PATIENCE LAKE TEST COVER PROJECT – GLACIAL TILL CAPILLARY BARRIER COVER PERFORMANCE

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ABSTRACT
A glacial till-capillary barrier test cover for potash waste constructed as part of a Saskatchewan Potash Producers Association (SPPA) research project is examined. The glacial till test cover or cap was constructed in the fall of 1989 on the abandoned tails pile located at what is now PCS Patience Lake minisite near Saskatoon, SK. The objective of the 1989 program was to examine how a prototype test cover would perform in the field in order to evaluate options for long-term management of waste at Saskatchewan potash mines. Due to the high solubility of the potash tailings in fresh (rain) water, the cover was constructed in order to minimize or eliminate fresh water percolation into the tailings by temporarily storing precipitation in the till layer to be released through evaporation. To the knowledge of the authors, this cover represents the first Canadian cover purposely designed to store and release precipitation. The cover was closely monitored (water content, dry density, permeability, soil suction, and soil temperature) for the first few years after construction, yielding a good initial baseline of information for evaluation. Visual examinations of the cover in 2004 and 2005 showed the cover to be in excellent condition with a fairly robust vegetative cover and no significant dissolution of the underlying tailings. Coupled soil-atmospheric modeling was conducted utilizing measured and estimated initial physical properties to confirm the store and release nature of the cover. Subsequently, a physical examination of the covers took place in 2006 in which samples of the cover were obtained and tested to examine the current physical properties of the cover materials in order to examine the evolution of the cover over time. Preliminary results indicate that much can be learned from this study in order to identify a plan for moving towards a “new” long-term decommissioning R&D framework for the potash industry.

RÉSUMÉ
Une couverture d'essai glaciaire de barrière de jusqu'-capillaire pour la perte de potasse construite en tant qu'élément d'un projet de recherche de (SPPA) de Association d'Producers de Potash de Saskatchewan est examinée. Le glaciaire jusqu'à ce que la couverture d'essai ait été construite en automne de 1989 sur la pile abandonnée de queues située à, ce qui est maintenant, mine site de PCS Patience Lake situé près du Saskatoon, SK. L'objectif du programme 1989 était d'examiner comment une couverture d'essai de prototype exécuterait dans le domaine afin d'évaluer des options pour la gestion à long terme de la perte aux mines de potasse de Saskatchewan. En raison de la solubilité élevée des produits de queue de potasse dans l'eau fraîche (de pluie), la couverture a été construite afin de réduire au minimum ou éliminer la percolation d'eau doux dans les produits de queue en stockant temporairement la précipitation dans jusqu'à ce que couche à libérer par l'évaporation. À la connaissance des auteurs, cette couverture représente la première couverture canadienne exprès conçue pour stocker et libérer la précipitation. La couverture a été étroitement surveillée (teneur en eau, densité sèche, perméabilité, aspiration de sol, et température de sol) pendant les années premières après construction, rapportant une bonne ligne de base initiale d'information pour l'évaluation. Les examens visuels de la couverture en 2004 et 2005 ont montré que la couverture était en excellent état avec une couverture végétative assez robuste et aucune dissolution significative des produits de queue fondamentaux. Modéliser sol atmosphérique couplé a été conduit utilisant les propriétés physiques initiales mesurées et estimées pour confirmer le magasin et pour libérer la nature de la couverture. Plus tard, un examen physique des couvertures a eu lieu en 2006 l' où des échantillons de la couverture ont été obtenus et examinés pour examiner les propriétés physiques courantes des matériaux de couverture afin d'examiner l'évolution de la couverture avec le temps. Les résultats préliminaires indiquent que beaucoup peut être appris de cette étude afin d'identifier un plan pour se déplacer vers un "nouveau" cadre le désarmement à long terme pour l'industrie de potasse.

1. INTRODUCTION
The Saskatchewan potash industry has been operating since 1962, with an estimated 400 million tonnes of waste produced over the past 44 years. There are currently 9 potash waste piles in the province of Saskatchewan (Figure 1). The potash waste is composed primarily of sodium chloride (90 to 95%) with minor amounts of sylvite (0.2 to 3.0%), magnesium chloride (0.0 to 3.0%), and insolubles (0.3 to 3.0%) made up of clay minerals and rock flour (Landine et al. 1993). These wastes are stacked in large piles at the mine site. The large potash piles are surrounded by agricultural land and are often underlain by local or regional aquifers (Landine et al. 1993). Contamination of surface and ground water by brine originating from the dissolution of the waste piles is a major concern for the Saskatchewan
potash industry. Even at relatively low concentrations, the brine, which is high in sodium (Na\(^+\)) and chloride (Cl\(^-\)) ions, is harmful to plant and aquatic life.

When the potash mine is no longer operational it will become necessary to decommission the waste pile. Due to the high solubility of the potash tailings in fresh (rain) water, any long term management system must seek to “isolate” the waste to mitigate the continued development of brine after closure.

The objective of this paper was to evaluate a glacial till-capillary barrier as a potential long-term decommissioning strategy for Saskatchewan potash wastes. This paper discusses the initial design, construction, and monitoring of the cover as well as the evolution of the cover over the past 17 years.

2. BACKGROUND

The use of soil covers to isolate waste from precipitation has gained considerable acceptance over the past number of years due to significant advances in design, construction, and monitoring. Engineered soil covers have been utilized extensively in both the mineral resource industry as well as in the municipal sector as a viable method to decommission waste storage areas.

There are few examples of covers being utilized to “seal” potash waste piles. However, similar cover systems have been constructed in West Germany in the late 1970’s and early 1980’s (Haug, 1989).

The Hansa potash pile, located near Hannover, West Germany, contains over 2 million tonnes of potash waste, with the dissolution of the pile due to precipitation (average 750 mm/yr) estimated to generate 60,000 m\(^3\) of brine per year. The construction of a cover (or cap) began in 1981, with the expected completion in the year 2000. The goal of the cover system was to isolate the underlying waste in order to transform the pile into a commercially viable sports and recreation facility. The cap was designed as a layered system consisting, in ascending order, of coarse rubble (building demolition material), sands and gravels, clay, and topsoil. The rubble was place in a layer 2 to 3 m thick which was designed to form a capillary break beneath the surficial soil materials (clay and topsoil). The sand and gravel layer was designed to act as a filter to prevent migration of the overlying clay, which acts as a low permeability surface seal. The entire cover was then capped with topsoil and seeded to grass. The maximum thickness of the cover system was 10 m. A close inspection of the cover in 1989 (approximately 50% completion) found no evidence of salt migrating upward through the compacted earth. Furthermore, there was no evidence of sink holes or collapse of the cover caused by dissolution of the salt from moisture percolation (Haug, 1989).

A second potash pile (Friedrickshall) located near Hannover, was partially covered with soil underlain by a geomembrane. The uncontaminated runoff collect by the geomembrane is collected separately from the brine and transported to a canal system. The surface of the overlying soil is vegetated with grass. A site visit in 1989
recorded healthy growth on the surficial material (Haug, 1989).

The Sigmundshall mine, also located near Hannover, was approximated to be over 145 m high in 1989. A small scale test cover plot was constructed along a section of the steep sideslope (approx 36°) of the tailings pile. The cover was consisted of soil cover material held in place by a network of plastic containers. The soil cover material, for this plot, was in direct contact with the salt tails. Dissolution has taken place beneath the cover, with numerous sinkholes causing breakdown of the vegetation at the surface. In addition, the cover plot has not formed a sufficient bond with the surface of the tailings and must be anchored from above (Haug, 1989).

Despite the relative success of the Hanover cover, 10 m thick engineered soil covers may not be a viable economic alternative for Canadian potash mines. As well, there are fundamental differences between cover design for tailings piles in Germany compared to those located in the province of Saskatchewan. In general, German potash piles are significantly higher than those in Saskatchewan due to more competent foundations soils. The Wintershall pile is in excess of 240 m high, while the highest pile heights in Saskatchewan approach 80 m. Potash tailings in most European mines are dry stacked by conveyer belts rather than pumped as slurry through pipelines. As a result, German mines may not experience segregation issues that are present at Saskatchewan mines. Their tailings may be more “uniform” and such their physical properties are easier to quantify. Lastly, and perhaps most importantly, the average annual precipitation is significantly higher for the mines examined. Average yearly precipitation of 750 mm was recorded near Hannover, while for Saskatchewan this value is closer to 400 mm.

Designing a cover system to prevent percolation into the underlying waste is a complex operation that takes all these factors into account and, as such, no two cover designs are alike.

3. DESIGN AND CONSTRUCTION

The till test cover was designed as a store and release cover to limit moisture percolation into the underlying tailings and prevent upward wicking of the brine into the till layer. A coarse granular layer was placed between the tailings and the till, which was overlaid with less coarse sands and gravels. The coarse granular was designed to act as a capillary break beneath the overlying till, while the less coarse material acted as a filter to prevent downward migration of soil particles. The overlying till was intended to store water from large precipitation and meltwater events until it could be released during periods of high evaporation. The primary advantage of using a glacial till for the cover system is that it is generally accessible to most Saskatchewan potash mines (Haug et al., 1991).

The cover was constructed on an abandoned potash tailings pile located at, what is now, the PCS Patience Lake Potash Mine (Figure 1). The minesite is situated in a groundwater discharge area, surrounded by a till plain.

For the coarse granular layer, well graded, coarse material with little fines was required. Large boulders (maximum 0.3 m diameter) were obtained from hand-picked rock piles located near the site. The less coarse sands and gravels, as well as the Battleford Formation till were also sourced near the site.

Table 1 shows the measured grain size distributions for the cover materials. A grain size distribution for typical Saskatchewan tailings is also included (Landine, 1993).

Table 1. Grain size distribution of cover materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Filter material</th>
<th>Till</th>
<th>Coarse layer</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tailings</td>
<td>0</td>
<td>7</td>
<td>92</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse layer</td>
<td>75</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filter material</td>
<td>0</td>
<td>50</td>
<td>49</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Till</td>
<td>0</td>
<td>8</td>
<td>48</td>
<td>34</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screened Gravel</td>
<td>0</td>
<td>92</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cobbles or greater particle size > 60 mm
Gravel 2 mm < particle size < 60 mm
Sand 0.06 mm < particle size < 2 mm
Silt 0.002 mm < particle size < 0.06 mm
Clay particle size < 0.002 mm

The construction of the till cover commenced in the summer of 1989. A 20 m x 20 m area was selected on the surface of the tailings for the placement of the cover. The surface of the tailings at this location was sloped at approximately 4.5% and the cover was orientated such that it was parallel to the slope. An initial, 0.3 m layer of coarse granular material (rocks) was placed directly on the surface of the tailings. This was followed by a 0.25 m layer of less coarse, filter material. The till layer (1.0 m thick) was compacted in five 0.2 m thick lifts to a density approaching 100% of standard Proctor maximum. Each lift was tested for density and moisture content using a nuclear densometer. The surface of the till was then covered with a 0.05 m layer of screened gravel to reduce desiccation during dry periods and mitigate surface erosion. The total thickness of the cover was approximately 1.6 m.

Figure 2 shows a photograph of the final grading of the till cover before the placement of the screened gravel on surface.
4. INITIAL MONITORING

A major effort was undertaken from 1990 through to 1993 to monitor the test cover. The monitoring included examining changes in water content, density, permeability, soil suction, and temperature.

4.1 Density and Water Content

During construction of the till cover, the water content and density of each lift were monitored using a Troxler nuclear gauge. Subsequent measurements of water content and density of the upper 0.35 m of the cover were recorded annually from 1991 to 1993. Table 2 shows the average measured water content and density of the upper 0.35 m of the till for the first three years of cover life.

Table 2. Initial monitoring of density and water content.

<table>
<thead>
<tr>
<th>Year</th>
<th>Average density (kg/m³)</th>
<th>Average water content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1986</td>
<td>10.3</td>
</tr>
<tr>
<td>1991</td>
<td>1955</td>
<td>9.8</td>
</tr>
<tr>
<td>1992</td>
<td>1955</td>
<td>10.6</td>
</tr>
<tr>
<td>1993</td>
<td>1924</td>
<td>11.9</td>
</tr>
</tbody>
</table>

Table 2 illustrates that for the first three years of cover life, the density of the upper 0.35 m is decreasing. This is likely due to freeze/thaw cycles as well as the establishment of the vegetative root zone.

The measured water content values are highly dependant on the time of measurement. All measurements were taken in the fall; however the local climate (precipitation and evaporation) immediately prior to measurement, may have had a significant impact on the values. Above average annual precipitation was recorded from 1991 to 1992. This would account for the increased water contents recorded for 1992 and 1993.

4.2 Soil Suction and Temperature

The test cover was instrumented with a network of temperature and suction sensors in the fall of 1991. Eight thermal conductivity sensors were installed into the till test cover. The sensor was made up of a temperature sensing device and a heat source embedded in a porous block. A controlled amount of heat is applied by the ignition source for a specified period of time. The change in temperature at the point heat source is measured and is directly proportional to the suction in the soil.

The sensors were installed along both the upslope and downslope sides of the cover, approximately 4 m from the edge at depths of 0.25 m, 0.40 m, 0.60 m, and 0.80 m. Lead wires ran along the surface of the cover system to a weatherproof box, which contained the data acquisition system. The installation was completed in October of 1991.

The sensors functioned well from October of 1991 to June of 1992. Temperature readings showed that, in the winter months, the entire till layer was subject to
temperatures below zero. This was anticipated in the design of this cover and was not anticipated to adversely affect cover performance.

Initial suction readings recorded in the fall of 1991 showed average values of 130 kPa, 65 kPa, 90 kPa, and 120 kPa at depths of 0.25 m, 0.40 m, 0.60 m, and 0.80 m, respectively. However, during the winter months the sensors became frozen and no suction readings were recorded from December to April (Haug and Wong, 1991).

Problems with the power supply for the remainder of 1992 and for all of 1993 prevented no further information to be obtained from the sensors.

4.3 Permeability

Initial permeability testing was performed in the laboratory prior to construction, yielding a value of \(7.2 \times 10^{-10}\) m/s for the till. A single ring field infiltrometer was utilized in order to measure hydraulic conductivity on the surface if the actual cover. As well, field samples were obtained from the covers and tested in the laboratory.

Table 3 shows the results of the permeability testing. The testing was performed near the surface of the cover where it was anticipated that the greatest amount of change will take place. In cases where multiple tests were performed, the values were averaged.

<table>
<thead>
<tr>
<th>Date</th>
<th>Test Method</th>
<th>Permeability (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov-90</td>
<td>Laboratory Triaxial Cell on Field Sample</td>
<td>6.0 \times 10^{-16}</td>
</tr>
<tr>
<td>Nov-90</td>
<td>Field Infiltrometer</td>
<td>4.0 \times 10^{-6}</td>
</tr>
<tr>
<td>Aug-91</td>
<td>Field Infiltrometer</td>
<td>1.5 \times 10^{-6}</td>
</tr>
<tr>
<td>Sep-92</td>
<td>Field Infiltrometer (4 tests)</td>
<td>9.8 \times 10^{-6}</td>
</tr>
<tr>
<td>Sep-93</td>
<td>Field Infiltrometer (3 tests)</td>
<td>5.9 \times 10^{-6}</td>
</tr>
</tbody>
</table>

The results of the field infiltrometer testing showed that the permeability of the cover was decreasing throughout the measurement period. The rate of decrease is most pronounced in the first year of measurement (1990 to 1991) and then slows by 1993.

5. 17-YEAR ASSESSMENT

5.1 Field Program

Visual examinations of the cover were performed in November of 2004 and December of 2005. Observations noted that the glacial till cover has performed well over the past number of years. It appeared structurally sound (no dissolution) and had developed a fairly robust natural vegetative cover. Figure 3 shows the cover as in 2005.

A field drilling program was undertaken in March of 2006 in which two boreholes were drilled within the cover to obtain samples for laboratory testing. The boreholes were drilled with an ARGO mounted drill rig equipped with a continuous core sampler. Continuous core, Shelby tube, and bag samples were collected and tested to determine current physical properties of the cover. Table 4 presents the average values of the physical properties obtained for the upper 0.35 m of the cover layer.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m(^3))</td>
<td>1940</td>
</tr>
<tr>
<td>Water content (%)</td>
<td>12.4</td>
</tr>
<tr>
<td>Permeability (m/s)</td>
<td>(8.3 \times 10^{-10})</td>
</tr>
</tbody>
</table>

5.2 Finite Element Modelling (FEM)

Coupled soil-atmospheric modelling of the test cover was conducted using finite element modelling software. Climate data from 1990 to 2005 was obtained from Environment Canada and was used in the model as a surficial boundary condition. Physical properties of the cover materials input to the model including water characteristic curve and hydraulic conductivity function were estimated from measured parameters such as grain size distribution and \textit{in situ} hydraulic conductivity. The remaining parameters were estimated from “typical” values for the modelled materials.

The goal of the FEM was to evaluate the ability of the cover to store moisture during precipitation and meltwater events and release the moisture during periods of high evaporation. Annual simulations were conducted starting on November 1 and terminating on November 1 of the following year. A total of 15 simulations were conducted, with the final simulation ending 1 November 2005.

Annual precipitation rates varied significantly over the modelling period from a maximum of 499 mm (2004-2005) to a minimum of 176 mm (2000-2001), with an average of 348 mm. The first simulated first year (1990-1991) was the most “severe” year of the simulations conducted. Precipitation from 1 November 1990 to 1 November 1991 totalled 479 mm. As well, no vegetation was modelled for this scenario as cover construction was completed in the fall of 1990. A robust vegetative cover aids in the removal of moisture from the cover. Therefore, 1990-1991 was deemed more severe than 2004-2005 in which 499 m of precipitation was observed. The “severe” year was followed by a year of near average precipitation (329 mm). Figure 4 examines the moisture movement within the cover during the first 2 years of cover life.
Figure 3. Till test cover, 2005 visual investigation.

Figure 4. Simulated cumulative moisture flux within cover from 1990 to 1992.
A large, initial infiltration event is observed in March due to spring melting and runoff. Subsequent infiltrations are also noted throughout May and June due to large precipitation events. During this time the cover is acting to store moisture as can be inferred from the figure. On 15 May 1991, 98 mm of cumulative moisture flux has infiltrated at ground surface; at a depth of 0.6 m, 35 mm is observed. Approximately 63 mm of cumulative moisture has been stored in the upper 0.6 m of the cover. Furthermore, no cumulative moisture infiltration is predicted at the base of the till layer, thus the remaining 35 mm of infiltration is stored in the lower 0.4 m of the cover layer. Throughout the summer and fall months (July to October) a significant amount of evaporation is predicted from the cover as the stored water is released to the atmosphere. On 1 November 1991, at a depth of 0.6 m, the model predicts a net infiltration of 13 mm.

The simulation from 1991 to 1992 shows a similar trend in data. However, due to reduced precipitation, more water is evaporated from the cover and at a depth of 0.6 m a net evaporation of 5 mm is predicted (1 November 1992).

6. ANALYSIS OF CHANGE

The data obtained from the initial monitoring program was coupled in order to analyze the evolution of the cover. Changes in physical and chemical properties of the cover with time act to produce a final, long-term soil structure which is significantly different than the original design. Failure to take these processes into account may lead to poor, long-term cover performance.

Figure 5 presents change in density and water content for the upper 0.35 m of the cover. The density of the cover, in general, is decreasing with time. This is anticipated due to freeze/thaw cycles as well as other physical factors. The decrease was most dramatic in the first two years of cover life, and approached an equilibrium condition after approximately three years. The decrease in density increases the porosity of the soil, increasing the storage potential of the cover. Consequently, due to the increase in porosity, the average moisture content was increased with time as illustrated in Figure 5. However, the measured moisture content, in particular for the upper region of the cover, is highly dependant on the climate immediately before measurement (Figure 4).

The in situ permeability testing for the upper portion of the cover is presented in Figure 6. Testing was conducted on samples submitted to the laboratory utilizing a triaxial permeability apparatus. As well, air-entry permeameter testing was performed in the field to measure the in situ permeability. In general, the results from the laboratory analysis measure lower permeabilities than that of the air-entry permeameter. The laboratory testing conducted in 1990 and 2006 show that the permeability of the till cover has remained relatively constant, with a slight increase noted over the measurement period. The air-entry permeameter results show the permeability of the cover decreasing from 1990 to 1993. The majority of the decrease takes place in the first year of cover life and approaches an equilibrium value after 1992. No air-entry permeameter measurements were taken after 1993.

Figure 5. Measured density and water content within upper 0.35 m of till cover.
7. SUMMARY AND CONCLUSIONS

The modelling results coupled with the results of the physical testing of the cover indicate that a 1.6 m till-granular capillary break is a viable cover system for potash tailings. The cover system mitigates net infiltration to the tailings surface by storing precipitation and meltwater events in the upper till layer, while the underlying granular layer prevents upward migration of salt.

An evaluation of the evolution of the cover over the past 17 years has shown the cover to be performing adequately. Physical changes over the evaluation period have not diminished the functionality of the cover. The cover has developed a robust vegetative cover and no significant dissolution or erosion has been observed.

While 1.6 m till-granular capillary break cover systems may not be economically viable for all potash mines, much can be learned from this cover system in moving towards a “new” long-term decommissioning strategy for potash mines in the province of Saskatchewan.

8. ACKNOWLEDGEMENTS

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9. REFERENCES


