Monitoring a field application of a Green Liquor Dregs-till mixture in a sealing layer on top of sulfidic mine waste

Susanne Nigéus[1], Christian Maurice[1,2]

[1]Luleå University of Technology, Department of Civil, Environmental and Natural Resources Engineering, 971 87 Luleå, Sweden, susanne.nigeus@ltu.se
[2]Ramböll Sverige AB, Kyrkogatan 2, Box 850, SE-97126 Luleå, Sweden

Abstract

Sulfidic mine waste left unattended and in contact with oxygen oxidize and have potential to produce acid rock drainage (ARD). A typical method in Sweden to stop sulfide oxidation is to apply a dry cover on top of the mine waste. Using the non-hazardous industrial residue Green Liquor Dregs (GLD) in the cover is useful for the mining industry and the industry providing the residue and a large benefit for the environment. In this study, the effectiveness of a mixture of till and 10 wt. % of GLD in a dry cover was studied by monitoring temperature, oxygen- and moisture content. The conclusion is that the sealing layer in unaffected by frost, the oxygen concentrations are decreasing with time, but not in depth and the sealing layer with GLD-till mixture seem to be nearly saturated.

Keywords: Mine waste, ARD, Industrial residues, Green Liquor Dregs, Field application, Monitoring

Introduction

Mining industry generates massive amounts of mine waste worldwide, e.g. 110-million-ton mine waste in Sweden 2017, which accounted for 77 % of the annual waste produced (Swedish EPA 2018). 70 % of the Swedish mine waste contains sulphide minerals (SGU and Swedish EPA 2017) that if left unattended and in contact with oxygen oxidize and have potential to produce acid rock drainage (Saria, et al. 2006). ARD is a major long-term threat to the environment as metals and metalloids may become mobile (Saria et al. 2006). The GARD guide (Global Acid Rock Drainage guide; Verburg et al. 2009) categorize different methods to prevent ARD, after closure, into two main categories; engineered barriers and water covers. Engineered barriers can be divided into liners and dry covers, where liners are typically designed to act as a barrier for contaminant flow from the overlying waste into the receiving environment. Dry covers are typically designed to limit the ingress of water and oxygen into the underlying waste (Verburg et al. 2009). Under the relatively humid climatic conditions in Sweden a soil cover can be used to reduce oxygen flux to the underlying reactive wastes, and thus can reduce ARD (Collin and Rasmuson 1990; Bussière et al. 2003; Dagenais et al. 2006). The soil cover is a dry cover which usually consists of a sealing layer placed on top of the mine waste and above this, a protective layer. The sealing layer is made of a fine grained compacted material to preventing oxygen to diffuse to the waste underneath by keeping it close to saturation. The purpose of the protection layer is to protect the sealing layer from erosion and frost- and/or root penetration. Sealing layers in Sweden are usually made of a till, ideally a clayey till. However, the availability of clayey till nearby a mine is often limited and the need for alternative solutions are great, e.g. bentonite amendment to till. However, bentonite production is costly both economically and environmentally due to time- and resource consuming production. A suitable alternative material as an amendment to till could be a fine grained industrial residue. Previous studies have shown that the inert residue of pulp production, Green Liquor Dregs (GLD), has properties suitable as a sealing layer i.e. it is fine-grained (d100 < 63μm), commonly has an HC in the range of 10^{-8} and 10^{-9} m/s and a higher water retention capacity (WRC) compared to materials with similar particle size, such as clayey/sandy silt (Mäkitalo et al. 2014). To use the material in its own is however not technically possible due to its low shear strength and high water-content which makes it instable (Mäkitalo et al. 2014). Previous studies have however shown that mixing approximately 10 wt. % GLD with till keeps its positive properties and improve the drawbacks of the material (Mäkitalo et al. 2015). Using an industrial residue in a mine remediation program would serve as a large benefit for the environment, especially for the mining industry and the industry providing the residue.

The oxygen concentrations and water content are important factors to monitor for evaluating the function of the soil cover and if that the sealing layer is kept close to saturation to limit the oxygen diffusion to the mine waste. In humid environments, the general functions of a soil cover system are to reduce the transport of oxygen to the waste material and minimize the water infiltration fluxes. However, the oxygen fluxes through the soil cover is the key issue to control ARD generation (O'Kane 1995; Yanful 1993). This as oxygen together with pH and bacterial activity is the main driving factor in the oxidation process of sulfidic mine waste (Akcil and Koldas 2006). At a relatively low degree of saturation, most oxygen transport occurs through the partially air-filled pores (Aachib et al. 2004), due to the 10 000 times higher diffusion coefficient in the air than in water (Yanful 1993). The effective diffusion coefficient (De) can be explained by the average cross-sectional area open to diffusion and the distance traveled by molecules in the pores of the soil. In addition to a higher diffusion coefficient, the dissolved O2 concentrations in the air is around 20 000 times higher than in water (Höglund et al. 2004; Verburg et al. 2009). The transport of gaseous oxygen through fine-grained materials are mainly by molecular diffusion (Yanful 1993) and in general, the oxygen flux rates are at a minimum when the degree of saturation is greater than 85-90 %, this as the air-phase at a saturation greater than 85 % becomes discontinuous (Corey 1957). The oxygen is then transported through the water phase (Aubertin and Mbonimpa 2001; Aachib et al. 2004) and in a layer that is kept close to saturation, the De can be comparable to the De in water. It is small enough to reduce the oxygen flux to a level comparable to that of a water cover (Yanful 1993; Aachib et al. 2004). In addition to oxygen and moisture content the temperature is another important factor to monitor, especially in the northern Swedish climate with long winters. The low air temperature freezes the pore water in the soil and can create cracks which can increase the hydraulic conductivity of the soil and the oxygen diffusion as the sealing layer dries out.

In this study, the effectiveness of a sealing layer made of a mixture between till and 10 w. % of GLD was studied. An instrumented experimental area within a cover application of the waste rock dump of Näsliden mine was constructed in October 2017. The experimental area consists of sealing layers made of two different materials. One is a mixture of till and 10 wt. % GLD. The other a till and 4 wt. % bentonite. The objective of the study was to evaluate the effectiveness of the sealing layer made of the till-GLD mixture by measuring soil moisture content and oxygen concentrations in the sealing layer and temperature in the protection layer. Another objective of the study is to compare the results from the GLD-till area with the sealing layer made of till-bentonite to see if GLD works as well as the well-studied bentonite in a sealing layer. There is much work done on the evaluation and monitoring of mine waste covers, but no published work yet done on the evaluation of the use of a GLD-till mixture in mine waste remediation.

Methods

An instrumented test area within a cover application of Näsliden mine was constructed in August 2016 and October 2017. The experimental area consists of sealing layers made of two different materials. One is a mixture of till and 10 wt. % GLD, which was constructed in August 2016. The other is a till and 4 wt. % bentonite and was constructed in October 2017 (**Figure 1**).

An observation well and a pit was installed in each monitoring surface and from these four temperature probes (PT1000, EMS Brno) and two soil moisture probes (SM150T, Delta T-devices) were drilled into the different layers at various depth. In addition, 8 oxygen probes (SO110, Apogee instruments)

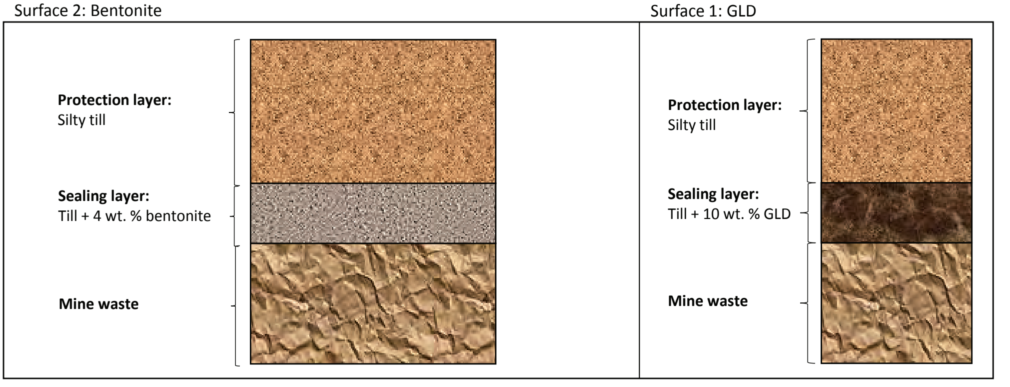

Figure 1. *Overview of the monitoring surfaces.*

were installed under and on top of the sealing layers. Air pressure measurements to compare to the oxygen concentration were collected from the Swedish Meteorological and Hydrological Institute (SMHI). Unlike the other probes, the oxygen probes were installed vertically before the sealing- and the protection layers were applied to prevent leachate from oxygen through the cables. The probes were connected to two data loggers (Railbox RB32P4, EMS Brno) that were installed in the observation wells. The probes to measure temperature and soil moisture were installed in four vertical profiles, two in observation wells and two in pits, both in the GLD-surface and the bentonite-surface. The observation-wells of 2.7 m height and 1.5 m diameter were placed on the mine waste before the cover was constructed. After installation, the cover was and compacted around the wells by hand-driven machinery. After the cover was applied the pits were dug to a depth of approximately two decimeters on top of the sealing layer. After installation of probes, the pits were backfilled with the same material. The probes were drilled with a machine-driven drill of 40 mm diameter (⌀) and 800 mm lenght. When the soil moisture probes with ⌀ 50 mm were installed a hand-driven drill of ⌀ 60 mm was used. The hand driven drill was also used for bore-holes more than 800 mm long. The cables from all probes were collected to tubes that were led to the observation wells and connected to the loggers there. The loggers are powered by solar panels. The boreholes in the observation wells and tubes were sealed with sealing foam to prevent air and water to pass through the tubes to the probes. The part of the observation well above ground was isolated to prevent the atmospheric temperature to influence the temperature measurements.

Results and discussion

The winter in northern Sweden stretches from October to April and is associated with minus degrees and a thick snow layer. This leads to frost penetration into the soil and a dry period considering water percolation through the soil cover.

The results from the monitoring show that temperature has, as expected, declined and leveled out as the winter approaches and continues (**Figure 2:A-D**). The temperature is also, as expected in winter, lowest closest to the surface and warmer further down the cover. Only the probes closest to the surface (0.3-0.5 m depth) seems to be affected by frost, expect from in the observation well in the bentonite surface where frost seems to have reached 0.8 m depth in early spring (**Figure 2:D**). Comparing the temperatures in the pit and the observation wells, the temperatures in the observation well is lower further down than in the pit (**Figure 2:A-B**), both in the GLD and bentonite surface (**Figure 2:C-D**). This indicates that the observation wells are not fully isolated from the cold air. The conclusion is that the protection layer has protected the sealing layer from frost penetration, which was its purpose.

The purpose of the sealing layer is to act as a barrier towards oxygen diffusion and decrease the oxygen levels close to 0 % un-

***Figure 2.** Temperature, soil moisture and oxygen measurements in the pits and observation wells in the GLD and bentonite-surfaces. Atmospheric air pressure is presented together with the oxygen measurements.*

derneath the sealing layer. It was therefore expected that the concentrations below the sealing layer would be lower than above the sealing layer. No trends comparing concentrations below or above the sealing layer can however be seen in this study (**Figure 2:E-F**). The oxygen concentrations in the different places studied here varies between 3-18 % (**Figure 2:E-F**), where the lowest values can be seen in the bentonite layer (**Figure 2:F**). Comparing the results with oxygen measurements done under the cover of the Storgruve dump in Sweden (Lundgren 2001), the results in this study are higher. The variation in oxygen concentrations is great and attuned in most of the probes (**Figure 2:E-F**). Even though cover system behaviour is known to be dynamic and rarely reaching stable conditions in field under a relatively humid climate (Ricard et al. 1997; Ricard et al. 1999; Bussière et al. 2003; Dagenais et al. 2006), the variations was not expected to be attuned. The explanation for the attuned variation is in the atmospheric pressure, which has been found to affect the gas diffusion in a soils vadose zone (Massmann and Farrier 1992). The atmospheric pressure and the oxygen concentrations varies in the same way (**Figure 2:E-F**). The strong variations in oxygen concentrations in the O_2-4 below probe in the bentonite can likely be explained by leakage of atmospheric oxygen through where the cables were connected to the observation well. Some decreasing trends in oxygen measurements can be detected in the oxygen probes in the bentonite layer (**Figure 2:F**). This decrease is seen in Lundgren's (2001) study as well and was expected as the oxygen derived from when the material was exposed to the atmosphere is depleted. In summary a slight decreasing trend with time can be seen in the oxygen concentrations, but not in depth. The oxygen concentrations are greatly affected by the atmospheric pressure and at least one probe seems to be affected by leakage of oxygen from the atmosphere.

The volumetric soil water content show how much of the total volume of the soil is water and the value depend on the pore volume. The more compacted the material, the less pore volume and possibility of water in them. If the total pore volume is filled with water, the material is saturated. The volumetric soil moisture content in this study varies between 12 and 20 % in the bentonite and 0-40 % in the GLD cover. When the material was compacted in laboratory with a standard proctor compaction method (SS-EN 13286-2:2010) a volumetric water content of 30 % was reached. A pilot study with a similar cover made of till and 10 wt. % of GLD in the sealing layer, constructed three years ago, (not published data) shows a volumetric soil moisture of 3-4 %. The pilot cell with only a half meter of protection cover on top of the sealing layer shows a volumetric soil moisture of 8-10 % in the bottom of the layer and 0.5-18.5 % in the surface of the sealing layer that is more exposed to the precipitation. Greater variation is expected in a sealing layer with closer contact to the atmosphere. However, a volumetric soil moisture 3-4 % is a low value and indicate drying of the sealing layer. This might be due to the design of the pilot cell that with its elongated form supports surface runoff rather than infiltration. Bussière et al. (2006) studied a compacted till under topsoil in Ontario, Canada and measured volumetric soil moisture contents of 10-37 %, which corresponds well with the values in this study. The value of 40 % volumetric moisture content measured in the GLD-till mixture, 1.7 m from the observation-well, is higher than the value reached in laboratory (30 %) and indicate saturation. Two other studies that also show volumetric soil moisture levels of approximately 40 % is clay layers constructed at 20-30 cm depth in New Brunswick, Canada (Yanful 1993) and a moisture retaining layer in an oxygen-limiting cover in Quebec, Canada (Simms and Yanful 1999).

The soil moisture in the sealing layers in this study has generally decreased somewhat with time (**Figure 2:G-H**), this might be due to the dry winter period where the water is frozen. In the GLD layer, the soil moisture was higher in the lower parts of the sealing layer (Figure 2:G). However, it seems unlikely that the level in the upper part of the sealing layer reaches under 0 % and might be a instrument error or that the probe is measuring towards a rock. High soil moisture levels in the GLD-mixture is expected due to the high WRC of the GLD (Mäkitalo et al. 2014), which means that the water that percolates through the protection layer is retained in the sealing layer. This trend is also seen in the pilot study discussed above with a similar cover system. In the bentonite layer, the soil moisture content is somewhat lower at depth (**Figure 2:H**). The high WRC and the higher wt. % of GLD in the sealing layer is likely the reason of the higher soil moisture contents in this layer compared to in the bentonite layer. It is however too early to draw any conclusions between the data, as the bentonite layer was constructed this year and the GLD layer a year before. The GLD layer has therefore had a year more for water to penetrate through the protection layer, compared to the bentonite layer.

In summary the soil moisture content is decreasing with time, likely due to the dry winter period. The GLD has a higher moisture content with depth and the bentonite layer a lower content with depth. The GLD-layer indicate saturation in one of the measuring points.

Conclusions

The conclusion of the data set so far is that the protection layer work as a protection from frost penetration and has kept the sealing layer intact. The oxygen concentrations show no decrease in concentrations comparing measurements under and on top of the sealing layer. A decreasing trend in oxygen concentrations is seen in the bentonite layer with time, but the oxygen concentrations are still too high for a sealing layer. At least one of the probes seem to be affected by leakage and the cable-well-connections need improvement in the sealing. The atmospheric pressure is affecting the oxygen concentrations greatly which makes it difficult to detect trends. The soil moisture data indicate that the sealing layer of GLD-till mixtures is nearly saturated at parts. The collected data indicate a slight difference between the data from the bentonite- and GLD surfaces, with higher moisture levels in the GLD. More data and a longer monitoring time are needed to detect any trends between seasons and sealing layer materials.

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