# Estimation of Total Soluble Solids in MSW Incineration Bottom Ash by Higher Dilution Method: Assessment for Geotechnical Reuse

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**Abstract.** The unavailability of new space and brimming of the existing ones to dump municipal solid waste (MSW) in cities like Delhi has caused the Government to switch to MSW incineration (MSWI) in waste-to-energy (WtE) plants. Attempts are being made worldwide to utilize the residues from WtE plants as a substitute for natural soil in civil engineering applications. Though adequate from the strength perspective, MSWI bottom ash (BA) has significantly high total soluble solids (SS) which need to be addressed before being put to reuse. The present study assesses whether the existing Indian Standards IS-2720 Part-XXI for estimating SS in soil can be used for soil-like-fraction of MSWI BA or if certain modifications are required. The study identifies that the dilution ratio (DR) or liquid-to-solid ratio of 10 l/kg used in the standard method to dissolve all the soluble solids is inadequate for estimation of SS in the soil-like-fraction from MSWI BA. SS was measured in MSWI BA collected from three WtE plants in Delhi and the results were compared with coal BA from a thermal power plant and two locally available soils. The procedure as mentioned in IS-2720 Part-XXI was adopted but with minor modifications and with varying DR ranging from 10 to 200 l/kg. DR of 10 l/kg, though adequate for SS determination in coal BA and local soils, underestimated SS levels in MSWI BA substantially. It is recommended that IS-code method be used with caution for estimating SS in materials which are soil-like but not exactly soil.

**Keywords:** Total Soluble Solids, MSW Incineration, Bottom Ash

## 1 Introduction

Rapid urbanization, population explosion and increase in the standard of living has laden the natural resources disproportionately and exacerbated the problems of waste disposal. Cities like Delhi, which have outgrown their boundaries are striving hard for additional space to dump these alarming quantities of waste. The fallout has caused India to witness the rise of waste-to-energy plants wherein municipal solid waste (MSW) is burnt to ashes and energy is recovered as a by-product. This process of incineration reduces the waste quantities substantially. Literature reports 70-80% of mass reduction and up to 90% volume reduction of MSW in such plants worldwide [1-9].

Temperatures as huge as 850-1000°C in incinerator furnace eliminates most of the organic material present in incoming MSW, leaving behind inorganic ash residues, namely, bottom ash and fly ash. MSW incineration (MSWI) bottom ash constitutes 80-90% of these residues and relatively small quantities of fly ash are generated [1-9].

Coal combustion residues (CCRs) from thermal power plants have widely been recognized as a substitute for natural materials in numerous geotechnical applications and in building construction materials [10,11]. Akin to CCRs, the residues from MSW incineration has similar potential and attempts are being made worldwide to reuse it in earthworks, road pavements, as landfill cover material, building construction material etc. [1-9].

MSWI BA is a mixture of sand and gravel and though it has been found to perform satisfactorily from strength and mechanical perspective [1,2,8,9], its environmental performance remains contentious. The non-volatile and incombustible salts which get concentrated in the bottom ash after incineration tends to leach out in various disposal or reuse scenarios. In literature, contamination potential of MSWI BA has been widely assessed in the context of heavy metal or metalloid leaching but not much attention is focused on the leaching of other soluble solids such as salts [2,3,6,12,13]. This is generally because their presence in excess does not classify them as a hazardous material. The most widely used toxicity characteristic leaching procedure (TCLP) omit the presence of such salts as a regulatory criterion for material's classification as hazardous or non-hazardous and hence misinterpreted sometimes as it does not necessarily suggest that the material's reusability but suggests only material's disposal condition.

Correct estimation of total soluble solids (SS) can provide a fair idea of the proportion of the total leachable components present in MSWI BA over its life cycle and would be beneficial to address its long-term impact on the environment. The present study contemplates the existing Indian standard practice IS-2720 Part-XXI [14] of estimating SS in soil and comprehends if the same can be used as such or with some modifications to assess SS in soil-like-fraction of MSWI BA. The study emphasizes the role of dilution ratio (DR) or liquid-to-solid ratio on the accurate estimation of SS. It also draws a comparison between SS values of two locally available soils, coal bottom ash and MSWI bottom ash.

## 2 Material and Methods

MSWI BA was collected from three waste-to-energy plants in Delhi, P1, P2 and P3. The three plants combinedly contribute approximately 45 MW of power generation and accommodate nearly 5000 tons per day of MSW which is almost half of the city's daily MSW generation. All the three plants pre-segregated the incoming MSW through a various combination of techniques such as size-based segregation through trommels, density-based segregation through ballistic separators, metal segregation through magnetic separators etc. The objective of pre-segregation operations aimed to increase the calorific value of the waste being fed to the furnace.

These plants reported a similar mass reduction of around 70% of the incoming MSW as reported worldwide. Bottom ash was recovered through hoppers after the water-quenching operation. Bottom ash averaged to be approximately 80-90% of the total residues and its laboratory grain-size analysis indicated the proportions of the soil-like-fraction (passing 4.75 mm) and gravel-like-fraction (above 4.75 mm) as given in Fig. 1. Bottom ash is being referred to as a combination of soil-like and gravel-like-fraction because it is neither natural soil nor natural gravel but only appears to be so by the naked eyes. A stockpile of MSWI BA from one of the WtE plant and its soil-like fraction obtained after initial processing is shown in Fig, 2. If this soil-like fraction from MSWI BA can substitute natural soil in various applications, completely or partially, nearly 40-60% utilization of WtE rejects can be achieved. Only the soil-like fraction has been targeted for this study.

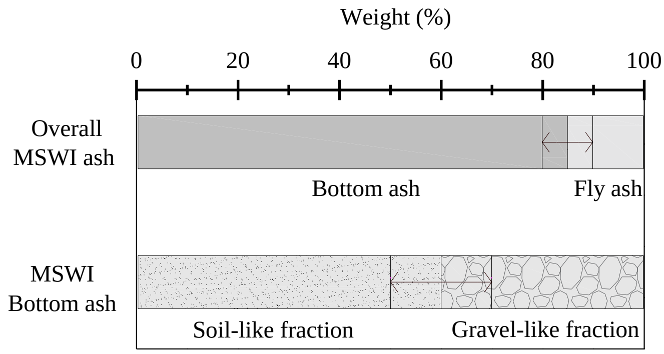


**Fig. 1.** Rejects from WtE plant.

(a) (b)

**Fig. 2.** (a) Stockpile of MSWI bottom ash, (b) Soil-like-fraction from MSWI bottom ash

Coal bottom ash from a local thermal power plant and two locally available soils, Yamuna sand and Badarpur sand were subjected to the same testing sequence for the comparison of results. Yamuna sand is natural river sand whereas Badarpur sand is quarried sand.

## 2.1 Sample Collection

The incoming waste fed to the incinerators may vary from day-to-day, season-to-season and regions-to-region. In order to capture the heterogeneity of the ash being generated in these WtE plants, the sampling was carried out in various seasons between 2017-2019. At each point of sampling, approximately a ton of bottom ash was collected in a period of 5-10 days. The material was then exposed to natural atmosphere under a shed at a landfill site for partial air-drying for a period of 4-5 days. MSWI BA was later sieved through various large-sized screens on-site and the material passing 4.75 mm was collected and stored in plastic containers in the laboratory. Details of sample collection and the abbreviations used for different samples are given in Table 1.

**Table 1.** Sample collection details and the abbreviations used for different samples

| Sample | Sampling period | Abbreviations used |
|---|---|---|
| | Monsoon 2017 | BA $P1_M$ |
| MSWI bottom ash P1 | Winter 2018 | BA $P1_W$ |
| | Summer 2018 | BA $P1_S$ |
| | Monsoon 2017 | BA $P2_M$ |
| MSWI bottom ash P2 | Winter 2018 | BA $P2_W$ |
| | Summer 2018 | BA $P2_S$ |
| MSWI bottom ash P3 | Winter 2019 | BA $P3_W$ |
| Coal bottom ash | - | CBA |
| Badarpur sand | - | BS |
| Yamuna sand | - | YS |

## 2.2 Experimental Methodology

**Existing Practice for Estimation of SS.** SS in soil is determined as per Indian Standard IS 2720-Part XXI. The existing practice requires at least 10 g of sample (passing 2 mm) to be mixed with 100 ml of distilled water and shaken overnight for at least 15 hours. The soil is then decanted and the filtered through Whatman no. 42 filter paper. The filtrate is then oven-dried to estimate SS. This method identifies the dilution ratio (DR) or liquid-to-solid ratio of 10 l/kg for SS determination. However, the DR of 10 l/kg may not allow the complete dissolution of soluble solids in MSWI BA as the solution may get saturated due to elevated concentration of salts in ash in comparison to natural soil. Hence, higher DR may be required to for SS estimation in MSWI BA.

**Modified Procedure for Estimation of SS.** The study aimed to determine DR that would be just necessary and enough to allow the complete dissolution of soluble solids in MSWI BA. SS was estimated at DR of 10, 20, 50, 100, 150 and 200 l/kg for all the samples mentioned in Table 1. If two successive DR would give negligible change in SS, the lower DR would be the required dilution for estimation of SS in the soil-like fraction from MSWI BA.

Since the capacity of flasks that could be placed on a rotary shaker was fixed to 500 ml, the amount of sample taken for each dilution was changed. To ensure that a representative quantity of sample is taken for the test, the number of repetitions were fixed such that at least 20 g of sample was used at each dilution. At least 3 repetitions were performed at each dilution. Table 2 shows the details of sample preparation. The samples were crushed in mortar and pestle to pass 425 μm sieve to ensure homogeneity. The samples were agitated at 200-250 rpm to ensure good mixing. The samples were later vacuum filtered. After measuring the pH, the entire extract was oven-dried at 105 ± 5$^{o}$C to estimate SS. All the weight calculations were done using a weighing balance of 0.1 mg readability.

**Table 2.** Details of sample preparation for SS estimation

| Dilution ratio (l/kg) | Diluted volume (ml) | Sample quantity for each iteration (g) | Number of repetitions | Total quantity of sample (g) |
|---|---|---|---|---|
| 10 | 500 | 50.0 | 3 | 150 |
| 20 | 500 | 25.0 | 3 | 75 |
| 50 | 500 | 10.0 | 3 | 30 |
| 100 | 500 | 5.0 | 4 | 20 |
| 150 | 500 | 3.3 | 6 | 20 |
| 200 | 500 | 2.5 | 8 | 20 |

**Estimation of Constituents of SS.** After fixing on a DR from the above-modified method, the SS extract was prepared again at that DR and tested for its constituents. The SS extract of each sample was tested for volatile solids (VS), anions (chlorides and sulphates) and metal/metalloids using APHA standards [15].

VS gives a rough estimate of the organic component of total soluble solids that volatilize at temperatures up to 550$^{o}$C. The loss in weight when the SS residues were ignited from 105 ± 5$^{o}$C to 550 ± 5$^{o}$C is reported as VS. Chlorides were determined by Mohr's method using silver nitrate titration. Sulphates were determined using the turbidimetric method. Metals/metalloids in SS extract were determined using inductively coupled plasma mass spectrometry (ICP-MS).

# 3 Results and Discussion

Table 3 shows the change in SS of samples on increasing the DR. Fig. 3 shows a comparison of SS in MSWI BA of three plants with YS, BS and CBA. Table 4 shows the pH value, estimated SS, VS and ratio of VS to SS for all the samples.

## 3.1 Effect of DR on Estimation of Total Soluble solids for Local Soils and Coal Bottom Ash

From Table 3, it is evident that the change in SS for Yamuna sand, Badarpur sand and coal bottom ash at higher dilutions is insignificant. The slight increase in SS at higher dilution for the above three materials can also be attributed to the experimental error or heterogeneity of the samples. DR 10 is adequate to dissolve most of the soluble solids for soil or coal bottom ash.

## 3.2 Effect of DR on Estimation of Total Soluble Solids for MSWI Bottom Ash

In contrary to YS, BS and CBA, SS in MSWI bottom ash increases significantly at higher dilutions for all the three plants, for all the seasons. It almost gets stabilized at DR 100 for MSWI BA from WtE P2 whereas SS for MSWI BA from P1 and P3 gets evened out around DR 150. MSWI BA from P1 shows higher values of SS in comparison to P2 and P3. SS in soil-like-fraction of MSWI BA is in the range of 2.5-3.6 %. This value is considerably higher than the two local soils and the coal bottom ash having SS of the order of 0.1 %.

Results suggest that higher concentration of soluble salts in MSWI BA saturates the water solution at lower DR preventing the further dissolution of salts. This results in underestimating the value of SS in soil-like-fraction of MSWI BA. MSWI BA needs to be diluted at least 150 times to allow the complete dissolution of soluble solids.

## 3.3 pH and Volatile Solids

In Table 4, high pH values of MSWI BA are suggestive of their alkaline nature that may be due to the presence of soluble alkalis and alkaline earth metals such as Na, K and Ca. The lower values of pH for BA $P3_W$ may be attributed to carbonation during the on-site processing of samples.

VS is ranging between 0.6-1.2% in MSWI BA whereas it is found to be insignificant in local soils and coal bottom ash indicating the absence of any soluble organic solids in the same. Low VS/SS ratio signifies a little proportion of soluble organics in total soluble solids for YS and BS. This proportion is around 20-25 % in MSWI BA and CBA and up to 40 % in some MSWI BA samples.

**Table 3**. Total soluble solids at various dilutions (average ± standard deviation) in wt. %

| Sample | Dilution ratio (l/kg) | | | | | |
|---|---|---|---|---|---|---|
| | 10 | 20 | 50 | 100 | 150 | 200 |
| YS | 0.06 ± 0.01 | 0.07 ± 0.01 | 0.11 ± 0.01 | - | - | - |
| BS | 0.04 ± 0.01 | 0.05 ± 0.01 | 0.07 ± 0.01 | - | - | - |
| CBA | 0.07 ± 0.00 | 0.12 ± 0.00 | 0.21 ± 0.03 | - | - | - |
| BA $P1_M$ | - | - | - | - | 3.13 ± 0.07 | 3.21 ± 0.11 |
| BA $P1_W$ | 1.78 ± 0.01 | - | 2.31 ± 0.03 | 2.80±0.11 | 3.46 ± 0.05 | 3.57 ± 0.06 |
| BA $P1_S$ | 1.77 ± 0.02 | - | 2.41 ± 0.01 | 2.86 ± 0.02 | 3.46 ± 0.07 | 3.57 ± 0.10 |
| BA $P2_M$ | - | - | - | 2.36 ± 0.07 | 2.43 ± 0.04 | 2.54 ± 0.06 |
| BA $P2_W$ | 1.86 ± 0.06 | - | 2.27 ± 0.04 | 2.52 ± 0.07 | - | 2.65 ± 0.05 |
| BA $P2_S$ | 1.31 ± 0.03 | - | 1.96 ± 0.03 | 2.47 ± 0.08 | - | 2.65 ± 0.03 |
| BA $P3_W$ | 1.95 ± 0.09 | - | 2.29 ± 0.03 | 2.46 ± 0.06 | - | 2.79 ± 0.12 |

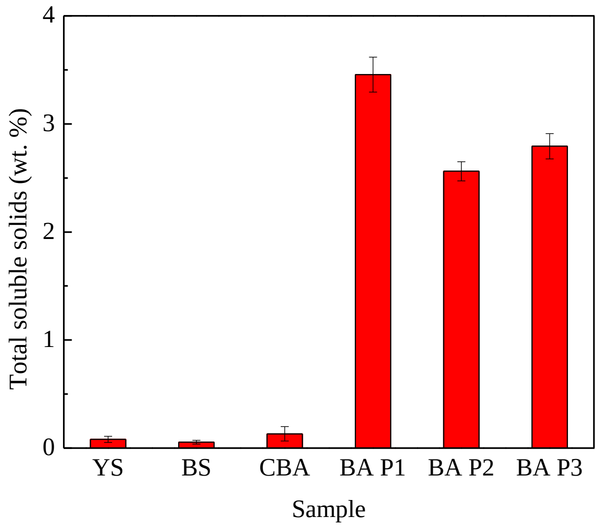


**Fig. 3.** Comparison of total soluble solids in MSWI BA, local soils and coal bottom ash

### 3.4 Chemical constituents of SS in MSWI BA

Preliminary studies show that soluble solids in MSWI ash comprised of high levels of chlorides and sulphates. Chlorides were in the range of 10-20 %, whereas sulphates were of the order of 30 % of the weight of total soluble solids in MSWI BA

Major and minor metal ions present (in decreasing order of their weight percentage) were sodium, potassium, calcium, aluminium and iron. They combinedly constituted 10-15 % of the total soluble solids in MSWI BA. Other metals/metalloids present in trace amounts were zinc, copper, chromium, lead, antimony, nickel, vanadium, molybdenum and manganese. These were approximately 0.1-0.2 % of the total soluble solids in MSWI BA.

**Table 4.** pH, SS, VS and ratio of VS/SS

| Sample | pH | SS* | VS* | VS/SS |
|---|---|---|---|---|
| YS | 7.7 | 0.08 ± 0.03 | 0.01 ± 0.01 | 0.12 |
| BS | 8.3 | 0.05 ± 0.02 | 0.01 ± 0.01 | 0.07 |
| CBA | 7.9 | 0.13 ± 0.07 | 0.02 ± 0.01 | 0.17 |
| BA $P1_M$ | 10.3 | 3.18 ± 0.07 | 0.80 ± 0.06 | 0.25 |
| BA $P1_W$ | 10.5 | 3.54 ± 0.07 | 0.83 ± 0.05 | 0.23 |
| BA $P1_S$ | 10.6 | 3.5 ± 0.09 | 0.80 ± 0.10 | 0.23 |
| BA $P2_M$ | 9.3 | 2.54 ± 0.06 | 0.57 ± 0.11 | 0.22 |
| BA $P2_W$ | 9.5 | 2.58 ± 0.07 | 1.10 ± 1.10 | 0.43 |
| BA $P2_S$ | 10.1 | 2.58 ± 0.10 | 0.75 ± 0.13 | 0.29 |
| BA $P3_W$ | 8.9 | 2.79 ± 0.13 | 1.17 ± 0.12 | 0.42 |

* weight % (average ± standard deviation)

## 4 Conclusion

Previous studies [5,6] indicate that the bulk utilization of soil-like-fraction of MSWI bottom ash in geotechnical applications is feasible but the presence of soluble solids may thwart the same. Substituting it as backfill material in reinforced soil structures, for an instance, 20 m wide, 5 m high and a kilometre long, would involve 0.1 million cubic metres of earthwork. With a compacted density of 1.5 g/cc [5], 0.15 million tonnes of MSWI BA would be used. An average of 3 % of total soluble solids in MSWI BA would mean approximately 4500 tonnes of soluble solids that are likely to release into environment from backfill during its lifetime. Hence, precautionary design measures to isolate such material from external environmental factors such as groundwater table and rainfall using impermeable barriers are crucial for bulk reuse in geotechnical applications.

Soil-like-fraction of MSWI bottom ash, though a look-alike of natural soil or coal bottom ash, is not as benign as it may appear. The concentration of soluble solids in MSWI BA is highly elevated and may pose a serious risk to the environment. If used in an unbound form such as in earthworks, filling of low-lying areas or deep mining pits, it can potentially contaminate groundwater table. If used in a bound form such as in concrete, bricks etc., soluble solids may interfere with the associated chemical reactions resulting in poor quality products.

It is therefore essential to estimate the SS values accurately and gauge its deleterious effect on the environment before putting it to reuse. It is recommended that IS-code method be used with due caution for estimating SS in materials when more soluble solids are anticipated. The requirement of higher dilution ratio should be verified for such materials. An understanding of the mass balance of SS which will quantify all the soluble metals, metalloids, total organic carbon and anions such as chlorides, sulphates, fluorides, nitrates, carbonates etc. in the SS extract would be beneficial to address its long-term impact on the environment and studies are underway to investigate the same.

## References

1. An, J., Kim, J., Golestani, B., Tasneem, K. M., Al Muhit, B. A., Nam, B. H., Behzadan, A. H.: Evaluating the use of waste-to-energy bottom ash as road construction materials. Office of Materials, State of Florida Department of Transportation, Contract No.: BDK78-977-20 (2014).
2. Arm, M.: Variation in deformation properties of processed MSWI bottom ash: results from triaxial tests. Waste Management 24(10), 1035-1042 (2004).
3. Chang, F. Y., Wey, M. Y.: Comparison of the characteristics of bottom and fly ashes generated from various incineration processes. Journal of Hazardous Materials, 138(3), 594-603 (2006).
4. Forteza, R., Far, M., Seguı, C., Cerda, V.: Characterization of bottom ash in municipal solid waste incinerators for its use in road base. Waste Management 24(9), 899-909 (2004).
5. Garima Gupta, Manoj Datta, G.V. Ramana, B.J. Alappat, S. Bishnoi: Laboratory Investigations on Geotechnical Properties of Bottom Ash from Two MSW Incineration Plants in Delhi. In: Indian Geotechnical Conference, Indian Institute of Science, Bengaluru, India (2018).
6. Gupta, G., Datta, M., Ramana, G.V., Alappat, B.J.: Feasibility of Reuse of Bottom Ash from MSW Waste-to-Energy Plants in India. In: The 8$^{th}$ International Congress on Environmental Geotechnics, Springer, Singapore, pp. 344-350 (2018).
7. Gupta, G., Datta, M., Ramana, G.V., Alappat, B.J.: Feasibility of using MSW incinerator ash in geotechnical applications. In: Indian Geotechnical Conference, IIT Guwahati, India (2017).
8. Lynn, C. J., Ghataora, G. S., OBE, R. K. D.: Municipal incinerated bottom ash (MIBA) characteristics and potential for use in road pavements. International Journal of Pavement Research and Technology 10(2), 185-201 (2017).
9. Margallo, M., Taddei, M. B. M., Hernández-Pellón, A., Aldaco, R., Irabien, A.: Environmental sustainability assessment of the management of municipal solid waste incineration residues: a review of the current situation. Clean Technologies and Environmental Policy 17(5), 1333-1353 (2015).
10. Blissett, R. S., Rowson, N. A.: A review of the multi-component utilization of coal fly ash. Fuel, 97, 1-23 (2012).
11. Kim, H. K., Lee, H. K.: Coal bottom ash in field of civil engineering: A review of advanced applications and environmental considerations. KSCE Journal of Civil Engineering, 19(6), 1802-1818 (2015).
12. Huang, C. M., Yang, W. F., Ma, H. W., Song, Y. R.: The potential of recycling and reusing municipal solid waste incinerator ash in Taiwan. Waste Management, 26(9), 979-987 (2006).
13. Lin, C. F., Wu, C. H., Ho, H. M.: Recovery of municipal waste incineration bottom ash and water treatment sludge to water permeable pavement materials. Waste Management, 26(9), 970-978 (2006).

14. Code, Indian Standard IS 2720-Part XXI: Determination of Total Soluble Solids (First revision) (1977).
15. APHA, AWWA, WEF: Standard methods for examination of water and wastewater, American Public Health Association, Washington DC (2012).