Overview of geomembrane history in the mining industry

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ABSTRACT: Geomembrane liners have been used significantly in the mining industry since about 1970 for lining solution and evaporation ponds, tailings impoundments and heap leach pads. The most extensive use of the geomembrane liners has been, and remains, in the construction of evaporation ponds, starting in the early 1970's, and heap leach pads starting in the late 1970's. Tailings impoundments have historically been mostly soil lined, but increasing in their use of geomembrane liners in recent times. This paper will present an overview of the geomembrane liner history in the mining industry from the 1970's to present day. The historic state of practice will be discussed, in addition to the major engineering concerns and the emerging issues in heap leaching.

1 INTRODUCTION

Mining uses geomembrane liners principally for three areas: evaporation (or solar) ponds for recovery of salts, heap leaching of mineral-bearing rock, and disposal of mill tailings (rock that has had most of the mineral value removed). Evaporation ponds and heap leaching are the largest applications of geomembranes in mining, and heap leaching is the most complex. Given the size and complexity, heap leaching will be the focus of this paper, but other areas will also be discussed. A good introduction to heap leaching is given by Thiel & Smith (2004). A large Andean valley fill heap leach project is shown in Photo 1.

Photo 1: Andean Heap Leach Facility (150 ha ultimate area)

2 35-YEARS OF HISTORY

2.1 *Clay, geomembrane and composite liners*

The first large-scale use of geomembranes in mining was probably solar ponds for either Tenneco Minerals in Utah, USA, or Sociedada Química y Minera de Chile S.A. (SQM) in Northern Chile. Tenneco installed 230 hectares (ha) in 1970, and SQM's first installations were at about the same time and size. Prior to this, mining applications consisted mostly of small chemical ponds.

The first heap leach projects were copper dump leach facilities and used only natural containment. With gold and silver heap leaching starting in Montana and Nevada, USA, in the late 1970's, cyanide was introduced to heap leach technology and natural containment was no longer viable politically, if not technically. Most of the first gold and silver operations, constructed in 1974 to 1983 in Nevada, used low permeability soil liners only, though be 1983 geomembrane liners were becoming more common. No modern large-scale leach pads use soil-only liners.

Large scale copper heap leaching began in Chile in 1980 with the Lo Aquirre project. By the early 1990's Chile had about 10 major copper heap leach operations; now there are dozens and the vast majority of such facilities now use geomembranes. SQM first started heap leaching nitrate ores in northern Chile in 1985, choosing polyvinyl chloride (PVC) liners for high multi-axial elongation properties due to the presence of up to 30% soluble salts in the foundation soils. These salts allow even a small defect to grow progressively into a major failure if the liner cannot accommodate the resulting differential settlement.

The now-infamous Summitville gold project in Colorado, USA, which was ultimately classified as a Superfund site, was originally designed in 1984 using PVC for the valley fill leach pad liner, but that was changed in construction to high density polyethylene (HDPE) in 1985. This was one of the first large scale HDPE applications in gold mining.

Very low density polyethylene (VLDPE) was first used for small applications in the mid 1980's and for larger lined tailings impoundments like the Ridgeway gold tailings dam (South Carolina, USA, 1986). The first large embankment dam with a geomembrane core seepage barrier used VLDPE (the TS Ranch, Nevada) in 1989. Another large scale mining application was a solar pond for a potassium solution mining facility in northwestern Argentina, where 12 ha were installed in 1992. Unfortunately, the high ultra violet exposure resulted in serious deterioration of the liner and abandonment of the pond in about one year. VLDPE made a much bigger entry into the leach pad industry by the early 1990's where the material's relatively high multi-axial elongation and good frictional resistance provided design benefits. Its use in heap leaching continued to grow until it was discontinued in 1994. Within about 2 years, however, various formulations of linear low density polyethylene (LLDPE) began to take over as a preferred liner for leach pads due to improved elongation and frictional resistance in comparison to HDPE.

The first major composite geomembrane lined leach pad was the Zortman-Landusky valley fill gold project in Montana, first constructed in 1979 and expanded several times over the next dozen years and ultimately with 150 m of ore over the liner. Zortman-Landusky used PVC, which was the geomembrane in common use for leach pads until about 1985, when HDPE liners started to dominate the industry. Now the world's largest composite lined leach pad is at Newmont's Yanacocha gold complex in North-central Perú. Most valley fill leach pads now use composite liners above the maximum water storage level and double geomembrane liners below that level.

Single geomembrane liners are still the most common liners for copper leach pads with composite liners more common for gold and silver leach pads. Copper run-of-mine dumps are generally unlined though this technology is also converting to geomembranes. HDPE and LLDPE liners at 1.5 to 2.0 mm in thickness and PVC liners at 0.75 to 1.0 mm thickness are the most common types and thicknesses of liners currently used in the mining industry.

2.2 *Double geomembrane liners*

Process ponds started using double liners in the 1980's in Nevada, but double liner use on large applications, such as leach pads, is still not common. Mining has resisted double geomembrane technology for a variety of reasons, ranging from higher cost to decreased stability, but primarily due to the success of the single and composite liner systems. By 1995 there were only six double lined leach pads with some of the larger ones including: Amax Gold's El Guanaco project (Chile), Hecla's La Cholla project (Mexico) and Piedmont's Mother Load project (Nevada, USA). Now there are several, primarily gold valley leach operations, which impound water within the heap and thus can develop significant hydraulic heads over the liner, in one case of up to 40 m. The best known being the Pierina (Photo 1) mine in Perú, the Veladero mine in Argentina, and the Cripple Creek mine in Colorado, USA, all of which use double liner systems below the maximum water level. Ore depth over the liner system ranges from 125 to 160 m for these projects.

Part of the resistance to double liners has been cost. Conventional leach pads in Chile cost US $5 to $11/m^2 (Smith, 2002). Adding a secondary geomembrane and leak collection and recovery system (LCRS) would add 30 to 100% to the installed cost. However, constructability is also an important factor. For example, the largest leach pads in Chile can exceed 150 ha. The time to construct is frequently limited by qualified installer capacity, especially limited in the developing world. Internal stability is another key factor. Valley fill leach pads are commonly constructed on steep slopes. For impounding valley fills, double geomembrane liners are common (with composite bottom liners) below the maximum water level. Above that level composite liners are the standard. Slopes can exceed 0.75 horizontal to 1 vertical. Leach ore is stacked intentionally in a very loose state to improve solution distribution and percolation; this results in very large settlement potential upon wetting and with progressive stacking (Breitenbach, 2004). Therefore, along the steep slopes the potential for settling ore to drag the liner is significant. Using a double geomembrane liner would increase this risk. While this can be managed in design, it nevertheless presents another strong rational to guide projects towards composite liners.

There is also the social issue. When applying the principals of sustainable development, as is now required by lenders and investors for most multi-national projects, a broader perspective is required. For a large-scale copper mine in the Atacama Desert, where groundwater may be deeper than 300 m, is often saline and rarely has local users, the cost to upgrade an average leach pad to a double geomembrane would typically cost US $5 to $10 million. That same money could fund - in perpetuity – the local elementary school.

2.3 *On/off leach pads*

When dynamic heap leach technology entered the industry, first with gold and now including copper, most on/off leach pads were constructed of asphaltic concrete (AC) for structural support during loading and unloading. Various approaches were used to create a low permeability barrier, ranging from simply using a high bitumen content AC (e.g., the Bluebird copper mine, Arizona, USA, 1967 and the Borealis gold mine, Nevada, 1982) to more creative solutions including plain or rubberized bitumen layered between lifts of AC (e.g., the Gilt Edge mine, South Dakota, 1986). Overall, this approach was not very successful and the industry has switched to geomembrane liners with aggressive protective layers with the first large-scale application probably being the Cerro Colorado copper mine in Chile (1991). The standard design is now 1.5 to 2.0 mm thick HDPE or LLDPE with 1 to 2 meters of gravel cover.

2.4 *Rain coats & interlift liners*

Temporary covers, often called rain coats, have been used on heap leach pads primarily in the Philippines, Central America and Perú since about 1988, where high rainfall dilutes operating solutions and surplus water can trigger the need for significant water treatment costs. The rain coats generally include PVC liners (typically 0.75 mm) for a temporary cover until the next dry season, and thicker HDPE liners (.75 to 1.5 mm) for more permanent or reusable applications.

Interlift liners have been used in more than a dozen copper mine leach pads since 1993, mainly in South America to reduce acid consumption in leach solutions for copper oxide heaps. The interlift liners, most commonly PVC (.45 to .75 mm) or LDPE (.75 to 1.0 mm) can have some allowable leakage with the underlying leach pad base liner as the environmental barrier. One case study indicated that typical leakage rates through thin interlift liners is 1 to 3% of the leach solution volume.

3 EMERGING ISSUES IN HEAP LEACHING

3.1 *High loads*

Heap leaching presents a combination of extreme base pressures and high moisture conditions not present in any other containment application. Often these sites, by virtue of being associated with mineralized ground, are in high seismic zones. For example, central Chile was the site of the largest earthquake ever recorded in 1960 where a magnitude 9.5 event devastated the country. Over the past 35 years typical heap depths have increased from about 15 m to over 100 m, and now projects with 160 to 230 m of ore are being considered (Breitenbach & Thiel, 2005, Thiel & Smith, 2004). Increasing heap heights are not just a matter of economics. Some sites simply do not have sufficient acceptable ground to economically allow lower heaps. The general trend, with drivers ranging from closure and reclamation costs to minimizing diversion of agricultural land and encouraging sustainable development, is to reduce the amount of land impacted by mining. A higher heap means fewer hectares of disturbance.

3.2 *Pipe deformation & concentration of loads*

Dual wall corrugated perforated polyethylene pipes are the standard design for leach pad drainage systems at the base of the ore. With the extreme depths of modern heaps, pipe deformations often approach the collapse point for the pipes, which can be up to 30%. Predicting pipe behavior at extreme loads is the subject of on-going research in laboratories and the field (Smith et al, 2005). An important corollary issue is the increase in stress on the geomembrane near the deforming pipe. It is logical that the pressure here would increase, since the arching affect of the flexible pipe causes the vertical load on the pipe to decrease and force equilibrium requires a compensating increase elsewhere. Load cells in one set of large scale tests, and subsequent finite element analyses, found that this over-pressurization reaches a peak value of about 125% of the average vertical stress at a distance of one pipe diameter away from the pipe (Leduc & Smith 2004). Thus a more robust liner system maybe be required than would otherwise be indicated.

3.3 *Temperature affects*

Most copper leach operations are using bio-chemical processes to recover copper from sulfide ores. The biological reactions are exothermic and operating temperatures at the base of a large sulfide heap are estimated to reach up to 50°C. High temperatures soften thermoplastics which can weaken drainage pipes and soften geomembranes. Research for a major operation in Chile produced high load pipe deflection data that suggests that pipe deflection is not significantly affected by temperatures of up to 60°C (Smith et al 2005). However, geomembrane softening resulted in a significant increase in deformations under laboratory conditions, as shown in Photos 2 and 3 (neither sample was punctured). Samples of the same geomembrane were tested for 48 hours under identical conditions to simulated ore depths of 100 m, with only the test temperature varied.

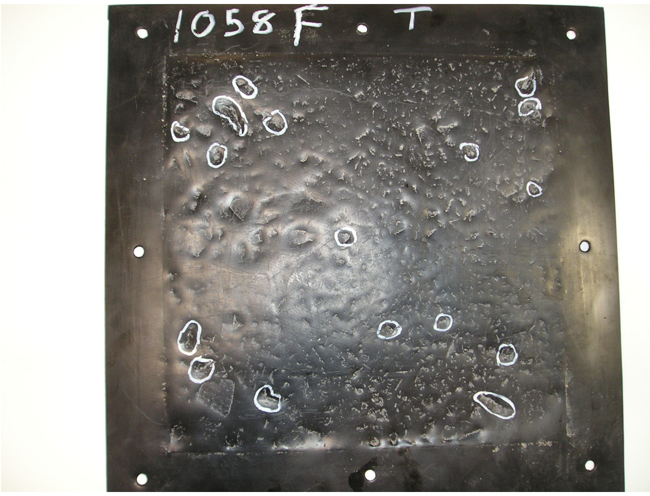

Photo 2: 1.5mm HDPE tested for puncture at 21°C.

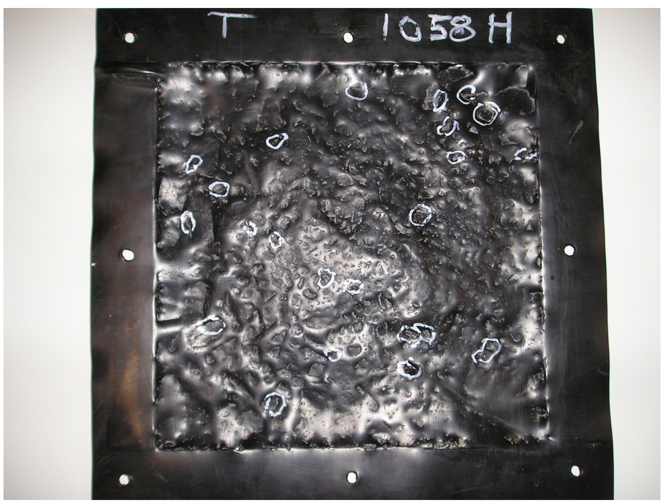

Photo 3: 1.5mm HDPE tested for puncture at 60°C

3.4 *Geoelectric leak location surveys*

Considering the value of the metals and reagents in leach solution, Theil et al (2005) has shown that geoelectric surveys make sense from a strict economic viewpoint without regard to the reduction in environmental, political and social risk. Nevertheless, the mining industry has been reluctant to embrace geoelectric leak survey technology, although that may be changing in recent times. One of the first applications of this technology to mining was a valley fill heap leach operation in Nevada in 1995, where placement of the overliner system was believed to have damaged the geomembrane. The technology is now becoming more commonly used in Chile, and the first applications in Perú and Argentina were at valley fill operations in 2005. Solar ponds in Chile are now commonly using geoelectric leak location surveys with 500 to 1,000 ha per year being surveyed. Informal data suggests that the typical frequency of defects found in these surveys, after conventional construction quality assurance, are 1 to 8 per ha.

CONCLUSIONS FROM 35 YEARS

The mining industry is using geomembrane liners more frequently in recent times for solar ponds, heap leach pads and tailings impoundments. Annual installation rates probably exceed 2,000 ha of base liner systems with additional geomembrane areas used for rain coats and interlift liners (in some cases these additional areas are significant). HDPE and LLDPE dominates the leach pad industry (with LLDPE increasing in market share annually) with 1.5mm to 2.0mm the most common thicknesses. PVC still dominates in the solar pond business, with 0.75 to 1.0 mm thicknesses most common; this seems to be changing with HDPE becoming more common. Emerging issues in heap leaching include: the extreme loads (soon to exceed 200 m of ore depth) applied to the geomembrane and drainage pipes; slope stability and earthquake response; zones of overstress on the geomembrane near drainage pipes under high loads; temperature effects especially with respect to geomembrane puncturing; and increasing use of geoelectric surveys.

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