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Application of electro-osmosis to the consolidation of sand quarry tailings

Application de l'électro-osmose à la consolidation des résidus de carrière de sable

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ABSTRACT: The need for an effective and efficient consolidation method for mine operations has significantly increased throughout the past decade. In comparison to inefficient, conventional consolidation methods, electro-osmosis consolidation has shown great potential in consolidating tailings, with measured benefits demonstrated from laboratory experiments and some civil engineering applications. However, in order to achieve large scale field implementation in mining operations, a comprehensive, optimised electro-osmosis operation procedure is required. The aim of this paper is to examine the efficiency and effectiveness of the electro-osmosis consolidation method with respect to sand quarry tailings. This laboratory-scale study is the initial part of a larger research endeavour which seeks to upscale the findings to operational quarries. In this paper, experiments were undertaken on sand quarry tailings in testing tanks at two different scales, containing approximately 0.06 m^3 and 1.07 m^3 of tailings. Tests were conducted using steel electrodes. The results indicate a positive outcome of using electro-osmosis consolidation, and a more optimised outcome may be achieved with the implementation of intermittent current and polarity reversal.

RÉSUMÉ : Le besoin d'une méthode de consolidation efficace et effective pour les opérations minières s'est considérablement accru au cours de la dernière décennie. Par rapport aux méthodes de consolidation conventionnelles inefficaces, la consolidation par électro-osmose a montré un grand potentiel dans la consolidation des résidus, avec des avantages mesurés démontrés à partir d'expériences en laboratoire et de certaines applications de génie civil. Néanmoins, la réalisation d'une mise en œuvre à grande échelle sur le terrain dans les opérations minières exige un processus électro-osmotique compréhensif et optimisé. L'objectif de cet article est d'examiner l'efficacité et l'effectivité de la méthode de consolidation par électro-osmose par rapport aux résidus de carrières de sable. Cette étude à l'échelle du laboratoire est la première partie d'un effort de recherche plus vaste qui cherche à mettre les résultats à l'échelle des carrières opérationnelles. Dans cet article, des expériences ont été menées sur des résidus de carrières de sable dans des réservoirs d'essai de deux tailles différentes, contenant environ 0,06 m^3 et 1,07 m^3 de résidus. Les tests ont été effectués en utilisant des électrodes en acier et les résultats indiquent un résultat positif de l'utilisation de la consolidation par électro-osmose, et un résultat plus optimisé pourrait être obtenu avec la mise en œuvre du courant intermittent et du renversement de polarité.

KEYWORDS: tailings, dewatering, electro-osmosis, consolidation, intermittent current.

1 INTRODUCTION

1.1 *Background*

Waste materials are being produced as by-products from a wide variety of mining operations. Leading international authorities in mine waste stated in 2019 that mine wastes present themselves as the largest waste problem to the planet, environmentally, due to the enormous quantities being produced annually (Vallero & Blight 2019). From their report, the worldwide production rate of mining waste is estimated to be 350 × 109 tonnes per annum, which, for example, would bury the entire country of Ireland beneath 2 metres of waste. A significant subset of mine waste, known as tailings, is the focus of this project. The process of sand washing is generally involved in quarrying construction and silica sands, which produces significant quantities of fine-grained tailings with a high water content.

Tailings produced by the quarrying of sands present a significant engineering challenge. Solutions are needed, both in Australia and globally. Tailings storage facilities (TSFs), where the tailings are stored in-situ, are a particular challenge for quarry operators, both operationally and environmentally, when their capacity has been reached. In such circumstances, the tailings will be transferred to other available TSFs or, more often, the facility will be decommissioned so that the land can be made suitable for industrial, housing or recreational purposes. However, consolidating tailings is challenging because of the significant time needed, which is usually in the order of several years, due to its low permeability and low strength, combined with its high water content.

1.2 *Electro-osmosis*

The objective of consolidating problematic mine tailings has been examined by researchers for many years. For example, it was reported that at least 3,500 TSFs are active globally and the number continues to grow each year and the need for providing a tangible solution is also ongoing (Fourie et al. 2007).

Conventional consolidation methods, namely surcharge and vacuum preloading consolidation, have been proven, by numerous research studies, to perform poorly in fine-grained soils. Both kinds of the preloading methods involve the use prefabricated vertical drains (PVDs) for water drainage, which relies on the soils' hydraulic permeability (Kaniraj et al. 2010, Liu et al. 2017). Furthermore, researchers have found that, when applying vacuum preloading to fine or ultra-fine soils, one most likely encounters clogging or 'caking', where a considerable amount of the soils adhere to the drainage outlets, such as PVDs. According to Cai et al. (2017), during vacuum preloading, extremely fine soil particles are able to move with the water and then accumulate on the filtration surface of the PVDs, resulting in a dense solid layer inhibiting water flow.

In contrast, the electro-osmosis (EO) method offers the potential for dewatering and consolidating fine to ultra-fine soils, such as mine tailings. Instead of relying on the hydraulic permeability of the soil, EO mostly relates to soil's electrical conductivity and electro-osmosis permeability, which are less influenced by grain size, therefore making the dewatering of fine-grained soils much more feasible than conventional methods (Lamont-Black et al. 2016).

In brief, the electro-osmosis method underwent early development in the 1950s (Casagrande 1949, Bjerrum & Eide

1967), was refined in the 1990s with electrokinetics (Mitchell 1991, Shang & Lo 1997), and the examination of geosynthetic electrode materials in the early 2000s (Fourie et al. 2007, Fourie 2008). Summarising the recent three decades of research in this area, there are two main goals in achieving successful electro-osmosis consolidation: (a) Prolonging the effective consolidation period; (b) Optimising energy consumption. Subdividing these goals further, reveals three key aspects of electrode-osmosis research: (1) Electrode material; (2) Electrical techniques; and (3) Optimisation with the combination of other techniques or consolidation methods.

1.2.1 *Electrode material*

The electrode material is one of the key aspects for the efficient operation of EO, since it relates to the life span of the dewatering process. Conventional metallic materials, such as iron, copper, steel and brass, experience corrosion due to electrical-chemical reactions and require ongoing replacement in long-term dewatering projects that run for months, which increases the economic burden and significantly reduces efficiency. Unfortunately, it is well appreciated, and established by numerous experiments (Bjerrum et al. 1967, Lockhart 1983, Fourie et al. 2007, Fourie & Jones 2010), that the dewatering rate and efficiency are directly related to the applied voltage, where a high applied voltage accelerates dewatering, but at the same time increases corrosion. Therefore, the common approaches are to carefully design the electrical treatment plan mitigating the corrosion, or to replace corrosive electrodes with an electrically conductive material that will be resistant to corrosion. According to Fourie et al. (2007, 2008) electrokinetic geosynthetics (EKGs), which are non-metallic based electrically conductive materials, have shown great potential in solving the corrosion problem. Experiments on different fine tailings indicated high durability against corrosion with an extremely long operation time (Fourie et al. 2007, 2008, Fourie and Jones 2010). Further research has also shown that EKGs can be deployed to a wide range of applications, including dewatering of nuclear contaminated waste (Lamont-Black et al. 2015) and slope stabilisation (Lamont-Black et al. 2016). Similar polymer based electrically conductive materials have also been used on coastal land reclamation projects (Chew et al. 2004, Karunaratne 2011). In short, EKGs have shown promise for long-term EO consolidation applications.

1.2.2 *Electrical techniques*

The electrical techniques applied to the EO method is another key aspect that affects the energy consumption and dewatering life span. First, the voltage gradient is an important electrical parameter to be determined carefully as it greatly affects the energy consumption and electrode corrosion rate (e.g. Bjerrum et al. 1967, Esrig 1968, Shang and Lo 1997, Fourie et al. 2007, Jeyakanthan 2011). Secondly, techniques and treatments by manipulation on the electrical side are to address inevitable issues such as energy consumption, soil cracking, soil settlement, and as mentioned above, the mitigation of electrode corrosion.

Voltage gradient is usually expressed in the form of the applied voltage divided by the distance between the electrodes, using the units of V/m or V/cm. Suggested by Mitchell (1991) and widely acknowledged amongst EO researchers, electrokinetic dewatering would be viable when its material conductivity is above 2.5 mS/cm. Common theories established by Bjerrum et al. (1967) and Lockhart (1983), which were later confirmed by Fourie et al. (2007), suggest that a low voltage gradient generally tends to result in low energy consumption. However, despite many attempts in the past the relationship between voltage gradient, electrical current, and energy consumption optimisation still remains an unsolved question and usually solutions are case dependent.

Furthermore, other than simply manipulating the applied voltage and controlled current, there are two electrical techniques that many studies have demonstrated improving electro-osmosis effectiveness, namely intermittent current and polarity reversal. Intermittent current (IC) is the application of current in discrete intervals, as opposed to it being applied continuously. In theory, IC may reduce the power consumption while maintaining a relatively efficient dewatering rate. It has been shown to be effective in some research studies (Lamont-Black et al. 2016) and appears to be a possible energy saving approach worth examining further. Polarity reversal (PR) involves switching the polarity of the electrodes in the experiment within a predetermined schedule. It is reported to aid in forming a more uniform settlement surface and reduce or delay the occurrence of soil cracking (Hamir et al. 2001). In contrast, some argued it performed poorly as it may consume more electricity and reduce water discharge (Sun et al. 2017).

1.2.3 *Method combination*

Method combination is the third aspect that many previous studies have considered when adopting the electro-osmosis method. In general, this involves two aspects: (1) whether EO is combined with other, traditional, consolidation methods, and (2) if so, how these techniques can be used together in an optimal fashion. Combined consolidation methods have been undertaken by a number of researchers across different areas (Peng et al. 2013, 2015, Shen et al., 2016, Sun et al. 2015, 2017, Wang et al. 2016, 2018, 2019). However, common observations across these research studies indicate that the optimisation of the various factors affecting its performance need to be determined on a case-by-case basis. Therefore, method combination will not be considered in this study due to operational constraints and difficulties.

2 AIMS

From the previous section, it is evident that previous researchers have been exploring potential dewatering and consolidation methods for fine-grained silt or clay soils. However, many of the studies have been confined to the experimental domain and at a relatively small scale. This begs the question: "How can findings from small-scale be transferred to larger scale and eventually leads to engineering application?"

The aims of this paper are to: (1) Examine experimentally, at laboratory- and meso-scale, the efficacy of EO in constructive and silica sands tailings; and (2) Examine upscaling from the laboratory scale to a meso-scale application.

3 METHODOLOGY

This research project incorporates two scales of laboratory experiments; laboratory-scale and meso-scale, and the dimensions are presented in Table 1.

In order to maintain compatibility between the two scales of experiment, the tailings and electrode materials, electrode arrangement, drainage method, and data acquisition devices all remain the same across the experiments.

The tailings used in this study were acquired from a sand quarry tailings storage facility, located in Golden Grove, Adelaide, South Australia, the properties of which are given in Table 2.

Table 1. Size differences between laboratory- and meso-scale experiments.

Experimental scale	Lab-scale	Meso-scale
Plan dimensions (m)	0.5 × 0.5 (square)	0.6 (diameter)

Depth (m)	0.25	0.60, 0.95
Volume (m^3)	0.06	0.68, 1.07

Table 2. Geotechnical properties of sand quarry tailings.

Soil type	Silty clay
Grain size	95% < 0.075
Specific gravity	2.60
Liquid limit	55%
Plasticity limit	23%
Original water content	130% – 168%

3.1 *Laboratory scale experiments*

The lab-scale experiments were designed to examine the feasibility and efficacy of EO and the related techniques on the sand quarry tailings used in this study. The experiments included 8 separate tests, which examined the EO performance by the following variables:

1. Apply a low voltage gradient (LV1);
2. Apply an intermittent current with two different time intervals (IC1 and IC2) at the same low voltage gradient and intermittent ratio;
3. Alternate the electrode polarity with different reversal time intervals (PR1 and PR2) at the same low voltage gradient and polarity ratio; and
4. Optimise the consolidation by changing the applied electrical technique and its detail settings (Opt1, 2 and 3) at the same low voltage gradient.

Details of each experiment are given in Table 3, and there are a few points to note:

(a) The intermittent ratio is defined as the ratio between the powered ON time divided by the powered OFF time.

(b) Similarly, the polarity ratio is defined as the ratio between the normal polarity runtime divided by the reversed polarity runtime;

(c) Experiments Opt1, 2 & 3, which are the optimisation trials, only intermittent current was implemented due to the results of the polarity reversal experiments deemed to be suboptimal. Opt3 doubled the voltage gradient, with full power on for the first half, and intermittent current was applied for the remainder of the test; and

(d) The initial water content of all the tests are set between 69% to 71% to facilitate effective comparison.

The laboratory scale experiment setup is shown in Figure 1. As can be seen in Fig. 1(b), 6 laser transducers were used for surface settlement measurement.

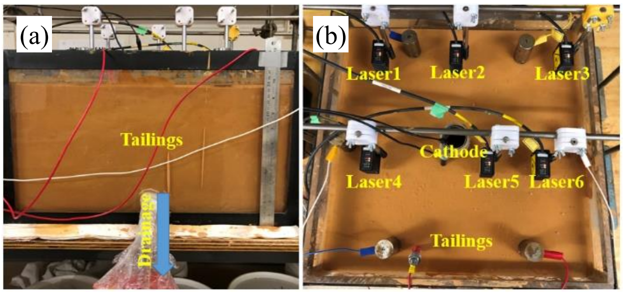

Figure 1. Laboratory scale experimental setup: (a) front view; (b) plan view.

This series of experiments was conducted using a square, clear acrylic tank, with the dimensions given previously in Table 1. A hexagonal arrangement of electrodes was adopted, which included 6 solid steel rods as anodes, surrounded by a hollow steel cathode at the centre. Drainage occurred through the central cathode tube by gravity to an outside beaker which was continually weighing using a load cell. The cathode was wrapped with a geotextile to provide a filter. To minimise variations in evaporation, the ambient temperature was controlled to between approx. 20°C to 25°C. Electro-osmotic performance was evaluated in terms of the amount of water removed from the tailings slurry, soil surface settlement and electrical energy consumption.

3.2 *Meso-scale experiments*

The meso-scale experiments were conducted to examine the efficacy of an optimised solution in an upscaled scenario, and to study scaling effects. Two experiments were conducted using a cylindrical tank, with a diameter of 1.2 m and height of 1.2 m. The setup is as illustrated in Figure 2, in which 5 laser transducers were placed between the anode to cathodes and one was placed at the geometric centre. In addition, as shown in Fig. 2, water content was measured by 6 volumetric water content (VWC) sensors, and pore water pressure was measured by 3 probes. Due to space constraints, the pore water pressure measurements will not be presented.

The first test, Meso1, adopted the original base experiment setting from the lab-scale experiment, and served as a preliminary experiment for later iterative improvements. Based on the results of Meso1, the second test, Meso2, sought to improved dewatering by using a higher voltage gradient. To study scaling effects, the meso-scale experiments adopted the same hexagonal electrode arrangement, steel electrodes, gravitational drainage system and geotextile filter as the lab-scale experiments, however, the voltage gradient was varied, as given in Table 4.

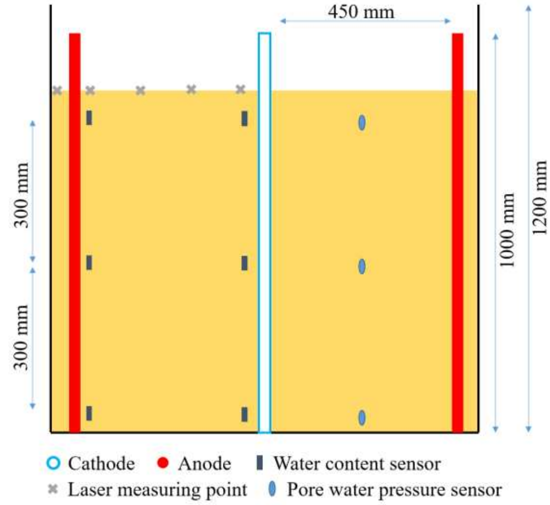

Figure 2. Meso-scale experiment setup.

4 RESULTS

4.1 *Laboratory-scale experiments*

The results of the laboratory-scale experiments are presented in Table 5, where *water removal percentage* is defined as the percentage of water removed, by weight, against the initial total weight of the tailings; *surface settlement* is the final average soil settlement across the 6 laser measuring points; and *energy consumption* is the total cumulative electricity usage, in Wh, over

15 days of runtime. In summary, with a higher voltage gradient, hence higher energy consumption, enhanced dewatering occurs with greater soil surface settlement, as one might expect.

Table 3. Laboratory-scale experiment details.

Experiment No.	LV1	IC1	IC2	PR1	PR2	Opt1	Opt2	Opt3
Intermittent ratio	–	1.5	1.5	–	–	1.5	1.5	1.5
Intermittent ON time (hours)	–	3	14.4	–	–	14.4	3	3
Polarity ratio	–	–	–	0.2	0.1	–	–	–
Polarity ON time (hours)	–	–	–	12	13	–	–	–
Voltage gradient (V/cm)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Effective runtime (days)	15	15	15	15	15	15	15	15

Table 4. Meso-scale experiment details.

Experiment No.	Meso1	Meso2
Voltage gradient (V/cm)	0.1	0.4
Effective runtime (days)	28	78

Table 5. Results of laboratory-scale experiments.

No.	*Water Removal Percentage*	*Surface Settlement* (mm)	*Energy* (Wh)
LV1	33.0%	27.6	57.0
IC1	20.9%	30.9	32.4
IC2	20.2%	45.2	37.0
PR1	18.8%	44.7	54.0
PR2	17.1%	37.9	51.0
Opt1	21.6%	49.2	40.6
Opt2	19.0%	44.0	39.5
Opt3	30.5%	62.2	77.5

4.1.1 *Water removal*

In order to facilitate effective comparison between tests, the laboratory experiments included almost identical amounts of tailings, with an initial water content, which varied between 69% to 71%. At a low voltage gradient of 0.1 V/cm, all experiments demonstrated enhanced dewatering due to EO, with varying degrees of efficiency. This is clearly demonstrated by comparing the performance of EO against natural drainage (red line in Figure 3), and as a result, EO is highly effective.

In terms of the influence of the various electrical techniques on EO performance, IC dewaters the tailings at a rate of approximately 65–70% of that with continuous EO (i.e. LV1), whilst consuming 60–80% of the energy. At the same intermittent ratio, a longer power-on time interval results in superior performance, which is in contrast with observations made by some other researchers (Fu et al. 2017, Liu et al. 2019). PR demonstrated less efficient performance with respect to dewatering, which was not unexpected.

In summary, EO at a relatively low voltage gradient demonstrated satisfactory performance in relation to dewatering at small-scale, and both IC and PR have shown positive results.

The laser transducer measurements suggest that soil settlement is strongly correlated to water removal, whereby the overall settlement follows a similar, but delayed trend (approx. up to 5 hours), with respect to the water removal results. The total average soil settlements were approximately 40 to 45 mm (i.e. 16%-18%). Soil cracking appears to be an important factor affecting EO performance, and was observed in all of the experiments. Major cracks formed between the electrodes and compromised the EO process.

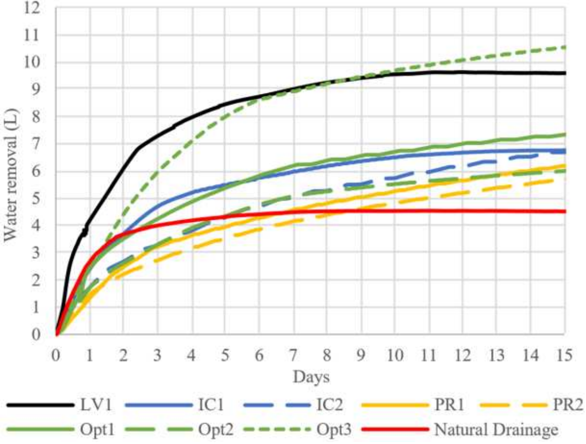

Figure 3. Water removal from laboratory-scale experiments.

4.1.2 *Electrical energy consumption*

As shown in Table 5, as one would expect, energy consumption is reduced with the adoption of both IC and PR. However, in order to minimise cracking, PR sacrifices energy consumption. In addition, for those tests that incorporated IC and PR, a greater water removal rate is observed at the end of the experiments, when compared against the flattening slope in the natural drainage and LV1 tests.

It is important to note that, in the first half of experiment Opt3, the same power-on setting as LV1 was adopted, hence it follows a similar trend, as expected. However, in the second half of Opt3, the intermittent current was applied at two times of the voltage, hence the significantly higher energy consumption. By doubling the voltage applied, hence doubling the voltage gradient, the amount and rate of water removal are both higher than the other experiments that used IC. This indicates that the application of a higher voltage in conjunction with IC produces superior performance.

The electrical consumption with respect to water removal is summarised in Table 6 for each of the tests, where *E/W* refers to the energy consumption versus water removal, in Wh/L. When comparing the electrical energy consumption to the amount of water removal, conclusions can be made which are similar to those given previously in §4.1.1, that a longer intermittent current time interval generates more efficient energy usage with respect to water removal.

Table 6. Electrical energy consumption versus water removal.

No.	LV1	IC1	IC2	PR1
E/W (Wh/L)	5.7	4.8	5.6	8.7
No.	PR2	Opt1	Opt2	Opt3
E/W (Wh/L)	9.0	5.5	6.6	7.3

4.2 *Meso-scale experiments*

The experimental results are presented in Table 7 and Figure 4. As shown previously in Table 4, Meso1 was conducted over a period of 28 days, whereas Meso2 continued for 78 days to observe performance over a longer period. The results of the meso-scale experiments demonstrated similarities, but also significant differences after the upscaling. For example, the application of a higher voltage resulted in enhanced dewatering, however, the effects of soil cracking were more severe. The results suggest that: (1) upscaling is non-linear; and (2) soil cracking and surface deformation are more significant.

Table 7. Results of Meso-scale experiments.

No.	*Initial Water Content*	*Water Removal Percentage*	*Surface Settlement* (mm)	*Energy* (Wh)	*E/W* (Wh/L)
Meso1	176.4%	25.1%	134.9	1,738	12.4
Meso2	129.6%	45.4%	> 400	38,495	102.3

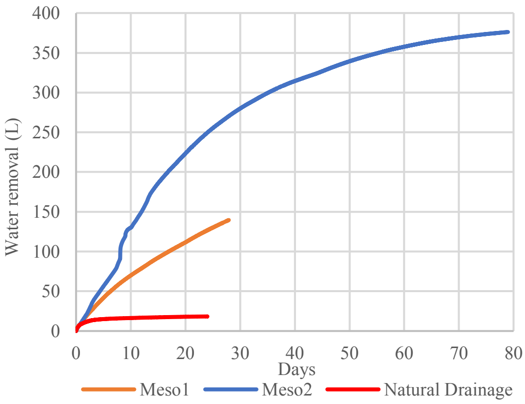

Figure 4. Water removal from meso-scale experiments.

Comparing the water removal and energy consumption associated with Meso1 with the laboratory-scale experiments, it is observed that the larger scale results in diminished performance. For example, when comparing the energy consumption versus water removal factor, *E/W*, for LV1 and Meso1 (Tables 6 and 7), which were performed at the same voltage gradient without IC and PR, Meso1 yields 12.4 Wh/L, which is much greater than the 3.9 Wh/L obtained for LV1. This suggests that, when upscaling, the EO voltage gradient is not the only factor that needs to be considered, as the soil depth and volume also affect performance. While the same voltage gradient was applied, Meso1 did not achieve the same level of dewatering as at the lab-scale. The water removal curve given also supports this conclusion. For example, in Fig. 3, LV1 exhibits a water removal curve which plateaus after approx. 7 days, whereas in Fig. 4, Meso1 has a relatively linear water removal curve. In addition, as shown in Table 7, Meso1 removed a lower percentage of water (25.1%) when compared against LV1 (33%) in Table 5. Therefore, in the next test iteration, for Meso2, the power input was increased by adopting a higher voltage gradient.

As can be seen from Table 7 and Fig. 4, the volume of water removed by Meso2 increased significantly due to the higher voltage gradient, which also led to a greater surface settlement and energy consumption. At the time of writing, IC and PR had not been applied at the meso-scale. As a result, further testing is required to confirm whether or not the parameters applied to Meso2 are optimal or not.

When comparing Meso1 with Meso2, the following were observed in both: (1) the over-saturated initial water content diminishes the effectiveness of EO, in which the design voltage gradient was unable to be achieved until preliminary dewatering reduced the water content to some degree; (2) as observed in the lab-scale experiments, significant soil cracking formed vertically along the electrodes and horizontally between the anodes and the cathode; and (3) the energy consumption of both Meso1 and Meso2 was significantly greater and less efficient when compared to the lab-scale experiments.

For Meso2, Figure 5 presents the water content changes versus time at the cathode and one of the anodes at 3 different electrode depths; top, centre and bottom (see Fig. 2). As can be seen in Fig. 5, dewatering occurred fastest at the soil surface at both electrodes and, after about 10–15 days, soil cracking occurred across the electrodes which compromised the ongoing recording of water content. In the central layer, the anode dewatering rate experienced a slight rise (between 15 – 20 days) after the surface layer dried out and cracked, while the cathode side dewatered and maintained about 90% gravimetric water content (35% – 40% VWC). Cracking did not reach the depth of the bottom layer and the anode side behaved somewhat similar to the cathode centre, where it might be concluded that layers beneath the cracks have a VWC ranging around 30% – 40% VWC. Since the cathode was the outlet for water drainage, the bottom layer on the cathode side remained saturated.

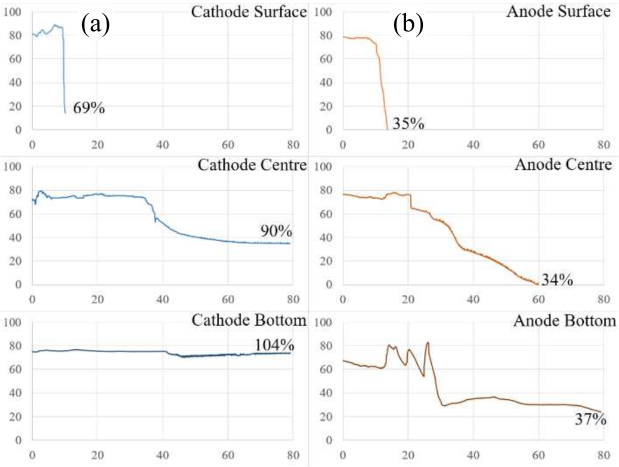

Figure 5. Volumetric water content profile of Meso2: (a) cathode; (b) anode. Note: x-axis: time (days); y-axis: volumetric water content (%); and gravimetric water content at end of test also given.

When comparing LV1 with Meso2, both of which were continually powered during the experiments, the following conclusions in relation to the EO upscaling effects were deduced: (1) The effectiveness determined by the energy consumption versus water removal factor, *E/W*, reduced significantly in both the 15-day and 80-day periods (see Table 8); (2) The significantly reduced EO effectiveness are likely not to be the result of drainage clogging or a drop in permeability since samples from adjacent to the Meso2 cathode were soft and saturated, with no evidence of clogging; (3) Upscaling increases the physical size and quantity of the tailings but not the particle and void sizes. Hence, the reduced *E/W* is the result of significantly higher energy consumption and reduced water drainage effectiveness. As shown in Table 8, the *drainage path* is the longest horizontal distance that a water molecule travels in the tailings which, in the laboratory-scale is half of the diagonal length, and in the meso-scale is the radius of the chamber (i.e.

0.35 m and 0.6 m, respectively, Table 8). The combined effect of the increased tailings volume and the increased drainage path length contribute to the reduction in the effectiveness of the drainage; and (4) Drainage at the cathode in the experiments presented in this study may be considered sufficient as no water accumulation was observed, but the drainage path length could be further optimised with respect to the different scale.

Table 8. EO effectiveness differences in upscaling.

No.	*Tailings Volume (m^3)*	*Drainage Length (m)*	*E/W (15 days)*	*E/W (Total)*
LV1	0.06	0.35	5.70	5.70
Meso2	1.07	0.60	60.68	102.30

In summary, the meso-scale experiments demonstrated promising potential for dewatering sand tailings with the application of EO when compared against natural gravitational drainage. However, the comparison between the laboratory- and meso-scales indicates a non-linear scaling effect and further optimisation will need to focus on increasing dewatering effectiveness.

5 CONCLUSIONS

This paper has presented the results of several electro-osmosis (EO) tests performed on tailings from the quarrying of construction and silica sands. Tests were performed at two different scales, namely laboratory- and meso-scale. At both experimental scales, the application of EO consolidation was found to enhance and accelerate water removal significantly, and it shows promise at the operational scale of a tailings storage facility. When translating the results of the lab-scale tests to those at the meso-scale, it was observed that upscaling was not linear and further work is needed to determine the nature of the upscaling relationship. In addition, soil cracking was observed at both scales, and this was shown to reduce the overall efficacy of EO. Finally, further work is needed to refine the EO parameters in order to optimise the energy consumption versus volume and rate of water removal.

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