METAL DISTRIBUTION IN INCINERATION RESIDUES OF MUNICIPAL SOLID WASTE (MSW) IN JAPAN

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Abstract

This study aimed to identify distribution of metals and the influential factor on metal concentration in incineration residues. Bottom ash and fly ash were sampled from nineteen stoker and seven fluidized bed incinerators, which were selected to have the variety of furnace capacity, furnace temperature and input waste. As results, shredded bulky waste in input waste increased the concentration of some metals, such as Cd and Pb, and the effect was confirmed by the analysis of shredded bulky waste. During MSW incineration, lithophilic metals such as Fe, Cu, Cr and Al remained mainly in the bottom ash while Cd volatilized from furnace and condensed to the fly ash. About two-third of Pb and Zn was found in bottom ash despite their high volatility. Finally, based on the results obtained in this study, metal amount in incineration residues of MSW was calculated and the loss of metal was estimated in terms of mass and money. Considerable amount of metals was found to be lost as waste material by landfilling incineration residues.

Key Words :

MSW incineration, Metal, Fly ash, Bottom ash, Metal distribution, Shredded bulky waste

1. Introduction

In Japan, “The Basic Law for Establishing the Recycling-based Society” was enacted in May 2000 to change a “Throw-away Society” to a “Recycling-based Society”. Following the enactment of the law, comprehensive measures for waste management and recycling have been promoted by the national government. Ultimate goals for these measures are the reduction of natural resource consumption and environmental burden. In this context, metals should be given higher priority since they are valuable resources and some of them have hazardous characteristics. For better management of metals, it is fundamental and essential to identify the flow in the society. Statistics are available for production and consumption, but studies on the flow in solid waste management (SWM) process were limited so far although SWM is critical process to determine the fate of metals. This paper focused on incinerator process which treats about 80% of municipal solid waste (MSW) generated in Japan and aimed to identify metal distribution in incineration residues.

Brunner & Monch (1986) investigated the metal distribution for two MSW incinerators, in which different flue gas cooling methods were used. Belevi et al. (2000) fed household waste and mixed waste with commercial waste to a MSW incinerator and determined the distribution of metals. In Japan, Nakamura et al. (1996) and Watanabe et al. (1999) carried out the similar study for selected metals (Pb, Cd, Sn, As) in MSW incinerator. For theoretical approach, Verhulst et al. (1996) studied behavior of metals based on thermodynamic analysis approach. Fernandez et al. (1992) and Abanades et al. (2002) performed the simulation analysis and compared the results with experimental data. Although much work has been done to date, in Japan, only a few studies were found in literature. And waste material flow in treatment and disposal processes of MSW was changed after Electric Household Appliance Recycling (EHAR) Law was enacted on April 2001. Hence, more studies on metal distribution in incineration of MSW need. Furthermore, most studies previously mentioned

were done in one or two incinerators, but the metal distribution might be affected by the type of incineration furnace, furnace capacity, and input waste.

In this paper, therefore, twenty six incinerators, which were selected to have various conditions, were investigated for metal distribution. Specifically, influential factors on metal concentration and the distribution of metals in incineration residues (bottom ash and fly ash) were studied. Prior to experimental work, literature survey was also conducted because a lot of analytical data of metal concentrations in incineration residues of MSW have been reported up to now in Japan. The result was analyzed statistically to assess the appropriateness of the data for metal distribution.

2. Experimental work

2.1 Determination of target metal

Target metals in this study were selected based on scarcity and toxicity. Table 1 shows reserves (R), productions (P), and the possible use year (R/P) of metals in the world (World Resources 1996-97; Tateda *et al.* 1997). The metals of R/P below 100 years were defined scare metals. Lead, tin, zinc, cadmium, copper, selenium, and bismuth are included in this group. Special attention should be given to these metals due to their highly strained situations. Arsenic, chromium and antimony are selected as toxic metals, while some scare metals, such as cadmium, selenium and lead, are also toxic. Widespread metals, aluminum and iron, were added in the target metals. Table 2 lists the metals selected for this study.

2.2 Description of incineration facilities

In Japan, stoker and fluidized bed types of incinerators are widely used ; the stoker burns 85 % of MSW treated in incineration process and the fluidized bed burns 12 % according to

waste management statistics. Nineteen stoker and seven fluidized bed incinerators were selected to have variety of furnace temperature, furnace capacity and waste input. Table 3 shows the general description for these incinerators. While Al, D1, D5, E1 and E2 plants receive only combustible waste, the other plants treat shredded bulky waste in addition to combustible waste. Ash production was calculated on a dry basis and chemical agent amount used for ash treatment was subtracted.

2.3 Sampling and sample preparation

Sampling work of bottom ash and fly ash were performed during a period of 5 months (August 2001-December 2001). Bottom ash of 5 kg was taken three or four times in a day with 2 hr interval from an ash pit after water quenching. Fly ash of 3 kg was sampled four or five times in a day with 2 hr interval before it was treated by chemical agent. Sample preparation was done as shown in Figure 1. Bottom ash samples were dried at 105 ℃ for 24 hrs, ground for 2 hrs in a ball mill and sieved through a 0.5 mm screen. The materials passing the screen were mixed well to get composite sample. Then, the composite sample was divided into three equal sized samples (sub-samples) for metal element analysis. The same procedure was used for fly ash.

Shredded bulky waste was analyzed to investigate the contribution of the waste to metal concentration in incineration residues. Approximately 10 kg of shredded bulky waste, which was sieved overflow fraction fed to incinerators, was taken twice from E3 plant. Sampled wastes were sorted into 11 groups : plastics except film, textile, plastic film, paper, power cord, sponge, electric board, can, rubber, wood and ferrous metals. Each component was cut and ground to particles smaller than 2 mm with a cutting mill (Mitamura Riken 182900/SM-1). Two sub-samples for each component were prepared for analysis of metal content.

2.4 Analytical technique

In Japan, aqua regia (AR, HCl:HNO_3=3:1, v/v) digestion is generally used to prepare sample for metal concentration analysis. AR does not provide total dissolution of metals from silicate matrices when incineration residues are digested, so hydrofluoric acid (HF) digestion step should be added. A couple of days are needed for sample dissolution. In this study, Microwave assisted (MW) digestion method was used. This method needs one or two hours to dissolve samples, dramatically reduce the time, yet produces accurate results (Kingston & Walter 1992). AR and HF digestion are based on Sewage Test Method and Sediment Test Method of Japan. MW digestion was conducted using microwave techniques (CEM, MDS-2000) similar to proposed SW-846 Method 3052 (EPA). Figures 2 and 3 explain the procedure of AR digestion, HF digestion and MW digestion, respectively. In the last step, the boric acid was added to dissolve fluoride precipitates and to eliminate the excess HF in hydrofluoric acid digestion (Abanades et al. 2002 ; Kirby et al. 1993).

Concentrations of metal elements were measured by an atomic absorption spectrometry (AAS, Hitachi A-2000 and Z-8200). Aluminum, antimony, bismuth, cadmium, chromium, copper, iron, lead, tin and zinc were analyzed by flame AAS (Al: nitrous oxide/acetylene flame, the others:Air acetylene flame). Arsenic and selenium were determined by graphite furnace AAS. Palladium matrix modifier was added to improve the sensitivity.

3. Results and discussion

3.1 Literature survey on metal concentration in incineration residues

Data were collected from scientific journals concerning to waste management, which were published from 1993 to 2000 in Japan. The summary of survey was given in Table 4. In fluidized bed incinerators, no bottom ash is produced except discharged incombustibles. Data of bismuth, antimony, and tin were not found in fly ash. Also, the number of data for arsenic,

selenium, and antimony are very limited. The concentration vary widely for most metals and coefficient of variation is very high.

As factors causing such a high variation, parameters for incineration (furnace type, capacity, furnace temperature, waste input) and experimental parameters for metal concentrations analysis (sampling method, sample preparation method, analytical method) were considered. But it was impossible to investigate the effect because no information was presented in most literatures. Furthermore the data obtained from literature were expressed in “Concentration”. So, they are useless to calculate metal distribution without ash production amount. Consequently, direct sampling and analytical work was conducted.

3.2 Comparison of digestion methods

To check the reliability of MW digestion, bottom ash and fly ash from plant E1 and E3 were analyzed. As explained in 2.4, AR+HF digestion is stronger than AR digestion. So, in Figure 4, MW digestion was compared with AR+HF digestion. For most metals, the ratio of AR+HF digestion to MW digestion is around unity. Lower metal concentration of As and Bi in AR+HF digestion than that in MW digestion might be caused by volatilization. Generally, AR and HF digestion method cause many errors resulting from losses and atmospheric contamination during dissolution (Kingston & Walter 1992). On the other hand, MW digestion prevents both volatilization and atmospheric contamination encountered in open system. It is therefore concluded that MW digestion method is an efficient and speedy sample dissolution method to get metal concentrations from incineration residues.

3.3 Metal concentration in fly ash and bottom ash

Table 5 shows the results of experimental work. Lithophilic metals such as iron, copper and aluminum showed high concentrations in bottom ash while volatile metals such as cadmium, lead and zinc were concentrated in fly ash. When compared with literature survey in Table 4 the concentrations of most metals were lower than those from the literature. The EHAR (Electric Household Appliance Recycling) Law, which was enacted on April 2001, presumably contributed to the decrease by averting refrigerators, TV sets, air conditioners and washing machines from waste stream. And as can be seen in Table 5 the high coefficients of variation and broad concentration range for most metals are still found although the same sampling method, sample pretreatment, and analytical method were used. This suggests that the experimental factors do not influence the variation of metal concentrations in incineration residues.

3.4 Factors causing variation of metal concentration in incineration residues

To find the influential factor on metal concentration in incineration residues, the correlations between metal concentration and incineration parameters such as furnace type, capacity, temperature and waste input, were investigated.

Furnace type and capacity

Metal concentrations with furnace type were shown in Table 5. Al and Cr in fly ash from fluidized bed incinerator were confirmed higher than those from stoker incinerator with 1% of significance level, and Cu and Fe were higher with 5 % of significance level by T-test. They are all lithophilic metals whose volatility are low, so higher turbulence and entrainment of solid particle to the fly ash in fluidized bed might cause the difference.

Figure 5 illustrates the relationship between furnace capacity and metal concentration in fly ash from stoker type incinerator for Pb and Zn. In general, a big-incinerator has an advantage

to get stable combustion because of insensitivity to the fluctuation of waste feed. But as shown in Figure 5, metal concentration varied regardless of capacity of furnace. The other metals in fly ash and bottom ash also showed the similar result for both types of incinerators.

Furnace temperature

In general, volatilization of metals increases with furnace temperature. So, volatile metals such as Cd, Pb, Zn and As are expected to have higher transfer rate to the fly ash as furnace temperature increases. Figure 6 illustrates the correlation between furnace temperature and metal concentration in fly ash from stoker incinerators for Pb and Cd. No correlation was found. It means that the effect of furnace temperature is not significant in the range 850 - 950℃. The other metal elements in incineration residues from stoker and fluidized bed incinerator showed the similar result.

Waste input

Waste fed into incinerators was divided further into three categories in this study ; 1) combustible waste, 2) shredded bulky waste, 3) others (sludge, plastics, incombustible waste). The ratios of waste input were shown in Table 3. The correlation between waste input and metal concentration was investigated. As a result, Cd, Pb, Sb, Se and Sn for fly ash and Cu, Sb and Zn for bottom ash were confirmed to be correlated with the ratio of bulky waste residue (with significant level of 0.05) as shown in Figure 7.

So, shredded bulky waste was sampled at plant E3, which is stoker type incinerator treating bulky waste (8.8%) in addition to combustible waste, and contribution ratio of bulky waste residue to metal contents was estimated. The composition and metal contents of bulky waste were determined as shown in Table 6, and estimated contribution, which is the ratio of metal amount in shredded bulky waste to total metal amount in incineration residues, is shown in

Figure 8. The result is consistent with the previous result of statistical test, i.e. metals (Sn, Cu, Sb, Se, Cd) which have high correlation coefficient show high contribution ratio of shredded bulky waste in Figure 8.

3.5 Distribution of metals to fly ash and bottom ash

It is quite significant to identify the distribution of metals in fly ash and bottom ash for recycling of valuable metals and environmental control of hazardous metals. Distribution ratio of metal elements to fly ash and bottom ash for stoker incinerators was calculated using ash amount generated in incineration of MSW and metal content in fly ash and bottom ash. Distribution of metal elements to exhaust gas was assumed to be zero in this study. Figure 9 presents the result, in which the abscissa represents metal contents in incineration residues (bottom ash + fly ash) per 1 ton of waste and the ordinate shows distribution ratio of metal elements to fly ash. Despite that production rate of ashes are considered to have some error, distribution ratios of metals could be presumed.

Lithophilic metal elements : Fe, Al, Cu, Cr

Iron and aluminum are mostly fed to incinerators in metallic form and their oxides are very stable, so no volatilization occurs during incineration of MSW. Small fractions found in fly ash are due to particulate matters carried over from the furnace in the flue gas (Chandler *et al.* 1997). The behavior of copper in incineration of MSW is similar to that of iron. Chromium compounds are not considered thermally mobile during incineration and therefore should remain mainly in the bottom ash.

Volatile metal elements : Cd, Zn, Pb, As, Sb

According to thermodynamic calculation, cadmium and cadmium oxide are preferentially converted into $CdCl_2$ during incineration. Furthermore, not only the metal itself, but cadmium chloride and a limited extent cadmium oxide can be vaporized (Verhulst *et al.* 1996; Chandler *et al.* 1997). Consequently, the bulk of cadmium entering the incinerator will be transferred to fly ash as shown in Figure 9. Zinc is not as volatile as cadmium, but the $ZnCl_2$ and traces of metallic zinc are volatilized. However, the conversion into $ZnCl_2$ is limited since a substantial amount of the zinc is already present in the waste in the oxide form. Eventually, the bulk of the zinc remained in the bottom ash. The metallic form of lead is potentially volatile. The most preferential reaction for lead during the incineration process is to produce $PbCl_2$, then vaporizes (Verhulst *et al.* 1996; Chandler *et al.* 1997). Unexpectedly low distribution of lead to fly ash in Figure 9 is speculated to be caused by that the metal melts and drips through the grates before reaching the vaporization temperature (Chandler *et al.* 1997). The distribution of arsenic and antimony in incineration residues was quite different according to incinerator, as shown in Figure 9.

Others : Bi, Se, Sn

The concentration of bismuth and selenium in fly ash and bottom ash is very low or nil. Selenium is slightly enriched in fly ash. The distribution ratio of bismuth and selenium to fly ash is quite variable with incinerator. Tin can volatilize in reducing circumstances, thermodynamically (Verhulst *et al.* 1996). Tin was found only in fly ash for most plants except A2 plant.

The distributions of metal elements in incineration residues of MSW in this study were compared with those from literature of Switzerland, Germany, Austria, and Japan. As can be seen Figure 10, the ratio of most metals among incineration residues is highly similar

between studies. In thermodynamic equilibrium calculations, Zn and Pb are easily volatilized due to their high volatility and As is also completely volatilized above 650 ℃ (Verhulst *et al.* 1996). But, in real plants, about two-thirds of Pb, Zn and As are distributed to bottom ash and one-thirds in fly ash. The fact that distribution ratio of metals to exhaust gas is almost zero verifies our assumption to neglect metals in gas phase.

3.6 Metal amount in incineration residues of MSW

Based on the result obtained in this study, amount of metals in incineration residues of MSW in Japan were calculated. Assumption used and procedure of calculation were shown in Table 7. And, the loss of valuable metals was estimated in terms of mass and money by using annual consumption of metals and international market price. The result reveals that considerable amounts of metals are lost as waste material because incineration residues are landfilled directly without any recycling process.

4. Conclusion

To study the influential factor on metal concentration and the distribution of metals in incineration residues of MSW, nineteen stoker and seven fluidized bed full-scale incinerators were investigated. The results obtained are as follows;

- Literature survey showed a high variation of data of metal concentrations in fly ash and bottom ash.
- Factors causing variation of metal concentration in incineration residues are studied. Correlation with furnace type, capacity, furnace temperature and waste input was investigated. Among these parameters, shredded bulky waste in waste input was the most influential factor to the variation of metal concentrations in fly ash and bottom

ash. The concentrations of Cd, Pb, Sb, Se and Sn in fly ash and Cu, Sb and Zn in bottom ash increased with the ratio of shredded bulky waste in feed waste.

- During incineration, lithophilic metals such as Fe, Cu, Cr and Al remained mainly in bottom ash while volatile Cd transferred to fly ash. Two-third of Pb and Zn remained in bottom ash despite their high volatility.
- Finally, based on the results obtained from this study, the loss of metal was calculated in terms of mass and money. Considerable amount of metal elements was found to be lost by landfilling incineration residues.

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Table 1 World reserve and production of metals

Element	Reserves(R) (1,000t)	Productions (P) (1,000t/y)	R/P (years)
Aluminum*	28,000,000	111,024	252
Antimony	4,700	36	130
Arsenic	11,000	35	314
Bismuth	250	3	83
Cadmium*	970	18	53
Chromium	6,700,000	10,000	670
Copper*	590,000	9,523	62
Iron*	230,000,000	988,797	233
Lead*	130,000	2,765	47
Selenium	130	2	75
Tin	10,000	206	49
Zinc*	330,000	6,895	48

* : Data of 1994 (World Resources 1996-97)
Others : Data of 1993 (Tateda et al. 1997)

Table 2 Target metals determined based on the possible use year (R/P) and toxicity

Group 1	Scarce metals	Lead, Zinc, Tin, Cadmium, Copper, Selenium, Bismuth
Group 2	Hazardous metals	Arsenic, Chromium, Antimony
Group 3	Widespread metals	Aluminum, Iron

Table 3 General information of incineration for sampling

Furnace type	Facility	Capacity (t/d)	Operation Beginning Year	Operating Type	Furnace temp.(℃)	Input waste(%)			Ash production[6] (kg/t-feedstock)	
						C[1]	SBW[2]	Others[3]	BA[4]	FA[5]
Stoker	A1	60*2	1978	SC[7]	900	100	-	-	90.2	12.6
	A2	60*2	1994	SC	900	76.9	23.1	-	64.6	38.3
	A3	60*2	1984	FC[8]	850	91.5	8.5	-	88.4	17.5
	A4	60*2	1988	SC	921	96.4	3.2	0.4	68.3	18.3
	B1	120*2	1994	FC	900	91.3	3.0	5.7	68.2	36.1
	C1	150*2	1994	FC	865	95.4	4.6	-	109.3	36.2
	C2	150*3	1998	FC	900	82.9	17.2	-	67.4	45.3
	C3	150*3	1992	FC	850	95.6	4.4	-	127.6	27.7
	C4	150*3	1996	FC	850	97.9	2.1	-	60.3	34.0
	D1	200*2	1979	FC	900	100	-	-	63.3	11.7
	D2	200*3	1983	FC	900	95.8	2.1	2.1	71.8	30.2
	D3	200*3	1995	FC	900	89.4	10.6	-	76.5	18.7
	D4	200*3	1986	FC	850	98.4	1.6	-	72.2	21.6
	D5	200*2	1976	FC	885	100	-	-	66.0	19.9
	E1	300*2	1974	FC	901	100	-	-	102.6	24.4
	E2	300*3	2001	FC	850	100	-	-	82.5	18.3
	E3	300*2	1992	FC	884	91.3	8.8	-	120.9	19.9
	E4	300*2	1995	FC	950	90.5	8.7	-	105.0	26.5
	F1	500*3	1997	FC	900	80.0	20.0	-	167.3	34.1
Fluidized bed	G1	50*2	1992	SC	875	92.8	4.3	3.0	-[9]	106.3
	G2	50*2	1996	SC	885	97.6	2.4	-	-	65.5
	G3	50*2	1989	SC	850	97.8	2.2	-	-	86.3
	G4	50*2	1992	SC	900	87.6	12.4	-	-	85.1
	H1	150*2	1986	FC	900	87.6	12.4	-	-	92.5
	H2	150*1	1984	FC	875	98.5	-	1.5	-	109.0
	H3	150*2	1994	FC	950	97.7	2.3	-	-	75.1

[1] Combustible waste [2] Shredded bulky waste [3] Sludge, Incombustible waste [4] Bottom ash [5] Fly ash (ESP or BF ash) [6] Ash production was calculated on dry basis and chemical agent amount used for ash treatment was subtracted. [7] Semi-continuous incinerator [8] Full-continuous incinerator [9] In fluidized bed incinerators, incombustible material remained in the bottom of furnace, called bottom ash, is very small percentage or nil, so it is ignored in this study.

Table 4 Metal concentration in fly ash and bottom ash from literature

	Stoker										Fluidized bed				
	Fly ash					Bottom ash					Fly ash				
	n	Min	Max	Average	CV	n	Min	Max	Average	CV	n	Min	Max	Average	CV
Al	46	8,468	92,800	47,562	55	79	10,600	147,000	71,377	36	20	24,600	93,146	58,186	29
As	34	0.5	37	14	81	67	0	93	6	185	5	8.3	10.0	7.4	56
Bi	-	-	-	-	-	15	1	23	4	135	-	-	-	-	-
Cd	52	0.3	573	124	86	77	0.04	91	15	112	12	4	73	24	83
Cr	37	62	1,170	355	80	74	6.6	2,260	375	95	11	134	1,020	387	69
Cu	49	316	10,600	1,232	150	86	77	13,200	2,818	107	17	264	7,700	3,650	52
Fe	53	3,000	24,200	10,794	50	103	500	200,000	45,874	72	18	12,000	129,000	37,863	76
Hg	34	0.03	41	8	131	63	0.001	5.5	0.7	170	5	0.3	1.7	0.9	-
Pb	63	223	79,500	4,460	226	104	8	10,900	1,288	102	17	738	4,100	1,681	56
Sb	7	140	560	352	46	18	5	306	67	133	-	-	-	-	-
Se	8	0.4	100	27	181	7	0.1	2.0	0.6	108	1	-	-	0.6	-
Sn	-	-	-	-	-	16	53	1,364	359	107	1	-	-	240	-
Zn	62	400	207,000	15,848	180	103	500	33,000	4,229	99	21	1,300	10,700	4,719	21

Min, Max, Average : [mg/kg-ash] CV(coefficient of variation=standard deviation/average) : [%]

Table 5 Metal concentration in fly ash and bottom ash from experiment in this study

	Stoker (n=19)								Fluidized bed (n=7)				Detection Limit (mg/L)
	Fly ash				Bottom ash				Fly ash				
	Min	Max	Average	CV	Min	Max	Average	CV	Min	Max	Average	CV	
Al	12,860	70,630	34,127	50	43,420	68,060	54,675	13	70,460	129,600	97,217	28	0.1
As	1.5	20.8	4.9	88	0.1	3.5	1.3	65	0.3	5.5	1.8	94	0.01
Bi	-	845	89	225	-	88	18	136	-	56	13	164	0.06
Cd	26	380	98	94	0.8	14.0	5.5	79	8	28	17	44	0.002
Cr	20	128	61	48	60	256	112	47	90	316	192	36	0.02
Cu	210	930	520	42	414	3,720	2,081	47	940	6,240	3,517	54	0.01
Fe	3,180	13,340	6,682	42	22,000	86,800	44,421	44	14,820	53,000	30,289	48	0.02
Pb	286	4,940	1,878	70	140	1,320	673	53	414	2,640	1,274	57	0.05
Sb	98	1,350	435	81	37	192	98	44	80	300	155	45	0.07
Se	0.6	8.8	3.0	81	0.5	4.5	2.0	76	0.2	4.7	2.9	75	0.005
Sn	-	714	202	106	-	876	46	436	-	234	113	95	0.8
Zn	3,400	17,600	8,347	49	1,280	4,800	2,446	41	3,000	6,600	5,029	29	0.005

Min, Max, Average : [mg/kg-ash] , CV(coefficient of variation=standard deviation/average) : [%], '-' : Not detective

Table 6 Metal content in shredded bulky waste

	Weight %	As	Bi	Cd	Cr	Cu	Pb	Sb	Se	Sn	Zn
Plastic	7.3	0.18	-	3.6	2.3	1	7	210	1.4	8	16
Textile	2.5	-	-	0.02	4.3	2	5	2	0.01	-	27
Plastic film	0.3	-	-	-	0.2	3	2	3	0.01	-	1.2
Paper	0.2	-	-	-	-	0.1	0.2	0.1	-	-	1.0
Power cord	1.6	0.03	-	-	1.3	9,399	37	13	0.01	11	3.0
Sponge	1.7	0.02	0.4	-	0.7	22	12	6	0.02	15	21
Electric circuit board	0.7	0.06	-	2.5	1.5	1,193	37	4	0.02	51	35
Can	0.7	-	-	-	0.1	6	0.1	0.7	-	-	0.5
Rubber	2.5	0.14	-	0.3	4.7	12	10	19	0.02	-	98
Wood	63.5	-	-	0.6	-	11	31	39	0.27	-	155
Total		0.4	0.4	7.1	15.1	10,648	141	295	1.7	85	358

Unit : [mg/kg-shredded bulky waste], ‘-’ : not detective

Table 7 Metal amount in incineration residues of MSW in Japan

	Metal amount in incineration residues (ton/year) (D)[1)]	Annual consumption of metal (C)[2)]	D/C*100 [%]	International market price of metal ($/kg) (P)[3)]	Monetary loss (L)[4)] (dollar/year)
Al	233,626	3,852,000	6.1	1.4	327,076,000
As	9	-	-	1.1	9,900
Bi	139	452	30.8	6.3	875,700
Cd	112	2,512	4.5	1.5	138,000
Cr	468	522,000	0.1	4.0	1,872,000
Cu	8,118	1,489,300	0.5	1.6	12,988,800
Fe	151,392	128,715,000	0.1	0.25	37,848,000
Pb	4,218	270,600	1.6	0.5	2,109,000
Sb	748	564	132	2.6	1,944,800
Se	10	177	5.6	8.3	83,000
Sn	365	27,814	1.3	4.4	1,606,000
Zn	16,862	622,400	2.7	0.8	13,489,600
				Total	400,040,800

[1)] D : Metal amount in incineration residues

$D = \Sigma Mj \times Aj$ (j = type of ash)

Where, Mj : Metal content (See average in Table 5)

Aj : Annual ash generation = MSW incinerated (a) × Ash generation rate (b)

A1 : Stoker fly ash = 35million tons/year × 25.8 kg/ton = 0.9 million tons/year

A2 : Stoker bottom ash = 35 million tons/year × 88.0 kg/ton = 3.0 million tons/year

A3 : Fluidized bed fly ash = 5 million tons/year × 88.5 kg/ton = 0.4 million tons/ year

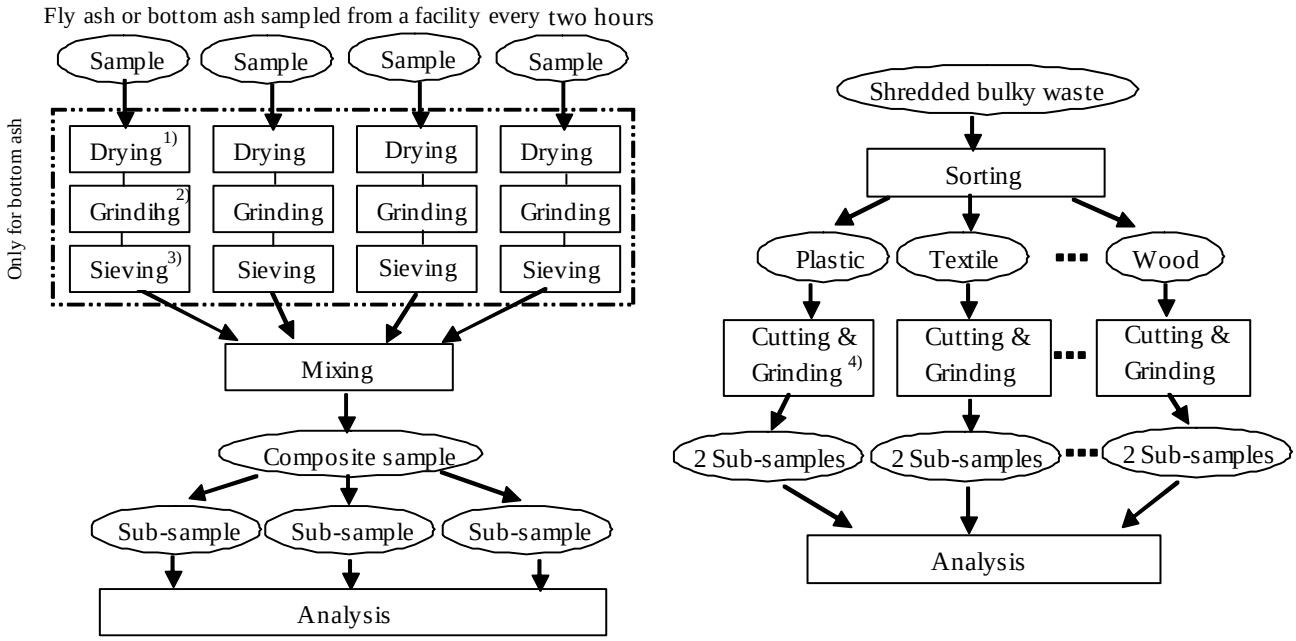
(a) MSW incinerated was based on national statistics on MSW management

(b) Ash generation rate : Average value calculated from Table 3 was used

[2)] C was obtained from Mineral handbook published by Research Institute of Economy and Trade in Japan

[3)] P was from 'Metalbulletin.com (http://www.metalbulletin.com)' and 'Metalprice.com (http://www.metalprice.com)'

[4)] L = D * P



(a) Fly ash and bottom ash

(b) Shredded bulky waste

Figure 1 Procedure of sample preparation for metal concentration analysis. [1)] 24 hrs at 105 ℃, [2)] 2 hrs in a ball mill, [3)] sieving through a 0.5 mm screen, [4)] smaller than 2mm.

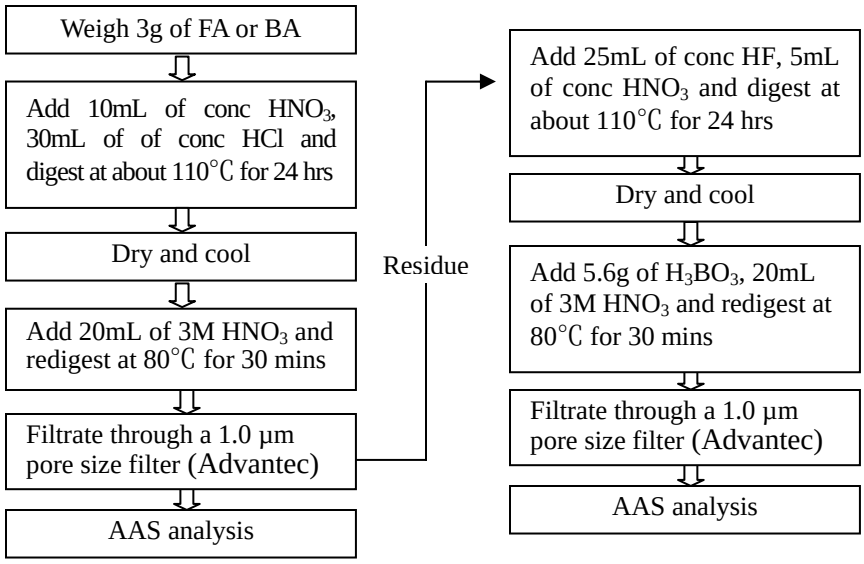


Figure 2 Procedure of aqua-regia and hydrofluoric acid digestion. Chemicals used were JIS (Japanese Industrial Standards) special grade manufactured by Wako, Japan.

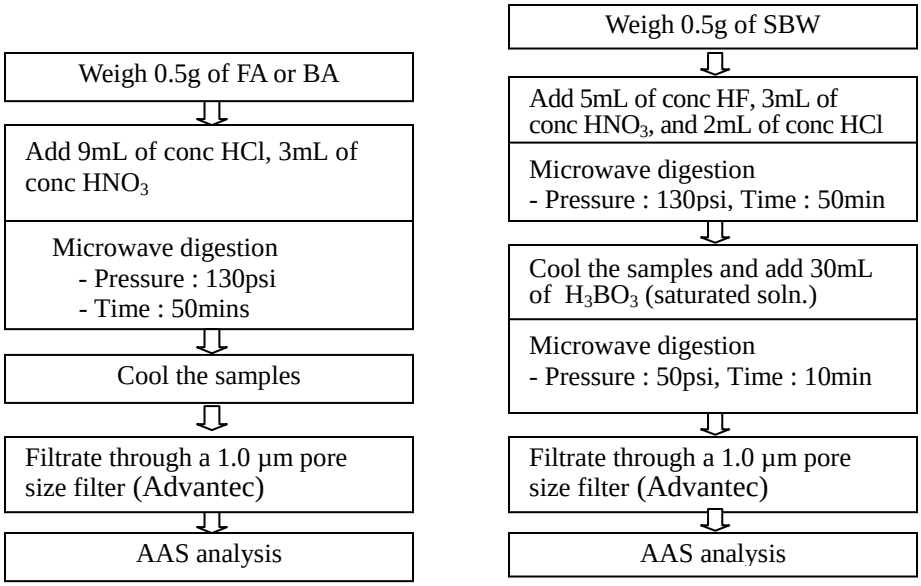


Figure 3 Procedure of microwave assisted digestion. Chemicals used were JIS (Japanese Industrial Standards) special grade manufactured by Wako, Japan.

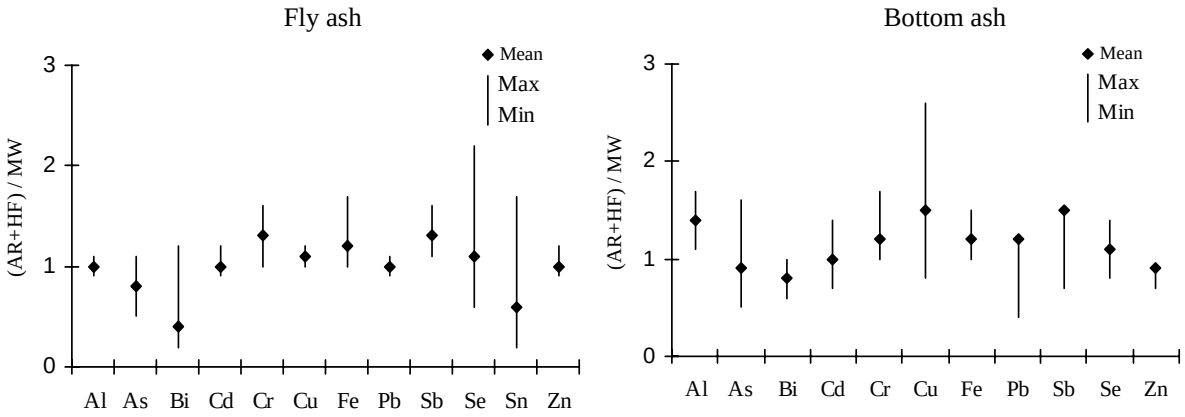


Figure 4 Comparison of microwave assisted (MW) digestion versus aqua regia and hydrofluoric acid (AR+HF) digestion. Values of 24 samples (2 facilities * 4 samples/day * 3 days) were used.

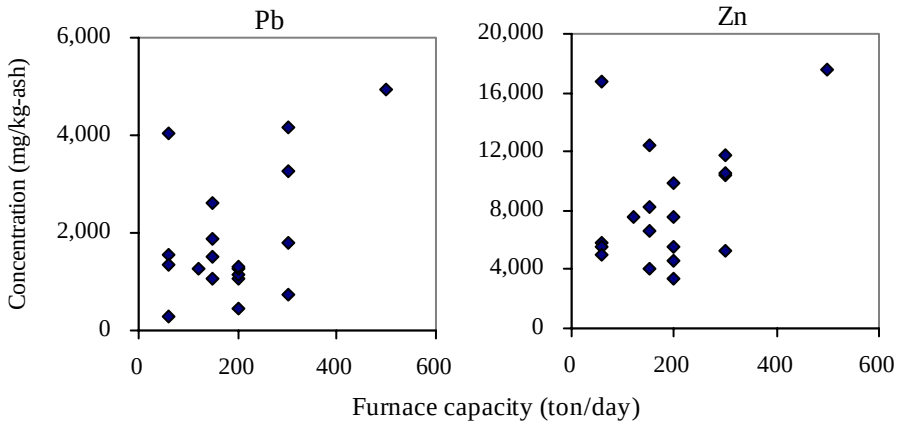


Figure 5 Correlation between metal concentration in fly ash and furnace capacity (in stoker)

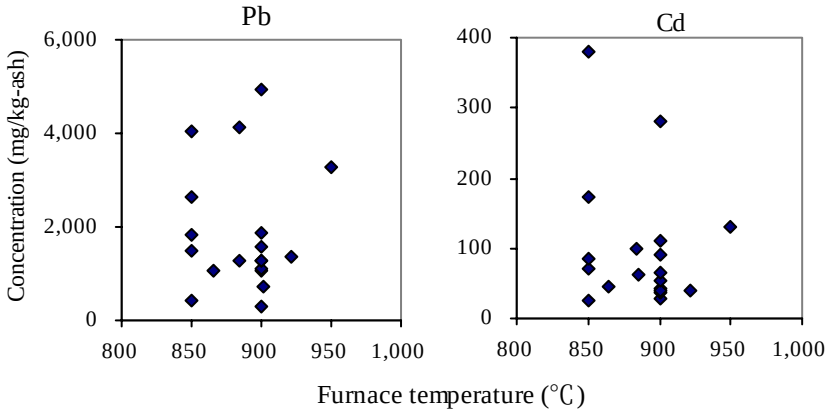


Figure 6 Correlation between metal concentration in fly ash and furnace temperature (in stoker)

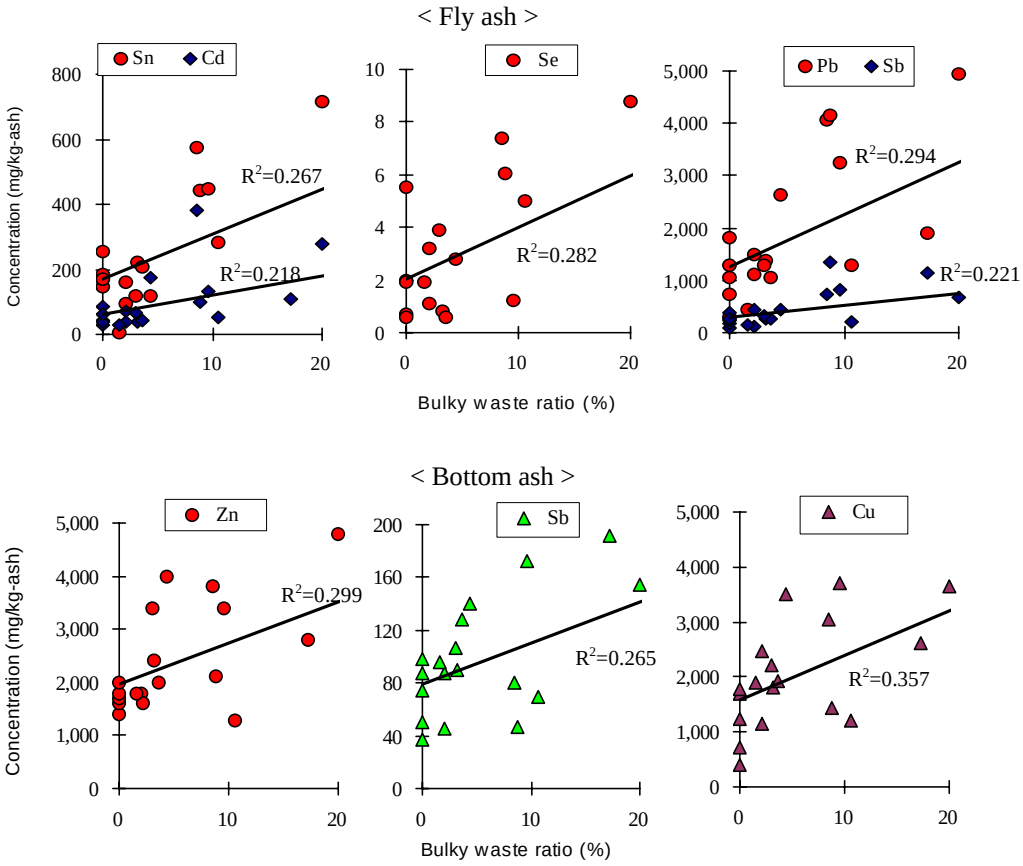


Figure 7 Metal concentrations in fly ash and bottom ash with the ratio of shredded bulky waste in waste input

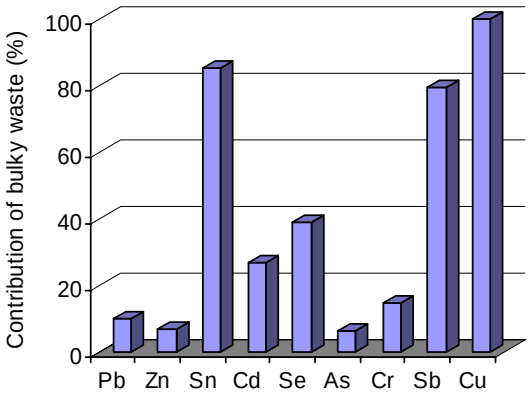


Figure 8 Contribution ratio of shredded bulky waste to metal content in incineration residues at Plant E3

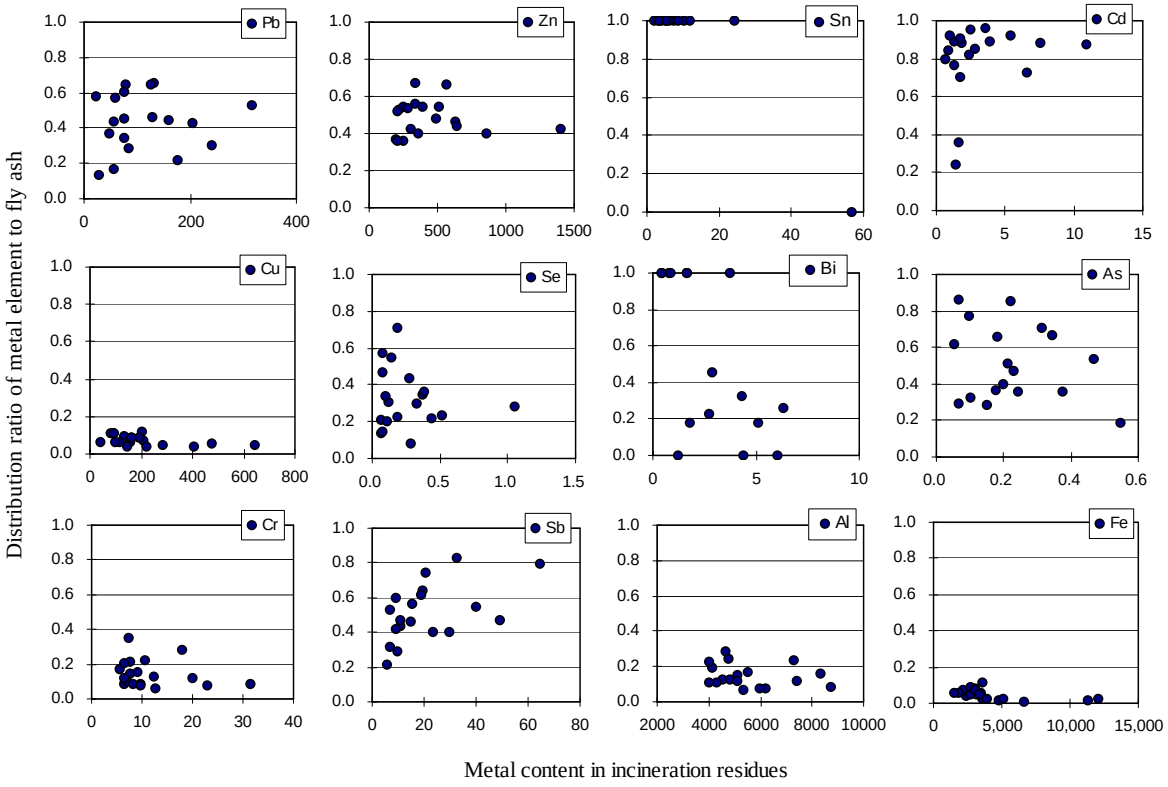


Figure 9 Distribution of metal elements to fly ash in stoker incinerators. X : Metal contents in incineration residues (fly ash + bottom ash), per 1 ton of waste, Y : Distribution ratio of metal elements to fly ash, in no-dimension.

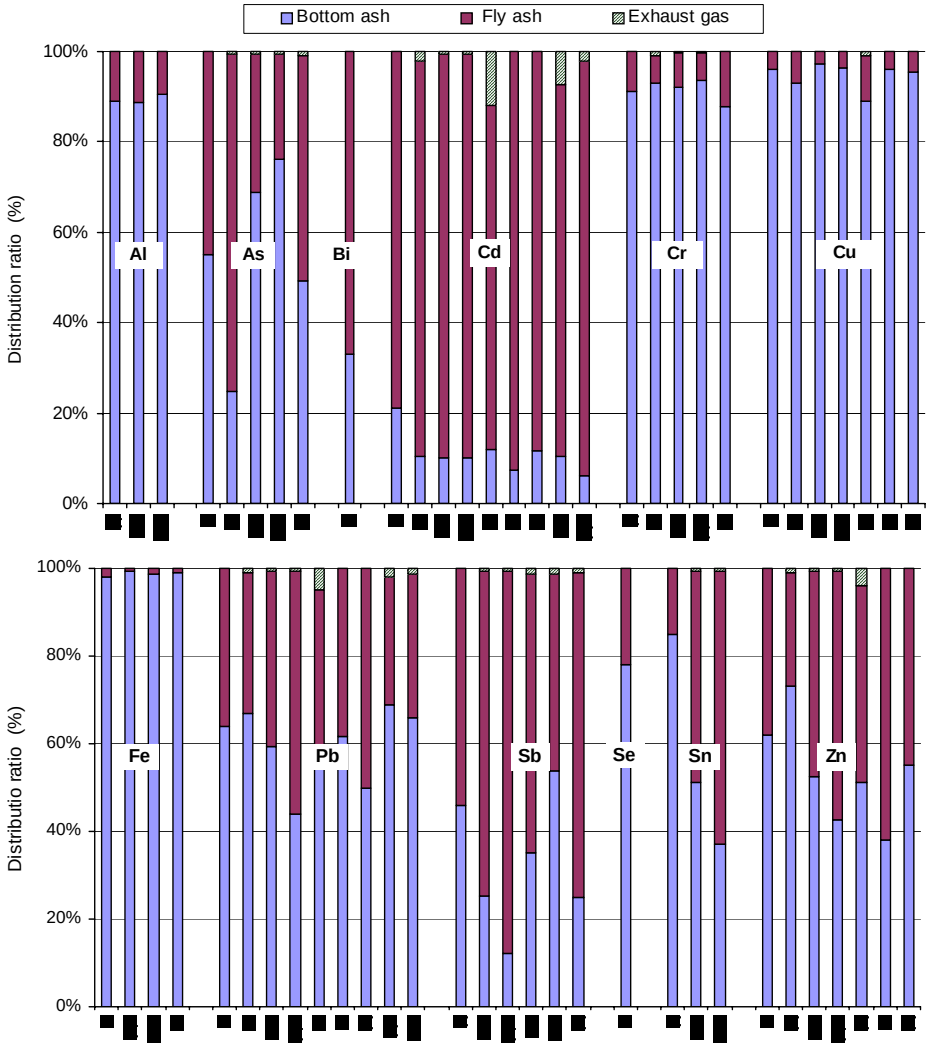


Figure 10 Comparison of this study versus literature for distribution ratio of metals in output products of MSW incineration. *Waste input* ; (2)-1: household waste, (2)-2: Mixed waste of commercial and residential orign, (6): Regular MSW from residential as well as trade and commerce sources, (7)-1: Household waste, (7)-2: Household waste + Shredded bulky waste, (8): Mainly household waste