The Use of Geomembranes in Chilean Mining Industry

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ABSTRACT: This article presents the main results pertaining to CQA programs on geomembranes lining more than 4 800 000 m^2 on 83 impervious works related to the Chilean mining industry. The mining industry operates many types of lined containment works using geosynthetics. Heap leaching is a technology using lined pads where crushed ore is leached with chemical solutions (cyanide for gold and sulfuric acid for copper) to extract the desired metal. Containment works used for heap leaching are leaching pads, ponds for pregnant leach solution (PLS) and ponds for water storage. Loss of solution through the liner system of heap leach pads and PLS ponds will produce environmental impact by ground contamination. Solar evaporation ponds, used extensively to concentrate brine and harvest crystalline salts from saturated solutions, are parts of a process for lithium, nitrate, potassium and iodine production. Very large solar ponds using PVC and PE geomembranes are exploited in Northern Chile including in the Atacama Desert. Liner's damages have direct impact on the loss of brine affecting the global process of salts precipitation. Containment ponds are also used for mine waste disposal and water (being a rare commodity in any desert). Leakage of process solutions is causing major economical and environmental impacts such that the mining industry adopts improved construction quality control programs to minimize the leakage rates. In this article the types of geomembrane materials used, the electrical leak location survey technique performed on exposed liners, the leak density observed, as well as an analysis of the type of leaks encountered are presented.

1. INTRODUCTION

Electrical Leak Location Survey (ELLS) technology has been performed over the past 20 years in environmental applications such as in landfills and containment ponds. GRI White Paper #8, January 2006 on "Construction Quality Assurance-Inspectors Certification Program (CQA-ICP)" inserted a section (#2.0) on ELLS to support that there is a direct relationship between leak occurrence and the presence or absence of a credible CQA program (Forget *et al.*, 2005). Recently, ELLS surveys have been introduced steadily in the mining industry to insure the integrity of their containment ponds and leaching pads securing environmental and economical impacts. Based on over 3 000 000 m² of geo-electric leak detection surveyed liner, it was concluded that increasing the liner thickness represents an easy solution to improved performance of geomembranes by six fold in some cases (Marcotte *et al.,* 2009). Results gathered from surveys performed over the last four years in 83 operating and under construction ponds in Chile have been used to demonstrate benefits of performing ELLS's on containment basins and ponds operated by the mining industry (Jacquelin *et al.*, 2008). In this paper, ELLS techniques are briefly presented and statistics regarding detected leaks in geomembranes are presented to support that the leak density decreases as the surveyed area increases. Also the results support that repair areas or patches bonded with solvent represent between 60 to 80 % of all detected leaks in thin PVC liners.

2. CONTAINMENT WORKS IN THE MINING INDUSTRY

The mining industry operates many types of lined containment ponds using PE and PVC geomembranes. Heap leaching is a processing technology using lined pads covered with crushed ore to be leached with chemical solutions. Geomembranes are installed at the bottom of the heap leaching pads, as liners in pregnant leach solution (PLS) ponds to contain the solutions and in water storage ponds. These ponds are lined to minimize environmental impact by contaminating the ground with chemicals and dissolved heavy metals. This contamination aspect becomes more important in the Northern desert region of Chile that is a virtually rainless plateau in South America, extending between the Andes Mountains and the Pacific Ocean.

Being the world's largest natural supply of lithium and sodium nitrate, solar evaporation ponds are used extensively to concentrate brine and harvest crystalline salts from saturated solutions in the production of iodine, nitrate, potassium and lithium. For example, very huge containment ponds lined with a geomembrane are exploited in the Atacama Desert such as shown in Figures 1 and 2 (Berube *et al.*, 2007). Damage to liners has a direct impact on the loss of brine, which is accountable by the Environmental Chilean Agency, affecting the global process of salts precipitation by disturbing the thermodynamic equilibrium in containment ponds.

Containment ponds are also used for mine waste disposal. Because works and mining process facilities are generally located where the mineral resource is being extracted, their waste disposal location cannot solely be based upon a site selection study. The Atacama Desert is the driest place on Earth, and is virtually sterile because it is blocked from moisture on both sides by the Andes Mountains and by coastal mountains. The average rainfall in this Chilean region is just 1 mm per year, and at one time no rain fell in the entire desert for 400 years. The water collected in the Andes must be conveyed to the mining sites by pipelines and stored in containment ponds, water being a rare commodity in any desert.

Figure 1. Picture of evaporation ponds

Figure 2. Picture of evaporation ponds

3. ELECTRICAL LEAK LOCATION SURVEY ON EXPOSED GEOMEMBRANE

ELLS performed on geomembranes have been described in many publications, such as Peggs (1989, 1990, 1993), Forget *et al.* (2005 a to c), Laine *et al.* (1989, 1991,1993), Jacquelin *et al.* (2008), Marcotte *et al.* (2009) and Rollin *et al.* (1999, 2002, 2004). They are recognized in standards such as ASTM D6747 (Standard Guide for Selection of Techniques for Electrical Detection of Potential Leak Paths in Geomembranes), ASTM D7002 (Standard Practice for Leak Location on Exposed Geomembrane Using the Water Puddle System) and ASTM D7007 (Standard Practices for Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earth Materials).

The water puddle method consists in the creation of a potential difference between a soil under an exposed geomembrane and a puddle of water projected from a diffuser onto the surface. Most geomembranes are highly resistant electrical insulators and inhibit electrical currents. As soon as water percolates through a perforation and reaches the supporting soil, a 'bridge' is created between these two potentials which generate an electrical current. A detector signals the presence of an infiltration to the operator (via acoustical and visual signals). This technique permits the detection of leaks with dimensions of 1 mm^2 or greater (ASTM D7002). On-site preparation is minimal and generally permits the survey to proceed during the geomembrane installation. The prospecting rate is approximately 5 000 m^2/day/operator, depending on site conditions. To achieve this survey rate, a continuous water supply of approximately 4 m^3/day/operator is necessary. This water supply may be provided from a tanker or a direct connection to a municipal network. If a water supply proves difficult, the use of a closed circuit with a low point is also possible. Figure 3 provides a general schematic of the water puddle method. A photograph of this technique, coming from a leak location survey in the Atacama Desert area, is shown in Figure 4.

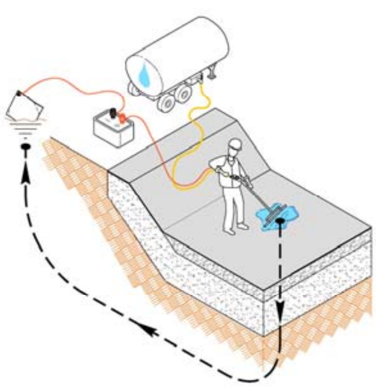

Figure 3. Water puddle technique on exposed géomembranes

Figure 4. Leak location survey using the water puddle technique

4. RESULTS FROM LEAK LOCATION SURVEYS

Leaks in a geomembrane are a result of many factors involved such as the installer experience and professionalism, the Quality Control procedures implemented during the installation, the geomembrane thickness, the subgrade quality and the pond design. The results obtained during Electrical Leak Location Surveys performed on 83 ponds located in 9 different mining sites are presented in Table 1. These sites are related to copper and lithium mining, totaling more than 4.8 millions m^2 of surveyed geomembrane. These surveys have been performed during the 2002 to 2008 period using ELLS techniques on exposed geomembrane (ref. ASTM D7002).

The ELLS's results have been presented by grouped projects with similar liner material. For example, the first line in Table 1 shows the survey results obtained in four ponds lined with 0.5 mm thick PVC liner. The given area represents the total area surveyed for the four ponds, as well as the total number of leaks detected.

It can be noted on the last line of the Table 1 that 3 506 leaks have been located with a mean leak density of 7.25 leaks per hectare (10 000 m^2) for the 4.8 millions square meters prospected.

Data collected in ponds lined with PVC geomembrane can be used to support that the expected number of leaks is inversely proportional to the liner thickness as shown in Table 2. Data issued from ELLS's on evaporation ponds lined with a 0.5 mm thick PVC geomembrane are compared with those obtained in ponds lined with a 0.75 mm thick PVC geomembrane. This comparison stands since all ponds were constructed with similar conditions: same soil conditions, same PVC formulation and supplier, same installer following proved Quality Control procedures, and huge covered areas. As expected, the leak density found in ponds lined with the 0.5 mm thick geomembrane (16.3 leaks/hectare) is four time greater than the one obtained in the ponds lined with the 0.75 mm thick geomembrane (4.5 leaks/hectare).

Data collected in ponds lined with a HDPE geomembrane cannot be used to support that the expected number of leaks is inversely proportional to the liner thickness as shown in Table 1 but can be used to support that there is a direct relationship between leak occurrence and the presence or absence of a credible CQA program (Forget *et al.*, 2005).

The percentages of leaks located in liners are presented in Table 3. Leaks have been reported as per their size and their location in the surveyed liner. For PVC liners, leaks located at chemical field seams such as performed at patches during the liner repair have been accounted independently from field dual-wedge seams and factory seams.

For PVC geomembrane of 0.50 mm thickness the majority of identified leaks have been located at patches where solvent bonding is used (see Table 4). For thicker PVC liner, such as for 0.75 mm thick, the leaks at patches and at seam represent respectively 1 % and 33 % of all detected leaks.

Table 1. Results from ELLS in mining applications in Chile

Type of geomembrane	Thickness (mm)	Number of projects	Total area (m^2)	Number of leaks	Leak density (leaks/ha)	Leaks per project	Occurrence (area/leaks)
PVC	0.5	4	1 145 000	2 127	18.58	531.8	538
PVC	0.5	1	444 886	472	10.61	472.0	941
PVC	0.75	2	600 000	267	4.45	133.5	2 239
LLDPE	1.0	5	9 951	25	25.12	5.0	383
HDPE	1.0	50	2 525 092	522	2.07	10.4	4 828
HDPE	1.5	12	92 362	79	8.55	6.6	1 155
HDPE	2	9	20 380	14	6.87	1.6	1 359
Total		**83**	**4 837 671**	**3 506**			
Average value					**7.25**	**42.2**	**1 380**

Table 2: Results from ELLS's on exposed PVC Geomembranes

Containment Application	Type of geomembrane	Geomembrane thickness (mm)	Total areas surveyed (m^2)	Number of leaks detected	Leak density (leaks per hectare)
Solar Evaporation Ponds	PVC	0.50 mm	1 589 886	2 599	16.3
Solar Evaporation Ponds	PVC	0.75 mm	600 000	267	4.5

Table 3. Leak distribution from ELLS at mining applications in Chile

Leaks			Puncture	Tear	Knife cut	Seam		
Size (mm)	Number	Percent				Field seam	Solvent (patches)	Factory fusion
PVC, 0.5 mm (444 886 m^2)								
0-5	371	78.6	0.0 %	6.1 %	5.8 %	14.3 %	52.4 %	0.0 %
6-25	39	8.3	0.0 %	0.6 %	0.6 %	1.5 %	5.5 %	0.0 %
26-100	54	11.4	0.0 %	0.8 %	0.8 %	2.1 %	7.6 %	0.0 %
> 100	8	1.7	0.0 %	0.1 %	0.1 %	0.3 %	1.1 %	0.0 %
Total	**472**	**100.0**	**0.0 %**	**7.6 %**	**7.3 %**	**18.2 %**	**66.6 %**	**0.0 %**
PVC, 0.5 mm (1 147 500 m^2)								
0-5	2 101	94.7	0.0 %	5.9 %	7.9 %	6.0 %	75.0 %	0.0 %
6-25	83	3.7	0.0 %	0.2 %	0.3 %	0.2 %	3.0 %	0.0 %
26-100	35	1.6	0.0 %	0.1 %	0.1 %	0.1 %	1.2 %	0.0 %
> 100	0	0.0	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Total	**2 219**	**100.0**	**0.0 %**	**6.2 %**	**8.3 %**	**6.3 %**	**79.2 %**	**0.0 %**
PVC, 0.75 mm (600 000 m^2)								
0-5	182	71.0	3.4 %	1.0 %	42.1 %	21.1 %	1.0 %	2.4 %
6-25	58	20.0	1.0 %	0.3 %	11.9 %	6.0 %	0.3 %	0.7 %
26-100	18	9.0	0.4 %	0.1 %	5.3 %	2.7 %	0.1 %	0.3 %
> 100	0	0.0	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Total	**258**	**100.0**	**4.8 %**	**1.4 %**	**59.3 %**	**29.8 %**	**1.4 %**	**3.4 %**
HDPE, 1.0 mm (2 183 754 m^2)								
0-5	54	17.7	9.5 %	2.2 %	1.1 %	2.7 %	0.9 %	1.4 %
6-25	165	53.9	28.8 %	6.7 %	3.3 %	8.1 %	2.8 %	4.2 %
26-100	65	21.3	11.4 %	2.6 %	1.3 %	3.2 %	1.1 %	1.7 %
> 100	22	7.1	3.8 %	0.9 %	0.4 %	1.1 %	0.5 %	0.6 %
Total	**306**	**100.0**	**53.5 %**	**12.4 %**	**6.1 %**	**15.1 %**	**5.3 %**	**7.9 %**

Table 4: Results from ELLS's on exposed liners

Material	Thickness	% leak located at patches	% leak located at field seams	% leak located in liner
PVC	0.50 mm	60 to 80 %	7 to 27 %	13 %
PVC	0.75 mm	1.4 %	34.1 %	64.5 %

The leak density for the 83 projects with surveyed areas varying from 600 to 2 000 000 m^2 is presented in Figure 5. Those results, as well as statistics published in other papers (Colluci *et al.*, 1995), support that the leak density decreases with pond area.

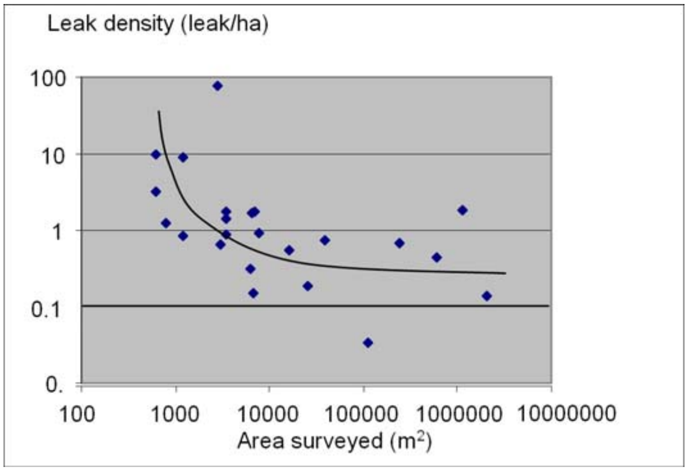

Figure 5. Leak density as a function of surveyed areas

ELLS data in Table 1 for thick HDPE geomembrane (1.5 and 2.0 mm) obtained on ponds having many years of operation support that the selection of a thick geomembrane does not guarantee low leak densities in all the cases Those results, as well as statistics published in other papers, support the geomembrane thickness influence on leaks potential. However the relation between geomembrane leak density and the application, or not, of a rigorous CQA program during installation and covering has been found to be crucial (Forget *et al.*, 2005a). The CQA allows a preventive control of leaks, and considerably reduces their number.

5. CONCLUSION

ELLS has been introduced steadily in the Chilean mining industry to insure the integrity of their containment ponds and leaching pads securing environmental concerns and economical impact. Data resulting from these surveys performed over more than 83 ponds indicate the necessity of performing ELLS during geomembrane installation. Data collected in ponds lined with PVC geomembranes can be used to support that the expected number of leaks is inversely proportional to the liner thickness and that the majority of identified leaks have been located at patches where solvent bonding have been performed for PVC geomembrane of 0.50 mm thickness. On a short term basis, leak detection allows to qualify the geomembrane and to ensure its integrity at the time it is put into operation. QA and electrical leak detection, when used jointly, are today the best guarantee of short and long term integrity of containment ponds using geomembranes.

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