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Long-term evaluation of coal fly ash and mine tailings co-placement: A site-specific study

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ABSTRACT

This study presents the results of a laboratory investigation conducted to evaluate the efficiency of coal fly ash to control the formation of acid mine drainage (AMD) from mine waste. Site-specific materials, coal fly ash from Atikokan Thermal Generating Station and mine tailings from Musselwhite mine, were mixed at different proportions for the investigation of the drainage chemistry and the optimal mix using static testing (acid–base accounting) and kinetic (column) testing. The acid–base accounting (ABA) results indicated that the fly ash possessed strong alkaline (neutralization) potential (NP) and could be used in the management of reactive mine tailings, thus ensuring prevention of AMD in the long-term. Column tests conducted in the laboratory to further investigate long-term performance of fly ash in the neutralization and prevention of acid mine drainage from tailings similarly showed that mixing fly ash with mine tailings reduces dissolution of many heavy metals from tailings by providing alkalinity to the system. It was found that a fly ash to tailings mass ratio equal to or greater than 15% can effectively prevent AMD generation from Musselwhite mine tailings in the co-placement approach.

1. Introduction

Understanding the physico-chemical properties of mine wastes and predicting their long-term leaching behavior are critical for assessing the long-term environmental impact of mining at a site and for choosing a waste management method to minimize that impact (Benzaazoua et al., 2004; Ritcey, 1989). Given that mineralogy and other factors affecting acid mine drainage (AMD) formation are highly variable from site to site, predicting the potential for AMD can be exceedingly challenging and costly (U.S. EPA, 1994). Static and kinetic tests have been developed and are used on a regular basis, primarily to establish if and when a given material will generate acid. Static tests are designed to determine the overall balance between acid generating and acid neutralizing minerals, and the results provide a preliminary indication of whether a sample is likely to produce acidic drainage in the environment (Sobek et al., 1978; Price et al., 1997). Acid–base accounting (ABA) is the most commonly used static test to predict acid mine drainage from mine wastes. The acid–base accounting evaluates the balance between acid generation processes (oxidation of sulfide minerals) and acid neutralizing processes (dissolution of alkaline carbonates, displacement of exchangeable bases, and weathering of silicates) (Sobek et al., 1978; Ritcey, 1989). Static tests are fast and cost-effective, but are considered qualitative and have a relatively large uncertainty zone for which it is impossible to state on the long-term acid generation potential (Morin and Hutt, 1994).

Kinetic tests involve weathering of samples under laboratory or on-site conditions, in order to potentially generate net acidity, to determine the rate of acid formation, sulphide oxidation, neutralization, metal dissolution, and to test control and treatment techniques (Campbell et al., 2001). Humidity cells and column tests are the most commonly used kinetic tests. It is generally accepted that leaching column tests tend to simulate actual field conditions more closely than humidity cells (Bradham and Caruccio, 1990). However, achieving the desired observation takes months and may be years (MEND, 1989). Due to the complexity of the physical, chemical and biological processes involved in producing and neutralizing AMD, no individual test (static or kinetic) alone has proven completely adequate, and a combination of static and kinetic methods is usually relied upon to increase prediction accuracy (Filipek et al., 1999; Schafer, 2000).

Various techniques have been developed to prevent AMD formation. One of such techniques is the addition of alkaline materials, by either mixing with the acid generating mine waste or concentrated placement, to inhibit acid formation and to neutralize

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any generated acidity in situ. Various alkaline materials such as limestone, lime, sodium bicarbonate, red mud, and lime kiln dust have been used to control acid mine formation from mine wastes. According to Mylona et al. (2000), limestone (a commonly used alkaline material) may control pyrite oxidation through one or a combination of the following mechanisms: (i) raising the pH of pore water to high values ($pH = 6.1–8.4$), thus impairing the activity of the iron oxidizing bacteria *Thiobacillus ferrooxidans* (Nicholson et al., 1988); (ii) enhancing the precipitation of ferric iron in the hydroxide form, thus inhibiting further participation as an oxidizing agent in the dissolution of pyrites (Kelley and Tuovinen, 1988); (iii) enhancing the precipitation of oxidized compounds on the sulphides surface. It is reported that when carbonate minerals are present and available to neutralize the acid produced during the oxidation of pyrite, a protective ferric oxy-hydroxide layer will accumulate around the pyrite grains, impairing its further dissolution (Nicholson et al., 1990); and (iv) enhancing the formation of cemented layers (hardpan) on the stockpile surface. The hardpan consists of the oxidation–neutralization products such as ferric oxy-hydroxide and gypsum that cement the tailings together forming a low permeability mass that acts as an oxygen and water diffusion barrier (Blowes et al., 1991; Tasse et al., 1997).

Fly ash has been mixed with mine tailings to control mine tailings oxidation due to its alkaline nature. Ciccu et al. (2003) evaluated the use of fly ash, red mud and bauxite ores for immobilizing metallic and metalloid elements contained in severely contaminated soil samples taken from a tailings pond. Addition of fly ash or red mud, or a combination of the two, to contaminated soils drastically reduced the heavy metal concentrations from effluents, as observed from results of columns containing the mixtures of the additives and the contaminated soil. Studies have also been conducted into the use of fly ash in conjunction with lime for preventing the formation of acidity in sulphidic soils (Golab et al., 2006; Indraratna et al., 2006). Perez-Lopez et al. (2007a,b) similarly showed that addition of fly ash to a mining residue from the Iberian Pyrite Belt resulted in acid neutralization, metal retention in neoformed precipitates, and therefore, the improvement of the quality of the leachates. Under these conditions, Fe-precipitation formed a coating on pyrite surfaces (microencapsulation technology) that may prevent interaction between oxidizing agents and pyrite grains, thus halting pyrite oxidation and AMD production (Pérez-López et al., 2007c). The research conducted by Bayat (1998) also indicated that coal fly ash has potential applications in mine tailings management in view of its chemical and mineralogical properties making the ash a good alkaline binding agent and a possible substitute for gypsum, anhydrite, lime or limestone.

Economic and environmental considerations play a major role in the rapid increase for usages of by-products such as fly ash for various environmental applications such as mine waste management (Yeheyis et al., 2008). Utilization of fly ash reduces disposal costs while actually increasing revenues through the sale of fly ash. The main cost component of coal fly ash is transportation. Moreover, utilization of fly ash for mine waste management can reduce green house gas emission by replacing other alkaline materials such as cement/lime which normally contribute CO_2 during their production.

In this study, the effectiveness of mixing coal fly ash (alkaline producing material) with mine tailings (acid producing material) to mitigate acid mine drainage was evaluated. The study had three specific objectives; namely, first, to characterize the Musselwhite mine tailings and its acid generation potential; second, to examine whether mixing coal fly ash with mine tailings would affect the overall net neutralization potential, and to determine the optimum fly ash–tailings mixture using static test (acid–base accounting); and third, to evaluate the long-term performance of the fly ash in the neutralization and prevention of acid mine drainage using column testing.

2. Materials and experimental methods

2.1. Materials

This study is a site-specific study carried out to assess the suitability of utilizing Atikokan coal fly ash in the management of reactive Musselwhite mine tailings. Atikokan coal fly ash (AFA) is collected directly from the Atikokan Thermal Power Generating Station (Atikokan TPGS) precipitators, which is a lignite coal-fired 200 MW generating facility, located in northwestern Ontario. Musselwhite mine tailings (MT) is obtained from the Musselwhite Mine; a gold mine located 400 km North of Atikokan TPGS. At present, 4000 tonnes of tailings are produced daily and it is projected that more than 20 million tonnes of tailings would be produced by 2012. Currently much of the tailings are disposed under water in a nearby tailings pond. The capacity of the basin under water cover is 13 million tonnes, which means alternative methods for tailings disposal must be implemented for the remaining tailings that will be produced. Co-disposal of the remaining mine tailings with coal fly ash from Atikokan was investigated in this study as one of the alternatives for the on-land disposal of the mine tailings.

2.2. Experimental methods

2.2.1. Bulk geochemical and mineralogical compositions

The bulk composition and mineralogy of mine tailings and fly ash materials were studied since both are important in predicting long-term performance during co-placement. The chemical composition (major oxides and trace elements) of AFA and MT samples was determined using X-ray florescence spectrometry (XRF), and inductively coupled plasma atomic emission spectrometry (ICP-AES). X-ray diffraction (XRD) spectra of the powder mounts of the AFA and MT were obtained by using a Rigaku powder diffractometer, equipped with a rotating anode and a Co-Kα source, operated at 160 mA and 45 kV. The samples were scanned from 2° to 82° 2θ at a rate of 10^{o} 2θ/min and a step size of 0.02^{o} 2θ.

2.2.2. Geochemical static test (acid–base accounting method)

The acid–base accounting method is conducted on mine tailings and mine tailings–fly ash mixtures to evaluate the effect of coal fly ash on the net neutralization potential of the mixtures, as well as to determine how much coal fly ash is needed to neutralize all of the acid that could potentially be produced from the mine tailings. The procedure used involves a laboratory static test that measures the acid producing potential (AP) and the inherent neutralization potential (NP) of a sample. Mixtures of mine tailings and coal fly ash were prepared, which contained 0, 2.5, 5, 7.5, 10, 12.5, 15, 20, 30, 40 and 50% dry coal fly ash (w/w). The AP of each sample was determined by multiplying the percent of sulphide sulfur (%S) in the sample by a conversion factor ($AP = 31.25 \times \%S$), assuming 1%S requires approximately 31.25 kg of $CaCO_3$ per tonne of material for neutralization (Sobek et al., 1978). The sulphide sulfur in coal fly ash was also assumed to contribute to acid formation and it is included during the calculation of AP of the fly ash–tailings mixtures.

The neutralization potential (NP) of each sample was determined by using the modified Sobek method (Lawrence and Wang, 1997). The NP was determined first by giving each sample a fizz rating (none, slight, moderate, or strong) in order to determine the amount and concentration of acid required to be used in the test. Each sample was then reacted with a known and standardized