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Utilization of phosphorus loaded alkaline residue to immobilize lead in a shooting range soil

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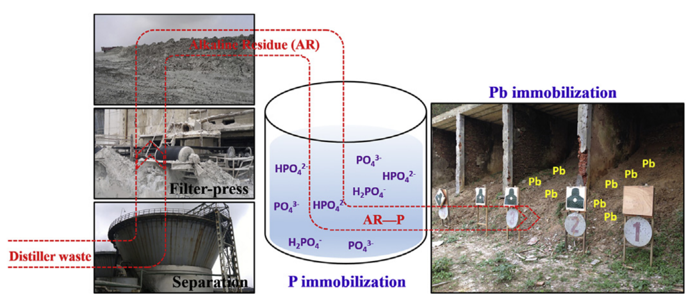
HIGHLIGHTS

- Alkaline residue collected from phosphorus adsorption process was further reused to immobilize Pb in a small shooting range soil.
- Phosphorus loaded alkaline residue significantly reduced leachability, bioaccessibility, and phytoavailability of Pb in studied soil.
- Phosphorus loaded alkaline residue mildly released P as a nutrient in treated soil.
- Phosphorus loaded alkaline residue can be considered as a low cost and efficient amendment for the remediation of Pb contaminated soils.

GRAPHICAL ABSTRACT



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ABSTRACT

The alkaline residue generated from the production of soda ash using the ammonia-soda method has been successfully used in removing phosphorus (P) from aqueous solution. But the accumulation of P-containing solid after P removal is an undesirable menace to the environment. To achieve the goal of recycling, this study explored the feasibility of reusing the P loaded alkaline residue as an amendment for immobilization of lead (Pb) in a shooting range soil. The main crystalline phase and micromorphology of amendments were determined using X-ray diffraction (XRD) and scanning electron microscopy-electron dispersion spectroscopy (SEM-EDS) methods. The toxicity characteristic leaching procedure (TCLP), sequential extraction procedure, and physiologically based extraction test (PBET) were employed to evaluate the effectiveness of Pb immobilization in soil after 45 d incubation. Treatment with P loaded alkaline residue was significantly effective in reducing the TCLP and PBET extractable Pb concentrations in contrast to the untreated soil. Moreover, a positive change in the distribution of Pb fractions was observed in the treated soil, i.e., more than 60% of soil-Pb was transformed to the residual fraction compared to the original soil. On the other hand, P loaded amendments also resulted in a drastic

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Shooting range soil
Bioavailability

reduction in phytoavailable Pb to the winter wheat and a mild release of P as a nutrient in treated soil, which also confirmed the improvement of soil quality.

1. Introduction

In China, the rapid development of the real-estate sector, textiles, flat glass manufacturing, metallurgical industry, etc. has resulted in an increasing demand on soda ash (Na_2CO_3). In 2010, approximately 2 million tons of soda ash was produced in China, accounting for 42% of the world's total yield (CSIA, 2011). The ammonia-soda process (Fig. 1) (Gao et al., 2007) has been widely adopted for the production of soda ash in large soda ash plants of China (eg., Lianyungang soda ash plant). Briefly, ammonia (NH_3) is adsorbed in the saturated and purified brine. Bicarbonate ($NaHCO_3$) precipitate is formed by carbonation with CO_2, which is mainly obtained from the process of limestone burning. In this step, the obtained filtration liquor (residual mother liquor) is an important by-product. Calcination leads to decomposition of bicarbonate and to the formation of soda ash product. CaO, another product of limestone burning, is used to form milk of lime ($Ca(OH)_2$) which is used for the recovery of NH_3 from residual mother liquor by distillation. After separation of distiller waste, the solid fraction is commonly known as alkaline residue (Kasikowski et al., 2004; Steinhauser, 2008). Due to its huge quantities (about 300–350 kg per ton of produced soda ash), high alkalinity (about pH 9–11) and fine grain size (about 1–5 μm of the average particle size), alkaline residue has become one of the biggest factors restricting the development of the ammonia-soda industry. Moreover, a considerable portion of it is inappropriately disposed in open landfills, posing a severe threat to the surrounding environment. Therefore, numerous attempts are being made to relieve the stress on solid waste treatment of soda ash plants.

In previous studies, we have focused on the use of chemically modified alkaline residue for immobilization of phosphorus (P) from aqueous media. The treatments of alkali (Yan et al., 2014a) and calcination (Yan et al., 2014b) significantly improved the affinity of alkaline residue for P. On the other hand, the indiscriminate disposal of the waste generated from the process of P immobilization could cause secondary pollution on the environment. Thus finding a potential market to utilize this resource may be an economically viable solution to this problem.

Lead (Pb) is regarded as the priority contaminant by the Agency for Toxic Substances and Disease Registry (ATSDR) and the U.S. Environmental Protection Agency (USEPA) (ATSDR, 1999). Accumulation of Pb in human body can deactivate the proteins by replacing their constituent elements (e.g., Ca, Zn), thereby posing negative impacts on almost every organ, especially on the

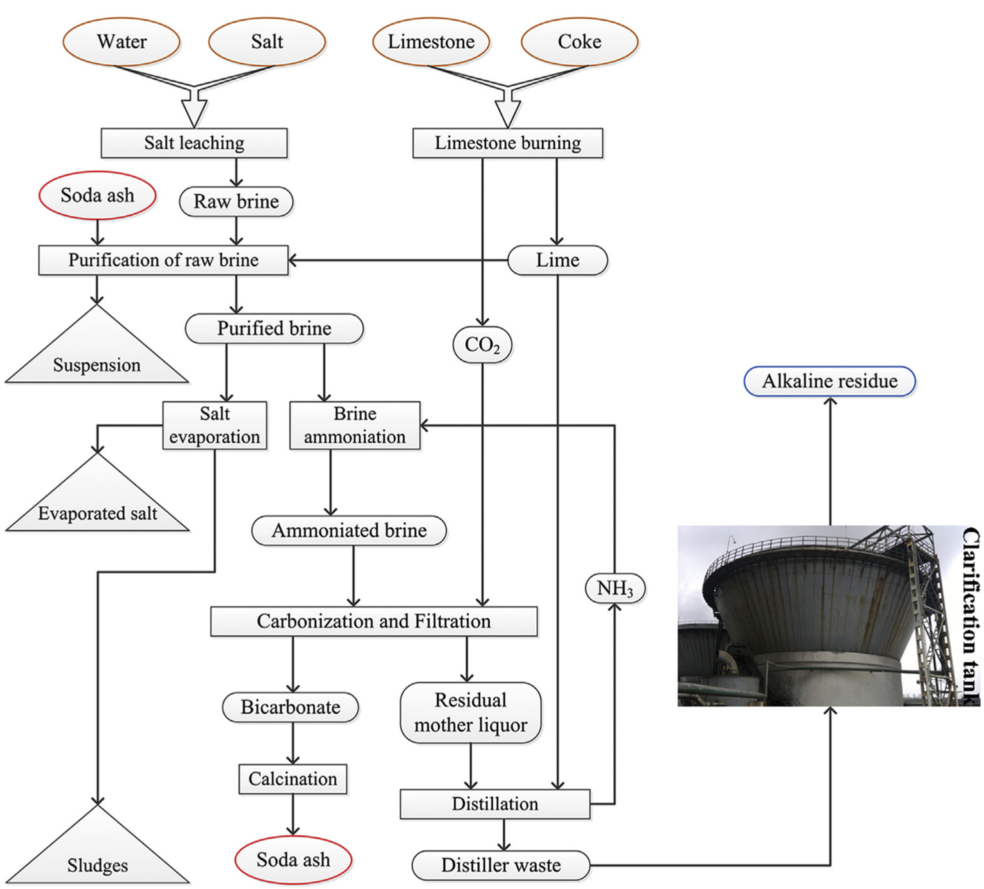

Fig. 1. Flow chart of the ammonia-soda method for production of soda ash.