J. KOSAE Vol. 22, No. E2 (2006) pp. 49~56
Journal of Korean Society for Atmospheric Environment

A Pilot Study on Emissions of Air Pollutants Produced from Incineration of Some Municipal Solid Wastes

Haengah Kim, Byeong-Kyu Lee[1),*] and Jungbum Cho[2)]
Environmental Studies Ph.D. Program, University of Massachusetts, Lowell, MA 01854, USA
[1)]Department of Civil and Environmental Engineering, University of Ulsan, Ulsan 680-749, Korea
[2)]Korea Zinc Onsan Complex, Daejung-ri 505, Onsan-up, Ulju-gun, Ulsan, Korea

(Received 7 March 2006, accepted 18 December 2006)

Abstract

This pilot study focuses on emissions characterization of air pollutants produced from incineration of some municipal solid wastes (MSWs). The MSWs incinerated by an electric furnace maintained up to 600°C included food, paper, and plastic wastes. The pollutants analyzed in this study included concentrations of volatile organic compounds (VOCs), bottom ash contents, and heavy metals extracted from the bottom ash of each waste. The VOCs identified were classified based on their chemical structure. The total emissions of VOCs produced from incineration of the papers were identified as the highest followed by those from the plastics and the food wastes. Aliphatic alkenes were major VOC compounds produced from incineration of plastic or food wastes, while furans were major VOCs produced from incineration of papers. The second major VOCs produced from incineration of food, plastics, and papers were aromatics. In particular, hazardous air pollutants such as benzene were produced with considerable amount of emission concentration. The bottom ash contents of papers were usually much higher than those of food or plastic wastes. The bottom ash contents produced from incineration of food and plastics were much lower than those of other MSWs. In analysis of heavy metals extracted by an ultrasonic method from the bottom ashes of the papers, high concentrations of heavy metals were identified from incineration of newspapers and box (cardboard). In addition, it was identified that the general public might be exposed to considerable amounts of lead concentrations during incineration processes and uses of paper cup and from ashes.

Key words : MSWs, Incineration, Heavy metals, VOCs, Papers, Plastics, Food

1. INTRODUCTION

With continuous industrialization and urbanization and/or rise of living standards, the amounts of wastes generated from homes, various organizations and manufacturing sites have increased. Thus we have to pay more money to dispose of the wastes and have been faced more risks to be exposed to the toxics released from waste disposal (Lee *et al.*, 2004; Yasuda and Takahashi, 1998; Sicer *et al.*, 1996). This implies that it is very important to find effective disposal methods of the wastes. There are various disposal methods such as landfilling, recycling/reuse, and incineration of municipal solid wastes (MSWs) (US EPA, 2005). The landfilling is currently the most popular waste disposal method in

* Corresponding author. Tel : +82-52-259-2629,
Fax : +82-52-259-2864, E-mail : bklee@ulsan.ac.kr

Korea (UMC, 2005; KME, 2005). Although the number of operating landfills and available landfill space have decreased, it is very difficult to construct new landfills. This is because it is very difficult to find good or new landfill construction sites due to the narrowness of available land space, not-in my back yard (NIMBY) syndrome and high construction costs (Lee *et al.*, 2004; Lee, 1995). Recycling is a very ideal disposal method. However, the current recycling/reuse rates of MSWs except for aluminum and few metals are not high enough in Korea. This is because market and infrastructure for recycling/reuse have not been well established. This underdevelopment of the recycling market and/or infrastructure is because the general public believes that the material quality of the recycled/reused products as compared with virgin products will be low.

The next rising alternative disposal method in Korea is incineration (Shim *et al.*, 2003). Waste disposal of by incineration has several advantages such as high volume reduction of waste in a short time, prevention of disease generated from waste disposal and/or handling processes, and sometimes being harmless of hazardous materials (Yun and Lee, 2005; Lee, 1995; Lym, 1995). In addition, large amounts of combustible wastes have been generating from homes, organization, and manufacturing sites In Korea. About 84 wt% of Korean MSW was composed of combustible waste such as food, papers, plastics and rubbers, and woods in 2004 (UMC, 2005; KME, 2005). Thus, disposal of by landfilling of these combustible wastes has imposed a heavy burden on landfill or waste managers. Currently, the proportion of Korean MSW disposal of by incineration is less than 14.4 wt% in 2004 (UMC, 2005; KME, 2005). Therefore, the Korean government is trying to increase a proportion of MSW disposal of by incineration. From this point of views, many small- and or medium-scale manufacturing sites and organizations, such as schools and government offices, in Korea have been operated many small-scale incinerators for their combustible waste disposal (Yasuhiko, 2005; Yoo *et al.*, 2002; Dong, 2001; Kitakawa, 2000a, b). However, the only air pollution control device attached with small-scale incinerators, having a capacity of below 100 kg/hr, is a cyclone (Kitakawa, 2000b). Thus lots of hazardous air pollutants such as hazardous ashes, heavy metals, dioxins and furans, and volatile organic compounds (VOCs) have been emitting from incineration (Morselli *et al.*, 2002; Striebich *et al.*, 2002; Yoo *et al.*, 2002; Lee and Kim, 2000; Cudahy and Helsel, 2000; Wheatley *et al.*, 1993). Many people, who live in near the places which small-scale incinerators have been operated, may have been exposed to various hazardous air pollutants.

In this study the authors really focused on the incineration of the MSWs which was not disposed of by incineration previously. That is, this study deals with emission characteristics of air pollutants containing as VOCs and ashes produced from incineration of some food, papers, and plastics by the electrical furnace. Therefore, the result of this study will be useful for basic understanding of emission estimates of air pollutants produced from incineration of some MSWs by small scale incinerators.

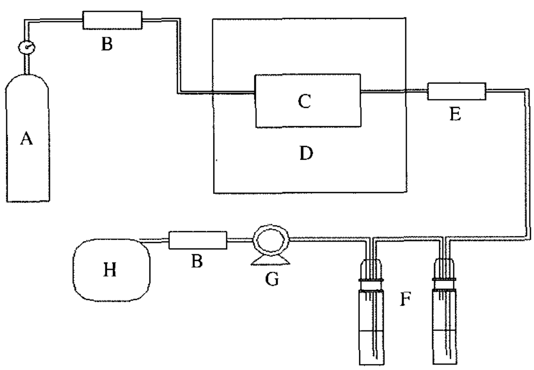
2. MATERIALS AND METHODS

2.1 Materials

The following MSWs obtained in typical residential areas of Ulsan have been used for the incineration study: 1) food waste containing rice, kimchi, vegetable, fruit, fish, meat, and chige wastes; 2) paper wastes containing A4 papers (virgin, inkjet printed, and laser printed A4 papers), box (cardboard), document envelope, news papers (bean oil printed and general ink printed), advertisement paper, paper cup, and tissue; and 3) plastic wastes containing polyethylene terephthalate (PET), high density polyethylene (HDPE), polyvinyl chloride (PVC), low density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), and other mixed plastics.

2.2 Experimental Methods

Fig. 1 shows a schematic diagram on sampling



A: Compressed air, B: Ball flow meter, C: Incineration chamber, D: Electric furnace, E: Filter, F: Impinger (for acid gases), G: Sampling pump, H: Air sampling bag (for VOCs)

Fig. 1. The schematic diagram for sampling of air pollutants produced from incineration of the MSWs by using an electric furnace.

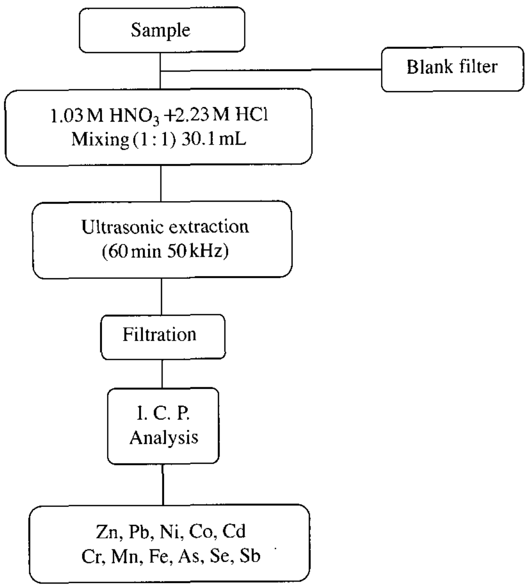


Fig. 2. A scheme for analysis of the heavy metals extracted from the bottom ashes.

system of air pollutants produced from incineration of the MSWs by the electric furnace (HY-8000S) used for this study. The incineration chamber temperature of the furnace is controlled by a thermal conduction sensor attached to the incineration sample part. The incineration chamber has a dimension of width of 10.5 cm, depth of 16 cm, and height of 31.5 cm. A filter to remove suspending particles generated from incineration was put at the sampling outlet of the chamber. For corrosion prevention of air sampling pump by acid gases produced from incineration and temperature reduction of emission gases for effective sampling of emissions into air sampling bags, two impingers of 250 mL containing 0.1 N NaOH solution were put in front of the air sampling system. Incineration samples of 30 g in crucible were put in the center of the incineration chamber and leveled with the chamber bottom.

For effective incineration compressed air (about 21% oxygen) is supplied into the chamber with a flow rate of 60 mL/min to collect, in an air bag of 10 L, all VOCs and gases generated during a period of approximately 1.5 hr heating up to 600°C and 1hr incineration time at 600°C (155 ± 3 min), in an air bag of 10 L. The incineration temperature was decided as 600°C because of a temperature limitation of the electric muffle furnace used in this study. The incineration temperature and products in this preliminary study may not be the same as real ones. The incineration was started at room temperature and the temperature was raised up to 600°C with a heating rate of 6 ~ 7°C/min. And then the incineration chamber was maintained at 600°C for 1 hour.

The total sampling time for incineration of the MSWs was 155 ± 3 min (including the heating up time, 95 min, from room temperature to 600°C). Acid gases produced during incineration were absorbed in the 1 N NaOH solution in the two impingers and pH of the solutions was analyzed by a pH-meter. Organic gases like VOCs were collected in Tedlar air sampling bags (10 L) by a personal air sampling pump (Gillian model) with a flow rate of 60 mL/min and analyzed GC-MS (HP 5890 GC, HP 5971A MSD, HP-PONA 50 m × 0.2 mm × 0.5 μm column) after cryogenic concentration (DS 5000 Aero-Trap) (Lee and Kim, 2004). The standard materials for VOCs analysis were the Supleco products including each 1 ppm of 39 VOCs (Scotty 104). The standards were diluted with zero air, which is pollution free, and then prepared for calibration curves for quantitative analysis. After completing incineration, the incineration chamber and the crucible with ashes were cool down to room temperature. The crucible with ashes was kept up for 3 days at H_2SO_4 desiccators and the ash contents were analyzed by using a gravimetric method. Heavy metals contained in the ashes (bottom ashes) remained in the crucible were extracted by using a ultrasonic extractor (Brasonic Co., Model 1210) and the extracted heavy metals were analyzed by using a Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES, Atom Scan 25) (Hwang *et al.*, 2005; Park and Chung, 2001; Jang *et al.*, 2000). Fig. 2 shows a schematic diagram of pre-treatment and analysis processes for analysis of heavy metals contained in the bottom ashes. After the MSW samples were kept up for 2 hours at a drying oven maintained with 105°C, a gravimetric method like analysis of the ash content was employed for analysis of moisture contents of the wastes.

3. RESULTS AND DISCUSSION

3.1 Analysis of VOCs

A lot of VOCs were produced from incineration by the electric furnace of food, papers, and plastics. It might be very valuable to find out a relation between VOCs produced from incineration and their chemical structure. VOCs produced from incineration of each waste of 30 g at the combustion chamber were properly classified according to their chemical structure (see Table 1). The concentrations shown in Table 1 are not a sum of normalized concentrations of each compound, but just a simple addition of each concentration of VOCs. It is difficult to evaluate the results statistically because 11 types of papers, 7 type of plastics and 7 type of food wastes were used in this study (see Materials section). Even though there was a small variation of VOCs within the same type of wastes, there was a considerable variation among the different types of wastes. Evaluating from the values shown in Table 1, the total concentrations of VOCs produced from incineration of papers were much higher than those of plastic or food wastes. Aliphatic alkenes were major compounds produced from incineration of plastic or food wastes, while furans were major compounds produced from incineration of papers. The second major compounds produced from incineration of food, plastics, and papers were aromatics. This is probably because aromatics and aliphatic alkenes and furans are more stable compounds in terms of formation energy than aliphatic alkanes and other oxidized compounds, respectively. In addition, high emissions of aromatics and aliphatic alkenes are probably due to the preferential formation of them, which is more stable or resistant to decomposition, before VOCs produced are oxidized with oxygen from incineration processes. High emissions of furans are probably because more stable (or less strain) five-membered ring structure was much more formed than other size ring structure from incineration of papers. The simple sum of concentrations of aromatics, aliphatics, and oxidized forms, such as aldehydes or ketones, occupies more than 80% or 90% of VOCs produced from incineration processes of food or plastics. Also, more than 40% of VOCs produced from incineration of papers

Table 1. Classification of average VOCs produced from incineration of MSWs.

Waste	Food		Papers		Plastics	
Concentration	ppm	%	ppm	%	ppm	%
Aromatics	131.4	19.6	267.0	21.7	273.3	32.0
Aliphatic alkenes	365.7	54.4	234.7	19.0	513.3	60.2
Aliphatic alkanes	74.8	11.1	16.0	1.4	136.7	4.3
Chlorine compounds	47.1	7.0	2.7	0.2	3.3	0.4
Oxidized compounds	33.3	5.0	4.3	0.3	3.3	0.4
Furanoses	19.5	2.9	708.3	57.4	23.3	2.7
Total VOCs	671.8	100	1,233.0	100	953.2	100

Table 2. Analysis of EPA's average air toxics obtained from incineration of MSWs.

Waste	Food		Papers		Plastics	
Concentration	ppm	μg/kg	ppm	μg/kg	ppm	μg/kg
Benzene	103.3	2,970.1	197.6	5,681.5	81.6	2,346.2
Chloroform	0.8	35.2	1.9	83.5	N.D.	N.D.
Ethylbenzene	N.D.		4.5	175.8	0.7	27.4
Hexane	11.1	352.1	5.0	158.6	2.6	82.5
Methylethylketone	5.4	143.3	24.1	639.7	N.D.	N.D.
Methylene chloride	27.8	869.1	2.4	75.0	0.8	25.0
Toluene	7.6	257.8	55.2	1,872.2	9.5	322.2
Xylenes	5.1	173.0	7.9	33.9	N.D.	N.D.
Total	161.1	4,800.6	290.7	8,720.2	95.2	2,803.3

were composed of aromatics, aliphatic alkenes, aldehydes and ketones. Since these compounds have double bonds within their chemical structure, they have a great potential of formation of ground level ozone or photochemical smog. Therefore, most of VOCs produced from incineration of food or plastics, and even papers could act as precursors of formation of the ground level ozone or photochemical smog.

Table 2 summarizes the concentrations of the VOCs identified in this study in VOC compounds designated as toxic air pollutants or air toxics by Clean Air Act Amendments (CAAA) of 1990. From incineration of food, papers, and plastics, benzene known as a strong carcinogen suspecting compound was produced with a very high emission concentration. This is maybe because benzene is a very stable aromatic compound which is relatively easily formed under incomplete combustion conditions. In addition, chloroform and methylene chloride, which have a strong toxicity or emit highly toxic fumes when heated to decomposition, were identified as considerable amount of emissions. Toluene was also produced with considerable amount of emissions and especially emission concentration of toluene from incineration of papers was very high. From incineration of food waste, chlorine compounds such as methylene chloride or chloroform are identified as relatively high concentration compared with papers or plastics. This is probably due to the use of high concentration of chlorine compounds such as salts in preparing food.

3.2 Ash Analysis

Table 3 shows contents of the bottom ashes produced from incineration of the food, paper, and plastic wastes. From incineration of the fish and meat wastes, relatively high ash contents were observed as compared with other food wastes. This is because most of fish and meat wastes had high content of bones (fish needles and spines, galbbi (ribs) bones). Even though fish and meat wastes have high bone content, disposal of by incineration could much reduce their waste volume. Other food wastes except for the wastes with bones showed very low bottom ash contents. From incineration of plastics, other plastics except for PVC also showed very much low bottom ash contents (see Table 3). Food and plastic wastes have been disposed of by landfill. From these results in terms of bottom ash content analysis, however, we could evaluate disposal potential by incineration of food and plastic wastes.

Since PVC decomposition to heat produces highly toxic fumes of HCl or benzene and holds a great potential of dioxin and furan formation, disposal of by incineration might have been reluctant to be accepted as a useful disposal method of PVC wastes.

The bottom ash contents produced from incineration of papers ranged from 0.9 wt% to 24.0 wt%. In particular, the bottom ash content produced from incineration of a department store advertisement paper was much higher ash content as compared with other papers. This is probably because the advertisement paper happened to be coated with some materials which have flame resistant charac-

Table 3. Analysis of ash content from incineration of MSWs.

Food		Papers		Plastics	
Waste	Ash content (wt%)	Waste	Ash content (wt%)	Waste	Ash content (wt%)
Rice	1.48	A4 (Virgin)	14.6	PETE	0.02
Kimchi	2.45	A4 (Inkjet)	14.0	HDPE	0.14
Chige	0.63	A4 (Laser)	10.9	PVC	7.45
Vegetable	0.43	Box (Cardboard)	8.2	LDPE	0.17
Fruit	0.59	Document envelope	0.9	PP	0.48
Fish (Bone)	7.37	News paper (Bean Oil)	6.1	PS	1.11
Meat (Ribs)	23.81	News paper (General Ink)	5.4	Other	0.61
		Advertisement	24.0		
		Paper cup	1.6		
		Tissue	1.4		

Table 4. Mean concentrations of heavy metals contained in the bottom ashes obtained from incineration of papers.

(Unit : ppmw)

	A4 paper			News paper		Box (Card board)	Documt. envlp.[2)]	Advert. paper[3)]	Paper cup	Tissue
	Virgin	Inkjet print	Laser print	Bean oil print	General ink print[1)]					
Zn	0.14	0.05	0.08	1.53	2.50	5.03	0.61	0.21	0.34	2.33
Pb	0.20	0.20	0.20	0.20	0.20	0.93	0.20	0.20	3.63	0.20
Cd	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Ni	0.04	0.04	0.03	0.13	0.16	0.05	0.05	0.09	0.03	0.07
Co	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Cr	0.05	0.01	0.02	0.36	0.39	0.64	0.05	0.06	0.18	0.19
Mn	0.83	0.87	1.23	2.73	2.10	18.60	3.80	1.63	0.73	1.67
Fe	6.99	N.D.	0.04	29.6	30.30	51.37	8.80	0.71	4.73	12.87
As	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01
Se	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Sb	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

[1)]General Ink Print stands for the news paper printed with a general newspaper ink.
[2)]Documt. Envlp. stands for the document envelope produced from a university.
[3)]Advert. Paper stands for the advertisement paper produced from a department store.

teristics. In addition, since the thickness of the advertisement paper was much greater than other papers, it is inferred that the effective incineration was not performed. The ash contents from incineration of the tissue, the paper cup, and the document envelope used in a university were much lower than other paper wastes. This is probably because the very thin thickness of the tissue, the materials coated on the paper cup and the document envelope made a possible to be performed effective incineration of the paper wastes. In comparison of A4 papers (virgin, inkjet printed, laser printed), the ash content of laser printed A4 was higher than other A4 papers. This is because the laser printed A4 paper was coated with carbon black which is already incinerated or not incinerated. That is, the combustible proportion of the waste is relatively low as compared with other A4 papers. The ash content of the inkjet printed A4 paper is slightly lower than the virgin A4 paper. This is because the inkjet coated on the A4 might help the incineration of the paper.

3.3 Heavy Metals

The concentrations of heavy metals (shown in Table 4) extracted from the bottom ashes of various papers by ultrasonic method were analyzed by the

Table 5. VOCs produced from incineration of newspapers by using an electric furnace.

Chemical name	Concentrations from newspaper printed with bean oil ink (ppb)	Concentrations from newspaper printed with general newspaper ink (ppb)
2-Methyl 1-propene	1,258.7	1,136.1
1-Butene	520.5	449.3
1-Pentene	272.6	339.0
2-Pentene	239.5	241.2
n-Pentane	0.0	50.5
Trans 1,2-dimethy cyclopropane	203.4	216.4
1-Hexene	350.0	483.6
n-Heptane	6.2	7.3
n-Octane	3.0	6.3
2-Methyl 2-propenal	253.8	397.3
Methyl ethyl ketone	136.5	216.2
Furan	228.2	497.7
2-Methyl furan	8,873.4	10,031.8
2-Ethyl furan	54.7	180.0
2,5-dimethyl furan	342.8	481.1
2,4-Methyl furan	33.6	268.9
Benzene	1,159.5	4,604.4
Toluene	567.9	569.4
Ethyl benzene	16.5	24.3
Styrene		6.5

ICP. In this study Cd, Co, Se, and Sb were not identified. The concentrations of the heavy metals identified from the A4 papers were relatively much lower than those of the other papers. The heavy metals obtained from the bottom ashes of the newspapers and the boxes (cardboard) were much higher than those of other papers. Manganese, iron, and zinc concentrations were identified as the highest ones from the bottom ashes of the box. From a comparison of heavy metals from the bottom ashes of the newspapers printed with the bean oil and the general newspaper ink, all heavy metals identified except for Mn were observed relatively lower concentrations in the bean oil newspaper. The newspaper printed with bean oil ink is safer than the general ink newspaper for protection of the public health, in terms of exposure to heavy metals, related to newspaper reading. This truth is also identified from a comparison of concentrations of VOCs produced from incineration of the two newspapers (see Table 5). The considerable amounts of lead were identified from the bottom ashes of the paper cup which is used fro drinking of coffee, tea, and water. This fact implies that we could be exposed to lead from incineration, bottom and fly ashes, and uses of the paper cup.

4. SUMMARY

The findings on the pilot study of emission analysis of air pollutants produced from incineration of some MSWs such as food, paper, and plastic wastes are summarized as follows:

1. The total concentrations of VOCs produced from incineration of papers were much greater than those of food or plastics. Aliphatic alkenes were major compounds produced from incineration of plastic or food wastes, while furans were major compounds produced from incineration of papers. The second major compounds produced from incineration of food, plastics, and papers were aromatics.
2. High concentrations of hazardous air pollutants such as benzene and dichloromethane were also identified from incineration of the MSWs.
3. Most of food and plastic wastes except for meat, fish and PVC showed a very low content of the bottom ashes.
4. Higher concentrations of heavy metals were extracted from the bottom ashes of the newspapers and the box (cardboard) compared with other paper wastes.

ACKNOWLEDGEMENTS

This work was supported by research funds of the University of Ulsan, Korea.

REFERENCES

Cudahy, J.J. and R.W. Helsel (2000) Removal of products of incomplete combustion with carbon, Waste Management, 20, 339-345.

Dong, J.I. (2001) Technical approaches for management of waste incineration facilities, J. of Korean

Solid Wastes Engineering Society, 18(3), 29-38.

Hwang, H.J., H.K. Kim, and C.-U. Ro (2005) Single-particle characterization of municipal solid waste (MSW) ash particles using low-Z particle electron probe X-ray microanalysis, J. of Korean Society for Atmospheric Environment, 21, 367-375.

Jang, S.-G., D.I. Choi, C.-H. Lym, and J.-S. Lee (2000) Component analysis of fly ashes produced from disposal facilities of municipal solid waste, J. of Korean Society of Analytical Sciences, 13, 215-221.

Kitakawa, G. (2000a) Technology trends of a small-scale incinerator (1), J. of Environmental Hi-Technology, 2, 46-49.

Kitakawa, G. (2000b) Technology trends of a small-scale incinerator (2), J. of Environmental Hi-Technology, 3, 60-65.

Korea Ministry of Environment (KME, 2005) 2004 Waste generation and disposal features in Korea. http://library.me.go.kr/DLiWeb15/components/searchir/20/detail/contentview.aspx?menuid=-1&cid=148031#.

Lee, B.K. (1995) A study of the characterization, disposal, recycling, and air emissions of medical and plastic wastes, Ph.D. Dissertation, UMASS, pp. 1-26.

Lee, B.K. and H.A. Kim (2004) Analysis of VOCs produced incineration of plastic wastes using a small-electric furnace, J. of Korean Society for Atmospheric Environment, 20, 759-771.

Lee, B.K. and H.A. Kim (2000) Analysis of the emission potential of hazardous pollutants produced form a disposal of the school solid waste by a small-scale Incinerator, J. of Korean Society for Atmospheric Environment, 16, 299-308.

Lee, B.K., M.J. Ellenbecker, and R. Moure-Eraso (2004) Alternatives for treatment and disposal cost reduction of regulated medical wastes. Waste Management, 24, 143-151.

Lym, G.-G. (1995) Analysis of waste incinerator and its selection, J. of Korea Air Pollution Research Association, 11, 108-117.

Morselli, L., F. Passarini, and M. Bartoli (2002) The environmental fate of heavy metals arising from a MSW incineration plant, Waste Management, 22, 875-881.

Park, H.-S. and J.-D. Chung (2001) A concentration analysis of heavy metal components in incineration ash, J. of Korean Solid Wastes Engineering Society, 18, 302-308.

Shim, Y.-S., Y.-K. Kim, S.-H. Kong, S.-W. Rhee, and W.-K. Lee (2003) The adsorption characteristics of heavy metals by various particle sizes of MSWI bottom ash, Waste Management, 23, 851-857.

Sicer, C.W., B.E. Buxton, M.W. Holdren, D.L. Smith, T.J. Kelley, S.W. Rust, A.D. Pate, G.M. Sverdrup, and J.C. Chuang (1996) Variability of hazardous air pollutants in an urban area, Atmospheric Environment, 30, 3443-3456.

Striebich, R.C., W.A. Rubey, and J.R. Klosterman (2002) Trace-level measurement of complex combustion effluents and residues using multidimensional gas chromatography-mass spectrometry (MDGC-MS), Waste Management, 22, 413-420.

Ulsan Metropolitan City (UMC, 2005) Characterization of municipal solid waste in the Ulsan: 2004, An Environmental White Paper.

U.S. Environmental Protection Agency (US EPA, 2005) Municipal solid waste in the United States: 2003 Facts and Figures and 2003 Data Tables, http://www.epa.gov/epaoswer/non-hw/muncpl/msw99.htm.

Yasuda, K. and M. Takahashi (1998) The emission of polycyclic aromatic hydrocarbons from municipal solid waste incinerators during the combustion cycle, J. of Air & Waste Management Association, 48, 441-447.

Yasuhiko, M. (2005) Recent design technologies and development of small-scale incinerator, J. of Environmental Hi-Technology, 4, 24-29.

Yoo, J.-I., K.-H. Kim, H.-N. Jang, Y.-C. Seo, K.-S. Seok, J.-H. Hong, and M. Jang (2002) Emission characteristics of particulate matter and heavy metals from small incinerators and boilers, Atmospheric Environment, 36, 5057-5066.

Yun, Y.-S. and S.M. Lee (2005) A new trend of domestic and international incineration technologies, J. of Environmental Hi-Technology, 4, 6-15.

Wheatley, L., Y.A. Levendls, and P. Vouros (1993) Expiratory study on the combustion and PAH emissions of selected municipal waste plastics, Environmental Science & Technology, 27, 2885-2895.