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Geotextiles and GeomembranesExamining metal migration through geotextiles during dewatering

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Abstract

This paper presents a study conducted to assess the influence that a filter cake deposited on the surface of the geotextile has on the mobility of three metals (Cu, Pb, Zn) during filtration of a contaminated sediment. Two chemical additives (cationic coagulant and cationic polymer) were introduced to the sediment to increase the particle size and improve the filtration efficiency. Bench scale experimentation was conducted to identify contaminant reduction using a small volume of sediment. A field test was applied to observe what effect three-dimensional filtration and a larger filter cake had on metal mobility. Analysis of the effluent was conducted to determine total and dissolved metal contaminants, as well as particulate matter. Effluent chemical properties (pH, ~~E_H~~E_h, and zeta potential) were analyzed to identify a possible rationale for variations in concentration during filtration. The results of the study show that as ~~t with~~ an increasing buildup of filter cake on the surface of a geotextile~~e~~ developed, ~~the effluent quality continued to improve, relative to the unfiltered material~~filtrate quality was improved with respect to the metal and particulate contaminants considered. In addition, the metals detected in the effluent were primarily in the solid state, suggesting further reduction could be achieved through subsequent filtration (if desired).

Keywords: Geotextile, Filtration, Metal, Filter cake, Effluent, Contaminated sediment

1. Introduction

Geotextile tubes (i.e. geotubes®) have previously been implemented during remediation efforts that involve large volumes of contaminated sediments and slurries (Fowler et al., 1997; Bhatia, 2004; Stephens et al., 2011). The application of this approach has been proven to be an effective method of managing high water content contaminated sediments by both retaining, and dewatering the material (Watts and Trainer, 2010). During the dewatering process, the liquid effluent by-product (produced from the separation of solid particulate and the associated water) may contain both dissolved contaminants as well as contaminants associated with any particulate matter that has migrated through the geotextile. If these contaminants are found in high enough concentrations (i.e. based on effluent criteria), the need for further effluent treatment may be required (Muthukumaran and Ilamparuthi, 2006).

The efficiency to which sediments are dewatered during this remediation technique has been well documented in the literature (e.g., Mastin et al., 2008; Muthukumaran and Ilamparuthi, 2006; Satyamurthy and Bhatia, 2009). Fowler et al. (1997) conducted research pertaining to the quality of the effluent with respect to particulate matter. Lassabatere et al. (2004) have examined effluent quality following dewatering with respect to metal contaminants. Jahan et al. (2018) described the potential application of geotextile fabric in combination with chemical conditioning (i.e. polymers) used for the removal of a single metal (aluminum) by retaining particulate matter during wastewater treatment. Gaps in the literature exist, however, concerning the effect of a build-up of sediment on the surface of the geotextile (known as a filter cake) which may further aid in the retention of particulate matter and in turn, any associated contaminants (Muthukumaran and Ilamparuthi, 2006). In addition to literature describing the effect of an established filter cake on contaminant transport (i.e. metals in this paper), little information can be found describing the mechanisms for migration of metal transport through geotextiles during dewatering. Information regarding the processes affecting migration, such as solubility, particle speciation, and the association of metals with particulate matter being retained during dewatering are all areas which comprehensive studies are lacking. Factors such as oxidation-reduction potential (~~E_H~~E_h), pH (Chuan et al., 1996; Gambrell et al., 1991; Hermann and Neumann-Mahlkau, 1985; Lange et al., 2004; Lassabatere et al., 2004) and surface charge (zeta potential) of particles (Larsson et al., 2012) have all been shown to impact the fate and transport of metals. Understanding the mechanisms responsible for metal transport (if any) during geotextile dewatering of contaminated sediments is important to ensure the effectiveness of the technique with respect to metal retention.

The primary aim of this research is to identify how an established sediment filter cake deposit on the surface of a geotextile can influence the migration of copper, lead, and zinc (Cu, Pb, and Zn) during dewatering. These metals were selected as the focus of this paper due to their varying solubility in natural environments (Hermann and Neumann-Mahlkau, 1985). A brief summary of the sediment characteristics, along with the conditioning regime utilized to improve filtration efficiency is included. Secondly, methodology and results (chemical and physical characteristics of the effluent) describing two scales of testing are presented. A vertical cell bench-scale test (filter positioned horizontally) was performed to identify the influence of an increasing filter cake in a controlled environment on metal migration during dewatering. Field-site experimentation was then conducted to observe the impact of a larger volume of material (cake) and the three-dimensional effect of a geotextile bag on metal transport, which is more representative of full-scale conditions due to the added influence of pressure (Stoltz et al., 2019). Finally, a discussion of the effect of the filter cake on metal retention, as well as a rationale for potential contaminant migration is explored.

2. Sediment and Geotextile Characterization

The woven polypropylene geotextile used in this study (i.e. GT500, henceforth referred to as "the geotextile") has an apparent opening size (AOS) of 430 µm with an average thickness of 1.8 mm. The pore size values for O$_{50}$ and O$_{95}$ are 80 µm and 195 µm, respectively (TenCate Corporation, 2015). This geotextile has been used in field dewatering applications and also formed the basis for research conducted by the authors in previous studies (e.g., Alimohammadi et al. (2019)). The latter consideration allowed comparison with these previous studies.

The sediment used for this study originated from Boat Harbour, Nova Scotia, Canada. At the time of this paper, the Boat Harbour facility consists of several stages for the treatment of wastewater primarily originating from a nearby bleached kraft pulp and paper mill. During wastewater treatment, effluent is directed into a stabilization lagoon, where the low energy environment allows for the settling of fine particulate matter over a residence period of approximately 30 days (Hoffman et al., 2017). An estimated 577,000 m^3 of unconsolidated sediment has been deposited in this lagoon over the industrial lifespan of the facility (50+ years) and is the primary focus of a scheduled remediation effort at this location (GHD Limited, 2018). The sediment selected for this research was sampled from the stabilization lagoon which was actively treating wastewater at the time of this study.

Several studies have documented the characteristics of the sediment in question. Preliminary characterization of the contaminated sediment, as well as the overlying water was conducted by Alimohammadi et al. (2020~~19a~~). The authors reported the in situ sediment to be unconsolidated (< 10 % solid content; > 1000 % moisture content), and contain approximately 30 percent organic content by dry mass. Hoffman et al. (2017) identified seven metals (As, Cd, Cr, Cu, Pb, Hg, and Zn) in the sediment, which were found to be frequently elevated above the Canadian Council of Ministers of the Environment interim sediment quality guidelines for both marine and freshwater (CCME, 2020). These metal contaminants were in addition to the presence of organic contaminants in the sediment (Hoffman et al., 2019).

Geotextile filtration of this sediment has been previously assessed by Alimohammadi et al. (2019~~b~~) for small volumes (i.e. 200 mL). Evaluation of both dewatering potential and filtrate quality (total suspended solids [TSS]) was completed following treatment with an optimum dosage of polymer and filtration through the geotextile. Following filtration, the authors reported a TSS of 31 mg L^{-1} in the effluent, a reduction of 98.8% from the original input. A study conducted by Tackley et al. (2020) measured the effect of various conditioning treatments on the migration potential of Cu, Pb, and Zn during bench-scale filtration using the geotextile. Similar to the study conducted by Alimohammadi et al. (2019~~b~~), analysis was conducted on 200 mL samples of 1 % solid content (SC) slurry. The geotextile was shown to effectively filter the conditioned material and yield a relatively clean effluent when compared to the untreated sample. TSS, particle concentration, particle size, and metal concentrations (Cu, Pb, Zn) were measured in the untreated sample (Table 1), and an optimal conditioning dosage (which yielded the highest quality filtrate as per the parameters listed above) was identified. The optimal dosage consisted of a two-stage conditioning regime which was capable of increasing the particle from the initial 6 µm reported by Alimohammadi et al. (2019~~b~~), to greater than 610 µm on average. The polymer conditioning applied was shown to significantly influence TSS and metal levels in the resulting effluent, with greater than 99 % reduction for each when compared to an untreated sample. This work did not evaluate the influence of a developed filter cake on the results. The optimal dosage identified by Tackley et al. (2020) was implemented during this study and will be discussed in further detail later in this paper.

3. Methods: Polymer Conditioning and Experimentation

3.1 *Bench-scale test*

A bench-scale rapid dewatering test (RDT) described by Tackley et al. (2020) was modified to further examine the influence that a filter cake had on the quality of filtrate produced during the sediment dewatering procedure (with respect to concentrations of Cu, Pb, Zn, and particulate matter). Tackley et al. (2020) used 200 mL volume samples to assess filtrate quality and hence did not examine the role of the filter cake on metal migration. The filtration of a total volume of 4000 mL of conditioned sediment slurry was completed during this ~~test~~study to allow for the accumulation of a filter cake and assess its role on metal migration. A modification from Tackley et al. (2020) consisted of the addition of an acrylic collar (Figure 1) to accommodate the increased volume (4000 mL) of sediment to be passed through the geotextile. The methods described below expand on those outlined by Tackley et al. (2020), however are specific to this study.

Twenty 200 mL sediment slurry samples (diluted to 1 % SC with water sampled from the stabilization basin) were prepared as described by Tackley et al. (2020). Each 200 mL sample will be henceforth referred to as a "trial". The polymer conditioning was performed to aggregate the sediment particles. A cationic flocculating agent (Solve 7118) was introduced to each sample (10 mL or 5 % of the sample volume), followed by an equal volume of cationic polymer (Solve 9244). Upon flocculation, the first 200 mL trial was poured into the RDT apparatus~~, with the effluent being collected in a flask placed below the funnel~~. The RDT apparatus consisted of a funnel placed in a Erlenmeyer flask and fitted with a sample of geotextile fabric. This apparatus allowed for the controlled filtration of sediment and collection of the filtrate. Following a collection period of 600 seconds, the flask was removed, and the filtrate extracted for analysis. The funnel was then placed in a clean flask, and a subsequent 200 mL sample of optimal dosage conditioned slurry was poured on the geotextile and accumulated filter cake from the previous 200 mL trial. The effluent was allowed to percolate through the previously established filter cake and geotextile for a further 600 seconds before again being removed for analysis. The time allowed for filtration prior to the replacement of the flask was increased at the 5th, 10th, and 15th trials (to 1200, 1800, 2400 seconds respectively) to allow for the effluent to pass through the accumulating filter cake ~~of sediment~~ on the geotextile. This procedure was repeated for twenty trials (for a total slurry volume of 4000 mL) during each of three repeated tests. Metal and particle analysis were carried out on the effluent generated from each 200 mL sample.

3.2 *Geotextile bag field test*

Field testing was performed using a specially prepared geotextile bag to assess the performance of the geotextile and additive dosage with respect to metal migration when subject to increased volume, as well as to examine the three-dimensional effect of the geotextile bag on filtration efficiency.

The geotextile bags for the field test were acquired from Bishop Water Technologies (Renfrew, Ontario, Canada) for field analysis and ~~consisted of~~were fabricated form the same geotextile material used during the bench-scale testing. The bags had an average side length of 55 cm (±5cm) and were stitched together along three of the sides (folded along the remaining side). A 7.6 cm diameter acrylonitrile-butadiene-styrene (ABS) plastic adapter was fitted to one side (the de facto top) of the bag (i.e. in the centre), by the manufacturer. A frame device used during the field-scale dewatering trial was designed and constructed at Dalhousie University. The field-scale apparatus (Figure 2) consisted of a cylindrical plastic drum (140 L) used to mix and hold the slurry prior to geotextile filtration. A 3.8 cm diameter ABS drainage pipe and flow ~~release~~ control valve were fastened to the bottom of the drum, and stepped up to match the diameter of the bag adapter. ~~The pipe was stepped up to 5 cm and connected to the bag via a quick release threading system, allowing for easy replacement between tests.~~ The geotextile bag was placed on a geonet suspended below the drum for support and to allow the sampling of effluent as it percolated through the textile. Prior to ~~the~~ commencement of the test, a geotextile bag was ~~connected~~ fastened to the drum via the connecting pipe, and the release valve was set to the closed position.

The procedure implemented during the field scale dewatering test was a three-stage process designed to be repeatable for each trial. The first stage involved the preparation of 100 L of 1% SC slurry. Both water and sediment were added to the holding drum and homogenized via an electric drill fitted with a stainless-steel mixing rod. The slurry was continually mixed at approximately 50 rpm to keep the particulate matter in suspension prior to the addition of the optimum additive dosage. The second stage ~~of each trial~~ involved the conditioning of the slurry with the optimal dosage of the flocculating agent. The additive was integrated into the slurry by the mixing rod which rotated at a rate of approximately 300 rpm for 2-3 minutes. The cationic polymer was then added and stirred at a rate of 300 rpm for 1-2 minutes, or until flocs became visible, followed by 5 minutes of stirring at approximately 50 rpm to ensure sufficient flocculation occurred. Stage three of the field test began following the formation of visible flocs in the holding drum. The flow control valve on the drainage pipe was set to the open position and the slurry was allowed to drain into the geotextile bag. Gentl~~il~~e mixing (approximately 50 rpm) of the flocculated material was continuous during this ~~phase~~stage to ensure the flocs remained in suspension (as to not clog the connecting pipe)~~. The flow control valve on the connecting duct was then set to the open position and the slurry was allowed to drain into the geotextile bag~~.

The filtrate was recovered at predetermined time intervals during the field experiment. At each desired interval, plastic centrifuge tubes were placed below a corner of the bag to collect approximately 50 mL of effluent. Excess effluent was returned to the stabilization basin. Triplicate analysis of each effluent sample was then conducted following the same methodology used during the bench-scale test. After the contents of the drum were expelled, the flow control valve was closed. The drum was subsequently ~~refilled~~refilled and the procedure was repeated until the bag was deemed to be full. During the field scale RDT experiment, a total of 200 L of slurry (two 100 L trials) was filtered through a single geotextile bag prior to termination of the test. ~~filtered through a single geotextile bag.~~

3.3 *Effluent analyses test methods*

Physical and chemical analysis of the effluent collected during both experimentation methods was completed to determine the effect of the geotextile and filter cake on filtrate quality, as well as on an unconditioned slurry sample to identify a baseline to which the effluent could be compared. A Brightwell Technologies Inc. DPA-4100 flow microscope was used to determine both particle size and particle concentration. The microscope was capable of measuring particles within the range of 2 µm – 300 µm up to a concentration of 175,000 particles per millilitre (Brightwell Technologies Inc., 2009). For each trial, 1 mL of effluent was pumped through an imaging field at a rate of 0.22 mL min^{-1} with images being analyzed via software. A HACH DR 5000 benchtop spectrophotometer was used to measure total TSS in the effluent. Each TSS measurement consisted of 10 mL of effluent being analyzed three times with the average value being calculated. The effective measurement range of the unit was between 5 - 750 mg L^{-1} of TSS (HACH Company, 2014).

Metal concentrations in each effluent sample were determined via a Thermo Scientific X Series 2 ICP-MS instrument in accordance with ASTM method D5673 – 16 (ASTM International, 2016b). Total metals were measured to determine the effect of the geotextile and filter cake on metals which were thought to be associated with any particulate matter which had transitioned the geotextile. During this analysis, 10 mL samples of effluent were treated with 0.5 mL of concentrated NaOH and digested using a Perkin Elmer SPB 50-24 block digester for 120 minutes at 105 °C. Following digestion, ASTM type 1 (ASTM International, 1999) water was added to each sample to return the volume to 10 mL, in accordance with the method outlined by APHA et al. (2005). Dissolved metal concentration measurements were conducted to identify the effect that filtration and sediment retention had on dissolved metals in the filtrate. A 45 µm Whatman cellulose nitrate membrane filter (25 mm diameter) was used to filter each 10 mL sample. Two drops of 0.2 M NaOH were then added to each sample for stabilization in accordance with APHA et al. (2005).

Zeta potential (ZP) was measured to identify the potential charge between particles present in the effluent. A Malvern Panalytical Zetasizer Nano ZS, which was capable of measuring particles ranging from 3.8 nm – 100 nm in diameter, was used for analysis. The instrument required 1.5 mL of effluent and used electrophoretic light scattering to determine ZP, accurate to within 0.12 um.cm/V.s (Malvern Instruments Ltd., 2019).

Oxidation-reduction potential (~~E_H~~E_h) was measured in accordance with APHA method 2850 (APHA et al. 2005). A Fisher Scientific Accumet Excel – XL60 millivolt meter in combination with a platinum pin Ag/AgCl combination electrode was used for the procedure. Effluent pH was measured in accordance with ASTM method D5464 (ASTM International, 2016a). The pH meter (Fisher Scientific Accumet Excel – XL50) was standardized (calibrated) using three pH buffer solutions (4.0, 7.0, and 10.0).

4. Bench and Field Test Results

4.1 *Bench test results*

Figure 3~~2~~a presents the mean total suspended solids measured in each trial's filtrate versus the total (cumulative) volume that previously passed through the geotextile. As shown on Figure 3~~2~~, the mean value of the repeated tests are presented, as well as the maximum and minimum values as identified by the error bars. As previously noted, the filtrate was collected for analysis following each 200 mL trial. The initial three 200 mL trials which were passed through the geotextile showed considerable variation between the tests. As the experiment proceeded, TSS values in the filtrate generally became more consistent. As one would expect, the results show an overall decrease in suspended solids as the effluent passed through the growing filter cake. The final 200 mL sample (trial 20), which was subject to filtration by both the geotextile and the filter cake established during the preceding 19 trials, produced an average TSS value of 15.8 mg L^{-1}. This value represents a 67.5 % reduction from the first trial (mean), and an over 99.9 % reduction when compared to the untreated 1 % SC slurry (13,120 mg L^{-1}).

Particle concentrations in the effluent (Figure 3~~2~~b) showed a similar trend to that of TSS. Filtration of the first 5 trials (1000 mL) yielded a reduction from the initial average of 1.8 x 10^8 particles per mL in the untreated control sample to below 500,000 particles per mL. The concentration was further reduced to an average of under 102,000 particles per mL in the effluent collected following the final (20th) trial. The average diameter of the particles found in the filtrate generally remained consistent throughout the 4000 mL RDT, ranging between 2.5 µm and 3.5 µm. Although TSS appeared to change over the course of the test, the mean particle size likely didn’t change much compared to the initial value (~6 µm) due to the presence of the filter cake, which when built up, reduced the opening size available for particles to migrate through the filter cake and geotextile. These smaller openings prevented the material that had flocculated from passing through; however, material which was yet to aggregate or collect on the cake was likely able to transition the geotextile along with the filtrate.

Total and dissolved metals measured in the bench scale effluent are presented in Figure 4~~3~~. The figure presents statistical data acquired through triplicate analysis of samples taken from three individual tests in the form of a box and whisker plot for each 200 mL trial. Copper values ranged from a mean concentration of 18 µg L^{-1} in the first trial to 4 µg L^{-1} by the twentieth trial. The dissolved fraction of copper was consistent throughout the duration of the 4000 mL RDT, maintaining a concentration of between 4 and 1 µg L^{-1} for all tests. Total lead remained generally constant in the effluent, with mean concentrations ranging between 16 and 5 µg L^{-1}. Similar to copper, the average concentration of dissolved lead generally remained consistent, fluctuating between 0.9 and 0.7 µg L^{-1} over the course of the experiment. The range of total zinc seen throughout the experiment was generally greater than that seen for both copper and lead, with early trial (i.e the first cumulative 1000 mL) mean concentrations reaching 85 µg L^{-1}, before decreasing to between 55 and 30 µg L^{-1} near the end of each test. The dissolved zinc concertation found in the filtrate averaged 22 µg L^{-1} over the course of the bench-scale RDT. The dissolved fraction of this metal remained generally consistent throughout the duration of the test, however, was found to represent a relatively higher fraction of the total concentration detected when compared to the other two metals. Table 2 presents the mean metal concentration for the initial three and 20th trials as well as mean reduction percentage for the initial and final trials (compared to 1 % SC slurry sample) seen for the three metals over the course of the 4000 mL RDT.

Upon conditioning and filtration, the zeta potential found in the effluent collected during the 4000 mL RDT had an average absolute value of + 6.3 mV. The ~~E_H~~ E_h (oxidation-reduction potential) and pH values generally remained constant throughout the treatment and bench-scale filtration test, with no identifiable trend visible as the experiment progressed. The bench scale effluent yielded an average ~~E_H~~ E_h value of + 358 mV and a pH range of between 7.4 and 7.9.

4.2 *Field test results*

~~As previously discussed, the field test consisted of two 100 L trials, which were drawn into a single geotextile bag.~~ TSS measured for both trials can be seen in Figure 5~~4~~a. Initial TSS in the untreated control sample (13,120 mg L^{-1}) was reduced to 333 mg L^{-1} in the effluent sampled following 15 seconds of filtration during trial 1 and showed further reduction to approximately 43 mg L^{-1} after 30 seconds. The TSS values continued to trend downward for the duration of the trial, with a TSS concentration of 18 mg L^{-1} being achieved following 600 seconds of filtration. The second trial showed an initial spike, which peaked at 7 mg L^{-1} after 780 seconds of filtration (3 minutes – trial 2). All values recorded during the second trial were found to be lower than the final value recorded during the initial trial, with a decreasing trend (which was less evident than that identified in the first trial) found following the initial spike. The duration of the second trial was significantly longer than that of the first, culminating after over two hours of filtration. The final TSS recorded value, taken at the 2 hour mark of the second trial (or 7800 s of total filtration time) was approximately 2 mg L^{-1}, which was equal to 0.6 % of that identified in the earliest sampled filtrate from the initial trial (15 seconds – trial 1).

Figure 54b presents the particle concentration data for both trials. Similar to TSS, an overall decrease in concentration can be observed with respect to time. The particle concentration found in the 15-second filtrate from trial 1 was found to be 2.3 million per mL. This value was quickly reduced, reaching less than 300,000 per mL in the 45-second sample, and continued to reduce further as the test proceeded. In the later samples taken from the second trial (t = 6000 s and 7800 s), this concentration was reduced to between 9,000 and 14,000 particles per mL. Over a 99.9 % decrease in particulate concentration was seen in the filtrate sampled at the end of the test when compared to the untreated sample (1.8×10^8 particles per mL in the untreated sample). The size of the particulate matter generally remained constant throughout both the individual trials, as well as the overall duration of the experiment. Particles were found to maintain a consistent range of between 2.5 µm and 4.5 µm (average of 3.3 µm).

Figure 6~~5~~ presents the total and dissolved metal data for the field test. Error bars on the graph denote the highest and lowest concentration determined for each respective data point via triplicate analysis. The initial sample (15 seconds - trial 1) showed the highest concentration level for all three metals. Following an additional 15 seconds (30 seconds - trial 1), an immediate reduction in concentration for all metals was observed. This reduced concentration was maintained for the remainder of the experiment for all three metals of concern. Similar to TSS and particulate concentration, a minor spike in total metals occurred immediately following the beginning of the second trial. However, some variation was seen, as several measurements taken both before and after this point showed values which exceeded this spike for all three metals.

When considering only the first trial, levels of copper were present ranging from a mean high of 40.6 µg L^{-1} in the filtrate sampled from trial 1 (15 seconds) to 2.6 µg L^{-1} after 10 minutes (600 s) of filtration. Concentrations of lead showed less of a reduction, ranging from a mean high of 36.2 µg L^{-1} to a low of 14.8 µg L^{-1}, while mean zinc ranged from 410.1 µg L^{-1} to 82.0 µg L^{-1}, over the same period. Similar to the bench scale tests, the dissolved fraction of copper and lead remained consistent throughout the duration of the trial. Concentrations of dissolved metals ranged from a high of 0.9 µg L^{-1} down to 0.4 µg L^{-1} for copper, and 0.3 µg L^{-1} to 0.1 µg L^{-1} for lead. A range of 92.4 µg L^{-1} to 9.5 µg L^{-1} was determined for dissolved zinc, with the highest value occurring in the filtrate sample at the 1-minute mark.

Less variation with respect to total zinc and copper was seen in the filtrate collected during the second trial, with values for copper ranging from a mean high of 3.2 µg L^{-1} (i.e. 45 seconds into trial 2) to a mean low of 0.7 µg L^{-1} (i.e. 7200 s into trial 2). Total lead showed a further reduction when compared to the first trial, however, it was considerably more variable than the other two metals. Lead maintained a range of concentrations between 22.7 and 3.9 µg L^{-1} over the course of the second trial, with maximum values seen in the filtrate sampled between 1 and 1.5 hours. Levels of zinc continued to show an overall decrease during the second trial, with a mean range of between 92.3 and 19.1 µg L^{-1}, however, similar to lead, some variation was observed. Dissolved metals generally maintained similar concentrations to the first trial, averaging 0.7 µg L^{-1} and 0.1 µg L^{-1} for copper and lead respectively, while dissolved zinc averaged 9.0 µg L^{-1}.

Filtrate sampled during the field-scale test yielded ZP measurements ranging between + 4.7 and + 7.7 mV, and ~~E_H~~ E_h ranging between + 327 mV and + 365 mV. The pH measured during the field trial was found to have an average value of 7.5. Similar to the bench scale analysis, no trend was observed throughout the field scale trial for the three aforementioned parameters.

5. Discussion of effluent quality results

A reduction in total concentration was seen for all metals over the duration of the 4000 mL RDT, when compared to the initial 1 % SC slurry. The filtrate quality continued to show improvement as each subsequent trial was required to pass through an increased amount of sediment deposited on the geotextile, with the majority (~ 98 %) of the reduction occurring within the first trial. As was shown in Figure 4~~3~~, it is possible to achieve an over 98.9 % reduction in metal concentrations (for Cu, Pb, and Zn) with the initial 200 mL passage of influent through the geotextile (i.e. without an established filter cake). This performance improved to a 99.6 % reduction upon the passage of only 4000 mL of sediment through the geotextile.

Concentrations of copper and zinc measured in the effluent collected during the field-scale test ~~did trend~~appeared in lower concentrations than those observed during the bench-scale analysis. Total lead occurred in lower concentrations during the field trial than were identified in the bench-scale effluent; however, due to the somewhat irregular concentrations produced (i.e. a less evident trend), it cannot be said that a definitive reduction has occurred over the field-scale~~is~~ test.

The field-scale testing was limited to two trials. As previously noted, Trial 1 took approximately 10 minutes to complete, and the filtrate quality changed continually over the course of the trial. Trial 2 took approximately 2 hours to complete and the filtrate quality was largely stable throughout the trial. It was expected that a third trial would show similar effluent quality results to trial 2, but that the time required to complete any subsequent filtration would be impractical based on access to the field site provided to the authors. As a result it was deemed that two trials was sufficient for this experiment.

The concentration of dissolved metals maintained a consistent range over the course of both ~~types of~~ experiments. Some variation was seen in the absolute concentration of each metal between the two scales. Early trial samples which experienced a relatively low volume of established filter cake (as evident by the values for total metals, TSS, particle concentration), as well as the consistency seen through the duration of the test suggest the discrepancy in dissolved metal levels found between the two experiments may be attributed to the chemical conditions present in the slurry (pH, ~~E_H~~E_h, ZP), rather than the presence of the filter cake. The results yielded through this experiment indicate that the development of a filter cake has little influence on the dissolved fraction of the metals; however, can significantly affect the total concentration in the effluent as these metals (with this particular sediment) are likely bound to the solid particulate being retained by the geotextile.

Although there appears to be an overall reduction in TSS, particle concentration, total copper, and total zinc as an increased volume of slurry is filtered during the field test, there existed some variation. The three-dimensional effect of the geotextile filtration procedure may have resulted in a section of filter cake where filtrate was more readily able to transition (due to micro-scale changes in density, variations in pore opening, etc.), which may have momentarily increased the flow rate of filtrate, and with it, increased the amount of particulate which was able to pass through. Additionally, the location at which the filtrate permeated through the geotextile was unknown, as samples were collected as the material drained off the corner of the bag. Sediment movement within the bag during filtration may, therefore, impart minor effects on effluent quality (and may serve as some explanation for the variability in lead concentrations seen during the test).

The correlation between filtrate quality and the presence of the filter cake can likely be attributed to the propensity for the particulate matter to aggregate, as it did during the initial formation of the flocs in the treated slurry. As the mass of the filter cake is increased, the pore size is reduced relative to the AOS of the geotextile encouraging the entrapment and binding of particles to the already established cake.

As a result of the association between these constituents (metals and particles), the reduction found in the concentration of metals can be attributed to the physical retention of the sediment. The concentration of TSS found in the effluent suggests that the flocs (and additional accumulated material which remained un-flocculated) were almost entirely retained by the geotextile. This result is likely due to both the attractive qualities of the sediment, as well as the fact that the average apparent opening size of the geotextile fabric (430 µm) was smaller than that of the average diameter of the flocs (610 µm).

The initial zeta potential determined for both the water and sediment was reasonably consistent, ranging from around -21 mV to -25 mV for both mediums. The negative charge associated with the material is likely the primary factor influencing the degree of repulsion between particles prior to treatment (Larsson et al., 2012), contributing to the materials resistance to aggregation without the aid of the chemical conditioning. Upon filtration, the zeta potential identified during both test scales was found to have an average absolute positive value (ranging between + 4.7 and + 7.7). The addition of the cationic polymer (ZP ≈ + 100 mV) has served to change the charge of the system and resulted in the much lower value (closer to zero). The effect of the low zeta potential seen in the filtrate is a reduction in the repulsive force between the individual particles, therefore improving the flocculation potential (Larsson et al., 2012). The majority of metal contaminants which were present in suspension (associated with the particulate matter) were likely bound to the flocs during treatment or amassed on the filter cake as additional contact between particles increased. Metals which were bound to particles failing to coalesce into flocs larger than the AOS (or be retained by the established filter cake) were able to permeate through the filter cake and geotextile. These metals may have then accumulated in the effluent (along with those not associated with particulate matter [dissolved]), and contributed to the higher total metal concentrations found in early trial samples.

Throughout the chemical conditioning and dewatering trials (both scales), pH values remained generally consistent, ranging between 7.4 and 7.9, indicating a neutral environment. The ~~E_H~~-E_h (oxidation-reduction potential) generally remained constant throughout the treatment and dewatering procedures for all mediums. An initial average value of + 380 mV (oxidizing) was determined for the untreated 1 % SC slurry prior to conditioning. This value was determined following the dilution from the initial raw sediment in the laboratory and was therefore subject to atmospheric influence through disturbance. This disturbance may have introduced oxygen to the system and had an effect on the measurement (Tack et al., 1996). However, these results mimic those conditions that might occur during the sediment extraction (dredging), during the geotextile filtration, and conditioning of the sediment, and therefore this result may be considered representative of the environmental conditions during remediation (Gambrell et al., 1991). The addition of the chemical additives had little effect on the ~~E_H~~-E_h of the system, which yielded values ranging between + 327 mV and + 365 mV. Following filtration, both the pH and reduction potential of the filtrate remained generally consistent, with no apparent trends identified over either test.

The average pH and ~~E_H~~-E_h conditions identified in the effluent (pH ≈ 7.5, ~~E_H~~-E_h ≈ + 350 mV) can be compared to known stability field diagrams (Hermann and Neumann-Mahlkau, 1985) to gain a qualitative rationale as to the occurrence of the dissolved and suspended metal fractions identified in the filtrate. When considering copper, the pH range spans the fields of both Cu^{2+} (dissolved) and $Cu_2(OH)_2CO_3$ (solid), however, primarily in the latter. The conditions present would suggest lead should occur entirely in the solid fraction, which reflect the experimental results (~99 % in the solid phase). Effluent conditions (pH and

~~E_H~~E_h) straddle the zinc stability fields of both the charged ion Zn^{2+} (dissolved) as well as the uncharged molecule $ZnCO_3$ (solid), with close proximity to the ($Zn(OH)_2$) (solid) field. Indeed, when comparing the effluent results produced during both scales of experimentation, a relatively large proportion of zinc exists in both the solid and dissolved state. This finding is in agreement with the experimental results presented in Figure 4~~3~~ and Figure 6~~5~~, which show the majority (> 70 %) of the metals in the filtrate occur in the solid phase for all three elements. This highlights the need to have a ~~good~~ proficient understanding of sediment and water chemistry before embarking on dewatering of contaminated sediments, to ~~ensure that~~identify if ~~the ability to ensure~~ dissolved ~~concentrations of~~ metals will remain below ~~any~~ target concentrations.

6. Summary and Conclusions

This study was conducted to assess how a filter cake established on the surface of a geotextile may influence the migration of copper, lead, and zinc during filtration operations. Chemical and physical analysis of the effluent by-product produced during two scales of experimentation examined the mechanism of transport and fate of the three metals.

Bench-scale analysis showed that geotextile filtration in combination with optimal polymer conditioning was able to prevent over 99 % of the three metal contaminants and total suspended solids from transitioning the filter. Metal concentrations in the effluent were reduced from the untreated levels immediately upon treatment and filtration. The establishment of only a small amount of filter cake further reduced metal concentrations in effluent sampled over 4000 mL of filtration. The result of the field dewatering test suggested that an even greater reduction in both total metal contaminants and TSS was achievable upon the filtration of a larger volume of conditioned sediment. Dissolved metal concentrations remained consistent throughout each test, suggesting the reduction in total metals seen is owed to the reduction in particulate matter in the effluent. The primary mechanism responsible for the metal reduction is therefore the physical retention of the associated particulate matter, which increases as the filter cake grows on the geotextile.

The behavior of the three metals under the chemical conditions (pH, ~~E_H~~E_h, ZP) present in the effluent provide an explanation for the high degree of retention seen during the experimentation. Understanding the propensity for a given metal to exist in a dissolved versus solid state for a given water/sediment geochemistry regime will improve the reliability in ensuring metals will be retained in sediment dewatering projects.

7. Acknowledgements

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Figure and table captions:

Figure 1: Bench-scale RDT apparatus as outlined by Tackley et al. (2020), modified via the addition of an acrylic collar.

Figure 2: Geotextile bag field testing apparatus.

Figure 3~~2~~: Average TSS (a) and particle concentration (b) in filtrate collected during the 4000 mL RDT.

Figure 4~~3~~: Metal concentrations in filtrate collected during the 4000 mL RDT. Statistical data shown for minimum, first quartile, median, third quartile, maximum, and mean values.

Figure 5~~4~~: TSS (a) and particle concentration (b) in field trial effluent (200 L).

Figure 6~~5~~: Total and dissolved metal concentrations found in field trial filtrate (vertical dotted grey line denotes beginning of second trial).

Table 1: Influent properties prior to conditioning and filtration (modified from Tackley et al., 2020).

Table 2: Average metals and reduction in filtrate collected during the 4000 mL RDT.

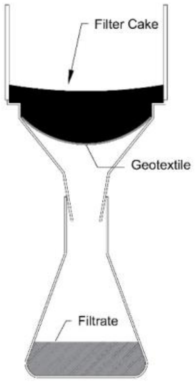


Figure 1

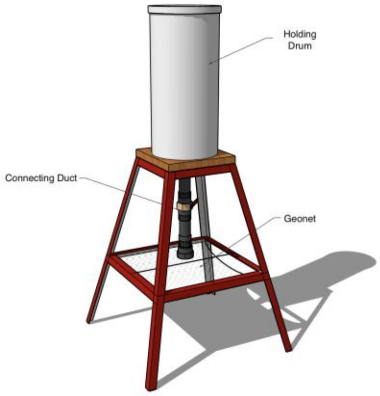


Figure 2

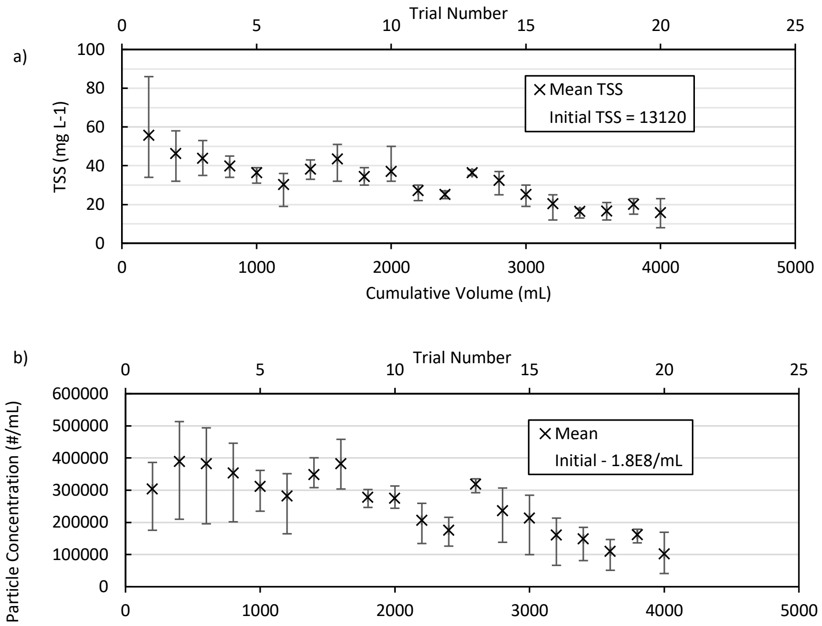
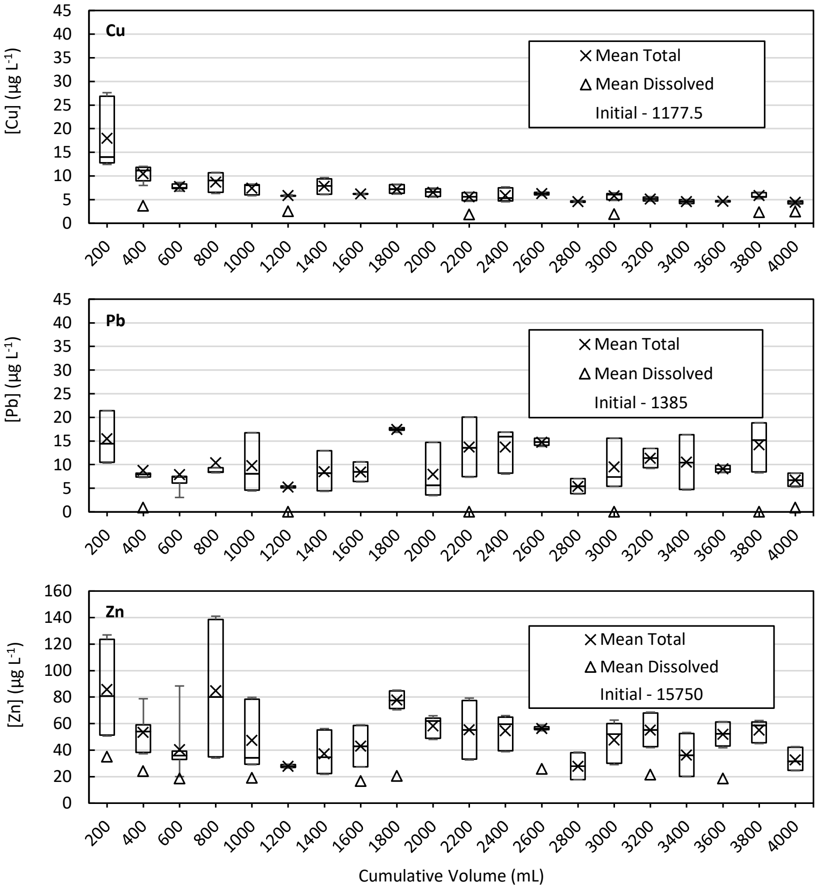

a)
Trial Number
0
5
10
15
20
25
TSS (mg L-1)
100
80
60
40
20
0
× Mean TSS
Initial TSS = 13120
0
1000
2000
3000
4000
5000
Cumulative Volume (mL)
b)
Trial Number
0
5
10
15
20
25
Particle Concentration (#/mL)
600000
500000
400000
300000
200000
100000
0
× Mean
Initial - 1.8E8/mL
0
1000
2000
3000
4000
5000
Cumulative Volume (mL)

Figure 3~~2~~


Cu
[Cu] (µg L-1)
45
40
35
30
25
20
15
10
5
0
× Mean Total
Δ Mean Dissolved
Initial - 1177.5
Pb
[Pb] (µg L-1)
× Mean Total
Δ Mean Dissolved
Initial - 1385
Zn
[Zn] (µg L-1)
160
140
120
100
80
60
40
20
0
× Mean Total
Δ Mean Dissolved
Initial - 15750
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
Cumulative Volume (mL)

µgµg L^{-1}

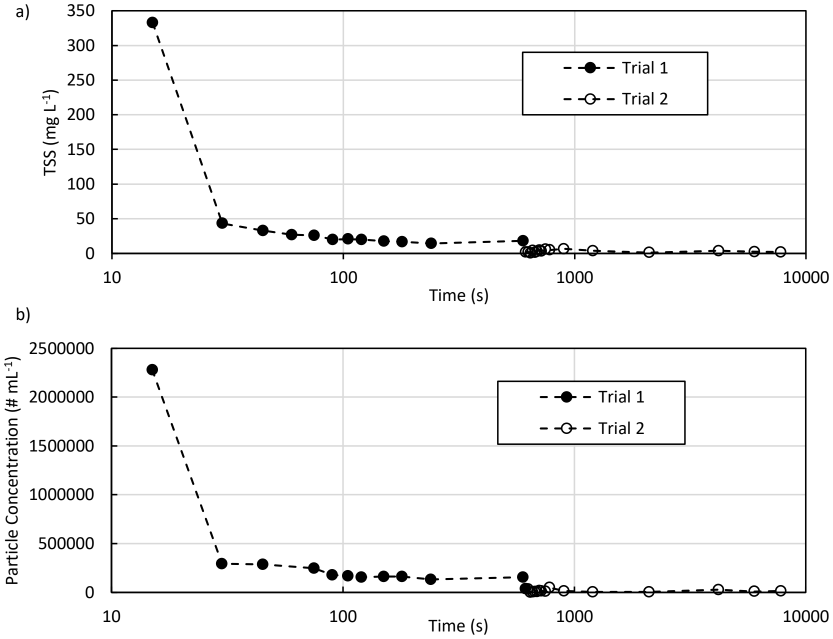


Figure 4~~3~~

Figure 5~~4~~

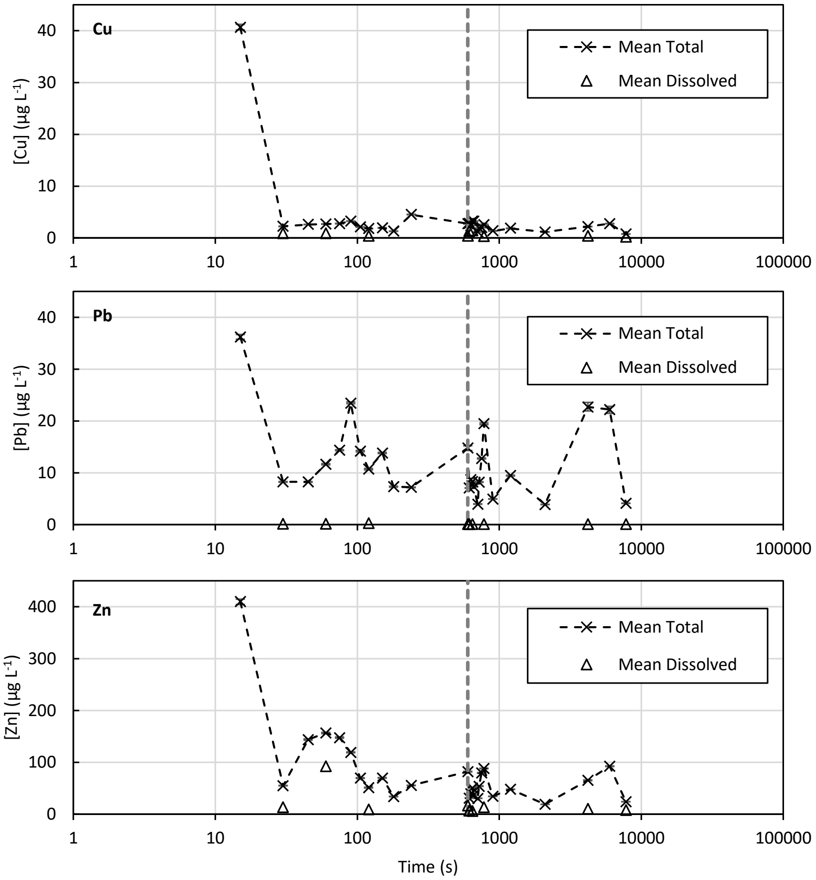

Cu
[Cu] (µg L-1)
40
30
20
10
0
Mean Total
Mean Dissolved
1
10
100
1000
10000
100000
Pb
[Pb] (µg L-1)
40
30
20
10
0
Mean Total
Mean Dissolved
1
10
100
1000
10000
100000
Zn
[Zn] (µg L-1)
400
300
200
100
0
Mean Total
Mean Dissolved
1
10
100
1000
10000
100000
Time (s)

Figure 6~~5~~

1 % SC Slurry Properties	
Average Particle Size (µm)	5.8
Particle Concentration (# mL^{-1})	1.8x10^{8}
TSS (mg L^{-1})	13,120
Copper (µg L^{-1})	1178
Lead (µg L^{-1})	1385
Zinc (µg L^{-1})	15750

Table 1

	Initial average concentration prior to filtration (µg L^{-1})	Total metals in 1st trial (µg L^{-1})	Total metals in 2nd trial (µg L^{-1})	Total metals in 3rd trial (µg L^{-1})	Total metals in 20th trial (µg L^{-1})	Average immediate reduction	Average final reduction
Cu	1177.5	17.9	11.5	7.9	4.4	98.5 %	99.6 %
Pb	1385.0	15.5	7.7	6.8	6.8	98.8 %	99.5 %
Zn	15750.0	85.9	46.1	36.0	33.8	99.5 %	99.8 %

Table 2