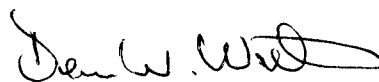


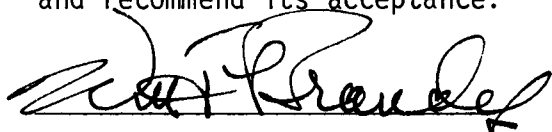
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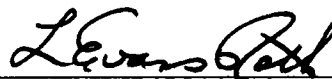
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Vice Chancellor
Graduate Studies and Research

THE TECHNICAL IMPACTS OF THE
RESOURCE CONSERVATION AND RECOVERY ACT
ON WOOD FIRED POWER PLANT WASTE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Hugh Thomas Carson
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3044874

ABSTRACT

Wood has become an important alternative energy source. This ash from wood fired energy sources contains trace toxic elements that are controlled by the "Resource Conservation and Recovery Act of 1976" (RCRA). This thesis investigates the impacts of RCRA on wood energy and evaluates the potential for use of wood ash in the chemical and agricultural industries. The historical uses for wood ash are presented and possible uses for the ash are investigated.

TABLE OF CONTENTS

SECTION	PAGE
I. INTRODUCTION.	1
A. Background.	1
B. "The Resource Conservation and Recovery Act".	1
C. Federal Regulations	2
D. State Regulations	3
II. LITERATURE DEFICIENCIES AND OBJECTIVES	4
III. LITERATURE REVIEW	5
A. Historic Uses	5
B. Analysis of Wood Ashes	7
C. Pesticides in Wood Ashes	11
D. Nutrient Removal by Wood	11
E. Potential for Use as a Soil Amendment	12
F. Potential for Mineral Recovery.	13
G. Land Application of Heavy Metals.	15
H. Summary of Literature	16
IV. MATERIALS AND METHODS.	17
A. Introduction.	17
B. Sample Selection.	17
C. RCRA Extraction Procedure	18
D. Settling Velocities	19
E. X-Ray Diffraction and X-Ray Fluorescence.	20
F. Pesticide Analysis.	20
G. Pelletization	21

V. LABORATORY TEST RESULTS.	22
A. RCRA Extraction Results	22
B. Pesticide Results	22
C. X-Ray Diffraction Analysis.	28
D. X-Ray Fluorescence.	28
E. Pelletization	29
F. Settling Velocities	30
G. Potash Distribution	31
VI. BURLINGTON VERMONT ELECTRIC DEPARTMENT WOOD FIRED POWER PLANT: RCRA IMPACT CASE STUDY.	35
A. Introduction.	35
B. The Generating Stations	35
C. Interviews.	36
D. Analysis of Interviews.	39
VII. SUMMARY.	40
VIII. CONCLUSIONS AND RECOMMENDATIONS	41
A. Conclusions	41
B. Recommendations for Further Research.	41
LIST OF REFERENCES	43
VITA	47

LIST OF TABLES

TABLE	PAGE
1. Analysis of Crude Potash.....	6
2. Ash Analysis of Common Woods.....	7
3. Differences in Inorganic Elements in Grand Fir Wood by Geographical Area.....	9
4. Mean Composition of Wood Ashes.....	10
5. Comparison of Conventional Fuel Usage Versus Quantity of Potentially Available Waste Wood Fuel, by Region and Estimation of Quantities and Percentages of Regional Demand of K_2O and P_2O_5	14
6. Pesticide Analysis of NE Ash.....	23
7. Northeastern Mixture (NE) Ash Extraction Data, Physical Description of Ash - Black, Gritty Powder.....	24
8. Southern Hardwood (ESC) Ash Extraction Data, Physical Description of Ash - Brown, Gritty Powder.....	25
9. Southern Softwood (SA) Ash Extraction Data, Physical Description of Ash - Brown, Fine Powder.....	26
10. Pelletized Northeastern Mixture (NE) Ash Extraction Data, Physical Description - 6 x 16 Mesh Dark Grey Pellets, Bulk Density of 37 lbs./cu. ft.....	27
11. Soluble K_2O of Wood Ash Samples.....	34

LIST OF FIGURES

FIGURE	PAGE
1. Plan and Section of Wood Ash Extraction Plant.....	5
2. Typical XRF Scan of Wood Ash.....	28
3. Conceptual Design of Continuous Flow Potash Extractor.....	30
4. Bottom Ash Settling Capacities at Different Potassium Hydroxide Concentrations.....	32
5. Fly Ash Settling Curve at Two Percent Potassium Hydroxide Concentration.....	33

I. INTRODUCTION

A. Background

The increases in fuel prices in recent years, especially oil, has caused the search for different fuel sources. Due to its renewable nature, wood is being rapidly developed as an alternative fuel source. Wood and wood waste is being used to produce electricity, steam, and heat for residential and commercial users.

Like many past ventures, few people have stopped to consider the true cost or impacts of their actions. An area that has not been considered is the disposal of the ash from a wood fired unit. Historically, wood ash has been used as a fertilizer, chemical raw material, or disposed in landfills. The usage of wood for energy in the future may be on a scale never before seen causing huge quantities of ash. The present concern over landfill disposal of "hazardous" materials and the passage of "The Resource Conservation and Recovery Act of 1976 (RCRA)" (PL 94-580) indicates the importance of this study.

B. "The Resource Conservation and Recovery Act"

In the Congressional Findings of RCRA¹, Congress stated "millions of tons of recoverable material which could be used are needlessly buried each year" and "disposal of solid waste and hazardous waste in or on the land without careful planning and management can present a danger to human health and the environment." RCRA has eight subtitles of which Subtitle C, "Hazardous Waste Management," and Subtitle D, "State or Regional Solid Waste Plan," are the most germane to wood ash disposal.

Subtitle C is the legal framework for the Administrator of the Environmental Protection Agency (EPA) to promulgate regulations to control a hazardous waste from "cradle to grave." Section D gives the states the right to set up a solid waste management plan and enforce their own rules and regulations if they are substantially equivalent to the federal regulations.

C. Federal Regulations

On December 18, 1978, the EPA promulgated a proposed set of regulations² to set the procedures for determining a hazardous waste. Under these regulations a waste is either listed as a hazardous waste, exempted, or must be tested. The three exceptions are (a) wastes generated by a retailer, farmer, or person amounting to less than 100 kilograms per month, (b) agricultural waste which is returned to the soil as a fertilizer or soil amendment, and (c) mining overburden. These regulations require testing for ignitability, corrosivity, reactivity, and toxicity. The test of primary concern with wood ash is toxicity. The toxicity test consists of taking a representative sample of at least 100 grams of the waste, mixing the waste with 16 times the samples weight in deionized water, and maintaining the pH at $5 \pm .2$ using 0.5N acetic acid until up to 4 ml acid per mg of solid is used or 24 hours passes. The waste-acid mixture is filtered and the extract is diluted to 20 times the weight of the solid. If the concentration of a metal or an organic pesticide exceeds 10 times the limit set by the Interim Primary Drinking Water Standards (IPDWS), the waste is hazardous.

On May 19, 1980 the EPA released Interim Final Regulations³. These regulations raised the extract level to 100 times the IPDWS,

and raised the minimum on testing to persons producing over 1,000 kilograms per month. These regulations also exempted fossil fuel fired power plant wastes from being classified as hazardous, but did not exempt wood fired power plant wastes.

D. State Regulation

Each state will either develop their own substantially equivalent solid and hazardous waste regulations or have the EPA administer the RCRA regulations in the state. Even if the wood ash is not classified as hazardous, the disposal method must not jeopardize the groundwater or surface water.³ A survey of the regulations of Vermont⁴, Tennessee⁵, Florida⁶, Texas⁷, and New Mexico⁸ revealed regulations ranging from no enforcement to very stringent enforcement. Any industry considering utilization or disposal of wood ash should check with the State Regulatory Agency.

II. LITERATURE DEFICIENCIES AND OBJECTIVES

A review of the literature indicates a void in disposal information on wood ash. There has been no reported work on the leachability of micro constituents from wood ash. Since large quantities of ash have not been available in recent history, there is no literature on disposal and resource recovery within our present market and legal constraints.

The objective of this study is to evaluate the disposal problems and resource recovery potential of wood ash. While conducting this evaluation, the hazardous waste potential and legal constraints on disposal or resource recovery will be evaluated.

III. LITERATURE REVIEW

A. Historic Uses

U. S. Patent No. 1 was issued to Samuel Hopkins of Burlington, Vermont for "An Improved Method of Making Pot and Pearl Ashes" from wood ash. The burning of wood for ashes was a large business in the Northeast from 1760 to 1810. In 1810, wood ash production was a \$2,000,000 business.⁹ Pot ash (lye) from wood ashes was used in the U.S. and exported to Europe to produce soap.¹⁰

Bateman¹¹ published a detailed description of a modern (1919) potash manufacturing plant. (Figure 1)

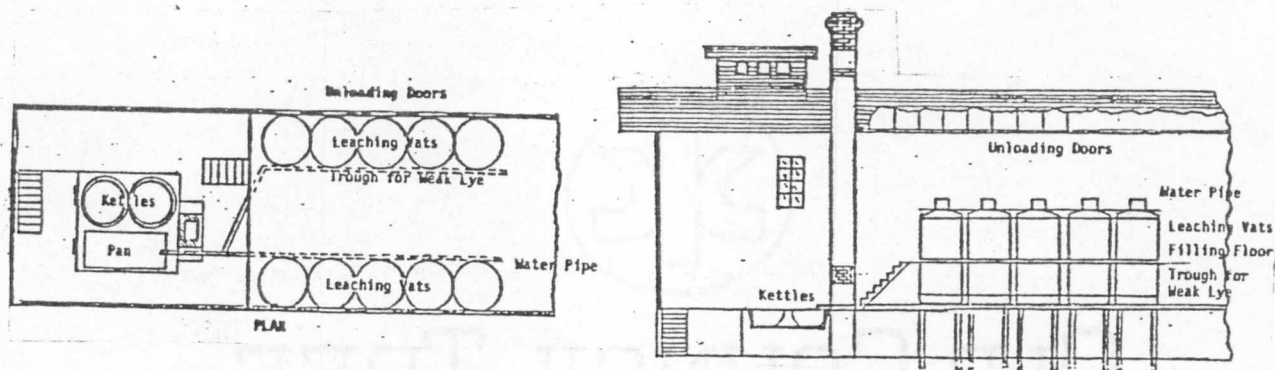


Figure 1 - Plan and Section of Wood Ash Extraction Plant

The wooden leachers were usually five feet in diameter and five feet high. The leachate filtered through a quicklime and straw filter and ran down a galvanized or black iron trough to the wrought iron evaporating pan. The evaporated liquid was transferred into the kettle and crude potash was produced.

Table 1 is a representative analysis of crude potash.

TABLE 1
ANALYSIS OF CRUDE POTASH

	Per Cent
Potassium hydroxide	65.64
Potassium carbonate	16.58
Potassium sulfate	16.03
Potassium chloride	0.35
Moisture and insoluble	1.40

Source: Batemen, Earnest, "Wood Ashes and Production of Potash,"
Chemical and Metallurgical Engineering, November 1919.

Bateman stated that little advance has been made in the process and most operations were carried on by rule-of-thumb methods. The economics of the plant consisted of 60% of all expense being labor and 17% being fuel.¹¹

Mitchell¹² stated in 1955 that potassium, phosphorus, and calcium from wood ashes are important fertilizer materials but can compete with commercial fertilizer matter only in site specific cases.

Whittemore¹³ investigated the possible use of wood fly ash in removing color, phenols, BOD, and COD from caustic waste produces in pulp and paper mills. He found that wood fly ash was effective but the effectiveness was proportionate to the CaO (lime) content. It was

determined that fly ash worked by chemical precipitation of chromophoric (color producing) and other organic substances within the waste.

B. Analysis of Wood Ashes

Work by Schronger,¹⁴ Karsten et al,¹⁵ and Junge¹⁶ described the variability of the major components of wood ash. The analysis presented by Junge¹⁶ in Table 2 is representative of the values found by these authors.

TABLE 2
ASH ANALYSIS OF COMMON WOODS

Ash Analysis % Weight	Pine Bark	Oak Bark	Spruce Bark	Redwood Bark
SiO ₂	39.0	11.1	32.0	14.3
Fe ₂ O ₃	3.0	3.3	6.4	3.5
TiO ₃	0.2	0.1	0.8	0.3
Al ₂ O ₃	14.0	0.1	11.0	4.0
Mn ₃ O ₄	trace	trace	25.3	0.1
CaO	25.5	64.5	25.3	6.0
MgO	6.5	1.2	4.1	6.6
Na ₂ O	1.3	8.9	8.0	18.0
K ₂ O	6.0	0.2	2.4	10.6
SO ₂	0.3	2.0	2.1	7.4
Cl	trace	trace	trace	18.4

Source: Junge, David C., Boilers Fired with Wood and Bark Residues, Research Bulletin 17, Plywood Research Foundation, 119A Street, Tacoma WA, 1975.

Ellis^{9, 17} did extensive work on the inorganic variation of geographically dispersed samples of the same species. Table 3 shows the variability of the different inorganic constituents of grand fir wood east and west of the Cascades.

Grossman analyzed 97 samples of various wood ashes in 1888. Table 4, a summary of Grossman's findings, shows the wide range of concentrations of the macro constituents in wood ash.

A literature search on the inorganic constituents of wood by Wise and Jahn¹⁸ in the early 1950's found barium, titanium, lead, zinc, copper, tin, cobalt, nickel, thallium, chromium, and gold in wood ash. Potash (K_2O) has been reported in the range of 1.5 - 40.6 percent of the inorganic elements of wood ash.¹⁸ Magnesia (MgO) content has been reported to range from 0.45 - 17 percent.¹⁸ Alumina (Al_2O_3) content has been reported as high as 75 percent.¹⁸

The presence of exceptionally high amounts of several elements such as gold, silver, manganese, iron, selenium, zinc, copper, vanadium, and cobalt in wood has long been associated with the presence of these in higher than normal levels in underlying soil and strata. Work by Warren et. al.¹⁹ analyzed wood ash as a method of prospecting for zinc and copper. They found that the concentration of zinc and copper in the wood ash was dependent on both the concentration of zinc and copper in the soil and the soil pH.

TABLE 3
DIFFERENCES IN INORGANIC ELEMENTS IN GRAND FIR
WOOD BY GEOGRAPHICAL AREA

Essential Elements:		Buttwood west and east of Cascades		Signif. level %
		West	East	
Major	No. samples	26	34	--
	Ash, % dry wt.	0.40	0.40	--
	Ca, ppm	549	872	99
	K, ppm	1092	468	99
	Mg, ppm	200	154	80
	Na, ppm	40	14	95
Minor	Ash, % dry wt.	0.33	0.45	90
	B, ppm	0.9	0.9	20
	Mn, ppm	21.1	17.9	50
	Fe, ppm	2.3	2.9	50
	Mo, ppm	0.01	0.01	99
	Cu, ppm	2.8	2.3	80
	Zn, ppm	0.24	1.44	99
Other Elements:	Ash, % dry wt.	0.33	0.45	90
	Ag, ppm	0.03	0.38	90
	Al, ppm	5.0	5.7	50
	Ba, ppm	10.2	27.8	99
	Co, ppm	0.01	0.02	99
	Cr, ppm	0.04	0.06	80
	Ni, ppm	0.15	0.08	90
	Pb, ppm	0.06	0.17	70
	Rb, ppm	1.7	2.2	50
	Sr, ppm	3.2	15.6	99
	Ti, ppm	0.14	0.08	95

(a) probability that differences are real and not alone due to chance.

Source: Ellis, Everett L., "Inorganic Elements in Wood," appearing in Cellular Ultrastructure of Woody Plants, Wilfred A. Cote, Jr., Editor, September, 1964, pp. 181-190.

TABLE 4
MEAN COMPOSITION OF WOOD ASHES

	Mean Per Cent	Maxima Per Cent	Minima Per Cent
Potash	5.5	10.2	2.5
Phos. Acid	1.9	4.0	0.3
Lime	34.3	50.9	18.0
Magnesia	3.5	7.5	2.3
Insoluble	12.9	27.9	2.1
Moisture	12.0	28.6	0.7
Co ₂ and Undetermined	29.9	----	----

Source: Bradley, Harlow, "Potash from Wood and Plant Ashes,"
Mettalurgical and Chemical Engineering, November 15, 1915.

C. Pesticides in Wood Ashes

The tendency for organic pesticides to accumulate in plant tissue is an area of concern due to proposed RCRA regulations.^{2, 3} Incineration is being considered as a means of pesticide destruction. A type 1 waste (similar to wood residue) incinerator was constructed to evaluate pesticide combustion. Six seconds at 600⁰ C. or two seconds at 1000⁰ C. was determined adequate to obtain 99.9% destruction of most organic pesticides. The maximum combustion temperature at the Burlington Vermont Plant is 1200⁰ C.²¹

D. Nutrient Removal by Wood

Ordinary soil contains from 3,500 to 12,000 pounds of potash per acre to a depth of one foot.¹⁵ Most of the potash is in rocks or insoluble complexes and becomes available through weathering.

The German government recognized the weathering phenomena and depletion of available potash. A pre-1900 quote explains a biological method of potash production and the consequences.¹⁵

Hermstad planned to plant wormwood (an artemesia) for the production of potash, as it grows on very poor soil. One Magdeburg acre (18,000 square feet) affords in a summer, three crops, or 20,000 pounds of the dry plant, which produces 2,364 pounds of ash, or 936.6 pounds of potashes. The plan was forbidden by the German Government as wormwood takes the potash out faster than it is produced by disintegration of the soil.

Bowersox et al.,²² have investigated the impact of continual total tree harvesting on the nutrient budget. They concluded that the levels of potassium (K) and phosphorus (P) in the soil would be depleted in a system of intensive harvesting of wood for energy, if fertilization is not used or the ashes returned to the soil.

E. Potential for Use as a Soil Amendment

Wood ash contains significant amounts of calcium (Ca), potassium (K), phosphorus (P), magnesium (Mg), boron (B), molybdenum (Mo), copper (Cu), and zinc (Zn)¹⁵ which have been cited as essential elements in plants.²³ The inherent alkalinity of wood ash¹⁰ and the presence of significant amounts of essential elements^{14, 15, 16} suggest the possible use of wood ash in neutralizing acid soil and increasing the content of essential elements. Increased pH reduces the available aluminum (Al) and manganese (Mn), both of which are toxic to plants, and major causes of acid soil mortality. Acid soils also block nitrification. The effect of soil acidity neutralization varies with each element.²³

Approximately 66% of the potash used in the United States is imported.²⁴ Potash is presently approximately \$55.00 per ton (60% K₂O) and shipping rates are approximately \$40.00 per ton.²⁵

Most phosphates in the United States are mined in Florida. The phosphates (43% P₂O₅) sell for approximately \$115.00 per ton plus approximately \$40.00 per ton for shipping.²⁵ The price of phosphates may increase due to diminishing supplies and impacts by RCRA. The overburden and slimes from phosphate surface mining are listed as "special wastes" under proposed RCRA regulations.²

Using the preceding figures, a 5% K_2O and 3% P_2O_5 sample would have a market value of approximately \$18.70 per ton when potassium and phosphorus alone are considered. Calcium, magnesium, and the trace elements will add to the value.

Hall²⁶ surveyed the available waste wood by region. Table 5 gives the estimates of waste wood from Hall's work and estimates of K_2O and P_2O_5 available if all the waste wood was used as a fuel. From Table 5 it appears that all the K_2O and P_2O_5 in wood ash can be utilized on a regional basis.

F. Potential for Mineral Recovery

Aluminum, potassium, calcium and magnesium appear in concentrations which would suggest possible resource recovery.¹⁵ Potassium has been extracted from wood ashes as a commercial venture.^{9, 11} The concept of recovery of aluminum from the coal ashes has existed for 50 years but was not economical.²⁷ The techniques may work with wood ash.

Three concepts today may make recovery more feasible. First, the cost of mining, extraction, and transportation of these minerals is rising rapidly. Second, many minerals are imported in high percentages and the concern over international cartel control of these minerals is increasing. Third, the recovery of these minerals may reduce the volume of residual solids that require disposal. Church, Weeter, and Davis present a detailed discussion of the several metal extraction procedures from fly ash.²⁸

TABLE 5

COMPARISON OF CONVENTIONAL FUEL USAGE VERSUS QUANTITY OF POTENTIALLY AVAILABLE WASTE WOOD FUEL, BY REGION (a)
AND ESTIMATION OF QUANTITIES AND PERCENTAGES OF REGIONAL DEMAND OF K_2O AND P_2O_5

Region	Conventional Fuel Usage (k)		Potentially Available Waste Wood Fuel		Potential (n) Ash Produced Tons x 10 ³	Potential Nutrients (o)		Approx. Percent of 1978 Usage K_2O P_2O_5
	10 ⁶ Coal Equivalent Tons	10 ⁶ cu ft	10 ⁶ Coal Equivalent Tons	Percent of Total		K_2O Tons	P_2O_5 Tons	
New England (b)	19	534	4.3	23	1.44	7,200	11,320	18
Middle Atlantic (c)	79	341	2.8	4	0.92	11,600	2,760	2
West North Central (d)	40	335	2.7	7	0.91	11,550	2,730	<1
East North Central (e)	115	752	6.1	5	2.00	10,000	6,000	<1
South Atlantic (f)	96	2,946	23.9	25	7.95	39,750	23,850	4
East South Central (g)	50	1,815	14.7	29	11.90	24,500	14,700	5
West South Central (h)	76	1,762	14.3	19	11.70	23,500	14,100	8
Mountain (i)	20	875	7.1	36	2.30	11,500	6,900	31
Pacific (j)	30	3,818	30.9	103	10.30	51,513	30,900	38

(a) Hall, E.H., et al., Comparison of Fossil and Wood Fuels, Battelle Columbus Laboratories for EPA Contract 68-02-1323, March 1976.

(b) Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut

(c) New York, New Jersey, Pennsylvania

(d) North Dakota, South Dakota, Iowa, Kansas, Nebraska, Missouri, Wisconsin, Minnesota

(e) Wisconsin, Michigan, Illinois, Ohio, Indiana

(f) West Virginia, Maryland, Virginia, Delaware, North Carolina, South Carolina, Georgia, Florida

(g) Kentucky, Tennessee, Mississippi, Alabama

(h) Arkansas, Louisiana, Texas, Oklahoma

(i) Wyoming, Montana, Colorado, New Mexico, Arizona, Utah, Nevada, Idaho

(j) Washington, Oregon, California

(k) Figures for 1970. Coal, oil, and gas.

(l) Total volume calculated based on cu ft removed in 1970. The volume was composed of three parts: (1) limbs and branches - 50 percent of removal, (2) rough and rotten - 25 percent of removal (3) plant residues - 20 percent of removal, including materials from primary, secondary industry normally sent to waste.

(m) Volume of wood converted into equivalent tons of coal based on: (1) density of green chips, 54 lb/ft³; (2) wood net heating value, 7.8x10⁶ Btu/ton after correcting for the lower boiler efficiency of wood as compared with coal (9.35 x 10⁶ x 0.684/0.820 = 7.8 x 10⁶); (3) coal heating value, 26.2 x 10⁶ Btu/ton.

(n) Assume 1% Ash (Amount is highly variable).

(o) Assume 5% K_2O and 3% P_2O_5 (Amounts are highly variable).

(p) Based on 1978 Fertilizer Summary Data by Norman L. Burgett and Janice T. Berry of National Fertilizer Development Center, Muscle Shoals, Alabama.

G. Land Application of Heavy Metals

Leeper²⁹ investigated the environmental effects of land application of heavy metals. Leeper reports that mercury is strongly held by soil and is not absorbed by plants. Lead is reported to be easily accessible by certain plants at lower pH's. Chromium is reported as being fairly insoluble but is chelated by organic anions. Barium commonly occurs in soils in the parts per thousand range, but most plants only accumulate barium in a few parts per million. The element of greatest concern is cadmium, because plants take up Cd^{+2} as easily as Ca^{+2} .

The metals of concern all appear as cations or chelates when migrating. Clayey soils are able to hold tightly many elements by cationic exchange. A sandy soil has little or no cationic exchange capacity, therefore, metals applied to sandy soils have a tendency to migrate until they can form insoluble compounds. Application of metal laden waste on sandy soils causes a greater risk of groundwater contamination.

Williams and Davis³⁰ studied the effect of cadmium application through the use of superphosphate fertilizers. They found an average cadmium content of 40 ppm in the superphosphate. Extraction of soils with HCl recovered 80% of the cadmium calculated to have been added to the soil over a 30-45 year period. Examination of plants grown on the land showed varying degrees of cadmium contamination. The study showed that grain crops are only slightly contaminated by cadmium. Hyde et. al.³¹ reported that the cadmium concentration in plants is controlled by the annual application rate and that at soil pH above 6.5 metals intake to plants was less.

H. Summary of Literature

Wood ash was found to contain highly variable amounts of both macro and micro constituents. The constituent concentrations varied with species, geographical area, and pH. Several of the micro constituents have extract levels controlled by the regulations.^{2, 3}

The potash in wood ash has been commercially extracted and the ash has been investigated as a potential fertilizer. A regional survey of waste wood was extrapolated to determine the K_2O and P_2O_5 content. The K_2O and P_2O_5 available from the waste wood was less than the regional demand for these elements in all cases.

IV. MATERIALS AND METHODS

A. Introduction

The ash samples used were from existing wood fired boilers. They were chosen for their geographic variability and type of wood burned. The intent of this study was not to characterize wood ash, but to determine if there was any potential for problems with utilization or disposal due to toxic properties.

Physical and engineering properties evaluated in the course of this study included acetic acid extraction specified in the regulations^{2, 3} and the same extraction with deionized water replacing the acetic acid. The initial series of samples was examined for pH, toxic metals, and pesticides. Later samples were examined for specific elements that appeared to have the highest extracts. The results from these extractions provided a basis for classification under RCRA.

The samples were analyzed for settling velocities to determine the feasibility of a continuous flow potash extractor similar to a waste water settling tank with recycle. Pelletization was also investigated.

B. Sample Selection

Three ashes were chosen from three geographically different areas. The New England sample (NE) comes from a large boiler that has fly ash collection equipment. The plant burns waste wood from the lumber and paper industries and chip wood from the reforestation

efforts. The wood is a mixture of both hard and soft woods. The ash is a gritty black powder with unburned wood chips. A second sample of this wood was pelletized (NEP).

The East South Central sample (ESC) comes from a turn of the century boiler that generated electricity until about 1970. The unit now just produces steam and heat. The unit burns oak waste from a furniture manufacturing process. There are not fly ash collectors therefore the ash tested is all bottom ash. The wood waste burned in this process is much cleaner than might be found with chipped wood. The ash is a gritty brown powder with pieces of uncharred wood.

The South Atlantic sample (SA) comes from a modern unit that has fly ash collection. The wood is primarily southern softwood. The ash is a very fine brown powder with no visible signs of uncombusted material.

All three plants are presently landfilling their ash. The New England Plant is now having trouble with the state environmental regulatory agency over ash disposal.

C. RCRA Extraction Procedure

A representative sample of each ash and a sample of the pelletized New England (NEP) ash was subjected to the extract procedure (EP).^{2, 3} Since wood ash is not specifically listed as hazardous or exempted from regulation and since each of the plants produces over 100 kilograms per month, the ash must be tested under the December 18, 1978 regulations.² Since the New England and East South Central plant generate over 1,000 kilograms per month, the ash must be tested under the May 19, 1980 regulations.³

The EP involves extracting at least 100 grams of ash with deionized water (DI) equaling 16 times the weight of the ash. The pH of the solution is adjusted to $5.0 \pm .2$ using 0.5N acetic acid and agitating with a stirrer for 24 hours. During the 24 hour period the pH is maintained at 5.0 by using up to 4.0 ml of the 0.5N acetic acid per gram of solid.

Also, DI water was substituted for the acetic acid. This procedure involved extracting at least 100 grams of ash with DI water equaling 20 times the weight of the ash. No attempt was made to change the pH of the solution.

The extractor used in both procedures was glass and the stirrers were either plexiglass or teflon. The stirrer rotation speed was 40 rpm.

After 24 hours the liquid portion of the extract is filtered through a 0.45 micron glass filter. The liquid was diluted with deionized water until its volume occupied the volume that 20 times the solid weight of water would occupy at 4° C.

The extract of the NEP sample was a viscous dark brown material, which clogged the filters. The liquid portion of the extract was obtained by centrifugation. The lignin liquor used in the pelletization process probably caused the filter clogging problems.

D. Settling Velocities

A continuous flow potash extractor was considered as a means of removing the potash in areas where an economical market did not exist for the ash. Wood ash was mixed with potassium hydroxide (KOH) solutions of different strengths in a 1:4 ratio. The solutions were placed in a 1,000 ml graduated cylinder and thoroughly mixed. The settling velocity was determined at the interface layer.

The purpose of this series of experiments was to determine the concentration of KOH the system could reach and still have settling velocities feasible for design. The higher the operating KOH the lower the energy requirements and volume required for extractors and evaporators.

E. X-Ray Diffraction and X-Ray Fluorescence

X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF) were investigated as methods of analysis of wood ash. XRD is used to identify crystalline compounds present in a substance. XRF only detects elements with an atomic number of 11 or greater. XRF gives a relative quantitative analysis of the elements detected that have a concentration greater than 0.5%.

F. Pesticide Analysis

The samples were analyzed for pesticides by Sylvester Davis of Division of Plant Industries, Tennessee Department of Agriculture, Nashville, Tennessee. The acetic acid extract of the three ashes were analyzed. The NE sample was also analyzed by the Acetonitril Extraction-Flourisil Column Method.³²

G. Pelletization

A sample of the NE ash was sent to Mars Mineral Corporation of Valencia, Pennsylvania for pelletization studies. A major problem in utilization or disposal is handling. The fine particles in the ash are very susceptible to dusting. Wetting the ash to prevent dusting causes a high pH solution. Pelletization was investigated as a means of handling the ash.

V. LABORATORY TEST RESULTS

A. RCRA Extraction Results

Chemical analyses of extracts produced by the acetic acid and deionized water extraction procedures are presented in Tables 6 through 9. The deionized water sample of the ESC was the only sample to violate the 10 times Interim Primary Drinking Water Standards (IPDWS). Barium, lead, and arsenic appeared in elevated concentrations in the other samples. Since wood ash is highly variable in elemental concentration, these elevated toxic element concentrations toxic hazardous classification for some wood ash, if the 10 times IPDWS are used. If the 100 times IPDWS are used, wood ash may never be classified as a toxic hazardous waste.

All extracts from the ash are very alkaline. If the waste is disposed in a landfill the pH of the leachate would be very high. Land application of the waste might cause pH shock to the vegetation.

B. Pesticide Results

The results of the pesticide analysis of the extracts appear in Tables 6 through 8. The heptachlor appearing in the NE and SA extracts does not have extract levels controlled by RCRA, but is listed as a Select Priority Pollutant.^{2, 3} The legal impacts of disposal or utilization of the heptachlor contaminated ash are unclear at this writing.

To verify the pesticide contamination the NE ash was analyzed for pesticide by the acetonitrile extraction florisil column method.³²

The results of the pesticide analysis of the NE ash appears in Table 10. This analysis verified the presence of heptachlor and found lindane. Lindane has extract levels controlled by the regulations.^{2, 3} Since the lindane was not soluble in the acetic acid extract, the regulations on lindane are not applicable.

The impact of the pesticide residue in the ash on utilization and disposal is unclear. Further studies on pesticide residue in the ash may be necessary to determine the impact.

TABLE 6
PESTICIDE ANALYSIS OF NE ASH

Endrin	ND
Lindane	13 ppb
Heptachlor	1.67 ppb
Heptachlor epoxide	ND
Toxaphene	ND

TABLE 7

NORTHEASTERN MIXTURE (NE) ASH EXTRACTION DATA
PHYSICAL DESCRIPTION OF ASH - BLACK, GRITTY POWDER

	Acetic	Deionized Water	10 Times Interim Primary Drinking Water Standards mg/l
Sample Size g	100	100	
D.I. Water ml	1600	2000	
Initial pH	11.7	11.8	
0.5N Acetic Acid ml	400	0	
pH at 24 hours	8.4	11.8	
Total Soluble Carbon	---	12 mg/l	
Total Inorganic Carbon	---	5 mg/l	
Total Organic Carbon	---	7 mg/l	
Arsenic	0.058	Matrix Problems*	0.50
Barium	< 2	< 2	1.00
Cadmium	0.0025	< 0.001	0.10
Chromium	0.037	0.028	0.50
Lead	0.001	0.008	0.50
Mercury	NF	NF	0.020
Selenium	Matrix Problems*	Matrix Problems*	0.10
Silver	< 0.2	< 0.2	0.50
Endrin	NF		0.0020
Lindane	NF		0.0400
Methoxychlor	NF		1.00
Toxaphene	NF		0.050
2,4 D	NR		1.00
2,4,5-7P	NR		0.10
Heptachlor ppb	8.9		Priority Pollutant

*The highly ionic nature of these mixtures caused problems in analysis of these elements.
The EPA is working on modification of analysis.

NF = None Found

NR = Not Run

TABLE 8

SOUTHERN HARDWOOD (ESC) ASH EXTRACTION DATA
PHYSICAL DESCRIPTION OF ASH - BROWN, GRITTY POWDER

	Acetic	Deionized Water	10 Times Interim Primary Drinking Water Standards mg/l
Sample Size g	100	100	
D.I. water ml	1600	2000	
Initial pH	11.3	11.2	
0.5N Acetic Acid ml	400	0	
pH at 24 hours	9.15	11.75	
Total Soluble Carbon	----	320 mg/l	
Total Inorganic Carbon	----	165 mg/l	
Total Organic Carbon	----	155 mg/l	
Arsenic	< 0.010	0.045	0.5
Barium	< 0.2	< 0.2	10.0
Cadmium	< 0.001	< 0.001	1.0
Chromium	0.200	0.620	5.0
Lead	0.001	0.0038	5.0
Mercury	ND	ND	0.02
Selenium	Matrix Problems*	Matrix Problems*	0.1
Silver	< 0.2	< 0.2	0.5
Endrin	NF		0.002
Lindane	NF		0.04
Methoxychlor	NR		1.0
Toxaphene	NF		0.05
2, 4	NR		1.0
2, 4, 5-7P	NR		0.2
Heptachlor ppb	NF		Priority Pollutant

*The highly ionic nature of these mixtures caused problems in analysis of these elements.

NF = None Found

NR = Not Run

TABLE 9

SOUTHERN SOFTWOOD (SA) ASH EXTRACTION DATA
PHYSICAL DESCRIPTION OF ASH - BROWN, FINE POWDER

	Acetic	Deionized Water	10 Times Interim Primary Drinking Water Standards mg/l
Sample Size g	100	100	
D.I. water ml	1600	2000	
Initial pH	11.7	11.7	
0.5N Acetic Acid ml	400	0	
pH at 24 hours	11.2	11.8	
Total Soluble Carbon	----	3 mg/l	
Total Inorganic Carbon	----	3 mg/l	
Total Organic Carbon	----	0 mg/l	
Arsenic	< .001	< .001	0.05
Barium	2.0	4.0	10.0
Cadmium	0.0025	0.001	0.10
Chromium	0.230	0.068	0.3
Lead	0.0042	0.010	0.5
Mercury	NF	NF	.02
Selenium	Matrix Problems*	Matrix Problems*	0.1
Silver	< 0.2	< 0.2	0.5
Endrin	NF		.002
Lindane	NF		0.04
Methoxychlor	NR		0.1
Toxaphene	NF		0.05
2, 4 TD	NF		1.0
2, 4, 5-7P	NR		0.10
Heptachlor ppb	14.9		Priority Pollution

*The highly ionic nature of these mixtures caused problems in analysis of these elements.

NF = None Found

NR = Not Run

TABLE 10

PELLETIZED NORTHEASTERN MIXTURE (NE) ASH EXTRACTION DATA
 PHYSICAL DESCRIPTION - 6 X 16 MESH DARK
 GRAY PELLETS, BULK DENSITY OF 37 LBS./CU.FT.

Sample Size g	<u>Acetic</u>	<u>Deionized Water</u>	10 Times	
			Interim	Primary Drinking
D.I. Water ml	100	100	Water	Standards mg/l
Initial pH	1600	2000		
0.5N Acetic Acid ml	11.5	11.5		
pH at 24 hours	400			
Barium mg/l	7.2 ¹	11.5		10.0
Chromium mg/l	Matrix Problems	7.2		0.50
Cadmium	<0.02	<0.02		0.10
	<0.02	<0.02		0.10

¹The sample buffered at this pH after the addition of 50 ml of the acid.

C. X-Ray Diffraction Analysis

XRD was investigated as a compound analysis method for wood ash. Due to the amorphous structure of many of the compounds and interference from a variety of elements and compounds, the method was abandoned. Silica (SiO_2) was the only compound identified by this method.

D. X-Ray Fluorescence

XRF proved to be a useful tool in identifying the macro elements in wood ash. Since elements below sodium on the periodic table are not detected by XRD, the use of this as a quantitative tool is limited. For the elements above sodium the relative peak heights are proportional to their concentration. Figure 2 is a typical XRF scan of a fly ash sample. Remembering that this method does not detect concentrations less than 0.5%, note the high barium concentration.

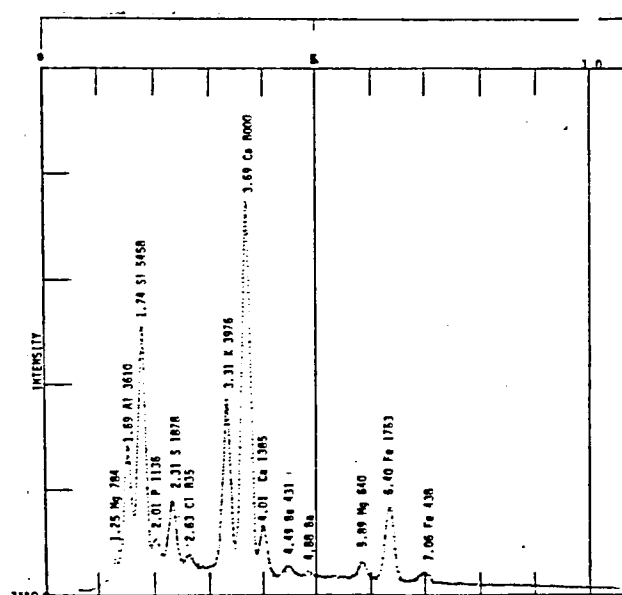


Figure 2 - Typical XRF Scan of Wood Ash.

E. Pelletization

Mars Mineral Company ran a series of pelletization studies on a sample of the NE ash. It was determined that a lignin liquor and water mixture was the best binder. To produce a fertilizer size pellet, the particles greater than a number 80 mesh sieve size were removed. The bottom ash contained approximately 70% (by weight) larger than the 80 mesh and 4% passing the 200 mesh sieve. The lignin liquor water mixture rate was approximately 50-50 by weight. The ash to binder ratio was 68-32 by weight. The process has not been studied for the optimum lignin-water mixture.

The samples were pelletized in a Mars DP-14 Agglo-Miser. The pellets air dried in 24 hours to a 7% moisture content and a bulk density of 37 lbs./cu.ft. Samples kept in the laboratory for six months still have their original structure and dusting has not become a problem.

The acetic acid extract of the pellets was buffered at pH 7.4. This buffering effect is valuable in agricultural applications where soil acidity is a problem. Unpelletized samples maintained high pH's during the acetic acid extraction.

A 50 MW wood fired power plant produces approximately 2 tons of ash per hour. A 2 ton per hour pelletizing machine has an initial capital cost of \$18,700.00. The unit comes with a five horsepower motor and requires approximately 320 pounds of lignin liquor per hour.

F. Settling Velocities

In areas where a market for pelletized wood ash might not be available or legal constraints make it impossible to use, extraction of the potassium might be a viable alternative. The early batch extractors were very labor intensive¹⁵, therefore a continuous flow extractor seemed to be the logical design. A design similar to Figure 3 was considered to be the most feasible design. The ash is rapidly mixed with recycle and makeup water and the insoluble portion settles to be removed to a filter drying bed or straight to the landfill. The K_2O is readily soluble up to a 50% concentration in the extractor. The potassium rich water is recycled at a rate necessary to maintain optimum operating conditions in the extractor. The excess potassium rich water is sent to an evaporator for concentration.

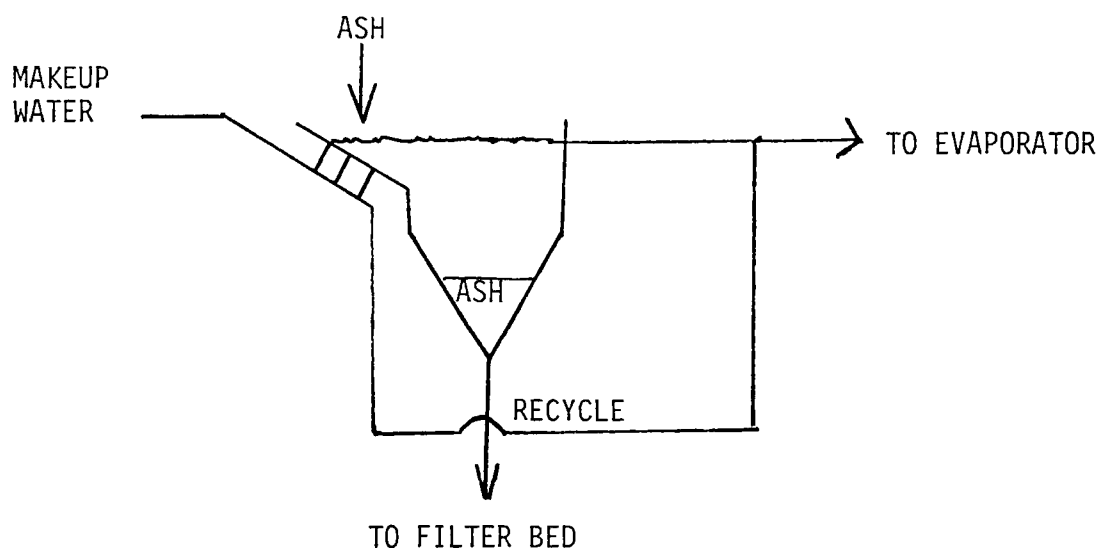


Figure 3 - Conceptual Design of Continuous Flow Potash Extractor

Settling velocity curves were run for fly and bottom ash at different potassium hydroxide concentrations to determine operating characteristics. Figure 4 is the settling curves of the bottom ash versus time at different potassium hydroxide concentrations. The bottom ash settled at rapid rates in the 6% and 15% solutions, but floated in the 30% potassium hydroxide solution. Figure 5 is the settling velocity curve of fly ash versus time in a 2% potassium hydroxide solution. At a 2% potassium hydroxide concentration the fly ash settled slowly into a low solids content sludge.

The settling curves suggest that the potassium might feasibly be extracted from the bottom ash, but not from the fly ash. The slow settling velocities of the fly ash at low potassium hydroxide concentrations and the low solids content sludge make this unattractive.

G. Potash Distribution

Since the large size particles could not be pelletized and the fly ash could not be feasibly extracted, a test was run on the potash content of the particle sizes greater than or less than 80 mesh. Table 11 shows the results of potassium solubility tests on various particle sizes of wood ash.

The bottom ash from the northern mixture greater than 80 mesh contains very little soluble K_2O and has little market value. In the boiler producing this ash, most of the potash appears in the fly ash.

The southern hardwood sample is bottom ash from a different boiler type. Not enough data is available to determine if the high concentration in the bottom ash is due to the difference in wood types, boiler types, or both.

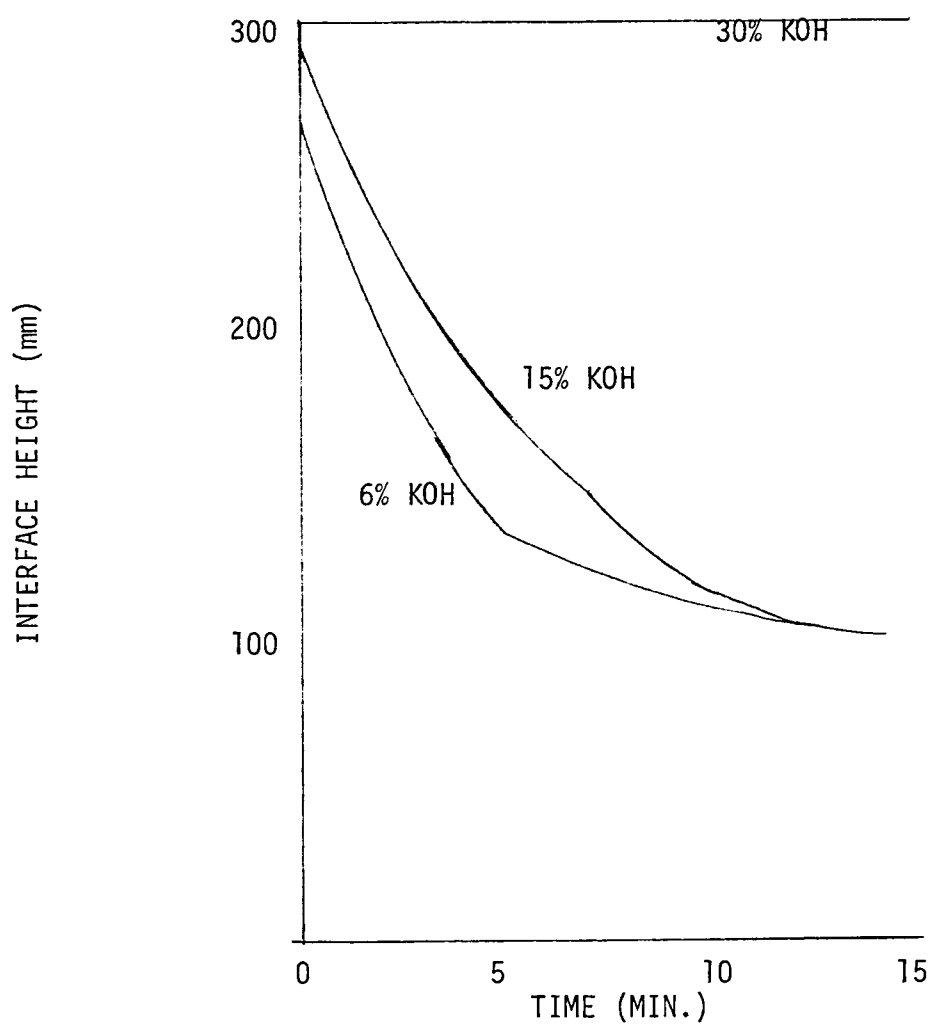


Figure 4 - Bottom Ash Settling Capacities at Different Potassium Hydroxide Concentrations

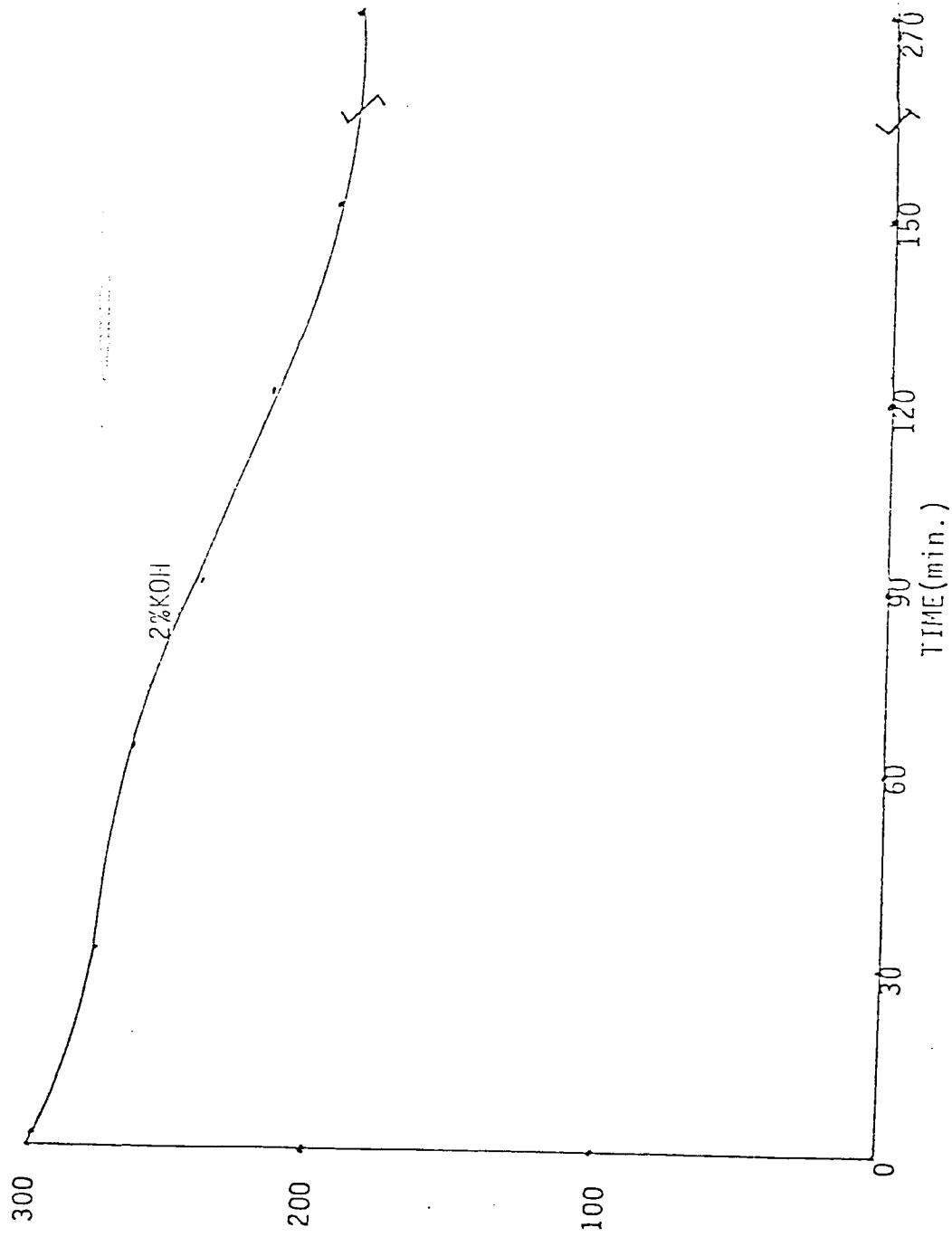


Figure 5 - Fly Ash Settling Curve at Two Percent Potassium Hydroxide Concentration

TABLE 11
SOLUBLE K_2O OF WOOD ASH SAMPLES

	% Readily Soluble K_2O
Northern Mixture	
Fly Ash	3.2
Bottom Ash > 80 Mesh	0.2
Bottom Ash < 80 Mesh	1.2
Pelletized Fly and Bottom Ash < 80 Mesh	2.3
Southern Hardwood	7.5

VI. BURLINGTON VERMONT ELECTRIC DEPARTMENT WOOD FIRED POWER PLANT: RCRA IMPACT CASE STUDY

A. Introduction

From September 4-7, 1979 the Burlington Electric Department, Moran Generating Station and the site of the proposed Joseph C. McNeill Generating Station were visited and interviews were conducted with the parties involved to determine the impacts of RCRA on this plant and to help infer impacts on other wood fired power plants.

B. The Generating Stations

The Burlington Vermont Electric Department (BED) is now generating approximately 16 MW from wood or a mixture of wood and oil or natural gas at their 25 year old Moral Plant. The plant is built on Lake Champlain in the city limits of Burlington. BED is municipally owned and prides itself in generating the least expensive electricity in New England. Ashes being generated by the Moral Plant are presently being dumped in the Burlington Municipal Landfill. The landfill is located near the Winooski River, but above the 100 year flood line.

BED purchased a parcel of land within the city limits of Burlington to build the proposed 50 MW McNeil Generating Station. The site is on the floodplain of the Winooski River but not in the floodway.³³ The site is adjacent to the municipal landfill and the Central Vermont Railroad. Plans call for the plant to be built on an elevation of 115 feet which will require placing of approximately 10 feet of fill.³³

C. Interviews

Mr. Thomas Carr, Generating Superintendant of BED and the BED employee most active in the permitting procedures, was interviewed on September 5, 1979. Mr. Carr explained that the people of Burlington had voted by a 71% majority to build the wood fired McNeil Station. Mr. Carr felt that the plant could offer a much needed market for cull wood in that area and in the long run improve the quality of local forests. He explained that the original plans called for the 16,000 to 19,000 tons of wood ash produced annually by the proposed plant to be dumped in the municipal landfill similar to what is presently being followed by the Moran Station. The Vermont Agency for Environmental Conservation (VAEC) has ruled this unacceptable for the new plant.

Present plans call for disposal ponds constructed on the western boundary of the plant. VAEC guidelines require "a vertical separation distance between the bottom of the landfill (lowest elevation) and the seasonal high groundwater table of at least ten feet of suitable base soil."⁴ "Suitable base soils contain at least 40% (by weight) passing the 270 sieve. In addition, the coefficient of permeability of the base soil should be greater than 10^{-5} cm./sec., as determined by field testing."⁴ The present disposal site has a seasonal groundwater high of only 3 feet below ground surface.³³ This would require between 7 and 10 feet of fill.

The guidelines issued by VAEC require that "no portion of a landfill shall be below the '100 year flood plain elevation.'"⁴ The bottom of the landfill will be near or below the 100 year flood level.

Clay berms will surround the ponds and protect them from the 100 year flood. VAEC is considering the proposal. Mr. Carr was concerned that there is no easy answer to their problem. VAEC is taking the stand that BED is to submit proposals until VAEC is satisfied with one. Mr. Carr wants VAEC to define what they would accept and BED would proceed to comply.

Andre J. Rouleau, Alan J. Fillip, and Cedric R. Sanborn of VAEC were interviewed on September 5, 1979 to obtain reasoning for the ban on wood ash in the municipal landfill. They were concerned that there is no information on the leachate from a mixture of wood ash and municipal waste and that long term problems could exist from heavy metals found in wood ash. The proposed RCRA 3001 testing procedures² are presently being conducted by BED's consultants and BAEC's laboratories. When asked what the chances are of VAEC disallowing the proposed on-site ash disposal for the new plant, Rouleau, Fillip and Sanborn set the odds at 50/50 and stated that a proper landfill on the site selected by BED would probably run from \$500,000 to \$1,000,000 or more to construct. They were aware of the floodplain and stated that the proof of no environmental harm was the responsibility of BED and their consultant Charles T. Main (CTM) of Boston.

The possibility of using the ash as a soil amendment was discussed with Rouleau, Fillip, and Sanborn. They were of the opinion that this usage would be acceptable if dust was controlled, applications did not risk pH shock in a stream, and the ashes were applied in an agriculturally acceptable manner. Rouleau stated that he used the ash from his wood stove in his garden.

Sanborn has applied for a three-part EPA grant to study the wood ash-municipal waste leachate from the Burlington Municipal Landfill, study the leachate from a wood ash only landfill, and study the effects of land application.

A November 16, 1979 newspaper article reports that the Agricultural Stabilization and Conservation Service in Gilman, Vermont has started a fifty percent cost of application subsidy for any farmer that will use wood ash as a fertilizer for field corn.³⁴ The article was furnished by Andre Rouleau of VAEC.

Dr. Richard Bartlett of the University of Vermont Department of Plant and Soil Science was interviewed on September 5, 1979 to determine the potential for usage of wood ash as a soil amendment. Dr. Bartlett found a mean P_2O_5 content of 3%, K_2O of 8% and MgO of 4%, plus calcium and many micronutrients. Dr. Bartlett said the wood ashes should be returned to the soil. He suggested the ashes be pelletized and sold or given away. He felt an initial advertising campaign would be necessary to develop a market, then the product would probably sell on its own merits.

Mr. Robert Weatherby, Director of Regulatory Services, College of Agriculture, University of Vermont, was interviewed on September 6, 1979 to obtain any legal constraints imposed on the commercial sale of wood ash. Mr. Weatherby felt that wood ash could not be sold as a fertilizer due to its variability, since a minimum analysis of nutrient content must be guaranteed in fertilizers. He stated that many states have adopted the Uniform Soil Amendment Bill³⁵ which would allow for more freedom in distribution of wood ashes in a commercial venture. Vermont has yet to adopt this bill, but Mr. Weatherby expects

them to in the near future. Mr. Weatherby knew of no readily available source of information on the quantity of the fertilizer elements in wood ash that could be used in a 40 mile radius of Burlington.

D. Analysis of Interviews

If the Burlington plant is an indication of the impact of RCRA on wood fired power plants, than the impact on this energy source will be far-reaching. Vermont's regulations⁴ are stringent on waste disposal in general. Vermont's regulations⁴ are similar to the "Criteria for Classification of Solid Waste Disposal Facilities and Practices"³⁶ authorized under section 4004 of RCRA¹. Even if wood ash is not hazardous, a secure landfill will be required.

Wood fired power plants will usually be 50 MW or less. The cost of site selection and ash disposal may be disproportionately higher for smaller units wood fired than larger coal fired plants. In the case of the Burlington plant, RCRA has erased a major reason for the site selection (nearness to municipal landfill) and may make ash disposal unacceptable at the proposed site.

VII. SUMMARY

From the literature review and laboratory analysis it was determined that wood ash is highly variable in both micro and macro elements. The macro elements, especially calcium, potassium, phosphorus, and magnesium, have potential for use as nutrients in agriculture. The micro elements controlled by RCRA create a potential for hazardous waste classification. While the samples analyzed by the acetic acid extraction^{2, 3} were not toxic (hazardous), the elevated extract levels of some of the elements suggest possible toxic classification if the 10 times IPDWS are used. One sample analyzed by the deionized water extract was found to have a toxic classification if the 10 times IPDWS are used. Neither method has consistently higher toxic metals concentration. The interim final regulations with the 100 times IPDWS may not cause this waste to be classified as toxic (hazardous). Hazardous or not, wood ash from major sources will be disposed in a secure landfill if disposal is the option chosen.

The potential for utilization is site specific and operation specific. In agricultural areas with acidic soil, pelletized wood could be used to neutralize the acidity and furnish significant quantities of essential nutrients. Areas with alkaline soil or non-agricultural areas would be candidates for potash or mineral extraction.

Careful planning in the plant design and site selection could turn the ash into a resource. Improper planning can create problems with utilization or disposal and increase the cost of building and operating the plant.

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The Conclusions of this study are:

1. Some heavy metals in wood ash are extractable by the RCRA extraction procedure in the range of the 10 times Interim Primary Drinking Water Standards.
2. There is no predictable difference in the acetic acid extraction and deionized water extraction of wood ash.
3. The ash fraction smaller than an 80 mesh can easily be pelletized into fertilizer size pellets for easier handling.
4. Combustion did not completely destroy the pesticide residue present in wood.

B. Recommendations for Further Research

The results of this study indicate the need for further research in the following areas:

1. Land application of wood ash should be studied for plant yield improvement and metal accumulation in plant, soil, and groundwater.
2. The possibility of using a landfill with leachate collection as a giant batch extractor should be evaluated. In areas where the ash is not marketable the landfill leachate could be collected and waste heat used to concentrate the potash.

3. The effect of the high pH leachate from wood ash landfills on the soil and groundwaters should be further studied.
4. The effect of disposal of wood ash with municipal garbage should be evaluated for metals, organics, and effect upon microorganisms.

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VITA

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