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Project Summary

Municipal Solid Waste (MSW) Combustor Ash Demonstration Program "The Boathouse"

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This report presents the results of a research program designed to examine the engineering and environmental acceptability of using municipal solid waste (MSW) combustor ash as an aggregate substitute in the manufacture of construction quality cement blocks. Approximately 350 tons of MSW combustor ash was combined with Portland cement to form standard hollow masonry blocks using conventional block making technology. The resultant stabilized combustor ash (SCA) blocks were used to construct a boathouse on the campus of the University at Stony Brook.

Periodically, over a 30-mo period, air samples collected within the boathouse were examined and compared to ambient air samples for the presence and concentrations of suspended particulates, particulate and vapor phase PCDD/PCDF, volatile and semi-volatile organic compounds and volatile mercury. Analyses of the air samples indicate no statistical difference between the air quality within the boathouse and ambient air samples. Rainwater samples following contact with the boathouse walls were collected and analyzed for the presence of trace elements. Results show that the SCA blocks retain contaminants of environmental concern within their cementitious matrix. Soil samples were collected prior to and following the construction of the boathouse and the results sµggest that block debris generated during the boathouse construction was responsible for elevated concentrations of trace elements in surface soils. Engineering tests show that the SCA blocks maintain their structural integrity and possess compressive strengths similar to standard concrete blocks.

This Project Summary was developed by EPA's National Risk Management Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Since 1985, scientists at the Waste Management Institute (WMI) of the Marine Sciences Research Center at the University at Stony Brook have been assessing the feasibility of using stabilized MSW combustor ash in a variety of marine and terrestrial applications. To date, two artificial reefs have been constructed on the sea floor of Long Island Sound using blocks of stabilized combustor ash. Over the past six years, results showed there was no release to the environment of either organic or inorganic constituents of environmental concern from the stabilized combustion residue blocks placed in Conscience Bay.

A second series of studies were initiated at Stony Brook to assess the potential use of MSW combustor ash as an aggregate substitute in the manufacture of construction quality cement blocks. Using combined ash from several resource recovery facilities, scientists manufactured standard construction quality cement blocks that meet or exceed ASTM performance standards.

The third series of studies began in 1990 with the construction of the boathouse. This phase of the investigation furthered the structural testing of the ash blocks and extended the scope of the environmental and health impact assessment in a terrestrial setting. Research was conducted to measure changes in ash block chemistry, surrounding soil chemistry, rain water chemistry, air quality within the boathouse, and to evaluate long-term structural performance of the stabilized combined and bottom ash blocks.

Results of this study lead to the manufacture of 14,000 stabilized ash blocks, using both bottom and combined ash from the Westchester County waste to energy (WTE) facility, located in Peekskill, NY. Block fabrication employed conventional block making machines currently used by the industry.

This investigation was initiated following the completion of construction activities. The primary objectives of this study were to determine if:

1) air quality within the boathouse was adversely impacted due to the presence of the SCA blocks, and was substantially different from outdoor ambient air samples;
2) metals of environmental concern leach from the SCA blocks following a rainfall event;
3) concentrations of trace metals associated with the soils surrounding the boathouse become elevated following the construction; and,
4) weathering effects adversely impact the structural integrity of the SCA blocks.

Boathouse Construction

Approximately 100 tons of combined ash and 250 tons of bottom ash were collected from the Westchester County Resource Recovery Facility, Peekskill, NY in spring 1990. The collected ash was processed at an aggregate processing facility on Long Island to remove ferrous metals and achieve the necessary particle size distribution for block fabrication. Following processing, the ash was transported to Barrasso & Sons, Islip Terrace, NY, a local cement block manufacturer, where approximately 4,000 combined SCA blocks and 10,000 bottom SCA blocks were produced.

The boathouse measures 27 m in length, 18 m in width and 7 m in height. The western and northern exterior walls were constructed using bottom SCA blocks while the eastern and southern exterior walls are composed of combined SCA blocks. The interior of the structure is divided into five separate rooms. All interior walls are constructed using bottom SCA blocks. The boathouse is supported by conventional concrete footings and pad.

Due to the impracticality of removing SCA blocks directly from the boathouse walls for experimentation, test walls were fabricated using both bottom and combined SCA blocks remaining following construction. Three walls were constructed one using the bottom ash blocks, a second using the combined ash blocks and a third using conventional cement blocks that were purchased from a local masonry supplier. Each wall was composed of 64 blocks, stacked 8 blocks high and 8 blocks across and was located adjacent to the boathouse.

Results and Discussion

Air Quality Determinations

Air samples were collected every 4 mo over a 2-yr period and analyzed for total suspended particulates, particulate and vapor phase PCDD/PCDF, volatile mercury and volatile and semi-volatile organic compounds. All air quality analyses, including PCDD/PCDF determinations, were conducted by the New York State Department of Health (DOH) in their laboratories in Albany, NY.

Total Suspended Particulates (TSP)

Boathouse TSP concentrations ranged from 4.8 $\mu g/M^3$ to 24 $\mu g/M^3$, with the exception of a spike of 168 $\mu g/M^3$ in September 1992. The outdoor control site also experienced a spike in particulate concentration, of 120 $\mu g/M^3$, during September 1992, but otherwise maintained a concentration range from 8.4 $\mu g/M^3$ to 64 $\mu g/M^3$ (Table 1). On average, suspended particulate levels measured at the outdoor control site were higher than inside the boathouse. A two-way ANOVA comparing the TSP data collected inside the boathouse to the outdoor control site yielded no statistical differences between these two data sets. The average TSP loads, both inside the boathouse and at the outdoor control site were well below the OSHA criteria of 5 mg/M^3

PCDD and PCDF Concentrations

Tables 2 and 3 present the particulate and vapor phase concentrations of PCDDs and PCDFs measured from Hi-volume air sampling experiments conducted both inside the boathouse and at an outdoor control site. For five of the six sampling events, total PCDD/PCDF concentrations within the boathouse environment ranged between 0.19 pg/M^3 to 3.62 pg/M^3. The September 1992 sampling event resulted in a total PCDD/PCDF concentration of 17.86 pg/M^3. At the control site, for five of the six sampling events, total PCDD/PCDF concentrations ranged between 0.70 pg/M^3 to 4.00 pg/M^3. The May 1992 sampling event resulted in a total PCDD/PCDF concentration of 22.5 pg/M^3.

The results of a two-way analysis of variance comparing total individual PCDDs and PCDFs inside the boathouse to the outdoor control site with respect to time revealed that no statistically significant difference existed for any of the isomers.

Volatile Mercury

Volatile mercury was detected during one of the six sampling events for both inside the boathouse and outdoor control site. The concentration of mercury measured inside the boathouse during May 1992 was 58 ng/M^3, while the outdoor control site during January 1992 was measured at 87 ng/M^3. Detection limits varied from 21-73 ng/M^3 according to the volume of air sampled and sensitivity of the analytical procedures employed.

No significant difference was measured for mercury concentrations measured inside the boathouse and the outdoor control site. All mercury concentrations were well below the NIOSH toxicity limit of 50,000 ng/M^3.

Volatile Organic Compounds

Two analytical techniques were employed in evaluating the presence and concentration of volatile organic compounds (VOCs). The USEPA canister method was used to measure 13 VOCs and the Porapak-N method was used to measure 44 VOCs. Porapak-N is a cavity rich polymer on which VOC's are easily trapped if an air flow is directed over the material. Between these two methods, the presence and concentration of 46 VOCs was determined.

Of the 46 VOCs analyzed, 11 were detected inside the boathouse and 12 were detected at the outdoor control site. Except for methylene chloride, every compound detected inside the boathouse was also observed at the outdoor control site. The compounds detected both inside the boathouse and outdoor control site included chloroform, chloromethane, tetrachloroethene, ethylbenzene, m/p-xylene, o-xylene, carbon tetrachloride, benzene, 1,1,1-trichloroethane, and toluene. Hexane was detected only at the outdoor control site. Table 4 lists all the detected VOC concentrations for both the canister and Porapak-N sampling methods.

Table 1. *Total Suspended Particulate Concentrations*

	Concentration (μg/M3)	
Sampling Events	*Inside Boathouse*	*Outside Boathouse*
Jan-92	*8.9*	*44*
May-92	*24*	*61*
Sept-02	*168*	*120*
Jan-93	*4.8*	*64*
May-93	*11*	*NA**
Sept-93	*6.8*	*8.4*

**May 93 control sample was not available due to analytical problems.*

Table 2. *PCDD/PCDF Concentrations (pg/M3) Measured Within the Boathouse*

	Inside Boathouse					
Analyte	*Jan-92*	*May-92*	*Sep-92*	*Jan-93*	*May-93*	*Sep-93*
2378 TCDD	*<0.04*	*<0.05*	*<0.013*	*<0.001*	*<0.003*	*0.007*
12378 PCDD	*<0.04*	*<0.07*	*0.02*	*<0.001*	*<0.003*	*<0.006*
123478 HxCDD	*<0.06*	*<0.12*	*<0.007*	*0.002*	*<0.005*	*0.01*
123678 HxCDD	*<0.06*	*<0.11*	*0.026*	*<0.003*	*<0.005*	*<0.009*
123789 HxCDD	*<0.05*	*<0.11*	*0.02*	*<0.005*	*<0.004*	*0.008*
1234678 HpCDD	*0.151*	*<0.17*	*0.17*	*0.015*	*0.064*	*0.076*
12346789 OCDD	*1.05*	*0.762*	*0.55*	*0.23*	*0.23*	*0.25*
2378 TCDF	*<0.03*	*<0.04*	*1.1*	*0.007*	*0.014*	*0.02*
12378 PCDF	*<0.03*	*<0.05*	*0.89*	*<0.003*	*0.007*	*0.006*
23478 PCDF	*<0.04*	*<0.06*	*0.61*	*<0.004*	*<0.002*	*0.01*
123478 HxCDF	*<0.03*	*<0.06*	*0.41*	*<0.007*	*0.003*	*0.011*
123678 HxCDF	*<0.04*	*<0.06*	*0.19*	*<0.003*	*<0.003*	*0.008*
234678 HxCDF	*<0.04*	*<0.08*	*0.025*	*<0.002*	*<0.003*	*0.009*
123789 HxCDF	*<0.04*	*<0.07*	*0.007*	*<0.002*	*<0.003*	*0.008*
1234678 HpCDF	*0.077*	*<0.10*	*0.11*	*0.015*	*0.019*	*0.023*
1234789 HpCDF	*<0.07*	*<0.17*	*0.026*	*<0.002*	*<0.009*	*0.011*
12346789 OCDF	*0.156*	*<0.19*	*0.094*	*0.016*	*<0.010*	*0.028*
OTHER TCDD	*<0.04*	*<0.05*	*0.089*	*0.003*	*<0.003*	*0.007*
OTHER PCDD	*<0.04*	*<0.07*	*0.023*	*<0.002*	*<0.003*	*<0.006*
OTHER HxCDD	*0.138*	*<0.11*	*0.054*	*<0.002*	*0.019*	*0.025*
OTHER HpCDD	*0.167*	*0.284*	*0.16*	*0.082*	*0.046*	*0.114*
OTHER TCDF	*0.121*	*0.328*	*6*	*0.01*	*0.071*	*0.079*
OTHER PCDF	*0.201*	*0.225*	*6.8*	*<0.002*	*0.03*	*0.02*
OTHER HxCDF	*0.16*	*0.182*	*10.68*	*0.011*	*<0.003*	*0.023*
OTHER HpCDF	*0.032*	*<0.10*	*0.044*	*0.003*	*<0.003*	*0.007*
TOTAL	***2.903***	***3.621***	***17.86***	***0.186***	***0.361***	***0.502***

Eight of the twelve compounds detected were greater inside the boathouse than the outdoor control site. It is generally the case that observed VOCs indoors are greater than measured outdoors. More importantly, 10 of the 11 compounds observed inside the boathouse were also detected at the outdoor control site, indicating the major factors influencing VOC content in the air were the same for both sampling sites.

Rain Water Evaluations

Rain water sampling consisted of four sample types; bottom ash blocks (BA), combined ash blocks (CA), cement blocks, and a blank. Two replicates of each of these four sample types were collected during each of the eight sampling events, distributed over a 29-mo period. Immediately following sample collection, the pH and volume of the rain water samples were recorded prior to chemical analyses. Chemical analyses consisted of measuring the concentration of calcium, cadmium, copper, and lead in the rainwater samples.

Rain Water pH

The pH was measured to ascertain the degree of influence the ash blocks may have had on rain water chemistry. The pH of the BA and CA rain samples decreased from 10.21 to 6.7 and 10.3 to 6.2, respectively, while the cement rain samples decreased from 9.5 to 6.7 following 29-mo of block exposure (Table 5). Althoμgh a decrease in pH was measured over time, the measured decrease in pH for the BA and CA rain water samples was not uniform. During this period the blank rain sample pH ranged from 4.9 to 6.9.

Rain Water Chemistry

Rain water chemistry was evaluated to determine the extent of inorganic leaching from the ash blocks. The rain water samples were each analyzed for a representative sub-set of the elements measured in the ash blocks including calcium, copper, cadmium, and lead (Table 6).

Results of a two-way ANOVA showed that the calcium concentration in the cement block rain water samples was statistically greater than the BA, CA, and blank rain water samples. Calcium content of the BA and CA rain water samples was not statistically different from the blank rain water samples. Calcium in the cement rain samples ranged from 9.5 to 25.6 mg/L, whereas the BA, CA and blank samples ranged from 0.3 to 1.9 mg/L, with one outlyer of 12.9 mg/L.

The results of a two-way ANOVA showed that no significant difference in cadmium concentration existed between the ash block and blank rain water samples. Cadmium content of the CA block rainwater ranged from <0.3 to 2.1 μg/L, while the cement block rain water ranged from <0.3 to 2.6 μg/L.

Copper in the cement and blank rain water samples were measured at <0.03 mg/L for every sampling event. Copper concentration in the BA rain water ranged from 0.51 to 0.70 mg/L, while the CA rain water ranged from <0.03 to 0.30 mg/L.

The BA rain sample collected in May 1992 had a lead concentration of 17.9 μg/L. All remaining rain water samples were below the instrumentation detection limit of <2.5 μg/L. The single detected lead value of 17.9 μg/L value surpassed the USEPA drinking water limit for lead of 15

Table 3. *PCDD/PCDF Concentrations (pg/M³) Measured*

Analyte	*Outside Boathouse - Control Site*					
	Jan-92	*May-92*	*Sep-92*	*Jan-93*	*May-93*	*Sep-93*
2378 TCDD	*<0.04*	*<0.09*	*<0.028*	*<0.016*	*<0.012*	*<0.014*
12378 PCDD	*<0.05*	*<0.13*	*0.002*	*<0.003*	*<0.013*	*<0.018*
123478 HxCDD	*<0.07*	*<0.23*	*<0.003*	*<0.011*	*<0.018*	*<0.027*
123678 HxCDD	*<0.07*	*<0.22*	*0.006*	*0.029*	*<0.017*	*<0.025*
123789 HxCDD	*<0.07*	*<0.21*	*<0.005*	*0.032*	*<0.015*	*<0.023*
1234678 HpCDD	*0.243*	*<0.36*	*0.067*	*0.29*	*0.094*	*0.16*
12346789 OCDD	*1.21*	*0.847*	*0.68*	*1.57*	*0.32*	*0.54*
2378 TCDF	*<0.04*	*1.067*	*0.033*	*0.052*	*0.033*	*0.028*
12378 PCDF	*0.079*	*1.006*	*0.006*	*0.016*	*0.018*	*0.016*
23478 PCDF	*0.051*	*0.496*	*0.009*	*0.035*	*0.023*	*0.029*
123478 HxCDF	*0.077*	*0.267*	*0.013*	*0.05*	*<0.010*	*0.028*
123678 HxCDF	*0.049*	*<0.12*	*<0.008*	*0.018*	*<0.01*	*0.022*
234678 HxCDF	*<0.05*	*<0.14*	*0.009*	*0.022*	*<0.012*	*0.027*
123789 HxCDF	*<0.05*	*<0.14*	*0.001*	*0.007*	*<0.011*	*<0.015*
1234678 HpCDF	*0.139*	*<0.19*	*0.045*	*0.11*	*0.027*	*0.14*
1234789 HpCDF	*<0.09*	*<0.32*	*0.009*	*0.011*	*<0.028*	*0.026*
12346789 OCDF	*0.172*	*<0.38*	*0.096*	*0.12*	*<0.046*	*0.11*
OTHER TCDD	*<0.04*	*<0.090*	*0.055*	*0.032*	*<0.012*	*<0.014*
OTHER PCDD	*<0.05*	*<0.130*	*0.027*	*0.011*	*<0.013*	*<0.018*
OTHER HxCDD	*0.205*	*<0.220*	*0.046*	*0.059*	*0.049*	*0.15*
OTHER HpCDD	*0.249*	*<0.460*	*0.063*	*0.3*	*0.086*	*0.21*
OTHER TCDF	*0.162*	*7.914*	*0.197*	*0.058*	*0.055*	*0.152*
OTHER PCDF	*0.458*	*6.392*	*0.077*	*0.089*	*0.069*	*0.115*
OTHER HxCDF	*0.246*	*0.885*	*0.046*	*0.053*	*0.026*	*0.103*
OTHER HpCDF	*0.044*	*<0.190*	*0.009*	*0.079*	*<0.003*	*0.034*
TOTAL	***4.004***	***22.49***	***0.764***	***1.383***	***0.70***	***1.394***

Table 4. *Range of VOC Concentrations*

Analyte µg/M³	*Detection Method*	*Inside Boathouse*	*Outdoor Control Site*	*Method Blank*
Hexane	*Canister*	*<dl*	*29.9*	*<dl*
Chloroform	*Porapak-N*	*4.5*	*1.0*	*0.01*
Chloromethane	*Canister*	*1.5*	*1.4 - 1.7*	*<dl*
Methylene Chloride	*Canister*	*2.8*	*<dl*	*<dl*
Tetrachloroethene	*Porapak-N*	*1.5*	*1.0*	*0.01*
Ethylbenzene	*Canister*	*5.4 - 5.5*	*4.7*	*<dl*
M/P-Xylene	*Canister*	*6.3 - 13.5*	*3.3*	*<dl*
O-Xylene	*Canister*	*5.5 - 17.4*	*4.8*	*<dl*
Carbon Tetrachloride	*Porapak-N*	*0.5 - 0.7*	*0.5 - 0.7*	*<dl*
Benzene	*Can/P-N*	*2.5 - 9.2*	*2.0 - 4.7*	*<dl*
1,1,1-Trichloroethane	*Porapak-N*	*1.1 - 24.0*	*1.0 - 2.7*	*0.01 - 0.2*
Toluene	*Can/P-N*	*3.0 - 47*	*2.8 - 68.0*	*0.01 - 0.7*

Table 5. *Mean pH and Volume of Rain Water Samples Analyzed*

Treatment	*pH/Volume (mL)*	*Jan 92*	*May 92*	*Sep 92*	*Jan 93*	*Sep 93*	*Mar 94*	*May 94*
Bottom Ash	*pH*	*10.2*	*9.9*	*8.3*	*9.1*	*8.5*	*6.7*	*6.7*
	Volume	*70*	*NA*	*460*	*2100*	*60*	*520*	*430*
Combined Ash	*pH*	*10.3*	*9.3*	*9.0*	*8.4*	*9.1*	*8.3*	*6.2*
	Volume	*150*	*NA*	*410*	*1600*	*230*	*865*	*1120*
Cement	*pH*	*9.5*	*8.1*	*7.6*	*8.1*	*8.6*	*7.0*	*6.7*
	Volume	*130*	*NA*	*300*	*1700*	*100*	*860*	*790*
Blank	*pH*	*5.3*	*6.2*	*5.5*	*4.9*	*6.9*	*5.5*	*5.8*
	Volume	*250*	*NA*	*720*	*1300*	*460*	*860*	*1130*

µg/L. Since every sample measured <2.5 µg/L, the value of 17.9 µg/L was attributed to sample contamination or an analytical error.

Soil Chemistry

The elemental content of soil surrounding the boathouse was examined to quantify any potential contribution of heavy metals from the boathouse blocks. Prior to the construction of the boathouse, soils samples were collected on three separate occasions. In addition, eight sampling events were conducted over a 30-mo period following construction. Soil samples were collected at four depths and analyzed for a representative sub-set of the metals measured in the ash blocks. The soil metal analyses consisted of calcium, cadmium, copper, lead, and zinc. The data from the two bottom ash wall soil sites (BASS) were combined to form one data set as were the two combined ash wall soil site (CASS) data. Only one control soil site (CSS) was used. The range of concentrations observed is presented in Table 7.

Calcium concentrations in soil collected from the 2 cm BASS increased, while samples from the 2, 8, 14, and 20 cm CASS decreased with time. The calcium content in the BASS, CASS, and CSS decreased statistically with respect to depth. At all measured depths, BASS and CASS concentrations were statistically greater than those measured at the CSS.

Calcium is a major component in the Portland cement used to fabricate the ash blocks, foundation and pad of the boathouse and the highly soluble nature of this constituent would explain the concentration variations between the treatment and control sites.

All post-placement soil data were statistically greater in cadmium than the pretreatment data sets.

Ash Block Chemistry

Metals are subdivided into one of three categories based on their concentrations. Major metals include those inorganic constituents with concentrations above 1000 µg/g. Minor metals are composed of components which ranged in concentration from 100 µg/g to 1000 µg/g, and trace metals include all constituents below 100 µg/g.

The constituents measured in the bottom and combined ash used in block fabrication are presented in Table 8. The major elements include iron, aluminum, zinc, lead, copper, and the salts; calcium, sodium, magnesium, and potassium. The minor metals consisted of barium, chromium, manganese and nickel. Arsenic and

Table 6. *Metal Concentrations in Rain Water Samples*

Analyte	Treatment	Concentration							
		Jan 92	May 92	Sep 92	Jan 93	Sep 93	Dec 93	Mar 94	May 94
Ca (mg/L)	Bottom ash	2.5 (0.1)	1.8 (0.4)	4.7 (0.4)	2.6 (0.7)	2.2 (1.0)	6.7 (0.8)	7.6 (0.6)	10.2 (2.9)
	Combined Ash	3.0 (0.7)	4.1 (1.1)	6.0 (1.9)	3.7 (0.1)	4.1 (0.7)	5.1 (1.4)	9.2 (2.8)	24.9 (2.5)
	Cement	11.2 (4.7)	10.6 (2.6)	22.2 (4.4)	25.6 (3.9)	15.4 (6.3)	9.5 (0.8)	21.7 (1.4)	10.2 (0.9)
	Blank	1.9 (1.6)	0.3 (0.1)	12.9 (17.2)	0.4 (0.0)	1.7 (0.6)	1.4 (0.2)	0.5 (0.0)	0.6 (0.8)
Cd (g/L)	Bottom ash	<0.3	5.1 (5.1)	<0.3	1.4 (1.4)	<0.3	2.1 (1.9)	<0.3	<0.3
	Combined Ash	<0.3	2.1 (0.6)	<0.3	1.7 (0.7)	<0.3	<0.3	<0.3	<0.3
	Cement	<0.3	<0.3	2.6 (3.3)	<0.3	<0.3	<0.3	<0.3	<0.3
	Blank	<0.3	<0.3	<0.3	1.2 (1.3)	0.3 (0.2)	<0.3	<0.3	<0.3
Cu (mg/L)	Bottom ash	0.6 (0.2)	0.7 (0.6	0.54 (0.69	0.51 (0.7)	0.55 (0.7)	<0.03	<0.03	<0.03
	Combined Ash	0.3 (0.02)	0.1 (0.02)	0.04 (0.02)	<0.03	0.05 (0.01)	<0.03	<0.03	<0.03
	Cement	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
	Blank	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Pb (g/L)	Bottom ash	<2.5	17.9 (23.5)	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
	Combined Ash	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
	Cement	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
	Blank	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5

Table 7. *Mean and Standard Deviation Range of Metal Concentrations (µg/g) Measured in Soil Samples*

Analyte	Treatment	Soil Depth	Pre-Boathouse	Post-Boathouse
Ca	Bottom Ash	2	Not Determined	2660 (1650) - 46300 (31300)
		8	Not Determined	610 (40) - 1880 (2120)
		14	Not Determined	210 (50) - 720 (440)
		20	Not Determined	160 (15) - 600 (180)
	Combined Ash	2	Not Determined	300 (260) - 14600 (1160)
		8	Not Determined	250 (180) - 1550 (280)
		14	Not Determined	170 (190) - 1600 (1180)
		20	Not Determined	150 (100) - 810 (160)
	Control	2	Not Determined	250 (20) - 380 (50)
		8	Not Determined	105 (15) - 410 (60)
		14	Not Determined	100 (60) - 270 (50)
		20	Not Determined	50 (20) - 220 (90)
Cd	Bottom Ash	2	<0.01 - 0.03 (0.01)	0.19 (.03) - 0.90 (0.27)
		8	Not Determined	0.11 (.03) - 0.99 (.021)
		14	Not Determined	0.05 (.03) - 2.33 (2.58)
		20	<0.01 - 0.03 (0.01)	.045 (.01) - 1.17 (0.75)
	Combined Ash	2	<0.01 - 0.24 (0.02)	0.14 (.07) - 1.54 (0.8)
		8	Not Determined	0.12 (0.04) - 1.47 (0.85)
		14	Not Determined	0.095 (.05) - 0.95 (0.5)
		20	<0.03 (0.01) - 0.05 (0.04)	0.23 (0.2) - 0.98 (0.8)
	Control	2	<0.01 - 0.08 (0.01)	0.09 (0.02) - 0.67 (1.0)
		8	Not Determined	0.11 (0.1) - 0.67 (0.5)
		14	Not Determined	0.06 (0.03) - 0.91 (1.0)
		20	<0.01 - 0.11 (0.03)	0.044 (0.009) - 0.78 (0.36)
Cu	Bottom Ash	2	6.5 (0.3) - 17.4 (0.1)	10.4 (4.0) - 100 (140)
		8	Not Determined	4.8 (0.9) - 49.1 (55)
		14	Not Determined	4.3 (.05) - 25.5 (5.2)
		20	5.8 (0.2) - 6.8 (0.3)	4.7 (0.4) - 27.5 (20)
	Combined Ash	2	5.8).6) - 7.1 (1.2)	8.8 (6.3) - 100 (74)
		8	Not Determined	6.2 (3.0) - 46.1 (19)
		14	Not Determined	4.5 (6.2) - 50.3 (46)
		20	3.5 (0.2) - 6.8 (0.3)	5.1 (5.6) - 26.0 (3.6)
	Control	2	6.5 (0.9) - 7.3 (0.6)	5.8 (1.7) - 14.9 (3.4)
		8	Not Determined	6.3 (1.0) - 16.6 (6.8)
		14	Not Determined	4.8 (1.0) - 12.5 (0.50
		20	4.2 (0.1) - 4.3 (0.3)	3.3 (1.0) - 19.9 (21)

(continued)

cadmium were present in trace amounts, whereas silver and selenium were never detected.

Chemical Composition of Ash Blocks

The metal content of the bottom and combined ash samples (Table 8) were generally greater than the BA and CA blocks (Table 9). This concentration differential resulted from a dilution effect caused by the addition of Portland cement and sand to the ash during block fabrication. The BA and CA blocks contained 55% and 64% ash respectively. The concentration of inorganic constituents measured in the ash blocks should have equaled either 55% or 64% of the inorganic material measured in the ash sand samples, plus any additional contribution from the sand and cement comprising 45% and 36% of the BA and CA blocks respectively. The metal concentrations measured in the control cement blocks (Table 10) were used to roµghly estimate the contribution of the ash cement fractions of the BA and CA blocks.

The measured concentrations in the BA blocks for arsenic, magnesium, manganese, sodium, and zinc, and in the CA blocks for arsenic, calcium, iron, and nickel did not agree with the calculated concentrations. The remaining nine metal concentrations in the BA and CA blocks were within expected concentrations.

The differential between the expected and actual ash block metal concentrations is an artifact of the non-homogeneity of the block mixes. The machinery which fed

Table 7. *Continued*

Analyte	*Treatment*	*Soil Depth*	*Pre-Boathouse*	*Post-Boathouse*
Pb	*Bottom Ash*	*2*	*6.7 (0.5) - 13.0 (6.2)*	*17.2 (11.6) - 40.6 (37.6)*
		8	*Not Determined*	*5.6 (1.5) - 52.3 (40.7)*
		14	*Not Determined*	*6.2 (1.5) - 15.0 (9.5)*
		20	*7.9 (0.2) - 11.0 (2.7)*	*6.2 (1.1) - 14.2 (5.2)*
	Combined Ash	*2*	*7.0 (1.0) - 7.5 (0.9)*	*13.4 (4.3) - 41.3 (17.4)*
		8	*Not Determined*	*7.6 (0.5) - 19.6 (17.5)*
		14	*Not Determined*	*3.6 (2.0) - 26.2 (17.9)*
		20	*6.0 (0.3) - 9.9 0.2)*	*4.5 (0.3) - 16.8 (12.9)*
	Control	*2*	*21.0 (1.6) - 40.0 (3.3)*	*9.4 (8.4) - 23.7 (1.1)*
		8	*Not Determined*	*12.1 (4.0) - 20.9 (5.9)*
		14	*Not Determined*	*5.6 (1.9) - 11.7 (2.2)*
		20	*6.4 (0.2) - 21.0 (1.3)*	*4.6 (4.4) - 6.8 (3.4)*
Zn	*Bottom Ash*	*2*	*17.0 (0.40) - 19.0 (0.9)*	*53.0 (23) - 170 (21)*
		8	*Not Determined*	*15.7 (24) - 46.6 (12)*
		14	*Not Determined*	*8.5 (2.1) - 48.6 (37)*
		20	*17.0 (0.4) - 18.0 (4.3)*	*16.5 (2.8) - 74.9 (80)*
	Combined Ash	*2*	*13.0 (1.6) - 55.0 (14.6)*	*23.0 (7.2) - 140 (85)*
		8	*Not Determined*	*17.8 (2.0) - 75.3 (20)*
		14	*Not Determined*	*14.0 (5.7) - 51.0 (11)*
		20	*15.0 (0.5) - 19.0 (0.4)*	*17.0 (0.2) - 41.1 (11)*
	Control	*2*	*20.0 (1.4) - 23.0 (1.0)*	*17.1 (12) - 28.7 (2.8)*
		8	*Not Determined*	*14.2 (9.3) - 31.2 (2.5)*
		14	*Not Determined*	*13.5 (16) - 29.4 (8.7)*
		20	*14.0 (0.4) - 16.0 (1.1)*	*10.8 (1.4) - 20.9 (2.5)*

Table 8. *Mean and Std. Dev. Concentration of Metals Measured in MSW Combustor Ash*

Analyte (μg/g)	*Bottom Ash*	*Combined Ash*
Fe	*89100 (15400)*	*80200 (1900)*
Ca	*64700 (7250)*	*72000 (3340)*
Al	*51700 (3200)*	*5200 (3700)*
Na	*47800 (1850)*	*37500 (750)*
Mg	*10500 (400)*	*11800 (310)*
K	*7500 (60)*	*11100 (400)*
Zn	*6080 (220)*	*5370 (120)*
Pb	*3260 (750)*	*4070 (120)*
Cu	*2200 (340)*	*1600 (330)*
Ba	*730 (65)*	*870 (45)*
Cr	*250 (10)*	*220 (40)*
Mn	*130 (10)*	*930 (30)*
Ni	*130 (20)*	*140 (20)*
As	*20.4 (3.2)*	*<25*
Cd	*26.5 (3.1)*	*59.4 (10)*
Ag	*<5*	*<5*
Se	*<19*	*<25*

the constituents (sand, ash, cement, and water) during block fabrication lacked the precision required to make each block chemically identical. Concrete block manufacturing does not require identical chemical composition. The boathouse blocks were manufactured in twelve separate batches, which added to the chemical deviance between blocks. Variability in the block mixes was further demonstrated by large standard deviations and concentration differences between samples encountered in block chemistry.

Trends Observed for the Block Metal Concentrations

In the BA blocks, calcium, chromium, sodium, and aluminum displayed concentration ranges that consistently overlapped each other for every sampling event.

In the CA blocks, lead, iron, magnesium, calcium, cadmium, chromium, potassium, sodium, manganese, barium, zinc, and aluminum displayed overlapping concentration ranges for each sampling event. Nickel concentrations in the CA blocks during November 1993 were greater than measured from November 1991 to May 1993 (Table 8).

Of the seventeen metals measured, only arsenic and copper appeared to decrease with time in both the BA and CA blocks. Ranges are discussed in the full report.

Block Compressive Strengths

Engineering studies conducted over a period of 30 mo show that the ash blocks have maintained their structural integrity possessing compressive strengths equal to conventional cement blocks. The compressive strengths of all BA, CA and control blocks are outlined in the full report.

Conclusions

Both bottom and combined MSW combustor ash, when combined with Portland cement, can be successfully stabilized into conventional construction quality cement blocks. The construction of a boathouse on the campus of the State University of New York demonstrated the potential for this utilization strategy. Engineering studies conducted over a period of 30 mo show that the ash blocks have maintained their structural integrity possessing compressive strengths equal to conventional cement blocks.

Air quality investigations demonstrate that within the boathouse the concentrations of suspended particulates, PCDD/PCDF, volatile organic compounds and volatile mercury are statistically similar to ambient air.

The pH and Ca content of rain water increased following contact with the stabilized ash blocks. Trace amounts of copper were measured following rain water contact with bottom ash blocks, but these concentrations were below public drinking water standards.

Enrichment in the inorganic content of surface soils was observed when compared to control site soils. Given the limited leaching of elements from the ash blocks surface soil elemental enrichment is attributed to ash block debris resulting from the construction of the boathouse.

Measurements of the chemical composition of the ash blocks reveal a non-homogeneous mix of reactants (ash, sand, Portland cement). The machinery used in the manufacture of the ash blocks lacks the precision to consistently blend the reactants in identical fashion. Numerous batches, each potentially having a slightly different ratio of ingredients, were required in fabricating the nearly 14,000 blocks used in the construction of the boathouse. The data suggest that each batch was sufficiently different in its chemistry to render non-conclusive any evaluation of block

Table 9. *Mean and Standard Deviation of Inorganic Concentrations (g/g) Measured in Stabilized Ash Blocks*

		Pre-Treatment		*Post-Treatment*							
Analyte	*Block Type*	*Nov 91*		*May 92*		*Nov 92*		*May 93*		*Nov 93*	
					Major Metals						
Ca	*BA*	*79300*	*(6200)*	*70500*	*(2100)*	*73400*	*(4300)*	*68700*	*(7000)*	*66800*	*(9900)*
	CA	*60100*	*(7300)*	*71900*	*(1600)*	*74800*	*(3700)*	*61200*	*(11900)*	*69800*	*(8600)*
Fe	*BA*	*81100*	*(7300)*	*31700*	*(3600)*	*33700*	*(1400)*	*37400*	*(220)*	*39300*	*(7400)*
	CA	*38200*	*(1900)*	*23800*	*(7700)*	*23200*	*(8400)*	*26500*	*(9100)*	*41100*	*(8100)*
Al	*BA*	*30900*	*(2200)*	*24500*	*(830)*	*24100*	*(1300)*	*27000*	*(1000)*	*NA*	
	CA	*38600*	*(7200)*	*29400*	*(660)*	*29300*	*(1000)*	*30000*	*(1000)*	*NA*	
Na	*BA*	*16000*	*(2500)*	*13600*	*(380)*	*12400*	*(220)*	*15900*	*(4000)*	*NA*	
	CA	*35000*	*(17300)*	*12400*	*(750)*	*11800*	*(650)*	*10000*	*(2100)*	*NA*	
Mg	*BA*	*8600*	*(680)*	*5100*	*(170)*	*5600*	*(270)*	*4900*	*(1500)*	*7300*	*(730)*
	CA	*8200*	*(340)*	*8000*	*(290)*	*8400*	*(290)*	*11400*	*(3100)*	*11700*	*(1400)*
K	*BA*	*7500*	*(690)*	*5100*	*(340)*	*4900*	*(310)*	*5500*	*(890)*	*5600*	*(320)*
	CA	*7700*	*(190)*	*7500*	*(340)*	*7700*	*(320)*	*8600*	*(2100)*	*7200*	*(420)*
Zn	*BA*	*5300*	*(860)*	*1400*	*(140)*	*1200*	*(300)*	*1700*	*(150)*	*3000*	*(350)*
	CA	*3200*	*(240)*	*3200*	*(140)*	*3200*	*(270)*	*3600*	*(320)*	*5800*	*(1200)*
Pb	*BA*	*2800*	*(380)*	*1800*	*(510)*	*1500*	*(430)*	*1600*	*(360)*	*1400*	*(240)*
	CA	*2300*	*(290)*	*2100*	*(320)*	*2100*	*(250)*	*2100*	*(370)*	*2400*	*(350)*
					Minor Metals						
Cu	*BA*	*830*	*(250)*	*720*	*(260)*	*650*	*(170)*	*690*	*(120)*	*510*	*(180)*
	CA	*1200*	*(400)*	*720*	*(80)*	*810*	*(100)*	*740*	*(150)*	*500*	*(160)*
Mn	*BA*	*760*	*(60)*	*530*	*(30)*	*550*	*(40)*	*570*	*(30)*	*500*	*(100)*
	CA	*550*	*(60)*	*520*	*(20)*	*530*	*(20)*	*550*	*(50)*	*550*	*(70)*
Ba	*BA*	*630*	*(70)*	*250*	*(20)*	*280*	*(40)*	*420*	*(50)*	*380*	*(140)*
	CA	*430*	*(30)*	*350*	*(20)*	*370*	*(40)*	*600*	*(70)*	*520*	*(120)*
					Trace Metals						
Cr	*BA*	*70.2*	*(10.8)*	*70.8*	*(15.1)*	*75.1*	*(6.4)*	*86.8*	*(24.5)*	*77.2*	*(7.0)*
	CA	*77.9*	*(3.8)*	*86.0*	*(15.1)*	*80.6*	*(3.4)*	*110*	*(35.3)*	*74.7*	*(6.8)*
Ni	*BA*	*100*	*(10.0)*	*30.0*	*(4.9)*	*34.0*	*(5.0)*	*26.0*	*(4.2)*	*120*	*(15.4)*
	CA	*45.0*	*(3.9)*	*55.0*	*(11.0)*	*45.0*	*(7.0)*	*40.0*	*(2.9)*	*35.2*	*(10.1)*
Cd	*BA*	*27.1*	*(6.1)*	*10.3*	*(1.1)*	*11.5*	*(1.8)*	*8.9*	*(1.3)*	*11.9*	*(2.1)*
	CA	*33.3*	*(1.6)*	*33.5*	*(1.4)*	*35.2*	*(2.4)*	*32.9*	*(1.1)*	*35.2*	*(10.1)*
As	*BA*	*21.0*	*(4.7)*	*19.8*	*(11.1)*	*<4.1*		*<4.1*		*4.9*	*(2.6)*
	CA	*24.3*	*(4.2)*	*47.7*	*(13.6)*	*12.2*	*(0.7)*	*5.5*	*(1.4)*	*8.9*	*(3.1)*
Ag	*BA*	*<0.1*		*<2.2*		*<2.2*		*<2.2*		*<2.2*	
	CA	*<2.2*		*<2.2*		*<2.2*		*<2.2*		*<2.2*	
Se	*BA*	*<0.2*		*<2.2*		*<2.2*		*<2.2*		*<2.2*	
	CA	*<2.2*		*<2.2*		*<2.2*		*<2.2*		*<2.2*	

Table 10. *Mean and Std. Dev. Concentration of Metals Measured in Control Blocks*

Analyte	*Concentration(g/g)*
Ag	*<1.1*
Al	*32300 (11100)*
As	*<5*
Ba	*190 (50)*
Ca	*23000 (6900)*
Cd	*<10*
Cr	*7.8 (1.3)*
Cu	*24 (12)*
Fe	*14500 (810)*
K	*5800 (1900)*
Mg	*1100 (380)*
Mn	*170 (10)*
Na	*28900 (3200)*
Ni	*8.6 (2.1)*
Pb	*<0.25*
Se	*<2.2*
Zn	*56 (13)*

chemistry alterations that may occur as a result of weathering.

To date, no adverse environmental or structural impacts have been observed in the boathouse due to the use of MSW combustor ash as an aggregate substitute in the cement blocks.

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The complete report, entitled "Municipal Solid Waste (MSW) Combustor Ash Demonstration Program "The Boathouse" (Order No. PB95-260279; Cost: $19.50, subject to change) will be available only from:
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