Minerals Engineering xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Use of acid mine drainage treatment sludge by combination with a natural soil as an oxygen barrier cover for mine waste reclamation: Laboratory column tests and intermediate scale field tests

Isabelle Demers [a,*], Mamert Mbonimpa [a], Mostafa Benzaazoua [a], Médard Bouda [b], Sylvette Awoh [a], Sylvain Lortie [c], Mario Gagnon [d]

[a] Research Institute in Mines and Environment, Université du Québec en Abitibi-Témiscamingue, 445 boul. de l'Université, Rouyn-Noranda, Quebec J9X 5E4, Canada
[b] Research Institute in Mines and Environment, Rouyn-Noranda, Quebec, Canada[1]
[c] IamGold, Westwood Mine, Rouyn-Noranda, Quebec, Canada
[d] IamGold Essakane SA, Ouagadougou, Burkina Faso[1]

ARTICLE INFO

Article history:
Received 27 July 2016
Revised 29 November 2016
Accepted 30 November 2016
Available online xxxx

Keywords:
Acid mine drainage
Sludge
Soil covers
Mine site reclamation
Oxygen barrier
Column tests
Intermediate field tests

ABSTRACT

Acid mine drainage (AMD) is often treated using active lime treatment, which generates a significant amount of sludge that contains mainly metal hydroxide precipitates, calcium sulfate, and unreacted lime. Previous work showed that sludge may have interesting geotechnical and geochemical properties to be used, in combination with a silty soil, as a part of covers (oxygen barriers) to prevent AMD generation from waste rock and tailings impoundments. The reuse of sludge can reduce the volume of natural soil required for site reclamation. Mixtures of sludge and a natural silty soil were tested in the laboratory (for over 500 days) and in field experiments (4 years) as an oxygen barrier cover placed over acid-generating tailings and waste rock. Data from the testwork include monitoring of leachate geochemical parameters (e.g. pH, conductivity, metal and sulfate content) and hydrogeological parameters (water content, suction, effluent flowrate). Results indicate that soil-sludge mixture is an efficient oxygen barrier.

1. Introduction

Mining operations generate large volumes of liquid and solid waste that must be managed properly to reduce environmental risk. Mine tailings, the residue from mineral processing, are generally deposited as slurry in large impoundments, or tailings storage facilities. Waste rock, barren material from mine excavation, is usually placed in piles that can reach several tens of metres in height. When tailings and waste rock contain sulfidic minerals, acid mine drainage (AMD) may be produced and contaminate the surrounding environment. AMD arises when sulfide minerals are in contact with water and atmospheric oxygen; sulfides oxidize and produce an acidic and metal-laden effluent. AMD is often treated by lime neutralisation, by which a clean effluent and sludge are produced (Skousen and Faulkner, 1996; Brown et al., 2002; Younger et al., 2002). The clean effluent can be released into the receiving environment, whereas the sludge must be stored on site. Mining companies are encouraged to valorise their solid waste to reduce the final volume that will remain in storage areas. Lime treatment sludge, being highly alkaline and fined-grained, has potential usage as a replacement for natural soil for reclamation purposes, and as a substrate for plant growth.

Indeed, the gold producer IAMGOLD (located in Abitibi, Québec, Canada) seeks to valorise its sludge that has been produced several years ago and placed into sludge ponds, for an estimated volume of nearly 1 million cubic meters. In the years after deposition, vegetation naturally implanted itself on the sludge ponds. Shrubs and even trees now grow on the sludge (Smirnova et al., 2013); this impressive vegetation inspired the company to investigate the potential use of sludge as part of the reclamation scenarios for its tailings and waste rock storage facilities.

1.1. Literature review

Sludge is produced by the chemical neutralisation of AMD with an alkaline agent, generally lime ($Ca(OH)_2$), quicklime (CaO) or limestone. Metal ions present in AMD can be precipitated as hydroxides, depending on the process pH. To reach regulatory

---

* Corresponding author.
E-mail address: Isabelle.demers@uqat.ca (I. Demers).
[1] Formerly.

http://dx.doi.org/10.1016/j.mineng.2016.11.017
0892-6875/© 2016 Elsevier Ltd. All rights reserved.

Please cite this article in press as: Demers, I., et al. Use of acid mine drainage treatment sludge by combination with a natural soil as an oxygen barrier cover for mine waste reclamation: Laboratory column tests and intermediate scale field tests. Miner. Eng. (2016), http://dx.doi.org/10.1016/j.mineng.2016.11.017

effluent quality, many AMD treatment plants operate at pH above 10.5, which promotes precipitation of Fe-, Cu-, Ni-hydroxides, among others. The precipitated sludge also comprises calcium sulfate (gypsum) and unreacted lime, which imparts high alkalinity (Zinck et al., 1997). Due to the short process residence time, most precipitates remain amorphous since they do not have enough time to crystallize. Sludge can be managed in different ways, several options were reviewed by Zinck (2005, 2006), Zinck et al. (2010), and Zinck and Griffith (2012, 2013). In mining operations, sludge is often deposited in specific ponds, or with tailings in tailings ponds. Other options were identified, such as sludge covers over tailings, sludge disposal in mine workings and pits, placement under a water cover, and use of sludge in cemented mine backfill. However, Zinck et al. (2010) reported that sludge cover over tailings cannot effectively prevent AMD formation from the tailings because the sludge layer can dry and crack and its alkalinity may not be sufficient to neutralize acidity and prevent metal mobilisation.

Demers et al. (2015a,b) designed experiments to evaluate the potential use of sludge mixed with tailings and waste rock as a material in mine site reclamation. Laboratory column tests and intermediate scale field tests were performed to evaluate the performance of sludge-tailings mixtures placed over acid-generating tailings, and of sludge waste-rock mixtures placed over acid-generating waste rock. An optimized sludge-tailings mixture was identified as a suitable cover material to limit oxygen transport by retaining a high degree of saturation and thereby reduced sulfide mineral oxidation. Geochemical analyses of the leachate confirmed the cover performance. The sludge-waste rock mixture was not effective as a cover to limit oxygen transport, but was able to temporarily reduce the contaminant load in the waste rock leachate. Also, the experiments highlighted that sludge is likely to dissolve when exposed to acidic conditions. Two sludge valorisation options were determined from that study; (1) reduction of metal loads from waste rock pile to regulate the feed to a water treatment plant, by deposition of sludge over waste rock; (2) mixtures of sludge and tailings, with or without cement, can become a component of a reclamation scenario to limit oxygen transport.

Mbonimpa et al. (2016) showed that soil-sludge mixtures possess appropriate geotechnical properties to be used in oxygen barrier covers and provided tools to estimate to which extent the quantity of borrow natural material required for covers can be reduced using appropriate soil-sludge mixtures.

The objective of this paper is to investigate the valorisation of sludge in mine site reclamation, particularly as a replacement of a portion of natural soil used for cover systems, by kinetic tests performed at the laboratory and intermediate field scales. Since soil-sludge mixtures have demonstrated their adequate geotechnical characteristics, the mixtures need to be tested in a reclamation scenario to evaluate the conditions in which they are the most effective as oxygen barriers.

2. Materials and methods

2.1. Sampling and characterization

All materials were collected from the Doyon-Westwood mine site (IAMGOLD). Tailings, waste rock and silty soil were sampled by IAMGOLD personnel and transported to the laboratory for homogenisation and characterization. Sludge was sampled through a sampling campaign designed to evaluate sludge variability over the two sludge ponds of the Doyon-Westwood mine site. Details of the sampling campaign are available in Demers et al. (2015b). Sludge water contents typically ranged from 100 (w/w) to 300%. A representative composite sludge sample was produced and used for all laboratory and field tests.

Mixtures of soil and sludge were prepared according to the procedure described in Mbonimpa et al. (2016). Several mixtures were prepared, with different proportions of soil and sludge, to determine the optimal mixture in terms of hydrogeotechnical properties. Results are presented in Mbonimpa et al. (2016). For the present study, mixtures of 25% by weight sludge and 75% by weight soil were used. In the laboratory, the wet sludge (initial water content 200% w/w) and soil (initial water content 12.5% w/w) were thoroughly mixed in a stand mixer until homogenized. The materials were not dried before mixing because sludge becomes very stiff when dry, which prevents homogeneous mixing.

The materials were characterized in the laboratory to obtain various parameters. Specific gravity (G_s) was evaluated for sludge, waste rock, tailings, and sludge-soil mixtures using a Micromeritics Accupyc 1330 helium pycnometer, according to ASTM D-550-06. Particle size distribution was obtained through wet and dry screening and laser particle size analyzer (Malvern Mastersizer) for sludge and tailings. Air-entry values were determined from the water retention curves evaluated for tailings, soil and sludge-soil mixtures using pressure plate extractor (Bouda et al., 2012). The chemical composition of sludge, waste rock and tailings was obtained by digestion in HNO_3/HCl/HF/Br followed by ICP-MS analyses. Acid generation potential was evaluated by the acid-base accounting procedure by Sobek modified by Lawrence and Scheske (1997), for sludge, waste rock and tailings samples. Mineralogical composition of the major crystallized phases was obtained through X-ray diffraction for sludge, tailings and waste rock, and quantified by the Rietveld method with the software TOPAS (Rietveld, 1993).

2.2. Laboratory column test procedure

Performance of cover systems to prevent AMD generation is often evaluated through laboratory column tests (e.g. Bellaloui et al., 1999; Yanful et al., 1999; Demers et al., 2008), in which the field configuration is replicated as a one-dimensional soil column. Instrumentation allows evaluating water and gas distribution in the unsaturated materials, as well as monitoring of the effluent quality. Six laboratory columns were installed for the present study: two columns representing a sludge-soil mixture cover placed over tailings, two columns representing a sludge-soil mixture cover over waste rock, and two control columns (uncovered tailings and uncovered waste rock). Fig. 1 shows a schematic view of the columns. The three columns with waste rock were made of a 35-cm diameter black PVC cylinder, while the other three columns, with tailings, were made of 15-cm diameter translucent PVC. All columns were first filled with 35 cm of waste rock or tailings (porosity of approximately 0.5). Then, the sludge-soil mixture was placed as a 35 cm layer for two columns (one waste rock and one tailings), and as a 20 cm layer for the other two columns (porosity of 0.5).

Effluent water quality was evaluated monthly following water input to the top of the columns. For waste rock columns, deionized water was added until all materials were flooded, whereas for tailings columns, 2 L of deionized water were added (representing the monthly rainfall for rainy months in the Abitibi region, west of Quebec). After 4 h of contact time, the valve at the bottom of the columns was opened and water was allowed to drain. The effluent was analyzed for pH, Eh, conductivity by probe readings, acidity and alkalinity by titration, and metal content by ICP-AES (Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Pb, Stotal, Sb, Se, Si, Ti, Zn). The columns were then left with their top exposed to the atmosphere for four weeks before beginning a new leaching

Please cite this article in press as: Demers, I., et al. Use of acid mine drainage treatment sludge by combination with a natural soil as an oxygen barrier cover for mine waste reclamation: Laboratory column tests and intermediate scale field tests. Miner. Eng. (2016), http://dx.doi.org/10.1016/j.mineng.2016.11.017