Massive mining evaporation ponds constructed in Chilean desert

| The Salar de Atacama in Chile is the site of the largest PVC geomembrane installation in the world—more than 16 million ft.^{2} utilized in mining operations since 1996.

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Photos courtesy of Solmax International unless cited

Photo 1 | In constructing the evaporation ponds, after the PVC liner is deployed, electrical leak-detection tests are done (see page 32).

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Photos 2a and 2b | Air-channel testing of the field seaming (see page 31).

The largest PVC geomembrane installation in the world is so immense that it can be seen from an orbiting space shuttle. The site is in the arid and isolated Atacama Desert region in northern Chile where these membrane applications helped create huge salar ("salt") evaporation ponds. This is a project that extracts natural resources through evaporation and crystallization of naturally occurring brine solutions and develops them into products such as sodium nitrate, potassium nitrate, potassium sulfate, and other specialty blends.

Where in the world?

The Salar de Atacama is located at the foot of the Andes Mountains (68° 24' South, 23° 30' East) at an elevation of 7,000 ft. (2,130m) in northern Chile, covering an area of approximately 1,800 mi.^{2} (3,000km^2). This area is near the Atacama Desert, one of the driest regions in the world. The site is situated near Chile's borders with Bolivia and Argentina. One of the most mineral-rich stretches of the Atacama region is known as the Salar de Atacama.

The Atacama Desert is a sun-drenched, virtually rainless plateau at the foot the Chilean Andes. The Salar de Atacama is an ancient seabed underlain by large reservoirs of liquid brine that is home to the world's third-largest expanse of salt flats.

Sociedad Quimica y Minera de Chile S.A. (SQM), with headquarters in Santiago, Chile, is one of the world's largest producers of specialty fertilizers, iodine, lithium, and other industrial chemicals. Many of the components of those products are extracted from the geomembrane-lined salar ponds operated by SQM.

In 2004, SQM began increasing its production of potassium chloride with the addition of two 300,000m^2 evaporation ponds in the salar region, where operational and environmental concerns dictated the use of an impervious geomembrane system.

The process

SQM has two production facilities at the salar. To mine the potassium and lithium salts, large amounts of brine are pumped to the surface by wells. The pumped brine is conveyed via canals and directed into the large, lined evaporation ponds. Clouds rarely form or persist over this region, and the area is extremely windy, providing an ideal environment to evaporate the large amounts of water required to deliver the brine into the ponds.

As a first step in the extraction process, a number of large pre-concentration ponds are constructed where, by taking advantage of the evaporation process, a portion of the sodium chloride in the brine is allowed to precipitate as an "undesirable by-product."

Photo 3 | A brine-filled evaporation pond at the Salar de Atacama in northern Chile. This photo shows one of the ponds filled with brine and undergoing evaporation. A pumping station in the brine-filled pond is shown in foreground. In the background are piles of extracted sodium chloride salt, with the Andes Mountains in the far background of this shot.

After a residence time, the now-concentrated brine is pumped into production ponds where the dry salt-mineral produced is mechanically removed and stockpiled.

Some of the important salts precipitating from the brine are: sodium chloride, potassium (often used for fertilizer), lithium, and boric acid as a by-product. SQM is a leader in production of salts used in fertilizers and provides 35% of the world's lithium, a component for batteries, pharmaceuticals, and sapphire glasses used in jewelry and aeronautics applications.

Potassium and lithium are produced in different ponds via a three-stage process. The product is mechanically routed to an on-site, chemical-processing facility where the desired minerals are extracted. Then the extremely concentrated brine is pumped to a fourth-stage pond for recovery of boric acid.

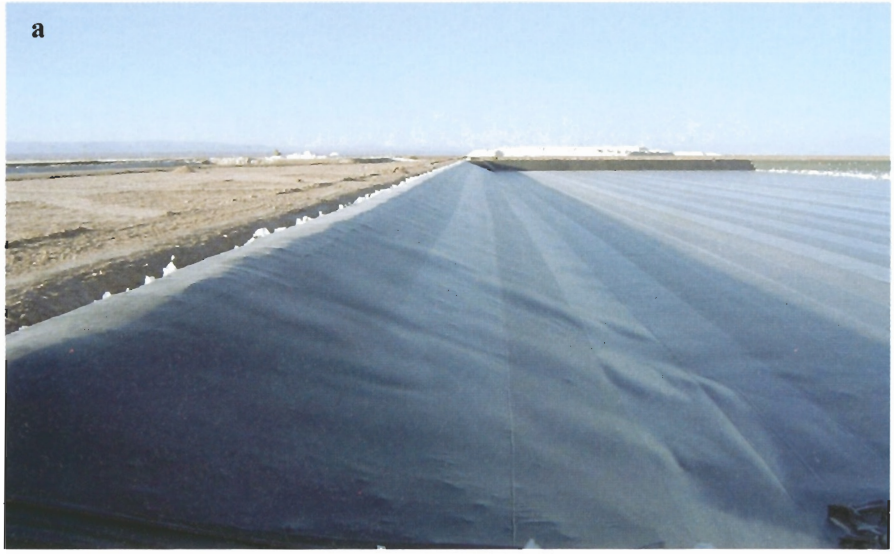
The underground brine is recharged, albeit at a reduced rate, by the melting snowcaps in the surrounding mountains. As the recharge water flows through the underground bedrock it dissolves the minerals in the sediment of the ancient seabed forming the concentrated brine. The concentrated brine is then pumped to the ground surface and contained in the ponds lined with PVC geomembranes.

Photo 3 shows one of the ponds filled with brine and undergoing evaporation.

After the water evaporates, the ponds are carefully mucked out, with the salts acting as a protection layer so the liner system is not damaged. For example, the bottom salt layer protecting the liner is sodium chloride in the ponds where sodium chloride is precipitating, potassium in ponds where potassium is forming, and lithium in the lithium production ponds. After the salts have been partially removed, the pond can be refilled and used repeatedly.

Holes in the geomembrane are extremely detrimental because the brine can flow out and return to the subsurface reservoirs. Not having holes in the geomembrane is important because it takes approximately one year to yield about 1m of salt, i.e., one year to evaporate a typical pond. Thus, losing brine and having to restart the process after patching a liner hole is time-consuming, costly, and reduces the annual production quantity.

In addition, holes in the geomembrane are difficult to detect because of the presence of muck, so it is imperative that the



Photos 4a, 4b, 4c | A new evaporation pond, with the final liner installation completed (a), the pond in preparation for the brine (b), and brine filling the pond (c).

geomembrane have excellent chemical resistance and resistance to pinholes in manufacturing, fabrication, deployment, and use. The properties that PVC has—high elongation and the tendency to drape around any protrusions on the compacted layer underneath the liner—helps minimize the occurrence of small holes and brine loss.

Photos 4a-c show the evolution of an evaporation pond, with the final liner installation completed **(a)**, the preparation for the brine to fill **(b)**, and the gradual filling of the pond with brine **(c)**.

These geomembranes are a likely choice for this application even though it is a harsh environment. The membranes are durable and offer excellent chemical resistance to the salts, which is important because of the long-term exposure of the geomembranes to the brine. PVC geomembranes also exhibit smaller wrinkles than some other geomembranes when installed because of a lower expansion coefficient, higher subgrade/geomembrane interface strength, flexibility **(Photos 4** and **5)**.

This is especially significant in this particular application because the smaller wrinkles result in substantial intimate contact between the geomembrane and subgrade and the protective salt layer. The benefit of intimate contact is a reduction in the lateral flow from a hole or leak in the geomembrane.

Liner system design and installation

The evaporation ponds have average dimensions of 10 ft.(3m) deep, 1,000 ft.(300m) wide, and 3,000 ft.(1,000m) long. The liner system of the first ponds consists of compacted soil PVC geomembrane. The current liner system utilizes nonwoven geotextile over a compacted natural salt layer PVC geomembrane.

To reduce field seaming in this harsh environment, the PVC geomembrane was fabricated into panels at the factory, a controlled environment that is more suitable for high-quality seaming than on-site at the salar. The panels are typically about 50 ft.(15m) wide and 1,000 ft.(300m) long when shipped to the site. Thus, the only field seaming required is the seaming of the panels. The panel size is usually limited by an allowable field handling weight, so a typical panel weighs about 6,600 lbs.(3,000kg).

The PVC geomembrane is field-seamed using a solvent or thermal fusion. With the thermal fusion method, a hot-wedge or hot-air welder is used. Thermal fusion is now the recommended technique because the produced seam can be air-channel tested if a dual-track weld is performed.

Testing of field seams and completed liner

A dual-track field seam was specified by SQM as the primary seaming method for the pond linings that were installed in 2004. Given the high cost of pumping and storing the brine, a seaming process that allowed the testing of the entire length of the field seams, instead of isolated areas with destructive samples, was sought. This resulted in the use of dual-track welds and air-channel testing of the field seam **(Photos 2a, 2b)**.

The air-channel testing of PVC field seams has gained popularity and provides a number of advantages over destructive testing of seams. One advantage is that the air-channel pressure can be used to verify the seam peel strength specified by the PVC Geomembrane Institute (PGI 2004) of 2.6 N/mm (15 lbs./in.), using the sheet temperature and a relationship presented by Stark et al. (2004) and shown in **Figure 1** (page 32). This relationship is incorporated into the new ASTM Standard Test Method D7177 (ASTM 2005) for air-channel testing of PVC field seams. Thus, if the air-channel holds the required pressure, the frequency of destructive sampling and testing is less.

The harsh desert environment produced sheet temperatures in excess of 158°F (70°C), making air-channel testing a challenge. Sheet temperatures greater than 158°F (70°C) are particularly challenging because the relationship between the air-channel pressure and the geomembrane sheet temperature for the PGI-specified seam peel strength of

Photo 5 | A 3.28-million-ft.^{2} (1-million-m^2) pond lined with PVC geomembrane filling with brine.

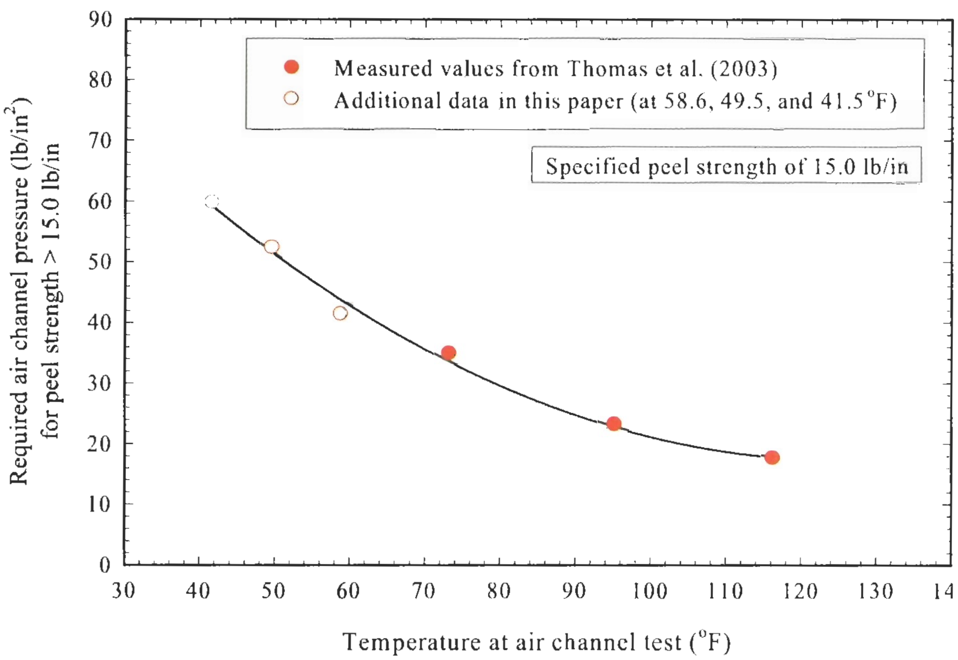


Figure 1 | Relationship between sheet temperature and required air-channel pressure to achieve seam peel strength of 2.6 N/mm (15 lbs./in.) from Stark et al. (2004)

2.6 N/mm (15 lbs./in.) in ASTM D7177 extends to a sheet temperature of 120°F (48°C), as seen in **Figure 1**.

Testing is currently being conducted to overcome this limitation. In the interim, the relationship shown in **Figure 1** (i.e., the relationship between air-channel pressure and geomembrane sheet temperature included in ASTM D7177) is extended to cover the range of sheet temperatures encountered on this project. Thus, the air-channel pressure required for the PGI-specified seam peel strength of 2.6 N/mm (15 lbs./in.) is about 60 kPa (9 psi) for a sheet temperature of 158°F (70°C).

Another advantage of air-channel testing of field PVC geomembrane seams is the flexible nature of these geomembranes that allows the inflated air-channel to expand like an inflated bicycle tube. This allows a visual examination of the entire inflated seam and identification of any seam defects even though the seam may pass the required air-channel pressure. These defects are usually visible on the outside of the air channel in the form of an aneurysm. The flexible nature permits the inspection of the air-channel as the air pressure migrates along the entire seam. If a defect is encountered, the inflation process will usually cease in the vicinity of the defect. This allows the entire length of field seam to be inspected and tested using the air-channel test procedure.

The project specifications initially required destructive field-seam tests every 1,000 ft. (300m) of field seam, but allowed the destructive samples to be obtained from the anchor trench and not on the production liner based on successful air-channel test results. This destructive sampling is significantly less frequent than traditional destructive tests that are conducted every 500 lineal feet (150 lineal meters) of field PVC geomembrane seam. The elimination of destructive samples from the production liner is noteworthy and should be adopted in other applications.

After the field seams are tested and approved, the integrity of the PVC geomembrane was also tested using electrical leak-location methods (**Photo 1, page 26**) to ensure the exposed geomembrane is defect free to protect the pumped brine. Electrical leak-location methods are readily used for these geomembranes and can locate extremely small defects.

Chile Ponds

Summary

The evaporation ponds in the Salar de Atacama region in northern Chile are lined with PVC geomembranes and they have performed well in this harsh environment. In addition, the use of a geomembrane-facilitated installation of a liner system in this dry and windy environment has succeeded because of the reduction in field seams due to the use of prefabricated panels.

The use of dual-track, thermal-fusion welds to create the field seams facilitated testing of the entire length of the field seam and omission of destructive tests on the completed liner with air-channel testing. Further, the use of prefabricated panels and fewer field seams resulted in completing the liners quicker than using 7m-wide geomembrane sheets, and that expedited the initiation of the evaporation process and generation of revenue. An average of 325,000 ft.^{2} (30,000m^2) of PVC geomembrane was deployed, welded, and tested on a daily basis.

SQM's Salar de Atacama evaporation ponds represent the largest PVC geomembrane installation in the world to date with more than 16 million ft.^{2} of geomembrane installed and utilized since 1996.

Acknowledgments

PVC manufacturer:
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QA/QC and electrical leak detection:
Solmers International Inc.

References

ASTM D 7177, 2005, "Standard test method for air-channel testing of field PVC Geomembrane Seams," American Society for Testing and Materials, West Conshohocken, Pa., USA.

PVC Geomembrane Institute (PGI), 2004, "PVC Geomembrane Material Specification 1104," University of Illinois, Urbana, IL, www.pvcgeomembrane.com, January 2004.

Stark, T.D., Choi, H., and Thomas, R.W., 2004, "Low Temperature Air Channel Testing of Thermally Bonded PVC Seams," Geosynthetics International Journal, Industrial Fabrics Association International (IFAI), Vol. 11, No. 6, December, pp. 481-490.