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A study on the cementlike properties of municipal waste incineration ashes

Wu-Jang Huang*, Suey-Chun Chu

Department of Environmental Science and Engineering, National Ping-Tun University of Science and Technology, 91201 Ping-Tun, Taiwan

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Abstract

This paper describes the origin of various ash wastes arising from municipal solid waste (MSW) incinerators, especially bag filter precipitator (BP) residue [called fly ash (FA)] and scrubber residue [called reaction product (RP)], which has cementlike compositions. This makes them suitable for immobilization for cement. The cementlike compositions are potential reuse as well as for stabilization treatments. The relations of ash wastes' alkalinity and salinity with lead leachability are correlated with composition.

Keywords: X-ray diffraction; Reaction; C-S-H; Characterization

1. Introduction

Treatment of municipal solid waste (MSW) by incineration has become to be a major method in Taiwan: 17 large MSW incineration plants are now running to reduce general waste. Combustion gives rise to four residues, two residues are produced in air pollution controlling designs (APCD); a semidry scrubber residue [called reaction product (RP)] and bag filter precipitator (BP) ash [called fly ash (FA)]. Boiler and bottom ashes are the other two residues. The generation rate of these four ash wastes has been predicted to be 2000 tons per day [1].

Serious toxicity of APCD residues is mainly caused from leaching of lead, which has an average value with 3800 μg/g RP and 420 μg/g FA. About 90% vaporized inorganic lead compounds are trapped. Cement-based solidification/stabilization (S/S) process has been recognized to be the best method to process these hazardous ashes. Glasser [2] and Connor [3] have reviewed the present state of this art, including its patent literature and fundamental aspects. In Taiwan, the solidification operation usually adds maximum of 25 wt.% cement and heavy metal chelator with ash waste. Solidified ash wastes are required to comply with the landfill regulatory directive, with 10 kg/cm^2 for unconfined single axial compressive strength (UCS) and 5 ppm (for lead) for toxicity characteristic leaching procedure (TCLP) test.

* Corresponding author. Tel.: +886-8-770-3202x7076; fax: +886-8-774-0256.

E-mail address: wjhuang@mail.npust.edu.tw (W.-J. Huang).

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We explore the reaction of RP and FA with cement. The relations hop between ash wastes' alkalinity and salinity, and lead leachability will be discussed.

2. Methods

2.1. Sampling

We selected seven large-scale MSW incineration plants from west Taiwan, each has a treatment capacity over 900 ton/day and cyclone, semidry lime scrubbing system and fabric (or bag) filter precipitator. Ash wastes (incineration residues) used in this paper were mainly collected from either electrostatic precipitator unit and are designed FA or from the scrubber, giving RP. These were collected separately from the sampling hole of the APCDs and aged for 3 days to stabilize the hydrophilic property of RP. The aging environment needs to keep these residues within temperature range 20–22 °C and a moisture range with 45–65% relative humidity. The boiler ash must not mix with FA or RP.

2.2. TCLP test

The TCLP test followed the standard method of Taiwan EPA [4]. Solid waste is graded to pass 10-mm standard sieves. Acidic extractant is made up by acetic anhydride and $NaOH_{(aq)}$. If the ash waste pH is less than 5.0, the buffer solution B with a pH of 2.88 is used. Otherwise, buffer solution A with a pH of 4.93 is used. The extraction

Table 1
Chemical analysis result of precipitator residue (FA)

Plant	SiO_2 (wt.%)	Al_2O_3 (wt.%)	CaO (wt.%)	CaO/SiO_2 (wt.%)	CaO/Al_2O_3 (wt.%)
1	9.26	26.33	55.21	5.96	0.35
2	9.12	16.15	50.75	5.56	0.56
3	17.57	32.30	42.36	2.41	0.54
4	3.12	42.82	41.39	13.27	0.19
5	3.76	37.48	45.65	12.14	0.10
6	6.80	16.40	55.20	8.12	0.41
7	3.91	37.93	42.60	10.90	0.10

procedure is to mix residues with a properly buffered solution at a liquid/solid (L/S) ratio of 20 and following a rotational shaking with a speed of 30 rpm for 18 h. Then the liquid was filtered through a 0.45-μm glass filter and the pH and metal concentration of filtered extracts determined by pH meter and atomic absorption spectrometry.

The TCLP test is intended to simulate the long-term leaching behavior following codisposal of hazardous waste with general solid waste in landfill. When the ash waste is extracted by 10 vol.% HNO_3 (pH = 0.1) with an L/S ratio 20, it represents the total lead amount ($[Pb]_o$) in ash waste [5].

2.3. Chemical analysis of ash composition

The analytical procedures used the Standard Testing Methods of Republic of China [6]. The levels of major components of Al_2O_3, SiO_2, CaO, and Fe_2O_3 and miner components of free CaO and $Ca(OH)_2$ were determined basing on differential wet chemistry. In the major component part, a 0.5-g dried sample was extracted in concentrated HCl and HNO_3 in an addition of 0.5 g NH_4Cl several times. The insoluble fraction was dried and weighted; it is attributed to the sum of SiO_2, $Al(OH)_3$, and Fe_2O_3. The residual filtrate was reheated, and NH_4NO_3 added, and the precipitate was collected after filtration. The filtered solution is used for determined $[CaO + Ca(OH)_2]$% and the weight of precipitated NH_4OH is used to calculate the $Al(OH)_3$% later. Titration of $KMnO_4$ solution with the final filtrate of above step is an optional method to the minor component in this method. The percentage of Fe_2O_3 was determined by titration of $K_2Cr_2O_7$ using a fresh sample dissolved in concentrated HCl and oxidized by $SnCl_{2(aq)}$. The difference of weight of NH_4OH and Fe_2O_3 is the weight of $Al(OH)_3$ and all compositions of residues are available.

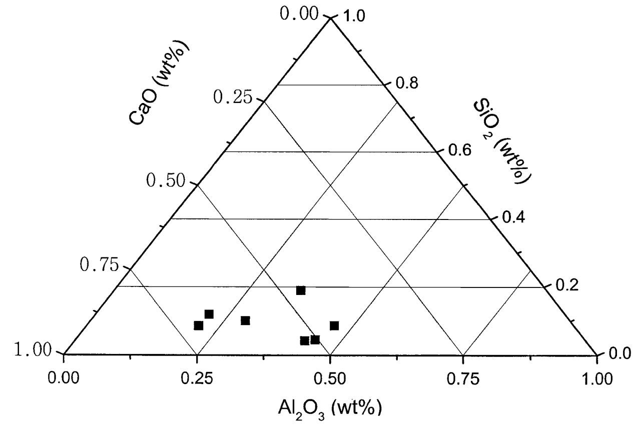

Fig. 1. The CaO-Al_2O_3-SiO_2 ternary grid of fly ash (data from Table 1).

2.4. Instrumental analysis

A Fisher Scientific Accruement pH meter was used to probe the pH value of the solution. A Solar-969 atomic absorption (AA) spectrometer made by Unicam, USA, was used to monitor concentrations of heavy metals. The reagent-grade chemicals were obtained from commercial products and were used directly without further purification.

3. Results and discussions

3.1. Chemical composition results

Many publications [7–9] described the chemical composition analysis by wet chemical, instrumental analysis of pure scrubber residue (RP), and BP residues (FA). Tables 1 and 2 summarize the main chemical composition of residues before TCLP extraction. Figs. 1 and 2 show the ternary composition grid [2], CaO-Al_2O_3-SiO_2 of FA and RP,

Table 2
Chemical analysis result of scrubber residue (RP)

Plant	SiO_2 (wt.%)	Al_2O_3 (wt.%)	CaO (wt.%)	CaO/SiO_2 (wt.%)	CaO/Al_2O_3 (wt.%)
1	32.20	12.0	38.45	1.19	3.20
2	20.60	39.31	26.71	1.30	0.68
3	19.60	46.31	32.20	1.64	0.69
4	36.48	32.63	26.25	0.72	0.80
5	21.08	44.71	26.14	1.24	0.58
6	24.28	33.59	38.28	1.58	1.14
7	36.68	24.61	28.16	0.77	1.14

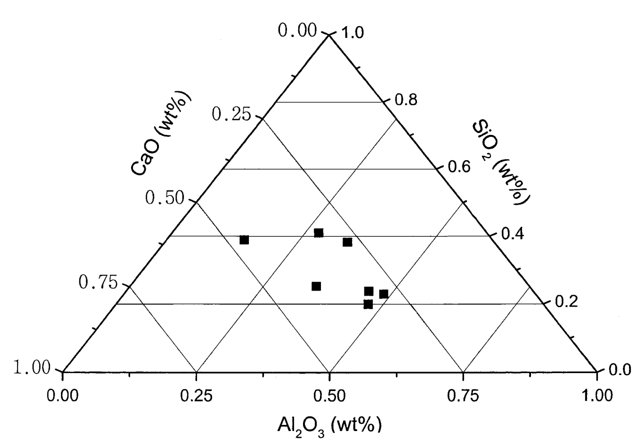

Fig. 2. The CaO-Al_2O_3-SiO_2 ternary grid of RP (data from Table 2).

Table 3
Lead metal leaching data of ash wastes

Method	FA			RP		
Plants	$[Pb]_o$ 10% HNO_3	[Pb] TCLP	$[Pb]/[Pb]_o$	$[Pb]_o$ 10% HNO_3	[Pb] TCLP	$[Pb]/[Pb]_o$ (%)
1	115.2	12.76	11.07	27.8	2.587	9.30
2	83.9	4.83	5.60	11.3	0.1087	0.96
3	126.7	0.11	0.08	31.1	0.261	0.84
4	263.5	73.30	27.80	133.9	0.696	0.52
5	147.6	38.04	25.80	22.4	0.065	0.29
6	79.1	9.72	12.30	27.0	0.63	2.33
7	172.8	38.61	22.30	17.0	0.46	2.71

Units of [Pb] and $[Pb]_o$ are both in parts per million.

respectively. It indicates that the compositions of RP are like high-alumina cement, while FA is like Portland cement. Table 3 shows the leaching test results of these residues. We also defined the lead leachability as the ratio of TCLP extracted amount to the nitric acid extractable amount (=$[Pb]/[Pb]_o$). The TCLP leaching data show that the lead concentration is from 2.5 to 0.06 ppm for RP while 73 to 0.1 for FA. The $[Pb]_o$ represents the total amount of lead in these ashes, and we have found that the percentage of lead extracted in normal TCLP is less than 10% for RP and 27% for FA. It indicates that leachability of lead is near 2.5 times high in FA more than in RP and demonstrates that the RP is not toxic ash waste but FA is.

3.2. Cementlike properties of bag filter residue

The residues are potentially pozzolanic materials. The principal hydration product of the TCLP would be calcium silicate hydrate (CaO-SiO_2-H_2O) gel or calcium aluminate hydrate (CaO-Al_2O_3-H_2O) gel. Activities of CaO-SiO_2-H_2O gels for $CaO/SiO_2>1$ have been reported by Rahman et al. [10], and they concluded that the dissolution of CaO-SiO_2-H_2O gel strongly depends on CaO/SiO_2 ratio in the range of. From Table 1, all of the chemical compositions of bag filter residues (FA) have a CaO/SiO_2 ratio exceeding 1.0. However, RP has CaO/SiO_2 ratios ranging from 0.7 to 1.6, Table 2. Fig. 3 shows the linear relationship between lead leachability and CaO/SiO_2 ratio in FA. The activity of $Ca(OH)_2$ (see Fig. 3 in Ref. [10]) seems to control the lead metal leaching behavior. In other words, with respect to, it also indicates that FA can be treated as a Portland cementlike material for waste utilization and recycling.

3.3. Cementlike properties of scrubber residue

The ash wastes CaO/Al_2O_3 ratio also affects leachability. From Table 1, all of the chemical compositions of scrubber residues (RP) have a range of CaO/Al_2O_3 ratios (which are calculated based on wt.%.) from 0.6 to 3.2. However, FA only possesses an average CaO/Al_2O_3 ratio close to 0.3 (Table 3). While the lead leachability of RP has a strong dependence on CaO/Al_2O_3 (Fig. 4). The activity of $Al(OH)_3$ [a proposed activity line following the activity of $Ca(OH)_2$] seems to be playing a role in the lead metal leaching behavior of RP. It also indicates that RP can be treated as a high-alumina cementlike material for waste utilization and recycling. Fig. 5 shows the X-ray spectra of FA and RP from Plant 7. The phase identification of diffraction peaks has been indicated.

Chemical and mineralogical analyses show that the residues approximate in some respects the compositions of Portland or high-alumina cements. Results show both of the

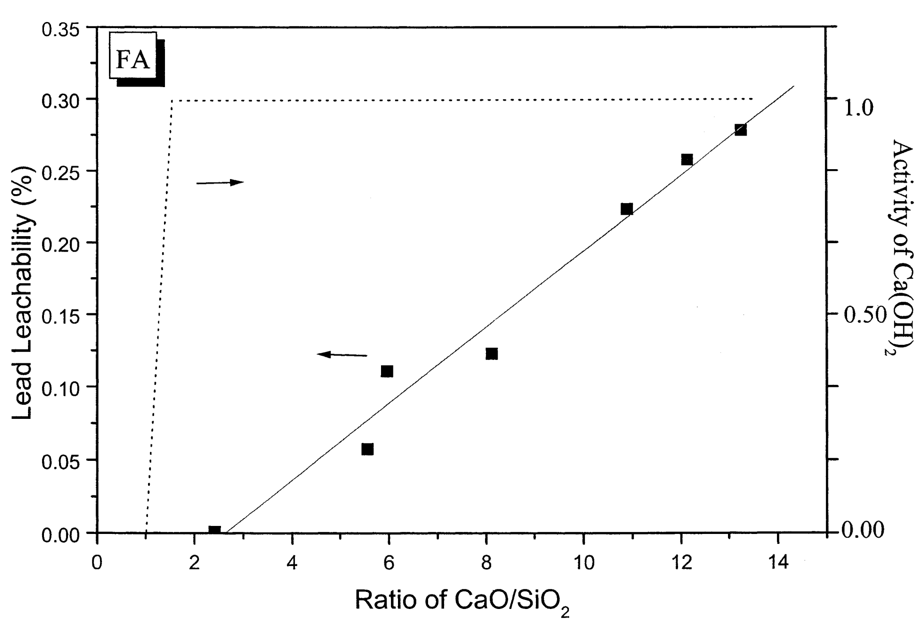

Fig. 3. Plot of CaO/SiO_2 ratio versus lead leachability of FA residues.

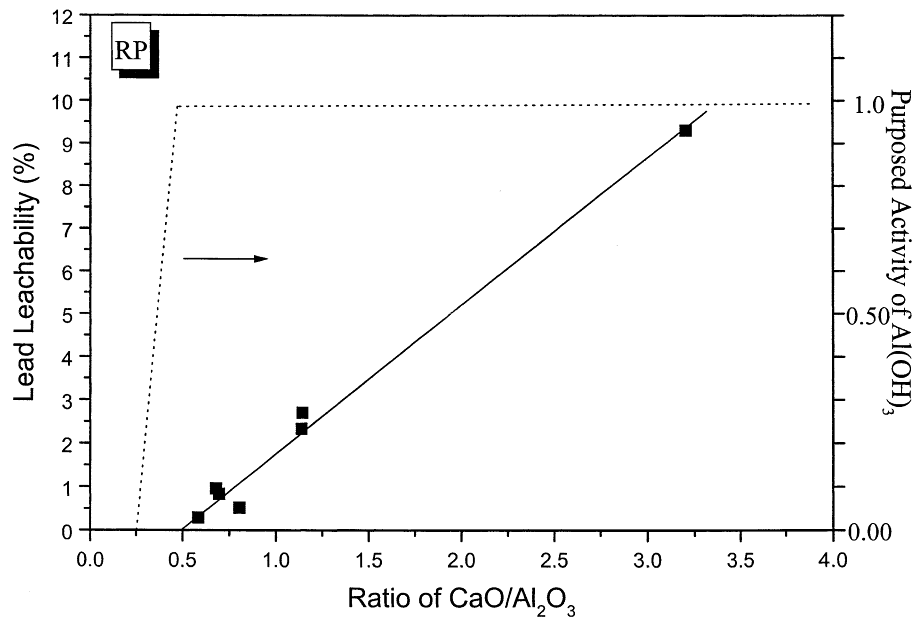

Fig. 4. Plot of CaO/Al_2O_3 ratio versus lead leachability of RP residues.

ash wastes, FA and RP, rising from large-scale MSW incinerator possess important cementlike compositions.

4. Conclusions

We have elucidated that BP residue (called FA) and scrubber residues (called RP) have cementlike properties. These residues approximate in some respects the compositions of Portland or high-alumina cements. A linear dependent relationship between lead leachability and CaO/SiO_2 ratios is shown in FA, but leachability of RP has a linear dependence on CaO/Al_2O_3. A detailed mechanical explanation at the effect of lead leachability on ratios of CaO/SiO_2 and CaO/Al_2O_3 will be published separately.

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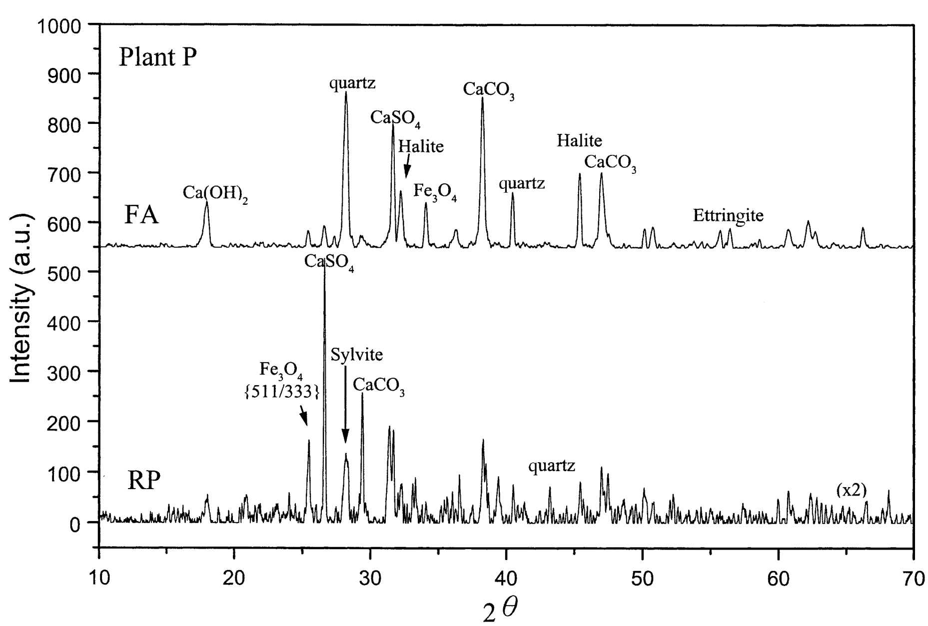

Fig. 5. X-ray diffraction spectra of FA and RP from Plant 7.

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