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Saturated hydraulic conductivity of self-sealing lining materials for desalination evaporation ponds

Amir M. González-Delgado[a]*, Manoj K. Shukla[a], April L. Ulery[a], A. Salim Bawazir[b], Patrick V. Brady[c]

[a]Plant and Environmental Sciences Department, [b]Civil and Geological Engineering Department,
New Mexico State University, MSC-3Q P.O. Box 30003, Las Cruces, NM 88003-8003, USA
Tel. +1 (575) 646-3405; Fax +1 (575) 646-6041; email: amgonz4@nmsu.edu
[c]Geoscience Research and Applications, Sandia National Laboratories, MS-0754, Albuquerque, NM 87185-0754, USA

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ABSTRACT

Evaporation ponds are used in the disposal of saline waste produced by desalination plants. An increase in concentration of saline wastewater by evaporation reduces the resistance of clay-based lining material commonly used in evaporation ponds and increases the risk of groundwater pollution. Self-sealing lining materials can add resistance to the lining system against advective flow through their capacity of reacting with the saline waste, unlike other liners. The objectives of this research were to quantify the effect of electrical conductivity (EC) of solution, duration of ponding of solution, bulk density of lining material and porous media, and wet-dry cycles on the saturated hydraulic conductivity (K_s) of porous media through laboratory experiments. The Alamogordo variant very fine sandy loam (Tularosa soil) and #1 dry-silica sand/SIL-CO-SIL 125-silica (synthetic soil) were the two soils used in this study. Sodium silicate, calcium hydroxide and magnesium hydroxide, were the lining materials used in this study because of their expected ability to form transport-limiting solids. The lining materials were packed as either a homogenized mixture of 5–10 g of lining material and 60 g of soil or as layering the lining material between 50 and 10 g of soil. A stock solution of 0.25 M of calcium chloride, magnesium chloride, sodium carbonate and sodium sulfate was diluted using DI water to prepare different solutions of EC 30, 20, 10, 5 and 2 dS/m. The K_s was determined by the constant head method in each soil column for different EC-solutions. Mostly, the layer of lining material produced lower K_s of porous media than the homogenized mixture. The K_s decreased with increasing EC, duration of ponding (1–14 d), and bulk density in columns packed with calcium hydroxide. X-ray diffraction results showed that calcium hydroxide reacted with the saline solution to form precipitates such as calcite and gypsum. The inverse relationship between K_s bulk density and amount of lining material showed that in order to achieve the EPA-recommended K_s, the porous media including the layer of lining material must be compacted to higher bulk density using greater amounts of lining material. This study demonstrated that calcium hydroxide could be used as a lining material with self-sealing capacity for desalination evaporation ponds.

Keywords: Saturated hydraulic conductivity; Bulk density; Lining material; Electrical conductivity; X-ray diffraction; Evaporation pond

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* Corresponding author.

1. Introduction

The disposal of saline wastes is a challenge for the industry of desalination, since inappropriate disposal of saline waste produces negative impacts on the environment. Currently there are several disposal methods of saline wastes including: surface water discharge, deep-well injection and evaporation ponds [1]. Evaporation ponds may be the best option for the final disposal of saline wastes where surface water discharge and deep-well injection methods are not feasible, conditions such as, low rainfall and high evaporation are present, and of poor quality land is available [2]. The disposal of saline wastes in evaporation ponds has a lower cost of operation compared to other disposal methods [3]. Evaporation ponds are designed to accumulate saline waste at the bottom of the ponds, where a liner is placed to prevent the leaking of saline wastes into the groundwater. Design criteria in the US Environmental Protection Agency (USEPA) Code of Federal Regulation Title 40 subpart D specify that a lining material must have a hydraulic conductivity (K_s) of 1×10^{-9} m/s or lower and a minimum thickness of three feet as an underlying layer of a compacted clay liner.

Compacted clay liner (CCL), geomembrane liner (GML) and geosynthetic clay liner (GCL) are the three types of lining materials currently used in evaporation ponds. A CCL is a layer of clay compacted to a K_s of 1×10^{-9} m/s or lower and usually has a thickness of 0.9 m [4]. However, resistance of CCL to fluids can be gradually reduced by the freeze–thaw and wet–dry cycle (WDC). During freeze the contact between clay particles is disrupted by the expansion of the porous media, such as clay and after thaw larger pore spaces remain [5]. The drying process during the WDC produces cracks in porous media that act as pathways for fluids to move through the CCL. Increase in concentration of solutes further reduces the resistance of clay-based lining materials to flow due to the change in the thickness of the diffuse double layer [6,7]. The compression of the diffuse double layer also promotes the flocculation of clay particles, thus creating more pore spaces.

The GMLs are flexible membranes made of plastics, either poly-vinyl chloride (PVC) or high-density polyethylene (HDPE) with a thickness of 30 mils (0.762 mm). A GML is a strong barrier against most chemicals and is water impermeable. Leakage of contaminants through GMLs can take place if the GML is physically damaged. Holes in a GML may result from puncture with sharp materials during the installation procedure [8]. GCLs are composed of a dry layer of bentonite-clay sandwiched between two GMLs. The bentonite-clay layer has a thickness of 5–10 mm, which allows the GCL to self-heal when water hydrates the bentonite-clay. The hydration process produces swelling of the bentonite-clay; therefore a continuous layer of bentonite-clay reduces the movement of contaminants [6]. One disadvantage of the GCL is that it is thin; therefore, movement of solutes could be faster than through the CCLs [9].

For GCLs and GMLs to be effective requires physical integrity of their impermeable geomembrane. Thus, studies are required to generate information on the development of better liners that can self-seal and self-heal and require relatively less maintenance. Self-sealing is an important characteristic that helps liner endure chemical and physical stress. A self-sealing liner can produce insoluble precipitates by the chemical reaction at the interface between two or more materials [10–13]. The formation and subsequent deposition of precipitates within the pore spaces can inhibit the movement of fluids by reducing the K_s of the porous media [14].

The hypothesis for this study was that the lining material will react with ions present in the soil solution or saline effluent from above to form insoluble precipitates-amorphous layered silicates, calcite ($CaCO_3$), or gypsum ($CaSO_4$ will be used as an abbreviation for $CaSO_4{\cdot}2H_2O$) that will seal the pore spaces and reduce the advective flow of water through the porous media. The objectives of this research were to: (1) quantify K_s of the porous media under different ECs and lining materials, (2) evaluate the effect of bulk density, duration of ponding of solution, and WDCs on the self-sealing capacity of the lining materials, and (3) identify a suitable lining material for evaporation ponds.

2. Materials and methods

2.1. Soil sample collection and analysis

A synthetic soil with a K_s similar to the Alamogordo variant very fine sandy loam (Fine-loamy, mixed, thermic Cambic Gypsiorthids) of Alamogordo, New Mexico was prepared by combining two materials #1 dry-silica sand (unground silica) and SIL-CO-SIL 125-silica sand (ground silica). The synthetic soil was composed of 99 % silicon dioxide (SiO_2). A ratio of 28:78 mass mixtures of #1 dry unground silica and SIL-CO-SIL 125 ground silica was used to replicate the soil from Alamogordo. Subsequently, soil samples were collected near the evaporation ponds located in the Tularosa Basin National Desalination Research Facility (TBNDRF), Alamogordo, New Mexico. The Alamogordo variant very fine sandy loam collected near the evaporation ponds in the TBNDRF will be known as Tularosa soil in this study. The soil was air-dried and sieved through a 2-mm sieve and particle size analysis was determined using the hydrometer method [15]. According to the United States Department of Agriculture (USDA) textural triangle the synthetic soil was classified as loamy sand (72.53% sand, 24.67% silt and 2.8% clay) and the Tularosa soil was classified as sandy loam (72.60% sand, 14.93% silt and 12.47% clay).

Plexiglas columns of 5.6 cm diameter and 15 cm length were used in this study. A total of 34 columns were packed

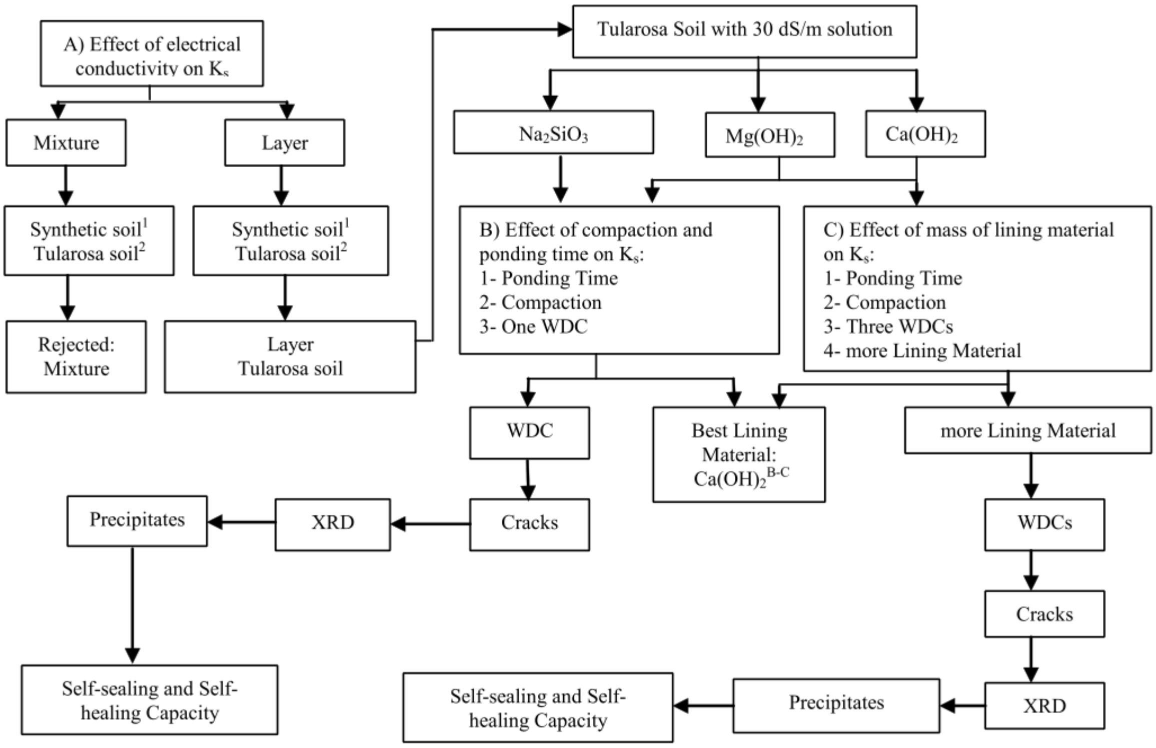

Fig. 1. Flowchart shows various experiments. Experiments conducted with the synthetic soil and Tularosa soil to evaluate the effect of electrical conductivity are identified by the letter A. Experiments conducted only with Tularosa soil to examine the combined effect of compaction, ponding time, and wet-dry cycles on K_s and the effect of amount of lining material on K_s are identified by the letters B and C, respectively.

with either a layer of lining material (5 or 10 g) sandwiched between a lower soil layer of 50 g (0.018 m thickness) and an upper soil layer of 10 g (0.004 m thickness) or a homogenized mixture of lining material and soil. The bulk density was determined using the method of [16]. All experiments were conducted at room temperature (25°C). Details on various experiments conducted with different soils and lining materials are presented in Fig. 1.

2.2. Lining materials and solution electrical conductivities

The lining materials used were calcium hydroxide ($Ca(OH)_2$), sodium silicate (Na_2SiO_3) and magnesium hydroxide ($Mg(OH)_2$). $Ca(OH)_2$ was used as a potential source of calcium for precipitation of $CaCO_3$ and $CaSO_4{\cdot}2H_2O$, e.g.:

$$\mathrm{Ca(OH)_2 + CO_2 \leftrightarrow CACO_3 + H_2O;\ \Delta G^o = -101.3\,KJ} \quad (1)$$

$$\mathrm{2H^+ + Ca(OH)_2 + SO_4^{2-} \leftrightarrow CaSO_4 \cdot 2H_2O;} \quad (2)$$
$$\mathrm{\Delta G^o = -141.1\,KJ}$$

where ΔG^o is the free energy of formation (Kilojoules; KJ). Na_2SiO_3 was considered in the hopes that it might precipitate amorphous silica in fluid pathways. $Mg(OH)_2$ was tested because of its tendency to rapidly form amorphous magnesium silicate layered silicates such as sepiolite at low temperatures. Separate columns of synthetic and Tularosa soils were packed with a 5 g-layer (0.001 m thickness) of lining material sandwiched between soil layers. Columns were also packed with the homogenized mixture of lining material and soil. Each column was initially saturated slowly from the bottom with tap water (EC = 0.5 dS/m = 0.5 mS/cm) to displace the air in the pores. Once columns were saturated, water was applied to the top of each soil column and a constant head of 10 cm was maintained. Four effluent samples once every 20 min were collected from the bottom of the soil columns packed with the synthetic soil and once every 10 min from columns packed with the Tularosa soil. The K_s was determined by the constant head method [17]:

$$K_{ss} = \frac{Q}{\left(\frac{h+L}{L}\right) \times A} \quad (3)$$

where Q is the volumetric rate of flow (m^3/s), A is the cross-sectional area (m^2), h is the constant head (m) applied during the experiment and L is the height (m) of the soil column.

After determining the K_s with tap water, columns were gradually permeated from the top with solutions of different ECs (2, 5, 10, 20, and 30 dS/m) starting with the lowest EC. The EC of solutions used in this study are within the range of the approximate EC values of 1.5 and 50 dS/m for freshwater and seawater, respectively. The K_s was determined separately for each solution. The tap water and saline solutions were applied into each soil column with a flexible tube connected to a Marriott bottle. A stock solution of 0.25 M of $CaCl_2$, $MgCl_2$, Na_2CO_3 and Na_2SO_4 with a pH value of 8 was prepared to mimic the concentrations of Ca^{2+}, Mg^{2+}, Na^+, Cl^-, CO_3^{2-} and SO_4^{2-} present in the saline waste from TBNDRF. The stock solution was prepared with 36.76 g of $CaCl_2$, 50.83 g of $MgCl_2$, 26.50 g of Na_2CO_3 and 35.51 g of Na_2SO_4 and subsequently diluted using DI water to prepare different solutions of 30, 20, 10, 5 and 2 dS/m. Since antiscalant (Nalco Perma Treat PC-191) was present in saline wastes, 20 mg/L of antiscalant was added to each solution. No precipitates were seen after dilution, although the solution was opaque. The EC of the solution was measured with an EC meter (Fisher Accument Method, Denver Instrument Company, CO).

2.3. Column packing and ponding times

The soil columns were compacted during preparation, saturated from the bottom and permeated with a 30 dS/m solution. The K_s was determined at the end of day one, day three, day seven and after two weeks of ponding. At the end of two weeks of ponding, the columns were allowed to drain and air dry. The drying process produced cracks in the soil columns. To evaluate the self-sealing capacity of the lining material, these columns were again saturated from the bottom with the same solution and K_s was determined again at the end of day 1, day 3, day 7 and day 14.

2.4. X-ray diffraction analysis

After the completion of K_s experiments, the columns were drained and dried for two weeks, the soil and lining material were extracted from the top of the Plexiglas columns, and lining materials were collected to be analyzed with a scanning electron microscope (SEM) and X-ray diffractometer. A Thermo Scientific SEM (model NORAN System Six, Thermo Electron Corporation, FL) was used to obtain pictures with 10.1 × 50 magnification from the lining materials. Portions of the lining materials were also ground to create powder samples for X-ray diffraction (XRD) analyses using a Rigaku diffractometer (model Miniflex, Rigaku/MSC, TX). The chemical composition of precipitates was determined by the application and subsequent scatter of the X-rays for each chemical compound based on their molecular structures. The differences in intensities were used to identify precipitates formed in the lining materials. The XRD analyses were performed with an angular range of 2–45° 2 theta at a rate of one degree per minute and a CuKα radiation (0.15418 nm) at a power setting of 30 kV and 15 mA.

3. Results

3.1. Effect of packing of lining materials and electrical conductivity on the K_s

The soil columns were prepared using a homogenized mixture of synthetic soil and lining materials ($Ca(OH)_2$, $Mg(OH)_2$, and Na_2SiO_3). The K_s of homogeneous columns packed with $Ca(OH)_2$ decreased with an increasing solution EC, remained almost unchanged in columns packed with $Mg(OH)_2$ and increased in columns packed with Na_2SiO_3 (Fig. 2a). Similar observations can be made for the columns packed with a layer of $Ca(OH)_2$ and $Mg(OH)_2$ in synthetic soil (Fig. 2b). However, the layer of Na_2SiO_3 displayed a slight decrease as EC of solution increased to 10 dS/m after that it stayed nearly similar.

The K_s for columns packed with Tularosa soil and a homogenized mixture of Na_2SiO_3 displayed erratic patterns (Fig. 3a). However, the K_s for columns packed with Tularosa soil and a layer of lining materials remained similar for EC ≥ to 10 dS/m (Fig. 3b). The effluents collected from columns packed with either a layer of Na_2SiO_3 or a homogenized mixture of Na_2SiO_3 and Tularosa soil were dark brown which could be due to the leaching of highly soluble Na_2SiO_3 as reported by [8]. However, K_s for a layer of Na_2SiO_3 with Tularosa soil did not change with increasing concentrations (Fig. 3b). In general, K_s was lower from columns packed with a layer of lining material than those packed with a homogenized mixture except for $Mg(OH)_2$. Therefore, only layers of lining materials were considered for further experiments.

3.2. Effect of drying and ponding time on K_s

The effect of drying and ponding time on the K_s of the porous media was first explored for one WDC (Fig. 4). Since synthetic soil contained mostly finer sand particles and a lower K_s than Tularosa soil, which had a wider distribution of coarse and fine sand particles, further experiments for WDC and ponding were conducted only with the Tularosa soil.

In these experiments, columns were packed initially with a 5 g layer of $Ca(OH)_2$, Na_2SiO_3 or $Mg(OH)_2$ sandwiched between Tularosa soil. The K_s of the porous media with a layer of Na_2SiO_3 increased with increasing time (Fig. 4). When columns were rewetted after 14 d of drying, the K_s for columns with a layer of Na_2SiO_3 became very high (data not shown on Fig. 4). Therefore, Na_2SiO_3 columns were not considered further. The K_s of the porous media was lower in columns packed with a layer of $Ca(OH)_2$ than in those with a layer of $Mg(OH)_2$.

The drying of the soil columns created cracks in the porous media, the image analysis of the cracks showed that they were generally ≤ 5 mm wide (Fig. 5).

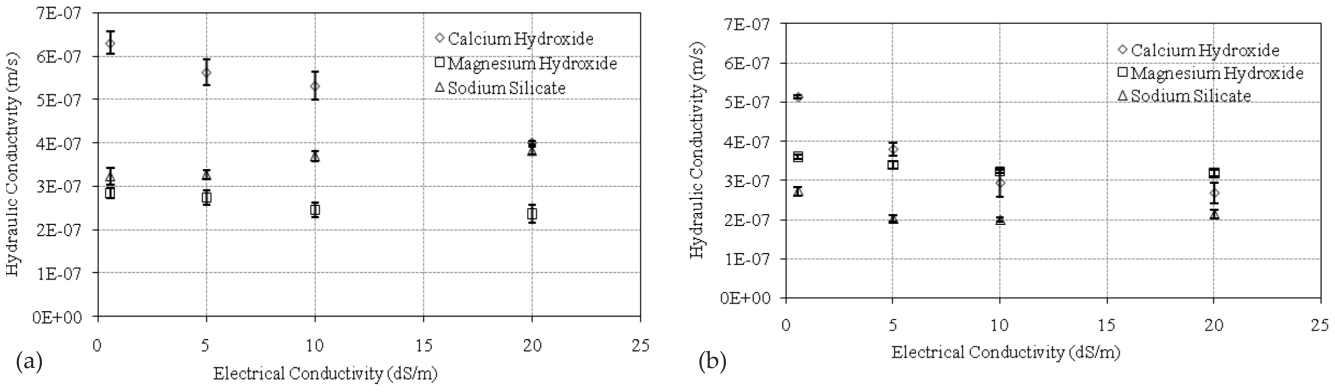

Fig. 2. Effect of increasing electrical conductivity on the K_s of synthetic soil with a) lining materials mixed with the synthetic soil; b) a layer of lining material sandwiched between synthetic soil.

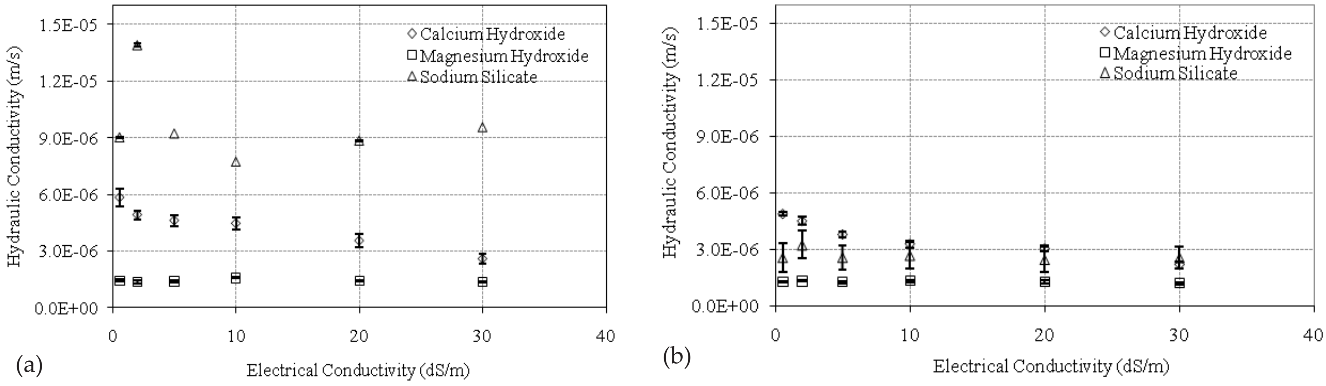

Fig. 3. Effect of increasing electrical conductivity on the K_s of Tularosa soil: a) lining materials mixed with the Tularosa soil; b) a layer of lining material sandwiched between Tularosa soil.

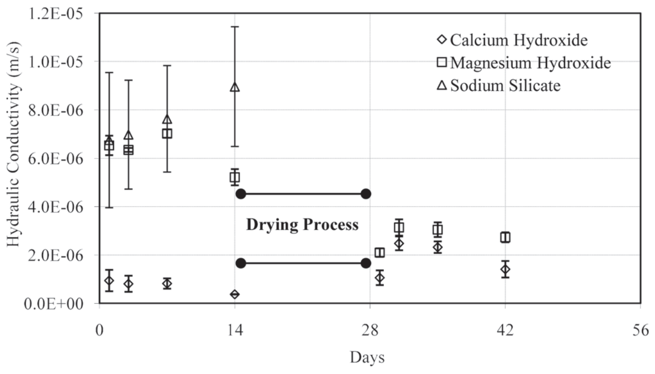

Fig. 4. Effect of wet–dry cycles on Ks of Tularosa soil columns packed with 5 g of lining materials during a period of 14 d before and after one wet–dry cycle.

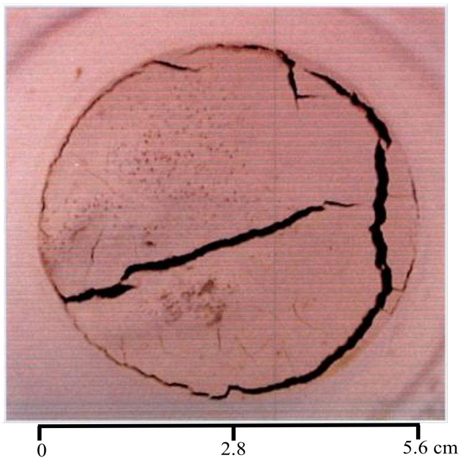

Fig. 5. View of soil column from top, cracks formed after the drying of column for 14 d. Column packed by layering 10 g of $Ca(OH)_2$ between 50 and 10 g of Tularosa soil.

After 14 d of drying, when the columns were rewetted, K_s of the porous media with a layer of $Ca(OH)_2$ slightly increased but decreased for columns with $Mg(OH)_2$ (Fig. 4). Although K_s for $Ca(OH)_2$ columns remained lower than $Mg(OH)_2$ columns. Since continued ponding decreased K_s values for $Mg(OH)_2$ columns, (Fig. 4) it was decided to explore the effect of WDCs in greater detail by packing columns with a 10 g layer of $Ca(OH)_2$ and $Mg(OH)_2$ sandwiched between Tularosa soil and subjecting them to more WDCs (Fig. 6). At the end of first, second and third WDC, the K_s of the porous media continued to be consistently lower in columns packed with a layer of $Ca(OH)_2$ than those packed with $Mg(OH)_2$ (Fig. 6). At the end of first WDC, when columns were rewetted, K_s for columns packed with $Ca(OH)_2$ decreased further. However, no measurable differences in K_s for columns packed with $Ca(OH)_2$ were seen afterwards. The decrease in K_s of the porous media after rewetting gave evidence of the sealing capacity of both lining materials. The lining material of $Ca(OH)_2$ reacted with the sulfate and bicarbonate present in the solution to form precipitates. SEM and XRD analyses were conducted to verify the self sealing capacity of the lining materials.

3.3. *X-ray diffraction and scanning electron microscope analyses*

The samples collected from the layers of both lining materials and Tularosa soils were analyzed separately with the XRD to determine their mineralogy. The XRD analysis showed that Tularosa soil without lining material contained $CaCO_3$, $CaSO_4$, quartz (SiO_2), and feldspars ($NaAlSi_3O_8$) (Fig. 7). The XRD analysis of the precipitates present in the layer of $Ca(OH)_2$ were $CaCO_3$ and $CaSO_4$ (Fig. 8) whereas precipitates present in the layer of $Mg(OH)_2$ were $CaCO_3$ and $Mg(OH)_2$ (Fig. 9). Mg-silicate clays were either X-ray amorphous or absent. The lining materials were also prepared to obtain a visual confirmation of the chemical reaction between the lining materials and the solution. SEM images showed that soil pores were sealed with the precipitates (Fig. 10).

3.4. *Effect of compaction and amount of lining material on the* K_s

Replicated soil columns ($n = 6$) packed with a 10 g layer of $Ca(OH)_2$ with Tularosa soils were compacted at three different bulk densities of 1.02 ± 0.02, 1.23 ± 0.03 and 1.32 ± 0.05 g/cm^3. As bulk density increased, K_s decreased exponentially (Fig. 11a), therefore, columns should be compacted to higher bulk densities to achieve EPA recommended value. The extrapolation of the curve indicated that the soil columns would have to be compacted to a bulk density of 2 g/cm^3. However, more experiments are needed to verify this.

The effect of the amount of lining material on the K_s was evaluated by packing soil columns with 10, 20 and 30 g of a $Ca(OH)_2$ layer. As the amount of lining material increased, the K_s of the porous media decreased linearly (Fig. 11b).

4. Discussion

The objectives of this research were to evaluated the Ks of three different lining materials using different solution ECs, examine the effect of bulk density, duration of ponding of solution, and WDCs on the lining materials, and identify a lining material with the best self-sealing capacity for evaporation ponds. The K_s of columns packed only with Tularosa soil, $Ca(OH)_2$ and $Mg(OH)_2$ were 9.78×10^{-6}, 2.10×10^{-7} and 3.08×10^{-7} m/s for the solution EC of 0.5 dS/m, respectively. The K_s of Tularosa soil without the lining material was 8.18×10^{-6}, 7.43×10^{-6}, 6.96×10^{-6} and 7.57×10^{-6} m/s for solution EC of 2, 5, 10 and 20 dS/m, respectively, and was always greater than those for the soil with a layer of $Ca(OH)_2$. Mostly, the layer of lining

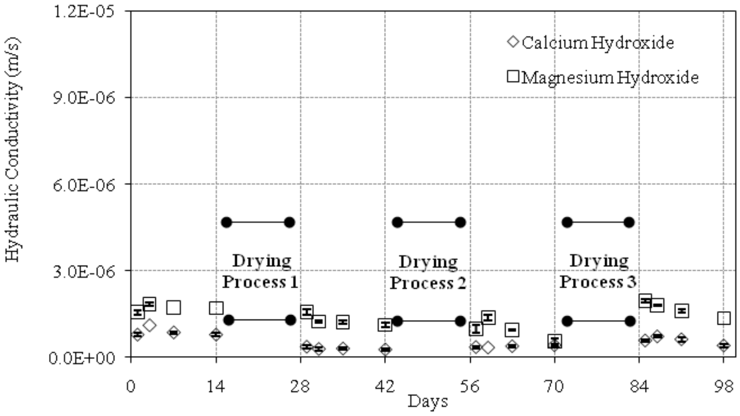

Fig. 6. Effect of wet–dry cycles on K_s of Tularosa soil columns packed with 10 g of lining materials during a period of 14 d before and after three wet–dry cycles.

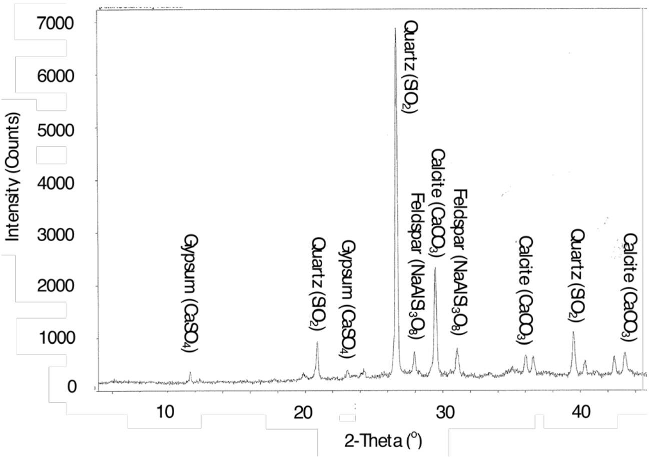

Fig. 7. Minerals present in the Tularosa soil before being in contact with the solutions used to evaluate the effect of electrical conductivity, bulk density and wet–dry cycles on its K_s (XRD image).

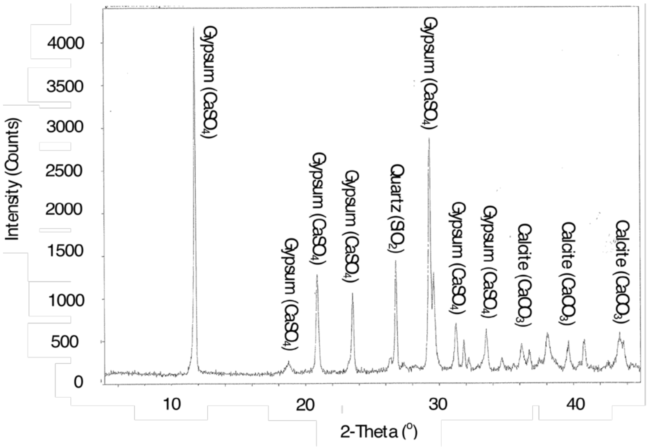

Fig. 8. Precipitates (gypsum and calcite) present in the layers of $Ca(OH)_2$ sandwiched by the Tularosa soil (XRD image).

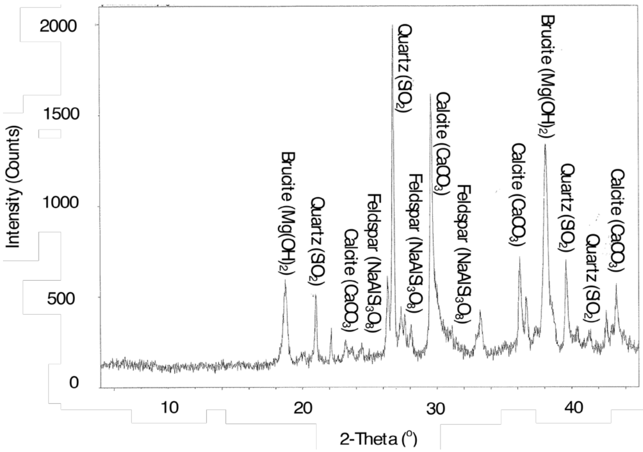

Fig. 9. Precipitate (calcite) present in the layers of $Mg(OH)_2$ sandwiched by the Tularosa soil (XRD image).

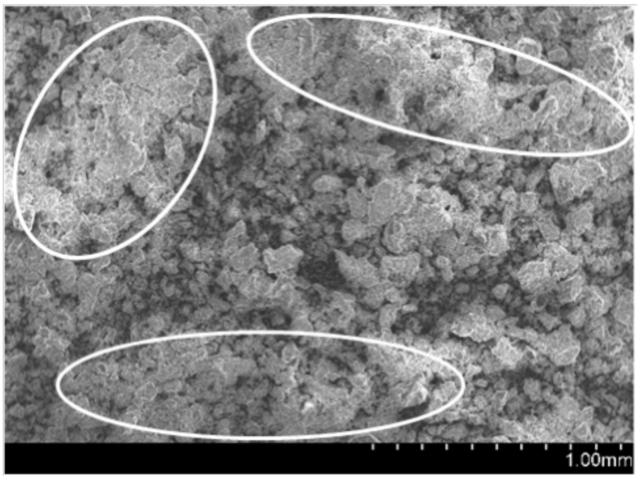

Fig. 10. Scanning electron microscope image of precipitates formed in the layer of $Ca(OH)_2$. Uniform structure of precipitates present in the layer of $Ca(OH)_2$ are identified with ovals.

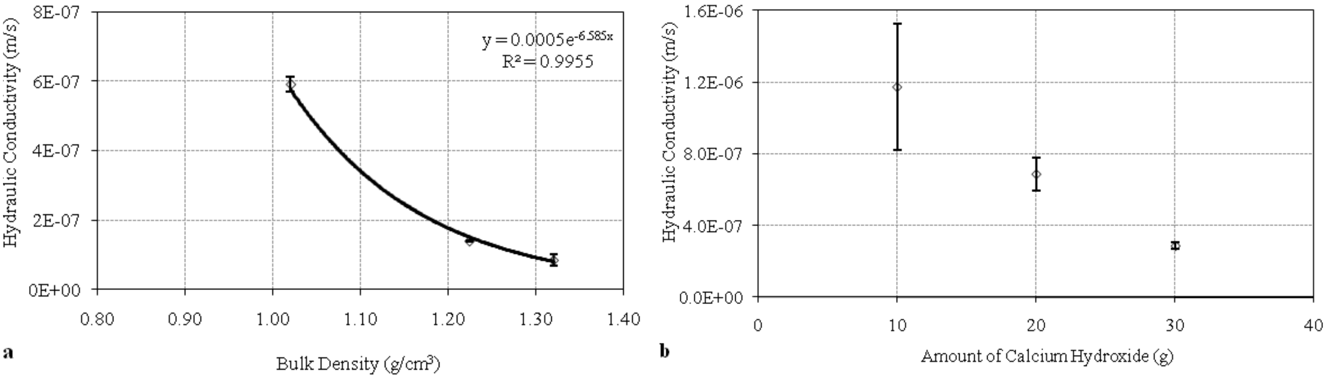

Fig. 11. The K_s of Tularosa soil with constant head method: a) effect of compaction on the K_s of Tularosa soil with $Ca(OH)_2$ layer, columns packed at bulk density of 1.00, 1.20 and 1.30 g/cm^3; b) effect of mass of $Ca(OH)_2$-lining material on K_s of porous medium, columns packed with 10, 20 and 30 g of $Ca(OH)_2$ layer.

material was found to be more effective than the homogenized mixture of lining material and soil probably because the layer provided a larger contiguous surface area for chemical reaction and subsequent precipitation. Another advantage of using the lining material as a layer is that its installation would be more practical at field scale than creating a homogenized mixture of soil with the lining material. Based on the reductions in the K_s, the layer of $Ca(OH)_2$ in columns packed with the synthetic as well as Tularosa soil was identified as the best lining material. The reduction of K_s was due to the formation of precipitates and subsequent deposition in pore spaces that inhibited the movement of liquid through the porous media. Unlike the layer of $Ca(OH)_2$, the layers of Na_2SiO_3 and $Mg(OH)_2$ did not show a progressive reduction in K_s with increasing EC. Since the EC is high in the evaporation ponds and can further increase with time, the $Ca(OH)_2$ can produce K_s values lower than those obtained with Na_2SiO_3 and $Mg(OH)_2$ in this study.

The K_s also decreased with increasing time of ponding indicating that the amount of precipitate formed within the pore spaces increased due to extended exposure of the lining material to the ions present in the solution. Yoon et al. [18] obtained similar results in their study of a self-sealing mineral liner used to reduce the migration of organic contaminants; K_s decreased as the seal self-formed at the interface of the materials. After a WDC, the K_s initially increased due to the formation of cracks in the porous media, but with prolonged ponding the K_s decreased over time likely due to the formation of a seal, swelling of porous media and deposition or clogging of cracks with precipitates. These results followed the self-sealing process described by Shi and Booth [19]. Once the soil columns were saturated, the K_s values decreased to an initial K_s obtained before the WDCs. A similar trend was observed by Boardman and Daniel [20] during their study of dry GCL. The K_s values were higher for experiments conducted with columns packed with Tularosa soil and 5 g-layer of $Ca(OH)_2$ under different ECs for 6 h (Fig. 3b) than those for experiments conducted over 14 d of continuous ponding with a 30 dS/m solution (Fig. 4). This was likely due to additional time available for reaction between lining material and saline solution and formation of precipitates. Na_2SiO_3 was leached out of the columns, therefore sufficient amount was unavailable to react with the saline solution and form precipitates leading to increasing K_s values with time of ponding (Fig. 4).

The XRD and SEM analyses supported the hypothesis that $Ca(OH)_2$ altered to form $CaCO_3$ and $CaSO_4$. The XRD analysis indicated that $Mg(OH)_2$ reacted very little. This could be due to its relatively low solubility or the short time span involved. The reduction of K_s in soil columns packed with $Mg(OH)_2$ after one WDC to three WDCs could be due to the clogging of the pore spaces with the $Mg(OH)_2$ since it is an insoluble fine material. The $CaCO_3$ found in the layer of $Mg(OH)_2$ during the XRD analysis was probably caused by contamination with soil particles that contained $CaCO_3$. Again, the $NaSiO_3$ reacted little and leached quickly.

Increasing bulk density of the porous media decreased the K_s and may have also impacted the diffuse double layer that influences the K_s [7,23,24]. Similarly, the K_s also decreased linearly with increasing amount of lining material. The Tularosa soil columns packed with the $Ca(OH)_2$ layer and subjected to a longer periods of ponding, compaction and one to three WDCs, had bulk density values between 1.00 and 1.50 g/cm^3 and 5–30 g of lining material. The lowest Ks from all of the soil columns used in this experiment did not meet the EPA standard of a K_s of 1×10^{-9} m/s. The inverse relationship between K_s and bulk density or amount of lining material showed that the columns should be compacted to higher bulk density and higher amounts of lining material should be used to meet the EPA standard. Further experiment should be conducted under field conditions to evaluate the suitability of $Ca(OH)_2$ as a self-sealing type of lining material for evaporation ponds.

5. Conclusions

This study demonstrated that the K_s of the porous media decreased with increasing EC in columns packed with a layer of lining material. The K_s also decreased with increasing bulk density, amount of lining material, and exposure time of the lining material to the ions present in the saline solution. The K_s values were lower in porous media packed with a layer of the lining material than in a homogenized mixture of soil and lining material. While $CaCO_3$ and $CaSO_4$ formed quickly, there was no evidence of silica formation. The layer of $Ca(OH)_2$ was found to be the best lining material in the synthetic and Tularosa soil. Insoluble precipitate in the form of $CaCO_3$ was formed in the layer of $Ca(OH)_2$. Also the layer of $Ca(OH)_2$ showed self-sealing capacity after three WDCs. Thus a layer of $Ca(OH)_2$ has the potential to be used as a self-sealing liner in evaporation ponds. More experiments should be conducted using higher amounts of $Ca(OH)_2$ compacted to higher bulk densities.

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