Étude pour la caractérisation des lixiviats de mâchefers et de cendres volantes

A Study of Leachate Generated from a Refuse Derived Fuel Incinerator Ash Monofill[1]

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Abstract - Northern States Power Company (NSP) owns and operates an ash monofill used for the disposal of incinerator ash produced from its refuse derived fuel (RDF) incinerator located in Red Wing, Minnesota. The leachate generated at this facility is collected and transported to the City of Red Wing Wastewater Treatment Plant (WWTP). From June 1, 1988 to May 31, 1989, NSP analyzed samples of leachate obtained from each discharge event from NSP's Red Wing Ash Storage Facility. The data suggest that the quality of the leachate generated at the RDF monofill approximates drinking water standards for most parameters, particularly the metals. The analyses of these samples suggest that concentrations of the chemical constituents in the leachate do not vary sufficiently to cause problems in the WWTP's ability to effectively treat the leachate. NSP has concluded that municipal wastewater treatment plants can effectively treat leachate produced at RDF ash monofills.

INTRODUCTION

Northern States Power Company (NSP), a Minnesota investor owned utility, owns and operates integrated solid waste management facilities in Minnesota. These facilities include two resource recovery facilities which process municipal solid waste into Refuse Derived Fuel (RDF). The RDF produced at these facilities is burned to produce electricity in two of NSP's utility power plants. Both of these plants were converted from coal to utilize RDF as a fuel.

In Minnesota mixed municipal solid waste incinerator ash is defined as a "special waste". As a special waste, incinerator ash must be stored and managed in accordance with the "Temporary Management Program for Mixed Municipal Solid Waste Incinerator Ash". Currently the Minnesota Pollution Control Agency (MPCA) is in the process of adopting rules.

The temporary program requires that owners and operators of Municipal Solid Waste (MSW) incineration facilities store ash in one of two types of ash storage facilities. This program defines two types of acceptable ash storage facilities, a type I facility and a type II facility. The type I facility is a temporary storage facility which consists of a clay liner and sedimentation basin. The thickness of

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the liner is based on the length of time that the ash will be stored in the facility. The contents of a type I facility must be removed. The type II facility is designed for the permanent disposal of incinerator ash but is not currently approved for the permanent disposal of incinerator ash. These types of facilities are being constructed with the prospect that they will become the accepted design for a permanent disposal facility when the MPCA adopts its Mixed Municipal Solid Waste Incinerator Ash Rules in 1991. The type II facility requires a liner, a leachate collection system and a leak detection system. The liner can be constructed with either a composite liner (HDPE liner and Clay liner) or from a clay liner constructed from minimum of a four feet of compacted clay.

NSP owns and operates an approved type II ash storage facility located in Red Wing, Minnesota. This facility is used for the disposal of the RDF incinerator ash produced from NSP's Red Wing Generating Plant. NSP's Red Wing Ash Storage Facility (facility) has been in operation since May of 1988. This facility is characterized by a 60 mil high density polyethylene (HDPE) liner, a leachate collection system, and a leak detection system (Figure 1).

NSP is permitted to discharge the leachate generated from this facility into the Red Wing Wastewater Treatment Plant (WWTP). The leachate collected at the ash storage facility is transported via a 6000 gallon tanker truck to a sewer intercept which discharges into the Red Wing WWTP. Discharge limits were established to prevent the addition of this leachate from negatively impacting the effectiveness of the WWTP. The Red Wing Leachate Management and Contingency Plan (management plan) was adopted to provide appropriate responses to changes in leachate quality. The discharge limits in this management plan were developed to provide acceptable discharge rates based on the concentrations of parameters of concern. Each of these parameters has a known inhibition concentration which could adversely affect the organisms present in the WWTP. The maximum discharge limits were developed assuming that NSP discharges high flows of its most concentrated leachate into the WWTP during periods of dry weather flow. In addition, a safety factor of two has been built into these maximum discharge limits to account for the delay from the leachate discharge to receipt of the analysis of the monthly composite samples.

NSP follows the sampling requirements as outlined in the solid waste permit (SW-307) and the management plan to determine the quality of the leachate generated at the Red Wing facility. In accordance with these requirements monthly composites are prepared from samples from each leachate discharge event for a calendar month. The results from the analysis of these composite samples are used to manage the discharge rates of the leachate from the facility into the Red Wing WWTP. The results from these analyses are compared to the maximum discharge limits as displayed in Table 7 Leachate Management and Contingency Plan.[1] When a constituent of the leachate has a concentration above the acceptable concentration for the approved discharge rate, the discharge rate is reduced accordingly.

During the first year of the operation of this facility NSP undertook extra sampling. The purpose of the additional samples was to collect representative data which supports and enhances the information obtained by NSP's required monthly leachate sampling program. During this year NSP analyzed samples of leachate obtained from each discharge event from June 1, 1988 to May 31, 1989.

METHODS

A two liter sample of leachate was obtained every time the contents of the 6000 gallon leachate collection tank were transferred to a tanker for transportation and discharge into the Red Wing WWTP. Half-way through the collection tank discharge event the sampling faucet was purged for two minutes to remove potential contaminants from the sampling apparatus.

Prior to collecting the sample, the two liter polyethylene sample container was rinsed once with leachate. This discharge event sample was split to provide NSP with approximately 500 ml for analysis. This 500 ml sample was acidified with nitric acid for preservation. All samples were refrigerated until delivered to the appropriate laboratory for analysis.

Within 24 hours the remainder of the discharge event sample was delivered to the City of Red Wing's chemical laboratory. The City of Red Wing's laboratory prepared a monthly composite sample from all of the individual discharge event samples collected during each month. This monthly composite was split into three sub-samples. One for sulfate analysis, another for metals analysis, and a third for C.O.D. analysis. Splits of these three samples were sent to NSP's Environmental Laboratory and an independent laboratory for analysis. Results obtained from these analyses were used in accordance with the management plan to determine leachate discharge rates for the facility.

The 500 ml bottles used to contain NSP's discharge event sample were prepared at NSP's Environmental Laboratory. These bottles contained measured amounts of nitric acid for sample preservation. All samples were labeled for proper identification, and were immediately refrigerated. NSP's 500 ml samples were transported to the environmental laboratory for analysis the first Monday of each month.

NSP performed a chemical analysis on each of the 274 discharge samples collected from June 1, 1988 through May 31, 1989. Since the samples were not digested with acid, the data represent the dissolved concentration of each parameter. Samples were analyzed in accordance with the methods as outlined in Table 1.

RESULTS/DISCUSSION

During the first year of the operation of NSP's Red Wing RDF Ash Storage Facility NSP analyzed samples of leachate from each leachate discharge event. The purpose of this investigation was to supplement the data obtained from NSP's required monitoring program.

NSP collected and analyzed 274 discharge event samples from June 1, 1988 through May 31, 1989. A summary of the results obtained from the analysis of these samples is found in Table 2. This table contains a simple descriptive statistical analysis of the data. The fifth column of the table reveals the number of values for each parameter which had a concentration greater than the method detection limit. We have found that leachate generated at the Red Wing facility rarely contained concentrations of cadmium, chromium, lead, and selenium above the method detection limits.

Table 2 also contains the standard deviation, average concentration, and the maximum and minimum concentrations for each parameter over this period. These data suggest that the observed variation in the concentrations for Ba, B, Cd, Cr, Pb, Mn, Hg, and Se over the sampling period was small. The concentration of sodium, chloride and sulfate in the leachate does vary noticeably from month to month, and day to day.

NSP analyzes two monthly leachate composites each month. The first prepared by the City of Red Wing's laboratory (City Sample-NSP Analysis) and the second prepared at NSP's Environmental Laboratory (NSP Sample-NSP Analysis). The results from these analyses are used to determine appropriate discharge rates for the leachate generated from the Red Wing facility. The data from the analyses of these monthly composites show that the variation in the concentration of the leachate has not been so extreme as to prevent the safety factors incorporated into the management plan from adequately protecting the WWTP from fluctuations in the leachate quality.[2]

The results from the analysis of the monthly composite samples are found in Figures 2 through 13. NSP calculated the average concentration of the discharge event samples for each calendar month. These average concentrations are also found on these figures. The results of these analyses are plotted against the drinking water standards for each analyzed parameter. These data suggest that the concentrations of As, Ba, Cr, Pb, Hg, Ni, Ag and Zn found in the leachate generated from the Red Wing RDF Ash Storage Facility are commonly below the drinking water standards. Since the detection limits for Cd and Se were above the drinking water standards it is difficult to determine whether they simply approximate or exceed drinking water standards. NSP has found that the concentrations of SO4 and Mn in the leachate frequently exceed the secondary drinking water standards. The concern associated with the elevated concentrations of these constituents is primarily with the objectionable odors and tastes of the water.

In addition to monitoring of the leachate as described above, NSP has collected other data that support our findings at the Red Wing facility.

Owners and operators of MSW incineration facilities in Minnesota are required by the MPCA's Temporary Program for Municipal Solid Waste Incinerator Ash to conduct an ash evaluation program. This program requires that facility owners collect, process, and analyze, on a quarterly basis, composite samples of incinerator ash collected over a fourteen day period. NSP has completed three quarters of ash testing at it's Red Wing Generating Plant. The ash evaluation program consists primarily of total composition analyses for both inorganic and organic parameters, and EPA method 1312 leach tests.

NSP has determined through its total composition analyses that the most prevalent elements found in RDF ash are Si, Ca, Fe, Mg, K, Na, and Ti. RDF ash also contains a broad spectrum of trace metals. Like in coal ash the highest concentrations of trace metals are present in the fly ash. The data from NSP's ash evaluation program show that RDF fly ash contains elements such as As, Ba, Cd, Cr, Pb, Ni, Ag and Zn in concentrations exceeding 10 ppm.[3]

To simulate the effect of acid rain leaching through the ash in an ash disposal facility the ash evaluation utilized a modified EPA Method 1312 leachate test. This modified method incorporated a mixture of 70/30 H2SO4/HNO3 to maintain a pH of 4.4. The results of this leach test demonstrated that many of the constituents of RDF ash are not available for leaching. The data obtained from the method 1312 leach of fly ash from NSP's ash evaluation program show that the concentrations of As, Ba, Cd, Cr, Cu, Ni, Se, Ag, and Zn are below the drinking water standards.[3]

CONCLUSION

In summary NSP has made three observations regarding the production of leachate from the RDF ash storage facilities:

1). Significant amounts of several trace metals occur in RDF ash. However, concentrations of these elements in the leachate obtained from both laboratory leach tests and from an operating type II ash storage facility approximate the drinking water standards.

2). NSP has learned that the leachate produced at the ash disposal facility does not vary in its composition sufficiently as to cause problems in the WWTP's ability to effectively treat the leachate. The observed concentrations of the constituents in the leachate are well below those concentrations known to cause shock to the WWTP system. The maximum observed concentrations for the leachate generated from June 1, 1988 to May 31, 1989 are well below these same criteria.

3). Through the use of the Leachate Management and Contingency Plan NSP can effectively manage the discharge of leachate into the Red Wing WWTP so that the leachate produced at NSP's Red Wing RDF Ash Storage Facility does not reduce the efficiency of Red Wing Wastewater Treatment Plant. To date the leachate from this facility has contained no constituents at concentrations high enough so that it could not be effectively managed.

REFERENCES

1. E.A. Hickok and Associates (1988) Leachate Management and Contingency Plan: Northern States Power Company Ash Disposal Site Red Wing, Minnesota, Eugene A. Hickok and Associates, Wayzata, Minnesota 55391.

2. Clarke, R.A. (1989) Leachate Management and Contingency Plan Annual Re-evaluation: NSP Red Wing RDF Ash Landfill Permit no. SW-307, Northern States Power Company, Minneapolis, Minnesota 55401.

3. Clarke, R.A. (1990) Incinerator Ash Testing Program Second and Third Quarter Results, Northern States Power Company, Minneapolis, Minnesota 55401.

Table 1
Parameters Analyzed By NSP's Environmental Laboratory
For Leachate Collection Tank Event Sampling

Parameters	Methods	Detection Limits
Arsenic	*EPA 206.2	0.01 mg/l
Barium	DC Plasma	0.1 mg/l
Boron	DC Plasma	0.1 mg/l
Cadmium	DC Plasma	0.02 mg/l
Chloride	*EPA 325.3	1.0 mg/l
Chromium	DC Plasma	0.02 mg/l
Lead	DC Plasma	0.05 mg/l
Manganese	DC Plasma	0.1 mg/l
Mercury	*EPA 245.1	0.001 mg/l
Molybdenum	DC Plasma	0.1 mg/l
Nickel	DC Plasma	0.01 mg/l
Selenium	*EPA 270.2	0.02 mg/l
Silver	DC Plasma	0.02 mg/l
Sodium	DC Plasma	10 mg/l
Sulfate	*EPA 375.4	5 mg/l
Zinc	DC Plasma	0.02 mg/l
C.O.D	OI Corp. Ampules	10 mg/l

* Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, March, 1983.

Table 2
Summary of the Leachate Discharge Event Sample Data

Parameter	Maximum mg/l	Minimum mg/l	* Average mg/l	* Standard Deviation	> d.l. Count
Barium	1.3	d.l.	0.4	0.15	271/274
Boron	0.4	d.l.	0.12	0.05	185/274
Cadmium	0.02	d.l.	0.02	0.0	3/274
Chloride	8430.	1450.	4340.	1747.	269/269
Chromium	0.02	d.l.	0.02	0.0	2/34
Lead	0.12	d.l.	0.085	0.035	2/274
Manganese	3.7	d.l.	1.98	0.66	34/34
Molybdenum	2.6	0.2	1.16	0.49	274/274
Nickel	0.03	d.l.	0.02	0.005	24/34
Selenium	0.05	d.l.	0.02	0.015	7/274
Silver	0.3	d.l.	0.07	0.093	10/34
Sodium	4870.	760.	2428.	969.5	269/269
Sulfate	2291.	300.	949.	351.1	269/269
Zinc	1.5	d.l.	0.11	0.18	224/274

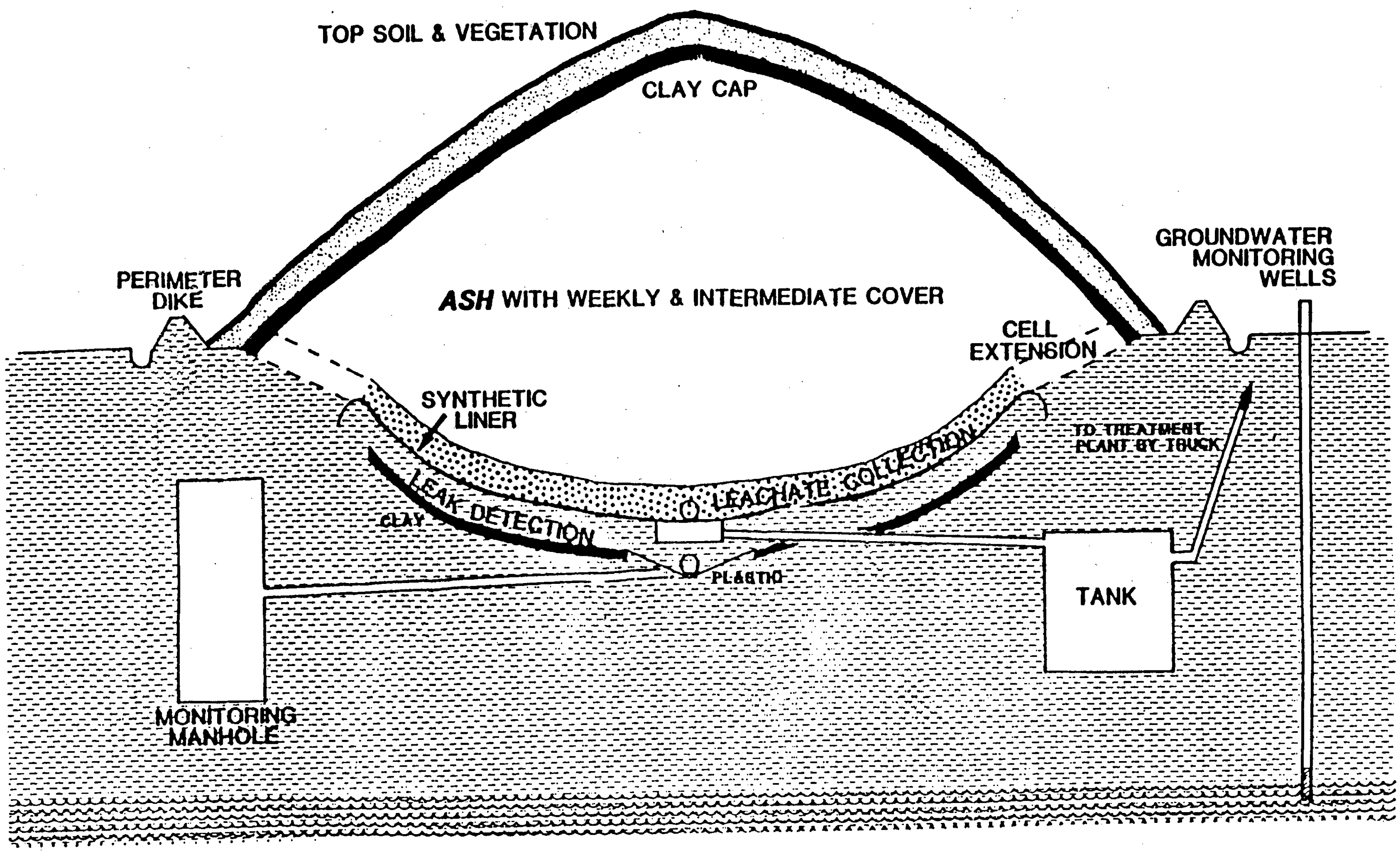
* Average and Standard Deviation calculated from concentration values greater than the detection limit for the analysis.

Note that the column with the heading "> d.l." is the number of values greater than the detection limit over the number of analysis performed (example 10/34 indicates 10 values greater than the detection limit and 34 total measurements taken).

d.l. signifies value equal to detection limit.

Figure 1

NSP's RED WING
RDF ASH DISPOSAL FACILITY



RED WING LEACHATE DATA

Arsenic vs Drinking Water Std
June 1, 1988 to May 31, 1989

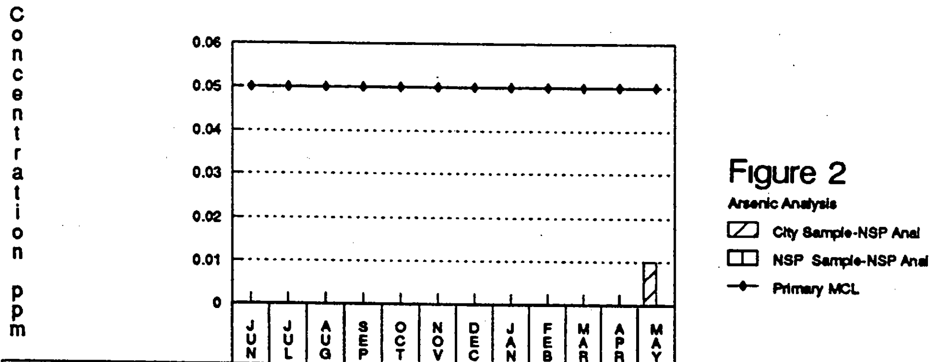


Figure 2

	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
City Sample-NSP Anal			0	0	0	0	0	0	0	0	0	0.01
NSP Sample-NSP Anal	0	0	0	0	0	0	0	0	0	0	0	0
Primary MCL	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 0.01 mg/l

RED WING LEACHATE DATA

Barium vs Drinking Water Std
June 1st 1988 to May 31st 1989

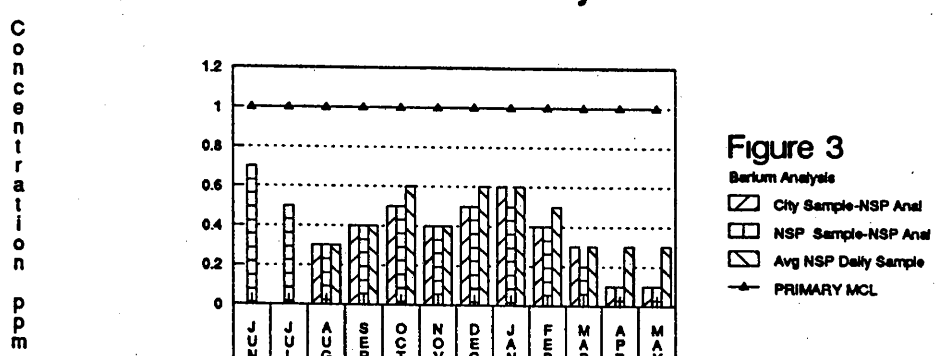


Figure 3

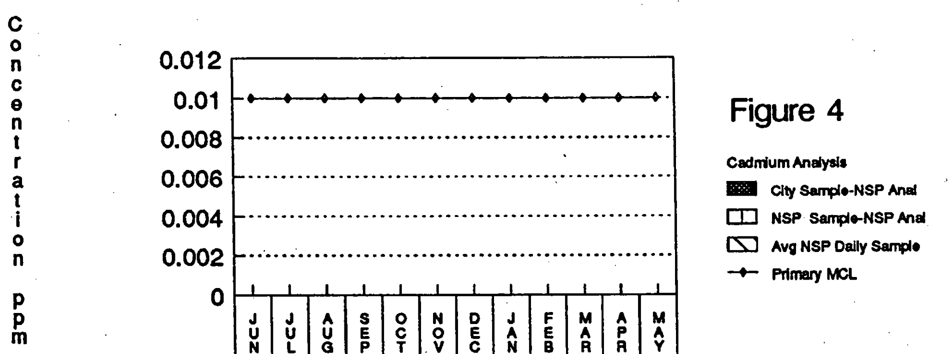
	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
City Sample-NSP Anal			0.3	0.4	0.5	0.4	0.5	0.6	0.4	0.3	0.1	0.1
NSP Sample-NSP Anal	0.7	0.5	0.3	0.4	0.5	0.4	0.5	0.6	0.4	0.2	0.1	0.1
Avg NSP Daily Sample			0.3	0.4	0.6	0.4	0.6	0.6	0.5	0.3	0.3	0.3
PRIMARY MCL	1	1	1	1	1	1	1	1	1	1	1	1

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 0.1 mg/l

RED WING LEACHATE DATA

Cadmium vs Drinking Water Std
June 1st 1988 to May 31st 1989



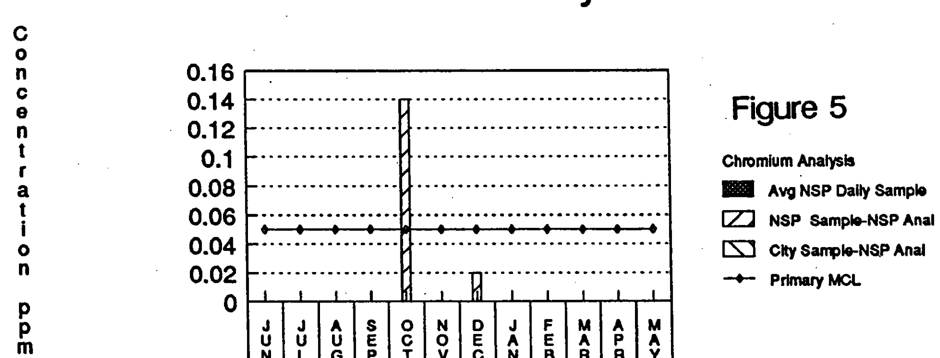
	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
City Sample-NSP Anal			0	0	0	0	0	0	0	0	0	0
NSP Sample-NSP Anal	0	0	0	0	0	0	0	0	0	0	0	0
Avg NSP Daily Sample		0	0	0	0	0	0	0	0	0	0	0
Primary MCL	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 0.02 mg/l

RED WING LEACHATE DATA

Chromium vs Drinking Water Std
June 1st 1988 to May 31st 1989



	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Avg NSP Daily Sample			0									
NSP Sample-NSP Anal	0	0	0	0	0.14	0	0.02	0	0	0	0	0
City Sample-NSP Anal			0	0	0	0	0	0	0	0	0	0
Primary MCL	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 0.02

RED WING LEACHATE DATA

Lead vs Drinking Water Std

June 1st 1988 to May 31st 1989

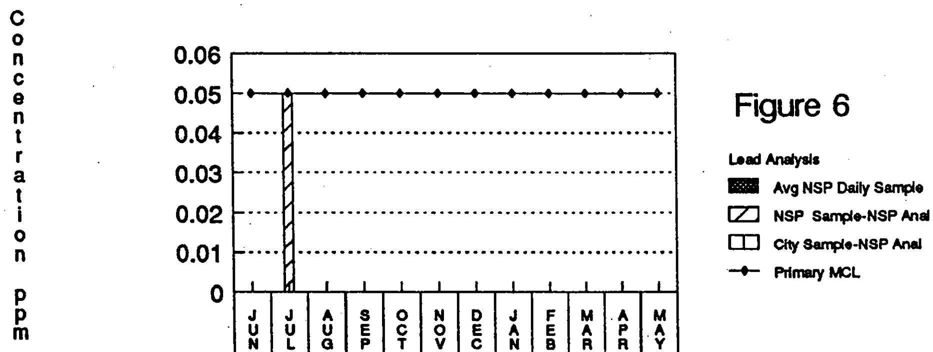


Figure 6

	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Avg NSP Daily Sample			0	0	0	0	0	0		0		
NSP Sample-NSP Anal	0	0.05	0	0	0	0	0	0	0	0	0	0
City Sample-NSP Anal			0	0	0	0	0	0	0	0	0	0
Primary MCL	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 0.05

RED WING LEACHATE DATA

Manganese vs Drinking Water Std

June 1st 1988 to May 31st 1989

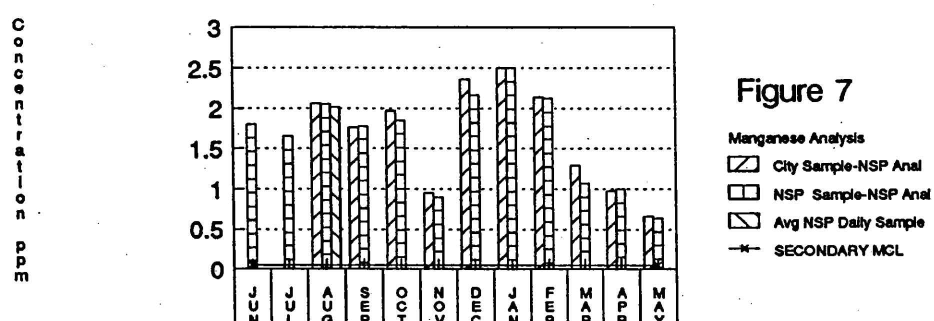


Figure 7

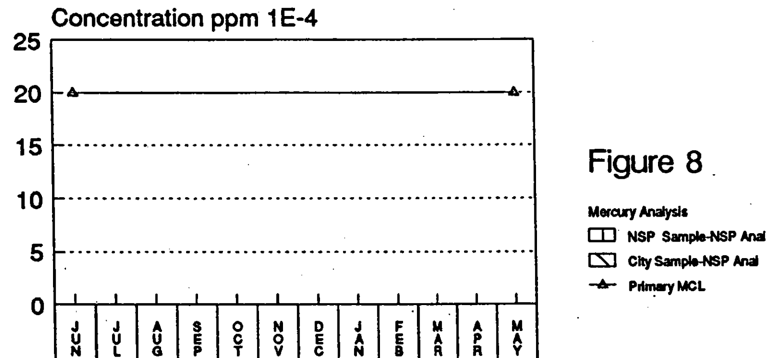
	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
City Sample-NSP Anal			2.06	1.76	1.97	0.95	2.36	2.5	2.14	1.29	0.98	0.66
NSP Sample-NSP Anal	1.8	1.65	2.05	1.78	1.85	0.9	2.16	2.5	2.12	1.07	1	0.64
Avg NSP Daily Sample			2.01									
SECONDARY MCL	0.05											0.05

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 0.1 mg/l

RED WING LEACHATE DATA

Mercury vs Drinking Water Std
June 1st 1988 to May 31st 1989



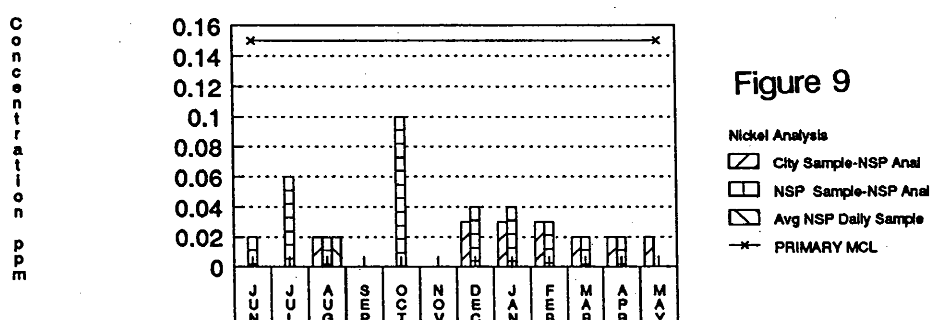
	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
NSP Sample-NSP Anal	0	0	0	0	0	0	0	0	0	0	0	0
City Sample-NSP Anal			0	0	0	0	0	0	0	0	0	0
Primary MCL	20											20

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 0.001

RED WING LEACHATE DATA

Nickel vs Drinking Water Std
June 1st 1988 to May 31st 1989



	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
City Sample-NSP Anal			0.02	0	0	0	0.03	0.03	0.03	0.02	0.02	0.02
NSP Sample-NSP Anal	0.02	0.06	0.02	0	0.1	0	0.04	0.04	0.03	0.02	0.02	0
Avg NSP Daily Sample			0.02									
PRIMARY MCL	0.15											0.15

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 0.02

RED WING LEACHATE DATA

Selenium vs Drinking Water Std

June 1st 1988 to May 31st 1989

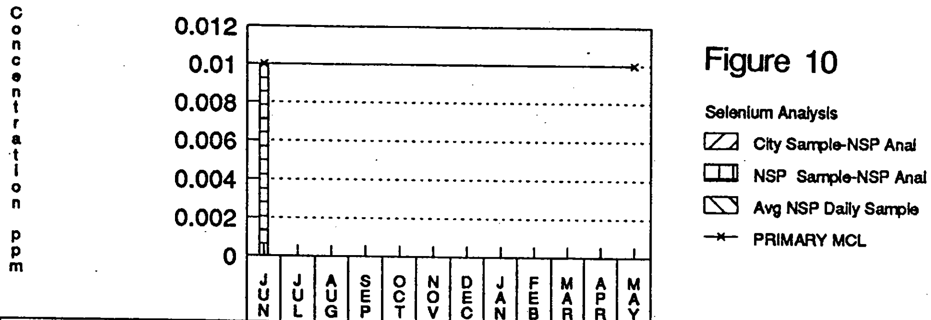


Figure 10

	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
City Sample-NSP Anal			0	0	0	0	0	0	0			0
NSP Sample-NSP Anal	0.01	0	0	0	0	0	0	0				0
Avg NSP Daily Sample			0	0		0	0	0	0	0		
PRIMARY MCL	0.01											0.01

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 0.02 to 0.01

RED WING LEACHATE DATA

Silver vs Drinking Water Std

June 1st 1988 to May 31st 1989

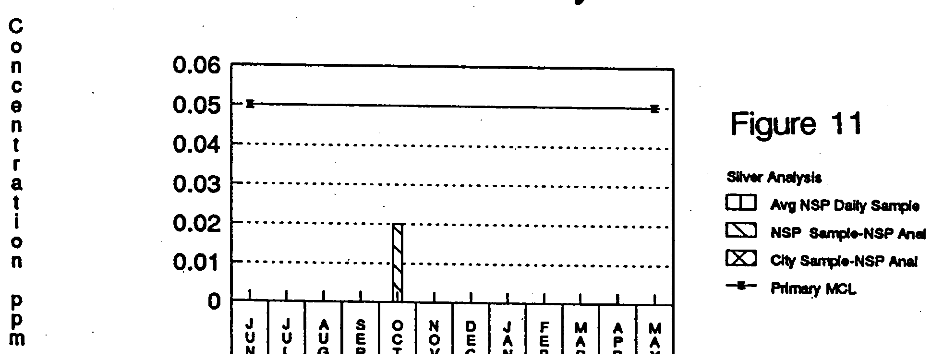


Figure 11

	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Avg NSP Daily Sample			0						0			
NSP Sample-NSP Anal	0	0	0	0	0.02	0	0	0	0	0	0	0
City Sample-NSP Anal			0	0	0	0	0	0	0	0	0	0
Primary MCL	0.05											0.05

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 0.02

RED WING LEACHATE DATA

Sulfate vs Drinking Water Std

June 1st 1988 to May 31st 1989

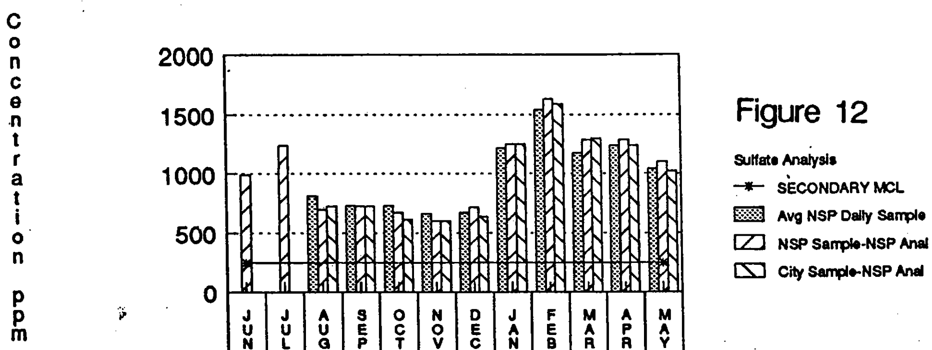


Figure 12

	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
SECONDARY MCL	250											250
Avg NSP Daily Sample			814	735	733	667	674	1220	1543	1177	1241	1045
NSP Sample-NSP Anal	990	1240	700	730	674	603	720	1250	1632	1290	1290	1100
City Sample-NSP Anal			730	730	615	603	640	1250	1590	1300	1240	1020

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 5 mg/l

RED WING LEACHATE DATA

Zinc vs Drinking Water Std

June 1st 1988 to May 31st 1989

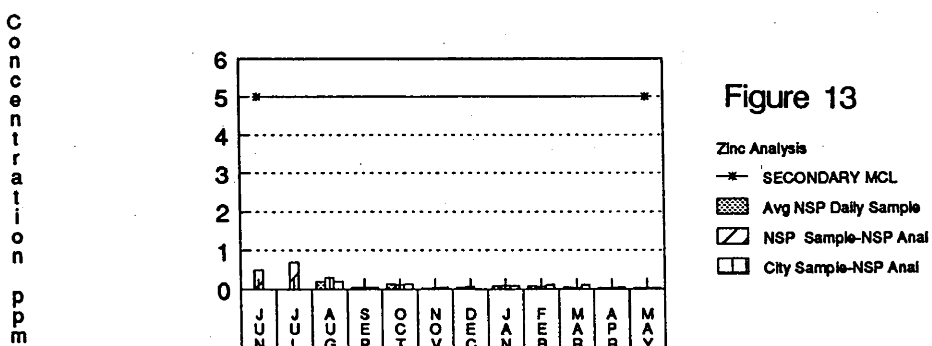


Figure 13

	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
SECONDARY MCL	5											5
Avg NSP Daily Sample			0.2	0.06	0.13	0.04	0.06	0.09	0.09	0.05	0.04	0.03
NSP Sample-NSP Anal	0.5	0.7	0.3	0.06	0.12	0.04	0.07	0.1	0.07	0.03	0.04	0.03
City Sample-NSP Anal			0.2	0.06	0.14	0.06		0.09	0.11	0.11	0.05	0.04

Month

Analysis by NSP's Environ. Laboratory
"0" = value below method detection limit
Method detection limit = 0.02 mg/l

A Geotechnical Characterization of Fly Ash from Solid Waste Incineration

By David J. Mitchell[1], and Abdul Shakoor[2]

Abstract: The engineering properties of fly ash from an Akron, Ohio, incinerator were determined with a focus on potential applications in geotechnical engineering. The fly ash was analyzed for index properties, moisture-density relationships, strength characteristics, permeability, and material chemistry. Results indicate the fly ash from the Akron facility has a mean water content of 33.4%, and mean particle specific gravity of 2.49. Grain size distribution analysis indicates the fly ash is a moderately well graded, fine silty sand. Investigation of moisture-density relationships yields a mean optimum water content of 38.4%, and an average maximum dry density at 66.9pcf. Shear strength analysis produced a mean peak friction angle of 44.0°, with an average cohesion of 402psf. The mean permeability of the material is 5.45×10^{-5} cm/s. Results of the bulk chemical analysis reveal the fly ash is mainly composed of the oxides of silicon, aluminum, and alkali and alkaline earth elements. Leachate analysis indicates the fly ash exceeds EPA limits for several metals. These properties suggest that the fly ash should be admixed with other materials, such as soil or lime, before it can effectively be used for engineering applications.

Introduction

The annual production of garbage and trash in the United States increased from 140 million tons in 1980 to nearly 150 million tons in 1985 (Neal and Schnubel,1987). In the state of Ohio alone, over 7 million tons of solid waste was generated in 1986, with the projected output growing to over 9 million tons by 1990 (The Ohio Alliance for the Environment,1986). As we move into the 1990's, our society's output of solid waste continues to expand on a yearly basis. With this growth, the question of how to effectively dispose of the waste becomes ever more important. Throughout the United States, landfills, which are the primary repositories for solid waste, are rapidly reaching maximum disposal capacity. Compounding this situation is the fact that it is increasingly more difficult to find potential new landfill sites due to environmental concerns and public opposition to their construction.

In response to this problem, municipalities are turning to the process of incineration as a means of waste management. Incineration subjects refuse to

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high temperature combustion (1500° to 1900° F), with the result being a net decrease in solid waste volume of 80 to 90 percent (Collins,1977), while also producing heat which can in turn be used for generating process steam or electricity.

While incineration appears to be an attractive means of reducing solid waste volume, substantial quantities of by-product, in the form of a residue, remains to be disposed of in an economical and environmentally safe manner. The residue produced from combustion constitutes approximately 20 to 40 percent by weight of the original refuse (Collins, 1978), and consists of a coarse bottom ash which falls to the base of the combustion units, and fly ash collected by electrostatic precipitators. In general, the bottom ash and fly ash are subsequently transported for emplacement in landfills. Landfilling becomes necessary because adequate information regarding the potential applications of this material is not available currently.

The focus of most studies concerning incinerator residue has been towards the coarser bottom ash or a combination of bottom ash and fly ash. Qualitative studies have been conducted to assess the potential for applications of incinerator residue by Collins (1977) and Vence (1985) among others. Their research indicates that incinerator residue has promise as a construction material and source of recycled metal and glass. Taft and Shakoor (1987) investigated the physical properties of combined bottom ash and fly ash, and concluded the material has the potential for use as a structural fill, landfill cover, and as an aggregate in bituminous mixtures.

Little research has been published which solely evaluates the fly ash fraction of incinerator residue. This point is notable since fly ash produced from the burning of coal has proven applications as a construction material. The study presented in this paper was undertaken to add to the meager existing data base on the geotechnical characterization of solid waste fly ash. The specific objective of the study was to determine the engineering properties of fly ash from an Akron, Ohio, incinerator and, based on these properties, assess the potential for its application in engineering.

Akron Recycle Energy System

The source of incinerator fly ash for this investigation was the Akron, Ohio, Recycle Energy System (RES):

> The Akron facility is a refuse-derived fuel (RDF) system. Prior to combustion, incoming municipal solid waste is mechanically shredded and approximately 5% ferrous product is removed. The facility's combustion units are three 130,000 pounds per hour Babcock and Wilcox boilers fitted with Detroit stoker rotogrates. These units currently process 1000 to 1100 tons of waste per day, seven days a week. Steam from combustion of the waste is sold to industry in the city of Akron with a portion drawn off for in-house use (Mclaughlin,1990).

Evaluation of Engineering Properties

Sample Collection

Twenty one samples were collected from the Akron facility over a nine month period beginning in August of 1988 and ending in April of 1989. Samples used in this investigation consisted of sixteen daily, four weekly, and one monthly sample. This schedule allowed for the evaluation of temporal changes in engineering properties of the fly ash. Sampling was carried out by removing bulk quantities from pugmills at the incinerator. The fly ash was collected in 5 gallon buckets containing plastic bags which were then sealed for storage.

Engineering Properties

In order to assess the engineering properties of the fly ash with a focus towards geotechnical applications, a comprehensive series of tests were performed on the samples. Parameters considered necessary in this investigation were:

1. **Index Properties**: water content, petrographic characteristics, specific gravity, and grain size distribution.
2. **Moisture-Density relationships.**
3. **Strength characteristics**: determined by direct shear, and unconfined compression.
4. **Permeability.**
5. **Material Chemistry**: bulk composition, leachate quality.

Where applicable, all testing conformed to ASTM guidelines and procedures.

Index Properties: Fly ash collected by the electrostatic precipitators is in a dry state. To facilitate handling of the material and keeping dust to a minimum, water is added to the fly ash at its point of deposition within the pugmills. Therefore, water content of the fly ash is controlled by in-house processes. The as received water content of the samples was determined using ASTM procedure D2216-80. Results indicate a range of water content from 7.4 to 54.0 percent with a mean of 33.4 percent. At the mean water content, the fly ash is easily handled and relatively dust free.

Particle morphological examination was performed using both optical and scanning electron microscopy. Optical investigation reveals the fly ash is composed of amorphous glass globules and spheres, some of which are hollow, distributed within a loose matrix of inorganic and combustible particles. Use of SEM techniques confirmed results of the optical investigation, while also showing no true crystalline forms appear to develop. Figure 1 is a 300X photomicrograph of the fly ash studied.

Specific gravity of the particles was determined by the pycnometer method as described in ASTM D854-83. This procedure indicated a range of specific gravity from 2.33 to 2.58 with a mean value of 2.49. This is a low value compared to naturally occurring soils whose specific gravity usually ranges from 2.5 to 2.8. The likely cause of the low specific gravity is the presence of hollow glass spheres in addition to a significant fraction of combustible material.

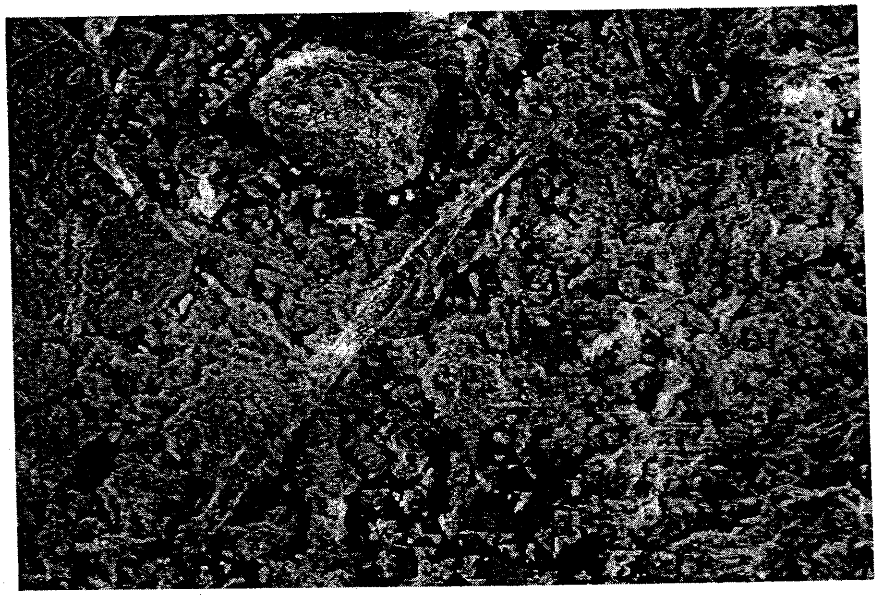

Figure 1. 300X Photomicrograph of Fly Ash from the Akron RES

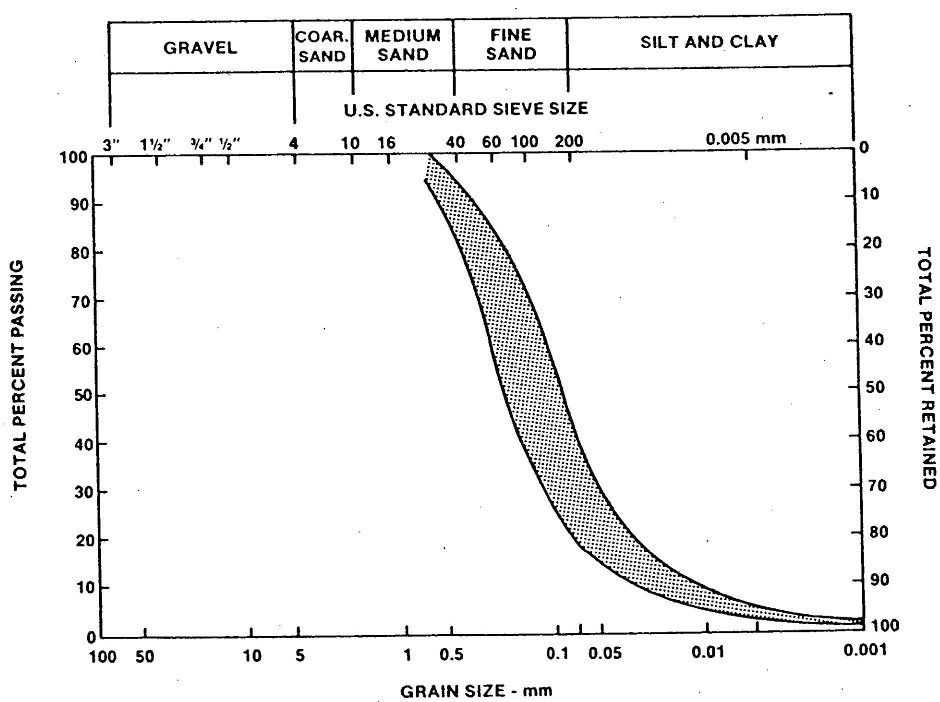

Figure 2. Grain Size Distribution Envelope for Solid Waste Fly Ash (Based on the USCS)

Particle size distribution is used to classify soils and soil-like materials. In addition to classification purposes, the variation and distribution of grain sizes within a material have an effect on many engineering parameters such as permeability, shear strength, and moisture-density relationships. Particle size analyses were carried out using the preparation method described in ASTM D421-85, followed by the mechanical sieve and hydrometer techniques given in ASTM D422-63. Figure 2 is a grain size distribution envelope constructed from the results of 21 individual distributions. As defined by the Unified Soil Classification System (USCS), the coefficient of uniformity, C_u, and coefficient of curvature, C_c, were calculated for the upper and lower bounds of the grain size envelope and yielded average results of $C_u = 8.6$ and $C_c = 1.8$. Based on these findings, the fly ash is considered to be a moderately well graded material. For classification purposes, Atterberg limits were performed on the minus #200 sieve fraction according to ASTM D4318-84. The Atterberg limits reveal the fines to be nonplastic. Results of the particle size analyses along with the Atterberg limits indicate that solid waste fly ash is classified as:

1. USCS - moderately well graded, fine silty sand, SM.
2. AASHTO system - silty sand, A-2-5.

Moisture-Density relationships: Compaction tests were performed on twenty-one samples of solid waste fly ash from the Akron RES using the standard Proctor test described in ASTM D698-80. Results indicate an upper limit of maximum dry density (MDD) of 73.7pcf with an optimum moisture content (OMC) of 30.2%, and a lower limit of maximum dry density of 61.8pcf with a corresponding OMC of 41.8% (Figure 3). The mean value of maximum dry density is 66.9pcf, with the mean OMC at 38.4%. Figure 4 shows the range of maximum dry density and optimum water content for the twenty-one samples analyzed. The average void ratio, e, at MDD and OMC is 1.33. These results indicate the MDD of solid waste fly ash is significantly lower than a natural soil which contains similar particle sizes and gradation.

Strength Characteristics: To obtain shear strength parameters, direct shear tests were performed on dry samples of solid waste fly ash compacted at 95% of maximum dry density. The tests were carried out in accordance with ASTM D3080-72. Results of the direct shear tests are given in Table 1. Testing produced a range of peak friction angles from 40.0° to 48.0° with a mean of 44.0°. Values of peak cohesion range from 0psf to 792psf, with an average of 402psf. Residual friction angles vary from a low of 32.5° to a high of 42.5°, with a mean of 38.5°. With a mean peak friction angle of 44.0°, solid waste fly ash can be considered to have a high shear resistance when compacted at MDD. The average value of cohesion is negligible, and should not be relied upon in engineering applications.

Fly ash compacted at maximum dry density and optimum water content has sufficient apparent cohesion to be tested in unconfined compression. Compression tests were performed on six samples compacted at MDD and OMC. The specimens tested were extruded from the standard compaction mold and therefore had a length to diameter ratio (L/D) of 1.15, as opposed to the standard L/D of 2 to 2.5. Results of the testing indicate a range of approximate compressive strength from 29.9psi to 44.1psi with a mean value of 36.2psi (2.6tons/sqft). In

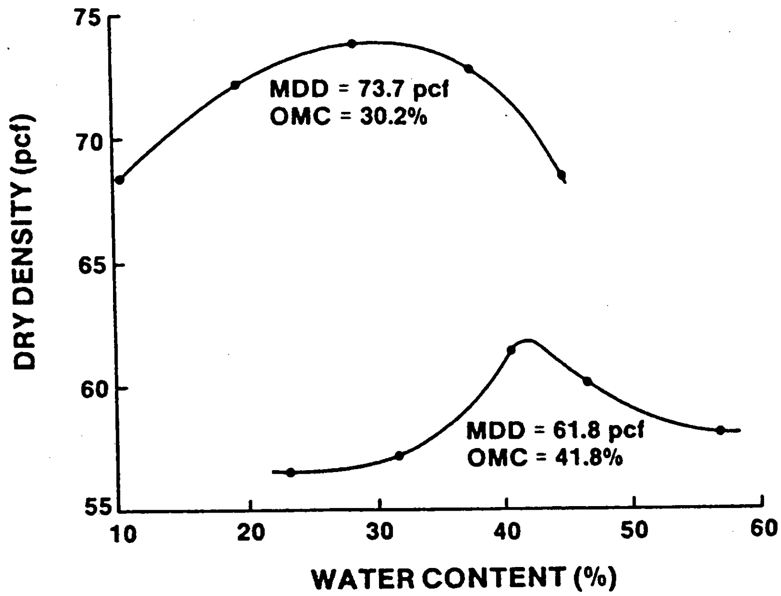

Figure 3. Upper and Lower Limits of Maximum Dry Density for Solid Waste Fly Ash

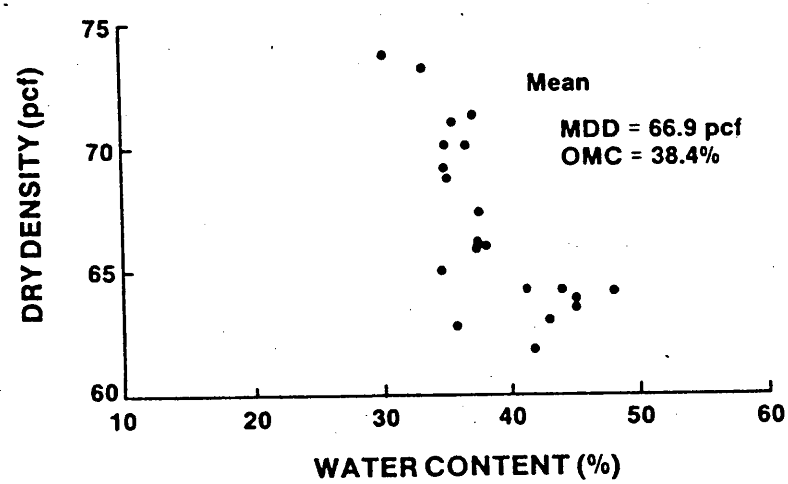

Figure 4. Range of Maximum Dry Density and Optimum Water Content for Solid Waste Fly Ash

qualitative terms, solid waste fly ash compacted at MDD and OMC has an unconfined compressive strength similar to that of a very stiff clay (Peck,Hansen and Thornburn,1974).

Permeability: The permeability of solid waste fly ash was determined using the constant head permeameter method described in ASTM D2434-68. Prior to testing, samples were compacted at maximum dry density and optimum water content. A relative density of no less than 95% was considered acceptable for this

Table 1. Results of Direct Shear Testing of Fly Ash from the Akron RES

Sample #	c(psf)	ϕ°p	ϕ°r
818	612	43.0	37.0
822	360	45.0	37.5
824	576	43.0	41.0
825	432	47.0	42.5
826	576	41.0	32.5
827	756	40.0	37.0
828	788	44.0	38.5
829	409	44.5	37.0
830	0	44.0	41.0
831	792	43.0	40.0
91	396	45.0	34.5
92	468	45.0	38.0
93	144	48.0	41.0
94	360	46.0	40.0
95	0	46.0	40.0
96	342	43.0	36.0
97	468	42.0	37.0
914	288	45.0	39.0
923	396	45.5	41.0
927	360	45.0	41.0
410	414	43.0	40.0
	Range: 0-792 Mean: 402	Range: 40.0-48.0 Mean: 44.0	Range: 32.5-42.5 Mean: 38.5

c = cohesion
ϕp = peak friction
ϕr = residual friction

investigation, with relative density being defined as the ratio of the density of the samples being tested to that of their respective MDD. Permeability values range from a low of 1.53×10^{-5} cm/s to a high of 1.37×10^{-4} cm/s, with the mean of all samples tested at 5.45×10^{-5} cm/s. These results fall into the range of permeability that is encountered with very fine sands and mixtures of sand, silt, and clay (Holtz and Kovacs,1981).

Material Chemistry: Ten samples of fly ash were prepared for bulk chemical analysis using a lithium-metaborate fusion followed by digestion in nitric acid. The samples were then analyzed by an inductively coupled plasma spectrophotometer (ICP) which allowed for the determination of weight percent oxides of the major constituents. As a means of quantifying the organic content remaining after combustion, loss on ignition (LOI) tests were also performed. Results of the ICP and LOI analyses are summarized in table 2. Fly ash obtained from the Akron RES is primarily an alumino-siliceous material containing significant fractions of alkali and alkaline earth oxides. Under ASTM designation C593-69, this material can be defined as an artificial pozzolon.

A major concern limiting the utilization of solid waste fly ash is the potential of toxic substances leaching from the material when it comes in contact with free water. A sample of solid waste fly ash was subjected to leachate extraction in accordance with the EPA SW-846-1310 preparation method. This procedure

Table 3. Analytical Results of Leachate Extracted from Solid Waste Fly Ash

Contaminant	Leachate Concentration (mg/L)*	Maximum Allowable Concentration (mg/L)**
Arsenic	< 0.025	5.0
Barium	1.560	100.0
Cadmium	1.360	1.0
Total Chromium	0.030	5.0
Lead	6.490	5.0
Mercury	0.002	0.2
Selenium	< 0.005	1.0
Silver	< 0.005	5.0

*Analysis performed by Microbac, Inc., J-Labs Div., Bradford, Pa.
** As specified in EPA 40 CFR 261.24.

Engineering Applications

Results of the testing program reveal solid waste fly ash has several characteristics which may limit application of the material. In comparison to natural soil with a similar particle size distribution, fly ash from the Akron RES achieves a significantly lower maximum dry density. In addition to the low MDD, the optimum water content required to reach peak density is quite high, and could create problems in actual field implementation. Although fly ash has a high angle of friction, it lacks true cohesion and therefore restricts applications in which a semi-cohesive to cohesive material would be called for. The major factors limiting the use of solid waste fly ash are excessive concentrations and leachability of toxic substances contained within the material.

Based on these findings, it is recommended that solid waste fly ash be stabilized by admixtures such as soil, lime, cement, etc., in order to improve its overall engineering properties. It is anticipated that the use of admixtures will increase the MDD, lower the OMC, and reduce the release of toxic substances contained within the material. If it is shown that stabilized fly ash effectively binds toxic substances, or minimizes the levels released, the stabilized form could find applications as a structural fill, or daily landfill capping material. A very promising application of solid waste fly ash, based upon it's classification by ASTM as an artificial pozzolon, is as an additive in hydraulic cement or low density concrete.

Summary and Conclusions

As a result of this investigation, the following conclusions may be drawn:

1. Fly ash is classified as a moderately well graded, fine silty sand (SM). The material has a low maximum dry density, averaging 66.9pcf, with a corresponding mean optimum water content of 38.4 percent. With a mean

peak friction angle of 44.0° at 95% of MDD, solid waste fly ash has high shear resistance. Cohesion of the material is negligible. The mean permeability of fly ash at MDD and OMC is 5.45×10^{-5} cm/s.

2. Bulk chemical analysis reveals the fly ash is mainly alumino-siliceous, with significant fractions of alkali and alkaline earth oxides present. Leachate analysis of one sample indicates the material exceeds EPA limits for lead and cadmium.

3. There appears to be little change in the physical properties and bulk chemical composition of fly ash over time.

4. Several physical and chemical characteristics of the fly ash limit it's application in engineering. Stabilization through the use of admixtures such as soil, lime, cement or other materials should improve the properties of solid waste fly ash.

5. Stabilized fly ash may find application as structural fill or landfill cover material. In unstabilized form, the material has potential as a pozzolinic additive in cement.

The authors suggest future investigations into the applications of solid waste fly ash should focus on stabilization of the material through the use of admixtures.

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