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Environmental Assessment of Ashes Generated From Medical Waste Incineration

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The nature of medical waste itself, which comprises of human pathological waste, items saturated or dripping with human blood, hypodermic needles etc. poses serious health threat to community, especially concerning spreading of infectious diseases, as well as causing pollutions to the environment. Incineration is one of the technologies adopted in many part of the world in dealing with medical wastes. However the process emits pollutants including toxic heavy metals, which are dispersed via the incineration stack, either vented directly to the atmosphere or are emitted after going through treatment in air pollution control unit. Meanwhile the remaining heavy product is concentrated into bottom and fly ash residues which are normally present in very small concentration or known as trace elements (TEs). This study was conducted to determine the concentration of TEs in bottom ash and fly ash of medical waste incinerator plant in Malaysia. In addition, it is a vital to understand the TEs behaviour and to assess the capability of the existing air pollution control (APC) technologies in Malaysia to comply with the new emission limits of the Environmental Quality (Clean Air) Regulation 2014 which replaces the Malaysia Environmental Quality (Clean Air) 1978. In this study, the APC designed with the electrostatic precipitator (ESP), fabric filter and spray scrubber with limestone were comply with the new specified emission limits but it need further improvement to improve the efficiency. The comparison of TEs behaviour in term of volatility; most volatile element (Hg) and less volatile element (Cr, Cd, As, Pb) in fly ash and bottom ash was also presented in this paper. The study showed that the samples of bottom ash and fly ash enriched of heavy metals of Pb, followed by As, Cd, Cr, and Hg. In environmental assessment, all of these TEs are found to be well below the Malaysian Department of Environment (DOE) Scheduled Waste Guideline limits except for Pb in fly ash which is above the emission limits. It is indicated that behaviour of TEs is related to TEs concentration in ash. In addition, the concentration of TEs also influenced the emission of TEs in flue gas.

1. Introduction

Incineration is one of the technologies that is widely adopted around the world for dealing with medical wastes. According to Zhou et al. (2010), although incineration can dispose the weight of medical waste by more than 70 %, there are still large amounts of combustion residues remained which can be divided into two categories - bottom ash and fly ash. Previous studies have indicated that the predominant component of medical waste in Malaysia is plastic materials or disposal metallic which is about 40 %. Therefore, ashes from medical waste incineration should be made a great concern as it may contain a high level of heavy metals (Ibáñez et al., 2000). Compared to fly ash, bottom ash is reported to contain fewer amounts of heavy metals and hence is considered to be safer (Stegemann et al., 1995). Bottom ash is collected from the bottom of the furnace and sent to special landfills for hazardous waste. On the other hand, fly ash can spread out to greater distance by wind. Apparently, they are harmful to the environment and public health. The exposure pathways to the receptors could be through air, soil, surface waters or even entering food chain.
The effectiveness of an incineration process is highly dependent on the capability of managing the emission of pollutants from such facility. This is very much affected by the selection of the flue gas cleaning system (FGCS). The selection of FGCS for the process must be able to meet the stringent air

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emission limit. The flue gas released into the atmosphere should comply with the established standard to prevent negative impacts on the air quality of a fairly large area. A study by Kimani (2007) highlighted that fly ash and bottom ash which are produced from medical waste incineration are typically enriched with heavy metals such as As, Cd, Cr, Pb, Hg, Zn, Ba, Cu, Pb, Mn, Cr, Ni and Sn. These pollutants are neurotoxic and may cause adverse effects on human especially to fetuses, infants and young children as they may cause respiratory, skin and lung irritation and eventually lead to the abnormalities of body system and systematic failure.

A study conducted by Meij (1995) found that the ash remains after waste incineration contains the same elements as those present in the waste, but their contents are enriched in the ash by a factor of equal to 100 / (ash content in %). The relative enrichment factor (RE) that describes the behaviour of the element observed is defined in Eq(1):

$$\mathrm{RE} = \frac{\text{element concentration in ash}}{\text{element concenration in medical waste}} \times \frac{\%\,\text{ash content in medical waste}}{100} \qquad (1)$$

According to Table 1, trace elements (TEs) in Class I are the least volatile elements, which have the highest boiling point and they are equally distributed in coarse residues (bottom ash) and finer particles (i.e. fly ash). TEs in Class II are divided into 3 groups with increasing volatility from IIc to IIa. The volatilisation may occur in boiler and condensation process may take place on the surface of fly ash particles in electrostatic precipitators (ESP). Meanwhile the most volatile TEs with the lowest dew point and some may be exist entirely in vapour phase are grouped in Class III. Based on the RE factor, the TEs can be classified according to their volatility as in Table 1 (Meij, 1995).

Table 1: Classification of elements according to RE factor

Class	RE factor	Example of TEs	Behaviour of TEs
I	~ 1	Al, Ca, Ce, Cs, Eu, Fe, Hf, K, La, Mg, Sc, Sm, Si, Sr, Th, Ti	Least volatile elements, equally distributed in bottom ash and fly ash
II	Class II is divided into 3 groups with increasing volatility from IIc to IIa		
IIc	< 0.7	Ba, Cr, Mn, Na, Rb, Sr	Volatilisation in boiler but condensation in ESP on the ash particles
IIb	< 0.7	Be, Co, Cu, Ni, P, U, V, W	
IIa	< 0.7	As, Cd, Ge, Mo, Pb, Sb, Tl, Zn	
III	<< 1	B, Br, C, Cl, F, Hg, I, N, S, Se	Very volatile, hardly any condensation on ash particles in ESP

2. Methodology

2.1 Description of the studied plant

Chapter 2 The studied plant is a medical waste incinerator located within an industrial estate in the northern part of Malaysia. The capacity of the plant is 650 kg/h of waste and operated on a 24 h/d basis. According to Figure 1, the plant has combustion system consisting of a rotary kiln system and it is equipped with electrostatic precipitators (ESP) and fabric filters as the air pollution control system to control the emission of TEs. The descriptions of the studied plant are summarized in Table 2. Basically, the volatilisation process of heavy metals that takes place in the incinerator is then followed by condensation and coagulation process due to an extreme decrement of temperature from about 1,500 °C to about 150 °C - this occurs throughout the units in the incinerator i.e. furnace, boiler, economiser and air pollution control device. In order to maintain the efficiency for handling residue of heavy metals, the temperature of ESP, scrubber and fabric filter cannot be less than 140 °C. Although the ESPs unit installed in medical waste incinerator is generally smaller in size than that in municipal solid waste (MSW) incinerator, the installation cost incurred is higher because of the complexity of the installation. In this studied medical waste incinerator, the type of scrubber used is wet scrubber requires lime spray injection at the upstream of an ESP. Hence in the incinerator that does not employ ESP, dry scrubber is not possible. The removal of hydrochloric acid, nitric acid, mercury, hydrofluoric acid, lead and residuary heavy metals from the incinerated waste is through absorption which involves dissolving the acid gases in a liquid contain alkali reagent. The operating condition in scrubber is set up at 150 °C and 1 bar. The wastewater, which comes out of scrubbers, is then passed through wastewater treatment plant. Like the air pollution control unit used in this studied plant, Jones et al. (2006) also tested the application of wet limestone in removing heavy metal with efficiency of 50 - 65 %. Meanwhile Tsuji and Shiraishi (1996) pointed out that apart from using limestone only to remove heavy metals, several pilot tests have shown that activated carbon can also be used in addition, to control mercury emission from medical waste incinerators. This is because mercury in vapour phase is insoluble in scrubber unit and hence cannot be simply removed. The combination of activated carbon and limestone as adsorbent is recommended for obtaining a much high removal efficiency of heavy metal and mercury in the range of 96 % - 100 %. However, the utilization of adsorbent (e.g. activated carbon) usually requires high cost, therefore, the amount of adsorbent should be minimized by identifying kinetic rate of process and optimal working condition to maximize the adsorbent capture capacity (Di Natale et al., 2014). The fabric filter is also used to remove the collected particles through cleaning mechanism by using blast air which is operated very effectively especially for fine particles as well as acid gas. The operating condition of the fabric filter is critical depending on the boiling point of the acid gas e.g. 110 °C for HCl (aq). The temperatures should be maintained at 150 °C to ensure that no surfaces are cooled below the dew point. Otherwise, the filter bag will degrade if the temperature reaches the maximum value. The removed particles are stored in a collection hopper until they are disposed - these particles are known as fly ash. The emissions from medical waste incinerator in Malaysia have to comply with the new emission limits of the Environmental Quality (Clean Air) Regulation 2014 - recently established to replace the Malaysia Environmental Quality (Clean Air) 1978.

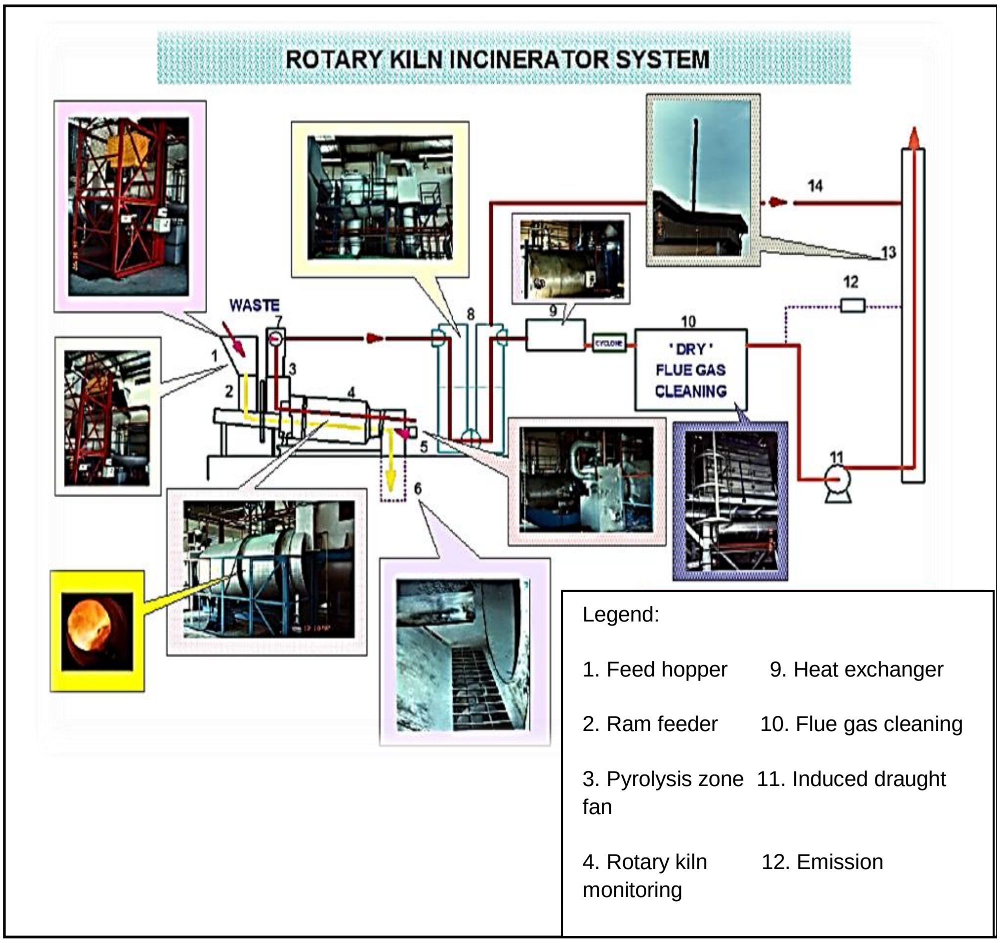

Figure 1: Schematic diagram of the studied plant (Sulaiman, 2012)

So far, there are no published studies on the TEs behaviour in bottom ash and fly ash from medical waste incinerator in Malaysia. The assessment on the adequacy of the existing air pollution control (APC) technologies in Malaysia has never been studied before as well. In this studied plant, toxic metals released into fly ash and bottom ash are enriched with heavy metals such as As, Cd, Cr, Pb and Hg. This is a bit brief compared to the study by Zhao et al. (2010) who considered more elements including Fe, Zn, Ti, Ba, Mn, Ni and Sn.

Table 2: Basic information of the studied medical waste incinerator

Incineration capacity (kg/h)	650 kg/h (max)
Auxiliary fuel	Natural gas
Air pollution control (APC) unit	ESP, Fabric filters + wet scrubber (limestone)
Number of stack	2
Stack height (m)	30
Stack diameter (m)	0.6
Velocity (m/s)	8.5
Flow rate of flue gas (m^3/s)	2.2

2.2 The analysis of ICP-OES and atomic absorption mercury analyser

The samples of bottom ash and fly ash were collected for analysis from the studied plant. The bottom ash sample was collected from the bottom hopper while the fly ash sample was collected from fly ash silo. Five heavy metals of As, Cd, Cr, Pb and Hg were considered in this study. The concentrations of As, Cd, Cr, and Pb in fly ash and bottom ash from the incinerator were determined by using the inductively coupled plasma optical emission spectrometry (ICP-OES) of the Perkin-Elmer Optima 5300 DV. It is a type of emission spectroscopy that uses the inductively coupled plasma to produce excited atoms and ions that emit electromagnetic radiation at wavelengths characteristic of a particular element. The intensity of this emission is indicative of the concentration of the element within the sample.

Firstly, the ICP-OES was calibrated using three calibration standards and the analysis can be conducted only if the analytical error is within 2 %. All the samples are in solid state; therefore dissolution of the samples needs to be carried out prior to analysis of the samples. The samples were digested by adding 6 ml of 20 % hydrochloric acid (HCl) and 2 mL of 20 % nitric acid (HNO_3) to approximately 0.1 g of solid sample.

Meanwhile for mercury content, an atomic absorption mercury analyser was used. For this analysis, two separate portions of samples from both bottom ash and fly ash was prepared by placing approximately one gram of each into 50 mL polypropylene tubes followed by 2 mL of 15N HNO_3 and 6 mL of 12N HCl. All the tubes were held at 80 °C for 1 h. Next, 36.5 mL of deionized water was added to each tube followed by 5 mL of 5 % potassium permanganate. After allowing ten minutes for oxidation, each tube was examined to ensure that there was an excess of oxidant. Finally, 0.5 mL of a 12 % sodium chloride/12 % hydroxylamine mixture was added to remove the excess oxidant and subsequently to complete the digestion process. The calibration standards and samples were then loaded into the auto-sampler of the mercury analyzer.

3. Result and discussion

According to Table 3, it shows the concentration of TEs in the studied plant. The study found that the emissions of TEs are well below the limits as in Environmental Quality (Clean Air) Regulation 2014 which replaces the Malaysia Environmental Quality (Clean Air) 1978.

Table 3: Concentration of TEs in the studied medical waste incinerator

Parameter	Average concentration (mg/Nm^3)	Limits as per new clean air regulation
Arsenic (As)	0.008	0.05
Cadmium (Cd)	< 0.03	0.1
Lead (Pb)	0.09	5.0
Chromium (Cr)	0.0235	0.05
Mercury (Hg)	0.04	0.1

The results of the solutions that has been analysed by the ICP-OES for As, Cd, Cr, Pb and mercury analyser for Hg are summarised in Table 4. This study shows that the amount of TEs in the fly ash were higher than their content in the bottom ash. This can be explained simply by their physical and chemical properties – the studied TEs are those that are easily volatile and thus, ended up more in the fly ash. Also, fly ash contains higher concentration of TEs compared to bottom ash due to the volatisation of TEs during the incineration on the surface of fly ash particles (Świetlik et al., 2012). Based on the result presented in Table 4, Hg in fly ash and bottom ash have lowest concentration compared to the other elements. This finding agrees well with the volatility of TEs as presented in Table 1 where the concentration of Hg is at detection limit. This could be due that Hg remained in volatized phase. It was found that volatility of TEs generated from the studied plant is in order of Cd < Cr < As < Pb < Hg.

Table 4: Concentration of TEs from analysis of ICP-OES

Parameter	Unit	Fly ash	Bottom ash
Arsenic (As)	mg/kg	4.0	< 0.5
Cadmium (Cd)	mg/kg	6.9	< 0.5
Lead (Pb)	mg/kg	6,100	340
Chromium (Cr)	mg/kg	150	130
Mercury (Hg)	mg/kg	< 0.1	< 0.1

The concentrations of TEs in bottom ash and fly ash analysed in this study were found to be well below the threshold limit concentrations as specified by Total Threshold Limit Concentration as specified in Department of Environment, Malaysian Guidelines for the Application limits of Special Management of Schedule Waste as shown in Table 5 This is true for all the studied TEs except for Pb in fly ash which is above the emission limits (6,100 mg/kg vs. the limit of 1,000 mg/kg). Therefore, the contaminant of lead in medical waste fly ash is comparatively higher leaching risks to the environment, whereas As, Cd, Cr and Hg are relatively safe. The high content of lead in the fly ash was contributed by the combustion of plastic from medical waste in the incinerator, as mentioned by Kimani (2007). As revealed by Altin et al. (2003), the predominant components of medical waste is plastic which is about 41, while study by Liberti et al. (1994) stated that 46 % of plastic is a major component compared to the other component such as paper, gloves, diapers, surgical garments and other solid wastes. This contributed to the high lead content in the fly ash emissions from the incinerator. Meanwhile, the results from this study also suggested that the bottom ash produced from the studied incinerator can be considered as non-hazardous since the risks are low (the emitted concentrations are below the emissions limits) for all the TEs.

Table 5: Limit concentration of TEs based on Department of Environment, Malaysian Guidelines for the Application limits of Special Management of Schedule Waste

Parameter	Unit	Limit Concentration
Arsenic (As)	mg/kg	500
Cadmium (Cd)	mg/kg	100
Lead (Pb)	mg/kg	1,000
Chromium (Cr)	mg/kg	2,500
Mercury (Hg)	mg/kg	20

4. Conclusion

This paper presents study on the determination of the trace elements (TEs) concentration in bottom ash and fly ash from a medical waste incinerator in Malaysia. The comparison in term of volatility have been made which Hg as the most volatile elements followed by the less volatile element Pb, As, Cd and Cr respectively. Besides, the emission control technology commonly used in removal of TEs in many medical waste incineration facilities was also compared with studied plant as presented in this paper, to determine the most effective configuration of the air pollution control (APC) units. Since the efficiency of the APC in the studied plant (using spray scrubber with limestone) is unsatisfactory, it may be necessary to add in special adsorbent, such as activated carbon to achieve high removal efficiency of heavy metal with more than 90 %. However, the emissions of TEs in this studied plant are well below the limits as in Environmental Quality (Clean Air) Regulation 2014. This study also found that the concentration of As, Cd, Cr, Pb and Hg from bottom ash of the studied plant complied well with the Malaysian Department of Environment (DOE) Scheduled Waste Guideline limits. However, for the fly ash, the content of Pb was higher than the established standard, hence demands for further attention to reduce it further, at least down to the acceptable level.

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