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Alkalinity and Buffer Capacity on Behavior of Cd and Pb in Municipal Waste Combustor Ash

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Abstract

Municipal waste combustor (MWC) ash was studied to determine the chemical properties of selected elemental composition, alkalinity, buffer capacity, and the behavior of Cd and Pb as a function of particle size of MWC bottom ash and combined ash produced at mass burn and refuse derived fuel facilities in Florida. Elemental analysis revealed that major elements (Al, Ca, Fe, and Si), minor element (Pb), and trace element (Cd) were found in all types of ashes. Calcium and Cd were enriched in particles smaller than 0.5 mm, whereas Fe and Si were enriched in particles from 0.5 mm to 9.5 mm. Aluminum and Pb varied little in concentration with respect to particle size. Different particle sizes possessed different alkalinity and buffer capacity; the particles smaller than 0.5 mm had higher alkalinity and buffer capacity than the particles from 0.5 mm to 9.5 mm. The carbonate content of the tested MWC ash was about 10-110 gram per kilogram of dried ash. The higher carbonate content (alkalinity) in MWC ash resulted in the higher ability of ash to neutralize acid solution. As MWC ash received increasing amounts of acid (pH 2.0, 3.5, and 5.5), Cd and Pb in ash can be retained if the buffer capacity of ash can maintain solution pH in the range 6-10. It was noted that, when the final pH was greater than 11, Pb was slightly released from ash into aqueous solution; however, no Cd releasing from ash was found.

Keywords: alkalinity, buffer capacity, cadmium, municipal waste combustor ash, lead.

1. Introduction

The generation of municipal waste combustor (MWC) ash has increased in the past decade. In Florida, for example, the MWC industry has grown from one MWC plant in 1980 to 13 operating MWC facilities in 1994, which have a capacity to combust a total 5,291,290 tons of municipal solid waste (MSW) per year (1) and to generate approximately 1,587,400 tons of ash per year. Currently, most MWC ash is disposed of in landfills. The trend of MWC ash management is to minimize the use of landfills because of the cost and limited landfill space. Thus, methodology and/or technology is being developed for utilization of MWC ash in civil or marine engineering applications, such as artificial reefs (2), roadbed aggregate, asphalt road surfacing (3), construction materials (4-5), concrete (6), precast concrete (7), highway fill materials (8), and polymer concrete (4). In considering utilization of MWC ash, we must understand its chemical characteristics before the ash can be used effectively and safely.

Little knowledge has been developed regarding the alkalinity and the buffer capacity on behavior of trace metals in MWC ash. Because MWC ash is enriched with metal oxides and $CaCO_3$ (9-11), it could be desirable to determine the alkalinity and the buffer capacity metal in ash particles. Results of the study could offer a useful application in wastewater management; MWC ash might also offer a potential to replace commercial-valued lime for neutralizing acid wastewater. The overall goal of this research was to determine the chemical properties including elemental compositions, alkalinity, buffer capacity, and behavior (retention/releasing) of Cd and Pb in MWC ash.

2. Materials and Methods

2.1 Municipal Waste Combustor (MWC) Ashes

The MWC facilities participating in this study included one mass burn facility (facility A) and one refuse derived fuel facility (facility B) all located in Florida. The MWC ashes used in this study were facility A bottom ash and combined ash, as well as facility B combined ash.

2.2 Sample Preparation

Three replicates of 10 kg each of collected ash samples were dried in an oven at 105 ± 5°C for at least 24 hours or until the weight change was less than 0.5% of previous weight. The dried sample was separated into two different particle size fractions: <0.5 mm (fine fraction) and 0.5 mm-9.5 mm (coarse fraction) by passing it through a U.S. Standard Siever. This was done to separate the major fly ash fraction from the whole ash. The separated particle size was determined for weight percentage of each size fraction. Table 1 lists the weight percentage of different size fraction for each ash sample. The facility A bottom ash had about 80 % of the ash matrix in the coarse fraction (0.5 mm-9.5 mm). The facility A combined ash and facility B combined ash, both had about 25-30 % in the fine fraction (<0.5 mm) reflecting the contribution of fine fly ash to the ash matrix. The two different particle sizes of the collected ash samples were used for all experiments conducted in triplicate.

Table 1 Weight percentage (F_e) of each particle size fraction of MWC ashes

MWC ashes	F_e (%)	
	Fine fraction	Coarse fraction
Facility A		
Bottom ash	17±1	83±1
Combined ash	26±1	74±1
Facility B		
Combined ash	28±2	72±2

n = 3 for all determinations.

2.3 Elemental Analysis

2.3.1 Acid digestion

The hydrofluoric-boric acid digest (HF-H_3BO_3) technique reported by Silberman and Fisher (12) was used to determine the concentrations of selected metals in ash samples.

2.3.2 Analysis of the acid digestion

A Perkin-Elmer Model 5100 Atomic Absorption Spectrophotometer (AAS) equipped with Zeeman background correction was used for analyzing the HF-H_3BO_3 digest. Elements such as Al, Ca, Fe, Si, Cd, and Pb were determined.

2.4 Determination of Alkalinity, Buffer Capacity, and Behavior of Cd and Pb in MWC Ash

To determine the alkalinity of MWC ash at different particle size, fractions (fine fraction and coarse fraction), were prepared for ash suspension at solid (dried ash)/liquid (DDW) ratio = 1:20, 1:50, and 1:100. Alkalinity was determined by the potentiometric titration method (with 0.1 N standard H_2SO_4 titrant) to pH 8.3 (Phenolphthalein alkalinity), 7.0 (Acid Neutralization Capacity), and 4.3 (Total alkalinity), respectively. The alkalinity and carbonate concentration were calculated according to the formula shown in Standard Methods for the Examination of Water and Wastewater, 1989 (13) and Sawyer and McCarty, 1978 (14).

The buffer capacity determined in this study is referred to as the change of pH over a period of reaction time. To determine the buffer capacity of MWC ash under various pH, the experiments were conducted by varying initial pH as a function of particle size fraction and solid/liquid ratios. The study was conducted at initial pH (IpH) 2.0, 3.5, and 5.5 by adding 0.1 N HNO_3 solution. To investigate the buffer capacity of MWC ash, the pH measurement was conducted to monitor the pH change on a daily basis until equilibrium was achieved.

To determine Cd and Pb behavior in MWC ash under various pH, the tests were conducted by varying initial pH (2.0, 3.5, and 5.5) as a function of particle size fraction at a solid/liquid ratio of 1:20. The reaction bottles were shaken under the above pH for 1 hour. The test solution was filtered and the filtrate was analyzed for the concentration of Cd and Pb, respectively.

3. Results and Discussion

3.1 Selected Elemental Composition of Municipal Waste Combustor Ash

Table 2 shows the elemental composition of the facility A (FA) bottom ash and combined ash, as well as the facility B (FB) combined ash. Ash samples used in this study had particle size fraction either fine fraction or coarse fraction. It was found that Al, Ca, Fe, and Si were major elements (>1% in concentration) for all types of ashes; Pb was a minor element (<1% but >100 μg/g in concentration) and Cd was a trace element (<100 μg/g in concentration) in the ashes. The distribution of elements between coarse and fine fraction from all types of MWC ashes were such that Ca and Cd concentration were high in fine fraction ash; whereas Fe and Si concentration were high in coarse fraction, and Al and Pb concentration varied little with the particle size fraction. Iron concentration in ash from the refused-derived fuel (RDF) facility (facility B) was lower than that from the mass burn facility (facility A).

Table 2 Concentration of selected elements in MWC ashes for fine fraction and coarse fraction

Element	FA bottom ash[a]	FA combined ash[b]	FB combined ash[c]
Fine fraction			
Al (%)	3.6±0.1	4.7±1.2	4.9±0.1
Ca (%)	10.8±0.1	10.4±0.2	17.0±0.0
Fe (%)	5.6±0.2	5.8±3.8	1.8±0.2
Si (%)	13.0±1.5	11.8±1.0	10.9±0.9
Cd (μg/g)	57.7±1.0	68.2±19.8	24.0±0.9
Pb (μg/g)	2,440±45	2,360±700	2,710±70
Coarse fraction			
Al (%)	3.6±0.1	4.2±1.2	4.8±0.2
Ca (%)	8.9±0.1	8.3±0.2	13.2±0.3
Fe (%)	10.0±0.1	11.8±2.5	3.2±0.2
Si (%)	15.3±2.7	18.5±2.4	15.8±0.8
Cd (μg/g)	9.1±0.2	7.9±7.8	17.6±0.9
Pb (μg/g)	2,080±50	1,710±60	2,640±30

[a] Facility A bottom ash.
[b] Facility A combined ash.
[c] Facility B combined ash.
n = 3 for all determinations..

3.2 Alkalinity of Municipal Waste Combustor Ash

The alkalinity determination of FA bottom and combined ash suspension as well as FB combined ash suspension at solid/liquid (S/L) ratios = 1:20, 1:50, and 1:100 were done in two different fractions. For fine fraction, the pH of ash suspension slightly decreased as the S/L ratio decreased; no significant difference in carbonate concentration, acid neutralization capacity ($ANC_{7.0}$), and total alkalinity (per kg dried ash) for samples at any S/L ratio was found. Similar results were found for coarse fraction (data not shown).

Table 3 provides the comparison of pH and alkalinity of MWC ashes between fine fraction and coarse fraction at S/L ratio = 1:100. Ash suspension pH for fine fraction was slightly higher than that for coarse fraction. The carbonate concentration, $ANC_{7.0}$, and total alkalinity for fine fraction were higher than those for coarse fraction.

Table 3 pH and Alkalinity of MWC ashes determined at solid/liquid ratio = 1:100

Parameter	FA bottom ash[a]	FA combined ash[b]	FB combined ash[c]
Fine fraction			
pH of ash suspension	10.2±0.1	9.2±0.2	11.3±0.1
Carbonate (g CO_3^{2-}/kg dried ash)	57.3±0.6	14.8±1.8	164.0±0.8
Alkalinity(g $CaCO_3$ /kg dried ash)			
Acid neutralization capacity	60.3±0.3	34.6±4.1	154.8±1.7
Total alkalinity	141.7±0.3	137.0±5.0	292.8±1.7
Coarse fraction			
pH of ash suspension	9.9±0.1	9.2±0.1	11.2±0.1
Carbonate (g CO_3^{2-}/kg dried ash)	8.7±0.9	5.1±0.3	86.8±3.7
Alkalinity (g $CaCO_3$ /kg dried ash)			
Acid neutralization capacity	16.3±0.5	7.2±0.5	88.1±2.2
Total alkalinity	28.2±0.2	25.9±2.1	172.3±0.9

[a] Facility A bottom ash., [b] Facility A combined ash., [c] Facility B combined ash., and n = 3 for all determinations.

Table 3 also shows that ash generated from different plants have different pH and alkalinity. For combined ash having fine fraction, pH of ash suspension for FB ash was higher than that for FA ash; carbonate concentration, ANC$_{7.0}$, and total alkalinity for FB were about 10, 4, and 2 times, respectively, higher than those for FA ash.

It was found that pH of MWC ash suspension determined in this study for both particle sizes ranged from 9 to 11. This might be due to the presence of lime-$Ca(OH)_2$, which is one of the major components of ash (9, 15-16). Calcium hydroxide is derived from CaO that is formed during combustion or associated with lime-based air pollution control systems (15, 17-18). CaO is a water-soluble phase (10-11, 19) and the possible main reaction taking place is given by equation (1).

$$CaO(s)+H_2O \Rightarrow Ca^{2+}+2OH^- \Leftrightarrow Ca(OH)_2(s) \quad (1)$$

The variation in ash suspension pH and alkalinity determined in this study was possibly due to the presence of a soluble Ca component, such as CaO that is formed during combustion and the addition of lime used to remove CO_2 and SO_2 in flue gas. High pH of ash suspension for FB combined ash was due to the excess treatment lime used for cleaning emissions that ended up in the solid ash matrix. The combined ash, particularly residue that included lime from the air pollution control system, was highly alkaline (18).

The pH of ash suspension for FA combined ash was lower than that for bottom ash. This might be due to the incinerator fly ash generated at the FA facility having been treated with phosphoric acid for the stabilization of lead. As a consequence FA combined ash had a lower pH and less acid consumption capacity or alkalinity than bottom ash.

In this study there appeared to be a correlation between the alkalinity of MWC ash and particle size. Carbonate concentration, ANC$_{7.0}$, and total alkalinity of MWC ash increased as particle size decreased. The alkalinity of ash for fine fraction was about 2-5 times higher than that for coarse fraction. The difference in alkalinity between fine fraction and coarse fraction was probably due to the high concentration of $CaCO_3$ that occurred in the flue gas and was sorbed onto the fine ash particles (3). Calcium carbonate was formed by the reaction of lime ($Ca(OH)_2$) with CO_2 in flue gas (20).

The results of the study have provided a possible consideration for the utilization of MWC ash to. neutralize industrial acid wastewater, which is generally accomplished by adding lime to the effluent. The MWC ash may be used to replace lime for the neutralization of acid wastewater to an effluent pH of 7. Table 4 compares the amount of lime and MWC ash required to neutralize 10,000 L of industrial acid waste (pH 2). For fine fraction, neutralization of acid waste with FA bottom ash required about 20 times higher quantity than that with lime; neutralization of acid waste with FA combined ash required at least 30 times higher quantity than that with lime; neutralization of acid waste with FB combined ash required about 7 times higher quantity than that with lime. For coarse fraction, neutralization of acid waste with FA bottom ash required about 70 times higher quantity than that with lime; neutralization of acid waste with FA combined ash required at least 160 times higher quantity than that with lime; neutralization of acid waste with FB combined ash required about 13 times higher quantity than that with lime.

If based on usage without prior size separation, neutralization of acid waste with FA bottom ash required about 45 times higher quantity than that with lime; neutralization of acid waste with FA combined ash required about 75 times higher quantity than that with lime; neutralization of acid waste with FB combined ash required about 10 times higher quantity than that with lime.

The results of alkalinity determined in term of $ANC_{7.0}$ indicated that it may be possible to utilize MWC ash, especially FB combined ash, as a lime replacement. The ability of FB combined ash to consume acid or raise solution pH was comparable to lime. However, the possible use of readily available MWC ash to substitute for lime in neutralization of acid wastewater (such as laboratory wastewater, sulfuric acid wastewater, and phosphoric acid wastewater, etc.) shall be assessed for more information in regard to the suitability of the field application, the characteristic of acid wastewater, the economic feasibility, and management acceptability of reacted MWC ash.

Table 4 Estimated amount of lime and MWC ashes for neutralization of 10,000 L of industrial acid wastewater (pH 2.0) to pH 7.0

Substances	mol H^+ consumed/kg	Amount of lime or MWC ash (kg)
Lime	23.2	4.3[a]
MWC (fine fraction)		
Facility A		
Bottom ash	1.2	83
Combined ash	0.6	160
Facility B		
Combined ash	3.1	32
MWC (coarse fraction)		
Facility A		
Bottom ash	0.3	300
Combined ash	0.1	710
Facility B		
Combined ash	1.8	57
MWC (without size separation)[b]		
Facility A		
Bottom ash	0.5	210
Combined ash	0.3	330
Facility B		
Combined ash	2.1	47

[a] 4.30 kg lime = 10,000 L×$[H^+]$×1 kg lime/23.2 mol H^+
= 10,000 L×10^{-2} mol H^+/1 L×1 kg lime/23.2 mol H^+

[b] Average amount of MWC ash in neutralization of industrial acid wastewater = 1/100 × Σ (C_e × F_e); C_e represents amount of MWC ash in neutralization of industrial acid wastewater in a particle size fraction; F_e represents the percent weight of the particle size fraction.

3.3 Buffer Capacity of Municipal Waste Combustor Ash

Buffer capacity of MWC ash was determined in term of pH changes over a period of time until equilibrium (i.e., no further observed changes) was reached. Figure 1 and 2 show the effect of initial solution pH (IpH = 2.0, 3.5, and 5.5) on buffer capacity for both particle size of FA bottom ash and combined ash as well as FB combined ash at S/L ratio = 1:100. For fine fraction (Figure 1), the pH of ash suspension having IpH 2.0 for FB combined ash increased final pH (FpH) 9.5 in 10 days; pH of ash sharply suspension for FA bottom ash increased slowly within the initial 10 days and reached FpH 7.0 after 15 days; while pH of ash suspension for FA combined ash increased very slowly within the initial 20 days and reached FpH 4.8 (Figure 1a).

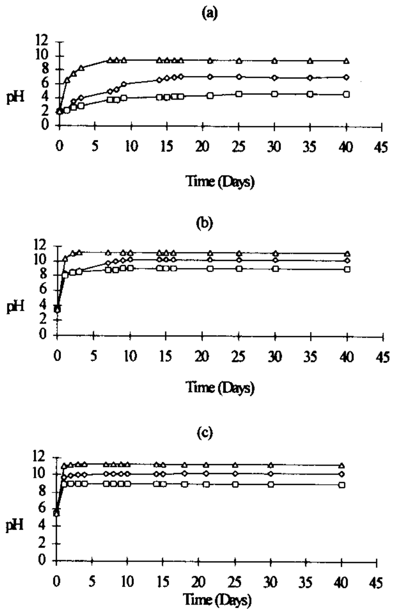

Figure 1 Buffer capacity of MWC ashes (fine fraction) in various solutions pH: (a) initial pH=2.0, (b) initial pH=3.5, and (c) initial pH=5.5 at S/L ratio = 1:100.

—◇— FA bottom ash —□— FA combined ash
—△— FB combined ash

The pH of ash suspension having IpH 3.5 for FB combined ash increased sharply within two hours and reached FpH 11.2 after four days; similar results were found for FA bottom ash and combined ash that had FpH 10 and 9, respectively (Figure 1b). The pH of ash suspension having IpH 5.5 was very similar to that for ash suspension having IpH 3.5; pH of ash suspension for FB combined ash, FA bottom ash, and FA combined ash increased sharply in the beginning and reached FpH 11.3, 10.2, and 9.1, respectively, within two hours (Figure 1c).

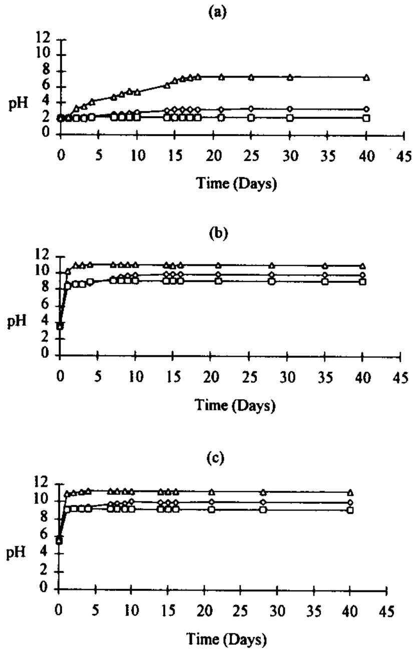

Figure 2 Buffer Capacity of MWC ashes (coarse fraction) in various solutions pH: (a) initial pH = 2.0, (b) initial pH = 3.5, and (c) initial pH = 5.5 at S/L ratio = 1:100.

—◇— FA bottom ash —□— FA combined ash
—△— FB combined ash

For coarse fraction (Figure 2), the pH of ash suspension having IpH 2.0 for FB combined ash increased gradually within the initial 15 days and reached FpH 7.2 in 17 days; for FA bottom ash and combined ash, pH increased very slowly and reached FpH 3.3 after 20 days (Figure 2a). The pH of MWC ash suspensions having IpH 3.5 and 5.5, respectively, was similar to that having fine fraction (Figure 1) which increased sharply within two hours and reached an FpH range of 9.1-11.2 (Figures 2b and 2c).

Table 5 summarizes the change of ash suspension pH presented as a function of particle size fraction and IpH (2.0, 3.5, and 5.5) at S/L ratio of 1:20. It shows the difference in ash suspension pH between FA bottom ash and combined ash. It was found that, in general, FA bottom ash had a higher buffer capacity than combined ash under various IpH for both particle sizes. Ash generated from different plants had different buffer capacities. For combined ash having fine fraction at IpH 2.0, pH of FB ash suspension was much higher than that for FA ash suspension; when IpH was 3.5 and 5.5, pH of FB ash suspension was also higher than that for FA ash suspension. Similar results were found for ash suspension having coarse fraction.

Table 5 Final solution pH (FpH) of MWC ashes at various initial pH at S/L ratio = 1:20

MWC ash	Initial pH of ash suspension		
	2.0	3.5	5.5
Fine fraction			
Facility A			
Bottom ash	9.3±0.1	10.4±0.1	10.9±0.1
Combined ash	8.3±0.1	9.3±0.1	9.7±0.2
Facility B			
Combined ash	11.6±0.1	11.7±0.2	11.9±0.1
Coarse fraction			
Facility A			
Bottom ash	6.0±0.1	10.3±0.2	10.6±0.2
Combined ash	5.4±0.1	9.4±0.2	9.8±0.2
Facility B			
Combined ash	11.4±0.2	11.5±0.1	11.7±0.2

n = 3 for all determinations.

In summary, when MWC ash was applied to a high acidity solution (IpH = 2.0), buffer capacity of large particle ash diminished faster than that for small particle ash. The fine fraction ash had a higher ability to neutralize acidic solution than the coarse fraction ash. When IpH was above 3.5 (lower acidity solution), no difference in buffer capacity for different ash particles was found. This resulted from the presence of carbonate content in the ash and the high alkalinity of ash. The carbonate content and alkalinity of small ash particles was higher than that of large ash particles (Tables 3); the higher carbonate concentration and alkalinity gave the higher ability to neutralize low pH in solution (21-22).

FB combined ash had a higher buffer capacity than FA bottom ash and combined ash. This was due to the fact that FB ash contained higher alkalinity or carbonate concentration than FA ash. It was likely that the high buffer capacity of ash was due to the consumption of acid by hydroxide and carbonate (21) presented in MWC ash. When ash combined with strong acid solution having low pH, it acted to elevate the solution pH.

Knowledge about the alkalinity/buffer capacity of ash is one of the main concerns in regard to determining the capacity of acid consumption by MWC ash. It may lead us to carry out a long-term assessment of solid/water phase interactions. The alkalinity/buffer capacity is one of the important properties of MWC ash to control pH affecting the mobility of trace metals (9, 23-25).

3.4 Effect of Alkalinity and Buffer Capacity on Cd and Pb behavior in ash suspension

The alkalinity and buffer capacity of MWC ashes affecting pH of solution was one of the most important properties of MWC ash in controlling trace metal mobility in ash suspension. Table 6 shows the effect of IpH on Cd and Pb behavior over a one hour contact time for FA bottom ash and combined ash as well as FB combined ash having particle size either fine or coarse fraction at S/L ratio of 1:20. The results show that the retention or releasing of Cd and Pb in ash suspension was pH-dependent. When ash having high alkalinity and buffer capacity was combined with strong acid solution having low pH, it acted to elevate the final solution pH (Table 5).

FA bottom ash and combined ash having particle size either fine fraction of coarse fraction was capable of retaining Cd and Pb in ash particles when encountering acid solution at IpH ≥ 2.0. The final pH of ash suspension was in the range 6-11. FB combined ash having particle size either fine fraction and coarse fraction encountered acid solution (IpH ≥ 2.0), the result indicated that the high final pH of ash suspension (>11) resulted in the release of Pb from ash particles to aqueous solution and Pb was released at about 25-70 μg/g ash. Within this pH range, Cd was completely retained in ash particles.

The behavior of Cd and Pb in ash suspension depends strongly on FpH of ash suspension affected by acid addition, alkalinity, and buffer capacity of ash suspension. The retention of Cd and Pb in ash suspension was found at the final pH 6-10. When the pH was above 11, especially FB combined ash, Pb was released from ash particle while the retention of Cd was found.

Table 6 Concentration of Cd and Pb in filtrate of MWC ash suspension under various initial pH

Initial pH	Cd concentration (μg/g ash)			Pb concentration (μg/g ash)		
	FABA[a]	FACA[b]	FBCA[c]	FABA[a]	FACA[b]	FBCA[c]
Fine fraction						
2.0	BDL[d]	BDL	BDL	BDL	BDL	59
3.5	BDL	BDL	BDL	BDL	BDL	67
5.5	BDL	BDL	BDL	BDL	BDL	68
Coarse fraction						
2.0	BDL	BDL	BDL	BDL	BDL	27
3.5	BDL	BDL	BDL	BDL	BDL	47
5.5	BDL	BDL	BDL	BDL	BDL	48

[a] Facility A Bottom Ash.
[b] Facility A Combined Ash.
[c] Facility B Combined Ash.
[d] Below Detection Limit: Cd < 0.02 μg/g ash and Pb < 0.1 μg/g ash.

4. Conclusions

This study has determined the chemical characteristics of bottom ash and combined ash from mass burn and RDF incinerator facilities. The studies resulted in the following conclusions.

(1) For elemental analysis, major elements (Al, Ca, Fe, and Si), minor element (Pb), and trace element (Cd) were found in all types of MWC ashes. Calcium and Cd concentrations were high in fine fraction ash (<0.5 mm); whereas Fe and Si concentrations were high in coarse fraction ash (0.5 mm-9.5 mm), and Al and Pb concentrations varied little with the particle size fraction. Fe concentrations in ash from the RDF facility was lower than that from the mass burn facility.

(2) Alkalinity determination showed that different particle size of MWC ash possessed different carbonate concentrations, $ANC_{7.0}$, and total alkalinity. The fine fraction ash had a higher carbonate concentration, $ANC_{7.0}$, and total alkalinity than the coarse fraction ash. The carbonate content of bottom ash and combined ash was between 10 and 110 g CO_3^{2-}/kg of dried ash. The higher carbonate content (alkalinity) in MWC ash resulted in a higher ability of the ash to neutralize acid solution. The knowledge gained from the alkalinity study is important in determining the acid consumption capability of MWC ash and in considering the possibility of using MWC ash to substitute lime in the neutralization of acid wastewater.

(3) Buffer capacity of MWC ashes between fine fraction and coarse fraction under various initial solution pH (2.0, 3.5, and 5.5) showed that at strong acid solution (IpH = 2.0), buffer capacity of coarse fraction ash diminished faster than that of fine fraction ash. The fine fraction ash had a higher ability to neutralize the acidic solution than the coarse fraction ash. When IpH was above 3.5, buffer capacity was similar among different ash particles. It is likely that the high buffer capacity of ash was due to the presence of hydroxide and carbonate in MWC ash. When ash encountered a strong acid solution, it acted to elevate the solution pH. Any acid solutions could be neutralized by MWC ash to a certain level, depending on the initial pH of the solution, the alkalinity, and buffer capacity of MWC ash.

(4) The metal behavior studies indicated that MWC bottom ash and combined ash was pH-dependent. It was found that the

final pH of ash suspension affecting the behavior (retention or releasing) of Cd and Pb in MWC ash was dependent upon the initial pH of the solution, the alkalinity, and the buffer capacity of ash. The retention of Cd and Pb was found at the final pH 6-10. When the pH was above 11, Pb was released from ash and the retention of Cd was found. It is suggested that to retain Pb in MWC ash, the final pH has to be maintained in the range of 7-10.

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