



Effectiveness of alkaline amendments in acid mine drainage remediation



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HIGHLIGHTS

- Effectiveness of alkalization for acid mine drainage neutralization.
- Calcium carbonate, calcium oxides and hydroxides is attractive in the remediation of acid mine tailing.
- Effective long term alkalization of acid mine drainage.
- Alkalinization as a promising agent for environmental protection.

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ABSTRACT

Acid mine drainage (AMD) generated from pyrite oxidation in sulfide mine tailings is a major geoenvironmental problem. This AMD is characterized by $\text{pH} < 3.5$ and high concentration of trace elements. Thus, liming is a prerequisite for sustainable stabilization and neutralization of acid-producing sulfide mine tailings. The use of agri-food waste and industrial by-products rich calcium carbonate or calcium oxides and hydroxides becomes attractive as an alternative limestone in the remediation of acid mine tailing impoundments. Addition effect of five different types of alkaline amendments into sulfide mine tailing (SMT) was studied. Two series of laboratory experiments were conducted on SMT to evaluate the use of chicken eggshell residue (CES) alone or in combination with neutralizing agents to neutralize acidity and prevent mobilization of trace elements in SMT. This study showed that tailing samples amended with cement or magnesium oxide are more highly buffered and resistant against anthropogenic re-acidification than tailing samples amended with CES, CAL or DOL. Materials rich in oxides, hydroxides and carbonates mixed with eggshells may confer to SMT long-term protection against acid atmospheric deposition or re-acidification of limed SMT. These results may have practical implications in tailing management for the reduction of acid generation and trace metal mobility in sulfide mine drainage system and of water contamination risk.

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1. Introduction

The importance of calcareous materials in supplying carbonates and calcium (Ca) ions to neutralize acidity, and contributing to buffer capacity of geological media (soil, mine tailing) is well recognized. Carbonate anion is a fairly strong base and plays a key role in the pH-buffering of either natural ecosystem (Calvet, 2013; Stumm and Morgan, 1996). Several studies of acid sulfate soils containing pyrite demonstrated that Ca ion was the most important alkaline cation that reacted

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with acidity (Janjirawuttikul et al., 2011). In agricultural soils, Ca is the most important acid neutralizing element (Bates and Johnston, 1997). Buffering capacity is the ability of soils, surface water or seawater to resist rapid changes of pH when adding acid or base (Donahue et al., 1977; Stumm and Morgan, 1996). Precisely, the buffer capacity (BC) of soils refers to the impact that addition of either acid or alkaline material has on the soil pH (Hill, 2003).

In soil system, the amount of liming material required to neutralize soil acidity depends on the neutralizing value of the liming material and pH buffering capacity of the soil (Bolan et al., 2003). Various constituents such as carbonates of basic cations (CaCO_3 in calcareous soils), clay, namely phyllosilicates, organic matter, basic cation-containing aluminosilicates, and iron, aluminum and manganese oxides contribute to pH buffering of soils at different pH values (Barrow, 1969; Calvet, 2013; Donahue et al., 1977; Kim, 2000; McLean, 1982). Generally, soils with high clay and/or 2:1 type of clays (smectites, vermiculites, micas, and chlorites), organic matter (OM) or alkaline carbonate (AC) contents exhibit higher BC than those with low clay, OM and AC. Soils with high BC require a greater amount of lime to be added than a soil with a lower BC for the same incremental change in pH. Soil acidity is corrected by the application of liming materials (Edmeades and Ridley, 2003) such as limestone (CaCO_3), lime ($\text{Ca}(\text{OH})_2$), or dolomite ($\text{CaMg}(\text{CO}_3)_2$) (Bolan et al., 2003; Goulding and Annis, 1998) according to a common soil test (quick) method, namely lime requirement (LR). The LR of an acid soil is the amount of agricultural limestone or any other basic material, required to neutralize that fraction of the total acidity (McLean, 1982) that must be neutralized to attain a desired soil pH that is favorable for crop growth and optimum yield production (Donahue et al., 1977; McLean, 1982). Many chemical methods have been developed and successfully used worldwide to determine LR of acid soils (Van Lierop, 1990). Soil-buffer equilibration is the most commonly used method for acid mineral and organic soils in Quebec, Canada (Tran and Van Lierop, 1981; Van Lierop, 1990; Van Lierop and Tran, 1983; Ziadi and Tran, 2008). In the laboratory, LR of an acid soil is usually determined by adding certain weight of soil to specified volume of a buffer solution composed of para-nitrophenol, potassium chromate, calcium chloride dehydrate, calcium acetate, and triethanolamine adjusted to pH 7.5 (Shoemaker et al., 1961; Ziadi and Tran, 2008) and noting the reduction in pH of the buffer. From the initial pH of the soil and reduction of pH of the buffer solution, the lime requirement could be calculated using standard tables (Adams and Evans, 1962; Van Lierop, 1990; Ziadi and Tran, 2008).

Whether a mine tailing is acidic, neutral, or basic has much to do with the occurrence of minerals producing acidity and alkalinity, the solubility of various compounds, and the buffer capacity (BC) of the tailing which is controlled by the different buffering minerals in mine tailing (Dold, 2014). These factors will ultimately control the quality of coal mine drainage (Caruccio and Geidel, 1978; Jurjovec, 2002). Strong mineral acid (sulfuric acid) in the sulfide mine tailing is normally the result of oxidation and hydrolysis of sulfides (Tucker et al., 1987). Generally, tailings with low BC or acid-neutralizing minerals are more adversely affected by high acidity than tailings with high acid-neutralizing mineral contents. Controlling acid mine drainage (AMD) and neutralization of acid after its formation in tailing is feasible by applying either limestone (Ritcey, 1989) or acid-neutralizing materials (Nehdi and Tariq, 2007). Limestone has often been used in passive systems to neutralize acid mine drainage. A few examples of treated acid coal mine drainage with different types of passive systems using limestone drain (LD) are given in Bernier et al. (2002). A limestone drain typically comprises a trench filled with crushed limestone rocks surrounded by impervious materials. The main purpose of a LD is to generate bicarbonate alkalinity that will increase the pH of pore water emanating from mine tailings water pH_{T5} from acidic conditions to net neutral or alkaline water.

In mine waste system, the buffer capacity of tailings is a function of their mineralogical and chemical composition. Laboratory testing and numerical simulation model highlighted the importance of the infiltration rate, the oxygen diffusion rate, the location of acidity production, and the buffering capacity of the engineered cover and tailings material in assessing acidity and metals production from cover and tailings profile (Dobchuk et al., 2003). Acid-buffering minerals such as calcite, dolomite, carbonate or bicarbonate in tailings provide high buffering capacity resulting in rapid neutralization of pore and surface water (Ritcey, 1989; Wilkin, 2007). Jurjovec et al. (1995) found that the dissolution of $(\text{Ca}, \text{Mn}, \text{Mg}, \text{Fe})\text{CO}_3$, $\text{Al}(\text{OH})_3$, and aluminosilicate minerals controls the pH_{T5} of the mine effluent water. The results showed that the buffering capacity of unoxidized mill-tailings was consumed more rapidly when natrojarosite, an acid-producing reaction, was added to the tailings collected at the Kidd Creek metallurgical site, near Timmins, Ontario. In another study conducted in laboratory on the same tailings, Jurjovec et al. (2004) assessed the acid neutralization reactions in the absence of sulfide oxidation using a fully-saturated laboratory column experiment. The column was packed with fresh unoxidized tailings and 0.1 M sulfuric acid was passed through the column continuously. Based on mineralogical analysis, the authors concluded that the pH_{T5} of effluent water is buffered by a consistent series of minerals such as ankerite–dolomite, siderite, gibbsite and chlorite, present in the tailings. Caruccio and Geidel (1978) reported that calcium carbonate content of coals and strata containing pyrite has the potential of generating an alkaline, highly buffered, and potentially neutralizing drainage. A study of pH_{T5} buffering capacity of copper-mine tailing containing calcite (CaCO_3) amended with a peat-moss and shrimp wastes compost, De Coninck et al. (2008) have shown that calcite mineral collected from the tailing site exhibited much higher buffering capacity than compost, mine tailing and compost-amended tailing. They concluded that carbonate buffer system was the major factor controlling the ability of copper-mine tailing system to withstand a large change in pH_{T5} when acid was added. Unlike copper-mine tailing and carbonaceous tailings, pH_{T5} buffer capacity of sulfide mine tailings (SMT) is low because they lack natural alkalinity, and therefore cannot neutralize acid naturally (Ritcey, 1989).

A range of management practices has been proposed to enhance the pH_{T5} of acid SMT or to control and mitigate AMD. Liming material (agricultural limestone) has undoubtedly received most attention, but other options that have been suggested include the application of alternative Ca-containing compounds such as cement concrete, stabilized alkaline

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