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Applicability of passive compost bioreactors for treatment of extremely acidic and saline waters in semi-arid climates

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ABSTRACT

Extremely acidic and saline groundwater occurs naturally in south-western Australia. Discharge of this water to surface waters has increased following extensive clearing of native vegetation for agriculture and is likely to have negative environmental impacts. The use of passive treatment systems to manage the acidic discharge and its impacts is complicated by the region's semi-arid climate with hot dry summers and resulting periods of no flow. This study evaluates the performance of a pilot-scale compost bioreactor treating extremely acidic and saline drainage under semi-arid climatic conditions over a period of 2.5 years. The bioreactor's substrate consisted of municipal waste organics (MWO) mixed with 10 wt% recycled limestone. After the start-up phase the compost bioreactor raised the pH from ≤3.7 to ≥7 and produced net alkaline outflow for 126 days. The bioreactor removed up to 28 g/m^2/d $CaCO_3$ equivalent of acidity and acidity removal was found to be load dependent during the first and third year. Extended drying over summer combined with high salinity caused the formation of a salt-clay surface layer on top of the substrate, which was both beneficial and detrimental for bioreactor performance. The surface layer prevented the dehydration of the substrate and ensured it remained waterlogged when the water level in the bioreactor fell below the substrate surface in summer. However, when flow resumed the salt-clay layer acted as a barrier between the water and substrate decreasing performance efficiency. Performance increased again when the surface layer was broken up indicating that the negative climatic impacts can be managed. Based on substrate analysis after 1.5 years of operation, limestone dissolution was found to be the dominant acidity removal process contributing up to

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78–91% of alkalinity generation, while bacterial sulfate reduction produced at least 9–22% of the total alkalinity. The substrate might last up to five years before the limestone is exhausted and would need to be replenished. The MWO substrate was found to release metals (Zn, Cu, Pb, Ni and Cr) and cannot be recommended for use in passive treatment systems unless the risk of metal release is addressed.

1. Introduction

Passive treatment systems for the remediation of acid mine drainage (AMD) have been developed in temperate climates (Younger et al., 2002; PIRAMID Consortium, 2003; Watzlaf et al., 2004). However, acidic surface and groundwaters also occur in semi-arid Mediterranean climates with hot dry summers and cool wet winters, such as in California (Druschel et al., 2004), Spain (Sánchez España et al., 2005) and Australia (Lillicrap and George, 2010). The application of passive treatment systems to acidic waters in such environments is complicated by high evaporation in summer, which can cause surface water bodies to dry out, restricting periods of surface water flow to winter and spring. The evaporation affects water quality and needs to be considered in passive treatment system design in semi-arid regions (Tyrrell et al., 1997; Degens, 2012).

Extremely acidic saline groundwater occurs naturally in the agricultural areas of south-western Australia known as the wheatbelt (Lillicrap and George, 2010), where nearly 47,000 km^2 of valley floors and flat terrain have been identified as having a high probability of acidic saline groundwater (Holmes and Lillicrap, 2011). Clearing for agriculture disturbed the hydrological cycle and has led to increased recharge causing groundwater tables to rise (Hatton et al., 2003). Dryland salinisation and increased groundwater baseflow into surface waters are consequences of the rising water tables. Deep drains, greater than one metre in depth, are used to manage dryland salinity. However, the discharge of acidic saline groundwater from arterial drainage networks into surface waters can result in acidification up to 30 km downstream of the drain outlet (Seewraj, 2010) with negative impacts on ecosystems (Jones et al., 2009; Stewart et al., 2009).

Acidic saline groundwater found in south-western Australia is similar to acid mine drainage (AMD) as it is characterised by pH values < 4 and high concentrations of metals such as aluminium, iron, lead, copper, nickel and zinc (Degens and Shand, 2010). The acidity, however, is not a result of pyrite oxidation but of ferrolysis (Mann, 1983; Lillicrap and George, 2010), with the sulfate in the system stemming from evaporation of marine aerosols (Bird et al., 1989). In addition, the groundwater is extremely saline with up to 100,000 mg/L of total dissolved solids dominated by sodium chloride (Degens and Shand, 2010).

The adoption of AMD abatement technologies in south-western Australia is hindered by the relatively low value of agricultural land and low profitability of many enterprises compared to mining. Active treatment technologies with high on-going costs are especially unsuitable on economic grounds. Passive treatment systems generally require no continual input of energy or chemicals and less maintenance than active systems (PIRAMID Consortium, 2003). Most of the passive technologies for AMD were developed for temperate climates and hilly landscapes, where water is often held in open ponds and where treatment is based on the natural hydraulic gradient providing the necessary flows. However, the use of passive treatment systems for acidic saline drainage in south-western Australia is complicated by extreme salinity, very low hydraulic gradients and high evaporation in summer (Tille et al., 2001).

Generally, passive treatment systems based on vertical flow are preferable to horizontal flow systems as they are more efficient, present smaller surface areas for evaporation and are less likely to suffer from preferential flow (Younger et al., 2002). Vertical flow systems with dispersed alkaline substrates have been used successfully to treat AMD in semi-arid landscapes (Caraballo et al., 2011). However, vertical flow systems require more than two metres hydraulic head to drive flow (PIRAMID Consortium, 2003). This makes them unsuitable for the Western Australian wheatbelt, where hydraulic gradients are in the order of 10–30 cm per 1000 m (Beard, 1999). Given the constraints of cost and low hydraulic head, horizontal flow compost wetlands or bioreactors would be the most suitable passive treatment technology. The efficacy of such treatment systems in a semi-arid climate with periods of no flow is poorly known (Degens, 2012).

Initial assessments indicate that it might be possible to adapt passive treatment systems for AMD to the semi-arid, flat landscapes of south-western Australia (Degens, 2009). Laboratory experiments showed that acidic saline drainage found in Western Australia can be treated by bacterial sulfate reduction (Santini et al., 2010). Two pilot-scale horizontal flow sulfate reducing compost bioreactors treating acidic saline drainage with wheat straw and composted sheep manure achieved net alkaline outflow for up to 183 days and partial acidity removal for up to 2.4 years (Degens, 2012). High evaporation in summer was found to impact system performance but neither bioreactor was subjected to extended drying periods where the substrate dried out completely. Substrate availability appeared to be the main limiting factor (Degens, 2012). Neither system used limestone as an additional source of alkalinity.

Compost derived from unsorted municipal solid waste (MSW) is a low-cost, relatively uniform and readily available organic substrate. Currently, Western Australia produces about 60,000 t of MSW-derived organics per year, for which markets are still under development. The suitability of this organic material for treating extremely acidic saline water has never been tested. This study evaluates the performance of a