

Removal of Cd²⁺, Cr³⁺, Cu²⁺, Hg²⁺, Pb²⁺ and Zn²⁺ cations and AsO₄³⁻ anions from aqueous solutions by mixed clay from Tundulu in Malawi and characterisation of the clay

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Abstract

Water and wastewater studies in Malawi have revealed very high levels of heavy metals in most streams and other water bodies particularly within urban areas. The metals are produced and released during industrial and agricultural activities, and also in vehicular emissions. These metals may pose serious threats to both human health and the environment. This study investigated the potential of mixed clay, obtained from the Tundulu area, in removing, Cd²⁺, Cr³⁺, Cu²⁺, Hg²⁺, Pb²⁺ and Zn²⁺ cations and AsO₄³⁻ anions from aqueous solutions using batch equilibrium technique. Qualitative mineralogical characterisation of the clay revealed that the clay contains illite, distorted kaolinite, mixed layer minerals and non-clay mineral carbonate fluoroapatite. pH_{pzc} for the raw clay, as determined by potentiometric titrations, was 9.66 while pH_{pzc} of pretreated clay was 9.63. Pretreatment of the clay involved removal of carbonates, iron oxides and organic matter. Initial total metal concentrations ranged from 3 to 5 mg/l. pH metal sorption dependence of the clay revealed Cr³⁺ removal from pH of 3 to complete removal at pH 5 with over 90% of the removal attributable to adsorption on the clay while the remaining 10% attributable to both adsorption and Cr(OH)₃ precipitation. Zn²⁺ complete removal occurred at pH above 7 with 92% attributable to adsorption while the rest could be from both adsorption and hydroxide precipitation. Cu²⁺ was removed from pH 4 and completely above pH 6.8 with 50% due to adsorption. Cd²⁺ removal was between pH of 6 and 9 with 85% due to adsorption to the clay. Lead was completely removed at pH greater than 7.67. Removal of Hg²⁺ at total Hg²⁺ concentration of 0.023 mM was pH independent fluctuating between 30 and 60%. No effective removal of AsO₄³⁻ anion was observed.

Keywords: heavy metals, illite, kaolinite, mixed layer minerals, carbonate fluoroapatite, pH_{pzc}

Introduction

Heavy metal water pollution is an area of major concern today in both developed and developing countries. Heavy metals occur naturally in soils, and they are widely used in industry especially in electronics and the rapidly growing information technology sector. Common anthropogenic sources include agricultural activities, atmospheric deposition, road run off, discharges from industrial plants and sewage works, acidic mine effluents and building of reservoirs. Agricultural activities provide important non-point sources of heavy metal pollutants such as cadmium, lead, and iron from phosphatic fertilisers. Phosphatic fertilisers, for example, are the most ubiquitous source of cadmium contamination because the rock phosphates used for the manufacture of fertilisers have relatively high concentrations of cadmium (Alloway, 1995; Harrison, 1996). The presence of high levels of these metals in the environment may cause long-term health risks to humans and ecosystems. It is therefore mandatory that their levels in drinking water, wastewater, and water used for agricultural and recreational purposes must be reduced to within the maximum allowable concentrations recommended by national and international health authorities such as the World Health Organisation (WHO, 2004).

Studies in Malawi have revealed high levels of particular heavy metals in several streams and soils in different areas of the country (Saka and Ambali, 1999; Lakudzala et al., 1999; Masamba and Chimbalanga, 2001; Kadewa, 2002). A recent quality inventory compilation of Blantyre streams (Limbe, Nasolo, and Mudi) and wastewater treatment plants (Limbe and Soche) reported levels of lead from 0.027 to 0.118 mg/l, cadmium from 0.002 to 0.015 mg/l, zinc from 0.166 to 0.630 mg/l, chromium from 0.028 to 0.479 mg/l, iron from 0.761 to 7.280 mg/l and copper from 0.006 to 0.046 mg/l (Sajidu et al., 2005). The concentrations at some sampling points were substantially higher than the World Health Organisation (WHO, 2004) maximum allowable limits for drinking water, which are 0.01, 0.003 and 0.05 mg/l please for lead, cadmium and chromium respectively.

Many processes for the removal of heavy metals from water and wastewater have been investigated. Chemical precipitation, physical treatment such as ion exchange, solvent extraction and adsorption are amongst the conventional methods for the removal of heavy metals. However, these methods are unsustainable in developing countries due to high maintenance costs and chemical importation with scarce convertible foreign currency and the general dwindling revenue base of water treatment companies or urban authorities. Recently, natural materials, which are good sorbents and inexpensive have received much attention in sorption of heavy metals from contaminated solutions. Their use would be a viable replacement or supplement to these chemicals.

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