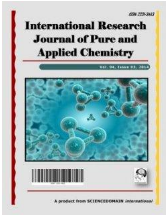

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Stabilization of Metal- Laden Soils Using Different Additives – A Review of Technologies

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Authors' contributions

This work was carried out in collaboration between both authors. Author CRR designed the study, wrote the protocol and wrote the first draft of the manuscript. Author SD managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The presentations of researchers who have carried out studies on the "Stabilization of metal laden hazardous wastes for disposal in to Secured Land Fill" are reviewed and documented in this paper. The importance of protecting ground water aquifers from getting polluted by leachates of heavy metal-laden soils need not be overemphasized. An attempt is made in this paper to review the present state of different technologies so that site-specific, cost-effective, environmentally sound, technically feasible and socially acceptable technologies can be adopted to solve this problem at local level.

Keywords: Hazardous; leachate; metals; stabilization.

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1. INTRODUCTION

Large-scale production of a variety of chemicals, energy and other developmental activities like agriculture, urbanization and health care have increased exponentially during the past four decades in India. These have led to the release of huge quantities of wastes into the environment in the form of solid, liquid and gases. A substantial amount of these wastes is potentially hazardous to the environment and are extremely dangerous to the living organisms including human beings. There is ample evidence to show that improper disposal of these wastes cause contamination of air (via volatilization and fugitive dust emissions); surface water (from surface runoff or overland flow and groundwater seepage); ground water (through leaching / infiltration); soils (due to erosion, including fugitive dust generation / deposition and tracking); sediments (from surface runoff / overland flow seepage and leaching) and biota (due to biological uptake and bioaccumulation). Contamination of ground water by landfill leachate posing a risk to downstream surface waters and wells is considered to constitute the major environmental concern associated with the landfilling of the waste [1]. In order to safeguard our environment, it is important to regulate such hazardous waste in an environmentally sound manner. The wastes released to air as emanations, naturally are regulated in site, as per legal requirements. Liquid effluent is treated at site or through common ETPs and the legal requirements are fulfilled before release. However, the situation is more complex with hazardous solid wastes. Total storage, disposal or utilization is not feasible in the premises in the long run. Such wastes need special collection and treatment [2]. Hazardous waste management is relatively a new concept for most of the Asian countries including India. The lack of technical and financial resources and the regulatory control for the management of hazardous wastes in the past had led to the unscientific disposal of hazardous wastes in India, which posed serious risks to human, animal and plant life. The problem of management is complicated by the heterogeneity of the waste in term of chemistry & toxicity. There are varying degrees of hazards associated with different waste streams. There are good advantages for ranking wastes according to the level of hazards they pose. They could be economic advantages and also an identification advantage wherein we can identify the compatibilities and / or non-compatibilities of the chemical constituents of waste streams for waste management programmes. For example, some wastes containing aluminum and chemical or alkaline cleaners will, when mixed, form a more dangerous toxic or hazardous substance. In contrast, waste containing some chemicals can help attenuate the hazards of other chemicals' toxicity. For instance, waste containing both selenium and mercury would be less likely to create toxicity problems than waste containing only mercury. Rapid growth of industries in India has resulted in generation of increasing volume of hazardous wastes. Wastes which are both indigenously generated and imported from other countries for recycling or reprocessing need scientific treatment and disposal. However, only a few secured landfill sites are available in the country for disposal of hazardous wastes in an environmentally sound manner. Various technologies have been developed to transform hazardous wastes and contaminants to nontoxic materials, or to reduce the potential release of toxic species into the environment. A review of technologies used for the stabilization of metal-laden soils using different additives is attempted in this paper.

2. METHODS ADOPTED FOR STABILIZATION

A Stabilization process of mineral residue contaminated with heavy metals and organic compounds was attempted by G. Depelsenaire – Solvay (2005) called the The Novosol® process. Studies were carried out by different research teams from 1998 to 2001 using the following strategies:

1. Incorporation in *concrete*
2. Incorporation in *road-building materials*

Their leachates, collected on impermeable membranes, have been monitored until June 2003. The process was successfully patented [3]. Bachelor B [4] presented an overview of waste stabilization with cement. Carlton and Wiles [5] reviewed stabilization and solidification technologies. Shing Tet Leong and Preecha Laortanakul [6] conducted pretests for solidification using different binding materials such as cement, rice husk ash, fly ash and sand at various weighed proportions, with a water / binder ratio of 0.4 -0.8. Optimum compressive strengths are obtained for binders: 0.30 rice husk ash/binder ratio (73.2 kg/cm^2) and 0.15 fly ash/binder ratio (69.4 kg/cm^2). This level of compressive strength indicates durability of the specimen. Sludge-binder ratio studies reveal that sludge / binder of 0.5 is the optimum mixture ratio that minimizes toxic elements and provides sufficient compressive strength. Experiments indicate that optimum water/binder ratios are chosen as 0.55 for ordinary Portland cement (OPC), 0.6 for fly ash (FAC) and 0.65 for rice husk ash (RHAC) mortars. The decreased leachate concentrations and increased compressive strength of solidified samples were found at higher curing time as the mortars underwent progressive hydration. In their experimental conditions, the sequence of metal contents in leachate concentration was found to be zinc > copper> lead > chromium. OPC samples possessed the highest compressive strength while those made from RHAC gave the least compressive strength. Results from extraction batch tests on various cementitious binders showed that leachate concentrations are highly pH-dependent for metals. The solubility of the metals is also increased by the decrease in pH. The maximum heavy metal desorption occured in a pH range of 4 to 5 for all solidified samples studied. The finding also revealed that hardened cement paste fixed by cementitious binders can be assessed to some extent by comparing Freundlich's desorptive capacity (K6") for the four metals studied.

Mohd. Akram Khan and Rajnish Shrivastava [7] carried out experiments on hazardous waste cake generated in secondary zinc extraction process during the recovery of electrolytic grade zinc and copper. The waste was collected from an industry located in the western part of India and generates around 5,000 TPA of waste cake. Toxicity Characteristics Leachate Procedure (TCLP) test was carried out for the waste and concentration of heavy metals present in the waste were estimated. The physical, chemical and engineering properties provided information on the characteristics and composition of the waste. Different binders like Portland Pozzolana Cement (PPC), fly ash and clay were used in different proportion using Indian Standard sand as admixture to prepare specimens and to study the Solidification / Stabilization (S/S) mechanism of the encapsulated mass. They found that the waste was found suitable for encapsulation with different binders like PPC, fly ash, clay and their combinations in defined proportion.

Choon-Keun Park [8] conducted studies on “Hydration and solidification of hazardous wastes containing heavy metals using modified cementitious materials”. He used three cementitious materials to investigate solidifying and stabilizing hazardous wastes containing heavy metals. The cementitious materials were (1) ordinary portland cement (OPC), (2) clinker kiln dust (CKD) modified OPC and (3) CKD and quick setting agent (QSA) modified OPC. High alkalies in CKD accelerated the setting and hydration of cement, and QSA influenced quick setting and increased compressive strength of cement. For the solidification and stabilization of heavy metals in the steel industry, dust high alkali CKD modified cement reduced heavy metals leached from the waste form and increased compressive strength of the waste form. The CKD and QSA modified cement presented the least amount of heavy metals leached and the highest compressive strength due to a large number of formation of hydrates, and most effective stabilization of hazardous wastes containing multi-heavy metals.

Sobiecka [9] investigated “The chemical stabilization of hazardous waste material ((fly ash) encapsulated in Portland cement”. She suggested as an effective stabilization (physico - chemical) method for hazardous waste. Her research explored the immobilization of metals in various mixtures of Portland cement and fly ash waste sampled from coal power plant in central Poland. The stabilization of fly ash in Portland cement was investigated under a wide range of pH conditions. Leachability tests were used to determine the efficiency of the encapsulation by studying the dissolution of alkaline metals (sodium, potassium) and alkaline earth metals (calcium, magnesium). The lowest value of leached metals was obtained for ratio of ash to cement of 1:10 in a case of sodium and calcium, while ratio 1:5 gave the lowest leached effects for potassium and magnesium. The high effectiveness of solidification / stabilization process was gained in high pH values.

Pritts et al. [10] studied stabilization of heavy metal containing hazardous wastes with byproducts from advanced clean coal technology systems. They used three advanced CCT byproducts: coal waste–fired circulating fluidized bed combustor residue, pressurized fluidized bed combustor residue, and spray drier residue. Seven metal-laden hazardous wastes were treated: three contaminated soils, two air pollution control dusts, wastewater treatment plant sludge, and sandblast waste. Each of the seven hazardous wastes was treated with each of the three CCT byproducts at dosages of 10, 30, and 50% by weight (byproduct: waste). The treatment effectiveness of each mixture was evaluated by the Toxicity Characteristic Leaching Procedure. Of the 63 mixtures evaluated, 21 produced non-hazardous residues. Treatment effectiveness can likely be attributed to mechanisms such as precipitation and encapsulation due to the formation of hydrated calcium silicates and calcium sulfo-aluminates. Results indicate that these residues have potential beneficial uses to the hazardous waste treatment community, possibly substituting for costly treatment chemicals.

Cobb et al. [11] experimented stabilization of metal-laden hazardous wastes using lime containing ash. They collected clean coal technology by-products from commercial operations. Under steady state conditions, they are reacted at bench-scale with metal-laden hazardous wastes. Reaction conditions involve mixing calibrated weight ratios of by-product to hazardous waste with attention to minimizing added moisture. Of the 15 heavy metals monitored, lead appeared to be the element of greatest concern both from a leaching and a regulatory point of view. While leaching information is focused on lead stabilization, similar information exists for other metals as well. Stabilized solid products of reactions are sampled for TCLP evaluations. For samples showing evidence of metal stabilization, further experimentation was conducted evaluating optimum moisture content, development of physical strength (measured as compressive strength) over time of curing. Results show that certain hazardous wastes are highly amenable to chemical stabilization, while others are not; certain by-products provided superior stabilization, but did not allow for strength generation over time.

Rachana Malviya and Rubina Chaudhary [12] conducted experiments on Leaching behavior and immobilization of heavy metals in solidified / stabilized products. Solidification / stabilization (S/S) of hazardous sludge from steel processing plant was studied. Mechanical strength and leaching behavior test of solidified / stabilized product was performed. Mechanical strength decreased with increase in waste content. Pb, Zn, Cu, Fe and Mn could be considerably immobilized by the solidification/stabilization process. The elements least immobilized were Na, K, and Cl. Leaching of heavy metals in the S/S matrix can be considered as pH -dependent and corresponding metal hydroxide solubility controlled process. Geochemical modeling was performed for the prediction of speciation. On the basis of test results, mobility and mechanism of leaching was assessed. Dominant leaching mechanism was surface wash off in the initial stages followed by diffusion for Pb, Zn, Cu, Fe and Mn. Diffusion coefficient was above 11.5 indicating low mobility in the cement matrix.

Ong Chuon Yi and Chui Peng Cheong [13] conducted solidification studies using ordinary Portland cement (OPC) and Municipal Solid Waste (MSW) incineration fly ash to solidify and stabilize three different types of industrial sludge. A total of eight mix proportions for each sludge type were prepared for compressive strength and leachate tests. The specimens were air-cured and tested for their 3-day and 7-day compressive strength. The results showed significant increase in the compressive strength of those specimens treated with fly ash and cement. Specimens with only 5%-15% cement content was observed to be insufficient to achieve the target compressive strength of 0.3 MPa required for landfill disposal. Fly ash was found to be a good material in stabilizing the heavy metal sludges. The optimum mix was found to be that having 45% fly ash, 5% cement and 50% sludge. TCLP tests indicated leaching from the stabilized matrix was reduced to very low levels.

Mohamed R. Lasheen et al. [14] investigated the efficiency of metals immobilization in sludge using pozzolanic materials fly ash and cement clinker dust (CCD). Thet also, estimated the optimum binder to waste ratio. Different leaching tests such as the standard European (EN) 12457-2 leaching tests; the toxicity characteristic leaching procedure; and the multiple extraction procedure test were used to evaluate the efficiency of metals stabilization in sludge matrix. They showed that the availability of metals leaching (Cd, Cu, Cr, Pb, Ni, Zn) from the stabilized sludge were lower than the permissible limit. Examination of the solidified sample for its compressive strength after curing for 28 days yielded a value of 1.55 and 4.57MPa for fly ash, and CCD which indicates that the treated sludge was well solidified and safe to be used in a wide variety of applications, for instance as a raw material for pavement blocks.

Olcay YILMAZ et al. [15] compared two leaching tests to assess the effectiveness of cement-based hazardous waste solidification / stabilization. In this study, the effectiveness of S/S in terms of the reduction of contaminant mobility was evaluated using a novel approach for stabilization of hazardous waste through two different leaching procedures. Heavy metal enriched mining residue was used as hazardous waste. For the S/S of mining waste, Portland cement as a binding agent was mixed with mining waste at different ratios (10 and 20%). Solidified samples were crushed into two different fractionation sizes (between 1 and 2 mm and greater than 2 mm) and subjected to the toxicity characteristic leaching procedure of the U.S. Environmental Protection Agency and the distilled water leaching procedure of the THWCR. The leaching test results showed that generally S/S produced efficiencies greater than 90% for the retention of metals in the solidified mass.

Gupta and Surwade [16] studied solidification and stabilization of hazardous sludge from steel plating industry containing Fe, Ni, Cr, Zn, Cu and Mn using cement. They reported that cement could restrict the mobility of heavy metals due to high pH and its caspability to precipitate the metals in insoluble form. Leaching of heavy metals from solidified matrix using Toxicity Characteristic Leaching Procedure (TCLP) at different pH were studied. Different combinations of cement and sludge were used to study the leaching behavior of heavy metals from solidified matrix at different pH. Upto 80% sludge was stabilized using cement as a binder. Compressive strength of solidified matrix required for secured landfill was also studied. Compressive strength was found to decrease with an increase in the sludge: cement ratio. Though TCLP study showed higher leaching concentrations of heavy metals, leaching of all metals using both tests were well below USEPA's limit.

Cubukcuoglu and Ouki [17] stabilized electric arc furnace waste using low grade MgO. They evaluated the potential of low grade MgO (LGMgO) for the stabilization / solidification (S/S) of heavy metals in steel electric arc furnace wastes. Relevant characteristics such as setting time, unconfined compressive strength (UCS) and leaching behavior were assessed by acid neutralisation capacity (ANC), monolithic and granular leaching tests. They were examined in light of the UK landfill Waste Acceptance Criteria (WAC) for disposal. The results demonstrated that all studied mix designs with Portland cement type 1 (CEM1) and LGMgO, CEM1–LGMgO 1:2 and 1:4 at 40% and 70% waste addition met the WAC requirements by means of UCS, initial and final setting times and consistence. The monolithic leaching test results showed that LGMgO performed satisfactorily with respect to S/S of Zn, as the metal component present at the highest concentration level in the waste exhibited very little leaching and passed the leaching test requirement at all mix ratios studied.

Singh et al. [18] carried out a mini assessment and stabilization of different wastes. The hazardous waste which comes from metal, automobile and steel industry were stabilized with combination of different binder in common ratio along with waste. The stabilized samples thus prepared were tested for TCLP. Leaching results indicated that stabilization technique was effective in terms of restraining of leaching of heavy metal ions like Zn, Mn, Ni & Pb. Metal and automobile industrial waste were stabilized more effectively by common ratio of binders. Steel industrial waste also was found to get stabilized but the effective ratio of binders was different from the other two industries.

Yilmaz et al. [19] conducted experiments on hazardous wastes containing metals and organic contaminants. Hazardous wastes, enriched mining residue, adsorbable organic halogens (AOX) containing pulp and paper sludge, and polychlorinated biphenyl (PCB), oil-contaminated soil were used. For S/S of waste, Portland cement as a binding agent was mixed with wastes at different ratios. Waste and cement mixtures were cured for 28 days after compacting the desired waste-cement mixtures at their predetermined optimum moisture contents yielding the corresponding maximum dry densities in cylindrical molds having a height of 71 mm and a diameter of 36 mm. At the end of the 28-day cure period, unconfined compressive strength and hydraulic conductivity measurements were conducted on the solidified samples. Subsequently, solidified samples were crushed for fractionation into two different aggregate sizes (between 1–2 and >2 mm) and subjected to the U.S. Environmental Protection Agency Toxicity Characteristic Leaching Procedure (TCLP). The effectiveness of S/S was assessed by comparing the chemical composition of leachates obtained from TCLP tests of untreated and treated S/S waste samples, and comparing values of strength and hydraulic conductivity of solidified waste samples with regulatory requirements. For mining waste, effective application of S/S was achieved for most cases. AOX containing sludge yielded acceptable results in terms of strength and hydraulic conductivity but leachate AOX concentrations were above regulatory levels. The effectiveness of S/S for coarse textured-soils contaminated with a PCB oil was not satisfactory, especially at a cement: soil ratio less than 35%.

Sophia and Swaminathan [20] carried out experiments on leaching of metals on stabilization of metal sludge using cement based materials. TCLP of zinc plating sludge was carried out to assess the leaching potential of the sludge and the leachates were analysed for heavy metals. Solidifiaction of zinc sludge was carried out using four binder systems consisting of cement mortar, fly ash, clay and lime and cured for 28 days. The ratio of sludge added varied from 60% to 80% by volume. The solidified products were tested for metal fixing efficiency and physical strength. It was observed that the volume of sludge added that resulted in maximum metal stabilization was 60% for all the combinations, above which the metal fixation decreased resulting in high values of zinc in the leachate. Addition of 5% sodium silicate enhanced the chemical fixation of metals in all the binder systems. Among the four fixing agents studied, mixture of fly ash: lime & cement mortar: lime stabilized zinc and other metals in the sludge effectively than other combinations.

Palomo and Palacios [21] studied the stabilization/solidification capacity of a cementing matrix, which was made using alkali activation of fly ash, in the presence of toxic elements chromium and lead. Its capacity was compared with that of Portland cement. Leaching tests carried out proved that this new matrix is able to stabilize and solidify lead in a very efficient way (lead concentrations from leaching were in parts per billion). However, it was not that efficient in chromium fixation since this element strongly disturbed the alkali-activation mechanism of the ash.

Senem Bayar and Ilhan Talinli [22] conducted Solidification / stabilization of hazardous waste sludge obtained from a chemical-metal finishing industry, which contained potentially toxic heavy metals and organics. The hazard characteristics of the waste were determined by means of extraction procedure toxicity test and DIN 38414-S4 Test. S/S studies were conducted using Portland cement to solidify the sludge containing high concentrations of total organic carbon, Cr, Cu, Hg, Ni, Pb, and Zn. The waste / binder ratios of 36 sludge specimens were kept between 0/100 and 40/100. The specimens were cured at room temperature for 7, 28, and 90 days. The compressive strengths of the specimens were measured to determine the feasibility of using solidified waste sludge as construction materials. The compressive strength values indicated that specimens could be potentially used as construction materials.

Chen et al. [23] reviewed the immobilization of heavy metal in cement-based solidification / stabilization. They discussed interactions of heavy metals and cement phases in the solidification / stabilization process. It provides a clarification of heavy metal effects on cement hydration. According to the decomposition rate of minerals, heavy metals accelerate the hydration of tricalcium silicate (C3S) and Portland cement, although they retard the precipitation of Portlandite due to the reduction of pH (resulted from hydrolyses of heavy metal ions). The chemical mechanism relevant to the accelerating effect of heavy metals is considered to be H+ attacks on cement phases and the precipitation of calcium heavy metal double hydroxides, which consumes calcium ions and then promotes the decomposition of C3S. In this work, molecular models of calcium silicate hydrate gel are presented based on the examination of 29Si solid-state magic angle spinning / nuclear magnetic resonance (MAS/NMR). This paper also reviewed immobilization mechanisms of heavy metals in hydrated cement matrices, focusing on the sorption, precipitation and chemical incorporation of cement hydration products. It is concluded that further research on the phase development during cement hydration in the presence of heavy metals and thermodynamic modeling is needed to improve effectiveness of cement-based s/s and extend this waste management technique.

Pereira et al. [24] studied the stabilization of electric arc furnace (EAF) dust containing hazardous metals such as Pb, Cd, Cr or Zn. The treatment involves a waste solidification / stabilization (S/S) process, using coal fly ash as the fundamental raw material and main binder. The efficacy of the process has been evaluated mainly through leaching tests on the solidified products and a novel approach for stabilization of hazardous waste compliance with some imposed leachate limits. The concentration of metals leaching from the S/S products was strongly leachate pH- dependent; thus, the final pH of the leachate is the most important variable in reaching the limits and, therefore, in meeting the stabilization goals. In this study, the dependence relationship between the leachate pH and the concentrations of metals in the leachate are analyzed. In some cases, this allows us to estimate the speciation of contaminants in the S/S solids and to understand the mechanism responsible for reduced leachability of heavy metals from solidified wastes.

Pariatamby et al. [25] conducted experiments on stabilization of fly ash. Fly ash samples from a mixed hazardous waste incinerator were subject to solidification and stabilization using ordinary Portland cement as the binder. Additives (activated carbon and rice husk) were also homogenized with the binder and waste to determine the effectiveness of the immobilization of heavy metals. The TCLP, Japanese Leaching Test (JLT) and the American Nuclear Test were conducted to gauge the leaching of heavy metals from the solidified matrixes. They also studied the compressibility strength of the solidified matrixes using ASTM test procedure for the compressive strength of hydraulic cement mortars. They found that addition of activated carbon / rice husk reduces heavy metal leaching from solidified fly ash. Effectiveness of additives for decreasing metal diffusibility is not significant in this study. They found that the addition of activated carbon/rice husk decreased unconfined compressive strength.

M. Lambert et al. [26] studied new methods of cleaning up heavy metals in soils and water during the 1990's. The expensive process of excavating and disposing contaminated soil has been augmented with new methods that treat the soil in place. In situ fixation is a process that creates new chemical coumpounds in which heavy metals are much less available to living things. This on-site cleanup is less disruptive to people's lives and to the environment compared to excavating and disposing contaminated soils elsewhere. Phytoremediation suggested by them uses plants by several methods to contain or clean up heavy metals. Phytoremediation has the benefit of being a relatively low-cost, natural solution to an environmental problem.

Roy and Eaton [27] studied solidification of a synthetic electroplating sludge in Cementitious binders containing Na OH. They used

a) Cement+fly ash(CFA),
b) lime+fly ash(LFA),
c) Ordinary Portand cement (OPC).

Mix ratios tried were

a) OPC:Flyash:sludge=0.2:0.5:1.0,
b) lime:flyash: sludge=0.3:0.5:1.0
c) OPC: sludge=0.3:1.0.

NaOH was added and CFA was found to be least affected by high pH produced by NaOH. Zbigniew Giergiczny and Anna Krol [28] studied immobilization of heavy metals in mineral additions containing concrete composites. They used ordinary Portland cement (OPC), biders containing large amount of mineral additives in its composition- Siliceous flyash (FA), fluidized bed combustion ash (FFA) and ground granulated blast furnace slag (GGBFS). Heavy metals were introduced to cementitious materials in the form of soluble salts as well as components of hazardous wastes (medical ash, metallurgical dust). Mortar with 85% GGBFS and 15% OPC gave highest immobilization levels. The microstructure, microchemistry and component phases present in the binders after curing were determined using SEM, Energy dispersive X ray Spectroscopy and X ray diffractometry.

Maria Anna Cinquepalmi et al. [29] studied reuse of cement-solidified municipal incinerator fly ash in cement mortars as an artificial aggregate. Porosity, compressive strength and leaching behavior of these specimens were tested. Relatively high compressive strength (upto 36N/sq.mm) and low leaching rates of heavy metals (Cr, Cu, Pb and Zn) were reported.

Saveeta [30] studied stabilization of hazardous waste to meet criteria for disposal into secured landfill using a novel patented material RBI Grade81. She reported that application of RBI Grade 81 in the process of stabilization proved to be highly efficient in reducing the heavy metals present in the wastes like Chromium soil, Chromium waste and Metal waste. The optimum dosage of the new binder RBI Grade 81 was observed as 5% at which maximum reduction in the concentration of chromium metal occurred with an optimum curing period of 10 days for all the three wastes studied.

Navarro-Blasco et al. [31] studied stabilization of toxic metals in Calcium aluminate cement (CAC) matrices. Studies were conducted under 2 curing temperatures - 20 deg C and 60 deg C. Changes in consistency and setting time were found upon addition of the nitrates of Pb, Zn and Cu(target metals). Both Pb and Cu caused a delay in CAC hydration, while Zn accelerated the stiffening of the mortar. Compressive strengths of the metal-doped mortars, when initially cured at

60ºC/100% RH, were comparable with that of the free-metal mortar. Three different pore size distribution patterns were identified and related to the compounds identified by XRD and SEM. Sorbent capacities of CAC for the toxic metals were excellent: a total uptake was achieved for up to 3 wt.% loading of the three metals. In this way, CAC mortars were perfectly able to encapsulate the toxic metals, allowing the use of CAC for waste management as proved by the leaching tests.

Recent studies by Tang et al. [32] indicated that spinal formation is the most crucial metal stabilization mechanism when multi phase copper sludge is sintered with aluminum-rich water works sludge.

Kaimin Shih and James O. Leckie [33] studied Nickel aluminate spinel formation during sintering of simulated Ni-laden sludge and kaolinite. Incorporating Ni-laden waste sludge into kaolinite-based construction ceramic materials appears promising. They based their observations on the identified nickel bearing phases, evaluated incorporation efficiency and nickel leachability of the products. Nickel aluminate spinel ($NiAl_2O_4$) results from sintering kaolinite and nickel oxide between 990 and 1480ºC, with more than 90% incorporation efficiency achieved at 1250ºC and 3 h sintering. At lower temperature (990ºC), ($NiAl_2O_4$) formed from the reaction between nickel oxide and the defect spinel generated from the kaolinite–mullite reaction series. In addition to sintering temperature and time, four raw material mixing procedures were employed, and the ball-milled slurry samples had the highest nickel incorporation efficiency. Prolonged leach testing of NiO, ($NiAl_2O_4$) and the product from sintered kaolinite + NiO mixtures was carried out using the TCLP extraction fluid #1 (pH 4.9) to evaluate the product stability, and the results revealed the superiority of spinel products over NiO in stabilizing nickel.

3. CONCLUSION

The summary of research carried out for Stabilization of metal laden hazardous wastes for disposal in to Secured Landfill is presented. It was observed from a detailed survey of literature that many combinations have been tried along with cement to immobilize and stabilize the metal-laden hazardous wastes. From the leaching tests using TCLP (Toxicity Characteristics Leachate Procedure) and strength tests using UTM (Universal Testing Machine), researchers have compared the performance of binders and additives like cement, lime, fly ash, blast furnace slag, sand, rice husk ash, clinker kiln dust, electric arc furnace ash, sintered waste sludge etc in their studies. An analysis of their findings reveals that use of sintered waste sludge along with cement and lime holds a great promise to stabilize metal-laden soils due to their cost-effectiveness. An attempt is made in this paper to review the present state of different technologies so that site-specific, cost-effective, environmentally sound, technically feasible and socially acceptable technologies can be adopted to solve this problem at local level.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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