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Review Article

BIO-MEDICAL WASTE INCINERATOR ASH: A REVIEW WITH SPECIAL FOCUS ON ITS CHARACTERIZATION, UTILIZATION AND LEACHATE ANALYSIS

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ABSTRACT
Waste generation has increased considerably worldwide in the last few decades. Solid wastes encompass the heterogeneous mass of throwaways from the urban community as well as the homogeneous accumulations of agricultural, industrial and mineral wastes. Waste generated from biomedical activities represents a real problem of living nature and human world. A proper waste management system should be required to dispose hazardous biomedical waste and incineration should be the best available technology to reduce the volume of this hazardous waste. The incineration process destroys pathogens and reduces the waste volume and weight but leaves a solid material called biomedical waste incineration ash as residue which increases the levels of heavy metals, inorganic salts and organic compounds in the environment. Disposal of biomedical waste ash in landfill without proper treatment may cause contamination of groundwater due to leachate as metals are not destroyed during incineration.
The limited space and the high cost for land disposal led to the development of recycling technologies and the reuse of ash in different systems. In order to minimize leaching of its hazardous components into the environment several studies confirmed the successful utilization of biomedical waste ash in agriculture and as structural and constructional material. This paper presents the overview of some of the research published on the beneficial use of ash in agriculture and construction materials and its leachate characteristics. This review also stressed on the need to further evaluate other suitable ways of disposing and utilizing the ashes and slag generated from biomedical waste incinerators.

Key Words: *Agriculture, biomedical waste ash, concrete, leachate.*

INTRODUCTION
Solid wastes are all the wastes arising from human and animal activities that are normally solid and that are discarded as useless or unwanted. The term is all-inclusive, and it encompasses the heterogeneous mass of throwaways from the urban community as well as the homogeneous accumulations of agricultural, industrial, and mineral wastes. Solid waste can be classified into different types depending on their source: a) Household waste is generally classified as municipal waste; b) Industrial waste as hazardous waste; and c) Biomedical waste or hospital waste as infectious waste.
Municipal solid waste consists of household waste, construction and demolition debris, sanitation residue, and waste from streets (mainly from residential and commercial complexes). In 1947 cities and towns in India generated an estimated 6 million tones of solid waste, whereas in 1997 it was about 48 million tones (SOER, 2009). More than 25% of the municipal solid waste is not collected at all. Surveys showed that 70% of the Indian cities lack adequate capacity to transport it and there are no sanitary landfills to dispose of the waste.
Industrial and hospital waste is considered hazardous as they may contain toxic substances (Hazardous waste). India generates around 7 million tones of hazardous wastes every year, most of which is concentrated in four states: Andhra Pradesh, Bihar, Uttar Pradesh, and Tamil Nadu (NEAS, 2006). Hospital waste or biomedical waste is generated during the diagnosis, treatment, or immunization of human beings or animals or in research activities in these fields or in the production or testing of

biological. Liquid waste may be divided in to two components: (a) liquid reagents/chemicals discarded; and (b) the cleaning and washing water channeled in to the drain.

Waste generation has increased considerably worldwide in the last few decades but the waste generated from biomedical activities has increased greatly and can be hazardous, toxic and even lethal. Also the waste generated from biomedical activities represents a real problem of living nature and human world. Thus, biomedical waste may be regarded as hazardous waste. It is necessary that all biomedical waste must be disposed in a manner which is least harmful to human beings and environment. According to Mastorakis *et al.*, (2011) "Biomedical waste means any solid and/or liquid waste including its container and any intermediate product, which is generated during the diagnosis, treatment or immunization of human beings or animals or in research pertaining thereto or in the production or testing thereof." The physico-chemical and biological nature of biomedical waste, their toxicity and potential hazard depend upon the origination of the waste. Biomedical waste is composed of human anatomical waste, microbiological, biotechnological waste, waste sharps such as needles, syringes, broken glass, scalpels etc, discarded medicines and drugs, liquid wastes (Blood, excrement, body fluid solutions, inorganic salts etc.), solid waste such as dressings, bandages, plaster casts, chemical waste, incinerator ash generated from hospitals and research centers.

Generation of Biomedical Waste Ash

The quality of biomedical waste generated will vary depending upon the hospital and research centre's policies and practices and the type of care being provided. In India, at present approximately 27.30 lakhs metric tons per annum (MTA) of land disposed waste is generated which is much more than the total waste handling capacity (disposal capacity) of common treatment, storage and disposal facilities which is approximately 15.01 lakhs MTA (CPCB, 2008). Thus, a proper waste management system should be required to dispose hazardous/biomedical waste. Several methods have been employed including incineration, steam sterilization, microwave sanitation, chemical disinfection, dry heat disinfection and superheated steam disinfection but the best available technology for disposing of biomedical waste is incineration (Altin *et al.*, 2003; Jang *et al.*, 2005). At present, 170 common biomedical waste treatment facilities are available having 140 incinerators throughout the country. The present generation of incinerable hazardous waste is 4.16 lakhs MTA but the incinerators have only the capacity of 3.28 lakhs MTA (CPCB, 2008). According to an estimate, only 6.67% of waste is incinerated and rest of the waste going to land filled and recycled.

The incineration process destroys pathogens and reduces the waste volume by 90% and weight by 75%. Incineration usually involves the combustion of mingled solid waste with the presence of air or sufficient oxygen. Typically, the temperature in the incinerator is more than 850ºC and the waste is converted into carbon dioxide and water. The incineration of hospital wastes not only releases toxic acid gases (CO, CO_2, NO_2, SO_2, etc), dioxides into the environment but also leaves a solid material called ash as residue includes bottom ash and fly ash which increases the levels of heavy metals, inorganic salts and organic compounds in the environment (Sabiha-Javied *et al.*, 2008). Most of the ash produced is bottom ash that is the residues inside the burner after incineration. Fly ash settles on post burner equipment such as scrubbers. The incinerated hospital waste ash when melted at 1200ºC then the ash is converted in to molten state and the molten ash is turned in to slag by cooling at room temperature. Metals are not destroyed during incineration, and often released into the environment along with ash. Disposal of ash in landfill without proper treatment may cause contamination of groundwater due to leachate. As per CPCB (2008) data on the incineration facilities in India, the incineration of 3.28 lakhs MTA (metric tons per annum) hazardous waste generates approx. 0.82 lakhs MTA of ash throughout the country. Due to increase in population and decreasing land space, such a huge amount of ash generated every year is a cause of concern for its disposal as landfill.

Toxic ash disposal in an environmentally sound manner is problematic and expensive. If handled properly, ash makes incineration prohibitively expensive for all, but if handled improperly it poses short and long term health and environment danger. It was observed that the better the polluting trapping device in an incinerator, the greater the quantity and toxicity content of the residues. A hundred times more dioxin may leave an incineration facility through ash, than in air emissions.

Physico-Chemical Properties of Biomedical Waste Ash

The quantities of bottom ash from the municipal incinerators in Canada and Massachusetts, USA have some difference in ash characteristics depending on the types of incinerator. The density of fly ash was found in the range 0.37-0.82 kg m^{-3} and the density of bottom ash was found in the range 0.73-1.04 kg m^{-3} (Ontiveros *et al.,* 1988). The elemental composition of the bio-medical waste ash can be determined by scanning electron microscope (SEM) or energy dispersive X-ray (EDX) analysis and revealed the presence of SiO_2, CaO, and Al_2O_3 in ash. Biomedical ash is generally composed of high concentration of toxic heavy metals such as mercury (Hg), arsenic (As), lead (Pb), cadmium (Cd), silver (Ag), iron (Fe), zinc (Zn) etc. Anastasiadou *et al.*, (2011) analyzed the composition of medical waste incineration fly and bottom ash by energy dispersive spectroscopy (EDS) and revealed that the major elements of the fly ash were CaO (89.2%), SiO_2 (6.0%) and Na_2O (2.5%), while the major elements of the bottom ash were SiO_2 (39.74%), CaO (27.77%), Na_2O (9.13%), Al_2O_3 (5.16%) and Fe_2O_3 (4.53%), respectively. The quantitative analysis from X-ray diffraction (XRD) showed that the slag produced consisted of residual components after the volatilization of low-boiling-point materials from the incinerated ash. Silicon (SiO_2), calcium (CaO), and aluminum (Al_2O_3) were the three main components of the slag. The dominant metals identified in the slag were Cu, Ba, and Ni. Azni and Katayon (2002) characterized the hospital waste incinerator slag by using X-ray diffraction (XRD) and X-ray fluorescence (XRF). The slag contained large amounts of SiO_2, CaO, Al_2O_3, Sn, Ni, Cu, Ba and B. XRD analysis revealed a moderate crystal structure for the melted slag and identified the main crystals as quartz (SiO_2), kaolinite ($Al_2Si_2O_5(OH)_4$), albite ($NaAlSi_3O_8$) and gibbsite ($Al(OH)_3$). It was observed that the crystal structure of the slag assists in preventing the leaching of heavy metals from the slag.

Zhao *et al.,* (2009) analyzed the chemical properties of heavy metals in hospital or bio-medical waste incinerator ash. The analysis indicated the presence of large amounts of metal salts of Al, Ca, Fe, K, Mg and Na with a concentration range of 1.8 – 325 g kg^{-1}. The high concentration of heavy metals such as Ag, As, Ba, Bi, Cd, Cr, Cu, Mn, Ni, Pb, Ti, Sb, Sr, Sn and Zn with a vast range of 1.1-1, 21, 411 g kg^{-1} was also observed. Furthermore, toxicity characteristic leaching procedure results indicated that leached amount of Cd, Cu, and Pb in all the ash samples exceeded the USEPA limits.

Sabiha-Javied *et al.*, (2008) analyzed the heavy metal (Cd, Cr, Cu, Pb and Zn) concentration in medical waste incineration ash by using flame atomic absorption spectrometer (FAAS). The concentration of Pb and Zn was found relatively higher than that of other constituents in the waste. Higher concentration of heavy metals and dioxins such as Polychlorinated dibenzodioxin (PCDDs) and polychlorinated dibenzofurans (PCDFs) was also observed in medical waste incinerator ash by several researchers (Gidarakos *et al.,* 2009; Racho and Jindal, 2004; Verma and Srivastava, 2000). Bag filter fly ash from hazardous waste incineration was characterized for particle size distribution, chemical composition, metal loading surface area, morphology and chemical environment before and after extraction with toluene (Cobo *et al.*, 2009). It was observed that fly ash consists of low surface area particles of SiO_2 smaller than 0.5 μm agglomerated in spheres between 20 and 100 μm. High concentration of sodium chloride, carbon, and heavy metals such as Cu, Fe, Pb, Hg, Cd, Co and Mn are deposited over the fly ash surface. The carbon is oxidized and forms different structures such as amorphous carbon black, nano balls and more crystalline fullerenes like nano onions. The high concentration of dioxins, furans and dioxin-like PCBs (superior to 185 ng WHO-TEQ g^{-1}) is favored by oxidized carbon, chlorine and metals such as Cu and Fe on the shell of the particles. Before and after toluene extraction, fly ash samples presented similar morphology. However, after extraction their particle size increased while their surface area decreased by 35% and the carbon and metal contents decreased by 35% and 50%, respectively.

Zhao *et al.*, (2008a) investigated the levels of polycyclic aromatic hydrocarbons (PAH) in different types of hospital waste incinerator ashes and found mean PAH levels in the range from 4.16 to 198.92 mg kg^{-1}. The mean concentration of carcinogenic PAHs ranged from 0.74 to 96.77 mg kg^{-1}, exceeding the

regulatory limits. Bottom ashes were dominated by low molecular weight PAHs (LM-PAH; containing two- to three-ringed PAHs) and medium molecular weight PAHs (MM-PAH; containing four-ringed PAHs), while fly ashes were abundant in MM-PAH and high molecular weight PAHs (HM-PAH, containing five- to six-ringed PAHs). Zhao *et al.,* (2008a) also found that PAHs in the ashes correlated highly with some metallic elements either positively (e.g. Fe, Ti, Mg) or negatively (Ca), indicating that these elements might promote or prevent PAH formation during hospital waste combustion. In addition to these, the most common phases include silicates (quartz), alumino-silicates of Ca and Na (plagioclase, ghelenite, pyroxene, olivine, alite, belite), metal oxides, hydroxides (portlandite), sulphates (anhydrite), carbonates (calcite, siderite) (Clozel-Leloup *et al.,* 1999; Zevenbergen and Comans, 1994).
Bottom ash samples (BASH) from the medical waste incinerator (in Athens, Greece) were investigated using Powder X-ray Diffraction (XRD) technique and the data showed BASH to be an amorphous material, analogous to basaltic glass. Bulk analysis by ICP-MS (inductive coupled plasma – mass spectrophotometer) and point analyses by SEM-EDS (scanning electron microscope - energy dispersive spectroscopy) indicated a high content of heavy metals, such as Fe, Cu and Cr, in samples. Gamma-ray measurements showed that the radioactivity of ash sample, due to natural and artificial radionuclides (^{137}Cs, ^{57}Co), was within the permissible levels recommended by IAEA (International Atomic Energy Agency). According to leaching tests, BASH was practically inert with regard to the mobility of the hazardous elements in aqueous media (Kougemitrou *et al.,* 2011). Zhao *et al.,* (2010) examined the presence of heavy metals and PAHs in medical waste incinerator bottom ash. X-ray fluorescence spectroscopy results indicated that CaO, SiO_2 and Al_2O_3 were the main components of the bottom ash. Inductively coupled plasma-optical emission spectroscopy (ICPES) showed that the bottom ash contained large amounts of heavy metals, including Zn, Ti, Ba, Cu, Pb, Mn, Cr, Ni and Sn. Most of the heavy metals (e.g., Ba, Cr, Ni, and Sn) presented in the residual fraction; whereas Mn, Pb and Zn presented in Fe–Mn oxides fraction, and Cu in organic-matter fraction. Zhao *et al.,* (2008b) also studied the chemical properties of rare earth elements (REE) in typical medical waste incinerator ashes in China. The total REE contents in the ash samples were from 10.2 to 78.9 mg kg^{-1} and the sequence of REE contents in the ashes was Ce>La>Nd>Y>Gd>Pr>Sm>Dy>Er>Yb>Ho>Eu>Tb>Lu>Tm. Sequential extraction results showed that REEs in the ash mainly presented as residual fraction and exchangeable and carbonate fractions were relatively low.
Santarsiero and Ottaviani (1995) discussed the landfilling of the solid residues (slags) from the hospital waste incineration in Italy and suggested that the heavy metal concentration should be controlled before the final disposal of the slag to landfill. Based on the analysis of the slag for heavy metal content conducted by atomic absorption spectrometer (AAS), the results showed the potential toxicity of Cd, Cr, Cu, Ni, Pb and Zn with reference to their concentration. The obtained results also showed that the absolute concentration of examined metals in slag is not such as to classify them as toxic and harmful.

Mechanical Properties

The mechanical properties of solidified fly ash and cement matrices products were investigated to study the compressive strength. Lombardi *et al.,* (1998) has studied the mechanical properties of cement solidified, hospital solid waste incinerator fly ash. Fly ash and Portland cement mixtures in ratios varying between 0.25 and 1.5 were tested. Tay (1987) has showed that bottom and fly ash, produced from incinerated hospital waste can be used for the production of concrete and bricks, after mixing (50-50) with the remainder materials. Woolley *et al.,* (2001) examined the toxicity of bottom ash and all the necessary measures must be taken in order to minimize leaching of its hazardous components into the environment. The limited space and the high cost for land disposal led to the development of recycling technologies and the reuse of bottom ash as structural and constructional material (Carbone *et al.,* 1989).

Applications

In several European countries high quantities of ash are reused for the manufacture of pavements, bridges and structural stones but also as sublayer in the manufacture of motorways and as daily cover of landfills.

In Concrete: Aubert *et al.,* (2004) studied the use of municipal solid waste incineration fly ash in concrete. The study was done on the compressive strength and the durability of the hardened concrete and its behavior to leaching. The leaching tests carried out on the concrete confirm that the process makes it possible to obtain materials without major risks for the environment. Also, these results as a whole suggest that the use of waste in concrete constitutes a potential means of adding value. Lombardi *et al.,* (1998) studied the mechanical properties of cement solidified hospital solid waste incinerator fly ash. The mechanical properties of solidified products were investigated fly ash and Portland cement mixtures in ratios varying between 0.25 and 1.5 were tested for unconfined compressive strength after curing in tap water at 20ºC.

Al-Mutairi *et al.,* (2004) compared the compressive strength of mixtures made with bottom and fly hospital ash with those of microsilica and conventional concretes in order to evaluate the effectiveness of reusing hospital incinerator ash. The effect of various percentages of microsilica, fly ash, and bottom ash on the compressive strength was also evaluated at 25°C, 150°C, 250°C, 500°C, 600°C, and 800°C. Results showed that when 5% microsilica and fly ash were incorporated, the compressive strength of the cubes was further increased, indicating a more significant effect. On the contrary, the replacement of cement by 15%, 20%, and 25% fly ash, bottom ash, and microsilica resulted in lower compressive strength. This reduction in the compressive strength at higher ratios of cement replacement could be attributed to the high absorption of free water by the microsilica which in turns reduces the workability. It could be clearly noticed that 5% replacement is optimal for silica and fly ash. As for bottom ash, its use of cement replacement did not achieve any increase in strength. This is hardly surprising since its coarser nature does not qualify it as pozzolonic material.

The decrease in compressive strength was also observed with the increase of percentage of cement replacement above 5% at all temperatures for all three types of concrete (i.e. concrete containing microsilica, fly ash and bottom ash). The maximum strength observed in the neighborhood of 200°C was attributed to the evaporation of free water content. This evaporation of free water reduced the volume of pores in the concrete making it more compact and therefore stronger, while at temperatures above 250°C, the evaporation of chemically bound water caused the disintegration of concrete, thus reducing its compressive strength. About 48% and 40% decrease in compressive strength occurred when 25% by mass of silica and bottom ash was added to the concrete mixture, respectively. However, as the amount of fly ash reached 25% by mass, the rate of decrease of strength becomes lower than 17%.

A comparison of the compressive strength of these three types of concrete compared to a control mixture, without any cement replacement was also observed by Al-Mutairi *et al.,* (2004). It was observed that silica and fly ash increased the compressive strength for 5% cement replacement. For all percentages of cement replacement, fly ash was the closest to the control mix in compressive strength compared to bottom ash and microsilica. An increase in the percentage of silica beyond 5% decreased its strength compared to other types of concrete. At 25% cement replacement above 250°C, the compressive strength of bottom ash and microsilica was almost equal.

In Portland cement mortars: Nowadays, most concretes incorporate mineral additions such as pozzolans, fly ash, silica fume, blast furnace slag, and calcareous filler among others. The chance of incorporating hospital waste ashes in Portland cement-based materials is presented here. Ash characterization was performed by chemical analysis, X-ray diffraction, radioactive material detection, and fineness and density tests. Conduction calorimetry and setting time tests were developed on pastes including ash contents from 0% to 100% (Genazzini *et al.,* 2003). Mortars were prepared including ash contents up to 50% of cement. The results of setting time, temperature development, flexural and compressive strengths, water absorption, density, and leachability are analyzed. Results indicate that Portland cement systems could become an alternative for the disposal of this type of ashes.

Al-Rawas *et al.,* (2005) investigated the potential use of incinerator ash as a replacement for sand and cement in cement mortars. Two sets of mixes were prepared. In the first set, cement and water quantities were fixed while incinerator ash was used at 0%, 10%, 20%, 30% and 40% replacement by weight for sand. In the second set, incinerator ash was used at 0%, 10%, 20% and 30% replacement by weight for cement while sand and water quantities were kept constant. The cement, sand and water mixing proportions were 1:3:0.7, respectively. Results indicated that incinerator ash caused a reduction in slump values when it was used as a replacement for sand while an opposite trend was observed when it was used as a replacement for cement. The replacement of sand by incinerator ash up to 40% exhibited a higher compressive strength than the control mix (0% incinerator ash) for most curing periods. The maximum compressive strength of 36.4 N/mm^2 was achieved using 20% incinerator ash after 28 days of curing. Specimens prepared using 20% incinerator ash replacement for cement yielded a higher compressive strength than the control mix after 14 and 28 days of curing. The maximum compressive strength (27.4 N mm^{-2}) was achieved at 28 days curing period.

In cement-based materials as containment systems: Waste generation has increased considerably worldwide in the last decades. As a consequence, incineration became an alternative for reducing waste volume, leading to the generation of ash as a new type of waste. The new cement–ash composite systems have been tested for future applications in building materials. The additions of hospital waste ash in cement matrices to be potentially used as construction elements. This involved the assessment of the effect of the additions (different proportions of ash and metal-spiked ash) on the physico mechanical properties of the building materials and the leachability of metals (Genazzini *et al.,* 2005). Anastasiadou *et al.,* (2011) evaluated the mechanical properties of the medical waste incineration bottom ash using different amounts of ordinary Portland cement (OPC) as a binder. The solidified matrix showed that the cement was able to immobilize the heavy metals found in fly and bottom ash. Cement-based solidification exhibited a compressive strength of 0.55-16.12 MPa. The strength decreased as the percentage of cement loading was reduced; the compressive strength was 2.52-12.7 MPa for 60% cement mixed with 40% fly ash and 6.62-16.12 MPa for a mixture of 60% cement and 40% bottom ash. The compressive strength reduced to 0.55-1.30 MPa when 30% cement was mixed with 70% fly ash and to 0.90-7.95 MPa when 30% cement was mixed with 70% bottom ash, respectively.

Filipponi *et al.,* (2003) prepared the different mixes by blending hospital waste incinerator bottom ash with ordinary Portland cement in different proportions and at different water dosages. The solidified products were then tested for the unconfined compressive strength (UCS) at different curing times. Results at curing times longer than 28 days and for waste dosages higher than 50% suggested that bottom ash exhibited weak pozzolanic property. Furthermore, due to such a weak pozzolanic effect, even at high curing ages (90 days) the specific UCS of the mixtures was lower than that of the control specimens, so that cement dilution still adversely affected the final strength of the products. Thus, this study suggested the need for further studies aimed at enhancing the reactivity of BA, either through an increase in the specific surface area of the material, or the addition of appropriate chemical activators able to promote pozzolanic reactions development.

In agriculture: Biomedical waste ash has potential for use in agriculture because it contains almost all macro as well as micronutrients except organic carbon and nitrogen. It may act as chemical fertilizer to increase the yield of various agricultural crops. The various doses of ash, cow dung, urea and super phosphate were used for the treatment of Fenugreek and Mustard (Goswami-Giri, 2007). Effect of these fertilizers depends upon the type of crop as well as the type of soil. The positive effect of ash application was observed on average growth of Fenugreek and Mustard. The yield of Fenugreek and Mustard is increased around 54-55% and 35% when compared with control, respectively. For this purpose 1.0 gm and 1.5 gm of ash was applied respectively, in all the treatments.

As a stabilizing agent in road and asphalt pavements: In Germany 50% of the ash produced from incinerated waste is used for the manufacturing of sound insulation walls at National roads, as well as, sub layers on the streets. 60% of the bottom ash is used for the construction of asphalt and as a sub layer of roads in Netherlands. Above 72% of ash is reused for the manufacture of parking spaces, cycling tracks and other roads in Denmark (Reijnders, 2005). The hospital waste in Selangor, Malaysia is incinerated and subsequently melted at 1200°C. Scanning election microscope (SEM)/EDX results showed that the

Review Article

hospital waste incinerator slag produced after melting the incinerator ash contained amounts of SiO_2, CaO, and Al_2O_3 in excess of 53%, 9%, and 16%, respectively (Azni *et al.,* 2005). The results from a leaching analysis on the slag produced proved that the melting process had successfully stabilized the heavy metals and this slag can be used as an alternative material to replace conventional aggregates for road construction. The results from aggregate and asphalt mix tests showed that the slag fulfills all the requirements of an alternative aggregate.

The suitability of using molten slag as an asphalt aggregate was also investigated by Azni *et al.,* (2005) by conducting a penetration test (ASTM D5) and a thin-film oven test (ASTM D1754), measuring the softening point (ASTM D36) and the bulk specific gravity (ASTM D70). The strength of the aggregates to resist abrasion and impact was evaluated using the Los Angeles abrasion test (ASTM C131). The abrasion test result was found to be 25.01%, which complies with the standard requirement (30%). The toughness of the aggregate to resist fracture under the impact of moving loads was 29.82%, which also reaches the required standard (30%). The aggregate crushing value of molten slag was measured as 15.94%. This value gives a relative measure of the resistance of the aggregate to crushing under a gradually increasing load, and also reaches the required standard (± 30%).

The angularity number, or absence of rounding, of the aggregate was recorded as 7, which is within the standard range of 6–9. The angularity number is an important property because it affects the workability and stability of an aggregate–asphalt mixture, which relies on the interlocking of the particles. Aggregates with more angular shapes provide good interlocking, stability and reliability. Other properties, including water absorption, polished stone value, and soundness, also complied with the standard requirement. In general, the results revealed that hospital waste molten slag fulfills all the requirements for aggregate application. Therefore, hospital waste slag was found to be suitable for use as a replacement aggregate.

Leachate Analysis

In environmental applications, leaching represents the source term for release of potentially hazardous substances. Assessing the leaching of pollutants to groundwater is one of the key pathways when evaluating the risk of solid wastes on human health and the environment. Leaching of waste generates leachate, a liquid that drains from the landfill and its composition varies widely depending upon the age and the waste contained landfill material. The risks of leachate generation can be mitigated by properly designed and engineered landfill sites.

Sukandar *et al.,* (2006) studied the metal leachability from medical waste incinerator fly ash by sequential extraction and toxicity characteristics leaching procedure (TCLP) analysis in each categorized particle size. Based on the study it was observed that Ba, Cd, Ni, Pb, and Zn in the medical waste incinerator fly ash showed high mobility. They tended to bind to carbonate and exchangeable fractions with the exception of a range of particle size 150 -106 µm. Arsenic (As), Cd, Cr, Ni, Pb, Sn, and Zn in particle size fraction of 150 -106 µm tended to bind to the Fe-Mn oxide matrix. Sequential extraction also demonstrated that both exchangeable and carbonate associated Cr concentrations were elevated in the bigger particle size sample whereas Ba was found in smaller particle fraction. Leachability of Cd, Cr, Cu, Hg, Ni, Sn, and Zn determined by TCLP method was not statistically different among the categorized particle size. Leachability of arsenic in particle size fraction of 38 µm tended to be higher than the other particle size fractions. Ba and Pb showed the highest leachability in the particle size fraction of 150-106 µm and 75-38 µm respectively. Toxicity characteristics leaching procedure (TCLP) test of medical waste incineration bottom ash conducted by Zhao *et al.,* (2010) indicated that the leached amounts of heavy metals were well below the limits. The sum of 16 US EPA priority PAHs (ΣPAHs) varied from 10.30 to 38.14 mg kg^{-1}, and the total amounts of carcinogenic PAHs ranged between 4.09 and 16.95 mg kg^{-1}, exceeding the regulatory limits.

Anastasiadou *et al.,* (2011) studied the cement based stabilization/solidification of fly and bottom ash generated from incinerated hospital waste to reduce the leachability of the heavy metals present in these materials. TCLP test of untreated medical waste incinerated fly ash showed high concentrations of Zn (13.2 mg l^{-1}) and Pb (5.21 mg l^{-1}), and lesser amounts of Cr, Fe, Ni, Cu, Cd and Ba

Review Article

in leachate. Aubert *et al.*, (2004) studied leachate analysis of municipal solid waste incineration fly ash containing concrete and showed that the process of utilizing the fly ash makes it possible to obtain materials without major risks or the environment. Also, these results as a whole suggest that the use of waste in concrete constitutes a potential means of adding value. Leaching behavior and mechanical properties of cement solidified hospital solid waste incinerator fly ash was also studied by Lombardi *et al.*, (1998). Leaching tests were performed both on fly ash and solidified/stabilized products using an acetic acid standard leaching test and dynamic leaching test.

Tan *et al.*, (2008) studied the influence of leaching time, pH and grain size on the leaching characteristics of heavy metal and the effect of melting on the stabilization of fly ash of medical waste. Results showed that following the leaching time extending, the leaching concentrations of heavy metals and lixiviate toxicity of heavy metals increased in the fly ash. At pH 7, the leaching concentrations of heavy metals were the lowest. When the grain size is the bigger or little, the leaching concentrations of heavy metals were lower, however when the grain size is 250-900 µm, the leaching concentrations were higher. After fly ash melted in the high temperature, the lixiviate toxicity of heavy metals greatly reduced, which explains that the effect of melting on heavy metals' stabilization is very good.

Valavanidis *et al.*, (2008) conducted a study to determine quantitatively the metal leachability of medical waste incineration fly ash and bottom ash by inductive coupled plasma emission spectrometry (ICPES) and by energy dispersive X-ray analysis (EDAX). Results showed that Pb, Cr, Cd, Cu and Zn have high leaching values in both the ashes extracted with water and kerosene. These results indicate that metals can become soluble and mobile if ash is deposited in landfills, thus restricting their landfilling according to EU regulations. Analysis of polychlorinated biphenyls and polycyclic aromatic hydrocarbons showed their very low concentrations in both fly and bottom ashes. Similar study was also conducted by Gidarakos *et al.*, (2009) in Greece.

Azni *et al.*, (2005) conducted leaching of metals in the hospital waste molten slag according to the Environmental Protection Agency extraction procedure (EPA EP) toxicity test. In EPA EP method the sample was extracted with distilled water at a ratio of 1:16 at different pH values (pH 3 and pH 5) for 24 h. The results of the EPA EP toxicity test on hospital waste molten slag are given in Table 1. It was observed that the metal concentrations in the leachate at both pH 3 and pH 5 were below the maximum limits specified by the US EPA. Thus, the study concluded that to stabilize the heavy metals in the waste melting method can be applied successfully, and it therefore appears that this is an effective method for disposal.

Table 1: Leaching of metals from the hospital waste molten slag[a] (Azni et al. 2005).

Metals ($mg\ l^{-1}$)	pH 3 (mean ± SD)	pH 5 (mean ± SD)	Standard limits ($mg\ l^{-1}$)[c]
As	3.14 ± 0.82	0.08 ± 0.01	5
Ag	1.25 ± 0.05	0.09 ± 0.01	5
Ba	35.1 ± 5.49	0.09 ± 0.01	100
Cd	0.02 ± 0.01	ND[b]	1
Cr	3.59 ± 0.96	1.46 ± 0.03	5
Cu	42.85 ± 9.17	36.19 ± 5.53	100
Hg	ND	ND	0.2
Ni	27.45 ± 2.14	9.19 ± 1.43	100
Pb	2.34 ± 0.05	1.17 ± 0.03	5
Se	0.01 ± 0.01	ND	1

a-All data are means of six samples
b-ND, not detected
c-United States Environmental Protection Agency maximum limits for disposal of waste to landfill

CONCLUSION

Waste generation has increased considerably worldwide in the last few decades. Biomedical wastes from hospitals and other healthcare and research centers has become an imperative environmental and public safety problem. So, it is necessary that the biomedical wastes should be disposed in a manner which is least harmful to the human beings. Incineration is the most appropriate alternative for reducing the waste volume but generates a new type of waste in the form of fly ash, bottom ash and molten slag. The uncontrolled disposal of these ashes and slag causes significant damages as these contaminates the soil as well as surface and underground water due to heavy metal toxicity and presence of dioxins and furans. Thus to minimize this, several work has been done on utilizing the biomedical waste incinerator ash and slag in cement and concrete and studied the mechanical properties of these building materials. Results of mechanical properties showed that the use of fly ash and bottom ash can be successfully utilized in cement and concrete systems. Utilization of biomedical waste incinerator slag as road and asphalt aggregate also showed promising results. Studies also showed the use of biomedical waste ash in the field of agriculture in the form of fertilizer as it contains macro and micro nutrients except carbon and nitrogen. Thus, this review provides critical information on the proper utilization of biomedical waste incineration ashes and slag, also there is need to further evaluate the other suitable ways of disposing and utilizing the ashes and slag generated from biomedical waste incinerators.

REFERENCES

Al-Mutairi N, Terro M and Al-Khaleefi AL (2004). Effect of recycling hospital ash on the compressive properties of concrete: statistical assessment and predicting model. *Building and Environment* **39** 557-566.

Al-Rawas AA, Hago AW, Taha R and Al-Kharousi K (2005). Use of incinerator ash as a replacement for cement and sand in cement mortars. *Building and Environment* **40** 1261-1266.

Altin S, Altin A, Elevli B and Cerit O (2003). Determination of hospital waste composition and disposal methods: a case study. *Polish Journal of Environmental Studies* **12** 251-255.

Anastasiadou K, Christopoulos K, Mousios E and Gidarakos E (2011). Solidification/stabilization of fly and bottom ash from medical waste incineration facility. *Journal of Hazardous Material* (Article in Press) doi: 10.1016/j.hazmat.2011.05.027

Aubert JE, Husson B and Vaquier A (2004). Use of municipal solid waste incineration fly ash in concrete. *Cement and Concrete Research* **34** 957-963.

Azni I and Katayon S (2002). Characteristics of slag produced from incinerated hospital waste. *Journal of Hazardous Material* **93** 201-208.

Azni I, Katayon S, Ratnasamy M and Johari MMNM (2005). Stabilization and utilization of hospital waste as road and asphalt aggregate. *Journal of Material Cycles and Waste Management* **7** 33-37.

Carbone LG, Gutenmann WH and Lisk DJ (1989). Element immobilization in refuse incinerator ashes by solidification in glass, ceramic or cement. *Chemosphere* **19** 1951–1958.

Clozel-Leloup B, Bodenan F and Piantone P (1999). Bottom ash from municipal solid waste incineration: mineralogy and distribution of metals, in: Mehu J, Keck G, Navarro A (ed) STAB & ENV 99. *Proceedings of the International Conference on Waste Stabilization and Environment*. Lyone Villeurbanne, France: Societ´ e Alpine de ´ Publications. pp 46–51

Cobo M, Galvez A, Conesa JA and de Correa CM (2009). Characterization of fly ash from a hazardous waste incinerator in Medellin, Colombia. *Journal of Hazardous Material* **168** 1223-1232.

CPCB (2008). *Hazardous waste management* [Online], Chapter 9. Highlights 2008, Central Pollution Control Board, India http://www.cpcb.nic.in/Highlights/2008/chapter-9.pdf

Filipponi P, Polettini A, Pomi R and Sirini P (2003). Physical and mechanical properties of cement based products containing incineration bottom ash. *Waste Management* **23** 145-156.

Genazzini C, Giaccio G, Ronco A and Zerbino R (2005). Cement-based materials as containment systems for ash from hospital waste incineration. *Waste Management* **25**: 649-654.

Genazzini C, Zerbino R., Ronco A, Batic O and Giaccio G (2003). Hospital waste ashes in Portland cement mortars. *Cement and Concrete Research* **33** 1643-1650.

Gidarakos E, Petrantonaki M, Anastasiadou K and Schramm KW (2009). Characterization and hazard evaluation of bottom ash produced from incinerated hospital waste. *Journal of Hazardous Material* **172** 935-942.

Goswami-Giri A (2007). Effect of biomedical waste ash on growth and yield fenugreek and mustard. *Bionano Frontiers* **1** 64-66.

Jang YC, Lee C, Yoon OS and Kim H (2005). Medical waste management in Korea. *Journal of Environmental Management* **80** 1-9.

Kougemitrou I, Godelitsas A, Tsabaris C, Stathopoulos V, Papandreou A, Gamaletsos P, Economou G and Papadopoulos D (2011). Characterisation and management of ash produced in the hospital waste incinerator of Athens, Greece. *Journal of Hazardous Material* **187** 421-432.

Lombardi F, Mangialardi T, Piga L and Sirini P (1998). Mechanical and leaching properties of cement solidified hospital solid waste incinerator fly ash. *Waste Management* **18** 99-106.

Mastorakis NE, Bulucea CA, Oprea TA, Bulucea CA and Dondon P (2011). Holistic approach of biomedical waste management system with regard to health and environmental risks. *International Journal of Energy and Environment* **5** 309-318.

NEAS (2006). *Solid waste management :principles and terminologies*. Prepared by Prakriti, Centre for Management Studies, Dibrugarh University as part of the National Environment Awareness Compaign 2006-07.

Ontiveros JL, Kosson DS and Ablert RC (1988). Leaching Characteristics and composition of Residual ashes from Various Municipal Incinerators. In: Wu (ed) *International Conference on Physico-chemical and Biological Detoxification of Hazardous Wastes* , Technomic Publishing, New Jersy, pp. 515-526.

Racho P and Jindal R (2004). Heavy metals in bottom ash from a medical waste incinerator in Thailand. *Practice Periodical of Hazardous Toxic Radioactive Waste Management* **8** 31–38.

Reijnders L (2005). Disposal, uses and treatments of combustion ashes: a review. *Resource Conservation and Recycling* **43** 313–336.

Sabiha-Javied, Tufail M and Khalid S (2008). Heavy metal pollution from medical waste incineration. *Microchemical Journal* **90** 77-81.

Santarsiero A and Ottaviani M (1995). Evaluation of heavy metals in slags from medical waste incinerator. *Microchemical Journal* **51** 166-169.

SOER (2009). *State of Environmental Report* [Online], India 2009. Ministry of environment and forests, Govt. of India. www.moef.nic.in/downloads/home/home-SOE-Report-2009.pdf

Sukandar S, Yasuda K, Tanaka M and Aoyama I (2006). Metals leachability from medical waste incinerator fly ash. A case study on particle size comparison. *Environmental Pollution* **144** 726-735.

Tan ZX, Liao HY, Xie JJ, Wang XB, Li HB and Zhao ZL (2008). Leaching and stabilization of heavy metal in the fly ash of medical wastes. *Huan Jing Ke Xue* **29** 1124-1132.

Tay JH (1987). Sludge ash as filler for Portland cement concrete. *Journal of Environmental Engineering ASCE* **113** 278–283.

Valavanidis A, Lliopoulos N, Fiotakis K and Gotsis G (2008). Metal leachability, heavy metals, polycyclic aromatic hydrocarbons and polychlorinated biphenyls in fly and bottom ashes of a medical waste incineration facility. *Waste Management* **26** 247-255.

Verma LK and Srivastava JN (2000). Dioxins and furans and hospital waste incineration. *Contemporary Issue* **56**: 53-54.

Woolley GR, Wainwright PJ and Goumans JJJM (2001). Science and engineering of recycling for environmental protection: an overview of the WASCON 2000 conference. *Waste Management* **21** 211–212.

Zevenbergen C and Comans RNJ (1994). Geochemical factors controlling the mobilization of major elements during weathering of MSWI bottom ash. *Environmental aspects of construction with waste materials*. Elsevier Science, BV Amsterdam 145-156.
Zhao L, Zhang FS, Chen M, Liu Z and Wu DBJ (2010). Typical pollutants in bottom ashes from a typical medical waste incinerator. *Journal of Hazardous Material* **173** 181-185.
Zhao L, Zhang FS, Hao Z and Wang H (2008b). Levels of polycyclic aromatic hydrocarbons in different type of hospital waste incinerator ashes. *Science of the Total Environment* **397** 24-30.
Zhao L, Zhang FS, Wang K and Zhu J (2009). Chemical properties of heavy metals in typical hospital waste incinerator ashes in China. *Waste Management* **29** 1114-1121.
Zhao L, Zhang FS and Zhang J (2008a). Chemical properties of rare earth elements in typical medical waste incinerator ashes in China. *Journal of Hazardous Material* **158** 465-470.