Liner Systems in Chilean Copper and Gold Heap Leaching

M. E. Smith
Vector Engineering, Inc., Grass Valley, CA, USA

P. M. Welkner
E. C. Rowe & Associates, Santiago, Chile

ABSTRACT. Chile is the world's largest copper producer and is becoming a major gold producer. In 1993 the heap leach mines used 3 million square meters of geomembrane. The authors summarize the liner systems used at many of Chile's major copper and gold heap leach producers - both operating and planned. The evolution in the state of the art is also discussed, considering both economic factors and Chile's burgeoning environmentalism.

1. INTRODUCTION AND HISTORY OF HEAP LEACHING IN CHILE

The starting point of copper heap leaching processes at larger scales in Chile can be set in November 1980, when the Lo Aguirre heap leach project was put into operation. At almost the same time the El Indio gold mine began production. While El Indio was not a heap leach project, it was Chile's first major bulk tonnage, open-pittable gold deposit, which paved the way for the introduction of North American gold heap leach technology in the early 1980's.

In the last 5 years, heap leaching has become more and more popular in Chile since it allows the exploitation of large but relatively low grade ore bodies at a reasonable cost.

Copper heap leaching has developed an interesting twist, called thin lift leaching. In this technology, used by many of the copper projects, a thin (typically about 0.3mm) geomembrane is placed between each lift of ore. While not a significant geomembrane engineering issue, this technology should get the attention of the geomembrane manufacturers since it can double or triple the total polymer weight consumed by a typical project.

2. CHILE'S GROWING ENVIRONMENTAL AWARENESS

Many people view Chile as having lax environmental laws. However, more than 1,000 such laws are on the books, some of which are more than 100 years old. But the government has lacked the capacity to enforce these laws.

This has been changing, though, since the new Constitution was approved by popular vote in 1980, introducing the concept of a citizen's right to live in a healthy environment.

A general but broad-based environmental law was adopted in late 1993 by Congress, which calls for the sustainable development of the country and is based on the following principals:

- All substantial enterprises have to prepare and present to the appropriate authorities an environmental impact study.
- If some form of pollution is impossible to avoid, the polluter has to pay the affected community for the damage caused to the environment.
- Two or more enterprises may come together into an agreement in order to compensate their discharges so as to stay below the permissible limits.
- Any citizen or governmental agency may sue a polluter who is not complying with the permissible limits.

Industry-specific requirements, ranging from simple discharge specifications to prescriptive design standards, are to be set by the minister of each industry.

3. UNIQUE GEOTECHNICAL ISSUES

Nearly all of Chile's heap leach projects are in the north. The climate of the north ranges from sub-arid to arid, with the Atacama the driest desert in the world. Most mines are very remote and offer several unique challenges to the designer.

Perhaps the most challenging of which is the presence of soluble salts in the soil. Salt is ubiquitous in Chile's northern soils (as evidenced by its history of nitrate, potassium and lithium mining), and these salts are soluble in acidic pregnant leach solutions which are used in copper heap leaching. (The authors know of no studies measuring solvability in alkali gold leach solutions.) Concentrations of acid-soluble salt range from less than 1% to in excess of 30 percent.

When leakage from a geomembrane enters these soils the salts can be dissolved. Since the salts are part of the soil matrix, their dissolution triggers settlement, which causes strain in the liner. At some point the strain enlarges the hole, increasing the leakage rate, causing more settlement and increasing the strain in the geomembrane.

Under the right conditions, even the smallest hole could expand into a major violation of the liner system. Proper testing and numerical modeling methods are required to ensure a reliable liner system.

4. SELECTED EXAMPLES

We have selected two sample projects to be highlighted. These were selected because they represent some unique liner applications.

The first project, Cerro Colorado, is the largest geomembrane-lined on/off pad known by the authors. The second project represents a liner placement and heap stacking methodology rare in other locations: concurrent stacking of heap and deployment of the liner.

4.1 Cerro Colorado

Located near the town of Maniña in the north of Chile, Cerro Colorado uses an on/off leach pad. In on/off technology ore is processed by stacking over the liner, followed by leaching and rinsing. The "spent" ore is then removed with heavy, rubber-tired equipment and the cycle repeated. On/off leach pads have traditionally been constructed of asphaltic concrete. Asphalt leach pads have been the source of many difficulties (Smith, 1993), and they are very expensive. Therefore, the owners elected to extend geomembrane technology to on/off pads.

The author's believe Cerro Colorado to be the largest geomembrane-lined on/off pad in existence.

Divided into 9 separate cells, the total leach pad area is over 540,000 square meters. The pad was constructed by filling the valleys with up to 30 meters of mine overburden and waste rock, placed dry and in lift thicknesses of 5 meters at the bottom decreasing to 2 meters at the top. The fill was monitored to verify that primary settlement was complete prior to installation of the geomembrane. Post-construction settlement was estimated at 0.5 to 1.0% of the fill thickness. The liner system is shown on Figure 1.

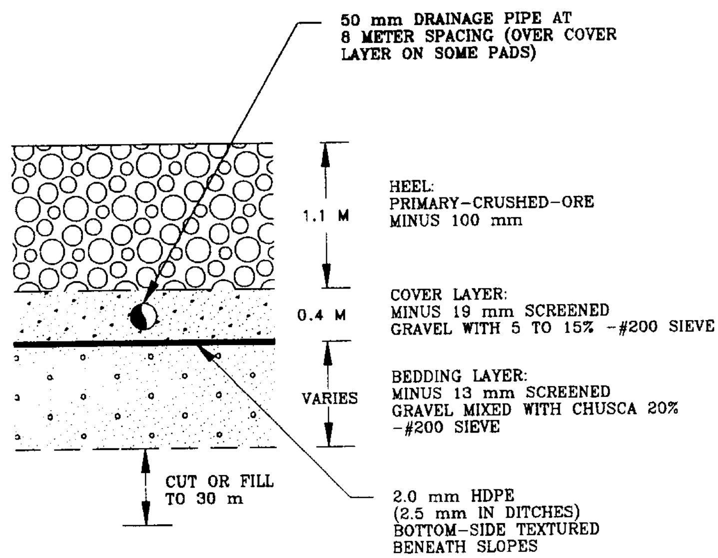

Figure 1: Cerro Colorado Liner System

Ore will be crushed to minus 19mm and stacked with a conveyor stacker to a maximum height of 8 meters. Once the leaching is complete, the spent ore (ripios) will be removed with a Cat 992c rubber-tired loader (with a gross weight of 92,000 kg) and 90t capacity trucks, and the cycle repeated.

The liner system design was driven by (1) sensitivity of the dry fill to water, (2) the high, repetitive loads induced by the off-loading equipment, and (3) the design life of 22 years.

The liner system design is summarized in Table 2. The key to the systems survivability is the "heel", which is a permanent layer of ore which isolates the geomembrane from the loader and trucks. The total heel thickness is 2 meters.

4.2 Ivan-Zar

Owned by Minera Rayrock, Ivan-Zar will be a relatively small but high grade heap leach project. Total pad area will be 266,000 square meters. Ultimate heap heights are 20 meters for the oxide heaps and 12 meters for sulphide and mixed ore heaps. Ivan-Zar should be commissioned in mid-1994.

Ore will be crushed to minus 12mm and stacked with conveyor stackers in lifts of 4m for both oxide and mixed ore.

The base liner (Figure 2) will be advanced continuously as the heap is stacked, with the edge of the liner always between the active face of the heap and the wheels of the stacker. This system has been in use for several years at the El Lince and Puhduel mines (Table 2). There will be no cover layer - the first lift of ore will be stacked directly over the geomembrane. Pipes will be placed over the liner for drainage.

After each lift of ore is completely leached, a 0.75mm geomembrane will be installed (oxide heaps only) and the next lift placed in the same manner as the first.

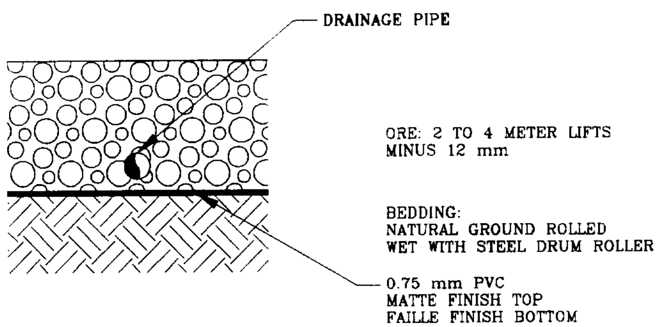

Figure 2: Ivan-Zar Liner System

5. ESTIMATES OF LEAKAGE RATES & LINER PERFORMANCE

The purpose of a liner is to restrict leakage to acceptable levels. Therefore, the best way to judge liner performance is by the leakage rates. When environmental protection is the goal then the allowable leakage rates are generally very low. But in the case of many Chilean mines the nature of the sites makes environmental protection a secondary consideration; the primary purpose becomes one of economics. The optimum liner system then becomes one which has the lowest net present value of the liner cost plus the value of the lost solution, including reasonable contingencies for failures and allowances for environmental risk. (Note that this is not appropriate at some Chilean sites, such as Andacollo, where environmental protection is critical and governs the design.)

While unlined dump leaches are almost a thing of the past in Chile as well as North America, the need for an engineered liner system - as opposed to a more modest liner - is still the subject of much debate in Chile.

Geomembrane liner systems can be broadly grouped into three categories. Non-engineered and thin liners are those that are typically not subject to engineering scrutiny. Engineered liners can be constructed with or without construction quality assurance (CQA), with corresponding levels of performance and reliability.

Solution loss cannot be precisely predicted, but we can make some deductions from experience on other projects and in other industries. Over the past decade in the U.S., Canada and Europe, the liner industry has shifted from single lined facilities to many double lined facilities with leak detection. This has produced very good data on the actual performance of upper, or primary liners, as summarized in Table 1.

Table 1: Comparison of Liner Performance

Liner System	Typical Range of Leakage		Occurrence of Failure
	L/day/ 1,000m^2	% of PLS[1]	
Non-Engineered & Thin Liners	2,000 to 10,000	0.8 to 4.2%	10 to 30%[2]
Engineered Liner with no CQA	20 to 500	0.01 to 0.2%	<10%
Engineered with CQA Control	5 to 20	<0.0 1%	nil

1. Based on a total PLS flow rate of nominally 400m^3/hr and 40,000m^2 wetted liner area.
2. Some practitioners claim as high as 50%. The authors' experience indicates 10 to 30%.

Unfortunately, essentially all of this data is for relatively thick primary liners, usually constructed with good CQA. Published and verifiable data on the performance of non-engineered, thin liner systems is almost non-existent. Using our experience, antidotal information, extrapolations of seepage models, and the limited data available for thin liners, we have made estimates of the probable leakage rates from so called thin systems, which are presented in Table 1. These values are consistent with reported rates through inter-lift liners at Pudhuel and El Lince.

In addition to typical leakage rates, another factor of equal or greater importance is the history of failures, which is also summarized in Table 1. Leakage data for liners which have failed is not included in the ranges of typical leakage rates. Data for failure rates was generated by in house research, unpublished reports and confidential sources. Because of the sensitive nature of most failures this data is generally unpublished, confidential, and therefore unverifiable.

6. RESULTS OF THE SURVEY

The survey was conducted by circulating project questionnaires, interviewing designers, owners and installers, and researching the project files of the author's firms. While every attempt was made to cross-check information, there is no doubt that some errors or omissions. For this we apologize.

6.1 Discussion

The types of liners being used or planned fall primarily into 2 categories: 1.5mm thick HDPE and .75mm thick PVC. With few exceptions, copper heap leaching is using almost exclusively 1.5mm HDPE liners. Gold projects show a little more diversity.

While 1.5mm HDPE is a good, versatile liner, it is by no means the best liner for every occasion. The overwhelming selection of this liner, combined with the complete absence of VLDPE projects, indicates that liners for most projects are being specified based upon prior experience rather than a rational engineering approach.

6.2 Predicting for the Future

Geomembrane liners will continue to play an important role in Chilean mining, with applications including tailings impoundments, water reservoirs and lining process vessels. Annual consumption is likely to grow given the projects in planning and the increasing focus on environmental protection.

To the extent that liner systems are not being truly engineered, the authors predict problems ranging from installation difficulties to complete failures. This very much duplicates the history of heap leaching in North America and elsewhere.

At the same time we are seeing increased attention being paid to the design of geomembranes. In part due to past failures and in part due to education, owners, installers and designers are putting more effort in the front end to result in an optimum product.

7. REFERENCES

Smith, M.E. (1993) The Gilt Edge Asphalt Leach Pad: A Case History, *proc. Geosynthetics '93*, Vancouver, 1203-1214

8. ACKNOWLEDGMENTS

The authors wish to express their gratitude to the following companies for providing valuable information for this study; Steffen Robertson and Kirsten (USA) and Mr. Rob Dorey, Cia. Minera Doña Ines de Collahuasi, S.A. and Sr. Louis De Beer, Cia. Minera Homestake Chile and Sr. Ricardo Palma, Mineria Rayrock Ltda. and Mr. Keith Belingheri, Cia. Minera Cerro Colorado and Mr. Frank Chesworth, Empress Minera Mantos Blancos, Emin Ingenieria and SLT North America.

Table 2: Summary of Liner Systems

Project Name & Owner/Operator Start-Up Year	Leach Pad Size, m^2 (Ult.Height)	Ore Size (mm)	Bedding	Geo-membrane	Cover Layer	Drainage System	Stacking Method & Remarks
Copper Heap Leach Projects							
Cerro Colorado Rio Algom 1994	540,000 (8)	-19	-19mm mixed with "Chusca"	2.0mm HDPE	40cm -19mm & 1.6m -100mm Ore	65mm pipe @ 14m Spacing	Conveyor Reusable on/off Pad
El Lince		-10	Fine Sand	0.2-0.3mm LDPE	Ore	50mm Pipe @ 2m Spacing	Sewn Seams Continuous Liner Advancement
El Teniente CODELCO 1993	27,191 (15)		-38mm @100mm Thick	1.5mm HDPE	Geotextile & 250mm Ripios	Geotextile & -100mm Gravel @ 20cm 100mm Pipes @ 20m	Re-usable Pad Impounding Heap Trucks
El Savador Original Pad CODELCO 1995	(40)	-10	Sand or Geotextile	1mm HDPE (textured some areas)	Geotextile		Conveyor Over Old Waste Dump
Ivan-Zar Minera Rayrock 1994	266,000 (20)	-12	Native In-situ	0.75mm PVC	None	60mm Pipes	Conveyor Continuous Liner Advancement
Mantoverde Empresa Minera Manto Blancos 1994	4,000,000 (15)	-10	Native In-situ	0.75mm PVC	None	60mm Pipes	Conveyor Continuous Liner Advancement
Punta del Cobre SPDCL 1993	35,000	-12	250cm Thick Sand	0.75mm HDPE	250mm Thick Sand	600mm Thick Gravel	Trucks & Front-end Loaders Reusable on/off Pad
Radomiro Tomic CODELCO (On Hold)	5,000,000 (80)	-50	Native In-situ	1.5mm HDPE or VLDPE	500mm Thick -19mm ore	1m Thick Course Ore Perf Pipes & Collection Headers	Conveyors & Trucks
Tuina Compañia Minera San Martin 1992	24,000 (15)		150mm Dune Sand	1.5mm HDPE	600mm Fine Gravel & Ripios		
Zaldivar (Heap) Placer Dome 1994-1995	2,300,000 (80)	-9.5	Native/Chusca 30cm Thick @ -20mm	1.5mm HDPE (Smooth & Textured)	Crushed Ore	Perf Pipes	Conveyor/ Stacker with Trucks
Zaldivar (Dump) Placer Dome 1994-1995	288,000 (100)	Run of Mine		2.0mm HDPE		Crushed Ore Without Pipes	
Minero Peru T & T Equipos 1993	40,000			1.5mm HDPE			Peru

Table 2, Summary of Liner Systems, continued

Project Name & Owner/Operator Start-Up Year	Leach Pad Size,m² (Ult.Height)	Ore Size (mm)	Bedding	Geo-membrane	Cover Layer	Drainage System	Stacking Method & Remarks
Quebrada Blanca Cominco 1994	1,500,000 (50)	-6	Native: 30cm Thick @-60mm, Top Racked to -30mm	1.5mm HDPE (Smooth & Textured)	60cm Thick -6mm Crushed Ore	Perf Pipes 100mm dia @4m	Conveyor (Fixed & Portable) Thin Lift
Disputada Exxon 1993	5,200 (2.5)	-6	200mm thick Sand	HDPE	100mm Thick Sand 400mm Compacted	Perf Pipes	Trucks & Front-end Loaders Reusable on/off Pad
Lo Aguirre Sociedad Minera Pudahuel			Fine Sand	0.2 to 0.3mm LDPE			Sewn Seams & Continuous Liner Advancement
Chuquicamata CODELCO-Chile	(70+)	ROM	None	None	None		Dump Leach
Collahuasi Anglo American & Shell 1998	1,900,000 (30)	25					In Feasibility Study
Gold Heap Leach Projects:							
Andacollo Oro Dayton Developments 1995	220,000 (60)	-19	100mm Thick -#4 Tailings $5x10^{-4}$cm/s	2.0mm HDPE	2m Thick -19mm Ore	100mm Perf Pipes @10m	Gold
San Cristobal 1990	132,000 (35)	-19	Geotextile	0.8mm PVC	Geotextile	60mm Perf Pipes @ 5m	Gold Trucks & Dozers
Refugio Bema/Amax 1995	2,300,000			1.5mm HDPE			Gold Conceptual Design
El Guanaco Amax Gold 1993	Ph I: 120,000 Ultimate: 480,000 (20)	-20	Native: 30cm Thick @ -50mm, Top Racked to -35mm	1.5mm HDPE (Smooth & Textured) over 1.0mm HDPE Geonet LCRS	-20mm Crushed Ore @ 60cm Thick	100-250mm dia Perf Pipe @ 4m	Impounding Heap-(Double Lined Below Storage Level) Truck Dump
Fachinal Coeur d'Alene unknown	186,000		Clay Liner with LCRS	2.0mm HDPE Over Clay	Ore	Perf Pipes	Gold HL May be Dropped
El Hueso Homestake Chile (21)	36,000 (39)	100% -25 80% -12	Geotextile (Polyfelt TS-600)	1.0mm Textured HDPE	Geotextile (TS-600) 50-80mm Cover of Ore		