle side slopes. Discontinued in lieu of higher cost but simpler operation option compared to enlarged treat-and-discharge system
1994 to c.1997	Carachugo gold, north-central Peru	Yanacocha Newmont Vector	1.0mm & 1.5mm HDPE raincoats. Used only on idle side slopes. Discontinued in lieu of higher cost but simpler operation option compared to enlarged treat-and-discharge system.
1994	Cerro Colorado copper & gold, western Panama (not constructed)	Tiomin Westec	0.5mm PVC raincoats for pre-feasibility design. 80 million tonne copper & gold with interlift liners, top surface liner cover to be reusable through wet seasons with side slope cover permanent, more than 4m of rainfall in 4-month period.
1994 to 1995	Santa Rosa gold, central Panama (now closed)	Minera Santa Rosa SRK	1.5mm HDPE raincoats used only on top surfaces during wet season. Used for 2 seasons then discontinued.
1996 & 2006	La Granja copper, northern Peru (not constructed)	Cambior / Westec Rio Tinto / Vector &KP	Conceptual studies only for primary sulfide leach. 550mt to more than 1,500mt operations considered.
1996	Kyisintaung copper, Northern Myanmar	Indochina Gold Westec	0.5mm PVC raincoat design discontinued with option in operations to reduce leaching application flows through the wet season.
1997–	Tarkwa gold, Ghana	Teberebie Goldfields Vector	Tropical laterite & saprolite ore.
1998–	Wassa gold, Ghana	Satelite Goldfields Vector	Tropical laterite & saprolite ore.
1998 to 2006	Gold heap leach, Mindanao, Philippines	Philex Mines Group	1.0mm HDPE raincoats; tropical laterite & saprolite ore.
1999 to 2006	Pierina gold, northern Peru	Barrick Vector	1.0mm to 1.5mm HDPE raincoats used on slopes and inactive areas. Experimented with various liner materials & thicknesses. 120mt heap with 130m maximum ore depth.
2006	Bellavista gold, western Costa Rica	Glencairn Vector & Tetra Tech	0.25mm LLDPE-reinforced used on side slopes, including active irrigation areas. Up to 3m of rainfall in 6 months.
2007	Confidential pilot project, Colombia	Confidential owner Vector	0.6 & 0.8 scrim reinforced EIA (PVC-uv) raincoats and floating covers for this pilot plant. Project is in construction now. Tropical laterite & saprolite ore.
Est. 2008	Area 118 copper, northern Brazil	CVRD Vector	1.0mm LLDPE raincoats to be installed. Lateritic & saprolitic copper ore. Currently in detailed design, construction to start in 2007.
Est. 2010	Confidential project, Colombia	Confidential client Vector	Design in conceptual design for heap raincoats and pond floating covers, considering both conventional and dynamic heap leaching (on/off pad). Tropical laterite & saprolite ore.
Est. 2010	Confidential project, Guatemala	Confidential client Vector	Design in conceptual design for heap raincoats and pond floating covers, considering both conventional and dynamic heap leaching (on/off pad). Tropical laterite & saprolite ore.
Est. 2010	Confidential project, Indonesia (2 projects)	Confidential client Vector	Design in conceptual design for heap raincoats and pond floating covers. Tropical laterite & saprolite ore.
Est. 2010	Confidential project, Philippines (2 projects)	Confidential client Vector	Design in conceptual design for heap raincoats and pond floating covers (considering both conventional and dynamic leaching). Tropical laterite & saprolite ore.

Similar cover technology has been adapted in recent years in the landfill industry as well, mainly to prevent buildup of excessive hydraulic heads and slope instability in the landfill materials (Breitenbach and Thiel, 2005). An example of a temporary EGC is shown in the photo of a Florida landfill **(Photo 5)**.

The landfill applications include relatively thin LLDPE-coated sheets with scrim reinforcement and with multiple trench anchorage or a more-recent combination of liner anchorage and suction-generating pipe tube air vents (MSW Management, 2005). The air vents in cover liners are relatively new to the landfill industry and should see more use on both landfills and leach pads, particularly in high-wind regions of the world.

Landfill EGCs in Cole and Polk counties in Florida also withstood high winds and heavy rainfall from three hurricanes in 2004 and 2005 with minimal damage reported. It is also interesting to note that the Costa Rica RCL shown in **Photos 3** and **4** withstood high winds to 152 km/hr (94 mph) before a 10m length of panel seam separated and required repair.

Lessons can be learned from the landfill EGC applications; however, the leach pad RCL covers are generally more robust to handle challenging placement on steep angle-of-repose ore lift slopes and sometimes on rugged run-of-mine (ROM) ore rock slope surfaces.

Heap leach water balance

A surplus water balance may develop in wet climate regions, where a significant amount of rain can fall in a relatively short time or over extended month-to-month wet season rainfall conditions.

Examples of extremely wet-season events include the 1998-1999 and 1999-2000 wet seasons in Peru, which experienced back-to-back El Niños—heap-leach operators there were forced to carry surplus water from one wet season through the next. On Oct. 31, 2006, a typhoon with 210 km/hr. winds hit the Philippines, with torrential rains causing major flood damage and landslides.

Some project sites have wet season precipitation in the range of 3-5 meters occurring principally in about six months (e.g., parts of Colombia, Brazil, Panama, Costa Rica, the Philippines, and Indonesia). The rainy days are associated with cloudy skies, cooler temperatures, and higher humidity, which result in minimal evaporation losses from the ore heap surface during the storm events. The end result is a temporary leach pad water balance surplus of rain water dilution in the lined process and storm holding ponds that require recycled storage within the ore heap, or treatment and release to the environment, or both.

The cyanide treatment-and-release process for gold and silver leach pads is ideally conducted with barren solution taken from the carbon column discharge flow as time allows (e.g., cyanide destruction using International Nickel Co. (INCO) treatment for discharge to receiving waters or peroxide quick treatment for land application).

Acid leach operations require principally pH adjustment before treatment, although in some cases metal removal may also be necessary. Thus, high-rainfall

Photo courtesy of GSE Lining Technology

Photo 5 | An aerial view of a completed exposed geomembrane cover on a landfill in Florida. Pipe vents were installed for wind protection.

heap leach operations have the option of exposing the heaps to the elements (then manage excess water balance precipitation inflows), or using RCL covers to reduce the excess water balance volume.

Often the use of raincoat liners provides a more efficient and economic way to separate and divert heavy rainfall flows to the environment, minimizing dilution of the process solutions, reducing the temporary storm pond storage requirements, and reducing the cost for treating surplus water for acceptable regulatory release to the environment.

Operation requirements

The operation requirements for precious and base metal heap raincoat liner systems typically include the following:

- temporary or permanent diversion of uphill storm runoff flows around the heap leach facilities to handle the design storm event;
- temporary diversion of water from exposed uphill lined pad areas, until the exposed liner is covered by ore (phased pad development in the uphill direction or blockage of sidehill pad cell runoff until ready for ore stacking and leaching, or a combination of both);
- consider options of lining heap slopes vs. the top surface areas for optimum pond sizing, depending on site topography and areas available for pad and pond development (in-heap valley leach or conventional pad with external ponds);
- consider raincoat liner options for year-round ore production and leaching, or for dry season production with continuous leaching of fresh ore (extra ore mined during the dry season) with buried or surface drip emitters placed beneath the RCL cover, until the ore surface can be exposed into the next dry season stacking;
- consider options for reuse of excess water balance storm flows as makeup water in leach operations in a timely manner to create pond storage for the design storm event;
- stack the ore lifts by truck or conveyor on a controlled top surface grade in the dry season to where wet season raincoat liner runoff can be routed by gravity flow to perimeter natural drainages;
- minimize mixing of high intensity storm runoff from exposed uphill ore slopes onto the raincoat-lined lower lift slopes or provide a temporary storm holding pond for sampling and testing of water quality before release to the natural drainages;
- consider raincoat liners covering all ore stack slopes with the top heap surface (if exposed) graded away from

the exterior slopes to allow 100% raincoat slope runoff to be diverted into the natural drainages.

Note that shutdown of heap leach ore production through the wet season generally is not a preferred option in most mine economics, but may be the only option in regions where extreme rainfall events or heavy continuous month to month rain events occur. Nickel and oxide copper operations, which require thin liners between lifts to reduce acid consumption, may consider conversion of the RCL covers to interlift liners after the wet season with supplemental drain pipes added to the raincoat/interlift liner surface for both aeration and drainage control.

Raincoat liners provide another operational benefit for ores that are easily degraded, such as agglomerated highly weathered or clayey ores and tropical laterite and saprolite ore. In such materials the impact of droplets from intense rainfall can degrade the surface of the heap (by damaging the agglomerated balls or causing detrimental fines migration), and result in a lower permeability and subsequent leaching problems. If used over fresh ore, an RCL cover provides protection against this action and in some cases warrants the use of RCL covers regardless of the water balance benefits.

Liner requirements

RCL cover material requirements generally include a combination of several of the following factors, depending on site-specific operational requirements, site conditions, and project economics:

- several years of UV (sunlight) liner exposure without degradation preferably to a minimum of five years of permanent use on side slopes and less for temporary wet season covers on the top ore lift surface;
- depending on heap geometry and size, liner flexibility may be preferred over more rigid liners (box vs. roll deployment and reuse) for ease in folding, shipping efficiency, site storage, and deployment from box containers on fork lift palates with the potential for removal to storage for subsequent reuse. Large pre-fabricated sheets may also have some benefit in ease of deployment and seaming;
- ability to move and re-deploy the temporary top surface RCL covers to site storage to allow stacking of the next lift and to encourage evaporation;
- the quality of seaming can be de-emphasized (relative to the base liner). Case studies in copper interlift liners have shown that even with sewn seams less than 3% of the solution bypasses the liner (Smith, Orman, et al., 1994), and for rainfall control this would often be an acceptable leakage rate;
- adequate deployment and puncture strength placed over rough ore rock surfaces and hang on steep angle-of-repose slopes with preference for minimal puncturing, temperature expansion/contraction, and downslope movement; also consider the durability requirements for seasonal removal of the RCL, if that is part of the operational plan;
- sufficient liner anchorage and deformation strength to resist uplift wind forces with ballast and air vents added as needed;
- suction pipe air vents suggested to be considered in high wind areas, based on the recent success of the landfill liner covers in Florida subjected to repeated hurricane-force winds with minimal reported damage.

Conclusions

The mining industry has used raincoat liners mainly on lined gold and silver heap leach pads located in the more extreme wet climate regions of Central America, South America, and Asia (Philippines). The technology, developed principally by the gold operations, is now being adapted to other metals with a large-scale copper application planned to go into construction in 2007 and several other base metal projects in the early planning stages.

The heap leach project sites that are located in wet climate regions or experience high seasonal rainfall events may be cost effective with temporary wet season or permanent year round raincoat liner covers for the following primary reasons:

- minimize stormwater dilution of the pregnant solution flow to the process plant;

• reduce the temporary storm or holding pond size to meet design storm storage requirements;

• reduce the required back-up pump and application pipeline system capacity for recirculation of excess water balance flows back to the heap surface as make up water;

• reduce the costs for any last resort emergency treatment and release to the environment;

• protect weak ore and agglomerates from degradation and fines migration loss of permeability.

References

Breitenbach, A.J., and Thiel, R.S. (December 2005), "A Tale of Two Conditions: Landfill vs. Heap Leach Pond Liner Strengths", NAGS 2005/GRI 19 Geosynthetics Conference, Las Vegas, Nevada.

Breitenbach, A.J., and Smith, M.E. (September 2006), "Overview of Geomembrane History and Design Practices in the Mining Industry", 8th International Conference on Geosynthetics (8-ICG), Yokohama, Japan.

MSW Management (April 2005), "Exposed Geomembrane Liner Cap Takes on Three Hurricanes in Polk County, South Central Florida" March/April, MSW Management magazine, www.mswmanagement.com , pp. 72-77.

Smith, M.E., "Leach Pad Technology Deals with Weather," Mining Engineering, November 1996.

Smith, M.E., Orman, M. and Queja, C., "Copper Heap Leaching—A Case for PVC Liners," PVC Geomembrane Institute Technical Bulletin, 1994.

Thiel, R.S. and Smith, M.E. (July 2004), "State of the Practice Review of Heap Leach Pad Design Issues," Geotextiles and Geomembranes, Elsevier Press.