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Characterization of red mud as a structural fill and embankment material using bioremediation

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ABSTRACT

Red mud (Bauxite residue), a by-product of aluminum industry possess very serious and alarming environmental concern. Globally, 120 million tonne of red mud is generated per year. Disposal of red mud requires huge land, abundant earth material, high cost and further monitoring. And also, it has a potential to pollute nearby water, air and land due to its high toxicity. The most important barrier to remediate, re-use and long term red mud/bauxite residue management is its high alkalinity having pH range of 10–13. Hence, in the present study, bio-neutralization, an eco-friendly approach on red mud is attempted using various indigenous and non-indigenous microbes. In this study, the effect of bio-neutralization on morphological, physical and geotechnical properties of red mud due to the biogeochemical reactions are investigated and compared with raw red mud. Results indicated that reduction in pH value to nearly 7.5 from high alkalinity value of 10.06 is achieved by adding dairy waste product, sugar molasses and rice water in red mud, which act as a cost effective source of microorganism's nutrient. Further, geotechnical characterization as consistency of the red mud is improved in terms of plasticity index. The compaction characteristic is improved in terms of low optimum moisture content and compressive strength after bio-treatment increased marginally. The unconfined compressive strength (UCS) value of bio-treated red mud increased up to 298.6 kPa compared to 136.5 kPa for untreated red mud. The observation made is not only an option to neutralize red mud but also assist in effective utilization of the bauxite residue and various industrial wastes as dairy waste, sugar molasses and etc. The present study shows that bio-treatment of red mud provides an ample opportunity to use it in huge quantities as a structural fill and embankment material.

1. Introduction

Rapid industrialization and faster growth are required for leading a proficient life but a holistic approach with environmental consideration is essential for sustainable development. Due to various anthropogenic activities, large quantities of industrial by product are generated worldwide, which hinder environmental and biota system. Among them, red mud also known as bauxite residue is an industrial waste resulting from aluminum industry, when alumina (Al_2O_3) is extracted from bauxite ore by the most feasible chemical, Bayer processes at elevated temperature and pressure, with the presence of sodium hydroxide (Hind et al., 1999; Brunori et al., 2005). Red mud is a perilous waste, contains high levels of residual alkalinity and toxic heavy metals viz. silica, aluminum, iron, calcium, titanium, as well as an array of minor constituents, namely: Na, K, Cr, V, Ni, Ba, Cu, Mn, Pb, Zn (Liu et al., 2007; Wang et al., 2008). About 0.8–1.5 t of red mud is generated per 1.0 t of alumina produced (Brunori et al., 2005; Liu and Zhang, 2011). Because of the huge volume of red mud being generated as a by-product, it causes serious disposal problems (Samal et al., 2013). Disposal method of red mud entails a huge land area and enormous mass of earth material for constructing tailing dam. Occasional failure of this red mud pond or dam causes flooding the land and contaminating the surface water. Ajka tailings pond failed on October 4, 2010, discharged nearly 0.6 million cubic meters of sludge, which killed ten and injured 120 people (Mayes et al., 2011; Renforth et al., 2012; Rout et al., 2012, 2013). Highly alkaline red mud (pH ranges of 11–13) can be easily carried away due to heavy downpour from the dumping site to the nearby residential areas. It cause contamination of ground water due to leaching of caustic

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liquor and associated toxic metals. Many countries are still disposing the residue directly into the ocean due to the shortage of land area and scarcity of earth material, but it possesses a threat to aquatic life (Power et al., 2011).

The environmental trouble linked with the disposal of red mud waste include high alkalinity, contamination of underground water due to seepage, vast tract of usable land for storage, stability of red mud pond, permanently extinction of plant life due to storage, and direct contact with skin and eyes causes severe complication and health hazards (Poulin et al., 2008; Rai et al., 2012). Instead of the above limitations and negative impacts, few attempts have been made to use red mud in various fields like in metallurgical sectors such as iron, titania rich slag and steel production, alumina and alkali production, minor constituents recovery, production of building materials as constructional brick, light weight aggregates, bricks roofing and flooring tiles, cements etc. (Fotini, 2008), ceramics material production like pottery, sanitary ware, special tiles and glasses, glazes, ferrites (Yanga et al., 2008) and other miscellaneous direct uses as in waste water treatment, as a filler, as a fertilizer etc. (Gupta et al., 2004; Tor et al., 2006; Cengeloglu et al., 2007; Huang et al., 2008). Even though, efforts are on to utilize the red mud in above uses, only 5% of it is being used, as above utilization processes use low volume of red mud.

Hence, there is a need to use red mud in large quantities as a structural fill and embankment material. Though, few attempts have been made to characterize red mud as a fill and embankment material (Rout et al., 2012. 2013; Newson et al., 2006), the critical issue of the residue is its alkalinity, which needs to be resolved for mass/bulk utilization of red mud. Neutralization of red mud will help to lessen the environmental impact caused due to its storage and also significantly lessen the ongoing management of deposits after closure of the tailing pond (Mcconchie et al., 2002; Khaitan et al., 2009; Power et al., 2011). Although, various research have already been carried out to neutralize red mud, but at the cost of other borne environmental problems. The most established methods that has been implemented till date is sea water neutralization to precipitate hydroxide, carbonate and aluminate ions with magnesium and calcium but, it includes covering of sea bed, destruction of associated ecosystem and further potential release of toxic metals to marine environment and increase turbidity of sea water (Palmer et al., 2010). The liquid and gaseous carbon dioxide neutralization is not feasible as red mud cannot be neutralized up to the considerable limit and the rate of neutralization is not fast enough to satisfy industrial needs (Chunmei et al., 2005; Khaitan et al., 2009). Addition of brine also reduces the alkalinity to a considerable limit. Similarly, neutralization by mineral acids does not provide any acid-base buffering capacity due to influence of solid hydroxides in the residue, nor does it improve the physical properties of the material.

Bioremediation utilizes organisms and their biochemical activity to reduce or eliminate environmental hazards resulting from the accumulation of toxic chemicals and other hazardous wastes. It is a versatile process because it can be adapted to suit the specific needs of each and individual site. Few injured microorganisms have already been isolated from bauxite residue intimating that their survival at high alkaline is possible (Williams and Hamdy, 1982). There are extremophilic microbial species that can survive at high pH environment like *Bacillus, Micrococcus, Lactobacillus, Streptococcus, Corynebacterium, Pseudomonas, Clostidium* etc. (Mussels et al., 1993). These microbial strains are effective in producing acids like; acetic acid, citric acid, lactic acid, propionic acid etc., and gives a possible method of neutralizing bauxite residue by utilizing carbon source for assessment of organic acid production (Mussels et al., 1993; Hamdy and Williams, 2001). Neutralization of red mud to pH around 8.0 is optimal because chemically adsorbed Na ion is released, alkaline buffer minerals are neutralized and toxic metals are insoluble at this pH (Hanahan et al., 2004; Zhang et al., 2014, 2015).

Hence, in the present study, neutralization of the highly alkaline red mud is done by various indigenous and non-indigenous microbes with the help of different organic wastes containing suitable carbon source for microbes. Further, morphological, mineralogical and geo-mechanical characterization of neutralized red mud is done and compared with raw red mud, which facilitate researchers and engineers to utilize the treated red mud as fill and embankment material. This research introduces a new paradigm to comprehend the biogeochemical treatment in geo-environmental community (Burbank et al., 2013).

2. Materials and methods

2.1. Red mud

Red mud (RM) was collected from National Aluminium Company (NALCO), Damanjodi, Odisha, India. About 1.5 t of red mud is generated per one tonne of alumina produced from the above plant and output of solid red mud is 200 t/h. The red mud is discharged in a slurry form to a red mud pond, which is about 212 ha. The slurry has a composition of 45% liquid and 55% solids. Basic chemical, mineralogical and morphological properties and geotechnical properties; specific gravity, particle size analysis, plasticity, compaction, unconfined compressive strength (UCS), hydraulic conductivity of red mud samples are analyzed and discussed in further sections.

2.2. Microorganisms and growth condition

Two non-indigenous bacteria, *Lactobacillus plantarum*, NCIM 2083 (LAB 2) and *Lactobacillus acidophilus,* NCIM 2660 (LAB 4) were collected from National centre for industrial microorganisms (NCIM), National Chemical Laboratory, Pune, India and were cultured in MRS broth periodically. Indigenous pure cultures of bacteria were isolated from red mud with most feasible serial dilution and streak plate technique. One gram of red mud was diluted in different dilution factors (10^{-1} to 10^{-5}). The liquefied, sterilized MRS agar and MGYP agar medium were prepared and poured in to petri plates for solidification. Each diluted sample was spread in to the solid medium with L-shaped bent loop by spreading plate method. The leveled petri plates were incubated at 37 °C for 48 h in BOD incubator for growth of microorganisms. Once the colony formed, with streak plate technique, pure cultures were obtained. Preparation of MGYP media is done by adding requisite amount of each powder to distilled water and mixing it. MRS agar typically contains (*w*/*v*) 1.0% peptone, beef extract of 0.8%, 0.4% yeast extract, 2.0% glucose,0.5% sodium acetate trihydrate, 0.1% polysorbate, 0.2% dipotassium hydrogen phosphate, 0.2% triammonium citrate, 0.02% magnesium sulfate heptahydrate, 0.005% manganese sulfate tetrahydrate, 1.0% agar, and pH adjusted to 6.2 at 25 °C. MRS agar media is formulated for abundant growth of lactose fermenting bacteria. No pathogenic bacteria can survive in this specialized media. All the microbiological experiments were repeated thrice and done in a laminar air flow chamber to avoid contamination. The results are also presented in terms of the average and coefficient of variation (COV) (%) values. The COV is defined as the ratio of standard deviation to average value of the sample.

Similarly, two pure culture were isolated from red mud in MGYP agar media and denoted as RM 1A and RM 2A. Similarly one more pure culture was isolated in the enriched MRS agar media and marked RM 3A. All the microbial species used in this experiment