PARAMETRIC STUDY ON THE WATER CONTENT PROFILES AND OXIDATION RATES IN NEARLY SATURATED TAILINGS ABOVE THE WATER TABLE[1]

Anne-Marie Dagenais[2], Michel Aubertin, and Bruno Bussière

Abstract. A promising concept, known as the elevated water table, is emerging as a management and possible closure technique to limit AMD production from tailings impoundments. This prevention approach is based on the principle that tailings in the capillary zone can be maintained in a state close to full saturation which minimizes oxygen diffusion and thus limits acid generation. A parametric study was conducted to evaluate the effect of various factors on the water content profiles in reactive tailings. The results presented here show that the position of the water table has a large influence on the water content profiles and on the oxygen flux at the tailings surface. For a water table depth value smaller or equal to the tailings' air entry value (ψ_a), the degree of saturation S_r varies between 90 to 99 % at the tailings surface, covered by a sand protection layer. These high S_r values yield effective diffusion coefficient D_e comparable to that of O_2 diffusion in water. The study also shows that the efficiency of the elevated water table concept can be negatively affected when the tailings are highly reactive.

Additional Key Words: elevated water table, modeling, water content profiles, oxygen flux, unsaturated conditions.

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Introduction

Acid mine drainage (AMD), also known as acid rock drainage (ARD), is produced from the oxidation of sulphide minerals in the presence of water. This natural phenomenon remains a critical challenge for the mining industry, especially in cases where the tailings or waste rocks contain reactive minerals. Studies on this subject have shown that in a relatively humid climate, where precipitations exceed evaporation, preventing oxygen from reaching the reactive material by using water constitutes a practical approach for effectively limiting the production of AMD (SRK, 1989; MEND, 2001).

Water retention in a porous media by capillary forces can be applied toward gas migration control. This physical process is used for instance in the case of covers with capillary barrier effects (CCBE) to create an oxygen barrier to prevent AMD (e.g. Collin and Rasmusson, 1988; Nicholson et al. 1989; Aachib et al. 1994; Bussière et al. 2003). The effective O_2 diffusion coefficient D_e in such a cover system, where a layer is kept close to saturation with degree of saturation values around 90 %, can become comparable to the O_2 diffusion coefficient in water. Such a low coefficient is considered small enough to reduce the O_2 flux to a level comparable to that of a water cover (e.g. Collin and Rasmuson 1990; Yanful 1993; Aubertin et al. 1995, 1999; Aachib et al. 2004). Therefore the nearly saturated tailings would have a low enough D_e value to inhibit the formation of AMD by limiting the O_2 availability (MEND, 1996; Orava et al., 1997).

Creating an elevated water table in a tailings impoundment is a promising concept that uses the tailings capillary properties to inhibit O_2 diffusion and control AMD generation (MEND, 1996; Dagenais, 2005; Ouangrawa et al. 2005). One of the main advantages of this approach lies in an improved geotechnical stability of the dykes, compared to the case of a water cover (which is a generally well accepted AMD prevention technique), because of the lower phreatic line position and smaller pore pressures. There is also a reduced risk of surface erosion from water and ice along the dyke's internal face. There can also be some possible costs reduction in the application of this concept, when compared to a water cover or to a layered cover system (MEND, 1996).

Figure 1 illustrates the distribution of water content and pore pressure along a typical profile in a tailings impoundment. The water table surface separates the phreatic zone, where the interstitial pressure is positive, from the vadose zone where the interstitial pressure is negative (i.e. smaller than the atmospheric air pressure). A capillary fringe exists in the vadose zone just above the water table, where the pores are near saturation (Freeze and Cherry, 1979; Domenico and Schwartz, 1998). The moisture content profile corresponding to the hydrostatic equilibrium, shown in Fig. 1, depends on the porous media pore size and distribution which can be related to its grain size distribution (Hillel, 1998). A fine grained material having small pores induces a higher capillary rise than a coarser one (e.g. Aubertin et al. 1998; 2003).

For a homogeneous deposit, the saturated capillary fringe, shown on Fig. 1, corresponds to the air entry value ψ_a on a water retention curve (Freeze and Cherry, 1979; Hillel, 1998). The ψ_a is defined as the negative pore pressure (or suction) at which the largest pores in a soil start to desaturate (Fredlund and Rahardjo, 1993; Hillel, 1998). As a general rule, the water table should be positioned so that the height of the tailings above it is smaller than their ψ_a (Orava et al., 1997; MEND, 2001); this is shown schematically in Fig. 2. For fine tailings, this might not be difficult to achieve. Fine grained tailings usually possess a grain size distribution that confers them favorable hydraulic characteristics, low permeability (from 10^{-4} to 10^{-7} cm/s) and large ψ_a (from 1.7 to 5 m of water), compatible with the application of the elevated water table concept (Aubertin et al., 1996, 1998). The application of this concept may be problematic for the coarser tailings generally located near the dykes. Other factors than the tailings hydraulic properties may also affect their water content in the vadose zone, in the tailings pond, such as the site water balance and the tailings management plan (MEND, 1996). These are to be taken into account before the implementation of this concept as a mitigation or reclamation measure.

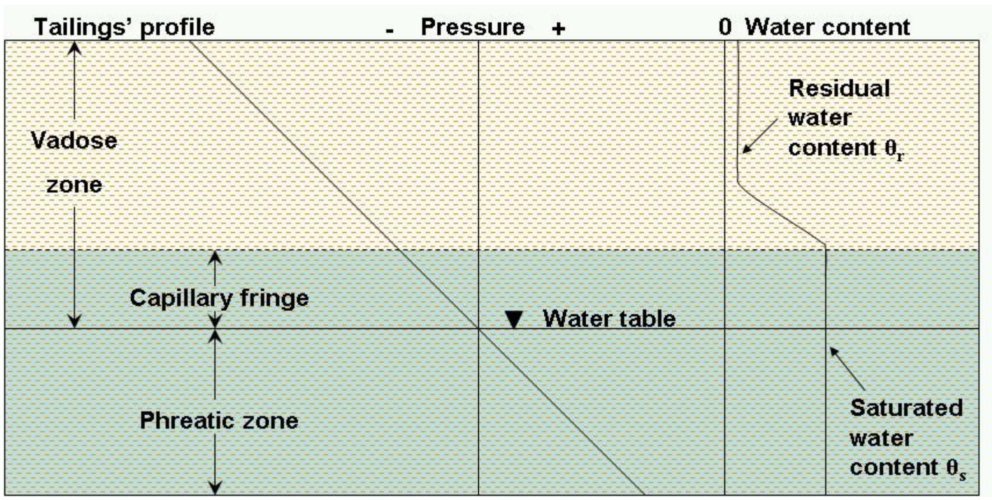


Figure 1. Conceptual view of a tailings profile showing pressure and water distribution (adapted from MEND, 1996).

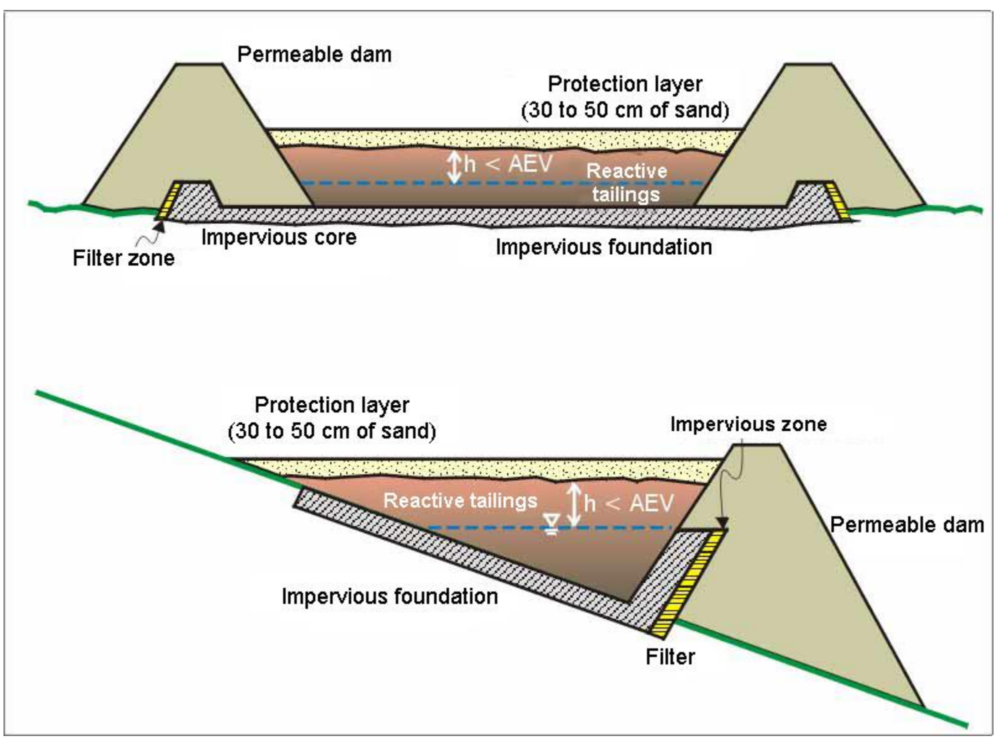


Figure 2. Conceptual view of a tailings impoundment with the phreatic surface positioned to maintain an "elevated water table" (Aubertin et al., 1999).

An experimental and numerical parametric study was conducted to evaluate the influence of various factors on the water content profile and on the O_2 flux in tailings, including the evaporation rate, the thickness and the properties of the protection (evaporation barrier) layer, the water table depth, and the hydraulic properties of the sulphide tailings. For the numerical calculation results shown here, the O_2 fluxes were evaluated for three sulphide reaction rate coefficients K_r based on different water content profiles. This paper reports the main results from the numerical parametric study and discusses the implications for the application of the concept to prevent AMD generation.

Model Description

The numerical study presented here follows a series of column tests performed in the laboratory; the experimental results can be found in Dagenais (2005). The model calculations make use of the hydraulic properties of four tailings having different grain size distributions. One of the tailings has a grain size distribution similar to the S-M tailings used in the column tests study just mentioned (2005). Two other tailings, named here "Fine" and "Coarse", are based on grain size distributions taken from Vick (1990). The properties of the fourth tailings, named T-T, are taken from a study done by Barbour et al. (1993) on thickened tailings. A sand layer is added in the model; it serves as a protection layer against excessive evaporation from the tailings. Its properties are those of a sandy soil used in the column tests study mentioned above. For the S-M tailings and the sand, the values from the grain size distribution, permeability and water retention curve (WRC) measured in the laboratory are used.

Material Properties

Table 1 list the values the coefficient of uniformity C_u, the diameter D_{10} (for 10 % passing) and the percentage % smaller than 80 µm for all the materials. These properties were used to estimate the saturated hydraulic conductivity k_{sat} of the Fine, the Coarse and the T-T tailings with the semi-empirical Kozeny-Carman modified (KCM) relationship proposed by Aubertin et al. (1996; see also Mbonimpa et al. 2002). The void ratio used in the calculations to obtain k_{sat} is fixed at 0.85, and corresponds to the mean void ratio of the tailings used in the column study (Dagenais 2005). This value compares well to the ones observed in actual tailings impoundment (e.g. Vick, 1990; Barbour et al., 1993). The k_{sat} values calculated for the Fine, Coarse and T-T tailings are presented in Table 1 along with the measured k_{sat} for the S-M tailings and the sand.

The WRC of the Fine, Coarse, and T-T tailings were estimated with the modified Kovacs (MK) model (Aubertin et al., 1998, 2003); this predictive model uses the C_u, D_{10} values presented in Table 1 (with a void ratio of 0.85). The calculated curves, along with the water retention data measured for the S-M tailings and the sand, were then fitted with the van Genuchten (1980) equation using the RETC code (van Genuchten et al., 1991), in order to obtain their hydraulic conductivity k functions. The k functions were drawn using the Mualem (1976)-van Genchten (1980) formulation. The parameters used in the RETC code to obtain the hydraulic functions of the materials (i.e. α_v and n_v fitting parameters, θ_s saturated volumetric water content, θ_r residual volumetric water content) are given in Table 2. The corresponding WRC and k functions are shown in Fig. 3. In Fig. 3a, the lines represent the WRC calculated with the van Genuchten (1980) equation, while the symbols represent the laboratory data or the data ensuing from the MK model, as explained above.

Table 1. Materials hydraulic properties used in the numerical calculations.

Parameter	Fine calculated	S-M measured	Coarse calculated	T-T calculated	Sand measured
D_{10} (mm)	0.0019	0.004	0.006	0.038	0.2
C_u	8.5	8	20	19	3
< 80 μm (%)	97	77	44	64	1
k_{sat} (cm/s)	1.8×10^{-5}	5.0×10^{-6}	2.3×10^{-4}	1.3×10^{-5}	5.2×10^{-2}
ψ_{90} (m of water)	4.5	1.25	0.55	9.3	0.19

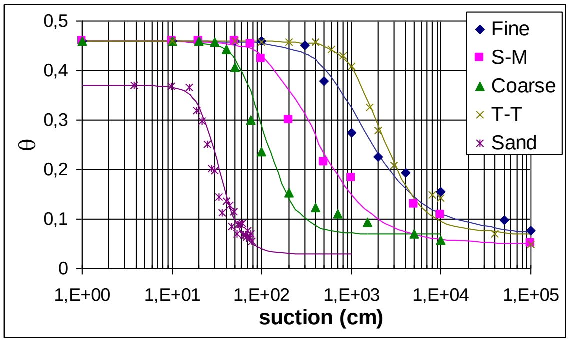
Table 2. Material parameters used in the RETC code.

Parameter	Fine	S-M	Coarse	T-T	Sand
θ_s	0.459	0.459	0.459	0.459	0.37
θ_r	0.07	0.07	0.05	0.07	0.03
α_v (cm^{-1})	0.0012	0.004	0.011	0.0006	0.033
n_v	1.9	2	3.1	2.5	4

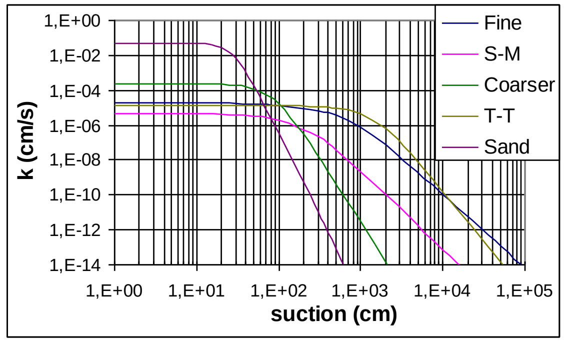
In this study, the ψ_a is determined on the WRC according to an approach proposed by Aubertin et al. (1998). It is based on the assumption that a continuous air path is created in a porous media when the degree of saturation reaches about 90%; this condition can be taken as somewhat equivalent to the ψ_a when assessing gas (O_2) flux. Thus, the ψ_a is taken here as the suction head (identified as ψ_{90}) when θ is equal to $0.9\theta_s$ on the WRCs shown in Fig. 3. This value varies from 0.55 to 9.3 m of water for the four tailings considered here; it is equal to 0.19 m of water for the sand (see Table 1).

Model Description and Boundary Conditions

The numerical code SoilCover (Unsaturated Soil Group, 1997) was used in this study to model soil-atmosphere interactions. SoilCover is a one-dimensional finite-element code that can predicts the rate of evaporation from soil surfaces based on coupled heat and mass transfer processes (Wilson et al., 1994; Swanson et al., 2003; Yanful et al., 2003). The numerical model constructed here is based on column tests, similar to those conducted for the experimental part of this study on the elevated water table concept (Dagenais 2005). In general, the soil water content profile of representative in situ conditions is best represented by a 2D model (e.g. Aubertin et al. 1997; Wels et al., 2001; Bussière et al., 2003). However, in this study, the influence of the 2D geometry was not considered. The simple 1D model retained is well suited to isolate the effect of the various influence factors, as investigated in the column tests.



a)



b)

Figure 3. Hydraulic functions used in the numerical study a) WRC b) k functions; based on the Mualem (1976)-van Genuchten (1980) model.

The hydraulic functions used in the model were presented in Table 1 and in Fig. 3. The thermal conductivity and volumetric specific heat functions of the materials were generated in SoilCover from their WRC, percentage of quartz and specific heat. The value of these last two parameters is taken as 90 % and 850 J/kg/ºC; these values are suggested in the SoilCover user's manual for tailings containing a high percentage of quartz mineral (Unsaturated Soil Group, 1997). The SoilCover numerical solutions have been found to be relatively insensitive to thermal conductivity and specific heat properties. The convergence criteria for the suction and temperature were set to 1 % and the maximum number of iterations per time step was limited to 25. The first and the minimum time steps was preset at 0.01 s, and the maximum time step was limited at 100 s. An adaptive time-stepping scheme is used to automatically calculate the size of the time step. The time step is controlled by specifying a maximum suction change and temperature change per step, here being 2.5 %.

The initial boundary conditions imposed for the calculations with the SoilCover model include a zero pressure condition at the bottom, simulating the water table at the base of the column, and a suction of 1 kPa at the top of the sand layer. This low surface suction enables the numerical simulation to start with the materials in a state close to saturation. To model different water table depths, the height of the tailings above the water table was changed (instead of changing the zero pressure boundary condition at the base). During the transient analyses, the zero pressure condition at the base was kept constant, and a value 0 mm/day for the rain/snow melt boundary condition was used, which means there is no infiltration in the soil column during the simulations. Typical reduced weather data, including air temperature, relative humidity and potential evaporation, was chosen for this study.

<u>**Calculated Water Content Profiles**</u>

The series of simulation results presented here pertain to the evaluation of the effect of the water table depth and of the tailings hydraulic properties on the water content profiles. Other simulations evaluating the effects of the evaporation rate, thickness of the protection layer and properties of the protection layer can be found in Dagenais (2005). The main conclusions ensuing from these calculations are summarized in the next paragraphs.

The simulations evaluating the effect of the rate of evaporation on the water content profiles showed that the actual evaporation rate is mainly controlled by suction at the surface of the protection layer, its hydraulic properties and by the potential evaporation (PE) rate. For the sand used here as the protection layer of 0.3 m thick, changing the PE rate from 1.8 mm/day to 13 mm/day (which corresponds to the highest PE value obtained in the laboratory during the column experiments) didn't affect significantly the moisture content at the tailings surface. The PE rate was fixed at 7.8 mm/day, which corresponds to average evaporation rates measured on sand during laboratory and field tests (e.g. Wilson et al., 1994; Wythers et al., 1999).

The simulations evaluating the effect of the thickness of the protection layer showed the importance of this parameter on the water content profiles in the tailings. Without a protection layer, the simulations yielded a degree of saturation (S_r) value ranging from 70 to 74 % near the surface of the tailings. With a sand protection layer (thicknesses ranging from 0.1 to 1 m), the value of S_r in the tailings remained above 95 %. The protection layer is effective to restrict the evaporation, leaving the tailings underneath close to saturation. In the remaining calculations, the thickness of the protection layer was set to 30 cm, based on these results and on the height of the protection layer of CCBE at the Les Terrains Aurifères (LTA) site and the Lorraine site, Québec, Canada (Ricard et al., 1997, 1999; Nastev et Aubertin, 2000). The simulations also showed the importance of having a protection layer made of a coarse material which posses different hydraulic properties than the tailings underneath. Once the protection layer is desaturated, the low hydraulic conductivity of this layer prevents upward moisture flow from the tailings.

Influence of the Water Table's Depth

Figure 4 shows the ψ and θ values, for a point taken at 2 cm under the S-M tailings surface, in relation to the water table depth, for drainage periods of 7, 15, 30, and 60 days. The full line drawn in Fig. 4 represents the hydrostatic equilibrium condition, and the dashed line represents the ψ_{90} of the S-M tailings (12.5 kPa). The results indicate that the suction varies with the drainage period and the water table depth. Over time, the suction tends toward the equilibrium condition. For a depth of 100 cm or less, the suction values are no more than 6 kPa above the hydrostatic equilibrium line (due to the influence of evaporation). As the depth of the water table reaches or exceeds the ψ_{90} head, results indicate that it takes longer to reach this hydrostatic equilibrium, but the suctions values at the tailings surface exceed nonetheless their ψ_{90}.

The high suction values developing over time, when the water table is deep enough, can cause the tailings to desaturate near the surface, as can be seen in Fig. 4b. For a water table depth smaller than 125 cm, the θ vary between 40.8 and 45.8 % (S_r between 89 and 99 %). These S_r values yield a low D_e which reduces the O_2 flux through the material. For a water table depth superior to 125 cm, the θ varies between 39.9 and 40.7 % (i.e. S_r between 87 and 88 %) for a drainage period of 30 days, and between 37.1 and 39.3 % (i.e. S_r between 81 and 86 %) for a drainage period of 60 days. The coefficient D_e associated to these values would be much higher, so O_2 flux could be significantly increased (e.g. Mbonimpa et al. 2003).

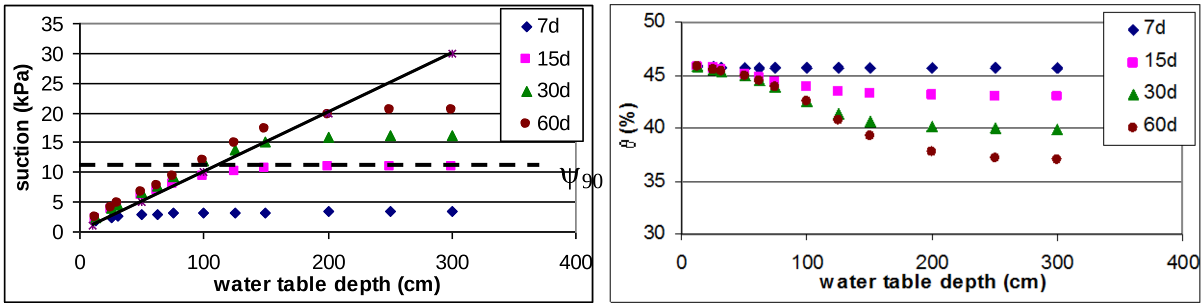


Figure 4. Calculated values of ψ (a) and θ (b) for a point located 2 cm below the S-M tailings surface, as a function of the depth of the water table, for different drainage period.

<u>Influence of Hydraulic Properties</u>

Figure 5 shows the calculated ψ and θ values, for a point taken at 2 cm underneath the surface of the four tailings, as a function of the water depth after 60 days of drainage. The line drawn in Fig. 6a represents the hydrostatic equilibrium. This figure shows that, for the four tailings, the suction varies with the water depth, and follows closely the hydrostatic equilibrium. As the suction near the surface exceeds the ψ_{90} of the Coarse (5.5 kPa) and the S-M tailings (12.5 kPa), the corresponding θ, shown in Fig. 5b, drops below 38 % (i.e S_r drops below 83 %). For the Fine and the T-T tailings, the suction near the surface is not high enough (or the water table deep enough) to induce a reduction of the water content below 40 % (i.e. S_r remains above 87%). The θ of the tailings near the surface is highly sensitive to the hydraulic properties of the tailings. The desaturation will be much more accentuated for coarser tailings, because of a smaller ψ_a.

Figures 6 shows the same results as found in the above, but using a suction and water depth that have been normalized by the ψ_{90} of the tailings. The normalized suction follows closely the dark line in the Fig. 6a, which represents a 1:1 relationship associated to the hydrostatic equilibrium. Fig. 6b shows that the volumetric water contents of the four tailings are grouped for a normalized depth equal or less than 1; in this case, θ varies between 40.8 % (S-M tailings) and 42.8 % (T-T tailings), which yields a S_r value between 89 and 93 %. Hence, for a normalized depth smaller than unity (i.e. a water table location at a depth less than the ψ_a), the hydrogeological behavior of the different tailings can be considered similar to one another.

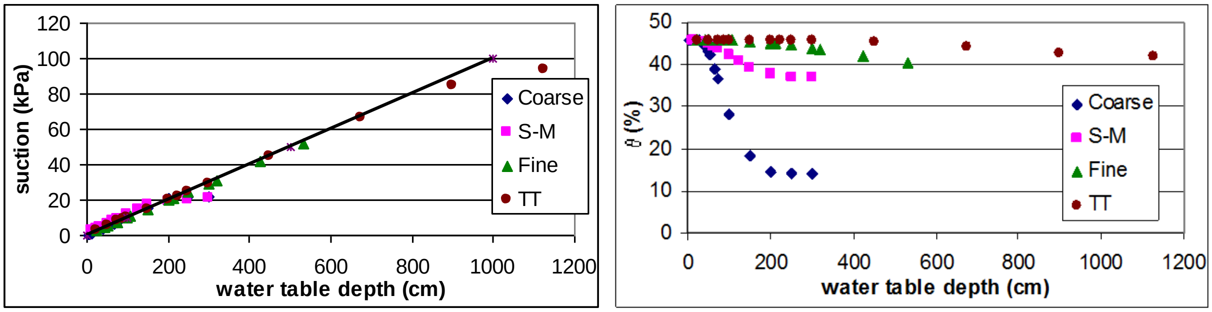


Figure 5. Calculated values of ψ and θ, for a point taken at 2 cm below the surface of the four tailings, as a function of the depth of the water table, after 60 days of drainage.

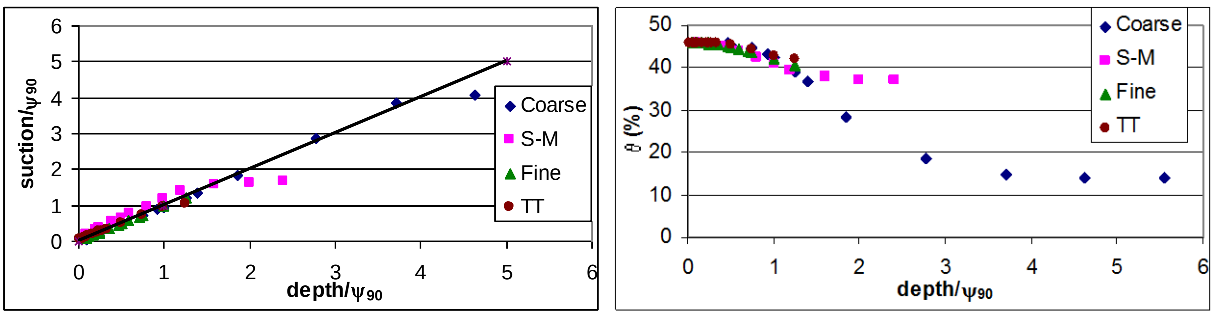


Figure 6. Normalized ψ and θ calculated at depth of 2 cm below surface of the four tailings, as a function of the normalized water table depth, after 60 days of drainage.

<u>Oxygen Flux Evaluation</u>

The volumetric water content profiles resulting from the SoilCover simulations have been used to evaluate the O_2 flux entering the tailings, for a given water table' depth. The O_2 flux entering the tailings is a function of both the tailings effective reaction rate coefficient K_r and the effective diffusion coefficient D_e (Nicholson et al., 1989; Elberling et Nicholson, 1996; Mbonimpa et al., 2003). It was shown in the previous section that the hydrogeological response of the four tailings is similar to one another for a normalized depth (z/ψ_{90}) of 1 or less. Hence, for this part of the study, only the results of the S-M tailings are used to illustrate the influence of K_r and to evaluate the O_2 flux. Three K_r are used in the following calculations: 11 year^{-1} (0.03 day^{-1}), 37 year^{-1} (0.1 day^{-1}) and 132 year^{-1} (0.36 day^{-1}), which correspond to a sulphur content in the tailings of 0.2, 9.1 and 25.2 % respectively.

<u>Model description</u>

The numerical solution for the O_2 flux is obtained using the POLLUTE 6.0 software (Rowe et al., 1998). The equations and numerical methods used in POLLUTE have been presented by Rowe and Booker (1985). This software has been employed extensively over the years to analyze test results and to evaluate the flux through various cover systems (e.g. Aubertin et al., 1995; 1999, 2000; Mackay et al., 1998; Yanful et al., 1999; Mbonimpa et al. 2003). It can be used for gas diffusion in unsaturated porous media when an equivalent porosity θ_{eq} is introduced in place of the total porosity of the materials (e.g. Aubertin et al. 1999; 2000). It is also possible to consider O_2 consumption in the tailings by introducing a K_r for the reactive tailings. In

POLLUTE, the K_r is defined by the half-time life of a material as an analogy to a radioactive decay parameter which, for a first order kinetic oxidation reaction (Nicholson et al., 1988; Elberling and Nicholson, 1996), can be expressed as:

$$t_{1/2}^{*} = \frac{\ln 2}{K^{*}} = \theta_{eq} \frac{\ln 2}{K_r} \qquad \textbf{(1)}$$

The parameters used in POLLUTE for modeling the diffusion and consumption of O_2 in the tailings are the height of the layers, the material dry density, the equivalent porosity and the global (bulk) diffusion coefficient D^*. D^* can be expressed as a function of D_e by $D^*=D_e/\theta_{eq}$, where $\theta_{eq}=\theta_a+H\theta_w$. (Aachib et al., 2002; Aubertin et al., 1999, 2000). H is the Henry equilibrium constant (0.03 for O_2 at 20°C); θ_a represents the volumetric air content of the material ($\theta_a = n-\theta_w$) and θ_w represents the volumetric water content of the material. For a given θ_w profile calculated by SoilCover, it is possible to calculate the associated D_e profile using the following equation (Aachib et al., 2002; Mbonimpa et al., 2003):

$$D_e = \frac{1}{n^2}\left[D_a^0\theta_a^{3.5} + HD_w^0\theta_w^{3.5}\right] \qquad \textbf{(2)}$$

where D_a^0 is the O_2 diffusion coefficient in air (≈1,8x10^{-5} m^2/s) and D_w^0 is the diffusion coefficient in water (≈2,5x10^{-9} m^2/s); n is the porosity. The tailings dry density is fixed at 1 620 kg/m^3 for all simulation. The upper boundary condition corresponds to a constant O_2 concentration of 0.285 kg/m^3 (i.e. atmospheric condition). The lower boundary condition is set as a nil concentration (i.e. 0 kg/m^3, with all the O_2 rapidly consumed by the tailings). This is a very conservative assumption that maximises the concentration gradient. The 30 cm thick sand layer, which shows a low S_r value, has little influence on the O_2 flux and is not included in the model calculations (Aachib et al., 1994). This sand material, with a D_{10} of 0.2 mm, 1 % passing 80 μm, and a ψ_{90} of 0,19 m of water, is coarser then the modeled tailings, and it tends to desaturate at the low suctions encountered in the simulations. The simulation results from POLLUTE indicate that two days are typically required to attain a steady-state for a given water content profile. The O_2 flux presented here is that obtained upon reaching steady-state, using the SoilCover water content profiles associated with drainage periods of 7 days, 15 days, 30 days and 60 days.

Influence of the Reaction Rate Coefficient

Figure 7 shows calculation results of the O_2 flux as a function of normalized depth for the three K_r, after 30 days of drainage. For a normalized depth below about 0.4, the O_2 flux is practically independent of the water table depth. The calculated value is 2.2x10^{-3} mol/m^2/day for a K_r of 11 year^{-1} (0.03 day^{-1}), 4.0x10^{-3} mol/m^2/day for a K_r of 37 year^{-1} (0.1 day^{-1}), and 7.6x10^{-3} mol/m^2/day for a K_r of 132 year^{-1} (0.36 day^{-1}). For higher normalized depth, the O_2 fluxes calculated show an increase caused by a small desaturation at the tailing surface, going from 97 % to 90 %. This desaturation is also more pronounced as the drainage period increases. At a normalized depth of 1, the O_2 flux increases from 3.3x10^{-2} to 4.1x10^{-2} mol/m^2/day when the drainage period increases from 30 to 60 days. The curves presented in figure 7, although offset from one another, have a similar shape for any given K_r. In this case, the O_2 flux is proportional to the square root of both the tailings D_e and K_r and a variation of this last parameter offsets the O_2 flux by the difference between the square root of the tailings' K_r or $\Delta(K_r^{0.5})$, for a given normalized depth.

Figure 8 presents the calculated O_2 fluxes as a function of the normalized depths, for the three K_r values considered and drainage periods of 15, 30, and 60 days (thus giving multiple points for given normalized depths and K_r). The dashed line shown in Fig. 9 represents the steady-state O_2 flux calculated by Li and al. (1997) for a 0.3 m water cover subject to natural exposure factors, including a wind of 2 m/s. This flux of 7.4×10^{-3} mol/m^2/d is added on the figure as a reference value, for comparative purposes.

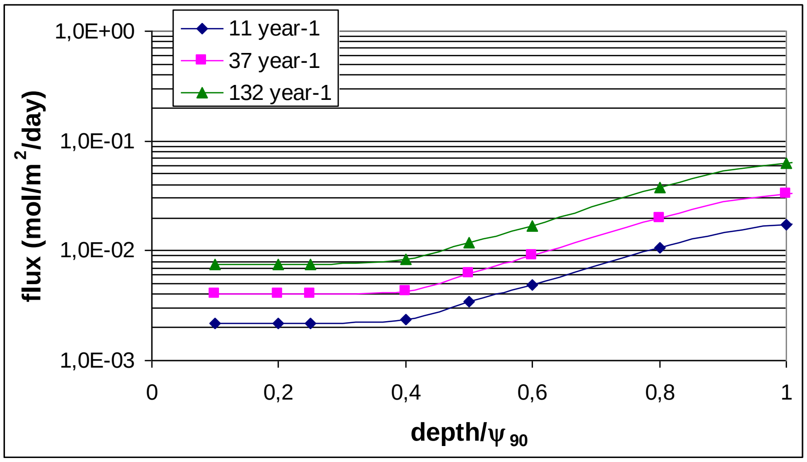


Figure 7. Oxygen flux calculated, as a function of the normalized depth, for different K_r after 30 days of drainage.

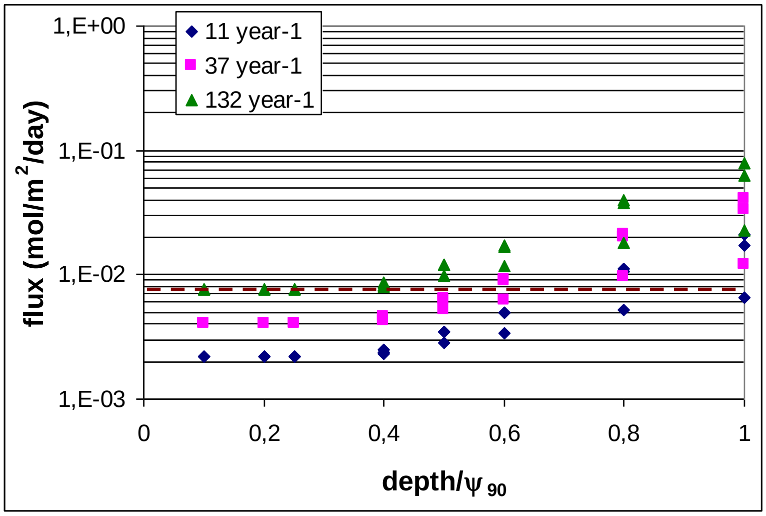


Figure 8. Calculated values of the O_2 flux, as a function of the normalized depth, for different K_r values and drainage period.

On Fig. 8, it can be seen that, depending on K_r , there is a normalized depth below which the O_2 flux is less than the reference flux calculated for an aerated water cover; this normalized depth varies between 0.4 (for highly reactive tailings after 60 days) to about 1 (for low sulfide content, after 15 days). One can also notice from this figure that as the K_r value increases (i.e. larger sulfide content, all other factors being equal), the O_2 flux also increases, and it can become larger than reference flux value (horizontal line) at a normalized depth of about 0.5, even for a short drainage period of 15 days. These results emphasize the need to properly assess the reactivity of the tailings and their hydraulic properties, in order to safely apply this concept to an actual tailings disposal site.

Conclusion

The elevated water table is emerging as a promising concept for reactive tailings management, which can also serve as a possible reclamation technique to limit AMD (or ARD) in impoundments. This concept is based on the fact that tailings in the capillary zone, just above the water table, are maintained in a state close to full saturation that minimizes O_2 diffusion and consumption. In this regard, fine grained tailings usually possess more favorable hydraulic characteristics (i.e. low permeability and large ψ_a), but that can be offset by a larger surface area that promotes a larger O_2 reactivity. Various factors, beside the hydraulic properties, affect the water content above the water table in the tailings pond. These are to be taken into account for the implementation of this concept as a mitigation measure or a restoration plan.

This parametric study illustrates, through a series of numerical calculation results, the importance of considering factors like the thickness and properties of the protection (evaporation barrier) layer, the depth of the water table, and the hydraulic properties of the tailings. These factors mainly affect the water content profile in the tailings. In addition, the kinetics of the oxidation reactions (and of the neutralisation reactions) must also be considered, for it has been shown here that the reaction rate coefficient of the tailings has a significant influence on the performance of this method.

The results of the study indicate that when the depth of the water table is below about $0.5\psi_{90}$ (expressed as a head), tailings, covered with a 30 cm layer of coarse sand, tend to remain close to saturation, for a period that can last up to 60 days without any water recharge from the surface. In such cases, the degree of saturation at the tailings surface is high enough to impede most of the O_2 flux. For a water table depth varying between $0.5\psi_{90}$ and ψ_{90}, the degree of saturation of tailings surface would typically vary between 90% to 99 %, depending on the drainage period, yielding an effective diffusion coefficient D_e comparable to that of a water cover. The study also shows that the elevated water table concept efficiency may be affected by the tailings reactive rate coefficient K_r. For highly reactive tailings, the O_2 flux reduction brought about by maintaining tailings near saturation might not be enough to prevent AMD.

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