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MSW Incinerated Ashes from Delhi: Study of Leaching Characteristics for Disposal and Reuse Options

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Abstract. Municipal Solid Waste (MSW) incineration (MSWI) in waste-to-energy (WtE) facilities generates about 20-25% residues as bottom ash (85%) and fly ash (15%). This study aims to determine the leaching behavior of these residues collected from two MSWI plants in Delhi to ascertain whether they are suitable for reuse in geotechnical applications or must be disposed in landfills. EN 12457-2/4 (2002) batch leaching tests were performed on bottom ash (BA), fly ash (FA), and combined ash (85% bottom ash and 15% fly ash). The leaching characteristics were compared to international regulatory standards for disposal to landfills and reuse in field applications. It was revealed that bottom ash and combined ash were acceptable for disposal to non-hazardous waste landfills, whereas fly ash can only be disposed in hazardous waste landfills due to excessive leaching of total dissolved solids (TDS), Cl^- and SO_4^{-2} from FA. BA was found acceptable for reuse in field applications in a restricted manner, whereas the issue of excess sulfates and chlorides needs to be addressed before unrestricted reuse. Mixing of BA and FA result in transfer of contaminants from highly contaminated FA to less contaminated bottom ash and thereby necessitate intensive treatment of CA prior to reuse in field applications. Hence, co-disposal of BA and FA is should be avoided.

Keywords: MSWI Bottom Ash, MSWI Fly Ash, Batch Leaching, Disposal, Reuse.

1 Introduction

India is witnessing the rise of MSW incineration (MSWI) plants wherein municipal solid waste (MSW) undergoes combustion in the temperature range of 850-1000°C. Typically, a MSWI plant produces 15-25% residues, comprising primarily of bottom ash (80-90%) and remaining fly ash (10-20%) [1,2]. While fly ash has mainly been categorized as hazardous in several countries, bottom ash can potentially be recycled in civil engineering applications [3-8]. However, in India, these residues are currently dumped in open dumps, MSW landfills, or mining pits due to the dearth of scientific studies in the country and the absence of any national regulatory framework governing their disposal or reuse [9]. India has regulated the mining of sand and other natural resources due to growing environmental concerns [10]. This has resulted in a shortage of natural resources for the construction purposes and a shift in the emphasis towards utilization of secondary/recycled aggregates. The reuse of incineration residues as a substitute to natural resources can contribute to the sustainable development goals of the country [11].

Globally, incineration residues have been used in road construction, landfill covers, building materials etc. [3-9,12]. However, several studies have revealed the variability in characteristics of MSWI ashes based on the composition of MSW, pre-processing of waste, and operating conditions of the incinerator [4,8,12]. Limited studies are available from India that have characterized MSW incineration ashes [13-14]. Only a single study has addressed the leaching of contaminants from the soil-sized fraction of bottom ash to assess its disposal and reuse options [9]. No study from the country has addressed the reuse and disposal of fly ash, the complete fraction of bottom ash, and combined ash, i.e., the mixture of bottom ash and fly ash.

The present study evaluates the leaching characteristics of MSWI ashes, i.e., bottom ash, fly ash, and the mixture of bottom ash and fly ash. This would assist in determining if they can be reused in field applications or should be disposed in landfills. The assessment of the same has been made based on European leaching tests and regulations as India is yet to develop a legal framework governing the fate of incineration residues.

2 Material and Methodology

2.1 Material Collection

Three MSWI plants are operational in different parts of Delhi [15]. In the current study, MSWI ash samples were collected from two of these plants, which are referred as Plant A and Plant B. These plants receive approximately 4000 tons of MSW daily [9], which after pre-processing is converted into refused derived fuel (RDF) and is fed to the incinerator. Bottom ash (BA) samples were collected from bottom ash hoppers after water quenching, whereas fly ash (FA) samples were collected from the fly ash silos located at the MSWI facility. FA stored in the silos is comprised of a combination of ashes collected from heat recovery systems and air pollution devices (i.e., lime scrubber and bag filter).

BA samples were air-dried under a shed for about a week. Thereafter, air-dried BA was screened to remove the oversized fraction (greater than 31.5 mm) which comprised of unburnt organics, cobbles, bricks, etc., and constituted only 5% of the total sample. The BA fraction passing 31.5 mm was sent to the laboratory for further testing. FA samples were stored as it is in air-tight containers. Fig.1 shows the representative samples of BA and FA.

Fig. 1. Representative samples of MSWI ashes; **(a)** BA **(b)** FA

2.2 Methodology

MSWI ashes were classified as per Unified Soil Classification System (USCS) based on grain size distribution (GSD) and plasticity. The GSD of BA was determined by wet sieve analysis using ASTM D6913/6913M-17 [16]. The GSD of FA was assessed by laser diffraction spectrometry [17] using Malvern Mastersizer 3000E. Plasticity of the samples were determined using ASTM D4318 and IS: 2720-5 (1985) [18-19].

Assessment of leaching of contaminants from the waste material is crucial in determining its options for disposal and reuse. EN 12457-2/4 leaching tests were performed on BA, FA, and combined ash (CA) as per the standard protocol [20-21]. Combined ash constituted 85% BA and 15% FA, which is the typical proportion of their generation at the MSWI plant. Combined ash is representative of the disposal scenario of incineration residues in India, i.e., co-disposal of BA and FA. It should be noted that the conventional USEPA TCLP (toxicity characteristics leaching procedure) method of leaching [22] has not been used in the present study because of its limitation of being conservative in estimating the leaching of contaminants from MSWI ash [9,23].

EN 12457-2/4 leaching method involves mixing of samples with deionized (DI) water at a liquid to solid ratio of 10 liters per kg in an end-to-end rotator for 24 hours. The suspension obtained is then filtered over a 0.45-micron filter and the filtrate is analyzed for pH, total dissolved solids (TDS), sulfates, chlorides, and trace metals. TDS, chlorides, and sulfates were determined using the gravimetric method, silver nitrate titration, and turbidimetric method, respectively, as per the APHA standards [24]. Trace metals were determined using inductively coupled plasma mass spectroscopy (ICP-MS).

The leaching concentration of the contaminants was compared with regulatory limits (shown in Table 1) established by the European Union [25] for disposal of waste to hazardous waste (HW), non-hazardous waste (NHW), and inert waste (IW) landfills and those given by Belgium, France, and the Netherlands [26-28] for reuse of waste in field applications. Some additional details on the reuse criteria are mentioned in Table 2.

Table 1. Regulatory limits for disposal and reuse of waste (in mg/kg)

Regulation origin	Disposal limits EU Council (2003)			Reuse limits Belgium (2001)	France (2011)	Netherlands (2007)	
Disposal/ Reuse type	IW landfills	NHW landfills	HW landfills	See Table 2			
Abbreviation	E-IW	E-NHW	E-HW	B1	F1	N1	N2
TDS	4000	60000	100000				
Cl^-	800	15000	25000	5000	5000	616	8800
SO_4^{-2}	1000	20000	50000	10000	5000	1730	20000
Ba	20	100	300	-	28	22	100
Cd	0.04	1	5	1	0.05	0.04	0.06
Co	-	-	-	1	-	0.54	2.4
Cr	0.5	10	70	1	1	0.63	7
Cu	2	50	100	20	50	0.9	10
Mo	0.5	10	30	1.5	2.8	1	15
Ni	0.4	10	40	2	0.5	0.44	2.1
Pb	0.5	10	50	2	1	2.3	8.3
Sb	0.06	0.7	5	2	0.6	0.32	0.7
Se	0.1	0.5	7	-	0.1	0.15	3
Zn	4	50	200	9	50	4.5	14

Table 2. Additional details on the regulatory criteria governing the reuse of waste

Reuse category	Reuse type	Additional restrictions other than leaching of contaminants
B1	Roads, foundations, development, and rehabilitation of landfills	Screening, metal removal, and ageing; Total leaching concentrations (Cd, Cr VI, Cu, Hg, Ni, Pb, Zn) < 50 mg/kg
F1	Technical backfill related to the road or shoulder infrastructure; underlays of pavement or shoulder of paved road structures (up to 6 m height)	Total organic carbon < 3%; Distance from the highest groundwater level > 0.5 m; Distance from any watercourse > 30 m; Use prohibited for the realization of draining systems or performing preloading operations; Use prohibited in flood plains, national parks, and outcrop karst areas

N1	**Open reuse:** material can be reused as such with allowed infiltration of 300 mm/year (up to 15 m height)	Loss on ignition < 5%
N2	**Isolated reuse:** material canbe reused with allowed infiltration of 6 mm/year (up to 15 m height)	Loss on ignition < 5%; Distance from highest groundwater level > 0.5 m

3 Results and Discussion

3.1 Classification of materials based on GSD and plasticity

The results of GSD and plasticity are presented in Table 3. Both, BA and FA, are non-plastic in nature and can be classified as silty sand with gravels and sandy silt, respectively, as per USCS. However, it is vital to understand their leaching characteristics prior to implementing their reuse as a replacement of gravel, sand or silt in field applications.

Table 3. Basic properties of MSWI ashes

Property	BA	FA
Gravel-sized fraction (> 4.75 mm), %	29.0-33.0	-
Sand-sized fraction (0.075mm - 4.75 mm), %	58.3-59.0	15-18
Fines (< 0.075 mm), %	8.7-11.0	82-85
Average Particle Size (D_{50}), mm	1.2-2.1	0.033-0.038
Plasticity	Non-plastic	Non-plastic
USCS classification	Silty sand with gravel	Sandy silt

3.2 Leaching test results

The leaching test results are presented in Fig. 2. The results are superimposed over disposal and reuse limits as specified in Table 1.

3.2.1 Comparison with disposal limits

It can be observed from Fig. 2 that BA is unsuitable for disposal to inert waste landfills as leaching concentration of Sb, TDS, Cl^- and SO_4^{-2} exceed the E-IW limits. However, it is acceptable for disposal in non-hazardous waste landfills. FA cannot be disposed in inert waste landfills as almost all the trace metals, TDS, Cl^- and SO_4^{-2} exceed the E-IW disposal criteria. FA should neither be disposed in non-hazardous waste landfills as leaching of Cd, Pb, TDS, Cl^- and SO_4^{-2} exceed E-NHW limits. Hence, FA must be disposed in hazardous waste landfills. CA is unsuitable for disposal to inert waste landfills as leaching concentration of Cd, Mo, Ni, Sb, TDS, Cl^- and SO_4^{-2} exceed E-IW limits. However, it can safely be disposed in non-hazardous waste landfills. Thus, co-disposal of BA and FA in NHW landfills appears to be a viable option.

Co-disposal of BA and FA in non-hazardous waste landfills would be advantageous for the plant operators as it would result in lower cost of disposal as isolated disposal of FA in hazardous waste landfills would incur higher expenditure. However, it is important to note that BA is less contaminated in comparison to FA but their co-disposal would increase the contamination level of the less contaminated fraction which was previously limited to only 15% of the total fraction i.e., FA. It would deter any future utility of the incineration residues and therefore, it is recommended BA and FA should be collected as well as stored independent to each other.

3.2.2 Comparison with reuse limits

The leaching characteristics of BA were found satisfactory with respect to Belgium reuse criteria which permits its use in roads, foundations, and the development and rehabilitation of landfills [26]. BA also seems to be acceptable for reuse with regard to French standard which permits its reuse in backfills and paved roads. BA was found unsuitable for open reuse but satisfactory for isolated reuse with allowable infiltration of 6 mm/year when compared with the reuse criteria given by The Netherlands [28]. However, it should be noted that the additional restrictions on reuse as specified in the regulations by Belgium, France or Netherlands (shown in Table 2) should also be adhered prior to implementation of reuse of BA.

FA and CA were found unacceptable for reuse in field applications as leaching concentration of most of the contaminants surpassed the reuse limits. FA has high concentration of TDS, Cl^-, SO_4^{-2} and trace metals (Cd, Cr, Mo, Pb, and Zn) compared to reuse limits, rendering it unsuitable for use in field applications. The contaminants in CA are higher when compared to BA but lower in comparison to FA. These contaminants are above the prescribed reuse limits, necessitating intensive treatment of CA prior to reuse.

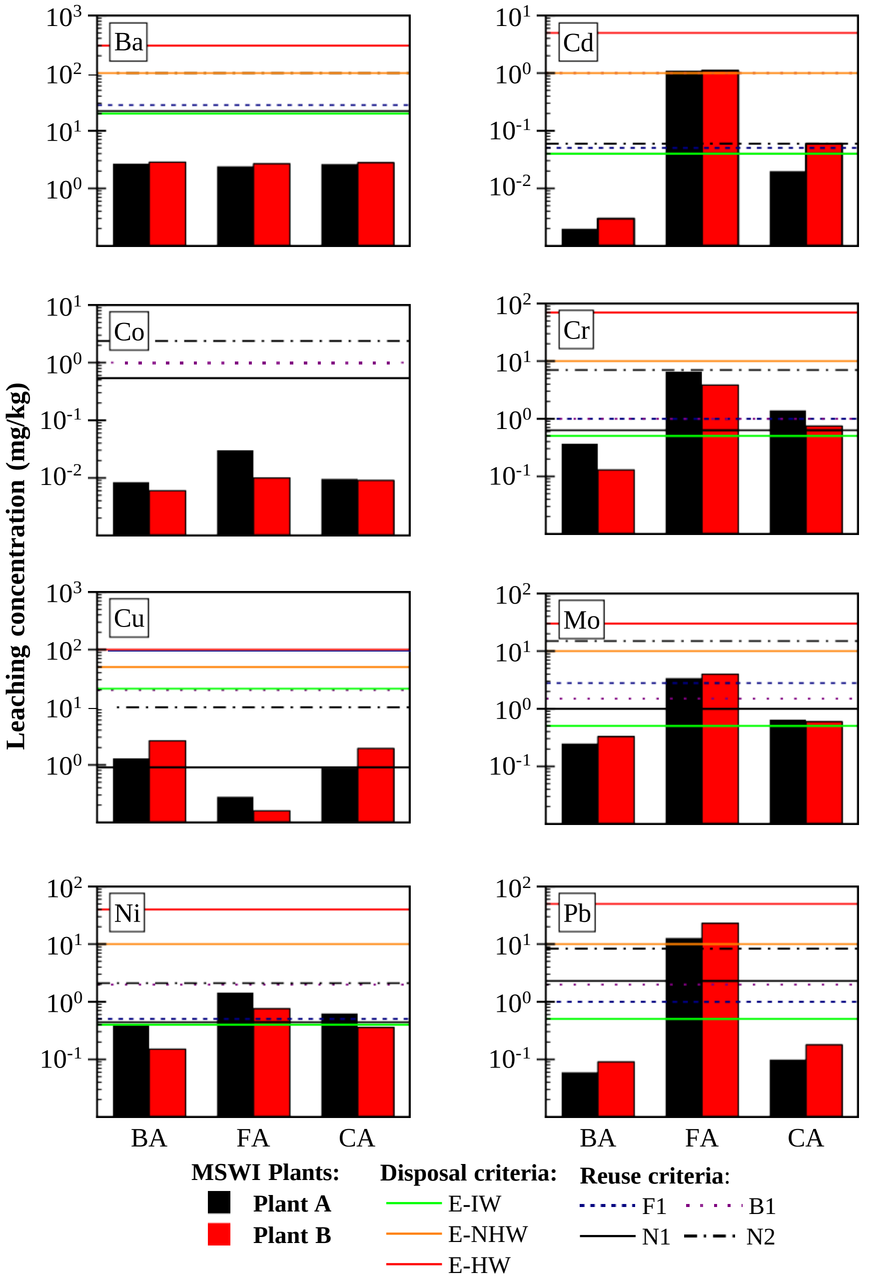

Fig. 2. Leaching concentration of MSWI ashes and comparison with disposal and reuse limits

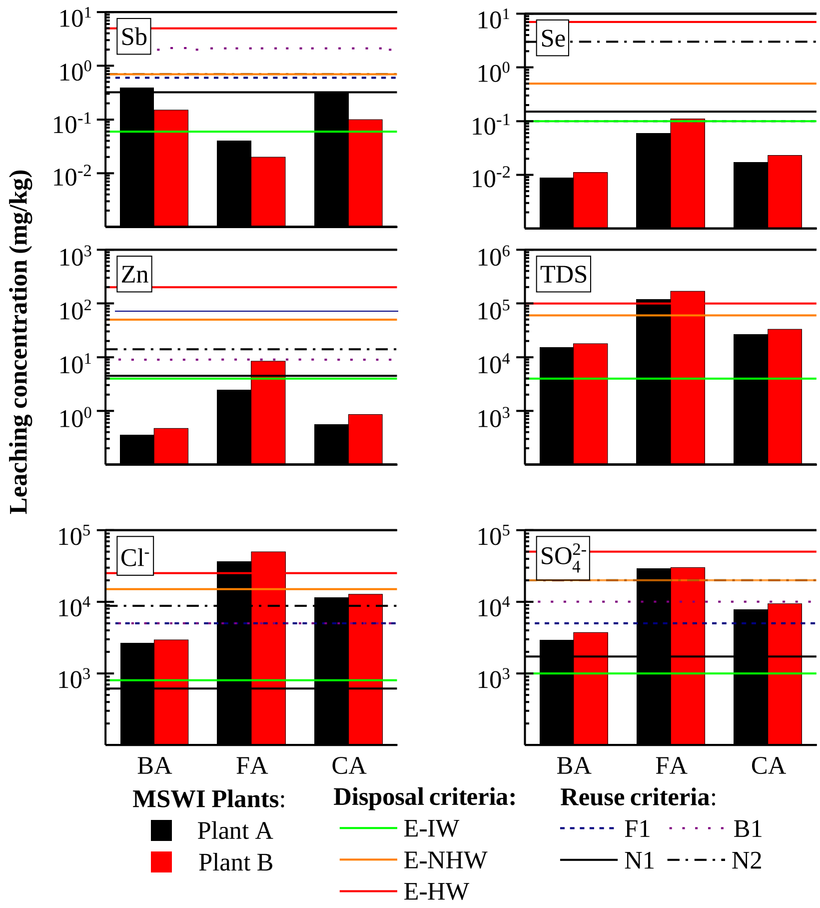

Fig. 2 (contd.) Leaching concentration of MSWI ashes and comparison with disposal and reuse limits

4 Conclusions

The study classified bottom ash and fly ash based on grain size distribution and plasticity characteristics. The study delved deeper to identify the options for disposal and reuse of bottom ash, fly ash and combined ash by investigating their leaching characteristics. It was revealed that MSWI ash samples are non-plastic in nature with bottom ash having grain size comparable to silty sand with gravels while fly ash is similar to sandy silt.

The results of leaching tests revealed that BA is not suitable for unrestricted reuse. However, it can potentially be reused in roads, backfills, foundations, etc. in restricted manner as per the regulations laid by Belgium, France and Netherlands. Bottom ash is not acceptable for disposal to inert waste landfills but can be disposed in non-hazardous waste landfills. Fly ash, on contrary, is neither suitable for reuse in field applications nor acceptable for disposal to non-hazardous waste landfills or inert waste landfills. Fly ash should, therefore, be disposed in hazardous waste landfills. The co-disposal of fly ash and bottom ash in non-hazardous landfills seems feasible. However, it is recommended to avoid co-disposal of bottom ash and fly ash as doing so would result in the transfer of contaminants from highly contaminated fly ash to less contaminated bottom ash and thereby limiting any possible reuse of bottom ash.

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