



Trace metal mobilization from oil sands froth treatment thickened tailings exhibiting acid rock drainage



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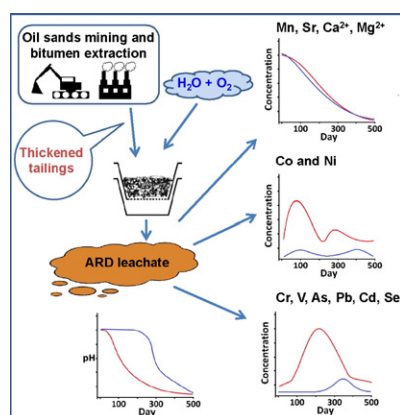
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HIGHLIGHTS

- First report on toxic metal release in drainage from oil sands thickened tailings
- Oxidation of pyrite in the tailings produces acidic leachate.
- Higher concentrations of toxic metals were observed in the leachate.
- The results have significant implications for effective management of tailings.

GRAPHICAL ABSTRACT



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ABSTRACT

Froth treatment thickened tailings (TT) are a waste product of bitumen extraction from surface-mined oil sands ores. When incubated in a laboratory under simulated moist oxic environmental conditions for ~450 d, two different types of TT (TT1 and TT2) exhibited the potential to generate acid rock drainage (ARD) by producing acid leachate after 250 and 50 d, respectively. We report here the release of toxic metals from TT via ARD, which could pose an environmental threat if oil sands TT deposits are not properly managed. Trace metal concentrations in leachate samples collected periodically revealed that Mn and Sr were released immediately even before the onset of ARD. Spikes in Co and Ni concentrations were observed both pre-ARD and during active ARD, particularly in TT1. For most elements measured (Fe, Cr, V, As, Cu, Pb, Zn, Cd, and Se), leaching was associated with ARD production. Though equivalent acidification (pH 2) was achieved in leachate from both TT types, greater metal release was observed from TT2 where concentrations reached 10,000 ppb for Ni, 5000 ppb for Co, 3000 ppb for As, 2000 ppb for V, and 1000 ppb for Cr. Generally, metal concentrations decreased in leachate with time during ARD and became negligible by the end of incubation (~450 d) despite appreciable metals remaining in the leached TT. These results suggest that using TT for land reclamation purposes or surface deposition for volume reduction may unfavorably impact the environment, and warrants application of appropriate strategies for management of pyrite-enriched oil sands tailings streams.

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1. Introduction

Surface mining of oil sands ores in northern Alberta, Canada generates ~1 million m³ of fluid fine tailings per day (Alberta Environment and Sustainable Resource Development, 2013) from bitumen extraction using a modified hot-water method (Schramm, et al., 2000). Oil sands tailings are an aqueous suspension of sand, silt, clay, unextracted bitumen (~5 wt%) and unrecovered solvent (<1 wt%) used in bitumen extraction. This waste slurry, which must be retained on-site, is deposited in enormous tailings ponds that currently occupy a surface area of 220 km² containing ~1 billion m³ of fluid fine tailings (<http://osip.alberta.ca/map/>) that consolidate very slowly, requiring decades to achieve a trafficable consistence. To manage the growing inventory of fluid fine tailings, the Alberta Energy Regulator issued Directive 074 (ERCB, 2009) requiring oil sands mine operators to reduce tailings volumes and increase their shear strength to accelerate effective reclamation.

The slow settling of fluid fine tailings retained in these anaerobic ponds hinders porewater recovery for recycling in the extraction process and consolidation for effective management and reclamation of tailings. The increasing footprint of stored tailings is compelling oil sands companies to seek different technologies to de-water and consolidate tailings. One such approach is production of thickened tailings (TT) in which fluid fine tailings are mixed with synthetic polymers such as polyacrylamide to flocculate the fine clays, followed by deposition in multiple thin layers on gentle slopes to enable de-watering by evaporative drying and collection of runoff ([http://www.suncor.com/BGC_Engineering_Inc., 2010](http://www.suncor.com/BGC_Engineering_Inc.,_2010)). This process can dramatically decrease the volume of fluid fine tailings stored in tailing ponds but it exposes TT to atmospheric oxygen (O₂) and natural precipitation (water). Among the various oil sands tailings streams that comprise different proportions of sand, silt, clay and unrecovered hydrocarbons, 'froth flotation tailings' contain significant proportions of sulfide minerals like pyrite (Kaminsky, et al., 2009) that would be particularly prone to generation of acid rock drainage (ARD) when exposed to O₂ during surface deposition with evaporative drying.

Along with acidification, the release of toxic metals during ARD is a serious environmental problem in other mining operations (Wei and Wolfe, 2013), as low pH increases the solubility of major minerals (Brantley, 2008) and potentially releases metals and metalloids in leachates. The composition of trace metals and the rate of their release depend on the ore's initial mineralogical composition and drainage conditions (amount of precipitation, flow rate, availability of oxygen), but ARD containing elevated concentrations of toxic metals poses risks to the environment (Johnson, 2003; Johnson and Hallberg, 2005) by threatening surface and ground water quality (Ahn, et al., 2005; Hazen, et al., 2002). Production of ARD may continue for many years (Oliás, et al., 2012), or may be mitigated by other minerals in the ores, as the balance between acid-producing processes (oxidation of sulfide minerals) and acid-neutralization processes (dissolution of carbonates and weathering of silicates) may prevent or delay ARD and release of metals from the ores (Johnson and Hallberg, 2005).

We previously demonstrated the potential for ARD generation by froth flotation TT incubated under simulated oxic environmental conditions in a laboratory (Kuznetsov et al., 2015). Two different TT samples were collected from an industry pilot-scale field trial of surface deposition with evaporative drying, and incubated in a long-term (~450 d) kinetic experiment (Kuznetsov, et al., 2015). The samples tested differed in pyrite and carbonate contents and were either pre-treated or not treated with polyacrylamide as a flocculant. Both TT samples produced ARD after 50–250 d, depending on their pyrite and carbonate contents (Kuznetsov, et al., 2015). To complement that study, here we further examined the effects of ARD on oil sands TT dissolution by measuring the types and concentrations of metals in leachates produced from that kinetic laboratory experiment. The aims of this study were to demonstrate the potential for metal and metalloid release from TT during

ARD under laboratory conditions and determine the patterns of release onset for individual metals of concern. The results will help oil sands tailings pond managers to evaluate the risks of subjecting TT to surface reclamation technologies, and to develop strategies for effective management of pyrite-enriched oil sands tailings streams during reclamation operations.

2. Materials and methods

2.1. Experimental approach

A laboratory experiment conducted previously (Kuznetsov et al., 2015) investigated the ARD potential of oil sands froth flotation thickened tailings (TT) that were sampled from a field trial established in the Athabasca region of northern Alberta to test evaporative drying of TT. A complete description of the laboratory experimental design, geochemical properties of TT used in the experiment and results about the occurrence of ARD, chemical changes/transformation in liquid and solid phases and enrichment of pyrite oxidizing bacteria during ARD have been reported previously (Kuznetsov, et al., 2015). Briefly, two different types of TT were used in this experiment: the two samples had different mineral contents; furthermore, one had been treated with polyacrylamide as a flocculant (TT2) prior to deposition in the field trial, and the other was untreated (TT1). A kinetic experiment was performed in duplicate polypropylene trays containing TT1 or TT2 (1.5–2 kg wet weight) to determine acid generation and metal leaching from TT under aerobic conditions provided by mechanical air flow (~19 L s⁻¹) and moist conditions provided by regular irrigation (Fig. A1). The bottom of each tray was perforated and placed into a second tray fitted with two ports: one for vacuum application and the other for leachate collection. A layer of glass wool was used to prevent loss of tailings sediments during irrigation. The trays were irrigated by misting from a hand spray pump twice per week (total 750 mL) to simulate rainfall, the volume of which was determined using records of annual precipitation for the Athabasca region (<http://www3.gov.ab.ca>) and surface area of the tailings in the irrigation trays. One of the trays containing TT1 was irrigated with distilled water (DW) and hence designated TT1-DW. The other tray containing TT1 (designated TT1-AR) was irrigated with 'artificial rainwater' (AR) (pH 5.5) having an ionic composition typical of rain precipitation in the Athabasca region (Table A1 in Kuznetsov, et al., 2015). This was done to determine if any significant difference in ARD production resulted from the composition of the irrigation water. Duplicate trays of sample TT2 were irrigated with distilled water (DW) (pH 7) and designated TT2-DW1 and TT2-DW2. Leachates from TT were collected weekly for measurement of pH, redox potential (Eh), electrical conductivity (EC), major soluble cations and anions, and trace metals. The results of pH and Eh are presented in Fig. A2.

2.2. Soluble cations, anions, and trace metals in the leachates from thickened tailings

Leachate samples collected weekly were filtered (PTFE 0.45 µm pore size filter, Fisher Scientific #033911C) and sub-samples for soluble cations and anions were analyzed in a day or two; acidified samples for metal(oid)s were stored at 4 °C for 1–4 weeks before analysis. Concentrations of soluble cations [calcium (Ca²⁺), magnesium (Mg²⁺), sodium (Na⁺) and potassium (K⁺)] were measured in the collected leachates using an atomic absorption spectrometer (AAS, SpectrAA 880) with hollow cathode lamps at specific wavelength (Ca at 422.7 nm, Mg at 285.2 nm, Na at 589.0 nm, K at 766.5 nm) with appropriate internal and external standards. Concentrations of soluble anions [chloride (Cl⁻), nitrate (NO₃⁻) and sulfate (SO₄²⁻)] were measured using an ion chromatograph (Dionex DX 600) equipped with a 4 mm analytical column (AS9-HC). Dissolved bicarbonates (HCO₃⁻) were determined using the methyl orange indicator method

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