In-depth comparison of exposed geomembrane leak location methods

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ABSTRACT: Leak location methods are commonly used on impervious works; however, the selection of the leak location method to be performed is not always a well-informed decision that takes into account the given project particularities. Are all methods therefore equal? If not, then how do they compare in terms of precision and complexity, and are there circumstances under which some methods are simply inappropriate?
This paper will compare three electrical leak location methods that are used on exposed geomembranes to validate 100% of the installed geomembrane: water puddle (ASTM D7002), arc testing (ASTM D7953), and spark testing (ASTM D7240). To begin, a description of each method will be given, detailing how each works. Then, based on field experience, indoor testing, and ASTM standards, an assessment of each method will be given based on how well or poorly adapted it is to certain common scenarios (e.g. on slopes, on top of wrinkles, on dirty/wet surfaces, and on different types of geomembranes, if applicable).
The goal of this paper is to give pertinent information to the industry, and to assist stakeholders in selecting the most appropriate leak location method based on site parameters, weather, access to a water source, type of liner to be surveyed, speed, accuracy, autonomy of batteries, setup time, and limitations (wrinkles, dirty or wet geomembrane etc.).

Keywords: Electrical leak location, Dipole, Liner Integrity Survey

1 INTRODUCTION

Understanding the nuances of the various electrical leak location (ELL) methods can be difficult, particularly when it comes time to select the most appropriate method for a project.

Although ASTM standard D6747 does provide a good general overview of the available methods, it does not necessarily address certain site-specific conditions that may influence the effectiveness of the methods and does not consider that most leak location companies develop their own equipment. Many of the parameters discussed are therefore different from one company to another, including typical speed of survey, cost, advantages, and limitations. It can therefore be difficult for a non-expert interested in an exposed liner integrity survey to select the best method.

Additionally, ASTM D6747 states that pinholes can be located with any method, so if they are all equally accurate, which parameter should influence a site owner to choose one method over another? Should the electrical leak location specialist alone choose the method, based on his experience with similar types of projects?

With 17 years of leak location experience, I am often asked which method would be best to use, or if it is preferable to perform a survey on a conductive geomembrane rather than on a traditional HDPE, PVC, or bituminous geomembrane (BGM). The answers to these questions are not simple or universal. In order to objectively weigh the methods, one must both fully understand all of the methods and know all of the project specifics. This paper will focus on three exposed leak location methods: water puddle method (WPM), arc test method (ATM) and spark test method (STM). The water lance method will not be discussed, as it is, in our opinion, obsolete and not nearly as efficient as the other three.

2 METHOD DESCRIPTIONS

2.1 *Water puddle method (ASTM D7002)*

The WPM (ASTM D7002) relies on the intrinsic insulation properties of geomembranes for the detection of small perforations (<1 mm²) in the geomembrane, generally produced at the time of the installation (see following figure). A continuous DC voltage is applied into the metallic water puddle structure, and a grounding electrode is placed outside the limits of the geomembrane. In the presence of a leak, the current will pass from the metallic structure, through the defect, into the subgrade and to the grounding electrode, thus producing a visual and auditory signal. This technique requires only a thin film of water on the surface of the geomembrane and provides a validation of the entire exposed surface surveyed.

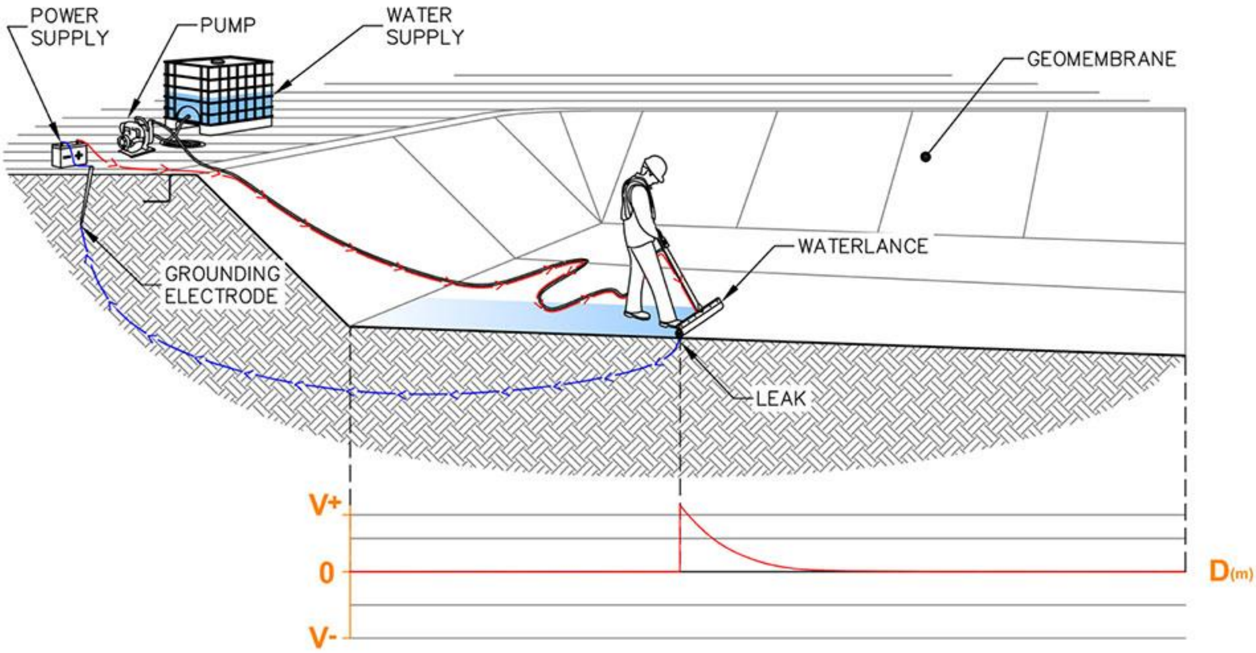

Figure 1. Water puddle method schematic

2.2 *Arc test method (ASTM D7953)*

As with the WPM, the ATM (ASTM D7953) relies on the intrinsic insulation properties of geomembranes for the detection of small perforations (<1 mm²) in the geomembrane, generally produced at the time of the installation (see following figure). A high voltage is applied to the arc test wand and a grounding electrode is placed outside of the limits of the geomembrane. No conductive medium, such as water, is required when performing the survey. In the presence of a leak, the current will create a spark that originates from the wand, passes through the defect into the subgrade, and terminates at the grounding electrode. An auditory signal will then be produced. This method provides a validation of the entire exposed surface surveyed. Since a spark acts as the contact between the wand and the subgrade, this technique is not limited by the degree of slope of the subgrade, as may be the case with a water-based leak location method.

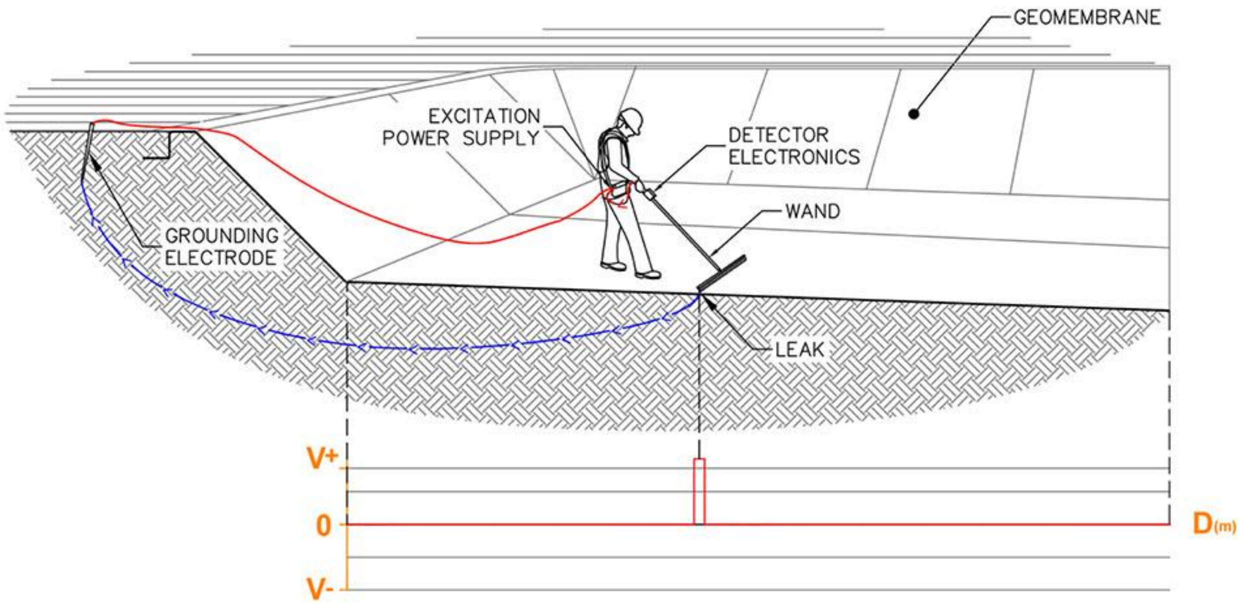

Figure 2. Arc Test method schematic

2.3 *Spark test method (ASTM D7240)*

Through co-extrusion technology, a polyethylene geomembrane can be manufactured that is electrically conductive on one side and non-conductive on the other. This geomembrane can then be surveyed for leaks using the STM. To perform the survey, the non-conductive side of the geomembrane must be installed face-up. A very high voltage power supply is used to charge an element (up to 36,000 V), such as a conductive neoprene pad, and through the capacitance effect, the electric charge is transferred to the conductive layer of the geomembrane. A conductive probe is then swept over the geomembrane's surface. When the probe passes over a leak, the high voltage causes a spark to pass through the hole, and a noise is generated. Depending on the area to be surveyed, different equipment is used: small, hand-held detectors are used in confined areas and large detectors are used generally on large, open areas. With this method, leaks as small as 1 mm^2, and sometimes smaller, can be detected.

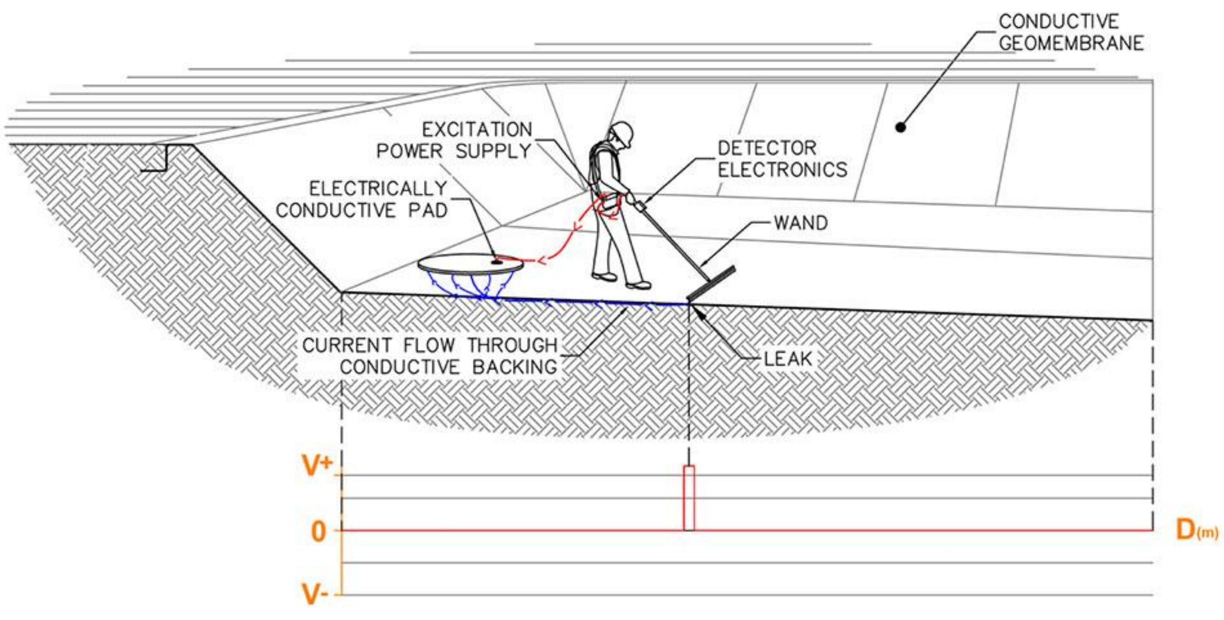

Figure 3. Spark Test method schematic

3 LABORATORY SIMULATIONS TO DETERMINE THE COMPATIBILITY OF THE VARIOUS METHODS WITH SOME COMMON SITE CONDITIONS

Controlled laboratory tests were conducted to confirm field observations that common site conditions can affect the functioning of the various ELL methods.

3.1 *Type of geomembrane, compatibility*

Firstly, the type of geomembrane to be installed can dictate the ELL method.

The WPM can be used on any geomembrane that is not entirely conductive. Ethylene Propylene Diene (EPDM), which is conductive throughout, would not be compatible, however, a “conductive geomembrane”, traditionally used with the STM, would be.

In contrast to this, the STM can only be used with conductive HDPE liners, as it was designed solely for that purpose.

While the ATM should work on all types of geomembranes, there have been instances where enormous, and unlikely, defect rates (~300 leaks/ha) have been reported on bituminous or PVC geomembranes. Because the voltage is high (up to 35,000 V), if the geomembrane is at all porous (cracks or air bubbles) or is simply thin, then an arc can make its way through the liner and create a pinhole.

3.2 *Wrinkles*

With the exception of BGM, wrinkles form in most geomembranes when exposed to heat or the sun. Generally speaking, intimate contact with the subgrade—the conductive medium—is required for most leak location methods.

One advantage of the STM is that the conductive medium is joined to the geomembrane and thus would also wrinkle. Therefore, for the purposes of leak location surveys, conductive geomembranes do not need to be in contact with the subgrade. However, since the sparks are generally less than two centimeters long, the entire wand ending must be in contact with the surface being surveyed. The operator must therefore survey perpendicularly to the wrinkles, which can be time consuming.

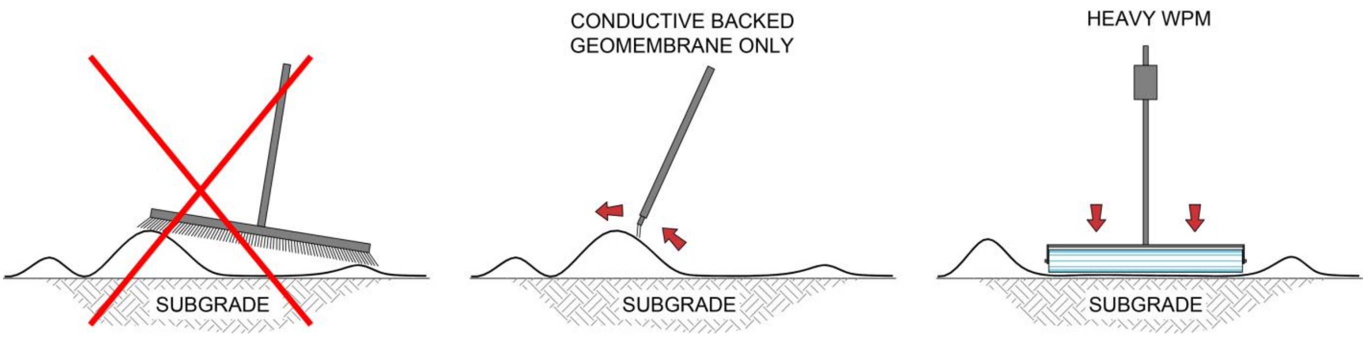

Figure 4. Survey over wrinkles

The equipment used for the WPM is usually heavier and studier than the equipment used for either of the high voltage methods; its weight alone can flatten small wrinkles and it can be pushed down on by the operator to ensure the necessary contact with the conductive subgrade. This is not possible with STM equipment, as it is less robust and charged with up to 35,000 V.

Not much can be done to mitigate the effect of wrinkles with the ATM aside from performing the survey early in the morning or at night when temperatures are cooler, as stated by Beck (2015): *“(...) an electrical arc will not form if the arc tester probe is too far away from the subgrade, as would be the case over a wrinkle. For both methods, effort is made to push down the wrinkles, or the survey is performed at night.*”

3.3 *Leaks on wet and/or dirty geomembranes*

While a clean and dry geomembrane is preferable when performing the WPM, it is a necessity when performing either of the high voltage methods. Because a spark will only occur on a dry surface, if a leak were located in a puddle during an ATM or STM survey, the equipment would not produce an electrical arc. The operator would therefore be left with the false impression that there was no leak in the puddle. With the WPM, however, a leak in a puddle can be detected, but the exact location of the leak must then be determined visually or once the surface has dried and been re-surveyed. Either way, if a leak were confirmed in a puddle, the area would nevertheless need to be dried in order to perform the repair.

Dirt (sand, dust, etc.) on a liner might trigger alarms or false positives with the high voltage methods as the electrical current discharges in the dirt. With the WPM however, the alarm will only sound if a hole is present. As with puddles, however, it may be necessary to clear the membrane in order determine the exact position of the leak.

Laboratory tests were conducted on both standard HDPE geomembrane and on conductive HDPE geomembrane that had 1 mm holes punched in them. Firstly, the clean liners were tested using all of the methods. Then the ATM and the STM were used to test the liners with dry sand overtop top (inherently the sand would not remain dry with the WPM method). Finally, all of the methods were used to test the liners with first wet sand overtop and then with a puddle overtop.

Results were straightforward with the WPM: under all of the conditions an obvious leak signal alarm was produced as soon as the electrical path from the structure to the hole was obtained.

The voltages used for the ATM and the SPM ranged from 800 - 34,000 V, with increments between 500 - 5,000 V. For the ATM, all tests conducted at 5,000 V or less produced negative results, meaning that the minimum tension for a spark is likely greater than 5,000 V. For the STM, a minimum of 15,000 V was required. The rest of the collected data for the STM and the ATM was ambiguous; sometimes a leak signal was heard when approaching a puddle but the alarm did not sound when the equipment was inside of the puddle and other times it did, and sometimes no leak signal was produced at all. The only firm conclusion was that STM never worked in the puddle; the rest is an accumulation of false positives and random signals.

3.4 *Slopes*

On slopes greater than 3H:1V, water tends to flow down the geomembrane rather than through any holes. As such, the STM and the ATM are the preferred method for steep slopes. The laboratory tests conducted on inclined bench-tests showed that the efficiency of the WPM greatly depended on the speed of the survey and the size of the hole. Decreasing the survey speed on slopes is therefore recommended to improve the chances of successfully finding small leaks.

3.5 *Low temperature survey (below 0 Celsius)*

At temperatures below zero, when the water in the subgrade freezes and becomes non-conductive, traditional ATM and WPM surveys are ineffective. However, if another conductive medium is used, such as a conductive geomembrane or conductive geotextile underneath the liner, then any method can be used. Performing a WPM survey in freezing conditions engenders many challenges since water is used. The hoses must have a constant flow of water through them, in order to prevent them from freezing, extra care must be taken when walking on geomembrane with a thin layer of ice, and finally, the hoses and the equipment must be drained completely at the end of the day or prior to taking a break.

4 OTHER FEATURES PROPER TO EACH METHOD

ASTM D6747 has a simple, structured table providing a variety of information on the three methods discussed in this paper, including the compatibility of the methods with different types of geomembrane and typical survey speeds. Below are some aspects not touched upon in ASTM D6747.

4.1 *Safety and hazards*

The WPM is the most physically exacting method for the operator, with the heavy equipment (lance and hoses) posing the greatest risk: muscle strain. The hoses and wet geomembrane also pose a slip, trip and fall hazard.

The other two methods carry an increased risk of high voltage shocks: no special permit or training is required to purchase or rent the equipment and certain brands are more prone to producing shocks. For projects in the oil and gas industry (which has strict static and shock policies when there is a risk of gas release in the environment), it is advisable to use the WPM, which can be used safely as its power source is less than 50 V.

4.2 *Water Puddle Method pros and cons*

4.2.1 *Advantages*

The greatest advantage of the WPM is its simplicity. Unless there is electrical interference and background noise to overcome, no field adjustments are required; the presence of a leak will trigger an ON/OFF response.

The second advantage is that leaks can even be located when they are in puddles or under dirt. Although it is not ideal to survey on a wet or dirty geomembrane, it is the only method that will work under these conditions. In addition to this, a very low voltage and current power source is required: a few 9 V batteries joined together provides a maximum of 50 mA, which is sufficient and will last for months.

Finally, generally speaking, the greatest survey speed can be attained with the WPM. This can be highly variable, however, and dependent on specific equipment properties and various field factors (width of the structure, helpers to pull the hoses, ratio of slopes, number of leaks found). Additionally, since the equipment uses water, it is easy to see what has been surveyed, so no area is surveyed twice, and no area is missed.

4.2.2 *Limitations and drawbacks*

The primary disadvantage of the WPM is the need for water: it typically requires two to four cubic meters of water per day. This can cause issues in areas where water supply is limited, thereby increasing the price or delaying the work. For landfill extension, the water can flow into the existing leachate collection system, creating additional leachate to be treated and higher costs. Similarly, if the installer is deploying downslope of the area to be surveyed, the water can flow into the work area and disrupt the work. This last can be mitigated by keeping a two-panel buffer when working on relatively flat areas, or by performing the survey after the installation has been completed.

Because a conductive layer must be directly in contact with the geomembrane being surveyed, the WPM cannot be performed on the primary layer of double-lined system that only has a drainage geosynthetic (e.g. geogrid) underneath, without some adjustments. The secondary drainage layer can be flooded with water to become conductive, but this can lead to complications (floating geomembrane, dry elevated areas). Alternatively, a conductive geotextile or geomembrane can be installed, but this must be planned in advance.

4.3 *Arc Test Method pros and cons*

4.3.1 *Advantages*

The main advantage of the ATM is that the set-up is quick, and the equipment is light, easy to manipulate, and compact for transportation. No extraneous equipment, such as hoses, is required. Additionally, no water is required with this method, which may reduce costs particularly if water is scarce.

Finally, both the ATM and STM are more effective than the WPM at detecting pinholes. With the water-based equipment, sufficient water must be able to pass through a defect in order to produce a signal, but the high-voltage methods only require holes large enough for an electric arc.

4.3.2 *Limitations and drawbacks*

The greatest disadvantage of the ATM is that the geomembrane must be dry and clean; in other words, freshly installed. Natural materials can cause false positives, and, more alarmingly, water on the geomembrane can be a safety concern due to the high voltage. Even with small puddles, if a leak is present it will be impossible for the ELL operator to know. If the wand contacts the leaky puddle, the battery will discharge but not produce enough resistance to create a spark—similar to a short-circuit—and the leak in the puddle will not be noticed.

The high voltage can also be a hazard to the geomembrane itself. The sparks have been known to puncture bituminous geomembranes, as well as thin PVC and LLDPE geomembranes; therefore the liner selected must be compatible with the ATM. A test pad is recommended to ensure that the sparks will not create pinholes and that real holes can still be found.

The ATM has the same difficulties with double-lined systems as the WPM. While flooding of the secondary drainage layer has not been tested with this method—and therefore cannot be attested to—using a conductive geomembrane would still be an effective bypass. And again, the temperature must be above 0 °C, otherwise a conductive geosynthetic must be used.

As detailed in section 3.2, a significant limitation of the ATM is the inability to survey when wrinkles are present. There must either be no wrinkles at all (night survey) or a custom ending must be used that can deform and follow the wrinkles, and maintain full contact with the geomembrane at all times.

It is also a must for an audible alarm to sound when a spark is generated. It is easy to miss a hole when relying only on visual or auditory indication of a spark on a construction site in broad daylight.

4.4 *Spark test*

4.4.1 *Advantages*

The main advantage of the STM is that a conductive geomembrane is planned for in advance, and therefore the conductivity of the subgrade/natural materials underneath is inconsequential. However, that is mainly an advantage of the conductive liner itself, as both the ATM and WPM can be used with the conductive geomembrane. The difference being that the STM "connects" with the conductive backed sheet via a conductive neoprene pad and capacitance effect, while the other two methods require direct contact with a wire. Testing a single sheet and then moving the wiring to the next one decreases productivity and may not be possible if a panel does not extend into the key trench along the edge. However, the panels can be bridged together with face-up pieces of conductive geomembrane, in order to have a single electrical connection, allowing for large areas to be surveyed.

Another advantage of the STM is the equipment's ease of portability/manipulation. The equipment is light, and the neoprene pad is moved with the survey, so there are no wires or hoses connected to the exterior. This is an advantage for large cells, where large lengths of hose and wires are required. This mainly benefits the ELL operator however, and does not necessarily impact the efficacy of the survey itself.

4.4.2 *Limitations and drawbacks*

With regards to the STM, the two mains limitations are that it only works on conductive HDPE geomembranes and, as with the ATM, requires a dry and clean surface.

While the following limitations are brand-specific, due to the limited number of brands available, site owners should be aware of them.

The greatest drawback of the equipment tested was the complexity of the detector. While the WPM and ATM operates as an ON/OFF system (either there is a current loop or not), the STM detector measures the amount of energy drawn by the battery, instead of the energy that goes out or into the wand where there is a spark. Furthermore, there is always a current circulating as the neoprene pad charges the geomembrane and current variations when the neoprene pad is moved or when the dirt on the geomembrane is charged.

The exact current consumption necessary to ignore these variations must be determined when setting the alarm. If the threshold is too high, however, actual sparks will not consume enough power from the battery in order to trigger the alarm. There are a finite number of threshold levels on the equipment and, depending on site conditions, one level may ignore real leaks while the next level will regularly produce false positives. Although this is mainly an issue for the operator, as it can cause delays and frustration, it is important for site owners to be aware that this survey is not necessarily straightforward. Subcontracting the leak location survey to the installer, or any contractor other than an experienced third-party leak location company, poses the risk that the survey will be done poorly. It can be tricky determining the proper settings in order to actually locate leaks, particularly small ones, but it is very easy to turn on the equipment, not adjust the settings, "survey" the liner, and claim that the liner is leak free.

Finally, the equipment tested had a very low battery life (approximately three operating hours), without any option to change the battery or use an external battery pack. This can be a huge drawback on sites, particularly if an area must be surveyed immediately to avoid delays but the battery is dead.

5 CONCLUSION

Electrical leak location is not absolute and each method's precision and efficacy will vary depending on site conditions and the operator. Additionally, there are several suppliers/equipment models available for the various methods and each has its own particularities. This article was based on equipment made by Groupe Alphard, as well as ATM and STM kits sold in the US. As such, many of the limitations mentioned in sections 3 and 4 can be overcome with customized leak location equipment.

Based on field experience, as well as the tests conducted in the laboratory, we would recommend the following types of surveys, all other conditions being equal:

- Mostly slopes, or slopes steeper than 3H:1V: ATM or STM;
- Wet or dirty geomembrane: WPM;
- Double-lined systems: STM;
- Large surfaces: STM;
- Chemical sites with potential release of explosive gas: WPM;
- Temperatures below freezing: STM;
- All remaining (standard) conditions: WPM, or whichever the ELL company is most comfortable with.

It is easy to think that a proper leak location survey is being performed, and claim that a liner has no holes, if one is unaware of the nuances of the various ELL methods. It is far more challenging however to maximize the efficacy of a leak location survey in order to have the greatest chance of finding the smallest of defects.

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