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Tailings dewatering with the EKS-DT process

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Abstract

The global inventory of tailings is currently >55 billion m^3 and is forecast to increase to almost 70 billion m^3 by 2025. The cost of these tailings includes the construction and maintenance of tailings storage facilities (TSFs), the liability of catastrophic releases, environmental damages, and erosion of social licence to continue mining. Billions of dollars and decades of research have been spent searching for improved technologies to better dewater tailings and reclaim TSFs.

The ElectroKinetic Solutions Inc. (EKS) tailings dewatering technology (EKS-DT) process has been developed to dewater legacy and fresh tailings in situ, using electrokinetics. Over more than a decade of lab and field-scale testing has significantly improved the technology's dewatering effectiveness and reliability and confirmed its commercial viability. The process is less costly compared to current tailings management technologies and excels in its ESG performance. EKS has shown through a field demonstration that very fine-grained tailings (i.e. average particle size <6 microns) with an initial solids content of 20% (kg/kg) can be dewatered to >60%.

EKS has also produced a forecasting model. The model accurately forecasts dewatering time and energy consumption for different designs and operating schedules, critical information for designing commercial installations.

A 1,700 m^3 field demonstration from 2019 to 2021 proved that the technology is commercially viable. During this time, over 1,100 m3 of water was removed from the tailings and the energy consumption was <15 kWh per m^3 of water released. The process was operated year-round through two harsh winters. The process operated as well during the ice-covered period as during warmer months. The installation was operated continuously by the automated control system without an onsite operator. The design of the first commercial installations of the technology is now underway.

The engineering design process for the field demonstration and for commercial systems will be discussed, including the role of the EKS model.

Keywords: *electrokinetics, tailings, dewatering, water recovery, increased capacity*

1 Introduction

The mining industry is facing significant pressure from investors, governments, and the public to address the environmental liability associated with the large inventories of unstable tailings and the continuing increase in this inventory. The costs incurred by the mining industry for tailings management, including tailings storage facility (TSF) construction, material transport and tailings dewatering, are significant (Baker et al. 2020). In addition, the water trapped in the tailings is unable to be used for ore processing, requiring more freshwater to be imported into the mining process. This water demand can be difficult to source and costly in arid regions (Ghorbani & Kuan 2017; Nasirov & Agostini 2018). Another major safety and environmental liability is the risk of dam failure and resulting catastrophic release of fluid tailings. This liability can be reduced by strengthening the tailings dams but is only removed when the tailings are dewatered and made geotechnically stable. Capping, closure, and remediation of the TSF also require that the risk of liquefaction be addressed (Owen et al. 2020; Roche et al. 2017).

The EKS tailings dewatering technology (the EKS-DT process), developed by ElectroKinetic Solutions Inc. (EKS), can rapidly dewater the tailings in a TSF, addressing the liability posed by the tailings. The EKS-DT process consists of many parallel pairs of horizontal electrodes deployed inside a TSF. Figure 1 is an end view schematic of EKS-DT electrodes below the tailings' surface in a TSF. Direct current (DC) is passed between the electrodes. The electrochemical reaction at the cathodes is hydrogen evolution (Equation 1). At the anodes, the two primary electrochemical reactions are oxygen evolution (Equation 2) and/or anode corrosion. Equation 3 shows a generalised corrosion reaction for a metal 'M' being oxidised from an oxidation state of 0 to + 'z' .

$$2H_2O + 2e^- \rightarrow H_{2\,(g)} + 2OH^- \tag{1}$$

$$2OH^- \rightarrow \frac{1}{2}O_{2\,(g)} + H_2O + 2e^- \tag{2}$$

$$M_{(s)} \rightarrow M^{z+} + ze^- \tag{3}$$

The passage of current through the tailings creates an electric field and as a result, the technology rapidly dewaters the tailings via electro-osmosis and electrophoresis. These electrokinetic (EK) processes have been studied extensively for decades (Casagrande 1949; Dixit et al. 1975; Islam 2014; Lockhart 1983; Shang 1997).

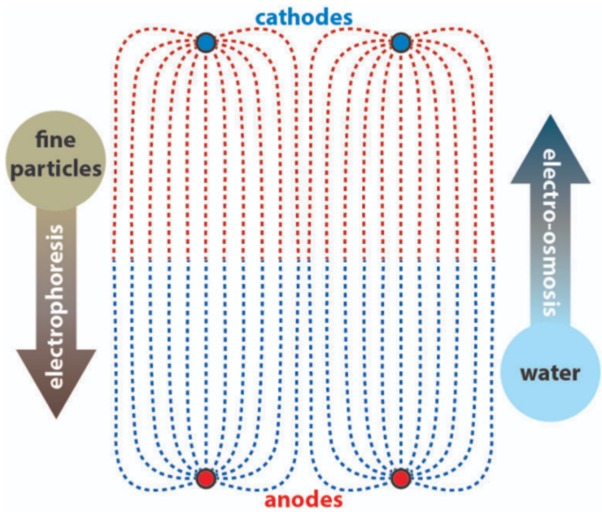

Figure 1 End view schematic of two EKS-DT electrode pairs, below the tailings' surface in a tailings storage facility

The increase in dewatering rate achieved by EK dewatering technologies, such as the EKS-DT process, relative to self-weight consolidation is most pronounced for tailings with a high fines content and low solids content (Abraham et al. 2018; Franks et al. 2011; Long et al. 2006; Sutherland et al. 2015). With current tailings management technologies, these tailings tend to be the most difficult and expensive to dewater. Many TSFs have a high fines content and are difficult to dewater with current technologies (McKenna & VanZyl 2020). The EKS-DT process is ideally suited to dewater these tailings.

Many opportunities are offered by the EKS-DT process to TSF operators, including increased TSF storage capacity, increased water conservation, reducing risk of tailings liquefaction, reducing material handling costs, eliminating the need for added chemicals for tailings treatment, reduced pollutant emissions from tailings and improved public perception. The increased TSF capacity and water conservation opportunities are discussed in this paper. For information on the other opportunities (www.eks.ca).

The EKS-DT process has been progressively and reliably scaled up through lab and field research. EKS has recently proven the EKS-DT process through a field demonstration in Alberta, Canada. This field demonstration successfully operated continuously, year-round from November 2019 to May 2021. The first purpose of this paper is to describe the dewatering performance achieved by the EKS technology during the field demonstration.

Fine-grained tailings are generally the most difficult to dewater (McKenna & VanZyl 2020; Shang & Xu 2019). Dewatering these tailings reduces the space they occupy in TSFs, increasing the TSF capacity available to store more tailings. The increased capacity within existing TSFs delays the need to expand existing or construct new TSFs, a major cost savings for many mining operations. The significantly increased dewatering rate of fine-grained tailings achieved by the EKS-DT process can deliver this cost saving. To quantify the value of the increased tailings capacity provided by the EKS technology, a second objective of this paper is to present a business case for deploying a hypothetical EKS-DT installation in a TSF.

2 Field demonstration methodology

A field demonstration of the EKS-DT process was carried out to prove that the technology scales as expected and that EKS can accurately forecast the performance of the technology. To determine whether these objectives were achieved, several key performance indicators (KPIs) were set for the field demonstration of the EKS technology. The target KPIs and the field demonstration results are shown in Table 1.

Table 1 Key performance indicators for the EKS-DT field demonstration

Metric	Target	Result	Achieved?
Water released	1,000 m^3	1,100 m^3	✓
Released water quality	Suitable for re-use	Achieved goal!	✓
Increased tailings storage capacity	+58%	+63%	✓
Maximum solids content between electrodes	>60% (kg/kg)	>60% (kg/kg)	✓
Energy consumption	<30 kWh/m^3 water released	15 kWh/ m^3 water released	✓
Year-round operation	Successful winter operation	Achieved goal!	✓

The field demonstration occurred at InnoTech Alberta's research facility at Vegreville, Alberta, Canada. An inactive sewage lagoon was excavated to create a test cell (Figure 2a).

The dimensions of the top of the test cell were 20 m x 25 m and its depth was 6 m; the walls of the test cell had a 1:1 slope. An impermeable liner was installed and over 1,700 m3 of oil sands tailings were pumped into the test cell (Figure 2b). The average solids content of the tailings was 18% by weight. The tailings solids were primarily fine particles; the particle size distribution is shown in Figure 3. The average particle size is about 6 microns and over 25% is <2 microns. These fine-grained tailings are very difficult to dewater with current tailings management practices (McKenna & VanZyl 2020).

(a) (b)

Figure 2 (a) Field demonstration test cell under construction; (b) Tailings pumping into the test cell

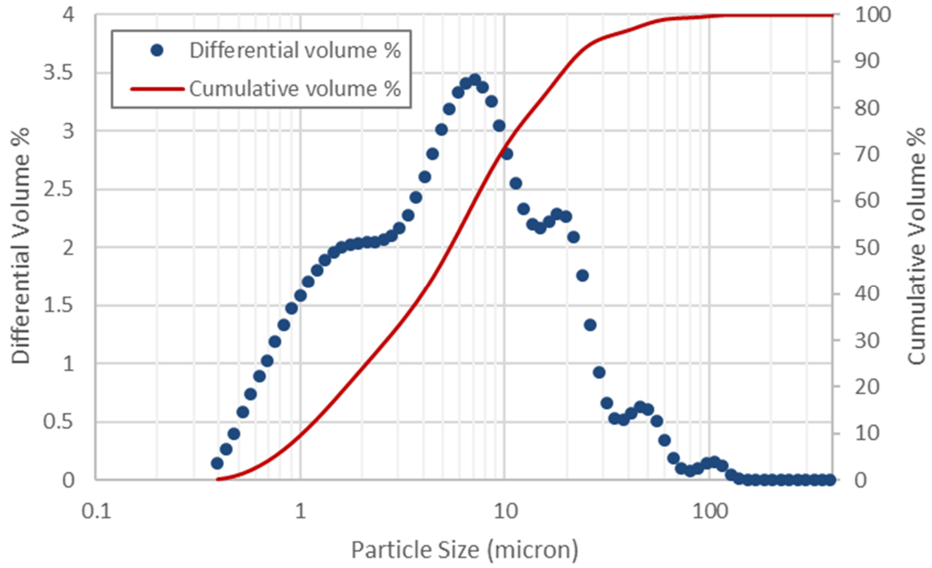

Figure 3 Particle size distribution for the tailings dewatered during the EKS-DT field demonstration

The electrode array consisted of 16 electrode pairs, each 10 m long. The electrodes were fabricated and deployed on site by local, casual, unskilled labour under the supervision of EKS. Most of the components used to fabricate the electrodes were off-the-shelf items, sourced locally. Figure 4 shows the local workers fabricating the field demonstration electrodes. The deployment of the electrodes occurred smoothly, without the use of heavy equipment.

Figure 4 Local workers fabricating EKS-DT electrodes for the field demonstration

A custom retrofitted sea container was designed to house the power supply and the central control system. Communication with the control system was via the internet. A primary purpose of the field test was to understand how the technology functions at scale and under field conditions. To support this objective, in situ sensors were installed in the test cell.

Once the electrodes, sensors, and power supply and control systems were deployed, the operation of the field demonstration was initiated. During operation of the field demonstration, the control system communicated with the rectifier which applied power continuously to the electrodes. The voltage and current applied to each individual electrode were monitored and recorded by the control system. Based on the measured dewatering performance, the control system adjusted the power applied to individual electrodes. Additional data collected continuously during the field demonstration included the electric field pattern in the tailings.

In addition to the continuous data recorded, physical sampling occurred approximately every six weeks. On each sample date, the water level within the test cell and the mudline depth at multiple locations within the test cell were measured. Core samples of tailings were also collected from multiple locations within the test cell using a custom-fabricated sampling device.

Each core was divided into sections and samples of each section were collected. For each section, including the sections that were above the mudline, the pH, electrolytic conductivity and solids content were measured. Other analyses, including particle size distribution and ionic concentrations were measured for select sample sections.

At the end of the field demonstration, an intensive physical sampling program was conducted. This sampling covered the entire test cell using the same sampling protocol that had been used throughout the test.

The continuous data recorded by the sensors as well as the physical samples collected from the test cell were used to quantify the performance of the technology and to compare that performance to the KPIs set for the field demonstration (Table 1). In addition, the performance of the field demonstration was forecast using the EKS Model, proprietary software developed by EKS. This model has been developed through extensive lab research and is a critical tool used by EKS to design and optimise commercial EKS-DT installations. The field demonstration results were also used to demonstrate the accuracy of the EKS Model and that EKS can accurately forecast the technology's performance.

3 Field demonstration results

The following sections summarise the key results achieved by the EKS-DT field demonstration. In summary, the field demonstration met or exceeded each of the KPIs specified in Table 1, demonstrating that the technology functions well in the field, at scale.

3.1 Water release

The EKS technology released water from the tailings during the field demonstration. The released water was left in place as a 'water cap' on top of the tailings. As water was released, the tailings volume decreased, and the water cap volume increased (i.e. the depth of the mudline increased) over time. By periodically measuring the depth of the mudline, the volume of water released from the tailings was determined. In addition, core samples were periodically collected from the test cell and divided into 0.5–1 m sections. Various tailings properties, including solids content, were measured for each core sample section. The volume of water released from the tailings was also determined based on the solids contents of the core samples. The water released over time, expressed as a fraction of the initial tailings volume, is shown in Figure 5. Both the values derived from the mudline measurements and the core samples are shown; the water release estimated by the EKS Model is also shown.

The mudline-derived and the sample-derived water release estimates are similar. In addition, the water release estimated by the EKS Model was consistent with the measured water release, demonstrating its ability to accurately forecast the performance of the EKS-DT process.

By the end of the field demonstration, the volume of water released was >60% of the initial tailings volume. This exceeded the KPI set for water release (58% of the initial tailings volume) shown in Table 1. The field demonstration was stopped due to schedule and budget constraints, not due to technical reasons. If the demonstration had been extended, more water would have been released. Figure 6 shows the surface of the tailings at the end of the field demonstration, after the recovered water had been removed.

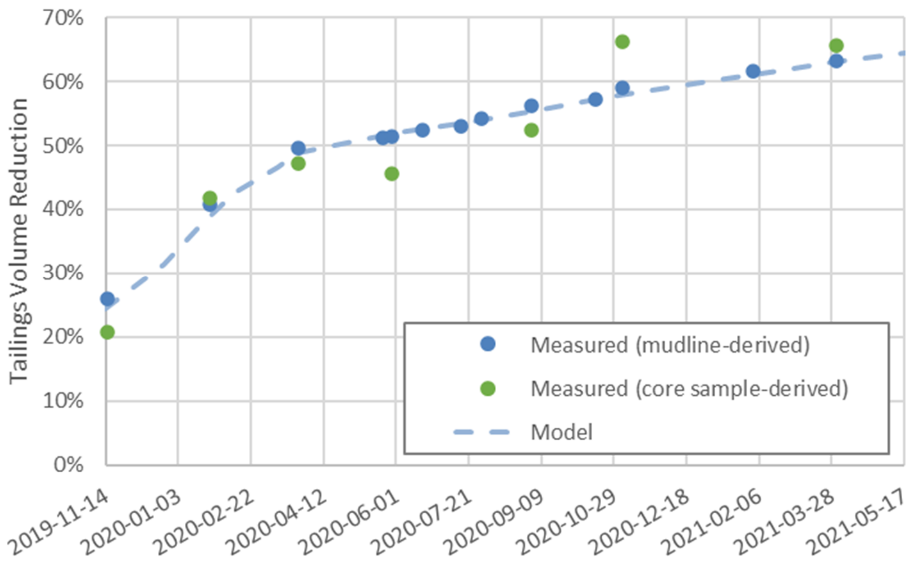

Figure 5 Forecast and measured tailings volume reduction during the field demonstration

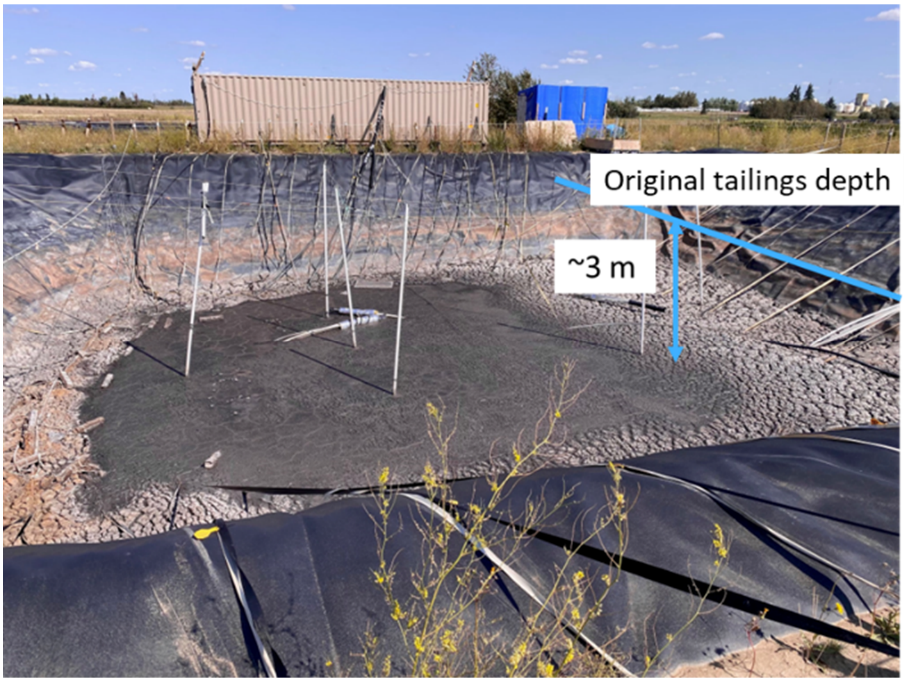

Figure 6 Surface of the tailings after the water cap was removed at the end of the field demonstration

For an active TSF, the released water would provide two significant benefits to the mine operator. Firstly, after the released water is recovered from the TSF, the TSF capacity would be increased by an equivalent volume. The field demonstration increased the capacity of the test cell by >60%. In section 4, the economic value of increased TSF capacity is discussed for a hypothetical commercial EKS installation.

In addition, the water released from the tailings by the EKS-DT process is available for re-use in the mineral extraction process, reducing the amount of freshwater that is required from local waterbodies. The value of this released water varies between operations but can be quite significant in arid regions.

Re-use of the released water is dependent on specific water quality criteria that may vary from one operation to the next. Two major concerns with re-use water are high cation concentrations, which can cause scaling, and the build-up of chlorides. Due to these concerns, analyses of the water released during the field demonstration were conducted on multiple occasions. These results are shown in Table 2. In summary, the released water was suitable for re-use, meeting that KPI for the field demonstration.

Table 2 Measured released water properties during the EKS-DT field demonstration

Parameter		Measured values		% change	Suitable for re-use?
		Initial	Final		
pH		7.6	9.5	**+25%**	✓
Concentration (mg/L)	Ca	37	4	**-89%**	✓
	Mg	18	2	**-89%**	✓
	Cl	120	97	**-19%**	✓

The values for individual parameters changed over time. The observed trends were consistent with the electrochemical processes occurring during the operation of the EKS-DT process. The pH near the cathodes increased over time due to the electrolysis of water at the cathodes producing OH^- ions and hydrogen gas. As a result of the elevated cathode pH, the pH of the released water also increased over time. A similar trend over time is expected with a commercial installation.

The final concentrations of calcium and magnesium cations decreased significantly over time. As the pH of the released water increases, the solubility of these cations decreases, forming calcium and magnesium hydroxide precipitates near the cathodes, reducing the concentrations of these cations in the water released from the tailings. Removing these scaling agents from the released water increases its value for re-use.

The electric field between the electrodes draws anions away from the cathodes, towards the anodes. The extent to which this electromigration concentrates anions near the anodes depends on the current density and the pH near the anodes. The higher the current density, the more H^+ ions are produced at the anodes, decreasing the pH near the anodes. The greater the pH difference between the anodes and the bulk of the tailings, the greater the concentration of anions will be at the anodes to maintain electroneutrality. As a result of electromigration, the chloride concentration near the cathodes and, therefore, in the released water decreased over time.

In summary, the water released from the tailings during the field demonstration was equivalent to >60% of the initial tailings volume and was accurately forecast by the EKS Model. The properties of the released water were more suitable than those of the tailings porewater for use in the bitumen extraction process. The properties of the initial tailings porewater and the released water may differ for different mineral extraction operations, but the changes in those properties over time will be similar to those observed during the field demonstration.

3.2 Solids content

The solids content at different depths and lateral locations within the test cell were determined from the core sample sections periodically collected during the field demonstration. This data was used to track the tailings solids content in the test cell over time, a trend shown in Figure 7. The anode solids content predicted by the EKS Model is also shown.

Initially, the solids content was approximately 30% by weight near the anodes. This value increased over time and was ~60% at the end of the field demonstration, meeting the KPI set for solids content (Table 1). This trend was accurately forecast by the EKS Model. A 'block' of oil sands tailings consolidated to >60% solids is shown in Figure 8.

Table 3 shows estimated properties for oil sands tailings at 60% solids. When the EKS-DT process is applied to an actual TSF and operated to produce tailings with similar properties as those shown in Table 3, the geotechnical stability of the material would be greatly increased, significantly reducing the risk of catastrophic liquefaction of the tailings. Furthermore, the EKS technology could be used to create a stable layer on the surface of a TSF, enabling the TSF to be reclaimed and its surface returned to its natural state sooner.

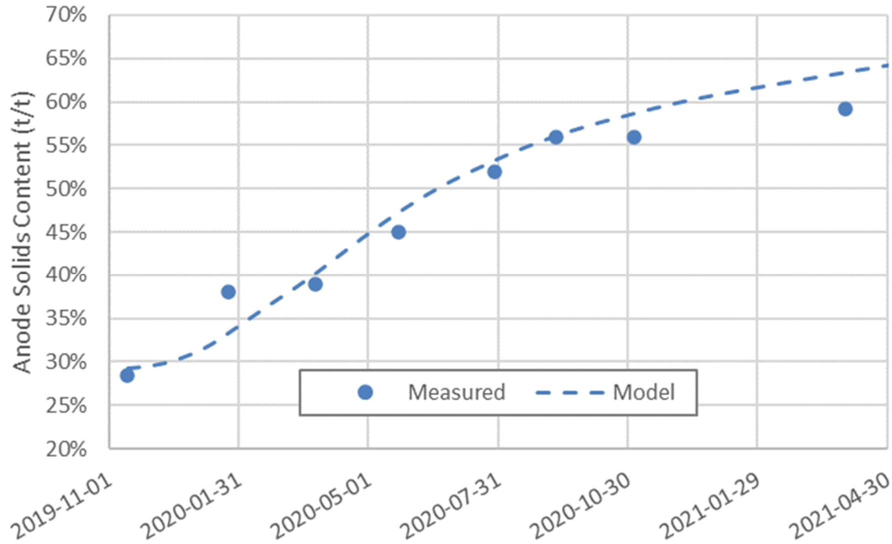

Figure 7 Forecast and measured tailings solids content near the anodes during the EKS-DT field demonstration

Figure 8 Tailings dewatered by the EKS-DT process to >60% solids

Table 3 Properties of oil sands tailings at 60% solids by weight

Property	Value	Reference
Density	1.57	Measured by EKS
Effective stress	7.7 kPa	(Jeeravipoolvarn et al. 2009)
Hydraulic conductivity	5.48 x 10-10 m/s	(Jeeravipoolvarn et al. 2009)

3.3 Energy consumption

The voltage and current applied to the electrodes were continuously recorded during the field demonstration. As the tailings were dewatered, the EKS control system was used to adjust the power signature applied to the electrodes to maximise the energy efficiency of the operation. The measured energy consumption of 14.8 kWh per m^3 of water released during the field demonstration was consistent with the prediction of the model of 16.2 kWh/m^3 of released water. Both values were significantly lower than the KPI of 30 kWh/m^3 set for the field demonstration.

Minimising energy consumption is an important consideration for optimising electrokinetic (EK) dewatering systems. Energy consumption is a function of the electric field pattern, the current density, the electrolytic conductivity of the porewater, and the porosity of the material being dewatered (Lo et al. 1990; Shang & Dunlap 1996). Setting an optimal 'applied voltage schedule' during the operation of an EK installation, considering the above factors, is essential to minimise energy consumption while maximising the dewatering rate. Through its technology development program, EKS has optimised the applied voltage schedule used by the EKS-DT process. The low energy consumption achieved during the field demonstration demonstrate the result of this power signature optimisation at scale.

3.4 Operation

The field test was operated remotely; no operator was required on site. An automated control system regulated the applied power and compiled and stored data from in situ sensors deployed in the test cell. The control system communicated with EKS via the internet. Where necessary, EKS sent instructions to the control system to modify the operating schedule. EKS was also able to review remotely all in situ sensor data in real time.

Occasional power failures occurred during the field demonstration. During power failures, the control system 'hibernated', and the dewatering process was paused as no power was being applied to the electrodes. When the power was restored, the control system resumed the application of power to the electrodes, causing the dewatering process to resume. The EKS-DT process can be turned off and on without special start-up or shutdown procedures required.

The EKS-DT field demonstration was successfully operated for two winters, as planned. Figure 9 shows the test cell when the surface of the water cap was frozen. Dewatering occurs below the mudline, which is below the frozen portion of the water cap. Since the EKS technology has no moving parts and requires no additives to the tailings, dewatering continues under the ice. The dewatering rate was not observed to be dependent on the season or whether the surface of the water cap was frozen.

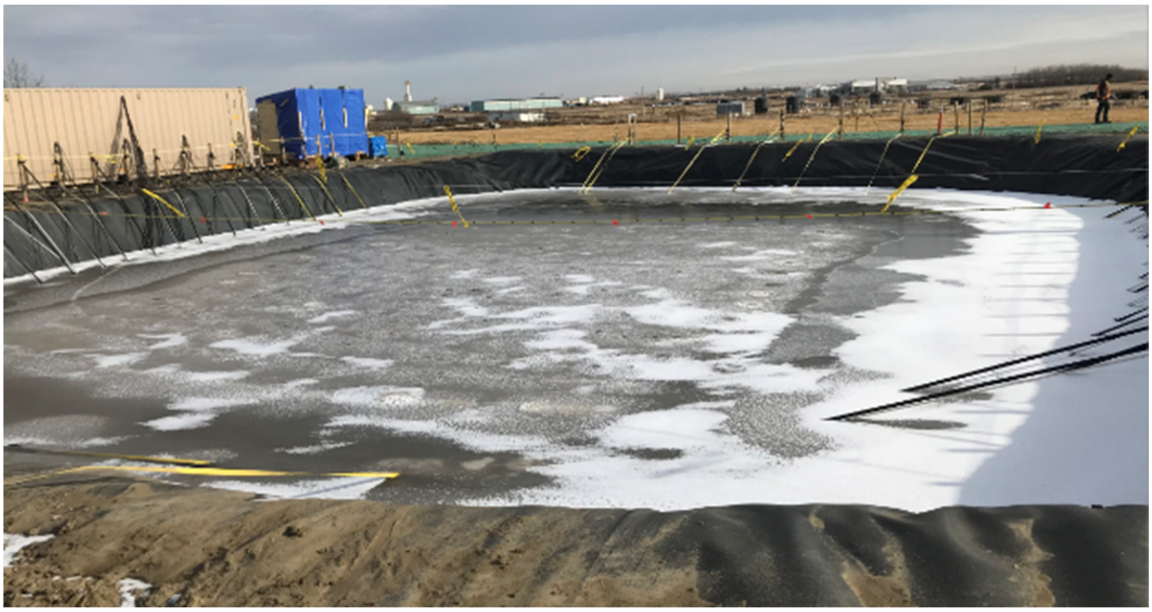

Figure 9 The EKS-DT field demonstration test cell during operation

The field demonstration showed that the EKS control system functioned as designed, and that the process can be reliably operated remotely, year-round without an onsite operator, achieving that KPI.

4 Commercial case study

The performance of the EKS-DT process and the accuracy of the EKS Model were proven during the field demonstration. However, further analyses were required to demonstrate the commercial value of the technology. As a result, a business case was prepared for a hypothetical 'case study' TSF to provide a quantitative example of the benefits offered by the EKS technology.

When the EKS-DT process releases water from tailings in a TSF, additional capacity to store tailings is created in the TSF. The value of this capacity can be significant for many mine operations, as it can significantly delay the required construction of new TSF or expansions to existing TSFs. The case study quantified the cost savings associated with the additional TSF capacity generated by the EKS technology and is described in the following sections.

4.1 Case study method

The case study is based on an avoided costs methodology. The benefit realised by the mining operation from deploying the EKS technology in the case study TSF would be the delay in the construction costs for expansion of the TSF as more tailings storage is required. This cost saving is the difference between the net present value of the total TSF costs with and without the deployment of the EKS technology (i.e. the difference in cost between the 'base' and 'EKS' cases).

For the base case, without the EKS technology, the only TSF costs considered are the construction costs required to expand the TSF when additional capacity is needed (i.e. the height of the tailings dam is raised). For the EKS case, the TSF costs include the TSF expansion construction costs, as well as the capital and operating costs of the EKS installation.

Equation 4 describes the calculation of the savings due to the EKS installation.

$$\Delta C = C_{d,EKS} + C_{c,EKS} + C_{o,EKS} - C_{d,B} \tag{4}$$

where:

ΔC = net present value of the cost savings from the EKS installation (negative values of ΔC indicate a cost savings).

$C_{d,EKS}$ and $C_{d,B}$ = net present costs to raise the TSF for the EKS and Base cases, respectively.

$C_{c,EKS}$ and $C_{o,EKS}$ = net present capital and operating costs, respectively of the EKS installation.

All capital and operating costs have been discounted to their corresponding net present value using standard accounting practices. Using present values allows direct comparisons between short- and long-term costs and benefits. All net present value calculations assume a discount rate of 6% and 2023 as year 0.

The following steps were followed to estimate the parameters included in Equation 4:

1. The rate of increase in the tailings height (i.e. the mudline) in the TSF for the base case is estimated.
2. As the tailings height increases, the tailings dam height must be periodically increased to increase the capacity of the TSF. Based on the rate at which the tailings height increases, the required dam raise schedule for the base case is estimated.
3. The dam raise construction costs are estimated and used to determine $C_{d,B}$, based on the base case dam raise schedule.
4. For the EKS case, the water release from the installation is forecast and used to determine the rate at which the tailings height increases, and the dam raise schedule for the EKS case.

5. $C_{d,EKS}$ is determined based on the EKS case dam raise schedule and the same construction costs estimated for the base case.
6. The capital and operating costs for the EKS installation are determined.
7. The net present value of the EKS installation costs (i.e. $C_{c,EKS}$ and $C_{o,EKS}$) are determined.
8. Equation 4 is used to determine ΔC, the cost savings resulting from the EKS installation.

This methodology assumes that the only value of the EKS installation is the cost savings due to deferring construction costs for the elevating of the tailings dam. As described in Section 1, the EKS technology has many advantages beyond simply increasing TSF capacity, but the value of these benefits has not been estimated as part of this case study. For example, in arid environments, water recovery is highly valuable. Adding the value of the recovered water to the increase in the TSF capacity would make the EKS technology even more attractive from an economic perspective.

4.2 Tailings storage facility properties

A schematic of the case study TSF is shown in Figure 10. The TSF is approximately 7.2 × 3.3 km. The tailings dam whose length is approximately 1 km is at the north-western corner of the TSF. An open water area (1.2 × 3.3 km) is impounded behind the dam. Below the water are unconsolidated fine-grained tailings. It is in this area that the EKS-DT electrodes are assumed to be located. Upstream is an exposed tailings beach. Fresh tailings are being continually added to the TSF along the eastern edge; as the tailings are discharged, the level of the tailings gradually rises.

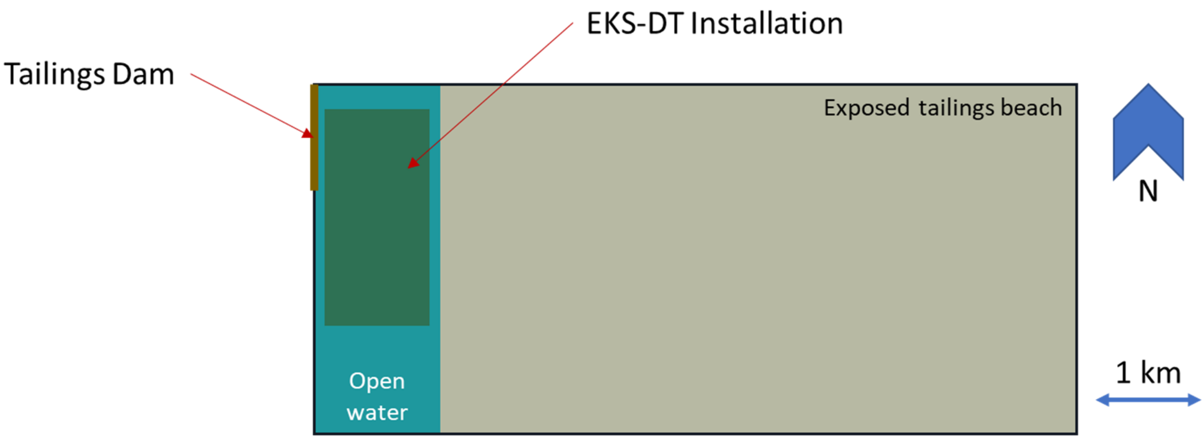

Figure 10 Schematic of the hypothetical TSF on which the case study is based

Settlement of the coarsest tailings occurs close to the discharge point. The finer the grain size of the tailings, the further they flow towards the tailings dam. The result is that the tailings are naturally segregated by grain size during the deposition process. The tailings are also segregated vertically for the same reason. The tailings at the bottom tend to have a higher average grain size than the tailings at the surface although this segregation is less pronounced further from the discharge point. Most of the coarse-grained particles rapidly settle out close to the discharge point leaving only fine tailings in much of the TSF.

A summary of the key TSF assumptions on which the case study is based are shown in Table 4.

Table 4 Hypothetical tailings storage facility properties

Tailings storage facility area	2,200 ha
Whole tailings rate	180,000 t/d
Whole tailings solids content	40% t/t

Base water release rate	13,000 m^3/d
Base mudline rise rate	2 m/year

The net tailings deposition rate is the difference between the rate at which whole tailings are deposited and the base water release rate. The rate at which the mudline rises is the net tailings deposition rate divided by the TSF area. In the absence of the EKS technology, the mudline in the TSF is estimated to rise by ~2 m per year.

To accommodate the rising mudline, three raises to the TSF dam over the next 10 years are required to accommodate the disposal of additional fresh tailings. Table 5 shows the trigger mudline height for each dam raise. When the mudline reaches the trigger height, construction of the dam raise is required. The forecast cost and schedule for each dam raise are shown in Table 5. Together, the costs for the three raises are forecast to be approximately $1 billion USD. These construction costs were independently estimated and the details are not presented in this document.

The case study is based on a single TSF that is reasonably representative of many TSFs. However, the precise increase in dewatering rate provided by the EKS-DT process and therefore the cost savings will vary from one TSF to another depending on the TSF and tailings properties.

Table 5 Case study tailings storage facility dam raise schedule and cost for both the base and EKS cases

Raise #	Trigger mudline height increase* (m)	Cost (USD)	Construction year	
			Base case	EKS case
1	4	$340 million	2024	2026
2	12	$350 million	2028	2034
3	20	$250 million	2032	2043

* Relative to the current mudline position

4.3 EKS-DT properties

Figure 10 shows a hypothetical EKS installation in the TSF. This installation (the green shaded rectangle) is in the section of open water behind the TSF dam. A key feature of the EKS technology is the design of the electrode array(s) to fit the specific dimensions of a TSF. Determining the optimal shape and size is part of the engineering design process.

The dewatering rate from the EKS technology is dependent on various factors including tailings characteristics (e.g. grain size, zeta potential, conductivity, water content), the surface area of the electrode array, the vertical and horizontal separation among the electrodes, and the voltage applied to the electrodes. Based on these factors, when the EKS technology is installed, water is rapidly released from the tailings within the electrode array.

As these tailings are dewatered, the mudline above the electrodes will drop. Concurrently, tailings continue to be deposited into the TSF, causing fresh tailings to flow into the depression over the electrode array and subsequently undergo dewatering. Due to the constant inflow of tailings into the electrode array, the solids content of the tailings between the electrodes will not vary greatly over time, leading to a relatively constant dewatering rate.

The EKS Model, proprietary software developed by EKS, was used to forecast the water release rate. This model has been developed through extensive lab research and a field demonstration. If a case study was being developed for a mining company, tailings samples would be collected, and the results of these analyses would be used to calibrate the EKS Model before producing dewatering forecasts for the TSF.

In this case study, the tailings are assumed to be fine textured and to have a low solids content. This assumption is reasonable based on the distance from the outfall at the head of the TSF to the open water area where the electrodes are positioned. However, the precise increase in dewatering rate provided by the EKS-DT process and, therefore, the cost savings will vary from one TSF to another depending on the existing capacity of the TSF, the costs of expanding the TSF or building a new TSF and the volume of fine-grained tailings requiring further dewatering.

The forecast dewatering rate of the EKS installation is 30 L/day per m^2 of electrode array area, or 3 cm/day. The EKS installation has a total area of about 212 ha and so a total of about 65,000 m^3 of water is forecast to be released per day. The increased rate of water release results reduces the rate at which the level of tailings in the TSF (i.e. the mudline) rises to about 0.95 m/year, 50% lower than the base case. This water release significantly increases the capacity of the TSF. Every cubic metre of water released is another cubic metre of capacity available to store tailings, assuming that the released water is recovered and reused or is released to the environment.

Table 5 shows the trigger mudline heights for each of the planned dam raises. The lower mudline rise rate achieved with the EKS case results in the schedule for these raises being extended, deferring the construction costs. The scheduled construction for the third dam raise is extended by 11 years, demonstrating the dramatic impact of the greater water release rate that can be achieved by the EKS installation.

The EKS technology is relatively simple. It involves no additives or moving parts and no large equipment and infrastructure. Most of the components for an EKS installation are fabricated locally and are deployed using local contractors. Deployment does not require specialised equipment. For this reason, the capital costs are largely dependent on local prices.

The capital and operating cost unit factors for the EKS installation were derived from the costs of the field demonstration in Canada. The all-in unit cost for the electrode array excluding the power supply system is forecast to be about $130/linear m of an electrode pair. The total cost for the array to be designed, fabricated and deployed is about $128 million.

A dedicated power supply line is required to connect the EKS installation with the local electricity grid. The local service is assumed to have adequate capacity to support this additional demand. Additional electrical equipment, including an AC-DC rectifier, is required to convert the AC power to DC power and to regulate the power applied to individual electrodes. These components are similar to what was required for the field demonstration. The capital cost for the power supply and control systems is estimated to be about $5 million.

The major operating cost with the EKS technology is electrical power. The technology involves no moving parts or additives. As well, no onsite operator is required. The installation is operated by a central control system that reports dewatering progress remotely to tailings managers. Minimal maintenance is required for the EKS installation. For the purposes of this analysis, the only operating cost included is electricity. A constant electricity price of $84 per MWh has been assumed. The forecast total electricity consumption for the is about 58,000 MWh per year.

Table 6 summarises the forecast capex and opex for the case study EKS-DT installation.

Table 6 Capital and operating costs for the case study EKS-DT installation

EKS electrode capex (USD)	$128,000,000
EKS power supply and control system capex (USD)	$4,700,000
Annual EKS opex (USD)	$4,800,000

4.4 Case study results

The annual costs for the base and EKS cases during the next 10 years were forecast based on the estimated TSF and EKS installation properties. This cost forecast is shown in Table 7.

Table 7 Annual costs for both the base and EKS cases

Year	Discount factor	Cost (USD/1,000)			
		Base case dam raises	EKS case dam raises	EKS-DT capex	EKS-DT opex
2023	1.00	$ –	$ –	$132,766	$4,836
2024	0.94	$340,000	$ –	$ –	$4,836
2025	0.89	$ –	$ –	$ –	$4,836
2026	0.84	$ –	$340,000	$ –	$4,836
2027	0.79	$ –	$ –	$ –	$4,836
2028	0.75	$350,000	$ –	$ –	$4,836
2029	0.70	$ –	$ –	$ –	$4,836
2030	0.67	$ –	$ –	$ –	$4,836
2031	0.63	$ –	$ –	$ –	$4,836
2032	0.59	$250,000	$ –	$ –	$4,836
Total net present cost		$730,270	$285,471	$132,766	$37,730

Based on Equation 4 and the costs shown in Table 7, the net present value of the cost savings provided by the EKS installation is about USD274 million. This corresponds to a rate of return >90% on the EKS installation capital costs.

5 Conclusion

The EKS-DT process has been developed by EKS over the past 12 years to enable the mining industry to practically and economically address the liability posed by unconsolidated tailings. EKS' technology offers many opportunities to TSF operators, including increased TSF storage capacity, increased water conservation, and a reduced risk of tailings liquefaction.

A 1,700 m^3 field demonstration of the technology was completed in 2021 in Alberta, Canada. During the field demonstration, the tailings volume was reduced by >60% and the solids content near the anodes was dewatered to 60% solids by weight. The average energy consumption was <15 kWh/m^3 of water released. These results were all consistent with the estimates produced by the EKS Model, demonstrating that EKS can accurately forecast the dewatering performance of the technology. In addition, the field demonstration results met or exceeded all KPIs that were set for the technology, proving that the technology scales up as designed and is commercially viable.

A case study of a commercial TSF was completed to quantify the potential cost savings that can be provided by the EKS technology due to the additional TSF capacity created. As a result of the forecast water release by the EKS-DT process, the rate at which the level of tailings in the TSF rises would be reduced by 50%. As a result, the tailings dam raises and associated construction costs planned for the case study TSF would be delayed by 2–11 years; a significant cost savings. The net present value of the cost savings offered by the EKS installation, net of the capital and operating cost of the installation is approximately USD274 million.

The case study results show that the EKS technology offers significant economic benefits to TSF operators. The value of the other benefits offered by the EKS-DT process (e.g. water recovery, reduced risk of tailings liquefaction) were not quantified as part of the case study. Adding the value of these other benefits to the analysis would make the EKS technology more attractive from both an economic and environmental perspective.

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References

Abraham, T, Lam, N, Xu, J, Zhang, D, Wadhawan, H, Kim, HJ, … & Thundat, T 2018, ‘Collapse of house-of-cards clay structures and corresponding tailings dewatering induced by alternating electric fields’, *Drying Technology*, vol. 37, no. 9, pp. 1053–1067.

Baker, E, Davies, M, Fourie, A, Mudd, G, & Thygesen, K 2020,‘Mine tailings facilities: overview and industry trends’, in B Oberle, D Brereton, & A Mihaylova (eds), *Towards Zero Harm – A Compendium of Papers Prepared for the Global Tailings Review*, St Gallen, pp.14–24.

Casagrande, L 1949, ‘Electro-osmosis in soils’, *Geotechnique*, vol. 1, no. 3, pp. 159–177.

Dixit, SP, Gombeer, R, & D’hoore, J 1975, ‘The electrophoretic mobility of natural clays and their potential mobility within the pedon’, *Geoderma*, vol. 13, issue 4, pp. 325–330.

Franks, DM, Boger, DV, Côte, CM & Mulligan, DR 2011, ‘Sustainable development principles for the disposal of mining and mineral processing wastes’, *Resources Policy*, vol. 36, no. 2, pp. 114–122.

Ghorbani, Y & Kuan, SH 2017, ‘A review of sustainable development in the Chilean mining sector: past, present and future’, *International Journal of Mining, Reclamation and Environment*, vol. 31, no. 2, pp. 137–165.

Islam, S 2014, *Thickening of Mature Fine Oil Sands Tailings*, PhD thesis, University of Western Ontario, London.

Jeeravipoolvarn, S, Scott, JD & Chalaturnyk, RJ 2009, ‘10 m standpipe tests on oil sands tailings: Longterm experimental results and prediction’, *Canadian Geotechnical Journal*, vol. 46, no. 8, pp. 875–888.

Lo, KY, Inculet, II & Ho, KS 1990, ‘Electroosmotic strengthening of soft sensitive clays’, *Canadian Geotechnical Journal*, vol. 28, pp. 62–73.

Lockhart, NC 1983, ‘Electroosmotic dewatering of clays. 1. influence of voltage’, *Cotloids and Surfaces*, vol. 6, pp. 229–238.

Long, J, Li, H, Xu, Z & Masliyah, JH 2006, ‘Role of colloidal interactions in oil sand tailings treatment’, *AIChE Journal*, vol. 52, no. 1, pp. 371–383.

McKenna, G & VanZyl, D 2020,‘Closure and reclamation’, in B Oberle, D Brereton, & A Mihaylova (eds), *Towards Zero Harm – A Compendium of Papers Prepared for the Global Tailings Review*, St Gallen, pp.109–127.

Nasirov, S & Agostini, CA 2018, ‘Mining experts’ perspectives on the determinants of solar technologies adoption in the Chilean mining industry’, *Renewable and Sustainable Energy Reviews*, vol. 95, no. July, pp. 194–202, https://doi.org/10.1016/j.rser.2018.07.038.

Owen, JR, Kemp, D, Lèbre, Svobodova, K & Pérez Murillo, G 2020, ‘Catastrophic tailings dam failures and disaster risk disclosure’, *International Journal of Disaster Risk Reduction*, vol. 42.

Roche, C, Thygesen, K & Baker, E 2017, *Mine Tailings Storage: Safety Is No Accident*, GRID Arendal, https://www.grida.no/publications/383

Shang, J & Dunlap, W 1996, ‘Improvement of soft clay by high voltage electronics’, *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 122, no. 4, pp. 274–280.

Shang, JQ & Xu, Y 2019, ‘Electrokinetic dewatering of mine tailings from hydrometallurgical processes’, in AJC Paterson, AB Fourie & D Reid (eds), *Paste 2019: Proceedings of the 22nd International Conference on Paste, Thickened and Filtered Tailings*, Australian Centre for Geomechanics, Perth, pp. 275–283, https://doi.org/10.36487/ACG_rep/1910_18_Shang

Shang, JQ 1997, ‘Electrokinetic sedimentation: a theoretical and experimental study’, *Canadian Geotechnical Journal*, vol. 34, pp. 305–314.

Sutherland, BR, Barrett, KJ, Gingras, MK, Sutherland, BR, Barrett, KJ & Gingras, MK 2015, ‘Clay Settling in Fresh and Salt Water’, *Environmental Fluid Mechanics*, vol. 15, pp. 147–160.