Electric leak detection and leak location on geosynthetic liners in the mining industry

Shawn Calendine
Hydrogeophysics, Tucson, Arizona, USA

Nigel Crook
Hydrogeophysics, Tucson, Arizona, USA

Chris Baldyga
Hydrogeophysics, Tucson, Arizona, USA

ABSTRACT: Geosynthetics are an integral component of the mining industry and are routinely used as containment barriers in the mining process. Physical examination of the many different varieties of geosynthetic liners can suggest that these materials are a robust barrier; however, when subjected to the harsh mining environment, they can be easily damaged. Consequently, the potential for leaks to occur over the lifespan of these containment systems is high. Left undetected, these leaks can increase the risk of shutdowns, regulatory fines, and extreme remediation costs. While the theory of electrical leak location works the same for many geosynthetic lined systems, proper consideration towards the potential challenges may determine the survey's success or failure. In this paper we will present an overview of geosynthetic leak location methods, and possible challenges related to the leak location process~~ss,~~ for fluid covered and earthen covered liners associated with containment structures in the mining industry.

1 INTRODUCTION

Beginning in the 1970s, solar ponds were likely the first large-scale use of geosynthetics in mining (Breitenbach & Smith 2006). Since then, geomembrane liners have rapidly become accepted as standard components of geosynthetic lining systems in the mining industry, primarily in ponds, heap leach pads, and tailings piles (Breitenbach & Smith 2006). With the development of large-scale geomembrane containment structures for industrial uses came the derivative need to ensure their integrity, as their primary function is to act as a competent barrier between the subsurface of the earth and the constituents they contain. To this end, construction quality assurance (CQA) standards were developed to abate leaks in geomembranes that may occur during the construction processes. The CQA process typically includes third party construction oversight along with non-destructive testing (air channel,~~ and~~ vacuum box~~ testing,~~ and spark testing), destructive testing (seam testing), insta~~i~~llation documentation, and visual surveys of completed construction. Studies by Forget et al. (2005) and others 'demonstrate the importance of quality assurance, by the fact that it helps prevent the formation of leaks during the construction process' (~~B.~~ Forget et al. 2005). However, the CQA process alone is not capable of ~~eradicating~~ finding all leaks during the construction process, and therefore, an additional method of leak detection is necessary to ensure the integrity of a liner before it is put into operation. Combining the CQA process with geoelectric leak detection is 'the best guarantee of short and long term integrity of a containment works using geomembranes' (Forget et al. 2005~~B. Forget 2005~~).

Geomembrane leak location surveys have been commercially available since 1985 and industry standards have been developed for the various implementations (Kemnitz 2013). The basic premise of geoelectrical integrity surveys is that electrical current will flow along the same pathways as water, i.e. galvanic currents will follow conductive pathways and be impeded by resistive pathways. Therefore, the distribution of injected current depends upon the electrical properties of the geosynthetic liner, substrate, and cover material. Geomembranes are typically highly resistive and act as an electrical sheet insulator while substrates and cover material (earth, water or both) are highly conductive in comparison.

Additionally, for impoundments such as ponds and piles in the mining industry, both substrates and cover boundaries designed for geosynthetic lined structures are highly homogeneous. As such, injected galvanic current distribution will be fairly uniform across these structures and current density will steadily decrease over distance. Electric leak location is governed by the inverse relationship between the conductive nature of boundary materials and the highly resistive nature of most geosynthetics. A hole then breaches the liners resistive nature, creating a local region of high conductivity. Accordingly, the electric potential relative to a hole in the liner is significant and measurable, while current levels remain low and uniform across intact and undamaged liner.

In theory, this methodology works as long as there is adequate connectivity through the hole into the substrate and the receiver is sensitive enough to measure a high localized current density symptomatic of a hole in the liner. While simple in concept, it is the application of this technology that can be fraught with challenges and frustration if the many different factors needed for a successful geoelectric survey are not met. The following sections discuss the state-of-the-practice for electrical leak location methods for geosynthetic lined systems on mining sites and several challenges associated with them. Although there are numerous potential challenges that may occur, the authors of this paper focus on more common challenges encountered during leak location surveys on currently in-use solution covered liners (ponds) and newly earthen covered liners for heap leach pads and tailings piles.

2 METHODS

2.1 Bare Liners

For completeness, as bare liner leak location techniques they are occasionally used to locate leaks in operational active containment systems such as heaps, ponds, and tailings, the following is a brief discussion of the water puddle and water lance leak location methods used on exposed geosynthetic liners, or bare liners.

Sensitive enough to detect pinhole sized leaks, both methods work by creating a circuit using a power source, water, and an ammeter between the liner to be tested and its substrate. Induced electric current is delivered via water through a mobile device that sprays the charged water source onto the liner, with the power source providing the electrical current being grounded to the substrate below the liner. When the charged water flows through a hole in the liner and contacts the substrate, the circuit closes and the ammeter, detecting the closed circuit, emits an audible tone to alert the operator to mark the area for repair.

When conducting either a wWater pPuddle or wWater lLance lLeak lLocation test, cover material, liquid, and deposits such as silt, sand or other debris need to be completely removed from the testing area. The cleaning process for these materials can damage the liner and create more leaks, as debris removal may involve pressure washers, industrial vacuums, shovels, and other tools. Consequently, using this method of leak detection is expensive and poses a risk for additional damage from the cleaning process for lined structures already in use. Exposed geosynthetic liner electric leak location testing is typically used for newly installed liners and can be a required part of CQA when constructing new geosynthetic lined containment systems.

2.1.1 Water Puddle

WThe ater puddle leak location methods are described in ASTM D7002 Water Puddle Leak Location. The water Thispuddle method uses multiple low pressure nozzles that distribute a thin even sheet or mist, creating small connected puddles. Water puddle methods are typically used for flat areas and gentle slopes.

2.1.2 Water Lance Leak Location

~~The~~ Water lance leak location methods are described in ASTM D7703~~ Water Lance Leak Location~~. The water lance consists of a single nozzle emitting a single stream of water at moderate pressure, and is intended for~~ extreme~~ slopes, vertical walls, and large wrinkles.

2.2 Covered Liners

Over the last 30 years the geosynthetic leak location industry has developed various types of proprietary data acquisition devices that use the dipole or pole measurement method. Typically, the equipment requires intensive and highly skilled interaction with a human operator. Both fluid covered and soil covered methods are described in ASTM D7007. As mentioned in the introduction, leak location on covered liners uses the cover media to distribute current from the current source electrode and measurements are made to locate potential distribution changes relative to a reference electrode. Current is applied to the survey area via a generator or battery operated equipment. The current source supplies steady regulated electric current delivered via two electrodes (conventional current flow); one is placed into the soil or water column on top of a liner and the other is grounded to the conductive media under the liner.

It is extremely important to understand the engineering and construction of the structure to be tested. This is because~~ the~~ modern mining site uses a variety of engineering and ~~construction~~assembly techniques to build containment facilities based on a host of factors such as geology, chemistry, regulatory requirements, and cost~~.~~. Therefore, how a site is constructed will influence how leak location methods are applied and their potential success. Additionally, it is critical to understand what type of liner is being used and whether the system is single or double lined. For example, whether the containment system is single, double, or composite lined dictates where current electrodes are located. If single lined, the second electrode would be placed in the soil adjacent to the lined system; if double lined, the second electrode would be placed between the two liners in the annulus.

2.2.2 Earthen Material Covered Liners

The methods are described in ASTM D7007 Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earthen Materials. For soil covered surveys, an operator~~ hand~~ carries a lightweight frame that typically stands approximately waist high and may consist of two or four supporting legs. The feet of the device are electrodes typically spaced at a distance of 0.5 to 3 meters. The electrode spacing distance is determined based on the methodology needed to support individual site characteristics for optimal leak location. During the survey, electrodes are pressed into the substrate by the operator and a single measurement taken. The operator then picks up the device and moves it a predetermined distance forward in a linear fashion and takes another measurement. When a voltage spike is observed across the positive electrode in the equipment's display the operator acquires additional data in the potential leak area to narrow down the leak location. Once a potential location is determined, the operator marks the site and then resumes the original survey pattern until another voltage spike occurs, signaling another potential leak response.

2.2.1 Fluid Covered Liners

The methods are described in ASTM D7007 Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earthen Materials. For fluid covered impoundments (ponds), the fluid level is lowered to a reasonable depth so an operator can safely wade through the water column. While the same in concept as above, devices for ponds are slightly different to allow for better movement through water. Some companies use a towed probe; however, the more common approach is to wade through the water column using a device analogous to the classic metal detector. Lines are evenly spaced at intervals predetermined for optimal leak detection ability. Typically, when the electrical field changes, an ammeter detects the closed circuit and the change is visible in a display or an audible tone is emitted alerting the operator to a hole in the liner.

For both earthen and fluid covered liners, a sensitivity or leak detection distance test is performed to determine maximum grid line separation within the system being surveyed and for the specific type of equipment used. The test may include an artificial or actual leak and the procedure is detailed in ASTM D7007. The leak test site should remain in the same place and active throughout the survey as a reference point and the location should be reoccupied at the beginning, middle, and end of each working survey day. The reoccupation of the test site ensures that conditions within the survey area remain favorable for optimal leak location and assures that the equipment is functioning correctly.

3 CHALLENGES

The classic leak detection and location approach detailed in the ASTM D7007 works well if application methods are strictly followed, complex site conditions are effectively mitigated, and equipment operators are highly trained. Without active consideration for (these) key factors, and procedures set in place for monitoring and mediating potential challenges, the likelihood of a successful integrity test is drastically reduced.

While the list of challenging factors can be extensive, the scope of this paper is to discuss areas of concern that are not widely discussed in electric leak location literature. The authors consider issues associated with human error, equipment limitations, resolution in conductive substrates, and signal shadowing to be the most critical and common causes of an unsuccessful leak location survey. Furthermore, as the fundamentals of electric leak detection & location are fairly consistent across applications (bare, soil covered, and fluid covered) the authors will write in terms of challenges with all applications.

3.1 Human Error

In any scientific endeavor, human error is fundamentally the key component for success or failure. Industry standards such as ASTMs do not eliminate human error in application of method, acquiring data, interpreting data, or proper use of technology (Kemnitz –2013). A simple lack of experience in understanding the complexities of applying leak location methodology and acquiring appropriate usable data are obvious concerns in the industry. Below are some key factors that can determine the success or failure of leak location surveys. These factors are also highly prone to human error as they require a high degree of knowledge of leak location methodology and fundamental scientific principles involving physics, hydrology, and electrical engineering.

3.1.1 Boundary Conditions

Boundary conditions for electric leak location surveys consider all the elements in contact with the margins of the geosynthetics in a lined system. The 'condition' of these boundaries refers to how well the substrates below and above the liner can carry current, and the quality of electrical isolation in the area to be surveyed. It is the influence between the electrical properties of the substrates and resistive nature of geosynthetic liners that governs electric leak location. For example, fluid filled or metal pipes, soil bridges, or other electrical pathways connected to the survey area can bleed electrical current used in the leak detection process out of the survey area, reducing sensitivity beyond the ability of the sensors to detect. Conversely, if the substrate below the liner is dry and deisiccatedsected or contains resistive materials such as sand and aggregate mixtures, the flow of electric current may be strongly opposed, limiting measurable current.

Making sure the boundary conditions are acceptable when performing a survey is solely dependent on the operator's knowledge and attention to basic electrical principals. Consequently, missing key aspects of boundary conditions are a key concern and challenge with the leak location process.

3.1.2 Survey Equipment Set Up

-Of all the possibilities for human error in the process of leak location, incorrectly setting up the equipment may be one of the most common mistakes. While this typically does not lead to an unsuccessful survey, it can prolong the survey as the trial and error process is worked through during initial setup. Contemporary systems lack integrated checks and alarms letting operators know the system is working correctly. Therefore, setup requires that operators pay close attention to how they assemble equipment and perform initial testing procedures.

3.1.3 Geometry

In the mining industry, the size of lined containment structures such as ponds, heaps, and tailings piles can be significant. Ponds can be from a few acres to an order of magnitude larger, whereas heaps and tailings piles can be hundreds of acres in size. The larger the survey area, the more geometry of the leak location array matters. Additionally, variations in the resistive and conductive nature of fluid or earthen material covering liners may help or hinder the flow of current. If operators collect data beyond the viable survey area, current levels associated with leaks may be below the sensitivity of the detector.

3.1.4 Survey Line Separation

The leak detection distance depends on the leak size, the conductivity of the materials within, above, and below the leak, the electrical homogeneity of the material above the leak, the output level of the excitation power supply, the design of the measurement probe, the sensitivity of the detector electronics, the distance away from the leak, and the survey procedures (ASTM D7007). Sensitivity testing in the beginning of the survey considers the above ~~ASTM~~ factors, and when performed correctly, survey line separation is optimal. Challenges arise when operators do not recognize, correlate, and resolve all of the factors listed~~above factors~~. Additionally, economic considerations can enter the equation when cost is considered. Clients may request a larger line separation due to cost, regardless of a reduction in survey resolution, as closer line spacing may make a survey more costly.

3.1.5 Consistent Reoccupation of Initial Leak Test Site

The leak test site serves two important purposes for leak location surveys. First, the leak test determines the spacing between grid lines; second, the site is used as a local base station, where operators repeat a periodic sensitivity test to ensure site conditions have not changed and equipment is working properly. Each time an operative sensitivity test is performed, all data acquired between effective tests is considered acceptable. Should a test be unsuccessful, survey conditions will need to be corrected and data acquisition will need to be repeated based on the last successful test. The leak test site should be reoccupied at the beginning, middle, and end of each day at minimum. Not reoccupying the test site on a regular basis may lead to large portions of the survey area being untested because site characteristics or equipment functionality changed. Conventional leak location equipment is compartmentalized and divided into separate components that are independent of each other. Thus it is possible for one component to malfunction ~~or fail~~ while the operator continues the survey unaware of the failure.

3.1.6 Exhaustion and Complacency During Physical Data Acquisition

Exhaustion and fatigue are always a concern with any task and leak location surveys can be particularly demanding given the nature of large industrial complexes such as mine sites. These survey sites are typically large areas on uneven, slippery, or potentially unstable terrain exposed to inclement weather. Leak location survey operators often work in strenuous conditions for long hours performing repetitive physical movements and tasks. The ruggedness and repetitive nature of data acquisition can lead to complacency with regard to sensitivity tests and overall awareness of equipment functionality, recording errors in note taking, including missteps as simple as forgetting which survey line the operator is acquiring, and survey geometry errors.

3.2 Equipment Limitations

While human error is the common weak link in any course of action, the other notable weak link is limitations of leak location equipment. These include limitations such as low level automation, reduced survey area, limited resolution due to hole size, and difficulty with measurement in particularly conductive substrates.

3.2.1 Low Level Automation

Contemporary leak location equipment for covered systems is typically divided into two separate components: a current injector (transmitter) and a current detector (receiver). While both devices are used in concert, the fact that they are not connected means that system checks are operator-dependent rather than system-dependent. This means the operator is never completely aware of the functionality of the system during the survey. For instance, if the power supply (battery or generator) fails, the operator may be unaware that it has failed and continue the survey as if the full system is functioning. Similarly, if the detector malfunctions, the operator may not know until a system check or sensitivity test is performed. In either case, large areas could be surveyed without the operator knowing the system is not working, both extending survey time and missing potential leaks.

3.2.2 Survey Area Limitations

Survey area limitations can be an aspect of equipment limits. In general, with pond surveys, fluid depths need to be lowered to levels that an operator can operate in easily. However, because the fluid is necessary for the leak detection system to function properly, the total survey area is reduced to the water level of the pond. This means that large areas of the lined containment system go un-surveyed. For material covered liners in mining, such as tailings piles and heap leach pads, leak location equipment is limited by the depth of the material. As the depth of material increases, and since the injected current density will decrease with increasing depth, at some depth the resulting signal cannot be distinguished from background noise. This depth of investigation will be dependent on a combination of the injected current level, the conductivity of the cover material, and the moisture content of the cover material.

3.2.3 Resolution in Conductive Substrates and Signal Shadowing

Resolution limitations of leak detection systems can also create challenges. This occurs due to signal attenuation and signal shadowing. In the first case, conventional leak location systems can break down in highly conductive solutions or substrates. This is because current leaking through a hole where the media is highly conductive is attenuated to such an extent that the signal falls below the detector's ability to resolve it. In the second case, it is extremely difficult to resolve smaller holes in close proximity to larger ones. This is due to the large signal propagation associated with larger holes. When a large tear or puncture occurs, it intuitively creates a much larger signal pathway for available current. The high current flow floods the immediate area, shadowing or obscuring the location of smaller holes nearby. Leak location sensors in the vicinity of the large hole and propagating signal cannot distinguish the smaller signals within the high current area, as only the largest signal will be recorded.

4 CONCLUSION

For the mining industry, the development and use of geosynthetics has increased mineral production while reducing environmental impacts. However, with any new technology comes the additional necessity of ensuring quality and monitoring long term integrity. While industry standards have been developed for electrical leak location methods on geosynthetics, purveyors and consumers alike need a shared understanding of the capability and limits of both geosynthetic liners and conventional leak location technology. Successful leak location surveys depend not only on the performance of operators and equipment, but also on the understanding of interrelated key factors based on design, contents, and technological limitations. The current application of electric leak location methods are complex and require highly trained competent operators with considerable background in the geosciences. However, even with the best trained operators and quality equipment—, the application of this technology can be fraught with challenges and frustration if the many different factors needed for a successful geoelectric survey are not met.

While challenges exist with contemporary geoelectric leak location, there are solutions that can reduce human error, and improve equipment functionality. For instance, developing leak location equipment that condenses the technology into a single system where system functionality and data quality is continually monitored to ensure accurate reliable data acquisition; including alarms and warning systems to alert operators to problems with system functionality or operator errors; developing semi-automated data acquisition systems to reduce human error and increase safety, while making surveys consistent and repeatable. Automation and equipment advancements may also increase investigation areas, as ponds can be filled to capacity for more robust surveys and material covered liners can be surveyed at greater depths. Additionally, there needs to be a concerted effort to move away from traditional real-time leak location methods that rely exclusively on the subjective decision-making process of operators of the equipment, but rather to a process of stored data that is subsequently processed and analyzed for leak responses. Finally, improving data processing and analysis to confirm leaks, reducing false positives, will advance the state of liner leak location now and in the future.

Contemporary electrical leak location for geosynthetic lined systems is not only a viable method to detect and locate leaks in geosynthetics, it is also instrumental in reducing environmental challenges related to the mining process, while reducing costs and enhancing production for the industry as a whole. However, the current state of electric leak location is ripe for improvements - to solve longstanding challenges which limit the method's ability to locate leaks in liners within the wide variation of site engineering designs, construction practices, and containment contents.

REFERENCES

ASTM D7002 Standard Practice for Leak Location on Exposed Geomembrane Using the Water Puddle System.

ASTM D7007 Standard Practices for Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earth Materials.

ASTM D7703 Electrical Leak Location on Exposed Geomembranes Using the Water Lance Method.

Breitenbach, A.~~-~~J., Smith, M. E., P.E. 2006. Overview of geomembrane history in the mining industry. *Proceedings of the 8th bi-annual meeting of the International Geosynthetics Society (8IGS).*

Kemnitz, M.P.~~, Leak.~~ 2013. Removing Human Error from Geomembrane Leak Location Surveys. *Geosynthetics 2013 April 1-4 Long Beach, CA*

Forget, B., Rollin, A.L., Jacquelin, T.~~,~~ 2005 Impacts and Limitations of Quality Assurance On Geomembrane Integrity. *Sardinia's 2005 Conference Proceedings, Cagliari, Italy*