

## PARTITIONING OF HEAVY METALS IN THE ISTAC MEDICAL WASTE INCINERATOR

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### ABSTRACT

This study investigates the partition of heavy metals in slag from the rotary kiln (SL), second combustion chamber ashes (SCCA), filter cake (FC) from a bag filter and flue gas (FG) emissions (both in particulate and gas phases) of the Istanbul medical waste incinerator (ISTAC). Eleven targeted heavy metals (As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sb and Tl) in four matrices were analysed for eight different date samples in 2008. The results obtained were evaluated according to the metal species, furnace temperatures and other factors that affect the formation and accumulation of the metals in the incineration cycle. According to the results, combustion temperatures, reactor configuration and waste contents are the dominant parameters determining the volatility and partitioning of metals in the combustion systems. The biggest waste portions were obtained for the SL and the dominant metal species for the SL and SCCA were Cu (505,9±99,3 and 697,4±577,7 mg per kg dry mass for SL and SCCA respectively) and Mn (238,0±154,6 and 199,9±180,4 mg per kg dry mass for SL and SCCA respectively). In the FC, the dominant species was Cu (166,8±128,1 mg per kg dry mass) and this was followed by Mn, Ni and Hg. It is thought that cement and activated lignite, which were added to the process as adsorbent materials, were affecting the contents of the FC. Metals were divided into particulate and gas phases and maximum concentrations were observed for Ni, Mn and Cr in a particulate phase of FG. Emission factors were considered and mass balance calculations for metals were also conducted in the study.

**KEYWORDS:** Bottom Ash, Emissions, ISTAC; Heavy metals; Medical waste incineration.

### 1. INTRODUCTION

Incineration has become the main mechanism for hospital waste disposal. However, little information is available on the chemical properties of the incineration after-products in Turkey. Istanbul is the largest city in Turkey with 15 million people, so medical waste management in the city is very important. About 17% of hospitals, 20% of bed capacity, and 54% of private hospitals in Turkey are located in the city. It was found that the estimated quantity of medical waste (MW) from the hospitals is about 22 tons day<sup>-1</sup> and the average generation rate is 0.63 kg (bed-day)<sup>-1</sup> (Birpinar *et al.*, 2009; Demir *et al.*, 2002). Because of these high values, Istanbul is also a model city for all other cities in Turkey in terms of MW management.

In Turkey, regulations that deal with the control of MW were established by the Ministry of Environment and Forestry legislators in 1993 and revised in July 2005. It is the aim that the revised version of these regulations, which is a new Medical Waste Control Regulation (MWCR), are in accordance with the EU Environmental Directives. The principles for the collection, transportation, temporary storage in the healthcare facilities and removal of MW are determined by this regulation (Alagoz *et al.*, 2006; Birpinar *et al.*, 2009).

According to this regulation, waste generated from healthcare services is classified into four main groups as municipal waste (general waste from offices and kitchens and packaging waste, etc.), MW (infectious, pathological waste and sharp objects), hazardous waste (chemicals, cytotoxic medicine, amalgam waste, heavy metal containing waste, etc.) and radioactive waste (according to Turkey's Atomic Energy Council Act) (Birpinar *et al.*, 2009; Turkish Ministry of Environmental and Forestry, 2005).

Incineration is commonly used in the world because of reducing the hazardous mass and volume of waste before the final disposal (Yuan *et al.*, 2005). Although the weight of the waste is reduced by more than 70%, large amounts of combustion residues, especially bottom ash, still remain after incineration and are contaminated with heavy metals (Zhao *et al.*, 2010). It is well known that metals affect the immune system and some of the species are carcinogens (ATSDR, 1999) and one of the most important sources of heavy metals is incineration plants (Shi *et al.*, 2008; Zhao *et al.*, 2010; Yuan *et al.*, 2005).

Typically, MW consists of rubber, cotton, syringes, needles, scalpels, metal cans, plastics, glass and small metallic medical tools. The universal use of disposable plastic and/or metallic appliances during medical treatments is a significant contribution to the total generated waste. Therefore, the incineration production such as bottom ash, slag, FCs, flue gas (FG), etc. from MW incineration may contain a large proportion of toxic metallic elements or organic compounds that might hinder its reuse (Thipse and Dreizin, 2002; Yuan, 2005; Zhao *et al.*, 2008).

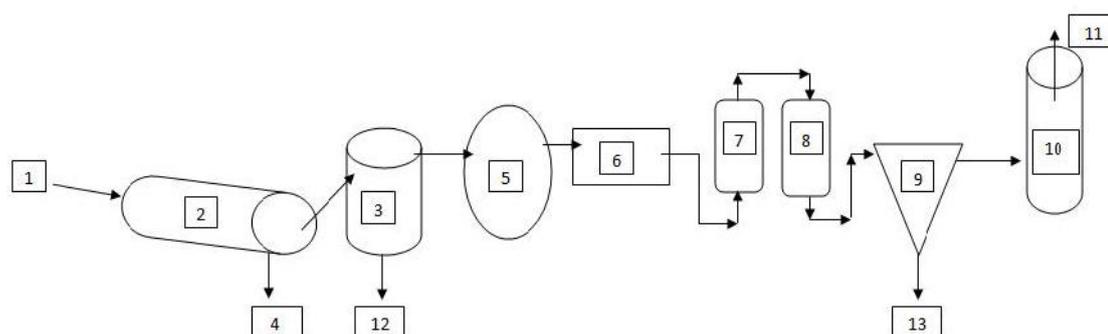
The fate and behaviour of metals during MW combustion processes have been examined in many research studies (Bakoglu *et al.*, 2003; Sukandar *et al.*, 2006; Zhao *et al.*, 2008; Valavanidis *et al.*, 2008; Taghipour and Mosaferi, 2009; Zhao *et al.*, 2010, etc.). The data obtained in the studies indicate that the ash and FG are enriched with various metallic elements.

In this study it is the aim that evaluations are carried out of the partitioning of eleven targeted heavy metals (As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sb and Tl) into the slag (from the rotary kiln) (SL), bottom ash from the secondary combustion chamber (SCCA), dust from bag filters (filter cake-FC) and in the particulate and gas phases of FG that are sourced by Istanbul's medical waste incinerator (ISTAC) of Istanbul Environment Management of Industry and Trade Co. Ltd. The factors affecting the partitioning of the heavy metals in these matrices were determined and simple mass balance equations were conducted in the system. The results obtained were also compared to those in the literature study and some emission factors (EFs).

### 1.1 Information about the Plant

ISTAC, the first MW incineration plant in Turkey, was constructed in Kemerburgaz, Istanbul. The plant began to accept MW in solid and liquid forms in 1995, and it has a capacity of 24 tons per day and three shifts working 24 hours per day. MW generated from hospitals is collected separately, transported to the incineration plant in special vehicles and disposed of in burning units at the plant.

The actual incineration capacity of the plant is approximately 15.000 tons per year. It has a two-stage combustion system consisting of a rotary kiln and secondary combustion chamber. Waste materials are incinerated firstly within a special refractory rotary kiln at a temperature between 1000 and 1200°C by substoichiometric ignition. The dimensions of the rotary kiln are 7.5 m (length) and 2.73 m (diameter), retention time is a minimum of one hour and speed is 0-12 rotations per hour. The capacity of the kiln is one ton h<sup>-1</sup> and the average calorific value of the combustible waste is 3.500 kcal kg<sup>-1</sup> (min. 2.000 kcal kg<sup>-1</sup> and max. 4.540 kcal kg<sup>-1</sup>). The thermal power of the plant is 4.07 MW. The slag, produced in the rotary kiln, is taken to an ash quench chamber and then it is transferred to landfill sites by a conveyor system. Since the incineration of most waste takes place in the rotary kiln, almost all of the bottom ash is comprised of the SL. The second stage of incineration occurs in the second combustion chamber with a 1.5 second retention time and at an average temperature of 1200°C, which ensures the complete destruction of hazardous organic compounds. After the second combustion, a boiler and economizer are used. After incineration, the waste volume and mass are reduced by 95% and 75%, respectively. A schematic flow diagram of the system is given in Figure 1.



- |   |  |
|---|--|
| 1. Inlet                                    | 8. Dosage of lime and activated carbon             |
| 2. Rotary kiln                              | 9. Bag filter                                      |
| 3. Second combustion chamber                | 10. Stack  |
| <b><u>4. Outlet of rotary kiln (BA)</u></b> | <b><u>11. Flue gas outlet (FG)</u></b>             |
| 5. Boiler                                   | <b><u>12. Outlet of SCC (SCCA)</u></b>             |
| 6. Economizer                               | <b><u>13. Dust outlet from bag filter (FC)</u></b> |
| 7. Spraying tank                            |  |

*Figure 1.* Schematic flow diagram of ISTAC  
(location of sampling points are indicated with bold and underlined letters)

Strict legislative controls and emission limits have been adopted by the Turkish Ministry of Environment in the plant (ISTAC J. S. Co., Birpınar *et al.*, 2009). The air pollution control system (APCS) consists of wet scrubber lime, an activated lignite injection and a bag filter. Waste gases, firstly, come into contact with water in a spraying tank, which is 8 m in height and 2.2 m in diameter. The FG enters at 170°C temperature and exits at 120°C. Then the FG is transferred to a scrubber for spraying with pulverized lime and activated lignite to remove any organic and acidic gases. The dimensions of the dosage tank are 7.5 m (length) and 1.6×1.6 m (area) with a feeding capacity of 10-200 kg per hour for lime and 3 kg-activated lignite per hour. FGs are finally transferred to a jet pulse type bag filter, which consists of 210 bags with a total collecting surface of 337 m<sup>2</sup>.

The solid residuals generated by the incinerator are classified into three parts: (i) SL, (ii) SCCA and (iii) FCs representing fly ash collected from the bag filters.

## 2. MATERIALS AND METHOD

In Figure 1, the localization of the sampling points is given. As can be seen from the figure samples were collected from the SL (outlet no 4), SCCA (outlet no 12), FC (outlet no 13) and FGs (outlet no 11) on eight different dates: 04/01/2008; 04/12/2008, 04/17/2008, 09/05/2008, 09/10/2008, 09/14/2008 and 09/19/2008.

A sample of 2 kg was taken for each group, except for FG, according to TS 12090 and ICS 13.03.10. The samples collected were cooled to room temperature for handling and transferred to the laboratory for analysing.

SL, SCCA and FC samples were homogenized by pulverizing using a mechanical grinder, mixed and taken to the analytical facility. Extraction procedures were carried out by the Berghoff MWS-2 model microwave extraction instrument. This method has two stages. In the first stage waste was incinerated at 140°C, 160°C and 195°C for 5, 10 and 10 minutes, respectively. This process was followed by waiting 15 minutes and adding 20 ml boric acid. In the second stage, incineration was carried out for 5 minutes at 190°C, 15 minutes at 200°C and 10 minutes at 160°C.

FG samples were collected with the Environ-supply C-5000 model stack gas sampler. Sampling points were selected according to EPA Method 1 (USEPA, 1994). The samplings and analysis of the samples were carried out according to EPA Method 29 (USEPA, 1999).

In EPA Method 29, the collecting of particulate matter was carried out by filters and impingers to condense and absorb gaseous metals. The system for condensing the sampling train was composed of four to seven impingers in a series with leak-free ground glass or non-contaminating fittings. The filters in front of the impingers were used to remove particles and to ensure that the FG was in the gas phase before it passed through the impingers. The first impinger was empty; this was

designed to remove moisture from the FG. The second and the third impingers, containing 100 ml (5% HNO<sub>3</sub>/10% H<sub>2</sub>O<sub>2</sub>) solution, were used to measure the concentration of volatile heavy metals and oxidized mercury (HgO and HgCl<sub>2</sub>) in the gas phase. The fifth and the sixth impingers, containing 4% KMnO<sub>4</sub>/10% H<sub>2</sub>SO<sub>4</sub>, were used to measure the elemental mercury concentration (as Hg<sup>0</sup>) in the gas phase. The fourth impinger was empty to prevent unwanted mixing between the 5% HNO<sub>3</sub>/10% H<sub>2</sub>O<sub>2</sub> and 4% KMnO<sub>4</sub>/10% H<sub>2</sub>SO<sub>4</sub> solutions. In addition, the seventh impinger, containing silica gel, was connected impingers (USEPA, 1999; Yuan *et al.*, 2005) to the apparatus to ensure that the FG was absolutely dry before it left.

Heavy metals were analysed with an atomic absorption instrument (the Perkin-Elmer AAS 800 model) with a graphite furnace, except for mercury. For analysing Hg the cold vapour method of atomic absorption (CVAAS) with the method outlined in EPA Method 7470A (USEPA; 1986) was used. The laboratory quality control procedures included sample triplicates. The relative standard deviations of the triplicate analyses were all below 10%.

### 3.RESULTS

The metal-partitioning studies showed that the combustion temperature is the major parameter determining the metal volatility, although there might be a number of other factors having significant effects in incinerators such as other operational conditions, the contents of the waste, the physico-chemical properties of heavy metals and compounds formed during combustion. The combustion of MW was conducted with high temperatures, which are desirable for the complete destruction of organic matter to minimize the formation of toxic organics during incineration, but they also enhance the metal volatility, resulting in an increase in the release of volatile metallic compounds, which could be also toxic, to the atmosphere (Wichmann *et al.*, 2000; Bakoglu *et al.*, 2003; Yuan *et al.*, 2005; Zhao *et al.*, 2010).

In this section, it was the aim to investigate the partitioning of the targeted metal species in ISTAC. In Table 1, the average concentration and load values of 11 targeted heavy metals are given with the melting and boiling points of the species. A detailed evaluation of the results is given below according to the sampling matrices.

Table 1. Some properties of targeted heavy metals and average values of analyzed samples\*

Element	Melting Point (°C)	Boiling Point (°C)	Average values ±Standard Deviations (mg kg dry mass <sup>-1</sup> ) **					
			SL (Slag from the rotary kiln)	SCCA (Bottom ash from the secondary combustion chamber)	FC (dust from bag filters-filter cake)	FG-G (flue gas-gas phase)	FG-P (Flue gas-particulate phase)	
Cadmium	Cd	765	321	1.7±0.6	1.3±1.9	3.0±1.7	0.004±0.002	0.19±0.16
Thallium	Tl	1457	304	21.1±8.9	19.8±11.6	0.5±0.7	1±1.4	6.46±7.54
Antimony	Sb	1750	630	13.8±11.8	8.7±10.0	0.8±0.8	0.05±0.07	0.24±0.19
Arsenic	As	613	817	1.6±1.8	4.6±4.9	-	0.4±0.6	1.28±3.44
Lead	Pb	1740	328	16.2±10.9	16.6±16.8	2.2±3.7	0.5±0.7	2.77±2.92
Chromium	Cr	2672	1857	78.9±37.8	84.7±47.7	23.9±25.2	0.2±0.3	18.75±7.82
Cobalt	Co	2870	1495	40.2±26.5	72.2±98.9	2.5±2.9	0.7±2	7.78±11.06
Copper	Cu	2567	1083	505.9±99.3	697.4±577.7	166.8±128.1	0.2±0.23	5.92±5.02
Manganese	Mn	1962	1245	238.0±154.6	199.9±180.4	52.84±65.3	1±1.3	33.96±45.66
Nickel	Ni	2732	1453	133.7±43.9	111.2±39.4	26.5±16.2	0.2±0.3	89.72±45.07
Mercury	Hg	357	-39	0.1±0.2	0.2±0.4	17.2±8.9	0.03±0.1	2.21±4.09

\*Presented values are average of triplicate analyses results

\*\*Samples were taken in the dates of 04/01/2008; 04/05/2008; 04/12/2008; 04/17/2008; 09/05/2008; 09/10/2008; 09/14/2008; 09/19/2008. "-" means below detection limits.

### 3.1 Bottom Ashes (SL and SCCA)

Because of the fact that disposing or reusing applications of bottom ash is an important part of MW's management, bottom ash is one of the most examined portion of medical wastes in literature (Gidakos *et al.*, 2009).

In the study, the SL and SCCA were evaluated together, because having similar properties. As can be seen from Table 1, the maximum values were determined for Cu, Mn, Ni and Cr, respectively, in the SL and SCCA and these species were almost equally partitioned between these bottom ashes. Since the incineration of most waste takes place in the rotary kiln, almost all of the bottom ash was comprised of the SL. As a result, the metal load for the SL was much higher than that for the SCCA, but the concentration values of these matrices were similar (Table 1).

Cr and Ni are generally not thermally mobile during the incineration process, and thus mainly remain in the bottom ash (Jung *et al.*, 2004; Zhao *et al.*, 2008). These metals were observed both in the bottom and fly ash samples and they did not easily react during the incineration process, and thus were mainly found in the stable matrices. Kuo *et al.* (1999) have also shown that high concentrations of Cr and Ni in MW bottom ash were found and, as a comparison, the concentration of Cr in their bottom ash was 17 times higher than that typically found in municipal solid waste ashes. These findings were comparable with our results.

A high Cu content in the organic matter fraction could be attributed to the fact that Cu had a catalytic effect in the formation of organic pollutants, for example PCDD/DF (Zhao *et al.*, 2010; Chang and Chung, 1998; Hatanaka *et al.*, 2004), and thus was typically found with the organic fraction of the ash samples.

Kiln temperatures in the sampling periods were compared with the measured heavy metal compounds in Figure 2. Average combustion temperatures were in the range of 927-1133°C for the rotary kiln and 1112-1186°C for the second combustion chamber in the eight sampling periods. As the temperature increased minor metal species changed in the range of 10-20% of the total emissions. Ni had the same value at almost all the temperatures, Cu slightly increased and Mn, Tl, Co and Cr had decreased as the temperature increased. It could be seen that increasing the temperature did not affect the Hg values in the SL.

Reactor configuration is another effective factor in metal partitioning. Incomplete mixing and local differences in temperature and reagent concentrations observed in the kiln are caused by a highly heterogeneous environment in the zone (Bakoglu *et al.*, 2003; Verhulst *et al.*, 1996; Mininni *et al.*, 2000). Metals that have lower melting points (such as Hg, As, Cd, Sb, Pb and Tl) had minimum values in the SL and SCCA in the study. It is thought that these species was formed in the colder zone of the kilns.

In comparing the availability of the metal species in the two kilns, it could be seen that Cd, Tl, Pb and Cr had similar values for the two kilns, while As, Co and Cu were higher in the SCCA. It is thought that these species and their compounds may convert to other types of metallic compounds by recombining in the secondary combustion chamber. On the other hand Sb, Mn and Ni were higher in the SL. As the temperature in the second stage increases, vaporization of metal species (on the particles coming from first stage) and subsequently, metal enrichment in ultrafine particles by condensation processes during gas cooling increases too (Shi *et al.*, 2008; Wei *et al.*, 1998; Bakoglu *et al.*, 2003).

Waste content is the other factor affecting the process of metal partitioning. The Cr, Ni, Co and Mn species are commonly used in medical facilities. These species exist in stainless alloys and are used in medical and surgical materials, such as needles and syringes, and plastics. Cu and Pb are also used in the manufacturing of Cu-Pb alloys, which are used in surgical materials, such as disposable medical materials, especially in recent years (Kuo *et al.*, 1999; Shim *et al.*, 2005).

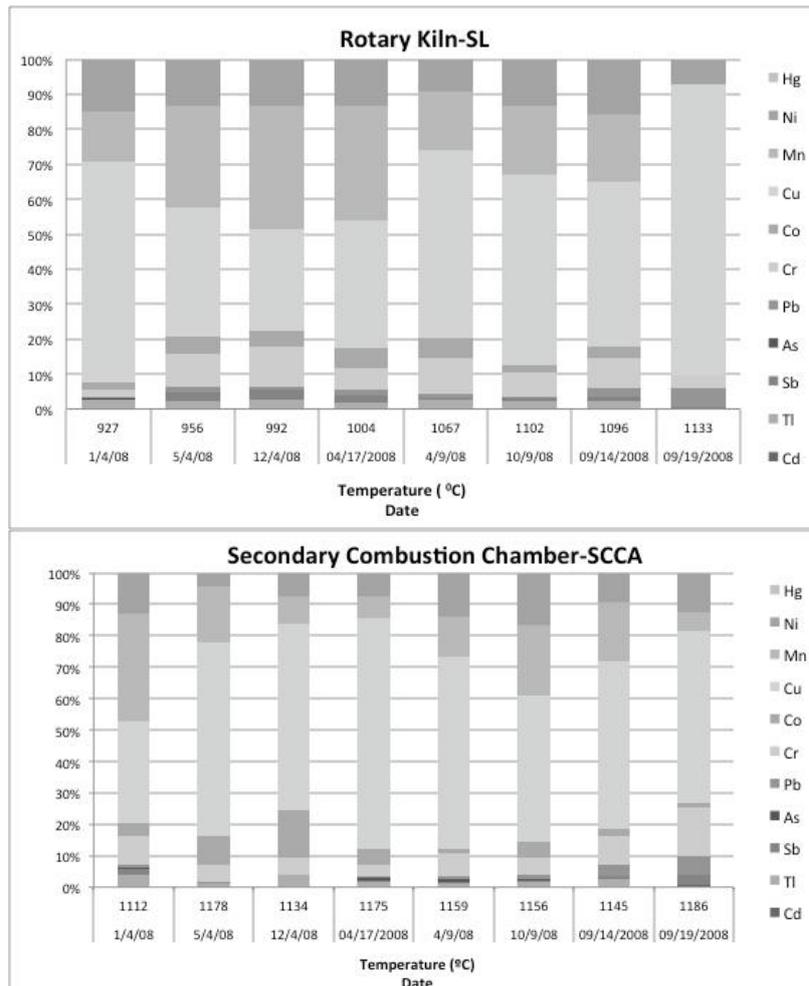


Figure 2. Heavy metal portions according to kiln temperatures

### 3.2 Filter Cake

Bag filters were used as an APCS, as they have high separation efficiency (> 99.9%) for coarse as well as fine particles, in ISTAC. Fly ash samples were taken from bag filter bunkers, known as the FC in the study. It is known that the availability of heavy metals in the FC is directly related to the particulate removal efficiency of APCSs and it is, therefore, important to characterize it.

During incineration, the mechanisms governing the fate of the metals, including nucleating, condensing by cooling before APCS and coagulating aerosols, are extremely complex. In the case of MW, it has been reported that the vapour phase of Cd, Pb, Cu and As is transferred into fly ash by nucleation and deposition and most of it exists in the form of metallic or metal oxide, which is easily soluble (Wey *et al.*, 2001; Wichmann *et al.*, 2000; Bakoglu *et al.*, 2003; Chimenos *et al.*, 1999; Linak and Wendt, 1993).

As can be seen from Table 1, FC samples were enriched the Cu, Mn, Ni and Hg species and As was not found. It is thought that increasing values of these species depends on two major factors: i) because the temperatures in the filter were lower than the boiling points of these metals, translating to a particulate phase occurred and 2) adsorption on lime and activated lignite particulates before filtration elevates their concentrations in the FC.

It is thought that the contents of adsorbent materials (lime and activated lignite) cause enrichment of some metal species in the FC. These materials are added to the process after secondary combustion chamber. In Table 2, the results from the analysis of the lime used and activated lignite are given. As can be seen from the table the materials Mn, Ni and Pb were high in content. We suggest that high portions of Mn, Ni and Pb in the FC were sourced by these adsorbent materials.

Table 2. Metal analyses of lime and activated lignite (mg per dry kg)\*

Metals	Lime	Activated lignite**
Cd	< 1	< 1
Tl	< 0,25	< 0,25
Sb	< 0,75	< 0,75
As	< 0,25	< 0,25
Pb	10,81	9,38
Cr	9,32	8,12
Co	< 1,75	< 1,75
Cu	< 1,5	< 1,5
Mn	79,12	110,9
Ni	10,05	6,63
Hg	0,5	0,75
Fe	2818	7558

\*Presented values are average of triplicate analyses results

\*\*Samples were taken in the dates of 04/12/2008; 09/05/2008; 09/19/2008.

Mercury has a low boiling point and was present in greater quantities in the gas phase than in the solid phase. However, in the plant the experimental results revealed that a significant amount of Hg (87% of total obtained Hg) was determined in the FC and it was thought that the major causes of the elevated concentration was a decrease in temperatures during filtration and condensing on the solid phase by adding activated lignite. Enriching concentrations of Hg in the FC are in accordance with the study by Yuan *et al.* (2005).

### 3.3 Flue Gas

Particles are formed in two possible processes in the waste incineration process: homogeneous nucleation and ash formation. Homogeneous nucleation results in the formation of small particles (<1 µm) from the gas phase, while ash formation yields large particles resulting in an enrichment of metals. These two mechanisms of particulate matter (PM) formation operate concurrently, and the rates of the reactions are related to the boiling points of the heavy metals, the combustion temperature and the amounts of chloride and sulphur in MW (Wichmann *et al.*, 2000; Bakoglu *et al.*, 2003; Chang *et al.*, 2000; Yuan, 2005).

Bag filtration removes larger fly ash particles but is less efficient for vapour and finer particles. In addition, it is likely that some of the fine and ultrafine particles escaping the bag filter remain aerosolized in the FG, since fine particles that mainly pass the filter are enriched in volatile metals and are removed by the additional treatment method (Bakoglu *et al.*, 2003). The experimental results revealed that most of the PM in the incineration plants were present in the fine mode. Finer particles contained more Pb, Cd, Zn and Cu, whereas coarser particles contained more Cr and Hg (Yuan *et al.*, 2005).

It can be seen from Table 1 that metallic compounds in the particulate phase were much higher than in the gas phase. Tl and Mn were the most abundant metal species in the gas phase and Ni, Mn and Cr had the maximum portions in the particulate phase of the FG. By the way, reducing the temperature in APCSSs, Mn, Cr, Co, Tl, which existed as low concentrations in other matrices, meant they had higher concentrations in the FG. The Hg concentration in the FG was 11% of the total.

According to Table 1, the Cr and Ni concentrations had the minimum value. According to Zhao *et al.* (2008), Cr and Ni, with high boiling points, were mainly transferred into the bottom ash, with only small amounts carried into the gaseous phase.

It is believed that fly ash contains more toxic elements compared to bottom ash and FC samples because some of the metals (for example, Hg, As, Tl, Pb and Cd) were in lower concentrations in the ash; these elements and their compounds are generally easily volatile at higher temperatures

and condense on the surface of the fly ash and thus end up in the FG-particulate phase (Zhao *et al.*, 2010; Shi *et al.*, 2008).

Furthermore, some of these easily volatile metal species, such as Pb and Cd, either have high volatility or can easily form high volatile compounds ( $\text{CdCl}_2$  and  $\text{PbCl}_2$ ), and thus tend to be transferred into fly ash during the incineration process (Verhulst *et al.*, 1996; Jung *et al.*, 2004; Shim *et al.*, 2005; Sukandar *et al.*, 2006). It has also been reported that As could be completely volatilized when the incineration temperature is above  $650^\circ\text{C}$  (Verhulst *et al.*, 1996). In the light of these findings, enriching levels of As, Hg and Pb species, especially in the particulate phase, can be explained by having high volatilization.

### 3.4 Mass Balance Equation

Mass balance equations were based on the overall mass to calculate the emitted PM, which are given in Table 3. According to this table inputs to the system were MW, lime, activated lignite and fuel and the total input was  $296 \text{ kg h}^{-1}$ , while the outputs were slag, ash from the SCC, the FC and PM from the FG emissions. To balance the inputs and outputs, PM from the FG was calculated as  $0.475 \text{ kg h}^{-1}$ . The FG-PM values determined in the study are compared with the calculated PM value and USEPA-AP-42 EF (USEPA, 1993) values in Table 4.

Table 3. Inputs and outputs to the system

Material	Mass
<b>Inputs</b>	
Medical waste: $1000 \text{ kg h}^{-1}$ (mass decreased 75%)	$250 \text{ kg h}^{-1}$ (after incineration)
Lime	$40 \text{ kg h}^{-1}$
Activated lignite	$3 \text{ kg h}^{-1}$
Fuel	$3 \text{ kg h}^{-1}$
<b>Total</b>	<b><math>296 \text{ kg h}^{-1}</math></b>
<b>Outputs</b>	
Slag	$200 \text{ kg h}^{-1}$
SCCA	$1 \text{ kg h}^{-1}$
Filter cake ( $95 \text{ kg h}^{-1}$ filtered by %99,95 efficient)	$94,53 \text{ kg h}^{-1}$
Flue Gas emissions-PM	$0,475 \text{ kg h}^{-1}$ (calculated)
<b>Total</b>	<b><math>296 \text{ kg h}^{-1}</math></b>

Table 4. Comparison of measured, calculated and emission factor values of PM

Origin of values	$\text{mg Nm}^{-3}$ for 11% $\text{O}_2$	$\text{kg h}^{-1}$
04.01.2008	37,04	0,16
04.05.2008	41,12	0,17
04.12.2008	18,94	0,09
04.17.2008	74,91	0,28
09.04.2008	52,2	0,23
09.10.2008	23,0	0,1
09.14.2008	34,1	0,16
09.19.2008	58,6	0,31
<b>Average</b>	<b>42,489</b>	<b>0,187</b>
<b>USEPA AP42</b>	-	<b>0,0378</b>
<b>Calculated from mass balance equation</b>	-	<b>0,475</b>

\*USEPA-AP42- Emission Factors from Emission Factor Documentation for AP-42-Section 2.6 Medical Waste Incineration: Rotary Kiln Medical Waste Incinerator Emission Factors for Metals APCs: Spray Dryer/Carbon Injection/Fabric Filter.

As can be seen from the table the USEPA-AP-42 EF of PM was much lower than the average measured and calculated values. The calculated and measured values were more comparable with each other and the average measurement values were lower than half of the calculated value. We think that PM emissions have a huge range of change (between 0.09-0.31) in measuring days and long-term PM data must be used in the comparison for a true evaluation.

The differences in the measured values and EFs for individual metals were also evaluated and are shown in Table 5. In the table the EFs were taken from the USEPA-AP-42 EFs in "Rotary Kiln Medical Waste Incinerator Emission Factors for Metals APCS: Spray Dryer/Carbon Injection/Fabric Filter" (USEPA, 1993). In the comparison, EFs for Cd and Hg were obtained that were lower than the USEPA-AP-42 EFs; Ni, Pb and Cr were found to be higher than the EFs and Sb and Cu were found to be very similar to the EFs.

**Table 5.** Comparison of EF and measured average values

Heavy Metals	USEPA AP42 Emission Factors (mg kg dust <sup>-1</sup> )*	Average Measured Values (mg kg dust <sup>-1</sup> )
<b>Cd</b>	1,21 E-05	4,13E-06
<b>Tl</b>	-	9,97 E-04
<b>Sb</b>	7,04 E-05	5,49E-05
<b>As</b>	-	4,13 E-04
<b>Pb</b>	3,69 E-05	54,4 E-05
<b>Cr</b>	3,86 E-05	22,2 E-05
<b>Co</b>	-	7,21 E-04
<b>Cu</b>	2,06 E-04	2,16 E-04
<b>Mn</b>	-	1,457 E-03
<b>Ni</b>	1,79 E-05	21,4 E-05
<b>Hg</b>	3,93 E-03	2,63E-05

\*USEPA-AP42- Emission Factors from Emission Factor Documentation for AP-42-Section 2.6 Medical Waste Incineration: Rotary Kiln Medical Waste Incinerator Emission Factors for Metals APCS: Spray Dryer/Carbon Injection/Fabric Filter.

### 3.5 Comparison with the Literature

The results obtained in this study were in a range comparable to those in other literature studies. For example, some of the previous studies have indicated that concentrations of some species, such as Pb, Cd, Zn, As and Hg, are in high levels in fly ash (Gidakos *et al.*, 2009; Shi *et al.*, 2008); on the other hand, Cu, Cr, Cd, Ni and Mn mainly exist in bottom ash (Ibanez *et al.*, 2000; Shi *et al.*, 2008; Zhao *et al.*, 2010,; Kou *et al.*, 1999). Similarly, these studies are comparable with our study in terms of the findings of enriched concentrations of Cu, Mn, Ni, Co and Cr in the SL and SCCA and the maximum values of Hg and Cd in the FC.

Besides, according to Gidakos *et al.* (2009), bottom ash must be managed as hazardous waste because of constituting a danger to drinking water and soil. In Gidakos's study Ni, Cu and Cd values were exceeded the permissible limits for the disposal of bottom ash as hazardous waste and limits for the extracts of non-hazardous solid waste in Greece.

A detailed evaluation of two studies was carried out: one of them was from China (Zhao *et al.*, 2008) and the other was from another incineration plant in Turkey (Bakoglu *et al.*, 2003).

Zhao *et al.* (2008) collected 22 ash samples, including 14 samples of bottom ash and eight samples of fly ash, from four typical hospital waste incineration plants located across China. In the other study (Bakoglu *et al.*, 2003), eight heavy metal species were measured in five trial burns in the Izmit hazardous and clinical waste incinerator (IZAYDAS) in Turkey for bottom ash, fly ash, FC and FG. A comparison of these studies is given in Table 6.

The results for bottom ash results were compared with all the SL and SCCA matrices in our study. Fly ashes are defined as particulates collected from bag filters in the study by Zhao *et al.* (2008) and from electrofilter bunkers in the study by Bakoglu *et al.* (200). The FC from the bag filter in our study was evaluated as fly ash for comparison.

It was found that the concentrations obtained in our study were in a lower range than the other two studies. As can be seen from the table the Mn and Pb values in this study were determined to be lower than in the other studies; while the Co, Cu and Ni concentrations were higher in the bottom ashes of Zhao *et al.* (2008). In general, the results of our study were more compatible with the findings of Zhao *et al.* (2008).

As in our study, Bakoglu *et al.* (2003) found high concentrations of Cu, Mn and Ni. However, the levels of these species were much higher. Generally, our results were at low levels when compared to the results of Bakoglu *et al.* (2003).

This study was different to these other two literature studies, as all of the targeted species in our study were in higher concentrations in bottom ashes than in fly ash, except for As and Hg. In Bakoglu *et al.*'s (2003) study, concentrations of Cu, Ni and Pb were very high in fly ash and these findings were explained by the fact that these species were carried as a gas phase and they could not be captured in electrofilters. When comparing our study, the performance of the bag filters and gas cooling system before APCS was higher in ISTAC.

Table 6. Comparison with literature studies

Heavy Metals	Bottom Ash, (mg kg <sup>-1</sup> )			Fly Ash, (mg kg <sup>-1</sup> )		
	IZAYDAS (Bakoglu <i>et al.</i> , 2003)	CHINA (Zhao <i>et al.</i> , 2008)	This Study	IZAYDAS (Bakoglu <i>et al.</i> , 2003)	CHINA (Zhao <i>et al.</i> , 2008)	This Study
			ISTAC Total (SL+SCCA)			ISTAC
<b>Ag</b>	-	8,4	-	-	113	-
<b>As</b>	-	27,8	<b>6,16</b>	-	170	-
<b>Bi</b>	-	103	-	-	165	-
<b>Cd</b>	-	5,3	<b>2,95</b>	-	237	<b>3,03</b>
<b>Co</b>	-	22,7	<b>112,34</b>	-	5,4	<b>2,53</b>
<b>Cr</b>	440	397	<b>163,69</b>	310	65,2	<b>23,98</b>
<b>Cu</b>	4730	487	<b>1203,4</b>	4950	1702	<b>166,75</b>
<b>Ni</b>	2830	111	<b>244,84</b>	1810	36	<b>26,53</b>
<b>Pb</b>	760	795	<b>32,79</b>	4920	3544	<b>2,15</b>
<b>Sn</b>	140	285	-	500	1149	-
<b>Ti</b>	-	6095	-	-	1940	-
<b>Zn</b>	3520	11,965	-	6010	78,686	-
<b>Tl</b>	-	-	<b>40,89</b>	-	-	<b>0,49</b>
<b>Sb</b>	-	103,53	<b>22,46</b>	-	162,775	<b>0,83</b>
<b>Mn</b>	1020	770	<b>437,91</b>	300	408,75	<b>54,03</b>
<b>Hg</b>	-	-	<b>0,32</b>	-	-	<b>17,21</b>

#### 4.CONCLUSIONS

In the ISTAC incinerator, metals are generally partitioned with the rank of SL, SCCA, FC (fly ash) FG-PM and FG-G. A larger fraction of metal is retained in the bottom ash. Bottom ash (SL and SCCA in this study) is generally considered to be safer than fly ash in terms of heavy metal contamination. However, our results indicate that MW bottom ash contains high levels of heavy

metals such as Cu, Mn, Ni and Cr and these levels make it difficult to cope with this waste in terms of disposal.

Based on the results obtained in the current study, the following mechanisms governing metal speciation could be deduced:

- i) physico-chemical properties of heavy metals (such as boiling-melting points, mobilization);
- ii) kiln temperatures (effect on volatilization and transfer of metals - in the study, as the temperature increased, minor metal species changed in the range of 10-20% of the total emissions.)
- iii) reactor configurations (causing changes in temperatures and mixing of waste);
- iv) waste content (especially raw material of medical and surgery material); and
- v) the contents of additional adsorbent material (in this study, it is found that the contents of adsorbent materials, such as lime and activated lignite, cause enrichment of some metal species in the FC)

were found to be the most effective factor in portioning in the study.

It could be also stated that USEPA-AP-42 EFs are not representative of ISTAC's PM and heavy metal emissions and long-term measurement data for generating EFs on the basis of ISTAC and Turkey are necessary for a true evaluation of environmental impacts.

Notwithstanding, lower levels of heavy metal compounds were obtained when compared with the heavy metal concentrations in ISTAC in the literature study; it could be stated that removal systems must be designed by considering of possible toxicity of volatile metallic compounds in such MW incinerators. Besides, examination and monitoring studies of MW incineration process in different phases are important in MW management studies and applications.

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