Lessons learned on the Performance of Multi-Linear Drainage Geocomposites for Mining Applications

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ABSTRACT: Tailings dewatering is a permanent concern for responsible mining companies. Soft and wet tailings can generally lead to stability issues in retaining ponds or dams, excessive environmental footprint because of their high water content and therefore a high volume to storage, and finally can increase the total process costs to a level that can eventually break the fragile equilibrium of the operation. This situation has become among the key issues to be solved, with higher environmental pressures and regulation authorities, as well as a market struggling since almost a decade. Traditional drainage geocomposites are commonly used in applications where the flow to be drained is average, the loads on the product are in the order of 500 kPa and the fines content of the soil to be drained is low. This paper presents a review of laboratory evaluations conducted on Multi-Linear Drainage Geocomposites (MLDG) to assess their applicability in tailings dewatering. Three studies were conducted. First, transmissivity tests were performed under very high normal loads, up to 2MPa, to reflect normal loads actually experienced in tailings and dams. Long-term flow tests were then conducted during 90 days. In addition, filtration tests modeling the mechanisms involved in the deposition of tailings in a slurry form were performed, using a modified version of ASTM D5101. A scale test has been conducted in Morocco accordingly. All these tests were found to be conclusive and confirmed the applicability of MLDG for tailings dewatering applications. A case study of a recent project in Canada will be presented as well.

1 INTRODUCTION

Management of tailings is one of the major operational and environmental challenges faced by the mining industry. Indeed, the consolidation rate of the high water-content tailings is generally limited by their high physical stability and low hydraulic conductivity. Extended laboratory work conducted in the last 7 years has shown that the use of Multi-Linear Drainage Geocomposites can accelerate the dewatering rate of tailings. Further to these laboratory evaluations, a full scale test was performed in Morroco and demonstrated the good functioning of a range of drainage's geocomposites for a better recovery of the water from the dikes and a good stability of the walls of proceed phosphate water flotation basins.

Multi-Linear Drainage Geocomposites (MLDG) have been used for decades in civil and environmental applications. This paper presents a series of studies conducted to assess their performance in mining applications.

The MLDG used in this study is described on Figure 1. It includes the following components:

- A non-woven geotextile, which acts as a filter. This layer is typically selected with consideration to the gradation and properties of the overlying material, with opening sized ranging from 44µm to 200 µm or more.

- A series of corrugated, perforated polypropylene tubes. The number of tuber per unit width can be adjusted to fit specific project's needs. These tubes provide most of the drainage capability of the product.
- Another non-woven geotextile, which is selected as a cushion, to protect the underlying geomembrane from puncture when exposed to coarse, angular gravels. This layer may also provide a secondary drainage medium.

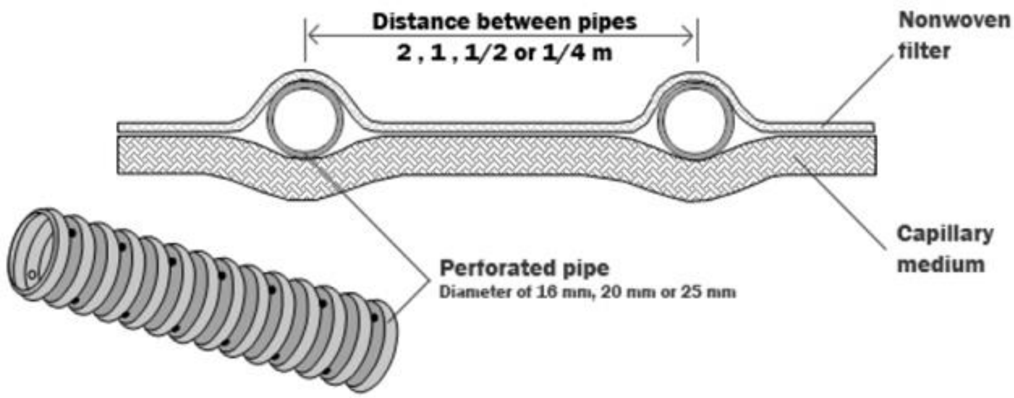


Figure 1 Multi-Linear drainage geocomposite

2 LABORATORY STUDY

2.1 *Long-Term Flow Test – for heap leach pad applications*

2.1.1 *Concept of the experiment*

Heap leach pads (HLPs) are among the world's largest man-made structures. The ore is typically staked at heights in the range of 40 to 70 meters, by successive 5 to 10 meters lifts (Breitenbach et al. 2005). Thiel and Smith (2004) even report heap leach pads 150 m and 230 m high in South America. Heap leaching is a mineral processing technology where large piles of crushed rock are leached with various chemical solutions that extract valuable minerals. This technique is used for copper, gold, nickel and uranium. The mined ore is crushed and heaped on a lined impermeable pad and irrigated with a leaching solution for an extended period of time (weeks, months or years). As the solution gradually percolates through the ore heap, it dissolves the valuable mineral, producing what is known as a 'pregnant solution'. This solution is collected at the base of the heap leach pad where a drainage base of crushed rock and embedded perforated pipes is installed above the liner system and below the ore heap. The importance of this drainage base cannot be overemphasized. This layer has to:

- Protect the geomembrane liner against puncture,
- Allow efficient removal of the ore-bearing solution from beneath the heap, and
- Ensure stability of the structure by maintaining a low hydraulic head, while preserving a high friction angle of liner interfaces.

In terms of structure, heap leach pads essentially consist in a liner and a drainage system, which are designed to permit recovery of the pregnant solution leaching through the ore. Considerations are also given to the global stability of the system, which may be affected by the performance of the drainage systems as well.

Filtration application in HLPs and more generally with mine residues may be challenging for geotextiles. First, the high seepage forces and suspended particles that must be filtered can lead to the blinding or clogging of the geotextile filter. Second, circulation of the pregnant solution can lead to chemical clogging (Faure, 2004; Fourie et al. 2010; Legge et al. 2009).

Long-term flow tests were conducted in SAGEOS laboratories in Canada to observe the performance of DTPG when subjected to acid circulation at a concentration representative of those used in the mining industry during 3 months. To run this test, 10 test cells (0.1m x 0.2m) were designed to replicate field conditions prevailing on the MLDG (Figure 2). The filter used was a polyester filter with a filtration opening size of 120 µm (per CGSB 148.1 n°10). The MLDG was installed at in the bottom of the cell, and then covered with by one kilogram of crushed copper ore with an average grade of 3% Cu from a Chilean copper mine (Lomas Bayas). The ore was covered by a geo-spacer to facilitate uniform infiltration of the solution. This latter component was then covered by a closed-cell foam pad, compressed by a rigid plate, in order to seal the system while applying a nominal stress of 100 kPa.

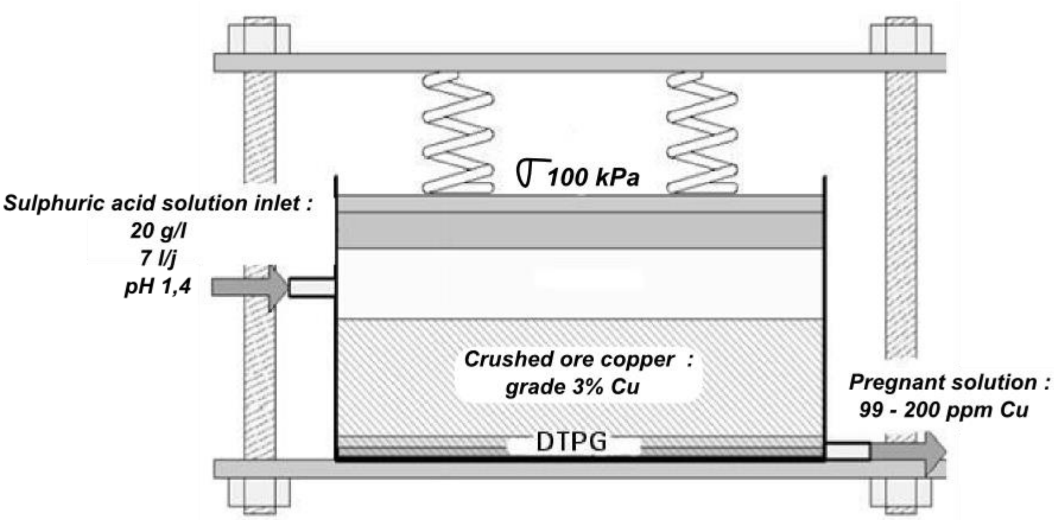


Figure 2 Cross-section of an experimental leaching cell. During 90 days, acid leachate percolates through the ore then the MLDG

An average daily flow of 15 L/h/m² of the 20 g/l sulphuric acid solution with a pH of 1.4 was recirculated during 90 days through each cell.

The solution was injected through the geo-spacer, in order to flow downward through the ore, then the MLDG, to eventually be drained out by the perforated tube. During the testing period, the solution was replaced 3 times to avoid excessive copper concentration and facilitate control of the pH, which was maintained to approximately 1.4.

The representativity of the extraction process modelled at the laboratory scale was assessed by monitoring periodically the copper concentration of the sulphuric acid. The observations are reported on Table 1.

Table 1 Copper concentration in the leaching solution during experiment

Days of leaching	Copper concentration (ppm)	Copper recovered (g / kg of ore)
20	267.5	2.40
40	120	1.08
60	122.5	1.10
80	111.5	1.00
90	99	0.89

These observations confirmed that the chemical reaction which is expected to take place in a leach pad was actually taking place at the laboratory scale.

2.1.2 *Flow rate*

The flow rate was monitored to determine the evolution of the hydraulic properties i.e. to observe a possible clogging of the system. Results are expressed as an ‘equivalent flow rate under a hydrostatic head of 5 mm'. This value does not have any significance by itself and cannot be related to the in-plane transmissivity of the geocomposite nor the permeability of the filter. However, it can be used as an indicator of the clogging of any component of the system, such as:

- Blinding or clogging of the filter;
- Clogging or collapse of the drainage media.
- Overall degradation of the product, i.e. chemical dissolution or any other issue

Figure 3 shows a typical flow rate curve as it has been monitored over time for each of the cells that were tested.

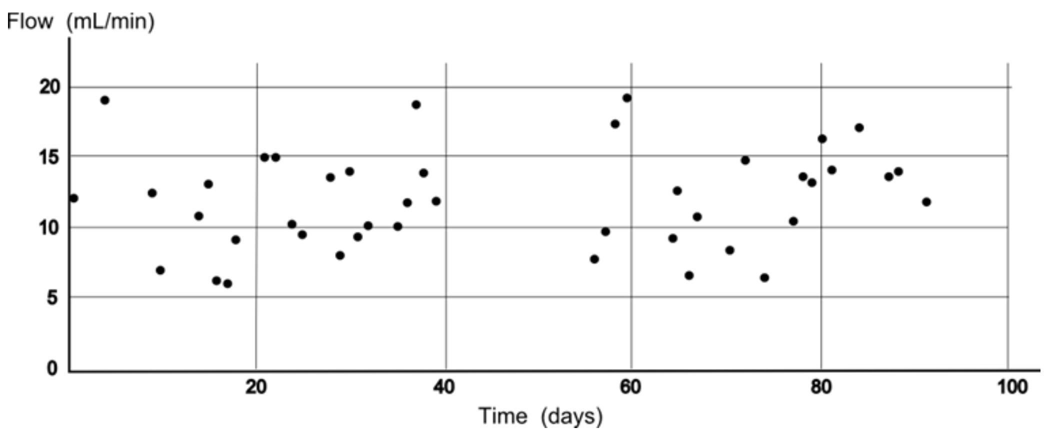


Figure 3 Typical flow rate under a hydraulic head of 5 mm.

From Figure 3, it is possible to observe that the flow rate remained relatively constant over time, which suggests that no clogging did occur and that the MLDG maintained its functionality over the duration of the test, or 90 days.

2.1.3 *Observation of the geocomposite at the end of the test*

After 3 months of continuous flow in the conditions described above, cells were dismantled to permit visual inspection of the geocomposites. Once observed that the integrity of the drainage pipe and perforated pipe had been fully maintained, three observations were made during these inspections:

- Quantity of particles retained on the upper geotextile (filter), making sure to remove the particles that were on top of the geotextile but not the embedded ones;
- Quantity of particles retained on the lower geotextile as well as trapped between the two geotextiles;
- Quantity of particles retained into the pipe.

A quantity of 80 g/m² of particles in average was observed into the upper geotextile, while only 10g/m² were found on the lower geotextile. On the other hand, the perforated drainage pipe was found to be completely free of particles.

Following these observations, permittivity tests were conducted on the filters. The tests were conducted with a hydraulic head of 10 mm to avoid excessive pressure that could have washed out the embedded particles. With these conditions, a reduction in permittivity in the range of 10% was observed, confirming the visual observation of a geotextile looking almost 'clean' on its inner side, compared to the outside, as can be seen on Figure 4.

Figure 4 external and internal view of the geocomposite after 3 months of percolation of sulphuric acid

2.2 *Behavior under high compressive load*

Compressive load on the drainage layer can reach 2 MPa (Thiel and Smith, 2004; Castillo, 2005). For traditional planar geocomposites involving a planar drainage core (such as biplanar or triplanar geonet), it has been shown by several authors that the hydraulic properties of these geosynthetics are adversely affected by such high compression stresses. Creep resistance is indeed a component that is taken in consideration in the selection of such products, and can be evaluated with ASTM standard D7341. However, Saunier et al. (2010) have shown that the particular structure of MLDG is favorable to the development of an arching effect around the pipe. This statement was made following the observation that transmissivity is not affected by compression stress, nor by time. Their results are reported on Figure 5.

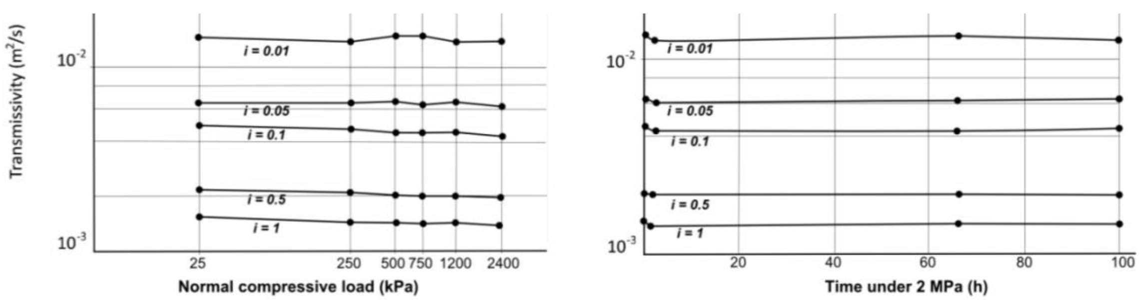


Figure 5 Transmissivity under different loads up to 2 Mpa and 100 h (i = hydraulic gradient) (after Saunier et al, 2010)

2.3 *Filtration Compatibility with tailings*

Tailings are conveyed to their storage facility in a slurry form. Slurries are highly challenging materials for geotextile filtration as the presence of a high concentration of fines segregated from the soil may create a cake on the surface of the geotextile, and reduce its permeability thus endanger the efficiency of the system and the geotechnical stability of the facility.

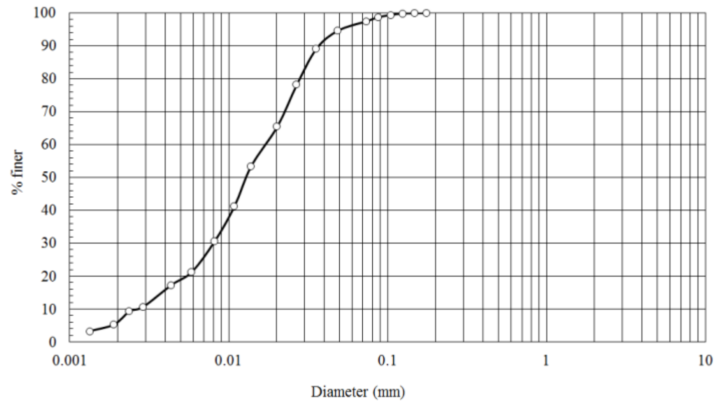
To assess the filtration behavior of the geotextile used as a filter in the MLDG, a modified gradient ratio test was developed to model the mechanisms prevailing at the time the slurry is deposited on the geotextile filter. The following hypotheses were considered to develop the experiment:

- First, the slurry reaches the geotextile with a solid / water ratio of 72% water / 28% solid – for the particular case that was analyzed.
- In the early stage of the slurry / geotextile interaction, the water head will be similar to the height of the slurry, and the system will settle.

- Eventually, more material will reach the deposit, and increase the water head, and eventually hydraulic gradient prevailing in the vicinity of the interface.

Considering these hypothesis, a testing strategy was developed, using a testing apparatus conforming to ASTM D5101, modified in order to model the above described scenario.

A slurry was prepared to the prescribed solid / water ratio, using the tailing which particle size distribution is presented on Figure 6-a. To initiate the test, this slurry was deposited in a liquid form (Figure 6-b) on the surface of the geotextile filter, selected for its filtration opening size of 60-70 µm (per CGSB 148.1 n°10). This led to a total head of about 300 mm above the geotextile.



(a) Gradation

(b) consistency for deposition

Figure 6 Gradation of the tailing

A valve located downstream the geotextile was opened immediately to initiate the test, by connecting the downstream section of the test cell to a container with a free surface maintained at a height of 150 mm above the geotextile. Given that, the initial conditions prevailing were a water (slurry) head of about 300 mm upstream the geotextile, and 150 mm downstream. A 'slurry head' of 150 mm was thus applied on the geotextile filter, initiating a flow through the geotextile at the same time the slurry was settling. Hydraulic head were monitored under the geotextile, at distances of 25 and 75mm and above the slurry, as well as the flow rate. This stage, combining a falling head and sedimentation of the tailing, was maintained until stabilization of the upstream head to 150 mm = same as the downstream head. During that stage, the soil / geotextile interface developed its structure in a fashion similar to what is likely to be taking place on-site.

After stabilization, the upper portion of the test cell was closed, and the standard gradient ratio test was initiated using the standard apparatus (Figure 7), using a hydraulic gradient of 1.0. During the test, the same hydraulic head were monitored, under the geotextile, at distances of 25 and 75mm and above the soil/slurry, as well as the flow rate.

Figure 7 Set-up of the filtration test (Gradient Ratio, ASTM D5101)

As there is no precise limit differentiating a ‘soil’ from a ‘slurry’ during the deposition stage, it was not possible to determine a flow length in the porous media, thus to calculate a permeability of a soil, geotextile, or obviously the slurry. It was thus decided to determine a ‘permittivity’ of the entire system, by dividing the flow rate by the total water head. This value was considered to be a sufficient indicator to observe a trend, i.e. an increase or a reduction of permeability over time. It is also a convenient way to normalize the flow rate to the water head, to analyze the geotextile interface behavior during the slurry deposition stage of the test.

Results and observations are presented in Figures 8 to 10.

(a) after 5 minutes (b) after 15 minutes (c) after 2 h 45 min (d) after 66 hours

Figure 8 Settlement of the slurry during the first stage of the test

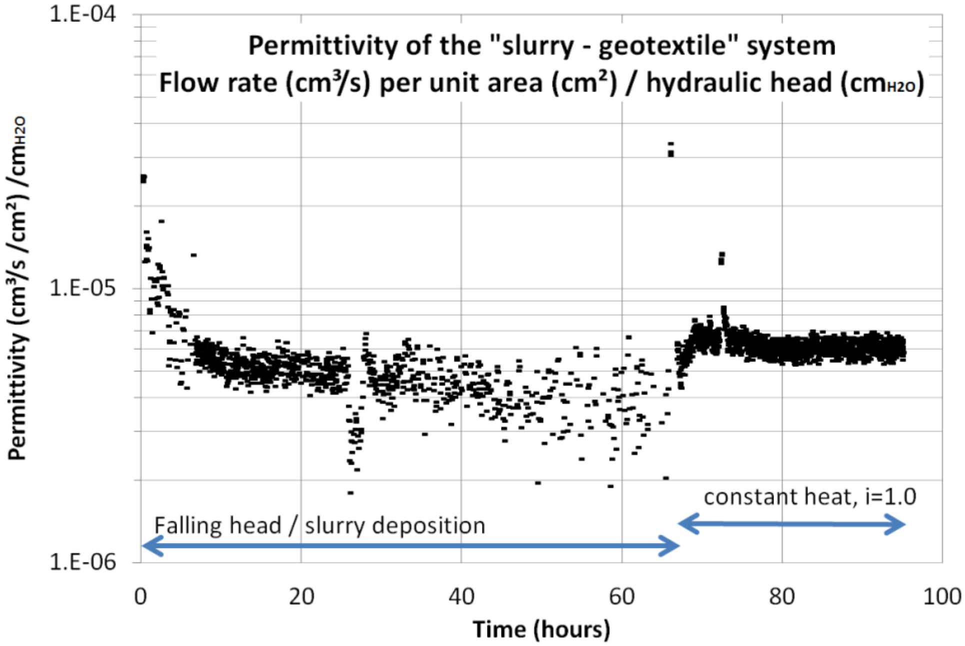


Figure 9 Permittivity versus time

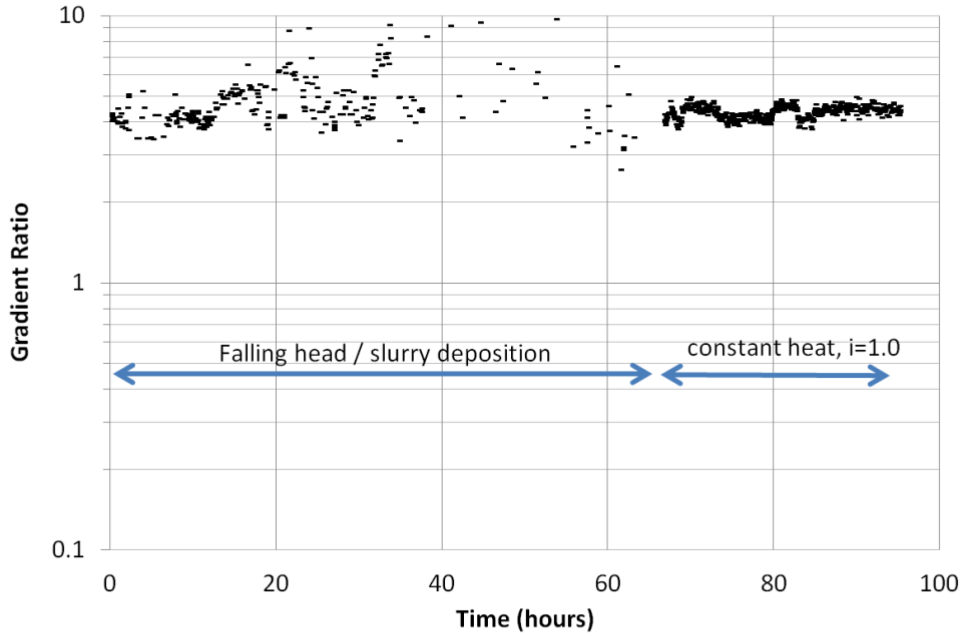


Figure 10 Gradient ratio versus time

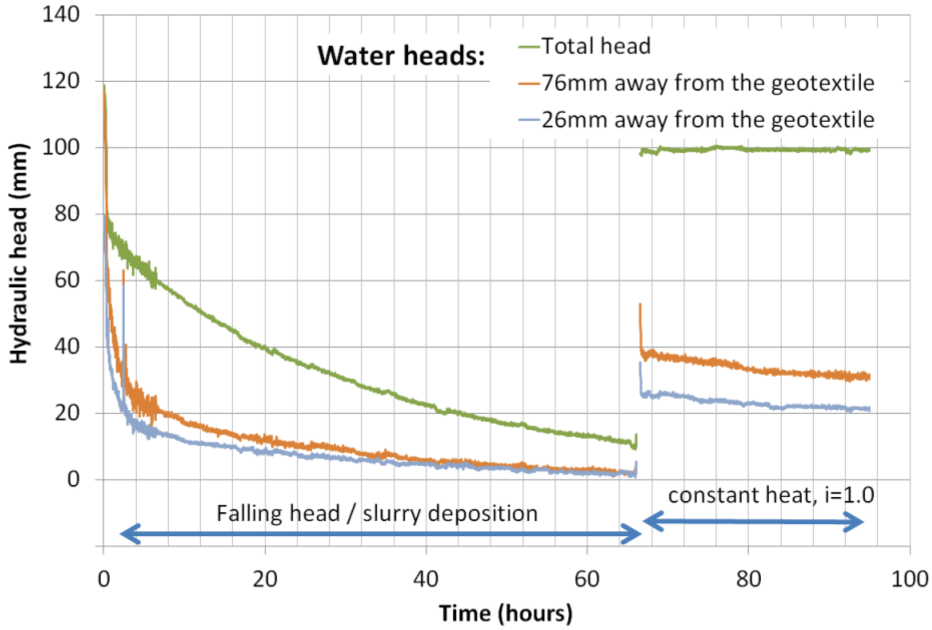


Figure 11 Water head versus time

The following observations were made:

- The 'permittivity' of the system, calculated by dividing the flow rate per unit area at a given time by the total hydraulic head, first decreased to reflect the accumulation of soil particles at the surface of the geotextile (Figure 9). It eventually stabilized to remain constant until the end of the first part of the test (sedimentation). After full settlement / deposition of the soil particles, the second phase of the test was initiated with the constant head test, and the permittivity stayed at the same level as what was measured before. It was thus concluded that the permittivity of the system was stable over time, thus that no clogging mechanism develops as the water flows through the system.

  In order to estimate the permeability of the tailing / geotextile system, the permittivity can be multiplied by the height of soil after deposition (measured from the outside of the cell, i.e. on Figure 8-d). A value of 6.10-5 cm/s was determined, which was reported to be similar to the permeability of the tailing as documented by the owner.

  With a permeability of the system similar to the permeability of the native material and no decrease of permeability over time, the system was considered to be stable.

- Gradient ratio values of approximately 3 were observed and remained stable through the duration of the test (Figure 10). Although 3 is on the upper bound of what is usually considered acceptable, it has to be analyzed considering two factors:
  - First, the soil was not compacted but installed in a slurry form. As a consequence, the arrangement of sedimented particles is likely to be more compact in the vicinity of the filter, where the water has the highest potential for being evacuated and let the soil arrange itself in a compact structure, by opposition to a slurry.
  - Second, it does not evolve through time, which indicates that the permeability of the tailing / geotextile interface does not decrease faster than the permeability of the tailing, measured at a distance of the interface.

  As a consequence, the gradient ratios were considered as reflecting a stable behavior of the geotextile / tailing interface, despite the value of 3, which is considered as reflecting clogging in ASTM D5101.

- Analysis of the evolution of the water heads (Figure 11) shows that more than half of the head loss occurs between the top of the soil and the piezometer located at a distance of 76mm from the geotextile, i.e. on the very top of the sedimented slurry. This observation can be explained by the sedimentation process, which favors segregation of the particles with the coarser particles settling first. As a consequence, the gradation of the soil progresses, with a decreasing concentration of coarser particles, as the distance to the geotextile increases. This mechanism favors creation of a very fine grained layer on the top of the soil surface, which exhibits a lower permeability, thus a higher head loss on the upper layer, as observed on Figure 11.

Overall, the observations made with this test led to the conclusion that the tested geotextile, with a FOS of 70µm (as measured per CGSB 148.1 n°10) has offered a good filtration performance of the tailing with the particle size distribution shown on Figure 6-a, prepared as a 28% solid / 72% water slurry, during both sedimentation and filtration under a hydraulic gradient of 1.0.

3 LARGE SCALE EXPERIMENTATION

Phosphate mining at the OCP Mrah laundromat (Morocco) leads to the production of 24,000 m³ of sludge every day. This sludge contains between 70 and 80% water. A significant portion of this water cannot be recycled in the mining operation, but is lost because of:

- Evaporation due to strong sunshine and high temperature, especially in summer;
- Seepage into the underlying soil, potentially polluting the environment;
- Too slow sedimentation of the solid component of the slurry, water staying trapped by the electrochemical interactions with the solid particles.

The mining company decided to build a large scale test pad, to assess the performance of MLDG as a drainage component in the bottom of a sedimentation basin. The MLDG described on Figure 1 was used as the single drainage media, in direct contact with the slurry – that is, with no granular cover. Each mini-pipe of the MLDG was connected to its related main collector with connectors designed specifically for the MLDG.

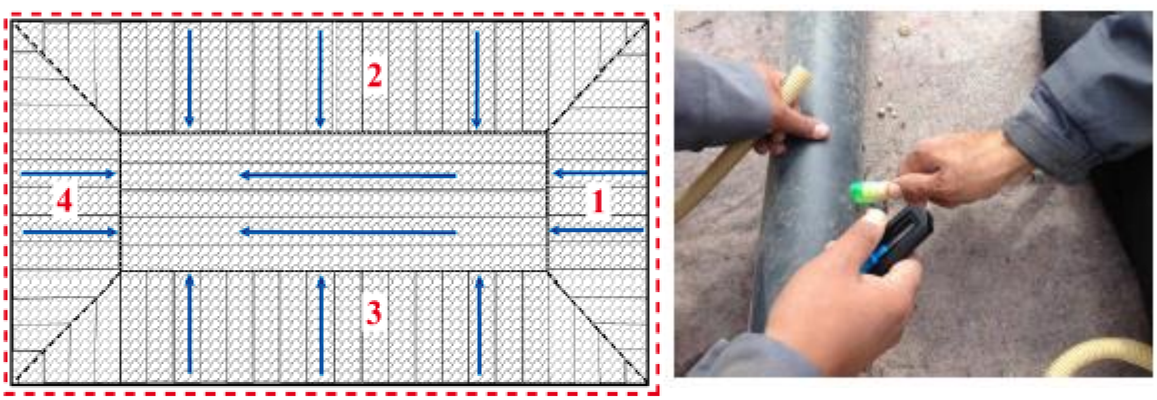


Figure 12: orientation of the MLDG and connection using connectors (photo courtesy Afitex-Texel)

The performance of the MLDG was compared to the one of a control basin, built using the traditional method, involving a granular drainage layer. The performance requirements set by the owner for the drainage component was as follow:

- Retention of solid particles in the basin;
- Free circulation of water toward, and into the drain;
- Capacity to transport water in its plane over a long distance (100 m).
- Minimize loss of water by infiltration into the soil – i.e. by waterproofing.

- Resist normal operating conditions, such as UV immediately after installation and before the first fill, and exposure to chemicals.

Photos of the structure are presented on Figures 13 and 14.

The quantity of recovered filtrate is a key performance factor which was monitored in both the control and the test basin. The use of MLDG led to about 20% more water recovery compared to the traditional solution. Furthermore, the filtration and drainage performance of the MLDG was found satisfactory in both the slopes and the floor of the basin. However, a flow of water could be observed more than two months after the owner stopped feeding the basin with sludge, which suggests that consolidation was still ongoing.

Presence of soil particles was observed in the filtrate samples recovered at the outlet of the test pond to assess its potential for subsequent reuse in the phosphate treatment process. Percentage of impurities below 1% were typically measured, which was considered by the OCP acceptable for phosphate's washing operations.

Figure 13: multi-linear drainage geocomposite used in a slurry dewatering facility (photo courtesy Afitex-Texel)

Figure 14: Slurry dewatering facility (photo courtesy Afitex-Texel)

Figure 15: system in operation – Collected water from the bottom on the test pond

4 CONCLUSION

The behavior of Multi-Linear Drainage Geocomposite (MLDG) as a pregnant solution collection layer in heap-leach pads was investigated considering existing and genuine laboratory work. The following observations were made:

- No evidence of clogging could be detected after 90 days of circulation of a 20 g/l sulphuric acid through a copper ore and the MLDG. As a consequence, it was concluded that the exceptional chemical composition of the pregnant solution is not likely to affect the performance of DTPG with respect to its filtration and drainage efficiency.
- High normal loads do not affect the transmissivity of MLDG as demonstrated by Saunier et al.
- A geotextile filter typically used for the filtration of fine-grained materials in MLDG, with a FOS of 70 µm as measured per CGSB 148.1 n°10, has offered an excellent filtration performance after receiving a slurry with a soil / water ratio of 28% solid / 72% water.

Based on these observations, Multi-Linear Drainage Geocomposites should be considered promising solutions for heap leach applications as well as other applications involving potentially harsh chemical conditions as well as very fine grained materials, including tailings.

For dewatering applications, the use of Multi-Linear Drainage Geocomposites in a tailing dewatering facility was evaluated in the lab, as well as on a large-scale test pad. Observations made on the large scale test showed several advantages associated to the use of MLDG compared to granular solutions:

- Slopes are protected from erosion and instability thanks to the presence of a continuous layer of geosynthetic.

- The filtrate recovered downstream had a percentage of impurity of less than 1%, which makes it reusable in the process.

Overall, the use of a MLDG was found to generate interesting opportunities for both mining applications considered, that is, heap leach pads and dewatering.

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