SOLIDIFICATION AND STABILIZATION DISPOSAL OF MEDICAL WASTE INCINERATOR FLY ASH USING CEMENT

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SUMMARY: Ash, which is the by-product of incineration, is normally disposed of into a landfill. The treatability of medical waste incineration fly ash by solidification / stabilization (S/S) of the ash using cement has been explored in this study. Many tests have been developed to evaluate the effectiveness of the solidified matrix, by subjecting the matrix to simulated landfill environment conditions in the laboratory. These tests include leachability studies using various protocols, unconfined compressive strength, durability tests (freeze/thaw and wet/dry cycle tests), and total waste analysis for organics. In this project the solidified waste matrix was tested for its leach characteristics and unconfined compressive strength.

1. INTRODUCTION

Fly ash is normally disposed into a landfill; however this could lead to surface and ground water contamination when the heavy metals in the ash migrate laterally. This became evident from the ground water monitoring conducted in 2002 by Department of Environment (DOE), where water collected from monitoring wells from solid waste dumping sites exceeded the acceptable value for raw water quality under the National Guidelines for Drinking Water (1990). Heavy metals contained in the fly ash could cause detrimental environmental damage, especially bioaccumulation in the food chain. Hence disposal of these heavy metal laden ashes must be done carefully to prevent these metals from re-entering the environment in high levels, this being the reason why treating the fly ash prior to disposal into a landfill is gaining importance in Malaysia.

Disposal of the ash should be in accordance to Regulation 4 of the Environmental Quality (Scheduled Wastes) Regulations, 1989 where scheduled wastes must only be disposed of after proper treatment at prescribed premises and as far as is practicable be rendered innocuous (EQA, 1974). These ashes are to be disposed of in secure landfills and not into municipal landfills. Given these regulatory constraints, this paper examines for flyash from clinical waste incineration:

a. an alternative effective treatment and disposal method by studying the solidification / stabilization of the flyash using cements (OPC, MSC, GGBS) and additives such as activated carbon and rice husk; and,

b. determination and comparison of the leachability characteristics of the solidified ash, based on 3 leaching protocols, namely TCLP, ANS 16.1 and JLT-13.

2. SOLIDIFICATION AND STABILIZATION (S/S) TECHNOLOGIES

Solidification and stabilization (S/S) is a waste treatment technology that is gaining prominence to treat a variety of mixed organic and inorganic industrial wastes. This technology has been around for 25 years having originally been used to treat low level radioactive waste (Pojasek, 1979, Subramanian and Mahalingam, 1980, Zamorani, 1994).

The technique employs selected materials to alter the physical and chemical characteristics of the waste stream prior to disposal. It improves waste handling and physical characteristics, decreases surface area across which pollutants can transfer or leach, limits the solubility when exposed to leaching solutions and detoxifies the hazardous constituents (Wiles, 1987). A wide spectrum of wastes can be stabilized and solidified. The wastes may contain both inorganic and organic contaminants (Côté, 1989, Lambge et. al., 1997).

2.1 Solidification and Stabilization Processes

Solidification is that component of S/S in which materials are added to the waste to produce a solid matrix. In addition to simple binding, it may also involve a chemical bonding between the toxic contaminant and an additive; also, when combined in right proportions, heavy metal fixation could occur by creating insoluble metal hydroxides. The binders used for this purpose also increase the strength and decrease the compressibility and permeability of the waste (LaGrega et al., 1994).

Stabilization is the other component of S/S where a physiochemical reaction is used to transform the contaminants to less mobile and less toxic forms to generate a chemically stable form (Means, 1995). This enables the contaminants in the waste to remain in the solidified matrix even though the matrix itself might deteriorate with time.

S/S technology is recognized in the Resource Conservation and Recovery Act (RCRA) as a Best Demonstrated Available Technology (BDAT) for treating hazardous wastes (Biyani et. al., 2001). According to USEPA (1989), solidification and stabilization of hazardous waste as a remediation technology is an important technology to be pursued. The common binder used for the S/S technology is cement. Cement solidification is suitable for inorganic wastes, especially those containing metals. Hydroxides of metals that are formed are less soluble as compared to the other ionic species of the metals. This method has been used to treat plating wastes that contain metals such as cadmium, chromium, copper, lead, nickel and zinc (USEPA, 1989). Once the cement-waste mixture reacts with water, the calcium silicate and calcium aluminate in the cement form hydrated silicate and aluminate compounds. The contaminants in the waste become entrapped within the pores of the porous gel structure, absorb on to the pores of the surfaces, react, or become incorporated into the gel matrix. At the same time calcium hydroxide is also created and this precipitates and becomes trapped in the pores. This creates a buffer capacity against acid attack of the matrix and a high pore water pH between 11-13 (Cheng et al., 1996).

Addition of additives such as activated carbon causes sorption of chemical properties and heavy metals in the solidified matrix (Chan et. al., 2000). The effectiveness of activated carbon in removing the materials is proportional to the high amount of surface area (600-100 m^2/g) of the activated carbon (Rhyner et al., 1995).

2.2 Leaching Process and Mechanisms

Leach test has been recognized as the primary and most widely used indicator evaluating the retention capacity of S/S waste mass. Leach tests are accelerated examinations of waste stability and are usually aggressive in an attempt to compensate for their short duration and thus provides conservative assessments of leaching performance. Leaching solutions are usually distilled water, deionised water or dilute acids. The solutions are used to assess the extent of waste stabilization affected during processing and the capacity of binding agents to neutralize aggressive leachants (Zamorani, 1994).

Leach tests available are classified as extraction tests, leach tests and column leach tests. Extraction tests such as Toxicity Characteristics Leaching Procedure (TCLP), Extraction Procedure (EP) Toxicity Tests and Japanese Leaching Test (JLT) involve agitation of ground/pulverized wastes in a leachant to achieve uniform mixing for a specific period. The leachant used may be acidic or neutral and usually has a leachant to waste ratio of 20:1. The leachant is analyzed for heavy metals and other constituents once the continuous mixing is stopped after a few hours (Chan, 1999). The release rates can be calculated as cumulative amount released over time to be compared with the total amount available for leaching (Cote et. al., 1983).

Most cement-solidified matrix leachate is in a pH range of 10-11. Most heavy metals such as As, Cr, Ni, Cu, Zn have minimum solubility at the pH range of 7.5-11, however, Pb shows higher solubility at both low and high pH but is generally insoluble at pH 7-11 (Chan et al., 2000). As leaching proceeds, the leached metals migrate through this surface skin before entering the leachate (Cheng et al., 1996).

Leaching of hazardous and trace elements from the solidified waste product is influenced by chemical, physical and biological factors (van der Sloot, et al, 1989). Usually the physical and chemical factors are studied, as biological factors are quite difficult to quantify.

2.3 Unconfined Compressive Strength

Unconfined compressive strength is measured to establish the cohesiveness of the materials. It also represents the effectiveness of the solidification and stabilization of the binder with the waste. According to the current USEPA regulations, solidified and stabilized waste products must have a minimum of 28 days-unconfined compressive strength of 50 psi. This is important, as it has been established that a minimum strength of 50 psi or more is suitable strength for stabilized materials to support loads of pressures placed on it in the landfill.

3. EXPERIMENTAL PROCEDURE

3.1 Leaching Tests

3.1.1 TCLP: Toxicity Characteristics Leaching Procedure (USEPA, 1992)

The TCLP protocol USEPA method 1311 was carried out on the samples after 28 days of curing. An extraction buffer of acetic acid and sodium hydroxide of pH 2.88 ± 0.05 was prepared. The ratio of extraction liquid to crushed particles used was 20:1. The leachant was then analyzed for heavy metals in the extract. The results are expressed in terms of the percentage of the leachable fraction (*f*) for each element. This shows the amount of a particular trace metal extracted relative to the amount in untreated ash, which actually shows the availability of metals for leaching from the solidified over a period of time.

3.1.2 JLT-13 : Japanese Leaching Test -Environment Agency Notification No. 13 (Mizutani et al., 2000)

For this test, an extraction buffer of hydrochloric acid and sodium hydroxide of pH 6.00 ± 0.05 was prepared and used at a liquid-to-solid (L/S) ratio of 10:1. The buffer was added to the crushed waste matrixes and mechanically shaken for 6 hours in an incubator shaker continuously at 200 rpm. After 6 hours, the leachate samples were filtered and the pH and heavy metals in the leachant were analyzed in the same manner as for TCLP. The results were also expressed in terms of the percentage of the leachable fraction (*f*) for each element.

3.1.3 American Nuclear Society 16.1 (ANS 16.1, modified)

This leaching procedure is a simplified and modified method from the American Nuclear Society for solidified low-level radioactive wastes in standard ANSI/ANS 16.1, which is conducted for 90 days. ANS 16.1 affords more information about the leaching rate of trace metals from the S/S waste-cement matrix compared to TCLP and JLT-13. The leaching of the samples as performed for 28 days with leachate sampling occurring on the 1st, 3rd, 7th, 14th and 28th days. The trace metals in the leachate were analyzed using Inductively Coupled Plasma-Atomic Emission Spectroscopy. The results were recorded in terms of leaching rate (*l*) and cumulative fraction leached (*CFL*) relative to the total mass of the waste sample. From these results, the leachability index (*Li*) was calculated. *Li* is an indication of the effectiveness of the S/S method used for the control of the leaching of trace metals. The larger the *Li* becomes, the lower the values of the diffusion of contaminants. The effective diffusion coefficient (*D*) is a measure of the diffusibility of the heavy metals of concern in the S/S waste for each leaching interval.

3.2 Unconfined Compressive Strength

This test was carried out according to the American Standard Testing Material (ASTM) Test method for the Compressive Strength of Hydraulic Cement Mortars C190/C 109M-95. The strength measurements of the cubes were performed using a calibrated hand-operated hydraulic compression apparatus (model ELE) on the 7th, 14th and 28th days of curing. The total maximum loads were recorded at the point of fracture of the cubes.

4. RESULTS AND DISCUSSIONS

The untreated medical waste fly ash (MWFA) exhibited high contents of Al (28300 mg/l), Fe (8040 mg/l) and Ti (12600 mg/l), however the highest metal content was Zn with 31100 mg/l. Other heavy metals such as Pb, Cu and Hg were also of concern as each revealed concentrations of 4870 mg/l, 1000 mg/l and 32601 μg/l respectively. Heavy metals such as Pb, Zn, Cd and Fe are found in sharps, radioisotope shielding, chemotherapy waste, laboratory chemicals as well as pigment and additives found in the plastics. Plastics in the medical wastes originate from packaging materials/equipment. Mercury content in the ash is possibly from disposal of metallic material such as small equipment supplies containing Hg or paints and coatings of the material containing Hg, discarded mercury thermometers, dental amalgams, and Hg batteries.

The TCLP method showed that the solidification of MWFA using ordinary portland cement (OPC) alone inhibited all metals except for Fe and Mn, however the percentage of leachable fraction was reduced to 1.6% for Fe (from 6.65 mg/L) and 4.7% for Mn from 3.85 mg/L in the untreated ash, as the cement loading increased (Figure 1). The incorporation of activated carbon gradually reduced the leaching of heavy metals especially Zn, from 24.81% (at 23% cement loading) to 0% (at 56% cement loading), Figure 2(b). Ac causes sorption of the chemical components and heavy metals into the solidified matrix (Chan *et al.,* 2000).

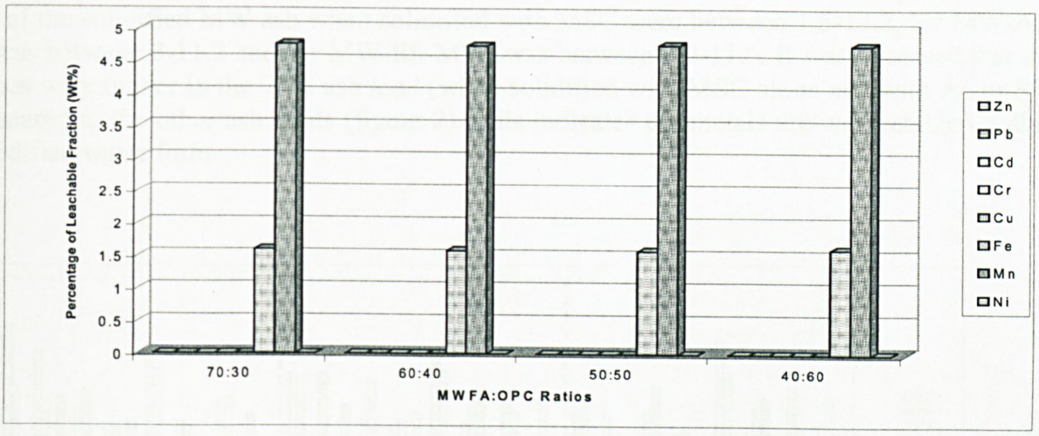

Figure 1. Percentage of leachate fractions of the heavy metals of concern in the leachate from Medical Waste (MW) ash- OPC treated samples.

MWFA when solidified with mascrete cement (MSC) alone and with rice husk (Rh) indicated that most of the metals were below detection levels for all the ash loading (70-40%). However when activated carbon (Ac) was added, Zn, Pb and Cd still leached between 0.05-0.32 mg/l. The solidification of all the ash with ground granulated blast slag (GGBS), it showed that most of the metals were found to reducing in the percentage of leachable fraction as the cement loading increased. However when Ac, was combined to the solidification, Pb was found to be increasing from 3.1-15.8% as the ash loading increased. The addition of Rh still had most metals leaching in the 70% and 60% ash load but in the 59% and 40% ash load, only Pb was found to be leaching.

As for the JLT-13 leaching test, the results showed that the MWFA solidified with OPC stabilized all metals especially when ash to cement ratio was 50:50 and 40:60. Addition of activated carbon or rice husk reduced leaching of most of the heavy metals to below the JLT and Malaysia Environmental Quality Act 1974, Environmental Quality (Sewage and Industrial Effluents) Regulations, 1979, Standard B limits. However Pb concentration for the medical waste: OPC: rice husk solidified samples increased from 3.78% to 16.31 % as cement loading increased. The MSC binder for the MWFA and the addition of Rh inhibited leaching of all metals. Addition of activated carbon, however, reduced the immobilization efficiency and showed an increase in leaching of Zn between 0.267 – 0.34 mg/L, Pb (0.045-0.319 mg/L) and Cd (0.101-0.103 mg/L) as cement loading increased. The leaching concentration of Cd tested in the extract was below the limits of both the standards. As for MWFA when solidified with GGBS alone and with Ac or Rh, managed to reduce the leaching of most metals of concern to below detection in the JLT leaching extract. The leachant from solidified ash samples showed a pH range between 5 & 12. Cr, Pb, Zn, Cu and Fe showed amphoteric behaviour by having higher solubility at both low (below 7) and high pH (above 11).

In general, from the ANS 16.1 test results, it was observed that most of the leaching rate for all the metals were descending as the leaching time prolonged. Only two metals, Cr and Ni reduced notably for all the sets of cement loads (70%, 60%, 50% and 40%). It was generally seen that all the metals showed increasing cumulative fraction leached (CFL) values, which corresponded to the square root of the leaching time in a linear increasing trend. This shows that the leaching of metals occur through the diffusion process. It was also observed that the CFL leaching values increased notably from the first day to the third day and thereafter increased slightly. The Li values of the solidified MW ash when solidified with MSC were between 1.5-12.2, for MW-Ac-MSC was between 3-11.2 and for MW-Rh-MSC was between 3.0-11.6. It was observed that the Li values were higher in the 70% ash load (when solidified with MSC alone and with Ac or Rh) as compared to the other ash loads (figure 2). This indicates the metals are well retained within the solidified waste form.

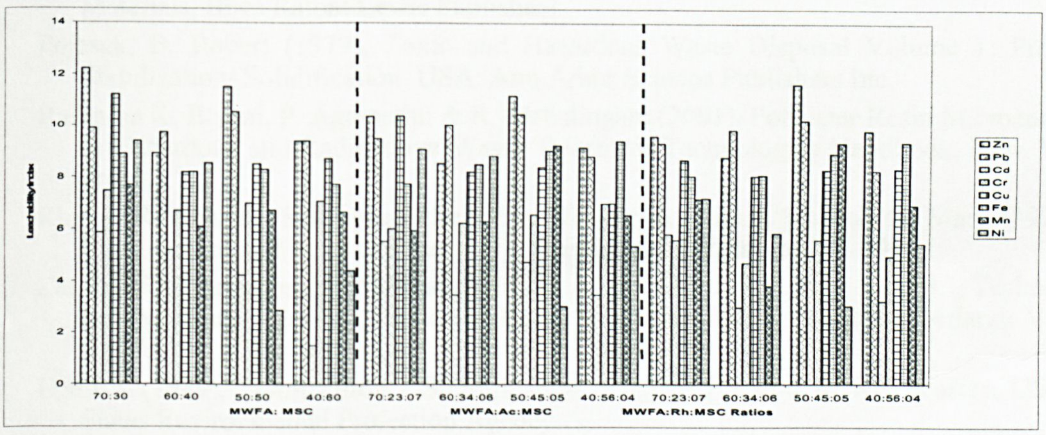

Figure 2. Leachability Index for MWFA treated with MSC and with Ac or Rh.

In the MW-MSC solidified waste, the compressive strength was between 0.6-1.8 MPa and when Ac and Rh were added, the compressive strength was between 0-1.9 MPa and 0.5-1.9 MPa respectively. As for the MW-GGBS solidified waste, the compressive strength was between 0-0.7MPa for the MW solidified with GGBS alone and for MW-Ac-GGBS was between 0-0.9 MPa and when added with Rh was between 0.3-0.8 MPa.

5. CONCLUSIONS

The solidification and stabilization treatment of ash from MW proved that our method is a good treatment option but the treatment is 3-5 times more costly compared to the direct landfilling of the ashes. However, the use of cement, in particular OPC, effectively reduced and bound the metals within the solidified matrix.

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