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SORBATE CHARACTERISTICS OF FLY ASH

Final Report

By
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August 1983

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New Jersey Institute of Technology
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SORBATE CHARACTERISTICS OF FLY ASH

FINAL REPORT

VOLUME I

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Submitted by

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ABSTRACT

The objective of this investigation is to correlate the sorbate and leaching characteristics of fly ash with coal properties and monitored combustion conditions in order to design a system for the inexpensive treatment of industrial wastes and leachate from industrial landfills using mixtures of fly ash as inexpensive sorbents. Such a low-cost treatment system could also treat ash pond effluent for water reuse by powerplants as cooling tower makeup.

Twelve unblended coals from 10 different mines were burned under monitored conditions in three different types of coal fired boilers in order to determine the influence of coal composition, ash fusion temperatures, boiler additives, combustion conditions and co-firing of natural gas or oil with the coal, on the leaching and sorbate characteristics of the fly ash produced. This included the determination of 1) SiO_2 , Al_2O_3 , Fe_2O_3 , CaO , K_2O , Na_2O , MgO , sulfur, ash fusion temperatures Ti, Cd, Sn, Ni, Pb, Mo, Cu, Cr, n, Mn, Ba and V in the coals and their respective fly ashes and bottom ashes, 2) Mössbauer spectra of a number of coals and their fly ashes, and, 3) surface analysis of the fly ashes using ESCA. The leaching exhibited by the fly ashes with regard to pH, Cd, B, Sn, Ni, Pb, Mo, Cu, Cr, Mn and Fe was examined. In addition, the removal of Cd, B, Sn, Ni, Pb, Mo, Cu, Cr, Fe, As and organics by fly ash was evaluated, using from actual ash pond samples to model realistic inlet concentrations.

The results show that fly ash can be used for the treatment of Cadmium, Boron, Tin, Molybdenum, Nickel, Lead, Copper, Chromium, Zinc, Manganese, Iron, Arsenic and organics in actual ash pond effluents. Removals of greater than

75 percent were achieved for all of the above elements with the exception of Boron and Molybdenum. Boron and Molybdenum removals of only 21% and 43% were achieved. The fly ashes were capable of reducing the concentrations of Cadmium, Lead, Copper, Chromium, Zinc, Manganese, Arsenic and Iron to concentration below the maximum allowable concentrations set for these elements under the National Interim Primary and Secondary Drinking Water Regulations. These drinking water regulations are used in this study as a benchmark. Under the Federal RCRA regulations, a material is considered non-hazardous if its concentration (in a specific EPA test procedure) does not exceed one hundred times (100x) the concentration specified for any element in the drinking water regulations.

The general sorbate characteristics of the fly ashes are favored by low fly ash fusion temperatures, combustion temperatures that favor the fusion of the fly ash during formation and the time that the fly ashes remain in the fused state. No correlation could be established between the sorbate characteristic of the fly ashes and their bulk major, minor and trace elemental compositions nor with their major and minor elemental surface compositions. Also, no correlation could be established between the treatment achieved with the fly ashes and particle size of the fly ash particles. Only the carbon content of the fly ash could be related to its organic removal properties.

The sorbate capacities of the fly ashes, identified in this investigation to provide the best treatment, average about 80 ug/gm for the Cadmium, Copper and Zinc, 3.4 ug/gm for Arsenic and 700 ug/gm for the organics. However, the sorbate capacity for Arsenic may be increased with further washing of the fly ashes.

These capacities were found to be independent of pH in the range from about 6 to 10. Also, the removals of Cadmium, Copper, Lead and Zinc were observed to be independent of their inlet concentrations in the ranges from 0.52 mg/l to 2.0 mg/l, 0.52 mg/l to 3.5 mg/l, 0.30 mg/l to 3.0 mg/l and 0.56 mg/l to 4.0 mg/l, respectively.

Greater than 75 percent removals of the Cadmium, Copper and Zinc present in the water samples were achieved within a 15 minute contact time between the fly ash and the sample.

The leaching results indicate that the leachable elements are contained to some extent within a water soluble component. The leachable amounts of each element can be in general related to 1) the amount of this element present in the fly ash provided that a major portion of the element is located at the surface, 2) the surface area of the fly ash particles and 3) the boiler temperatures encountered by the fly ashes during their formation. The smaller fly ash particles exhibited the greatest amount of leaching. Also, the fly ashes produced at lower boiler temperatures leached the greatest quantities of each of the above elements. High boiler temperatures apparently lead to some fixation of the above elements in the non-leachable portion of the fly ash particle. Appropriate treatment of the leachate with the fly ash (from which it originally leached) can result in the sorption of all the leached materials with remaining sorbate capacity to remove even more of these materials.

Interpretation of the Mössbauer spectra of the coals and their respective fly ashes reveal that 1) the forms of iron in the coal may influence its ash fusion temperatures, 2) the forms of iron in the fly ashes is indicative of the degree of fusion that has occurred and 3) the forms of iron

in the fly ashes reflect the combustion conditions encountered in the boiler by the fly ash during its formation.

The fixation of iron at high boiler temperature was followed using Mössbauer spectroscopy. Mössbauer spectroscopy was not able to provide a sensitive probe for small changes in boiler operating parameters under the conditions used in this study. However, this technique did provide an excellent general probe for the local environment of the iron in the coal ash. It was determined that at all boiler conditions used in this study there was substantial incorporation of iron into the alumina-silica matrix of the coal ash even for boilers operating well below the initial deformation temperature of the coal used in the boiler. The fly ash from the boilers operating at higher temperature contain more iron incorporated in the alumina-silica lattice. The iron incorporated in the alumina-silicate lattice ranged from very little incorporation when coal was ashed at 1080°F to very significant incorporation for the conditions encountered in a wet bottom boiler. There was complete incorporation of the iron in the slag collected from the wet bottom boiler. The incorporation of iron in the alumina-silica lattice was not total for the fly ash even in a boiler where the boiler flame temperature was much greater than the fluid temperature of the coal being burned. It is believed that a similar incorporation of other metal oxides in the ash is responsible for a significant reduction in their leaching characteristics.

INTRODUCTION

Increased reliance on coal combustion as an energy source can lead to significant waste management problems related to storage or disposal of fly ash generated as a result of this combustion. The identification of a large-scale and economically advantageous use for the large quantities of fly ash generated (typically thousands of tons per day per boiler for large utility units) would obviously be desirable. Such fly ash, where now collected directly from the ash hopper, is used for construction purposes (e.g. fill, concrete) (1) as well as cover material for landfill, and thus commands a low price. If it could be used to replace higher cost sorbents (e.g. ion-exchange resins, activated charcoal) in wastewater treatment, its economic value would be increased. Use of fly ash to treat ash pond effluent could also allow the recycling of the pond water within the plant to provide a closed loop system.

One application using sorbent properties of fly ashes can be the inexpensive treatment of leachate generated from industrial waste in landfills. Tens of millions of tons of hazardous wastes are produced annually from industrial processes and from air and water pollution control activities in this country. To date, most of the industrial waste has been disposed of in secure landfills. However, most of these landfills will leak eventually, and the leachate will cause contamination of ground and surface waters. The use of waste products, such as fly ash, to serve as sorbents for the heavy metals, toxic anions, and organic substances commonly found in such leachates, can provide an inexpensive treatment of the leachate originating from landfills.

Another use of fly ash can be the treatment of ash pond effluent for

reuse as cooling tower makeup. Fly ash has been shown by a number of investigators (2, 3, 4, 5) to leach boron, fluoride, molybdenum, selenium, arsenic, cadmium, chromium, copper, zinc, iron, mercury and nickel under batch conditions where a specific quantity of fly ash is mixed with a given volume of water at different pH's. Since the presence of trace quantities of cations and anions in ash pond water may inhibit the reuse of this water by the utility, the availability of inexpensive treatment of the cations and anions can encourage utilities to recycle this water.

In 1974, it was estimated that capital expenses alone for a conventional treatment system would be approximately \$100,000.⁽⁶⁾ Here, the general approach is to treat such cations as zinc, copper, nickel, lead, cadmium, etc. in the ash pond water by the addition of lime to the fly ash. This treatment however results in alkaline conditions which can significantly increase the solubilization of such anions as arsenic and fluoride which may be present in the ash pond water.^(5, 7)

For the past several years, an interdisciplinary team of faculty members at New Jersey Institute of Technology has been developing, under EPA Grants R803-717-01 and R803-717-02, a method for the treatment of leachates from industrial sludges disposed of in landfills. We have established, on both the laboratory and pilot scale that the use of fly ash in combination with clay minerals provides an inexpensive, effective treatment of leachates from industrial sludges disposed of in landfills. These fly ash-clay combinations were also found (under EPA Grant R805-666-010) to be an inexpensive means for the removal of heavy metals and toxic anions such as fluoride, cyanide, etc. from industrial waste stream effluents. Also, the combinations may be used for land reclamation since the spent sorbents retain the sorbed pollutants in the presence of rainwater.

During these investigations in the use of fly ash as a sorbent for waste treatment processes, two types of fly ash were repeatedly collected from the same electrostatic precipitator at a coal-burning boiler of an east coast U.S. electric utility at different times. These fly ashes exhibited different leaching and sorbent characteristics. Analysis of the leachate produced by mixing the fly ash with water in the weight ratios of 1:2.5 for 24 hours on Burrell Shaker which was found to provide a saturated leachate, revealed that one type of fly ash produced an acidic leachate and the other a basic leachate. The acidic leachate contained greater concentrations of the cations and anions than the basic leachate. However, when these two different fly ashes are placed in lysimeters (shown in Figure 1), and water is passed through the fly ash, leaching of the cations and anions occurs initially, but soon ceases as the pH of the effluent from the lysimeters approaches 7. In fact, when a neutral pH industrial sludge leachate which contained the same cations and anions found in the fly ash leachate passed through the lysimeters containing these fly ashes, the initial leaching of cations and anions is again observed until the effluent from the lysimeters approaches the neutral influent pH. Then, the cations and anions which were initially leached from the fly ash, are actually removed in greater quantities from the leachate by these same fly ash samples than was initially leached from the fly ash.⁽⁷⁾ For example, the fly ash whose effluent from the lysimeter was initially acidic exhibited leaching of copper and zinc that amounted to 0.69 micrograms of copper per gram of fly ash and 0.32 micrograms of zinc per gram of fly ash. When the leachate from the lysimeters approaches neutral pH, the leaching ceased and both the copper and zinc were removed from the neutral pH industrial sludge leachate. ⁽⁷⁾ The concentrations

Figure 1 Laboratory Arrangement of Lysimeters

of the copper and zinc were reduced from about 2.5 mg/l and 0.4 mg/l, respectively down to about 0.01 mg/l.⁽⁷⁾ The fly ash exhibited net removals, when the initial leaching is subtracted from the total removed, of 1.4 micrograms of copper removed per gram of fly ash and 1.7 micrograms of zinc removed per gram of fly ash.⁽⁷⁾ Remarkably, the fly ash which produced the initial acidic effluent and exhibited the greater initial leaching of cations and anions proved in general to be a better sorbent for the removal of the cations and anions in the neutral pH industrial sludge leachates than the fly ash which initially produced a basic effluent. However, a mixture of both types of fly ashes was required in the same lysimeter to effectively treat this neutral pH industrial sludge leachate since each fly ash exhibits different sorbent characteristics.

The above discussion indicates that inexpensive waste management technology can be developed for the environmentally safe operation of landfills or to improve the treatment and the reuse of the effluent from power plant ash ponds, provided that there is an adequate supply of the fly ashes with desired sorbent characteristics.

The development of this treatment technology would require 1) regulating the amount of the fly ashes with different sorbent characteristics that are mixed together; 2) possible pH adjustment of the collected leachate; and, 3) a treatment system that will allow the fly ash mixtures to be brought in contact with the leachate or effluent for specific lengths of time.

The development of this technology necessitates that we know the parameters during the generation of fly ash that influence the leaching of pollutants from fly ashes and when fly ash with desired sorbent characteristics will be produced by the utilities from their coal fired boilers.

The knowledge of the composition of the leachate generated by a specific fly ash can better define the sorbate characteristics required for treatment of the leachate. This information will insure that adequate supplies of the fly ashes with different sorbent characteristics will be available. However, the processes that control the leaching and sorbate characteristics of the fly ashes during the combustion of coal are not well understood at this time. Therefore, this investigation involving both New Jersey Institute of Technology and Public Service Electric and Gas Company was undertaken to identify those parameters which control the leaching and sorbent characteristics of the fly ash.

Arrangements were made for this investigation to have coal delivered directly to the test generating units from eight eastern U.S. sources so that the leaching and sorbate characteristics of fly ash produced by these coals could be related to the specific coal composition. Normal generating station practice is to mix coal from different shipments on the coal pile, which would have complicated this study. The sources were selected for this study because they could provide the generating stations with sufficient quantities of coal to carry out the combination of coal at minimum, intermediate and maximum load levels. In addition, the fly ash produced in the two other eastern U.S. facilities which primarily utilized coal mined on-site was also investigated.

The influence of four different types of coal fired boilers, one dry bottom (Boiler A) and one wet bottom (Boiler B) burning low sulfur coal, and two dry bottom, mine-mouth units burning high sulfur coal (Boilers C and D) on the leaching and sorbate characteristics of the fly ashes was investigated. During the sampling of the coal and their respective ashes, the temperature profile and the flame temperature in the boilers, the coal feed rate, and supplemental fuel feed rate (when used), the boiler additive feed rate, and

percent of capacity of air flow through the boiler were monitored.

Analysis of the major, minor, and trace elements in the coals and their respective ashes, surface analysis and Mössbauer analysis of the iron compounds in the fly ashes as well as the concentration of the trace elements including iron present in the leachate were carried out. The leachate was generated by passing water through the fly ashes in lysimeters. The removal of different concentrations of trace elements, iron, arsenic and organics in actual ash pond samples by different fly ashes were evaluated. Actual ash pond water rather than the leachate generated from each fly ash was used because the composition of the ash pond water is defined by a mixture of many fly ashes collected over a period of time and cannot be simulated by the leachate generated from one or several fly ashes. Also, the sorptive capacity of selected fly ashes for specific cations, anions and organics present in actual ash pond samples was determined over a range of pH's and influent concentration. The contact time required between the fly ash and the water sample to achieve maximum removal of specific cations was also determined.

The oxidation states of the iron compounds in the fly ash were examined because they may influence the leaching and sorbent characteristics of the fly ash. Oxides of iron in natural clay minerals were reported to be effective in the removal and retardation of As, Cd, Cr, Ca, Hg, Ni, Pb, Sr, V and Zn which are encountered in leachates from solid waste landfill sites.⁽⁹⁾ Also, the surrounding environment of the elements in the fly ashes were investigated to determine whether the leaching of these elements are influenced by their environment in the fly ash. This information could be of use in identifying the factors which may influence the leaching of materials from the ash since the fusion of ash in the boiler could lead to encapsulation

or fixation of many of the elements present in the coal ash.

Mössbauer spectroscopy was used to identify the state of iron in the original coal and the ash as a function of boiler type and conditions.

The changes in the state of iron oxide in the ash was used as a model to indicate the environment of the other elemental oxides in the ash.

EXPERIMENTAL

Boiler Type

Three different types of coal fired boilers were utilized for this study. These boilers were operated when power demand permitted at full, intermediate and minimum power output following planned test procedures to produce the fly ash being investigated. The test procedure for one coal fired boiler (Boiler A) is enclosed (see appendicies). It is representative of that which was followed during the test burns at the Boiler B. Coal fired Boilers A and B differ in that the Boiler A is designed to have flame being below the fluid temperature of the coal ash (dry bottom, 2600°F), while the Boiler B is designed to have a flame being higher than the fluid temperature of the coal ash (wet bottom). Boilers C and D are both tangentially fired boilers that burn coals mined on site with ash fusion characteristics that allow for dry removal.

Coal Sources

Coal from eight mines located in Pennsylvania, West Virginia and Virginia (see Table 1) were delivered directly unblended to coal fired Boilers A and B. Included in this list is a Blend whose source is unknown. Two separate deliveries of Wellmore Cactus coal were made to the Boiler B at different times. The coal from these mines for the Boilers A and B were selected for this study because they could provide the boilers with sufficient quantities of coal to carry out the planned test burns. Coal for the Boilers C and D are in general mined on site.

TABLE 1

COAL BURNED UNDER TEST CONDITIONS

<u>Mine</u>	<u>Location</u>
<u>High Fusion Coal</u>	
Militant	Pennsylvania
Deep Hollow	West Virginia
Upshur	West Virginia
Badger	West Virginia
Mine Mouth C	Pennsylvania
Mine Mouth D	Pennsylvania
<u>Low Fusion Coal</u>	
Wellmore Cactus	Virginia
Wellmore Ackiss	Virginia
Ellsworth	Pennsylvania
Nora	Pennsylvania
Blend	Not Known

Monitoring of Boiler Conditions and Collection of Samples for Analysis

According to test procedures outlined in the appendicies, the temperature profile encountered in the boilers along with the coal, natural gas, and oil feed rates when co-fired, or relative power outputs when the coal feed rate is unavailable, boiler additive feed rates, percent excess air, ambient air temperature and barometric pressure were monitored during the generation of maximum, intermediate and minimum power (see Table 2). The limited results on the boiler temperatures monitored during the combustion of the Deep Hollow and Militant coals at the Boiler A generating station was due to the fact that our water cooled thermocouple probes were unavailable because they were being modified during the time these samples were collected to fit the access ports in the boilers.

All temperatures were measured just prior to and after the collection of the coal samples and their respective fly ashes since it was physically impractical to collect the samples and measure the temperatures at the same times. In all cases, the temperatures remained essentially constant. An optical pyrometer was used to measure flame temperatures and water cooled jacketed thermocouples were used to monitor the boiler temperatures. The wall effects on the temperature measurements were minimized by insertion of the thermocouple into the boiler until temperature remained constant with distance upon further insertion of the thermocouple into the boiler.

During the combustion of the test coal, coal samples are collected at the entrance to each pulverizer that was in operation. The collection of fly ash and bottom ash samples are timed to correspond to the coal being burned. Different size distributions of the fly ash were obtained by the collection of samples from both the front and back row of electrostatic precipitator hoppers. Bottom ash samples could only be collected at the Boiler B and Boiler C generation station. The bottom ash from the Boiler A Station was not collected because direct access to the bottom ash produced from a given coal that is being sampled and burned was unavailable.

TABLE 2

Upper Reading Conditions of Coal Fired Boilers

Boiler A Generation Station						Additive Feed Rate		Boiler Temperature (F)			
Coal	Coal (TPH)	Oil %	Gas (MCF)	Pressure (MM/S)	Excess O ₂ %	LPH-40 Gal/hr	CTRL M Lbs/hr	Power	Flame	Above Basket	Super Heater
Militant	110	0	2900	30.8	5.4	18	25	full	-	-	-
Militant	108	0	400	30.5	8.0	18	25	min.	-	-	-
Militant	102	0	1125	30.5	6.6	18	25	int.	-	-	-
Militant	110	0	3145	30.5	3.9	17.5	25	full	-	-	-
Deep Hollow	140	32	0	29.65	5.4	14	25	full	-	-	-
Deep Hollow	114	0	0	29.65	8.0	14	25	low	-	1450	-
Deep Hollow	142	0	0	29.65	6.8	16	20	int.	-	1550	-
Upshur	198	0	0	29.8	4.7	18	0	full	2470	1590	1565
Badger	188	0	0	29.3	3.1	18	25	full	2550	1750	1440

Boiler B Generation Station				Additives Feed Rates		#11 Boiler Temp.			#12 Reheater Temp.		
Coal	Relative Power output %	Pressure (mmHg)	% Excess O ₂	LPA-40 gal/hr	Control M lbs/hr	Flame	Above Flame	Arch	Flame	Above Basket	Arch
Wellmore Cactus #1	89	-	3.8	32	0	3150	1620	2080	3150	1530	1480
Wellmore Cactus #2	100	27.8	3.3	28	0	3125	1400	1680	2970	1400	1320
Blend	95	27.8	3.4	28	0	3100	1815	2250	3100	1737	1835
Ellsworth	98	27.7	3.5	0	0	3100	1815	2240	3100	1740	1820
Wellmore	94	27.8		16	0	3050	1900	2180	2950	1725	1500
Ackiss	50	27.8	5.0	16	0	2870	1590	1780	2950	1620	1500
Nora	97	-	3.5	28	0	3100	1850	2175	3250	1700	1700

Boiler C and Boiler D Generation Station						Additive Feed Rate		Boiler Temperature			
Coal	Coal (TPH)	Pressure (mmHg)	% Excess O ₂	LPA-40 gal/hr	Control M lbs/hr	Power	Flame	Above Flame Basket	Arch		
Boiler C	313	-	4.2	0	0	full	-	2600	-		
Boiler D	303	-	4.7	0	0	full	2650	2700	2700		

The Boiler B fly ashes were collected from the two electrostatic precipitators which are located in parallel and simultaneously treat the emission from the #11 and #12 boilers which simultaneously burn the same coal. The flue gas from each boiler is fed through parallel ducts to opposite sides of the designated #11 and #12 precipitators for fly ash removal. Twenty percent of the flue gas from both boilers is fed to the #11 precipitator and 80 percent to the #12 precipitator. Collection of the fly ashes from the #11 and #12 precipitation hoppers diagonally opposite one another beneath the separate ducts permitted the fly ash from the #11 and #12 boilers to be sampled.

ANALYSIS OF SAMPLES

Coal

The coal samples were analyzed for %C, %S, %SiO₂, %Al₂O₃, %Fe₂O₃, %CaO, %K₂O, %Na₂O, %MgO, %TiO₂, and ppm of Cd, Cu, Cr, Pb, Zn, Sn, Ni and Mn, ash content, sulfur and ash fusion temperatures according to ASTM Methods. The ash fusion temperatures were measured to determine how the leaching and sorbent characteristics of the fly ash particles are influenced by their being either in the fluid or solid state in the Boiler A and Boiler B, respectively. The Boiler B which is a wet bottom type requires that the ash be in the fluid state whereas the Boiler A which is a dry bottom type requires that the ash remains in a solid state. The chemical forms of iron present in the coal was identified by Mössbauer spectroscopy. The digestion and proper analytical procedures for these analysis was established by first analyzing a standard test coal NBS-1632A obtained from the Bureau of Standards.

Fly Ash and Bottom Ash Samples

The fly ash and bottom ash samples have been analyzed for the same above elements as found in the ashes coal samples. The results of these analysis are compared to the surface composition of the fly ash as measured by ESCA to

determine if there is a preferential concentration of specific elements at the surface of the fly ash particle which could influence its sorbent characteristics. Also, a comparison is being made of the iron compounds as indicated by Mossbauer because the oxides of iron in natural clay minerals have been reported (1, 2) to be involved in the removal and retardation of As, Cd, Cr, Cu, Hg, Ni, Pb, Sr, V and Zn, which are encountered in leachate from solid waste landfill sites and ash pond leachate.

Mossbauer Analysis

The ^{57}Fe Mossbauer spectroscopy results were obtained using an Austin Scientific associates Model 702 Mossbauer drive operating in the flyback mode. The Mossbauer source was ^{57}Co in rhodium from Amersham. A Marquart's method for a nonlinear least square fit was used to calculate the position of the individual line. A Lorentzian line shape was assumed.

Surface Analysis

The surface composition data was obtained using a Varian I.E.F. spectrometer operating at around 1×10^{-6} torr. The powder samples were mounted on the probe using two sided tape. The relative compositions were calculated using Weingle's photoelectric cross sections as a measure of relative intensities.

Batch Studies

In order to determine the sorbent capacity of the fly ash samples for specific elements at different pH's batch reactor studies were utilized. Each fly ash sample was placed in a polypropylene Erlenmeyer bottle and mixed with fly ash pond effluent in certain planned mix-ratios. These bottles were sealed and agitated in the shaker for two hours at ambient temperature. At the end of this time, the mixture was filtered through a glass fiber filter and filtrate was then analyzed.

Lysimeter Studies

In order to simulate actual field conditions, lysimeters were used to evaluate the leaching and removal of Cd, B, Sn, Ni, Pb, Mo, Cu, Cr, Zn, Mn, Fe, COD and As using 500 grams of fly ash under continuous flow conditions.

Laboratory lysimeters were constructed of plexiglass tubing (6.2 cm i.d.; 0.6 cm wall thickness; 90 cm length), supported in a vertical position. The arrangement of these lysimeters is shown in Figure 1. A 164 micron pore size corundum disc (6.10 cm diameter; 0.6 cm thickness) was placed in each column directly over the drain hole in order to support the fly ash sorbent and to prevent clogging of the outlet.

The leaching characteristics of the fly ashes generated under the various combustion conditions were evaluated as to the extent that each fly ash leaches Cd, B, Sn, Ni, Pb, Mo, Cu, Cr, Zn, Mn and Fe. Deionized water was added to the lysimeters containing 500 grams of the fly ash and specific volumes of effluent leachate were collected and analyzed for the above elements until 4 liters of effluent was passed through each ash sample. It was observed that 500 grams of fly ash generally ceases to leach after 4 liters of water was passed through the fly ash.

The packed columns were then slowly wetted with ash pond effluent collected in 55 gallon drums from an actual ash pond to allow total saturation and to force all the air trapped in the voids out of the column packing. The column was then filled with ash pond effluent to the level of an overflowing drain, in order to permit a constant head condition. The ash pond effluent was fed to the top of the column through a valved manifold which distributed the effluent to all lysimeters, simultaneously, from a central reservoir. The central reservoir, a 100 liter polyethylene carbon, delivered the ash pond effluent to the manifold system by means of a gravity siphon feed arrangement. Any overflow from the constant

head drains was collected and pumped back to the central reservoir. All tubing in the system was made of Tygon tubing (3/8" i.d.). A constant hydraulic head was maintained in the lysimeters at all times and the volumes of effluent passing through the columns was continuously monitored. Samples of treated ash pond effluent were collected at intervals and analyzed to determine the concentration of all measurable constituents remaining in the effluent after a known volume of effluent had passed through the column. This was continued until breakthrough had occurred for all measurable contaminants or excessively low permeabilities were encountered. Breakthrough is defined as that condition when the concentrations of the species of concern in the treated ash pond effluent sample approached or exceeded that in the untreated samples.

RESULTS AND DISCUSSION

Elemental Composition Analysis of Coals and Their Respective Ashes

The results of the analysis for %SiO₂, %Al₂O₃, %Fe₂O₃, %CaO, %K₂O, %Na₂O, %MgO, Ti(ppm), Cd(ppm), Sn(ppm), Ni(ppm), Pb(ppm), Mo(ppm), Cu(ppm), Cr(ppm), Zn(ppm), Mn(ppm), Ba(ppm), and V(ppm), in the coals and their respective fly and bottom ashes collected from the different boilers under full, intermediate and minimum power generation are presented in Table 3 through 22.

An examination of the major and minor composition of the fly ashes in Tables 3 through Table 9 reveal that these compositions are not influenced by decreases in the level of power generation which are accompanied by decreases in boiler temperature. There is no significant differences or trends between the fly ashes produced at different power levels or produced in boilers #11 and #12, which differ significantly in temperatures measured at the arch (see Table 2). A comparison of the results of the analysis for the major and minor elements in the coal and their respective fly ashes and bottom ashes also shows no significant difference between the amount of these elements present in the coal and their respective ashes as a result of the combustion.

These results are in agreement with the results reported by Ray and Parker.⁽¹⁰⁾ Their results also indicate that Al, Fe, Mg, Cu, K and Si are distributed equally between the bottom ash and fly ash.

A comparison of the result of the analysis of the sulfur content in the fly ashes show some rather interesting results. In all cases for the Boiler B fly ashes, the percent sulfur in the fly ash collected from the #12 precipitators is higher than the percent sulfur in the fly ash collected from the #11 electrostatic precipitator even though both fly ashes were produced from the same coal at the same time (see Table 10).

TABLE 3

Percent SiO₂ in the Coal and Its Respective Ashes Generated
Under Different Power Levels

Boiler B Generation Station								
Source	Coal	Full No. 11	Fly Ash		Minimum		Bottom Ash	
			No. 12	No. 11	No. 12	Full	Minimum	
Wellmore Cactus #1	47.4-50.3	49.6	48.1				49.0	
Wellmore Cactus #2	51.0-51.9	49.8	50.3					
Mercer Blend	47.0-50.3	47.6	49.6				51.0	
Ellsworth	45.1-50.5	52.1	49.1				50.1	
Wellmore Ackiss	43.2-49.2	44.2	47.8	46.0	47.9	45.4	45.2	
Nora	42.9-46.4	44.3	45.8				48.3	

Boiler A Generation Station							
Source	Coal	Full		Fly Ash Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	45.9-54.0	48.0	50.4	49.7	49.3	50.3	50.5
Deep Hollow	47.5-51.4	49.4	48.0	49.6	50.5	50.1	49.8
		47.4	49.6				
Upshur	47.2-51.8	50.6	50.2				
		48.9	47.5				
Badger	45.9-51.7	48.3	46.2				

Boiler C and Boiler D Generation Station

Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	45.8-54.7	52.7	53.6
Boiler D	46.4-48.9	46.4	

TABLE 4

Percent Al_2O_3 in the Coal and Its Respective Ashes Generated

Under Different Power Levels

Boiler B Generation Station								
Source	Coal	No. 11	Fly Ash		Minimum		Bottom Ash	
			Full	No. 12	No. 11	No. 12	Full	Minimum
Wellmore Cactus #1	22.7-25.1	25.8		26.1			24.6	
Wellmore Cactus #2	24.7-25.1	27.0		25.1				
Mercer Blend	22.5-24.4	24.8		24.0			23.6	
Ellsworth	22.4-25.0	25.7		25.5			24.9	
Wellmore Ackiss	23.5-25.0	27.4		26.1	27.2	25.5	25.9	25.7
Nora	24.5-26.5	26.1		27.8			24.2	

Boiler A Generation Station							
Source	Coal	Full Front	Back	Fly Ash		Minimum	
				Intermediate Front	Back	Front	Back
Militant	25.1-29.8	31.2	29.1	29.3	31.2	28.0	28.9
		29.5	31.4				
Deep Hollow	23.2-28.3	31.9	30.0	29.5	29.1	28.8	29.6
		29.3	29.0				
Upshur	33.1-33.2	34.2	36.0				
Badger	26.8-30.2	32.9	33.6				

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	23.6-25.5	26.4	24.6
Boiler D	27.6	29.7	

TABLE 5

Percent Fe_2O_3 in the Coal and Its Respective Ashes Generated

Under Different Power Levels

Boiler B Generation Station								
Source	Coal	No. 11	Fly Ash		Minimum		Bottom Ash	
			Full No. 12	No. 11	No. 12	Full	Minimum	
Wellmore Cactus #1	14.7-17.0	13.8	14.6				15.4	
Wellmore Cactus #2	12.4-12.5	11.8	12.9					
Mercer Blend	13.1-17.5	13.5	13.3				14.1	
Ellsworth	16.7-17.7	15.4	13.4				19.9	
Wellmore Ackiss	18.9-20.6	17.4	15.2	16.1	15.7		17.7	18.5
Nora	14.6-17.3	15.6	14.3				17.6	

Boiler A Generation Station							
Source	Coal	Full		Fly Ash		Minimum	
		Front	Back	Intermediate Front	Back	Front	Back
Militant	11.8-15.0	12.4	11.8	13.8	11.5	12.8	11.7
Deep Hollow	16.9-18.2	13.9	12.7	13.2	12.4	13.5	12.5
		12.9	13.2				
Upshur	8.16-9.20	12.3	12.4	8.90	8.33		
		8.90	8.33				
Badger	15.7	11.8	12.1				

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	13.4-16.7	11.5	14.3
Boiler D	17.2	18.3	

TABLE 6

Percent CaO in the Coal and Its Respective Ashes Generated
Under Different Power Levels

Boiler B Generation Station							
Source	Coal	Full		Fly Ash		Bottom Ash	
		No. 11	No. 12	No. 11	Minimum No. 12	Full	Minimum
Wellmore Cactus #1	2.88-3.08	2.84	3.36			2.93	
Wellmore Cactus #2	2.86	2.60	3.71				
Mercer Blend	3.07-3.32	3.21	3.22			3.20	
Ellsworth	4.58-5.29		4.06				
Wellmore Ackiss	1.42-2.73	2.56	2.79	2.30	2.51	3.21	3.09
Nora	5.59-5.99	5.07	4.86			3.35	

Boiler A Generation Station							
Source	Coal	Full		Fly Ash		Minimum	
		Front	Back	Intermediate Front	Back	Front	Back
Militant	1.38-1.75	1.81	2.07	1.78	2.21	1.82	1.92
		1.74	2.38				
Deep Hollow	1.58-2.04	1.48	1.31	1.32	1.55	1.47	1.31
		1.48	1.71				
Upshur	1.54-1.57	2.09	1.46				
Badger	2.77-3.18	2.04	2.14				

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	2.21	1.65	0.77
Boiler D	1.88	2.18	

TABLE 7

Percent K_2O In the Coal and Its Respective Ashes Generated

Under Different Power Levels

Boiler B Generation Station							
Source	Coal	Full		Fly Ash		Minimum	
		No. 11	No. 12	No. 11	No. 12	Full	Minimum
Wellmore Cactus #1	3.63-3.82	3.59	3.39			3.72	
Wellmore Cactus #2	3.00-3.04	3.29	2.67				
Merger Blend	3.46-3.98	3.80	3.64			3.60	
Ellsworth	1.92-2.27	2.28	2.89			3.14	
Wellmore Ackiss	3.02-3.36	3.67	2.92	3.43	3.13	2.93	2.69
Nora	1.88-2.82	2.51	2.25			2.00	

Boiler A Generation Station							
Source	Coal	Full		Fly Ash		Minimum	
		Front	Back	Intermediate	Back	Front	Back
Militant	2.12-2.34	3.05	2.45	2.62	2.86	2.76	3.22
Deep Hollow	2.10-2.28	2.61	3.24	2.53	2.69	2.48	2.67
Upshur	1.57-2.06	2.67	2.58				
		2.45	2.67				
Badger	1.53-1.92	2.16	1.79				
		1.94	2.08				

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	2.59-3.21	3.18	2.74
Boiler D	1.97-2.17	2.76	

TABLE 8

Percent Na₂O in the Coal and Its Respective Ashes Generated
Under Different Power Levels

Boiler B Generation Station							
Source	Coal	No. 11	Fly Ash		Bottom Ash		
			Full	Minimum	Full	Minimum	
		No. 11	No. 12	No. 11	No. 12		
Wellmore Cactus #1	0.65-0.73	1.02	0.94			0.75	
Wellmore Cactus #2	0.85-0.86	1.06	1.04				
Mercer Blend	0.62-0.84		0.71				
Ellsworth	0.79-1.02	0.68	0.95			0.87	
Wellmore Ackiss	1.08-1.27	1.02	0.89	0.92	1.02	0.77	0.74
Nora	1.33	1.52	0.94			0.93	

Boiler A Generation Station							
Source	Coal	Full	Back	Fly Ash		Minimum	
				Intermediate	Back	Front	Back
Upshur	0.41-0.79	0.48	0.35				
Badger	0.41-0.48	0.44	0.44				

Boiler C and Boiler D Generation Station				
Source	Coal	Fly Ash	Bottom Ash	
		Full	Full	
Boiler C	0.67-0.91	0.58	0.42	
Boiler D	0.40-0.41	0.58		

TABLE 9

Percent MgO in the Coal and Its Respective Ashes Generated
Under Different Power Levels

Boiler B Generation Station							
Source	Coal	Fly Ash		Minimum		Bottom Ash	
		Full	Full	No. 11	No. 12	Full	Minimum
		No. 11	No. 12	No. 11	No. 12		
Wellmore Cactus #1	1.36-1.41	1.40	1.50			1.33	
Wellmore Cactus #2	1.40-1.43	1.52	1.33				
Mercer Blend	1.30-1.49	1.55	1.56			1.40	
Ellsworth	0.87-0.95	0.78	1.10			1.28	
Wellmore Ackiss	1.18-1.37	1.20	1.35	1.08	1.32	1.11	1.08
Nora	1.72-2.28	2.03	1.56			1.01	

Boiler A Generation Station							
Source	Coal	Fly Ash		Intermediate		Minimum	
		Full	Full	Front	Back	Front	Back
		Front	Back	Front	Back	Front	Back
Militant	0.59-0.73	0.79	0.84	0.76	0.89	0.77	0.90
		0.82	0.89				
Deep Hollow	0.61-0.75	0.66	0.67	0.71	0.70	0.64	0.81
		0.90	0.71				
Upshur	0.58-0.91	0.69	0.53				
Badger	0.66-0.90	0.63	0.80				

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Boiler C	0.86-1.13	0.93	0.74
Boiler D	0.62-0.63	0.81	

TABLE 10

Percent S in the coal and its respective ashes generated
under different power levels

Boiler B Generation Station							
Source	Coal	Fly Ash		Minimum		Bottom Ash	
		Full		Full		Full	Minimum
		No. 11	No. 12	No. 11	No. 12		
Wellmore Cactus #1	0.81-1.08	0.28	0.63			0.06	
Wellmore Cactus #2	0.63-0.82	0.31	0.53				
Mercer Elend	0.85-1.04						
Ellsworth	1.08-1.25	0.47	0.73			0	
Wellmore Ackiss	1.30-1.49	0.47	0.92			0	
Nora	1.09-1.31	0.55	0.88			0	

Boiler A Generation Station			
Source	Coal	Full	
Militant	1.25-1.60	0.37	
Deep Hollow	1.37-1.42	0.34	
Upshur	0.75-1.00	0.18	
Badger	0.64-1.02	0.25	

Boiler C and Boiler D Generation Station		
Source	Coal	Fly Ash Full
Boiler C	1.33-1.59	0.27
Boiler D	2.00-2.15	0.20

Apparently, the temperatures generated in the boilers above the flame basket regulates the sulfur content in the fly ash. The ash collected from the precipitator associated with the #11 boiler consistently encountered higher temperatures in the arch above the flame basket than #12 boiler even though the flame temperatures in both boilers were comparable. The temperatures measured at the arch in boiler #11 averaged about 400°F more than the arch temperatures in boiler #12 (see Table 2). Evaluations of the effect of boiler temperature on the sulfur content of the ash produced at the Hudson facility could not be made because of the limited amount of temperature measurements performed at this facility.

An examination of the results of the trace analysis for Sn, Ni, Mo, Cu, Cr, and Mn reveals that these elements tend to concentrate in the bottom ash as opposed to the fly ash for the low ash fusion coals burned in Boiler B (see Table 13, Table 14, Table 16, Table 17, Table 18 and Table 20). The elements Ti, Zn and Ba tend to concentrate in the fly ash (see Table 11, Table 19, and Table 21) and the Cd, Pb and V do not exhibit any preferential concentration either in the fly ash and bottom ash (see Table 12, Table 15, and Table 22). The analysis of the high fusion fly ash from Boiler C and its bottom ash shows that the majority of the above elements tend to concentrate in the bottom ash rather than in the fly ash. The elements Ti, Ni, An and Mn were found to concentrate in the fly ash.

Although, the amounts of a trace element present in the high fusion ashes can be related to its concentration in its respective coals (see Table 11 through Table 20), particle size also appears to be a factor in influencing the distribution of the trace elements in the fly ashes. The results of the analysis for the trace elements in the fly ashes which were produced at the same time and under the same boiler condition reveal that the particles collected from the back precipitator at the Hudson facility contains greater amounts

TABLE 21

Ti concentration (ug/g) in the coal and its respective ashes
generated under different power requirements

Boiler B Generation Station							
Source	Coal	Fly Ash		Minimum		Bottom Ash	
		Full No. 11	No. 12	No. 11	No. 12	Full	Minimum
Wellmore Cactus #1	7731-8253	7893	8651	-	-	6320	-
Wellmore Cactus #2	8838-9257	9073	9723	-	-	-	-
Mercer Blend	7604-9951	8662	8950	-	-	6407	-
Ellsworth	7354-9048	9064	9645	-	-	8054	-
Wellmore Ackiss	7702-9538	10065	10036	9652	10664	7794	7970
Nora	6422-6853	8355	9778	-	-	7608	

Boiler A Generation Station							
Source	Coal	Full		Fly Ash Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	8065-10350	9802	12015	9510	10781	9423	12176
Deep Hollow	10100-14200	9906 12933	13111 13205	12235	13832	12604	13014
Upshur	13612-14398	13565	12039	-	-	-	-
Badger	10093-10432	12788	12326	-	-		

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	7628-7958	8585	7955
Boiler D	7622-8878	10971	

TABLE 12

Cd($\mu\text{g/g}$) in the coal and its respective ashes generated
under different power requirements

Boiler B Generation Station							
Source	Coal	Fly Ash		Minimum		Bottom Ash	
		Full No. 11	No. 12	No. 11	No. 12	Full	Minimum
Wellmore Cactus #1	1.5-2.0	2.1	1.8	-	-	2.2	-
Wellmore Cactus #2	4.1-6.0	7.2	5.4	-	-	-	-
Mercer Blend	0.5-0.8	0.92	0.71	-	-	0.73	-
Ellsworth	2.1-2.4	2.4	2.4	-	-	1.8	-
Wellmore Ackiss	0.29-0.51	0.34	0.48	0.51	0.21	0.44	0.38
Nora	0.20-0.65	0.10	0.72	-	-	-	-

Boiler A Generation Station							
Source	Coal	Full		Fly Ash Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	2.4-3.8	3.6	4.9	3.0	4.8	3.6	7.8
Deep Hollow	3.2-5.5	3.9	5.3	4.6	6.2	4.8	5.4
Upshur	0.21-0.23	0.20	0.25	-	-	-	-
Badger	0.75-0.90	0.90	0.65	-	-	-	-

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	1.3-1.4	1.5	1.7
Boiler D	0.35-0.43	0.42	-

TABLE 13

Sn(μ g/g) in the coal and its respective ashes generated
under different power

Boiler B Generation Station							
Source	Coal	Fly Ash				Bottom Ash	
		Full	Full	Minimum	Minimum	Full	Minimum
		No. 11	No. 12	No. 11	No. 12		
Wellmore Cactus #1	1091-1164	1514	1635			2587	
Wellmore Cactus #2	251-341	257	269			-	
Mercer Blend	863-1027	1144	1207			2383	
Ellsworth	51.0-67.9	55.7	59.3			306	
Wellmore Ackiss	51.6-78.3	64.4	69.2	69.1	74.2	253	190
Nora	45-70	76.4	69.8			226	

Boiler A Generation Station							
Source	Coal	Full		Fly Ash		Minimum	
		Front	Back	Intermediate	Intermediate	Front	Back
				Front	Back		
Militant	505-778	722	818	776	798	802	893
		768	893				
Deep Hollow	284-348	342	348	363	385	376	392
Upshur	164-207	109	132				
Badger	211-282	174	215				

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	208-266	127	233
Boiler D	217-226	169	-
		29	

TABLE 14

Ni($\mu\text{g/g}$) in the coal and its respective ashes generated
under different power requirements

Boiler B Generation Station							
Source	Coal	Fly Ash		Minimum		Bottom Ash	
		Full No. 11	No. 12	No. 11	No. 12	Full	Minimum
Wellmore Cactus #1	271-496	231	246	-	-	2477	-
Wellmore Cactus #2	219-895	241	256	-	-	-	-
Mercer Blend	229-283	219	227	-	-	1872	-
Ellsworth	494-885	255	259	-	-	2713	-
Wellmore Ackiss	330-422	231	243	220	218	2298	2190
Nora	305-371	186	248	-	-	2939	-

Boiler A Generation Station							
Source	Coal	Full		Fly Ash		Minimum	
		Front	Back	Intermediate Front	Back	Front	Back
Militant	278-350	266	270	262	316	246	278
Deep Hollow	225-296	268	257	277	289	263	260
Upshur	213-233	253	226	-	-	-	-
Badger	360-380	240	247	-	-	-	-

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	152-196	181	153
Boiler D	195-235	210	-

TABLE 15

Pb($\mu\text{g/g}$) in the coal and its respective ashes generated
under different power requirements

Boiler B Generation Station							
Source	Coal	Fly Ash		Minimum		Bottom Ash	
		Full				Full	Minimum
		No. 11	No. 12	No. 11	No. 12		
Wellmore Cactus #1	567-642	405	509	-	-	445	-
Wellmore Cactus #2	477-495	377	507	-	-	-	-
Marcor Blend	256-507	321	442	-	-	251	-
Ellsworth	397-579	1154	1015	-	-	1082	-
Wellmore Ackiss	335-1280	922	1056	1123	1054	892	1005
Nora	880-994	271	359	-	-	453	-

Boiler A Generation Station							
Source	Coal	Full		Fly Ash		Minimum	
		Front	Back	Intermediate		Front	Back
				Front	Back		
Militant	565-668	520	861	482	779	425	787
		537	800				
Deep Hollow	348-541	379	413	-	501	378	485
Upshur	293-491	353	392	-	-	-	-
Badger	226-523	436	513	-	-	-	-

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash	Bottom Ash
		Full	Full
Boiler C	247-254	217	254
Boiler D	204-230	144	-

TABLE 16

Mo($\mu\text{g/g}$) in the coal and its respective ashes generated
under different power requirements

Boiler B Generation Station								
Source	Coal	Full No. 11	Fly Ash		Minimum		Bottom Ash	
			No. 12	No. 11	No. 12	Full	Minimum	
Wellmore Cactus #1	115-154	178	212				309	
Wellmore Cactus #2	116-138	113	128				-	
Mercer Blend	94-169	179	190				238	
Ellsworth	87-124	121	135				238	
Wellmore Ackiss	75-146	131	123	122		149	178	211
Nora	98.7-125	97	118				227	

Boiler A Generation Station							
Source	Coal	Full		Fly Ash		Minimum	
		Front	Back	Intermediate Front	Back	Front	Back
Militant	158-248	147 156	165 197	134	98	109	134
Deep Hollow	99-163	157	162	-	164	131	164
Upshur	81.0-116	84.8	77.8				
Badger	122-144	113	134				

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	76.9-93.2	51.9	59.7
Boiler D	68.4-88.0	48.1	-

TABLE 17

Cu($\mu\text{g/g}$) in the coal and its respective ashes generated
under different power requirements

Boiler B Generation Station							
Source	Coal	Full		Fly Ash		Bottom Ash	
		No. 11	No. 12	No. 11	Minimum No. 12	Full	Minimum
Wellmore Cactus #1	361-515	243	325	-	-	339	-
Wellmore Cactus #2	763-897	268	281	-	-	-	-
Mercer Blend	361-434	284	381	-	-	303	-
Ellsworth	640-1160	156	207	-	-	932	-
Wellmore Ackiss	968-1746	250	248	246	242	466	372
Nora	419-706	211	217	-	-	537	-

Boiler A Generation Station							
Source	Coal	Full		Fly Ash		Minimum	
		Front	Back	Intermediate Front	Back	Front	Back
Militant	273-421	251	290	279	319	261	304
		233	313				
Deep Hollow	226-388	345	296	318	359	308	322
Upshur	386-520	223	162	-	-	-	-
Badger	466-779	206	209	-	-	-	-

Boiler C and Boiler D Generation Station

Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	489-507	147	156
Boiler D	200-281	185	-
		33	

TABLE 18

Cr($\mu\text{g/g}$) in the coal and its respective ashes generated
under different power requirements

Boiler B Generation Station							
Source	Coal	Fly Ash				Bottom Ash	
		Full	Full	Minimum	Minimum	Full	Minimum
		No. 11	No. 12	No. 11	No. 12		
Wellmore Cactus #1	592-832	225	289	-	-	5113	-
Wellmore Cactus #2	298-479	222	275	-	-	-	-
Mercer Blend	219-284	268	247	-	-	3738	-
Ellsworth	990-1441	319	315	-	-	5611	-
Wellmore Ackiss	258-560	254	288	270	295	4310	-
Nora	311-534	180	257	-	-	5820	-

Boiler A Generation Station							
Source	Coal	Full		Fly Ash		Minimum	
		Front	Back	Intermediate	Intermediate	Front	Back
				Front	Back		
Militant	287-466	290	298	245	304	259	281
Deep Hollow	321-363	282 325	336 278	-	319	265	286
Upshur	343-386	279	319	-	-	-	-
Badger	317-530	300	340	-	-	-	-

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	208-217	178	186
Boiler D	228-240	244	-

TABLE 19

Zn($\mu\text{g/g}$) in the coal and its respective ashes generated
under different power requirements

Boiler B Generation Station							
Source	Coal	Fly Ash		Minimum		Bottom Ash	
		Full No. 11	No. 12	No. 11	No. 12	Full	Minimum
Wellmore Cactus #1	184-251	159	235	-	-	84	-
Wellmore Cactus #2	314-502	280	308	-	-	-	-
Mercer Blend	194-319	219	236	-	-	102	-
Ellsworth	435-729	187	305	-	-	295	-
Wellmore Ackiss	387-672	242	357	241	382	206	873
Nora	193-238	212	357	-	-	154	-

Boiler A Generation Station							
Source	Coal	Full		Fly Ash Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	287-585	379	479	331	453	298	496
Deep Hollow	297-362	454 264	307	503 301	396	258	266
Upshur	252-258	282	209	-	-	-	-
Badger	343-412	223	247	-	-	-	-

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	314-439	238	91
Boiler D	217-327	237	-

TABLE 20

Mn($\mu\text{g/g}$) in the coal and its respective ashes generated
under different power requirements

Boiler B Generation Station							
Source	Coal	Full		Fly Ash		Bottom Ash	
		No. 11	No. 12	No. 11	No. 12	Full	Minimum
Wellmore Cactus #1	323-483	300	316	-	-	803	-
Wellmore Cactus #2	319-380	271	250	-	-	-	-
Mercer Blend	298-351	364	379	-	-	701	-
Ellsworth	314-424	233	265	-	-	841	-
Wellmore Ackiss	288-403	237	296	242	313	737	700
Nora	314-360	289	268	-	-	856	-

Boiler A Generation Station							
Source	Coal	Full		Fly Ash		Minimum	
		Front	Back	Intermediate Front	Back	Front	Back
Militant	304-377	212	240	221	240	197	214
Deep Hollow	195-227	247	263	120	165	143	147
Upshur	76.8-103	155	153	-	-	-	-
Badger	154-213	166	59.2	-	-	-	-
		108	138	-	-	-	-

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	209-232	170	149
Boiler D	147-278	189	-

TABLE 21

Ba($\mu\text{g/g}$) in the coal and its respective ashes generated
under different power requirements

Boiler B Generation Station							
Source	Coal	Fly Ash		Minimum		Bottom Ash	
		Full No. 11	No. 12	No. 11	No. 12	Full	Minimum
Wellmore Cactus #1	1847-2679	1849	2326	-	-	1437	-
Wellmore Cactus #2	2531-2625	1751	2321	-	-	-	-
Mercer Blend	1904-2341	1895	1969	-	-	1272	-
Ellsworth	1767-1826	1269	1400	-	-	1478	-
Wellmore Ackiss	1899-2154	1858	1853	1659	2029	1293	-
Nora	1795-2345	2124	2044	-	-	1147	-

Boiler A Generation Station							
Source	Coal	Fly Ash		Minimum			
		Full Front	Back	Intermediate Front	Back	Front	Back
Militant	1801-2415	1407	1343	-	1809	1768	-
Deep Hollow	866-1024	765	725	-	786	765	711
Upshur	743-981	760	1149	-	-	-	-
Badger	993-1225	865	1124	-	-	-	-

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	613-673	674	794
Boiler D	869-979	877	

TABLE 22

V($\mu\text{g/g}$) in the coal and its respective ashes generated
under different power requirements

Boiler B Generation Station							
Source	Coal	Fly Ash		Minimum		Bottom Ash	
		Full No. 11	No. 12	No. 11	No. 12	Full	Minimum
Wellmore Cactus #1	405-451	392	552	-	-	409	-
Wellmore Cactus #2	605-667	539	654	-	-	-	-
Mercer Blend	352-417	336	413	-	-	295	-
Ellsworth	445-510	646	723	-	-	537	-
Wellmore Ackiss	491-733	627	663	658	713	458	529
Nora	426-551	405	615	-	-	451	-

Boiler A Generation Station							
Source	Coal	Full		Fly Ash Intermediate		Minimum	
		Front	Back	Front	Back	Front	Back
Militant	403-546	464	582	379	566	362	550
Deep Hollow	297-417	423	440	-	494	441	449
Upshur	633-711	568	609	-	-	-	-
Badger	500-759	641	704	-	-	-	-

Boiler C and Boiler D Generation Station			
Source	Coal	Fly Ash Full	Bottom Ash Full
Boiler C	379-454	339	384
Boiler D	446-465	449	

of the above trace elements (see Table 11 through 22). Only the barium was found to be in greater amounts in the particles, collected from the front precipitator, than the smaller particles collected from the back precipitator.

Analysis of the size distribution of the fly ash particles produced in the Boiler A reveal that the size distribution of the ashes collected from the back precipitator are in general smaller than the particles collected from the front precipitator (see Figure 2 through Figure 13). The presence of larger amounts of the trace elements in the particles collected from the back precipitator indicate that the smaller particles tend to concentrate the trace elements.

These results are in agreement with the results reported by Davison et al,⁽¹¹⁾ In this article, it was shown that the concentration of the elements Pb, Ti, Sb, Cd, Se, As, Zn, Ni, Cr and S are greater in the smaller particles than in the larger ash particles.

A comparison of the trace analysis of the fly ashes, produced from the same coal at the same time but at different boiler temperatures and collected from the #11 and #12 electrostatic precipitators at the Boiler B Station facility show in general that the #12 fly ashes contain the greater concentration of the above trace elements than the #11 fly ashes. Although the amount of the trace elements in the fly ashes are related to their amount in their respective coals (see Table 12 through Table 20), their distribution within the fly ash particles may be due either to differences in boiler temperatures or particle size or a combination of both.

The arrangement of the #11 precipitators and #12 precipitators with respect to their boilers favor in general the collection of larger particles in the #11 precipitator and smaller particles in the #12 precipitators. The emissions that feed the #12 precipitator result in a split in the gas stream just before

Figure 2 Size Analysis of Militant Fly Ash (Full)

Figure 3 Size Analysis of Militant Fly Ash (Intermediate)

Figure 4 Size Analysis of Boiler A Fly Ash (Minimum)

Figure 5 Size Analysis of Deep Hollow Fly Ash (Full)

Figure 6 Size Analysis of Deep Hollow Fly Ash (Intermediate)

Figure 7 Size Analysis of Deep Hollow Fly Ash (Minimum)

Figure 8 Size Analysis of Badger Fly Ash (Full)

Figure 9 Size Analysis of Blend Fly Ash (Full)

Figure 10 Size Analysis of Ellsworth Fly Ash (Full)

Figure 11 Size Analysis of Nora Fly Ash (Full)

Figure 12 Size Analysis of Wellmore Cactus #2 Fly Ash (Full)

Figure 13 Size Analysis of Wellmore Ackiss Fly Ash (Full)

it enters the #11 precipitator where one gas stream flows upward through a right angle elbow to the #12 precipitator without any change in flow direction. This change in flow directions would favor the smaller particles entering the #12 precipitator and the larger particles entering the #11 precipitator.

Particle size and permeability determinations on the different fly ash particles produced in the Boiler B facilities revealed that in general the particles collected in the #11 are larger than the particles collected in the #12 precipitator with the exception of the Wellmore Cactus #2 and Wellmore Ackiss fly ashes (see Figures 9 through Figure 13). The particle size of the Blend, Wellmore Cactus #1, Nora and Ellsworth fly ashes collected from the #11 precipitator were larger than that collected from #12 precipitator. The reverse was observed for the Wellmore Cactus #2 fly ash particles. Here, larger particles were found in the #12 precipitator than in the #11 precipitator. For the case of the Wellmore Ackiss fly ashes produced at full power generation, the size of the particles collected from the #11 and #12 precipitator were comparable.

An examination on the results of the analysis of the Boiler B fly ashes for Cadmium, Tin, Nickel, Molybdenum, Lead, Copper, Chromium, Zinc and Manganese reveals that both the size of the particles and boiler temperatures can be a factor in determining the amounts of the trace elements present in the fly ash particles. In general, the trace amount of the above elements were found to be greater in the #12 fly ashes than the #11 fly ashes. All of the #12 fly ash particles were exposed to high temperatures for shorter periods of time than the fly ash produced in the #11 boiler. Also, the #12 fly ash particles in general were smaller in size than the #11 fly ash particles.

The influence of boiler temperature on the distribution of trace elements in the low fusion fly ash can be seen from comparison of the size distribution and analysis of the trace elements in the Wellmore Cactus #2 and Wellmore Ackiss (full) produced at the same time from the same coal in the #11 and #12 boilers

(see Figure 12 and Figure 13). The size of the Wellmore Cactus #2 and Ackiss fly ash particles produced in the #12 boilers were larger or comparable, respectively, to the particles generated in the #11 boilers. If only size was a factor in the distribution of trace elements in the fly ash particles, the concentration of trace elements in the Wellmore Cactus #2 and Ackiss fly ash produced in the #11 boiler would be greater or comparable to that present in their respective fly ashes produced in the #12 boiler. However, this was not the case. The amount of trace elements present in the Wellmore Cactus #2 and Wellmore Ackiss fly ashes were observed to be greater in the #12 fly ash than the #11 fly ashes. Since the #12 fly ashes encountered the high boiler temperatures for the short periods of time, boiler temperatures must also be a significant factor in determining the amount of the above trace elements present in the low ash fusion coals because it more than compensated for the above anticipated effect of particle size.

Cadmium is the only trace element whose amount in the Boiler B fly ashes does not appear to be influenced by particle size and boiler temperature. The reason for this is not clear.

An examination of the trace amounts of cadmium present in the Blend, Wellmore Cactus #1, Nora, Wellmore Cactus #2, Ellsworth, and Wellmore Ackiss fly ashes collected from the #11 and #12 show no general correlation between particle size and boiler temperature. For example, only the Nora and Wellmore Ackiss fly ashes collected from the #12 precipitator contain more Cadmium than the fly ashes collected from the #11 precipitator; whereas, the Blend, Wellmore Cactus #1 and Wellmore Cactus #2 fly ashes collected from the #12 precipitator contain less Cadmium than the fly ashes collected from the #11 precipitator. The Ellsworth fly ashes on the other hand, collected from the #11 and #12 precipitators contain the same amount of Cadmium.

For the case of the high fusion fly ashes, a reduction in boiler temperature which results from power generation reduction does not appear to influence the trace elemental composition distribution. A comparison of trace element analysis of the Militant fly ashes collected from the front precipitator under full and intermediate power and Deep Hollow fly ashes collected from the back precipitator under full and intermediate power, both of which exhibit similar particle size distribution (see Figure 2, Figure 3, Figure 5 and Figure 6) show no correlation between a reduction in power output and the trace elemental composition of the fly ashes (see Tables 11 through 22). In the case of the Deep Hollow fly ashes, the fly ashes produced under intermediate power contain greater amounts of trace elements than the fly ashes produced under full power; whereas, the reverse is true in general for the Militant fly ashes. The Militant fly ash particles produced under the higher power generally contain greater amounts of the above elements than the ash samples produced under reduced power.

ESCA analysis of the fly ashes produced from the three types of coal fired boilers indicates that the atomic composition on their fly ash surfaces consists of oxygen, carbon, silicon, sulfur, aluminum, and calcium in decreasing order (see Table 23).

It should be noted that the percentage of oxygen and carbon on the surface of the fly ashes could be the result of the combustion process or the sorption of oxygen and carbon compounds on the surface of the ash particles upon standing. The contribution of each source of oxygen and carbon to the total amount measured on the surface is not known at this time.

The other elements that were observed on the surface of the fly ashes were nitrogen, potassium, iron, phosphorous, tin and titanium. However, their amounts on the surface of the fly ash were too low to be ranked as the most and least abundant by ESCA.

Boiler temperatures and levels of power generation do not appear to influence the surface composition of the fly ash as measured by ESCA since it is generally recognized that differences in ESCA results that are within a few percent are not considered significant. A comparison of the percentages of silicon, aluminum, calcium, and sulfur atoms measured on the surfaces of the #11 and #12 fly ashes as well as on the surface of those Boiler A fly ashes produced at full, intermediate and minimum power show no significant difference. All results in general show agreement within 1.5 percent (see Tables 24 through 27).

For example, the differences in the amounts of silicon on the surfaces of the #11 and #12 Wellmore Cactus #1 fly ashes is 0.9 percent. Similar results are obtained from a comparison of the amounts of silicon on the surfaces of the Militant or Deep Hollow fly ashes collected from the front precipitators produced under full, intermediate and minimum load. No fly ashes contain silicon on its surface in excess of 1.5 percent (see Table 24).

There appears to be no correlation between the amounts of the four elements, silicon, aluminum, sulfur and calcium measured on the surface of the fly ash and its particle size. A comparison of the percentage of each of the atoms on the surface of the larger Militant and Deep Hollow fly ash particles collected from the front precipitator with that present on the surface of the smaller particles collected from the back precipitator shows no significant difference.

For example, the percentage of silicon (7.9%) on the surface of the larger Militant fly ash particles collected from the front precipitator differs by less than 1.5% from the present (8.7%) on the surface of the fly ash particles collected from the back precipitator. Similarly, the percentage of silicon (8.7%) on the surface of the Deep Hollow fly ash collected from the front precipitator differs by less than 1.5 percent of the percentage of silicon (7.3%) present on the smaller particles collected from the back precipitator (see Table 14). Similar results are observed in general for the other atoms identified on the surface of the larger and smaller fly ash particles produced from the Militant and Deep Hollow coals (see Table 25 through Table 27).

Correlation of Fly Ash Bulk Composition with Surface Composition

A comparison of the bulk composition of the low ash fusion coals with their fly ashes reveals that the amounts of each element identified in the fly ash decreases in general in the same order as encountered in its parent coal. The most abundant element in these coals is identified as silicon followed by aluminum, iron, potassium, calcium, sulfur or titanium, barium and tin in decreasing order. The equivalent amounts of silicon oxide, aluminum oxide, calcium oxide and sulfur calculated from their atom percent of silicon, aluminum, calcium and sulfur on the surfaces of the fly ashes were also found to be in the same decreasing order as that present in the coal and fly ash bulk except for sulfur. The sulfur was found to be present on the surface of the fly ashes in amounts greater than the calcium; whereas,

TABLE 23

Percent Atom Composition on Surface of Fly Ashes Produced at full power

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Boiler B fly ashes from #11 precipitation					Boiler A			Boiler C and Boiler D fly ashes	
Nora	Blend	Wellmore Cactus #1	Ellsworth	Militant	Deep Hollow	Upshur	Badger	Boiler C	Boiler D
O (58.6)	O (56.4)	O (51.2)	O (57.2)	O (54.1)	O (49.7)	O (51.5)	O (45.5)	O (47.2)	O (52.4)
C (20.7)	C (20.1)	C (28.9)	C (18.4)	C (23.0)	C (25.6)	C (24.1)	C (33.7)	C (33.6)	C (25.2)
Si(7.3)	Si(8.5)	Si(7.2)	Si(13.0)	Si(8.1)	Si(8.1)	Si(13.4)	Si(10.8)	Si(11.7)	Si(9.6)
S (7.1)	S (6.6)	S (5.9)	S (4.1)	S (5.8)	Al(6.6)	Al(7.0)	Al(6.3)	Al(3.5)	Al(5.3)
Al(3.2)	Al(3.9)	Al(4.2)	Al(1.6)	Al(4.5)	S (5.0)	S (2.1)	S (2.0)	S (2.4)	S (5.0)
Ca(2.2)	Ca(1.8)	Ca(1.3)	Ca(1.6)	Ca(0.84)	Ca(0.90)	Ca(0.56)	Ca(0.73)	Ca(0.54)	Ca(0.69)

TABLE 24

Atom Percent Silicon at Surface of Fly Ash Produced in
Different Coal Fired Boilers Under Different Power Generation

Source	<u>Boiler B</u>	
	No. 11	No. 12
Wellmore Cactus #1	7.2	8.1
Blond	8.5	7.8
Ellsworth	13.0	13.7
Nora	7.3	9.2

Source	<u>Boiler A</u>					
	Full		Intermediate		Minimum	
	Front	Back	Front	Back	Front	Back
Militant	7.9	8.7	8.8	8.8	8.1	8.8
Deep Hollow	8.7	7.3	10.2	6.4	9.6	9.0
Upshur	13.4					
Badger	10.83					

Source	<u>Boiler C and Boiler D</u>	
	Full	
Mine Mouth C Boiler	9.6	
Mine Mouth D Boiler	11.7	

TABLE 25

Atom Percent Aluminum at Surface of Fly Ash Produced in
Different Coal Fired Boilers Under Different Power Generation

Source	<u>Boiler B</u>	
	<u>Full</u>	
	No. 11	No. 12
Wellmore Cactus #1	4.2	4.1
Blend	3.9	3.8
Ellsworth	1.6	1.6
Nora	3.2	3.5

Source	<u>Boiler A</u>					
	<u>Full</u>		<u>Intermediate</u>		<u>Minimum</u>	
	Front	Back	Front	Back	Front	Back
Militant	4.5	4.6	5.0	4.4	6.0	3.8
Deep Hollow	5.1	8.0	4.9	5.0	4.4	4.0
Upshur	7.0					
Badger	6.3					

Source	<u>Boiler C and Boiler D</u>	
	<u>Full</u>	
Mine Mouth C Boiler	5.3	
Mine Mouth D Boiler	3.5	

TABLE 26

Atom Percent Calcium at Surface of Fly Ash Produced in
Different Coal Fired Boilers Under Different Power Generation

Source	<u>Boiler B</u>	
	Full	
	No. 11	No. 12
Wellmore Cactus #1	1.3	1.2
Blend	1.8	1.4
Ellsworth	1.6	1.6
Nora	2.2	2.0

Source	<u>Boiler A</u>					
	Full		Intermediate		Minimum	
	Front	Back	Front	Back	Front	Back
Militant	0.66	1.20	0.67	0.92	0.56	0.90
Deep Hollow	1.10	0.70	0.54	0.77	0.46	0.80
Upshur	0.56					
Badger	0.73					

Source	<u>Boiler C and Boiler D</u>	
	Full	
Mine Mouth C Boiler	0.69	
Mine Mouth D Boiler	0.54	

TABLE 27

Atom Percent Sulfur at Surface of Fly Ash Produced in
Different Coal Fired Boilers Under Different Power Generation

Source	<u>Boiler B</u>	
	Full	
	No. 11	No. 12
Wellmore Cactus #1	5.9	7.2
Blend	6.6	7.0
Ellsworth	4.06	4.54
Nora	7.12	6.14

Source	<u>Boiler A</u>					
	Full		Intermediate		Minimum	
	Front	Back	Front	Back	Front	Back
Militant	5.70	6.00	5.20	5.4	5.30	5.20
Deep Hollow	5.60	4.30	4.80	5.0	5.20	4.80
Upshur	2.07					
Badger	2.11					

Source	<u>Boiler C and Boiler D</u>	
	Full	
Mine Mouth C Boiler	4.95	
Mine Mouth D Boiler	2.43	

the sulfur in the parent coal and its fly ash was less than the calcium (see Table 28 through 31).

The elements present in the high ash fusion coals burned at the Boiler A facilities in the bulk and on the surface of their respective fly ashes followed the same decreasing order of abundance. The most abundant element in these coals and their respective fly ashes collected from the front and back electrostatic precipitators at Boiler A Generation Station is silicon followed by aluminum, iron, potassium or calcium, sulfur or titanium, barium and tin in decreasing order. Again, the order of decreasing amounts of elements on the surface of the fly ash agree with the order of decreasing amounts of these elements in the bulk of the fly ash with the exception of sulfur. Silicon is the most abundant atom on the surface followed by aluminum, sulfur and calcium, in decreasing order (see Table 32 through Table 35).

One of the factors that appears to contribute to the amount of sulfur found on the surface of the fly ashes is the addition of LPA-40 (which contains sulfur compounds) to the combustion gases. The purpose of LPA-40 is to alter the resistivity of the fly ash particles for better removal by the electrostatic precipitators. The rates of feed of LPA-40 used in the various test burns is listed in Table 36.

TABLE 28

Percent Composition of Oxides in Wellmore Cactus #1 Coal,
Fly Ash and Equivalent Composition on Fly Ash Surface Collected

From No. 11 Precipitators

Element	Coal	Fly Ash Bulk	Fly Ash Surface eq. comp.
SiO ₂	47.4-50.3	49.6	36.4
Al ₂ O ₃	22.7-25.1	25.8	36.1
Fe ₂ O ₃	14.7-17.0	13.8	
K ₂ O	3.63-3.82	3.59	
CaO	2.88-3.08	2.84	6.14
S	0.81-1.08 (dry)	0.71	15.9
Ti	0.77-0.82	0.79	
Ba	0.18-0.27	0.18	
Sn	0.11-0.12	0.15	

TABLE 29

Percent Composition of Oxides in Blend Coal,
Fly Ash and Equivalent Composition on Fly Ash Surface Collected

From No. 11 Precipitators

Element	Coal	Fly Ash Bulk	Fly Ash Surface eq. comp.
SiO ₂	47.0-50.3	47.6	38.3
Al ₂ O ₃	22.5-24.4	24.8	29.9
Fe ₂ O ₃	13.1-17.5	13.5	
K ₂ O	3.46-3.98	3.8	
CaO	3.07-3.32	3.2	7.57
S	0.85-1.04 (dry)	1.6	15.9
Ti	0.76-1.0	0.87	
Ba	0.19-0.23	0.19	
Sn	0.09-0.11	0.11	

TABLE 30

Percent Composition of Oxides in Ellsworth Coal,
Fly Ash and Equivalent Composition on Fly Ash Surface Collected

Element	Coal	From No. 11 Precipitators	
		Fly Ash Bulk	Fly Ash Surface eq. comp.
SiO ₂	45.1-50.5	52.1	53.1
Al ₂ O ₃	22.4-25.0	25.7	28.0
Fe ₂ O ₃	16.7-17.7	15.4	
CaO	4.58-5.29	-	6.10
K ₂ O	1.92-2.27	2.28	
S	1.08-1.25 (dry)	0.47	8.83
Ti	0.74-0.90	0.91	
Ba	0.18-0.19	0.19	
Sn	0.05-0.07	0.06	

TABLE 31

Percent Composition of Oxides in Nora Coal, Fly Ash
and Equivalent Composition on Fly Ash Surface Collected

Element	Coal	From No. 11 Precipitators	
		Fly Ash Bulk	Fly Ash Surface eq. comp.
SiO ₂	42.9-46.4	44.3	37.7
Al ₂ O ₃	24.5-26.5	26.1	28.2
Fe ₂ O ₃	14.6-17.3	15.6	
CaO	5.59-5.99	5.07	10.8
K ₂ O	1.88-2.82	2.51	
S	1.09-1.31 (dry)	0.55	19.6
Ti	0.64-0.69	0.83	
Ba	0.18-0.23	0.21	
Sn	0.05-0.07	0.08	

TABLE 32.

Percent Composition of Oxides in Upshur Coal,
Its Fly Ash and Equivalent Composition on Fly Ash Surface

Collected From the Front and Back Precipitators Connected in Series at Full

Load

Element	Coal	Fly Ash		Fly Ash Surface Front eq. comp.
		Front	Back	
SiO ₂	47.2-51.8	48.9	47.5	47.9
Al ₂ O ₃	33.1-33.2	34.2	36.0	42.3
Fe ₂ O ₃	8.16-9.20	8.90	8.33	
K ₂ O	1.57-2.06	2.16	1.79	
CaO	1.54-1.57	2.09	1.46	1.87
Ti	1.36-1.44	1.36	1.20	
S	0.75-1.00 (dry)	0.18	-	3.94
Ba	0.07-0.10	0.08	0.11	
Sn	0.01-0.02	0.01	0.01	

TABLE 33

Percent Composition of Oxides in Badger Coal, Its
Fly Ash and Equivalent Composition on Fly Ash Surface Collected

From the Front and Back Precipitators Connected in Series at

Full Load

Element	Coal	Fly Ash		Fly Ash Surface Front eq. comp.
		Front	Back	
SiO ₂	45.9-51.7	48.3	46.2	44.6
Al ₂ O ₃	26.8-30.2	32.9	33.6	44.1
Fe ₂ O ₃	15.7-15.7	11.8	12.1	
CaO	2.77-3.18	2.04	2.14	2.81
K ₂ O	1.53-1.92	1.94	2.08	
TiO ₂	1.01-1.04	1.28	1.23	
S	0.84-1.02 (dry)	0.17	0.33	4.64
Ba	0.10-0.12	0.09	0.11	
Sn	0.02-0.03	0.02	0.02	

TABLE 34

Percent Composition of Oxides in Militant Coal,
Its Fly Ash and Equivalent Composition on Fly Ash Surface
Collected From the Front and Back Precipitators Connected in Series
at Full Load

Element	Coal	Fly Ash		Fly Ash Surface	
		Front	Back	Front	Back
SiO ₂	45.9-54.0	48.7	49.2	37.8	35.5
Al ₂ O ₃	25.1-29.8	29.9	30.3	36.6	31.9
Fe ₂ O ₃	11.8-15.0	13.2	12.3		
K ₂ O	2.12-2.34	2.83	2.85		
CaO	1.30-1.75	1.78	2.23	2.95	4.56
S	1.25-1.60 (dry)	0.91	-	14.6	13.0
Ti	0.81-1.04	0.98	1.26		
Ba	0.18-0.24	0.14	0.13		
Sn	0.05-0.08	0.07	0.09		

TABLE 35

Percent Composition of Oxides in Deep Hollow Coal,
Its Fly Ash and Equivalent Composition on Fly Ash Surface Collected
From the Front and Back Precipitators Connected in Series
at Full Load

Element	Coal	Fly Ash		Fly Ash Surface	
		Front	Back	Front	Back
SiO ₂	47.5-51.4	49.0	49.9	38.9	29.6
Al ₂ O ₃	23.2-28.3	30.6	29.5	38.7	55.2
Fe ₂ O ₃	16.9-18.2	12.6	12.8		
K ₂ O	2.10-2.28	2.56	2.63		
CaO	1.58-2.04	1.48	1.51	4.59	2.65
S	1.37-1.42 (dry)	1.08	-	13.3	9.31
Ti	1.29-1.32	1.29	1.32		
Ba	0.09-0.10	0.08	0.07		
Sn	0.03-0.04	0.03	0.03		

TABLE 36

Rate of feed of LPA-40 to combustion gases

<u>Coal</u>	<u>Boiler</u>	<u>Rate(gal/hr)</u>
Wellmore Cactus #1	B	28
Blend	B	28
Nora	B	28
Ellsworth	B	0
Militant	A	18
Deep Hollow	A	14
Upshur	A	18
Badger	A	18
Mine Mouth C	C	0
Mine Mouth D	D	0

In the case of the coals burned in Boiler A and Boiler B, LPA-40 was added to all their combustion gases except during the combustion of the Ellsworth coal. The amount of sulfur found on the surface of their respective fly ashes averaged about twice the amount of calcium found on these surfaces, with the exception of the Ellsworth fly ash; whereas, the amount of sulfur found in the parent coal and in its fly ash was significantly less than the calcium (see Tables 28 through 35). The amount of sulfur present on the surface of the Ellsworth fly ashes is only slightly higher than the amount of calcium present on the surface.

There appears to be additional factors which are not understood at this time that contributes to the amount of sulfur present on the surfaces of the fly ashes. Both the Ellsworth and Mine Mouth C combustion gases did not receive any LPA-40. The amount of calcium in both these coals and their respective fly ashes is considerably greater than the sulfur. Yet, the surfaces of their fly ashes contain greater amounts of sulfur than calcium (see Table 30 and Table 38).

Factors Influencing Leachate pH

The results of the analysis of the fly ash leachate indicates that the fly ashes produced acidic and basic leachates. The high fusion fly ashes generated in the dry bottom Boiler A produce acidic leachates. The pH of the leachate from these fly ashes ranged from a low of 2.7 up to a high of about 7.2 (see Table 39). The low fusion fly ashes produced in the wet bottom Boiler B, Boiler C and Boiler D in general range from a pH of about 6.6 up to a value of 12.3. The exceptions are the leachate from the Nora and Wellmore Ackiss fly ashes produced in the #12 Boiler B. The pH of their leachate ranges from 4.1 up to 6.8 (see Table 39). High boiler temperatures

TABLE 37

Percent composition of oxides in Boiler D,
its fly ash and equivalent composition on the fly ash surface
produced under full load

Element	Coal	Fly Ash	Fly Ash Surface eq. comp.
SiO ₂	46.4-48.9	46.4	57.0
Al ₂ O ₃	27.6-27.6	29.2	29.3
Fe ₂ O ₃	17.2-17.2	18.3	
S	2.00-2.15 (dry)	0.20	6.32
K ₂ O	1.97-2.17	2.76	
CaO	1.88-1.88	2.18	2.46
TiO ₂	0.76-0.89	1.11	
Ba	0.09-0.10 (ppm)	0.09 (ppm)	
Sn	0.02-0.02 (ppm)	0.02 (ppm)	

TABLE 38

Percent composition of oxides in Boiler C,
its fly ash and equivalent composition on the fly ash surface
produced under full load

Element	Coal	Fly Ash	Fly Ash Surface eq. comp.
SiO ₂	45.8-54.7	52.7	38.7
Al ₂ O ₃	23.6-25.5	26.4	36.4
Fe ₂ O ₃	13.4-16.7	11.5	
K ₂ O	2.59-3.21	3.18	
CaO	2.21-2.21	1.65	2.61
S	1.33-1.99 (dry)	0.27	10.7
TiO ₂	0.76-0.80	0.86	
Ba	0.06-0.07 (ppm)	0.07 (ppm)	
Sn	0.02-0.03 (ppm)	0.01 (ppm)	

accompanied by fusion reactions within the ash appears to favor the formation of fly ash that generates an alkaline leachate upon passage of water through the fly ash. In all cases, it can be noted in Table 27 that the fly ashes generated in boiler #11 are significantly more alkaline than the fly ashes produced in #12.

A comparison of the temperatures in #11 and #12 boilers especially at the arch are in the range of some 400-600 degrees higher in #11 boiler than in #12 boiler. These temperatures indicate that the fly ash in the #11 boiler were exposed to higher temperatures for longer period of times in the fusion state than the fly ash in #12 boiler. A comparison of flame temperatures encountered in both the #11 and #12 boilers as well as the ash fluid temperatures exhibited by the Boiler B fly ashes indicate that the flame temperatures are some 500°F higher than that required to melt the ash. Similar events also seem to have occurred with the Boiler C and Boiler D fly ashes. Both fly ashes also generate alkaline leachates (see Table 39). A comparison of the boiler temperatures that produced the Boiler C and Boiler D fly ashes and their ash fusion temperatures suggest that the boiler temperatures were high enough to cause fusion of their respective fly ashes within the boilers. Temperatures of 2600 and 2700°F were measured above the flame basket in the Boiler C and Boiler D, respectively. This is some 200° above the softening temperatures of the fly ashes. Apparently, the high temperatures encountered by the fly ash in the Boiler B, Boiler C and Boiler D have resulted in fusion reactions that have led to alkaline products that can be dissolved upon contact with water to form alkaline leachates.

In comparison, it can be seen from Table 39 that all the fly ashes produced in the Boiler A form acidic leachates. The Militant, Deep Hollow, Upshur and Badger fly ashes produced in the Boiler A encountered flame and

boiler temperatures that are below even the initial deformation temperatures of the fly ash. Hence, the fusion reactions probably did not occur that might have lead to formation of products that lead to an alkaline leachate.

It may be that the fly ashes produced in the Boilers B, C and D may also produce an acidic leachate when brought in contact with water if they had not undergone fusion within their respective boilers. This is evident from a comparison of the bulk compositions of all the fly ashes generated in the Boilers B, C, D and A. There appears to be no significant difference between these fly ashes with respect to their composition of major and minor constituents (compare Tables 3 through 10) which is generally considered a major factor in determining the pH of the leachate originating from fly ashes. This may be the reason for the Nora and Wellmore Ackiss fly ashes generated in the #12 boiler producing an acidic leachate; whereas, the fly ashes generated from the same coal in the #11 boiler producing a basic leachate. If the fusion reactions that may lead to the formation of the water soluble alkaline products was only partially complete, the pH of the leachate from the Nora and Wellmore Ackiss fly ashes produced in #12 boiler should remain acidic. The pH range of their leachates were 4.1 - 6.4, 5.1 - 6.8 and 5.6 - 5.8, respectively (see Table 39).

A reduction in the levels of power generation and the size of the fly ash particles do not appear to influence the pH of the leachate originating from the fly ash particles. A comparison of the pH ranges exhibited by the leachates from the Militant and Deep Hollow fly ashes produced at full, intermediate and minimum power generation show comparable values. These results are of interest in that they indicate that reduction in boiler temperature without fusion of the fly ash does not alter the pH of the leachate. The boiler temperatures maintained at the Boiler A facility must be kept below the ash fusion temperatures. Similarly, no differences were observed in the pH ranges exhibited by the leachate from the larger and smaller Militant and

Deep Hollow fly ash particles collected from the front and back electrostatic precipitators (see Table 39). Apparently, different particle sizes do not influence the pH of the leachate.

Leaching

The results of analysis for cadmium, boron, tin, molybdenum, nickel, lead, copper, chromium, zinc, manganese, and iron in the leachate generated by passing water through the fly ash samples contained in lysimeters is summarized in Tables 40 through Table 50. The experiment results from which the information in Table 40 through Table 50 was obtained is presented in Figures 65a through Figure 240 (see appendicies). An examination of the leaching results reveals with few exceptions that all the fly ash samples initially leach the above elements in varying amounts. However, a comparison of the results of the analysis after 1000 ml, 2000 ml and 4000 ml of water had been passed through the fly ash samples to form leachate, show a decrease in the concentration of the above elements upon the continuous addition of water. The rate of decrease in the concentration of elements in the leachate with the continuous addition of water suggests that most of the fly ash samples will cease to leach the above elements at some point beyond the addition of 4000 ml of water (see Tables 40 through Tables 50).

Low Fusion Fly Ashes

A comparison of the different leaching results from the low fusion fly ashes reveals that a relationship exists between the differences in amount of trace element that is leached and its amount in the fly ash for the majority of the trace elements considered in this investigation. The amount present in the fly ash shown earlier in most cases to be dependent upon its concentration in the coal, particle size and boiler temperature. The difference in amount of leaching of Cd, B, Sn, Cu, Cr, Zn, Mo, Pb and Mn exhibited by a majority of the fly ash samples can be related to the differences in the amounts of trace elements present in the fly ash samples (see Table 28 through Table 50).

Table 39. Relations of Boiler Conditions to Leachate pH

	Ash	Source	Power	Flame	Boiler Temp °F		Ash Fusion °F			pH range
					Above Basket	Arch	Init. Def	Soft	Fluid	
Boiler B:	Blend	No. 11	Full	3100	1815	2250	2143	2325	2665	7.7- 9.1
		No. 12	Full	3100	1737	1835	2188	2325	2353	7.3- 7.5
	Wellmore	No. 11	Full	3150	1620	2080	2120	2285	2570	8.3- 9.3
	Cactus (1)	No. 12	Full	3150	1530	1480	2135	2310	2555	6.9- 7.9
	Nora	No. 11	Full	3100	1850	2175	2130	2230	2330	9.4- 9.8
		No. 12	Full	3250	1700	1700	2145	2265	2480	4.1- 6.4
	Wellmore	No. 11	Full	3050	1900	2180	2135	2330	2625	7.3- 8.6
	Ackiss	No. 12	Full	2950	1725	1500	2110	2265	2440	5.1- 6.8
	Wellmore	No. 11	Min.	2870	1590	1780				7.2- 9.1
	Ackiss	No. 12	Min.	2950	1620	1500				5.6- 5.8
	Wellmore	No. 11	Full	3125	1400	1680	2190	2400	2695	9.8-11.5
	Cactus (2)	No. 12	Full	2970	1400	1320	2155	2215	2510	8.2- 9.0
	Ellsworth	No. 11	Full	3100	1815	2240	2150	2235	2445	10.5-12.3
		No. 12	Full	3100	1740	1820	2155	2275	2470	8.5- 9.4
Boiler A:	Boiler C		Full		2600		2183	2520	2700+	6.6- 8.1
	Boiler D		Full	2650	2700	2700	2125	2503	2700+	7.1-10.0
	Militant	Front	Full				2555	2700+	2700+	3.5- 6.6
		Back	Full							3.8- 6.8
	Militant	Front	Full							4.2- 6.7
		Back	Full							3.6- 6.9
	Militant	Front	Int.							3.8- 7.2
		Back	Int.							3.8- 5.9
	Militant	Front	Min.							3.7- 6.9
		Back	Min.							3.7- 7.3
	Deep Hollow	Front	Full				2605	2700	2700+	3.7- 5.1
		Back	Full							3.8- 5.5
	Deep Hollow	Front	Int.		1550					4.0- 6.1
		Back	Int.							3.6- 4.7
	Deep Hollow	Front	Min.		1450					3.8- 5.6
		Back	Min.							6.3- 7.0
	Upshur	Back	Full	2470	1590	1565	2700+	2700+	2700+	2.7- 4.5
	Badger	Front	Full	2550	1750	1440	2700+	2700+	2700+	2.8- 5.5
		Back	Full							3.6- 4.6

Table 40. Cadmium

Fly Ash	Source	Power	Bulk Trace Amount ug/g	Leaching, ug/ml			pH range	Influent conc. ug/ml	Treatment, ug/ml		
				1000ml	2000ml	4000ml			1500ml	3000ml	4000ml
Militant	Front	Full	3.6	0.07	N.D.	N.D.*	3.5- 6.6	0.02	N.D.	N.D.	N.D.*
	Back	Full	4.9	0.07	0.02	0.01	3.8- 6.8	0.02	N.D.	N.D.	N.D.
	Front	Full	3.9	0.20	0.02	0.01	4.2- 6.7	0.02	N.D.	N.D.	N.D.
	Back	Full	5.3	0.11	0.08	0.06	3.6- 6.9	0.02	N.D.	N.D.	N.D.
	Front	Inter-	3.0	0.01	0.02	0.03	3.8- 7.2	0.02	N.D.	N.D.	N.D.
	Back	mediate	4.8	0.12	0.11	0.11	3.8- 5.9	0.02	N.D.	N.D.	N.D.
	Front	Min.	3.6	0.04	0.01	N.D.	3.7- 6.9	0.02	N.D.	N.D.	N.D.
	Back	Min.	7.8	0.04	0.02	N.D.	3.7- 7.3	0.02	N.D.	N.D.	N.D.
Deep Hollow	Front	Full	5.0	0.12	0.12	0.12	3.7- 5.1	N.D.*	0.11	0.11	0.15
	Back	Full	5.8	0.18	0.02	N.D.	3.8- 5.5	N.D.	0.11	0.04	0.03
	Front	Inter-	4.6	0.07	0.05	0.05	4.0- 6.1	N.D.	0.09	0.10	0.10
	Back	mediate	6.2	0.12	0.08	0.05	3.6- 4.7	N.D.	0.10	0.10	0.10
	Front	Min.	4.8	0.17	0.10	0.07	3.8- 5.6	N.D.	0.08	0.05	0.07
	Back	Min.	5.4	0.20	0.16	0.15	6.3- 7.0	N.D.	0.07	0.10	0.10
Upshur	Back	Full	0.25	0.09	N.D.	N.D.	2.7- 4.5	0.02	N.D.	N.D.	N.D.
Badger	Front	Full	0.90	0.15	N.D.	N.D.	2.8- 5.5	0.02	N.D.	N.D.	N.D.
	Back	Full	0.65	0.07	N.D.	N.D.	3.6- 4.6	0.02	N.D.	N.D.	N.D.
Blend	No. 11	Full	0.92	0.03	0.03	N.D.	7.7- 9.1	N.D.	N.D.	N.D.	N.D.
	No. 12	Full	0.71	0.04	0.04	0.04	7.3- 7.5	N.D.	N.D.	N.D.	N.D.
Wellmore	No. 11	Full	2.1	0.02	0.04	0.06	8.3- 9.3	N.D.	N.D.	N.D.	N.D.
Cactus (1)	No. 12	Full	1.8	0.01	0.01	0.01	6.9- 7.9	N.D.	N.D.	N.D.	N.D.
Mine Mouth C	ppt.	Full	1.5	0.01	N.D.	N.D.	6.6- 8.1	N.D.	N.D.	N.D.	N.D.
Mine Mouth D	ppt.	Full	0.42	0.04	N.D.	N.D.	7.1-10.0	N.D.	N.D.	N.D.	N.D.
Nora	No. 11	Full	0.10	N.D.	N.D.	N.D.	9.4- 9.8	0.02	N.D.	N.D.	N.D.
	No. 12	Full	0.72	0.01	N.D.	N.D.	4.1- 6.4	0.02	N.D.	N.D.	N.D.
Wellmore	No. 11	Full	7.2	0.54	0.64	N.D.	9.8-11.5	0.02	N.D.	N.D.	N.D.
Cactus (2)	No. 12	Full	5.4	0.27	0.31	N.D.	8.2- 9.0	0.02	0.02	0.01	N.D.
Ellsworth	No. 11	Full	2.4	0.09	0.08	0.08	10.5-12.3	0.02	0.11	0.16	0.16
	No. 12	Full	2.4	0.08	0.08	0.08	8.5- 9.4	0.02	0.16	0.16	0.16
Wellmore Ackiss	No. 11	Full	0.34	N.D.	N.D.	N.D.	7.3- 8.6	0.02	N.D.	N.D.	N.D.
	No. 12	Full	0.48	0.08	N.D.	N.D.	5.1- 6.8	0.02	0.04	0.02	
	No. 11	Min.	0.51				7.2- 9.1	0.02	N.D.	N.D.	N.D.
	No. 12	Min.	0.21				5.6- 5.8	0.02	0.01	N.D.	

*N.D. - below measurable levels

Table 41. Boron

Fly Ash	Source	Power	Bulk Trace Amount ug/g	Leaching, ug/ml			pH range	Influent conc. ug/ml	Treatment, ug/ml		
				1000ml	2000ml	4000ml			1500ml	3000ml	4000ml
Militant	Front	Full	N.A.	0.5	0.1	0.1	3.5- 6.6	2.8	2.5	2.8	2.8
	Back	Full	N.A.	0.8	0.3	0.2	3.8- 6.8	2.8	2.5	2.8	2.8
	Front	Full	N.A.	0.6	0.2	0.1	4.2- 6.7	2.8	2.2	2.5	2.6
	Back	Full	N.A.	1.1	0.3	0.3	3.6- 6.9	2.8	2.6	2.6	2.6
	Front	Inter-	N.A.	0.4	0.2	0.1	3.8- 7.2	2.8	2.4	2.8	2.6
	Back	mediate	N.A.	1.4	0.2	0.2	3.8- 5.9	2.8	2.6	3.0	3.0
	Front	Min.	N.A.	0.8	0.1	0.1	3.7- 6.9	2.8	2.6	2.6	2.6
	Back	Min.	N.A.	1.1	0.8	0.1	3.7- 7.3	2.8	2.6	2.6	2.6
Deep Hollow	Front	Full	N.A.	1.0	0.5	0.2	3.7- 5.1	3.3	2.6	3.1	3.1
	Back	Full	N.A.	1.2	0.6	0.2	3.8- 5.5	3.3	2.8	3.0	3.0
	Front	Inter-	N.A.	0.9	0.4	0.1	4.0- 6.1	3.3	3.0	3.3	3.3
	Back	mediate	N.A.	0.6	0.3	0.2	3.6- 4.7	3.3	3.0	3.2	3.3
	Front	Min.	N.A.	5.2	0.5	0.2	3.8- 5.6	3.3	2.6	3.1	3.4
	Back	Min.	N.A.	1.7	0.9	0.4	6.3- 7.0	3.3	2.6	3.0	3.0
Upshur	Back	Full	N.A.	13.5	0.3	N.D.*	2.7- 4.5	2.8	2.6	2.8	2.8
Badger	Front	Full	N.A.	11.0	0.5	N.D.	2.8- 5.5	2.8	2.4	2.7	2.8
	Back	Full	N.A.	9.1	0.3	N.D.	3.6- 4.6	2.8	2.6	2.8	2.8
Blend	No. 11	Full	N.A.	0.6	0.4	0.4	7.7- 9.1	3.3	2.7	3.8	4.2
	No. 12	Full	N.A.	14.6	5.4	1.3	7.3- 7.5	3.3	3.3	3.3	3.3
Wellmore Cactus (1)	No. 11	Full	N.A.	1.4	0.8	0.5	8.3- 9.3	3.3	2.7	3.8	3.8
	No. 12	Full	N.A.	15.0	7.0	1.0	6.9- 7.9	3.3	3.6	3.8	3.8
Mine Mouth C	ppt.	Full	N.A.	6.4	1.4	0.6	6.6- 8.1	3.3	3.0	3.3	3.4
Mine Mouth D	ppt.	Full	N.A.	2.2	0.3	0.3	7.1-10.0	3.3	2.6	3.3	3.3
Nora	No. 11	Full	N.A.	4.0	1.2	N.D.	9.4- 9.8	2.8	13.0	6.6	4.8
	No. 12	Full	N.A.	12.5	2.5	N.D.	4.1- 6.4	2.8	3.8	3.0	2.8
Wellmore Cactus (2)	No. 11	Full	N.A.	4.1	3.7	0.7	9.8-11.5	2.8	8.0	3.5	3.0
	No. 12	Full	N.A.	23.0	8.5	0.9	8.2- 9.0	2.8	2.8	2.8	2.8
Ellsworth	No. 11	Full	N.A.	21.5	4.5	2.5	10.5-12.3	2.8	15.4	25.0	25.0
	No. 12	Full	N.A.	50.0	9.5	4.0	8.5- 9.4	2.8	7.5	4.8	4.6
Wellmore Ackiss	No. 11	Full	N.A.	19.0	2.3	N.D.	7.3- 8.6	2.8	2.8	3.0	3.0
	No. 12	Full	N.A.	36.0	3.2	N.D.	5.1- 6.8	2.8	3.0	3.0	3.0
	No. 11	Min.	N.A.				7.2- 9.1	2.8	2.6	2.7	2.8
	No. 12	Min.	N.A.				5.6- 5.8	2.8	3.0	3.7	3.8

*N.D. - below measurable limits

Table 42. Tin

Fly Ash	Source	Power	Bulk Trace Amount ug/g	Leaching, ug/ml			pH range	Influent conc. ug/ml	Treatment, ug/ml		
				1000ml	2000ml	4000ml			1500ml	3000ml	4000ml
Militant	Front	Full	722	0.08	0.06	0.04	3.5- 6.6	1.01	2.70	4.30	4.80
	Back	Full	818	0.53	0.35	0.35	3.8- 6.8	1.01	1.20	1.20	1.20
	Front	Full	768	0.31	0.19	0.06	4.2- 6.7	1.01	3.40	3.40	3.50
	Back	Full	893	0.73	0.60	0.57	3.6- 6.9	1.01	1.20	1.20	1.20
	Front	Inter-	776	0.37	0.37	0.37	3.8- 7.2	1.01	2.10	2.50	3.10
	Back	mediate	798	0.75	0.20	0.10	3.8- 5.9	1.01	1.00	1.00	1.00
	Front	Min.	802	0.26	0.22	N.D.*	3.7- 6.9	1.01	3.60	4.40	4.60
	Back	Min.	893	0.09	0.06	0.05	3.7- 7.3	1.01	1.10	1.20	1.20
Deep Hollow	Front	Full	342	0.08	0.08	0.15	3.7- 5.1	0.07	0.07	0.10	0.13
	Back	Full	348	0.75	0.50	0.32	3.8- 5.5	0.07	0.20	0.20	0.25
	Front	Inter-	363	0.27	0.16	0.11	4.0- 6.1	0.07	0.30	0.30	0.30
	Back	mediate	385	0.31	0.31	0.31	3.6- 4.7	0.07	0.38	0.40	0.40
	Front	Min.	376	0.95	0.66	0.58	3.8- 5.6	0.07	0.40	0.40	0.40
	Back	Min.	392	0.78	0.69	0.65	6.3- 7.0	0.07	0.25	0.55	0.60
Upshur	Back	Full	132	0.30	0.03	N.D.	2.7- 4.5	1.01	14.2	17.7	17.8
Badger	Front	Full	174	0.30	0.03	N.D.	2.8- 5.5	1.01	15.6	15.7	15.8
	Back	Full	215	0.13	0.05	N.D.	3.6- 4.6	1.01	14.6	17.4	17.8
Blend	No. 11	Full	1144	0.05	0.03	0.03	7.7- 9.1	0.90	0.08	0.11	0.15
	No. 12	Full	1207	0.26	0.08	0.04	7.3- 7.5	0.90	0.30	0.40	0.55
Wellmore Cactus (2)	No. 11	Full	1514	0.09	0.07	0.05	8.3- 9.3	0.90	0.20	0.28	0.28
	No. 12	Full	1635	0.16	0.11	0.09	6.9- 7.9	0.90	0.50	0.50	0.60
Mine Mouth C	ppt.	Full	127	0.05	0.03	N.D.	6.6- 8.1	0.90	0.10	0.10	0.10
Mine Mouth D	ppt.	Full	169	0.09	0.05	0.06	7.1-10.0	0.90	0.05	0.08	0.10
Nora	No. 11	Full	76.4	0.12	0.05	N.D.	9.4- 9.8	1.01	0.50	0.75	1.18
	No. 12	Full	69.8	0.23	0.01	N.D.	4.1- 6.4	1.01	1.30	1.82	2.00
Wellmore Cactus (2)	No. 11	Full	257	60.0	48.0	1.42	9.8-11.5	1.01	1.50	2.26	2.68
	No. 12	Full	269	32.1	26.0	1.50	8.2- 9.0	1.01	2.60	2.60	2.60
Ellsworth	No. 11	Full	55.7	0.15	0.12	0.07	10.5-12.3	1.01	0.50	1.44	
	No. 12	Full	59.3	0.14	0.11	0.04	8.5- 9.4	1.01	0.69	1.10	1.10
Wellmore	No. 11	Full	64.4	0.16	0.06	N.D.	7.3- 8.6	1.01	1.20	1.20	1.20
	No. 12	Full	69.2	0.31	0.05	N.D.	5.1- 6.8	1.01	2.20	2.35	2.40
	No. 11	Min.	69.1				7.2- 9.1	1.01	2.10	2.50	2.55
	No. 12	Min.	74.2				5.6- 5.8	1.01	1.01	1.20	1.20

*N.D. - below measurable limits

Table 43. Molybdenum

Fly Ash	Source	Power	Bulk Trace Amount ug/g	Leaching, ug/ml			pH range	Influent conc. ug/ml	Treatment, ug/ml		
				1000ml	2000ml	4000ml			1500ml	3000ml	4000ml
Mine Mouth C	ppt.	Full	51.9	2.0	1.0	0.31	6.6- 8.1	3.0	3.0	3.0	3.0
Mine Mouth D	ppt.	Full	48.1	2.9	1.3	0.20	7.1-10.0	3.0	2.8	3.0	3.0
Blend	No. 11	Full	179	0.41	0.18	0.02	7.7- 9.1	3.0	2.4	2.7	2.8
	No. 12	Full	190	6.0	1.0	0.20	7.3- 7.5	3.0	1.7	2.2	2.5
Wellmore	No. 11	Full	178	1.8	0.30	0.02	8.3- 9.3	3.0	2.0	2.2	2.4
Cactus (1)	No. 12	Full	212	4.2	0.70	0.20	6.9- 7.9	3.0	2.4	3.0	3.0
Badger	Front	Full	113	4.2	1.2	N.D.*	2.8- 5.5	0.41	1.6	1.2	1.0
	Back	Full	134	2.6	0.92	N.D.	3.6- 4.6	0.41	1.1	0.96	0.91
Upshur	Back	Full	77.8	0.60	0.20	N.D.	2.7- 4.5	0.41	1.2	1.2	1.0
77	Front	Full	147	5.2	5.1	5.0	3.5- 6.6	0.41	2.2	2.0	1.9
	Back	Full	165	5.8	4.7	2.6	3.8- 6.8	0.41	1.0	0.68	0.66
	Front	Full	156	8.5	4.0	0.70	4.2- 6.7	0.41	0.85	0.60	0.58
	Back	Full	197	6.5	5.0	2.6	3.6- 6.9	0.41	2.2	1.6	0.84
	Front	Inter-	134	2.8	1.4	0.26	3.8- 7.2	0.41	1.5	0.80	0.70
	Back	mediate	98	3.2	2.2	0.74	3.8- 5.9	0.41	3.0	1.7	1.5
	Front	Min.	109	10.3	1.7	0.20	3.7- 5.1	0.41	2.2	0.82	0.62
	Back	Min.	134	11.3	4.8	2.7	3.7- 7.3	0.41			
Daep Hollow	Front	Full	157	0.50	0.25	0.25	3.7- 5.1	2.7	2.6	2.8	2.8
	Back	Full	162	0.70	0.50	0.50	3.8- 5.5	2.7	3.0	5.4	5.6
	Front	Inter-		0.57	0.25	N.D.	4.0- 6.1	2.7	2.6	2.8	2.9
	Back	mediate	164				3.6- 4.7	2.7	2.7	3.0	3.1
	Front	Min.	131	0.38	0.30	0.10	3.8- 5.6	2.7	2.1	2.7	2.7
	Back	Min.	164	1.20	0.75	0.30	6.3- 7.0	2.7	2.5	2.6	2.6
Nora	No. 11	Full	97	1.3	0.20	N.D.	9.4- 9.8	0.41	1.2	0.77	0.65
	No. 12	Full	118	4.4	0.35	N.D.	4.1- 6.4	0.41	0.89	1.0	1.1
Wellmore	No. 11	Full	131	4.9	2.4	N.D.	7.3- 8.6	0.41	0.57	0.51	0.50
Ackiss	No. 12	Full	123	4.9	1.1	N.D.	5.1- 6.8	0.41	0.86	0.62	0.52
	No. 11	Min.	122				7.2- 9.1	0.41	0.80	0.60	0.53
	No. 12	Min.	149				5.6- 5.8	0.41	0.77	0.71	0.70
Ellsworth	No. 11	Full	121	2.3	0.30	0.05	10.5-12.3	0.41	1.1	1.2	1.3
	No. 12	Full	135	3.8	0.50	0.25	8.5- 9.4	0.41	1.0	1.1	1.1
Wellmore	No. 11	Full	113	7.0	2.6	0.26	9.8-11.5	0.41	0.70	0.44	0.33
Cactus (2)	No. 12	Full	128	10.00	2.4	0.51	8.2- 9.0	0.41	0.67	0.53	0.51

*N.D. - below measurable limits

Table 44. Nickel

Fly Ash	Source	Power	Bulk Trace Amount ug/g	Leaching, ug/ml			pH range	Influent conc. ug/ml	Treatment, ug/ml		
				1000ml	2000ml	4000ml			1500ml	3000ml	4000ml
Militant	Front	Full	266	0.12	0.02	N.D.*	3.5- 6.6	0.09	0.12	0.09	0.09
	Back	Full	270	0.11	0.05	0.05	3.8- 6.8	0.09	0.18	0.12	0.10
	Front	Full	270	0.15	0.10	0.09	4.2- 6.7	0.09	0.03	0.03	0.04
	Back	Full	301	0.23	0.12	0.10	3.6- 6.9	0.09	0.22	0.09	0.09
	Front	Inter-	262	0.02	0.01	0.01	3.8- 7.2	0.09	0.22	0.10	0.09
	Back	mediate	316	0.02	0.01	N.D.	3.8- 5.9	0.09	0.22	0.10	0.09
	Front	Min.	246	0.02	N.D.	N.D.	3.7- 6.9	0.09	0.25	0.11	0.09
	Back	Min.	278	0.02	N.D.	N.D.	3.7- 7.3	0.09	0.08	0.08	0.08
Deep Hollow	Front	Full	268	0.10	0.04	N.D.	3.7- 5.1	0.11	0.07	0.09	0.11
	Back	Full	257	0.15	0.05	0.05	3.8- 5.5	0.11	0.03	0.03	0.03
	Front	Inter-	277	0.15	0.05	0.05	4.0- 6.1	0.11	0.11	0.11	0.11
	Back	mediate	289	0.15	0.08	0.08	3.6- 4.7	0.11	0.10	0.11	0.11
	Front	Min.	263	1.7	0.10	0.10	3.8- 5.6	0.11	0.07	0.04	0.05
	Back	Min.	260	0.20	0.14	0.14	6.3- 7.0	0.11	0.06	0.05	0.05
Upshur	Back	Full	226	0.80	N.D.	N.D.	2.7- 4.5	0.09	0.08	0.08	0.08
Badger	Front	Full	240	1.41	N.D.	N.D.	2.8- 5.5	0.09	0.06	0.08	0.10
	Back	Full	247	0.45	N.D.	N.D.	3.6- 4.6	0.09	0.13	0.10	0.07
Blend	No. 11	Full	219	0.01	N.D.	N.D.	7.7- 9.1	0.26	0.01	0.02	0.03
	No. 12	Full	227	0.02	N.D.	N.D.	7.3- 7.5	0.26	0.05	0.06	0.10
Wellmore	No. 11	Full	231	0.01	0.01	0.01	8.3- 9.3	0.26	0.08	0.02	0.01
Cactus (1)	No. 12	Full	246	0.02	0.01	0.01	6.9- 7.9	0.26	0.09	0.11	0.12
Mine Mouth C	ppt.	Full	181	0.03	N.D.	N.D.	6.6- 8.1	0.26	0.01	0.01	0.01
Mine Mouth D	ppt.	Full	210	0.30	0.01	N.D.	7.1-10.0	0.26	0.01	0.01	0.01
Nora	No. 11	Full	186	N.D.	N.D.	N.D.	9.4- 9.8	0.09	0.02	0.02	0.03
	No. 12	Full	248	0.10	N.D.	N.D.	4.1- 6.4	0.09	0.04	0.04	0.04
Wellmore	No. 11	Full	241	4.00	3.00	N.D.	9.8-11.5	0.09	0.02	0.02	0.02
Cactus (2)	No. 12	Full	256	2.00	1.80	N.D.	8.2- 9.0	0.09	0.03	0.03	0.04
Ellsworth	No. 11	Full	255	0.04	0.03	0.02	10.5-12.3	0.09	0.13	0.17	0.17
	No. 12	Full	259	0.04	0.03	0.02	8.5- 9.4	0.09	0.09	0.10	0.10
Wellmore	No. 11	Full	231	0.12	N.D.	N.D.	7.3- 8.6	0.09	0.02	0.02	0.03
Ackiss	No. 12	Full	243	0.90	0.04	N.D.	5.1- 6.8	0.09	0.08	0.05	
	No. 11	Min.	220				7.2- 9.1	0.09	0.02	0.02	0.02
	No. 12	Min.	218				5.6- 5.8	0.09	0.06	0.06	0.06

*N.D. - below measurable levels

Table 45. Lead

Fly Ash	Source	Power	Bulk Trace Amount ug/g	Leaching, ug/ml			pH range	Influent conc. ug/ml	Treatment, ug/ml		
				1000ml	2000ml	4000ml			1500ml	3000ml	4000ml
Line Mouth C	ppt.	Full	217	0.31	0.25	N.D.*	6.6- 8.1	1.8	0.42	0.50	0.56
Mine Mouth D	ppt.	Full	144	0.30	0.15	0.07	7.1-10.0	1.8	0.38	0.43	0.44
Blend	No. 11	Full	321	0.50	0.19	N.D.	7.7- 9.1	1.8	0.47	0.62	0.71
	No. 12	Full	442	0.64	0.61	0.61	7.3- 7.5	1.8	1.02	1.03	1.03
Wellmore	No. 11	Full	405	0.35	0.27	0.16	8.3- 9.3	1.8	0.88	0.68	0.60
Cactus (1)	No. 12	Full	509	0.65	0.41	0.23	6.9- 7.9	1.8	1.38	1.52	1.60
Badger	Front	Full	436	0.07	N.D.	N.D.	2.8- 5.5	0.62	0.76	0.85	0.88
	Back	Full	513	0.06	N.D.	N.D.	3.6- 4.6	0.62	0.41	0.44	0.45
Upshur	Back	Full	392	0.14	N.D.	N.D.	2.7- 4.5	0.62	0.50	0.65	0.71
79 Militant	Front	Full	520	0.47	0.19	0.03	3.5- 6.6	0.62	0.57	0.54	0.48
	Back	Full	861	0.96	0.84	0.70	3.8- 6.8	0.62	0.65	0.57	0.53
	Front	Full	537				4.2- 6.7	0.62	0.55	0.57	0.60
	Back	Full	800	1.01	0.37	0.09	3.6- 6.9	0.62	0.71	0.68	0.67
	Front	Inter-	482	0.06	0.06	0.06	3.8- 7.2	0.62	0.44	0.49	0.50
	Back	mediate	779	1.10	0.55	0.07	3.8- 5.9	0.62	0.50	0.55	0.56
	Front	Min.	425	1.40	0.08	N.D.	3.7- 5.1	0.62	0.24	0.33	0.34
	Back	Min.	787	1.06	0.78	0.09	3.7- 7.3	0.62	0.88	0.51	0.28
Deep Hollow	Front	Full	379	1.33	0.88	0.75	3.7- 5.1	0.35	0.36	0.41	0.43
	Back	Full	413	1.72	0.76	0.05	3.8- 5.5	0.35	0.39	0.38	0.39
	Front	Inter-		0.51	0.34	0.28	4.0- 6.1	0.35	0.46	0.42	0.40
	Back	mediate	501	1.09	0.87	0.79	3.6- 4.7	0.35	0.40	0.45	0.46
	Front	Min.	378	1.66	1.24	1.05	3.8- 5.6	0.35	0.56	0.48	0.44
	Back	Min.	485	2.15	1.64	1.12	6.3- 7.0	0.35	0.35	0.60	0.70
Wellmore	No. 11	Full	377	2.30	2.00	0.02	10.5-12.3	0.62	0.68	0.45	0.45
Cactus (2)	No. 12	Full	507	2.00	2.00	0.10	8.5- 9.4	0.62	0.55	0.46	0.43
Wellmore Ackiss	No. 11	Full	922	0.12	N.D.	N.D.	7.3- 8.6	0.62	0.49	0.41	0.40
	No. 12	Full	1056	0.20	N.D.	N.D.	5.1- 6.8	0.62			
	No. 11	Min.	1123				7.2- 9.1	0.62	0.70	0.51	0.49
	No. 12	Min.	1054				5.6- 5.8	0.62			
Nora	No. 11	Full	271	0.07	N.D.	N.D.	9.4- 9.8	0.62	0.93	0.78	0.73
	No. 12	Full	359	0.09	N.D.	N.D.	4.1- 6.4	0.62	0.90	0.76	0.68
Ellsworth	No. 11	Full	1154	0.73	0.53	0.29	10.5-12.3	0.62	1.44	1.63	1.68
	No. 12	Full	1015	0.55	0.53	0.52	8.5- 9.4	0.62	1.46	1.15	0.80

*N.D. - below measurable limits

Table 46. Copper

Fly Ash	Source	Power	Bulk Trace Amount ug/g	Leaching, ug/ml			pH range	Influent conc. ug/ml	Treatment, ug/ml		
				1000ml	2000ml	4000ml			1500ml	3000ml	4000ml
Mine Mouth C Ppt.		Full	147	0.04	N.D.	N.D.*	6.6- 8.1	0.01	N.D.	N.D.	N.D.*
Mine Mouth D Ppt.		Full	185	1.70	N.D.	N.D.	7.1-10.0	0.01	N.D.	N.D.	N.D.
Blend	No. 11	Full	284	N.D.	N.D.	N.D.	7.7- 9.1	0.01	N.D.	N.D.	N.D.
	No. 12	Full	381	0.05	0.05	0.04	7.3- 7.5	0.01	N.D.	N.D.	N.D.
Wellmore	No. 11	Full	243	0.01	N.D.	N.D.	8.3- 9.3	0.01	N.D.	N.D.	N.D.
Cactus (1)	No. 12	Full	325	0.01	0.01	0.01	6.9- 7.9	0.01	N.D.	N.D.	N.D.
Badger	Front	Full	206	12.6	0.08	N.D.	2.8- 5.5	0.09	0.04	0.07	0.09
	Back	Full	209	4.25	0.17	N.D.	3.6- 4.6	0.09	0.22	0.23	0.24
Upshur	Back	Full	162	6.55	0.20	N.D.	2.7- 4.5	0.09	0.08	0.08	0.07
Militant	Front	Full	251	N.D.	N.D.	N.D.	3.5- 6.6				
	Back	Full	290	N.D.	N.D.	N.D.	3.8- 6.8				
	Front	Full	233	N.D.	N.D.	N.D.	4.2- 6.7	0.09	0.12	0.10	0.10
	Back	Full	313	N.D.	N.D.	N.D.	3.6- 6.9	0.09	0.17	0.13	0.12
	Front	Inter-	279	0.05	N.D.	N.D.	3.8- 7.2	0.09	0.27	0.19	0.15
	Back	mediate	319	0.40	0.30	N.D.	3.8- 5.9	0.09	0.27	0.42	0.45
	Front	Min.	261	0.90	N.D.	N.D.	3.7- 5.1	0.09	0.15	0.10	0.08
	Back	Min.	304	0.09	N.D.	N.D.	3.7- 7.3	0.09			
Deep Hollow	Front	Full	345	N.D.	N.D.	N.D.	3.7- 5.1	0.01	N.D.	N.D.	N.D.
	Back	Full	296	0.85	0.10	N.D.	3.8- 5.5	0.01	N.D.	N.D.	N.D.
	Front	Inter-	318	0.96	0.20	N.D.	4.0- 6.1	0.01	N.D.	N.D.	N.D.
	Back	mediate	359				3.6- 4.7	0.01	N.D.	N.D.	N.D.
	Front	Min.	308	0.28	N.D.	N.D.	3.8- 5.6	0.01	N.D.	N.D.	N.D.
	Back	Min.	322	0.72	0.34	0.09	6.3- 7.0	0.01	N.D.	N.D.	N.D.
Nora	No. 11	Full	211	N.D.	N.D.	N.D.	9.4- 9.8	0.09	0.02	0.03	0.04
	No. 12	Full	217	0.05	N.D.	N.D.	4.1- 6.4	0.09	0.05	0.08	0.09
Wellmore	No. 11	Full	250	0.04	N.D.	N.D.	7.3- 8.6	0.09	0.03	0.05	0.07
Ackiss	No. 12	Full	248	0.70	0.02	N.D.	5.1- 6.8	0.09	0.10	0.08	0.08
	No. 11	Min.	246				7.2- 9.1	0.09	0.04	0.05	0.06
	No. 12	Min.	242				5.6- 5.8	0.09	0.09	0.09	0.09
Ellsworth	No. 11	Full	156	0.01	N.D.	N.D.	10.5-12.3	0.09	0.05	0.06	0.05
	No. 12	Full	207	0.28	N.D.	N.D.	8.5- 9.4	0.09	0.05	0.05	0.05
Wellmore	No. 11	Full	268	1.15	1.15	N.D.	9.8-11.5	0.09	0.05	0.06	0.08
Cactus (2)	No. 12	Full	281	2.80	1.65	N.D.	8.2- 9.0	0.09	0.05	0.05	0.05

*N.D. - below measurable limits

Table 47. Chromium

Fly Ash	Source	Power	Bulk Trace Amount ug/g	Leaching, ug/ml			pH range	Influent conc. ug/ml	Treatment		
				1000ml	2000ml	4000ml			1500ml	3000ml	4000ml
Mine Mouth C	ppt.	Full	178	0.25	0.12	0.03	6.6- 8.1	0.48	0.19	0.19	0.19
Mine Mouth D	ppt.	Full	244	0.24	0.05	0.01	7.1-10.0	0.48	0.19	0.19	0.19
Blend	No. 11	Full	268	0.18	0.13	0.08	7.7- 9.1	0.48	0.30	0.30	0.30
	No. 12	Full	247	0.06	0.06	0.04	7.3- 7.5	0.48	0.30	0.30	0.30
Wellmore	No. 11	Full	225	0.17	0.14	0.13	8.3- 9.3	0.48	0.30	0.30	0.32
Cactus (1)	No. 12	Full	289	0.09	0.08	0.04	6.9- 7.9	0.48	0.30	0.40	0.43
Badger	Front	Full	300	0.95	0.03	N.D.*	2.8- 5.5	0.09	0.04	0.04	0.04
	Back	Full	340	0.07	N.D.	N.D.	3.6- 4.6	0.09	N.D.	N.D.	N.D.*
Upshur	Back	Full	319	1.50	N.D.	N.D.	2.7- 4.5	0.09	0.02	0.01	N.D.
81 Militant	Front	Full	290	0.05	0.05	N.D.	3.5- 6.6	0.09	0.09	0.09	0.09
	Back	Full	298	0.15	0.10	0.07	3.8- 6.8	0.09	0.02	0.02	0.02
	Front	Full	282	0.10	0.05	0.01	4.2- 6.7	0.09	0.05	N.D.	N.D.
	Back	Full	336	0.30	0.25	0.22	3.6- 6.9	0.09	0.05	N.D.	N.D.
	Front	Inter-	245	0.10	0.10	0.10	3.8- 7.2	0.09	0.05	0.05	0.05
	Back	mediate	304	0.10	N.D.	N.D.	3.8- 5.9	0.09	N.D.	N.D.	N.D.
	Front	Min.	259	0.18	0.03	N.D.	3.7- 5.1	0.09	N.D.	N.D.	N.D.
	Back	Min.	281	0.10	0.10	0.08	3.7- 7.3	0.09	0.05	N.D.	N.D.
Deep Hollow	Front	Full	325	0.20	0.14	0.13	3.7- 5.1	0.18	0.18	0.18	0.18
	Back	Full	278	0.20	0.04	N.D.	3.8- 5.5	0.18	0.18	0.18	0.18
	Front	Inter-		0.08	0.06	0.04	4.0- 6.1	0.18	0.18	0.18	0.18
	Back	mediate	319	0.19	0.16	0.14	3.6- 4.7	0.18	0.18	0.18	0.18
	Front	Min.	259	0.33	0.18	0.15	3.8- 5.6	0.18	0.18	0.18	0.18
	Back	Min.	281	0.49	0.24	0.18	6.3- 7.0	0.18	0.18	0.18	0.18
Nora	No. 11	Full	180	0.20	N.D.	N.D.	9.4- 9.8	0.09	0.30	0.24	0.23
	No. 12	Full	257	0.04	N.D.	N.D.	4.1- 6.4	0.09	0.15	0.09	0.07
Wellmore	No. 11	Full	254	0.05	N.D.	N.D.	7.3- 8.6	0.09	0.06	0.02	0.02
Ackiss	No. 12	Full	288	0.21	0.02	N.D.	5.1- 6.8	0.09	0.09	0.02	
	No. 11	Min.	270				7.2- 9.1	0.09	0.09	0.09	0.03
	No. 12	Min.	295				5.6- 5.8	0.09	0.09	0.03	
Ellsworth	No. 11	Full	319	0.86	0.59	0.34	10.5-12.3	0.09	1.02	0.84	0.67
	No. 12	Full	315	0.47	0.34	0.28	8.5- 9.4	0.09	0.40	0.31	0.27
Wellmore	No. 11	Full	222	0.13	0.06	0.03	9.8-11.5	0.09	0.20	0.10	
Cactus (2)	No. 12	Full	275	1.10	1.01	0.02	8.2- 9.0	0.09	0.09	0.07	0.06

*N.D. - below measurable limits

Table 48. Zinc

Fly Ash	Source	Power	Bulk Trace Amount ug/g	Leaching, ug/ml			pH range	Influent conc. ug/ml	Treatment, ug/ml		
				1000ml	2000ml	4000ml			1500ml	3000ml	4000ml
Mine Mouth C	ppt.	Full	238	0.23	0.01	0.01	6.6- 8.1	0.16	0.5	0.5	
Mine Mouth D	ppt.	Full	237	2.60	0.04	0.04	7.1-10.0	0.16	0.015	0.03	0.035
Blend	No. 11	Full	219	0.03	N.D.	N.D.*	7.7- 9.1	0.16	0.06	0.055	0.05
	No. 12	Full	236	0.08	0.08	0.08	7.3- 7.5	0.16	0.075	0.055	0.05
Wellmore	No. 11	Full	159	0.01	N.D.	N.D.	8.3- 9.3	0.16	0.02	0.04	0.06
Cactus (1)	No. 12	Full	235	0.07	0.07	0.07	6.9- 7.9	0.16	0.10	0.10	0.10
Badger	Back	Full	247	3.00	0.60	N.D.	3.6- 4.6	1.48	0.18	0.10	0.09
Upshur	Back	Full	209	3.50	0.42	0.21	2.7- 4.5	1.48	0.43	0.30	0.26
Militant	Front	Full	379				3.5- 6.6	1.48	0.05	0.06	0.06
	Back	Full	454	0.40	0.18	0.05	3.8- 6.8	1.48	0.14	0.13	0.11
	Front	Inter-	325	0.90	0.51	0.30	3.8- 7.2	1.48	0.35	0.30	0.30
	Back	mediate	453	1.60	1.20	0.27	3.8- 5.9	1.48	0.33	0.30	
	Front	Min.	298	0.25	0.15	0.07	3.7- 5.1	1.48	0.30	0.18	0.17
Deep Hollow	Front	Full	264	1.62	1.40	1.40	3.7- 5.1	0.06	0.33	0.23	0.20
	Back	Full	307	0.18	0.13	0.05	3.8- 5.5	0.06	0.33	0.23	0.20
	Front	Inter-	301	0.55	0.43	0.21	4.0- 6.1	0.06	0.40	0.34	0.34
	Back	mediate	396	2.38	1.50	1.50	3.6- 4.7	0.06	0.40	0.34	0.34
	Front	Min.	258	1.44	0.67	0.60	3.8- 5.6	0.06	0.11	0.09	0.09
	Back	Min.	266	0.18	0.08	0.02	6.3- 7.0	0.06	0.11	0.09	0.09
Nora	No. 11	Full	212	0.03	0.03	N.D.	9.4- 9.8	1.48	0.02	0.04	0.05
	No. 12	Full	357	3.00	N.D.	N.D.	4.1- 6.4	1.48	0.12	0.20	0.26
Wellmore	No. 11	Full	242	0.13	0.11	N.D.	7.3- 8.6	1.48	0.05	0.05	0.08
Ackiss	No. 12	Full	357	0.90	0.21	N.D.	5.1- 6.8	1.48	0.06		
	No. 11	Min.	241				7.2- 9.1	1.48	0.05	0.05	0.06
	No. 12	Min.	382				5.6- 5.8	1.48	0.44	0.63	
Ellsworth	No. 11	Full	187	N.D.	N.D.	N.D.	10.5-12.3	1.48	0.03	0.07	
	No. 12	Full	305	0.25	N.D.	N.D.	8.5- 9.4	1.48	0.12	0.15	
Wellmore	No. 11	Full	280	20.0	15.0	0.07	9.8-11.5	1.48	0.05	0.05	0.06
Cactus (2)	No. 12	Full	308	10.2	10.2	0.06	8.5- 9.0	1.48	0.05	0.05	0.06

*N.D. - below measurable levels

Table 49. Manganese

Fly Ash	Source	Power	Bulk Trace Amount ug/g	Leaching, ug/ml			pH range	Influent conc. ug/ml	Treatment, ug/ml		
				1000ml	2000ml	4000ml			1500ml	3000ml	4000ml
Mine Mouth C	ppt.	Full	170	0.03	N.D.	N.D.*	6.6- 8.1	0.24	0.02	0.02	
Mine Mouth D	ppt.	Full	189	0.30	0.04	0.04	7.1-10.0	0.24	0.02	0.02	0.02
Blend	No. 11	Full	364	N.D.	N.D.	N.D.	7.7- 9.1	0.24	0.03	0.04	0.04
	No. 12	Full	379	0.40	0.11	0.04	7.3- 7.5	0.24	0.05	0.04	
Wellmore	No. 11	Full	300	N.D.	N.D.	N.D.	8.3- 9.3	0.24	0.02	0.02	0.02
Cactus (1)	No. 12	Full	316	0.29	0.09	0.04	6.9- 7.9	0.24	0.05	0.06	0.06
Badger	Back	Full	138	0.65	0.01	N.D.	3.6- 4.6	0.40	1.77	1.60	1.58
Upshur	Back	Full	166	0.71	0.02	N.D.	2.7- 4.5	0.40	0.88	0.75	0.63
Militant ∞	Front	Full	212	0.95	0.40	0.10	3.5- 6.6	0.40	0.40	0.22	0.18
	Back	Full	240	1.20	0.60	0.03	3.8- 6.8	0.40	0.40	0.40	0.28
	Front	Full	247	2.50	0.73	0.20	4.2- 6.7	0.40	0.02	0.02	0.02
	Back	Full	263	2.12	0.87	0.17	3.6- 6.9	0.40	0.54	0.27	0.18
	Front	Inter-	221				3.8- 7.2	0.40	0.40	0.22	0.19
	Back	mediate	240				3.8- 5.9	0.40	0.54	0.25	
	Front	Min.	197				3.7- 5.1	0.40	0.48	0.36	0.25
	Back	Min.	214	0.10	N.D.	N.D.	3.7- 7.3	0.40	0.50	0.14	0.13
Deep Hollow	Front	Full	155	0.11	0.02	0.02	3.7- 5.1	0.24	0.17	0.24	0.24
	Back	Full	153	0.11	0.02	0.02	3.8- 5.5	0.24	0.05	0.05	0.05
	Front	Inter-	120	0.02	0.02	0.01	4.0- 6.1	0.24	0.24	0.24	0.24
	Back	mediate	165	0.10	0.05	0.02	3.6- 4.7	0.24	0.24	0.24	0.24
	Front	Min.	143	0.13	0.05	0.01	3.8- 5.6	0.24	0.07	0.07	0.07
	Back	Min.	147	0.13	0.03	0.01	6.3- 7.0	0.24	0.07	0.07	0.07
Nora	No. 11	Full	289	N.D.	N.D.	N.D.	9.4- 9.8	0.40	0.02	0.02	0.02
	No. 12	Full	268	0.15	N.D.	N.D.	4.1- 6.4	0.40	1.45	0.60	0.52
Wellmore	No. 11	Full	289	0.37	0.04	N.D.	7.3- 8.6	0.40	0.02	0.03	0.03
Ackiss	No. 12	Full	296	1.52	0.04	N.D.	5.1- 6.8	0.40	0.04	0.39	
	No. 11	Min.	242				7.2- 9.1	0.40	0.02	0.02	0.03
	No. 12	Min.	313				5.6- 5.8	0.40	0.34	0.33	
Ellsworth	No. 11	Full	233	0.02	0.03	0.04	10.5-12.3	0.40	0.19	0.22	
	No. 12	Full	265	N.D.	N.D.	N.D.	8.5- 9.4	0.40	0.22	0.27	
Wellmore	No. 11	Full	250	9.9	2.4	N.D.	9.8-11.5	0.40	0.03	0.05	0.05
Cactus (2)	No. 12	Full	271	5.7	4.8	0.07	8.5- 9.0	0.40	0.12	0.18	0.22

*N.D. - below measurable limits

Table 50. Iron

Fly Ash	Source	Power	Bulk Trace Amount ug/g	Leaching, ug/ml			pH range	Influent conc. ug/ml	Treatment, ug/ml		
				1000ml	2000ml	4000ml			1500ml	3000ml	4000ml
Mine Mouth C	ppt.	Full	52.7	0.12	0.01	N.D.*	6.6- 8.1	0.22	0.18	0.22	
Mine Mouth D	ppt.	Full	18.3	10.0	0.03	0.03	7.1-10.0	0.22	0.03	0.06	0.07
Blend	No. 11	Full	13.5	0.02	0.02	0.02	7.7- 9.1	0.22	0.01	0.05	0.07
	No. 12	Full	13.3	0.04	0.04	0.02	7.3- 7.5	0.22	0.08	0.10	
Wellmore	No. 11	Full	13.8	0.06	0.04	0.03	8.3- 9.3	0.22	0.06	0.06	0.07
Cactus (1)	No. 12	Full	14.6	0.03	0.03	0.03	6.9- 7.9	0.22	0.10	0.10	0.10
Badger	Front	Full	11.8	20.0	0.14	N.D.	2.8- 5.5	0.10	0.10	0.10	0.10
	Back	Full	12.1	3.25	0.01	N.D.	3.6- 4.6	0.10	0.06	0.06	0.06
Upshur	Back	Full	47.5	3.50	N.D.	N.D.	2.7- 4.5	0.10	0.08	0.10	0.10
84 Militant	Front	Full	12.4	0.50	N.D.	N.D.	3.5- 6.6	0.10	0.07	0.06	
	Back	Full	11.8	0.72	N.D.	N.D.	3.8- 6.8	0.10	0.09	0.10	
	Front	Full	13.9	0.45	N.D.	N.D.	4.2- 6.7	0.10	0.05	0.05	0.05
	Back	Full	12.7	0.75	N.D.	N.D.	3.6- 6.9	0.10	0.07	0.08	0.08
	Front	Inter-	13.8	0.90	N.D.	N.D.	3.8- 7.2	0.10	0.05	0.05	0.05
	Back	mediate	11.5	1.25	0.03	N.D.	3.8- 5.9	0.10	0.06	0.07	
	Front	Min.	13.8	0.95	N.D.	N.D.	3.7- 5.1	0.10	0.06	0.06	0.06
	Back	Min.	11.5	1.40	N.D.	N.D.	3.7- 7.3	0.10	0.09	0.06	
Deep Hollow	Front	Full	12.9	0.18	N.D.	N.D.	3.7- 5.1	0.05	0.08	0.08	0.08
	Back	Full	13.2	0.08	0.02	N.D.	3.8- 5.5	0.05	0.125	0.125	0.10
	Front	Inter-	13.2	0.27	0.03	N.D.	4.0- 6.1	0.05	0.04	0.04	0.03
	Back	mediate	12.4	0.30	N.D.	N.D.	3.6- 4.7	0.05	0.05	0.05	
	Front	Min.	13.5	0.35	N.D.	N.D.	3.8- 5.6	0.05	0.03	0.04	0.04
	Back	Min.	12.5	0.31	0.06	N.D.	6.3- 7.0	0.05	0.05	0.05	0.05
Nora	No. 11	Full	15.6	0.02	0.02	N.D.	9.4- 9.8	0.10	0.04	0.05	0.05
	No. 12	Full	14.3	0.23	N.D.	N.D.	4.1- 6.4	0.10	0.07	0.06	
Wellmore	No. 11	Full	17.4	N.D.	N.D.	N.D.	7.3- 8.6	0.10	0.05	0.07	0.08
Ackiss	No. 12	Full	15.2	0.08	N.D.	N.D.	5.1- 6.8	0.10	0.10	0.08	
	No. 11	Min.	16.1				7.2- 9.1	0.10	0.08	0.10	0.10
	No. 12	Min.	15.7				5.6- 5.8	0.10	0.10	0.10	
Ellsworth	No. 11	Full	15.4	0.05	0.05	0.03	10.5-12.3	0.10	0.22	0.25	
	No. 12	Full	13.4	0.14	0.05	N.D.	8.5- 9.4	0.10	0.175	0.20	
Wellmore	No. 11	Full	11.8	10.0	8.0	N.D.	9.8-11.5	0.10	0.10	0.10	
Cactus (2)	No. 12	Full	12.9	15.0	9.50	0.01	8.2- 9.0	0.10	0.10	0.10	

*N.D. - below measurable limits

The magnitude of leaching is indicated by the concentration of a specific element in the leachate sample after 1000 ml, 2000 ml and 4000 ml of leachates had been generated from the fly ash samples.

For the case of nickel where all of the #12 fly ashes contain more nickel than the #11 fly ashes, only the difference in the Nora and Wellmore Ackiss fly ashes leaching of nickel can be correlated with the differences in the amount of nickel present in these fly ashes. The Blend, Wellmore Cactus #1 and the Ellsworth fly ashes collected from the #11 and #12 precipitators exhibited comparable leaching. On the other hand, the Wellmore Cactus #2 fly ashes collected from the #11 precipitator leaches more nickel than their respective fly ashes collected from the #12 fly ashes (see Table 44).

For the case of the lead where five of the six fly ashes collected from the #12 precipitator contain more lead than the fly ashes collected from the #11 precipitator, only the Blend, Wellmore Cactus #1, Nora and Wellmore Ackiss fly ashes collected from the #12 precipitator leach more lead than the fly ashes collected from the #11 precipitator. The Ellsworth fly ash leaching properties can also be related to its amount in the fly ash, even though the #11 Ellsworth fly ash contained the larger amount of lead (see Table 45).

Only the difference in trace amount of chromium present between the Blend, Ellsworth, Wellmore Ackiss and Wellmore Cactus #2 fly ashes produced in the #11 and #12 boilers can be related to the difference in chromium leaching exhibited by these fly ashes (see Table 47). The fly ash with the greater amount of a specific element leaches more of this element. However, in contrast, the Nora and Wellmore Cactus #1 fly ashes which contained the smaller amounts of chromium exhibited more chromium leaching.

Only the amounts of iron present in the Wellmore Cactus #2 fly ashes collected from the #11 and #12 boiler can be correlated with the amount of iron

leaching exhibited by this fly ash. The member of the pair of Blend, Wellmore Cactus #1, Nora, Ellsworth, and Wellmore Ackiss fly ashes samples which contain the smaller amounts of iron are observed to exhibit the greatest amount of leaching.

The above results indicate that of the eleven elements analyzed in the leachate from the fly ash samples, only the difference in amounts of cadmium, boron, tin, molybdenum, manganese, chromium, lead, zinc and copper present in the fly ash samples can be correlated with the difference in leaching from the majority of the low fusion fly ashes examined. The lack of correlation between their differences in the amounts of nickel, and iron present in the majority of the fly ashes and their differences in leachability suggests that these elements are in a matrix that is readily not solubilized by the water wash used to generate the leachate. Hansen and Fischer ⁽¹²⁾ show the iron to be primarily in the insoluble aluminum silicate matrix and nickel appears to be associated with an acid insoluble phase.

High Fusion Fly Ashes

An examination of the different leaching results obtained with the high fusion fly ashes reveals that there is a correlation between the differences in concentration of the eleven elements analyzed in the leachate and the difference amounts of these elements present in all of the fly ash samples with the exception of the Badger fly ashes. The difference in amounts of the elements present in the high fusion fly ashes were shown earlier to be dependent upon their amounts in their respective coals and the particle size of the fly ash particles.

An examination of Table 40 through Table 49 reveals that in general the fly ash samples collected from the back precipitators contained greater

amounts of Cd, B, Sn, Mo, Ni, Pb, Cu, Cr, Zn and Mn and leached more of these elements than the fly ash samples collected from the front precipitators. The fly ash samples collected from the front and back precipitator were produced from their respective coals at the same time under the same boiler conditions. The Badger fly ashes on the other hand show no trend between its difference in leaching of the above elements and the difference in the amount of element present in this particular fly ash samples. Only the differences in leaching of Cd, Sn and Mn could be related to their differences in the amount present in the fly ash samples (see Table 40, Table 42 and Table 49). For the case of Mo, Ni, Pb, Cu, Cr and Fe, a comparison of the fly ash samples produced from the same Badger coal show that the fly ash samples with the smaller amounts of these elements actually leach the greater amounts of these elements (see Tables 43, 44, 45, 46, 47 and 50). The reasons for the Badger fly ashes exhibiting different leaching behavior than the other high fusion fly ashes examined cannot be explained.

Reduction in boiler temperatures as represented by power generation reduction appear to favor the leaching of the above elements from the high fusion fly ashes even though boiler temperatures was shown earlier not to influence the distributions of the above elements in these fly ash samples. This is shown by comparisons between the leaching exhibited by the Deep Hollow fly ashes collected from the front precipitators produced under intermediate and minimum power generation, or the Deep Hollow fly ashes collected from the back precipitators produced under full and minimum power. These comparisons are made because the size distribution of fly ash samples are comparable.

An comparison of the leaching results between the Deep Hollow fly ash samples collected in the front precipitator under intermediate and minimum power or the fly ash samples collected from the back precipitator under

intermediate and minimum power or the fly ash samples collected from the back precipitators under full and minimum power show that the fly ashes produced under minimum power leach more Cd, B, Sn, Mo, Ni, Cu, Cr, Zn, Mn and Fe than the fly ash samples produced under high power generation levels (see Tables 40, 41, 42, 43, 44, 45, 47, 48, 49, and 50). Only Copper is the exception. More Copper is leached from the fly ashes produced in the higher power levels than the lower power levels (see Table 46). In these comparisons, since the amount of the elements present in these fly ash samples produced at different power levels were either comparable or the fly ash samples produced at the higher power levels contain the larger amounts of the above elements. The effect of reduced power levels (lower boiler temperatures) appear to more than compensate for the influence of the larger amounts of the above elements in the ash samples on their leaching characteristics.

The reduction in boiler temperatures were also found to influence the leaching characteristic of the Militant high fusion fly ashes. Similar particle sizes were obtained with the fly ash samples collected from the (1) back precipitator produced during the first full power generation run and the front precipitator during the minimum power run, (2) collected from the back precipitator during the second full power run and the minimum power run, (3) collected from the front precipitator during the first full power run and the intermediate power run, and (4) collected from the precipitator during the second full power run and the back precipitator during the intermediate power run. Comparisons of the leaching exhibited by these Militant fly ash samples generated under different power levels show that reduced power generation (lower boiler temperatures) leads to greater

leaching of B, Mo, Pb, Cu, Cr, Zn and Fe. Only the leaching of Cd, Sn, Ni and Mn did not follow this behavior.

SUMMARY OF FACTORS INFLUENCING FLY ASH LEACHING

The difference in leaching of Cadmium, Boron, Tin, Molybdenum, Nickel, Lead, Copper, Chromium, Zinc, Manganese and Iron from both the high fusion and low fusion fly ashes in general were found to be dependent upon the differences in trace amounts of these elements present in the fly ash, the differences in the size of the fly ash particles and the differences in boiler temperatures encountered by the fly ashes during their generation.

The differences in the amount an element is leached from the fly ashes was found to be related directly to the concentration in the fly ash for a majority of the elements examined. The differences in the amount of an element present in the high fusion fly ashes in turn is determined by its concentration in the coal and the size of the fly ash particles. The smaller fly ash particles were found to contain greater amounts of a specific element than the larger particles. In comparison, the differences in the amount of a specific element found in the low ash fusion was observed to be dependent on its concentration in the coal, its particle size as well as boiler temperatures. The smaller low fusion fly ash particles and lower boiler temperatures when compared to the larger particles and higher boiler temperatures contained the greater amounts of the majority of the above elements.

There appears to be some correlation between the differences in trace element leaching observed for the fly ashes and the concentration of these elements at the surface of the fly ash particles provided that greater than 50% of the element is concentrated at the surface. Hansen and Fischer ⁽¹²⁾ have

shown that the major portion of the Cd, Cu, Zn, Cr, Pb and Mo present in the fly ash particles are concentrated at the surface of the fly ash particles. Our results reveal that the difference in leaching of the Cd, Cu, Zn, Cr, Pb and Mo by a majority of the fly ashes can be correlated with the differences in the amounts of those elements present in the fly ashes. However, when the trace elements are not concentrated at the surface, as was reported by Hansen and Fischer to be the case for Ni and Fe, ⁽¹²⁾ our results indicate no correlation between the difference in leaching by the fusion fly ashes and the differences in the amounts of these elements present in these fly ashes.

The exceptions to the above correlations is Mn, although, the concentration of Mn at the surface of the fly ash particles were reported by Hansen and Fischer to be less than 50%, our results show that most of the differences in leaching exhibited by the Blend, Wellmore Cactus #1, Militant, Deep Hollow and Wellmore Ackiss fly ashes can be correlated with the differences in the amount of manganese present in these fly ashes.

Differences in the leaching of the above elements as they relate to particle size and boiler temperatures is explained as follows. A comparison of the elements leached from small fly ash particles and large fly ash produced from the same coal under the same boiler conditions show the smaller particles in general leach greater quantities of the above elements than the larger particles. If the distribution of leachate elements within the different phases present in the fly ash are the same, the smaller particles would expose a greater leachable surface area.

Boiler temperatures probably influence the leaching characters of the fly ashes by fixation of the leachate elements. The different leaching results obtained with the low fusion fly ashes produced from the same coal at the same time indicated that operation of the boiler at temperatures

above the ash fusion temperatures along with the ash remaining in the fused state for longer lengths of time can reduce the leaching exhibited by the fly ashes. These conditions were encountered in the #11 Boiler B when compared to the conditions in the #12 Boiler B.

REMOVAL

Analysis of Ash Pond Effluents

Three separate ash pond samples were used during this investigation to evaluate the effectiveness of the fly ash in treating ash pond effluent. Three separate samples were collected from an actual ash pond at different times to provide a range of trace element concentrations that may be encountered in ash pond effluents. These results of the analysis of these three samples are presented in Table 51. A neutral pH of 7 was measured in all ash pond samples.

Sample A was used to evaluate the effectiveness of the Blend, Wellmore Cactus #1, Mine Mouth C and Mine Mouth D fly ashes in removing Cadmium, Boron, Tin, Nickel, Lead, Molybdenum, Copper, Chromium, Zinc, Manganese and Iron from ash pond effluent.

Sample B was used to evaluate the effectiveness of Deep Hollow fly ash produced at different power generating levels in treating these elements.

Wellmore Cactus #2, Ellsworth, Wellmore Ackiss, Nora, Militant produced at different power generating levels, Upshur and Badger fly ashes were evaluated using Sample C.

A comparison of the results obtained with these seven fly ashes using the same ash pond sample will permit evaluation of the effect of ash bulk and surface composition, ash fusion temperatures, boiler operating temperatures as well as different power level generation on sorbate characteristics of the fly ashes.

Table 51. Elemental Concentration of Actual Ash Pond Effluent Used
In Fly Ash Sorbate Characterization

Element	Sample A mg/l	Sample B mg/l	Sample C mg/l
Cadmium	N.D.*	N.D.*	0.02
Boron	3.30	3.30	2.80
Tin	0.90	2.07	1.01
Molybdenum	3.0	2.70	0.41
Nickel	0.26	0.11	0.09
Lead	1.80	0.35	0.62
Copper	.01	0.01	0.09
Chromium	.48	0.18	0.09
Zinc	.16	0.06	1.48
Manganese	.24	0.24	0.40
Iron	0.22	0.05	0.10
Arsenic	0.16	0.15	0.13

*N.D. - below measurable limits

The reduction in the concentration of the elements in the ash pond samples due to alkaline precipitation was examined by raising the pH of the ash pond samples to alkaline conditions. The addition of sodium hydroxide to the ash pond samples results in no significant reductions in the trace element concentration present in the ash pond samples.

Cadmium Removal

Only the fly ashes produced from the Militant, Upshur, Badger, Nora, Wellmore Cactus #2, Ellsworth and Wellmore Ackiss coals could be investigated for cadmium removal because only the ash pond sample (see Sample C - Table 52) used in this evaluation contained a low but measurable concentration of Cadmium (0.02 ppm). The experimental results from which the information in Table 40 through Table 50 was obtained is presented in Figures 241 through Figures 414 (see appendicies).

A comparison of the results of the analysis of Cadmium remaining in the ash pond effluent after treatment showed that the fly ashes produced from the Militant, Upshur, Badger, Wellmore Ackiss, Nora and Wellmore Cactus #2 coal, all provided Cadmium removals even though all of these fly ashes initially leached Cadmium. Analysis of the treated effluent in most cases revealed that the concentration of Cadmium in the ash pond was reduced to levels that could not be measured (see Table 40).

The treated effluent using the fly ashes produced from the Ellsworth, Deep Hollow coals and the #12 fly ash produced under full power from the Wellmore Ackiss Coal were found to continuously leach Cadmium (see Table 40). The Cadmium concentration in the ash pond effluent (Sample C) used to evaluate the Ellsworth fly ash is only 0.02 ppm. Yet, the average concentration of Cadmium in the effluent treated with the Ellsworth fly ash was approximately 0.15 ppm. For the case of the Deep Hollow fly ashes, no measurable

Cadmium was observed in ash pond Sample B. However, the treated ash pond sample using these fly ashes produced under full, intermediate and minimum power generation showed Cadmium concentrations in the 0.1 ppm range. The #12 Wellmore Ackiss fly ashes continued to leach Cadmium in the 0.02 ppm concentration range.

The reasons for the continued Cadmium leaching exhibited by the Ellsworth, Deep Hollow and #12 Wellmore Ackiss fly ashes is not understood at this time. The pH of the treated ash pond samples does not appear to be a factor in the continued leaching of Cadmium. The treated sample from the Deep Hollow and Wellmore Ackiss fly ashes exhibited acidic pH's, whereas, the treated samples from the Ellsworth fly ash are alkaline (see Table 40). Yet, these fly ashes exhibit significant leaching.

Boron Removal

The effectiveness of the fly ash samples produced from the twelve different coals under different boiler firing conditions were evaluated for Boron removal. A comparison of the results of the analysis for Boron removal in the ash pond Samples A and Sample B after treatment showed that some Boron removals were obtained with the fly ashes produced at different power levels from the Deep Hollow, Mine Mouth C and Mine Mouth D coals as well as the #11 fly ashes from the Blend and Wellmore Cactus #1 coals.

Ranking of these fly ashes based upon the amount of Boron remaining in the effluent after treatment of 1500 ml of ash pond samples show that the Deep Hollow high fusion fly ash samples collected from both front and back precipitator under full and minimum power and the Mine Mouth D fly ash all reduced the Boron from 3.30 ppm to essentially 2.60 ppm (see Table 41). This represents a Boron removal of about 20% after treatment of 1500 ml of ash pond sample. Analysis of the effluent after treatment of 3000 ml and 4000 ml

of ash pond sample showed only the Deep Hollow fly ashes continuing to reduce Boron from 3.30 ppm to an average of about 3.05 ppm. The analysis of the effluent after treatment with the Mine Mouth D fly ash indicated breakthrough base upon the concentration of the Boron in the treated effluent being equal to that in the initial ash pond samples.

A comparison of the results of the analysis for Boron concentration in the effluent after treatment of 1500 ml of ash pond Sample C with the Upshur, Badger, Nora, Wellmore Cactus #2, Ellsworth fly ashes and the Wellmore Ackiss fly ashes generated under full and minimum power generation show Boron removals being achieved with the Militant, Upshur, Badger and the outlet Wellmore Ackiss fly ashes. The rest of these fly ashes continued to leach significant amounts of Boron (see Table 41).

The most effective treatment of the Boron in ash pond Sample C was achieved with the high fusion Militant fly ash collected from the front precipitator under full power generation. This fly ash reduced the Boron in the ash pond Sample C from 2.8 ppm to 2.2 ppm. This reduction represents a Boron removal of about 20% after treatment of 1500 ml of ash pond samples.

An examination of the Boron treatment results achieved with the Blend, Wellmore Cactus #1, Nora, Wellmore Cactus #2, Ellsworth, Wellmore Ackiss low fusion fly ashes and the Militant, Deep Hollow, Badger, Upshur, Mine Mouth C and Mine Mouth D high fusion fly ashes indicate that the high fusion fly ashes provide better Boron treatment than the low fusion fly ashes. Neither the particle size of the high fusion fly ashes or boiler temperatures, as represented by power reductions, appear to influence the Boron removals. A comparison of the concentrations of the Boron remaining in the effluent after treatment of 1500 ml, 3000 ml, 4000 ml of ash pond samples with the Militant and Deep Hollow fly ashes show no clear trend where either the removals

achieved by larger fly ash or the smaller fly ash produced at the same boiler temperatures and collected from the front precipitator and back precipitators, respectively, predominate. Similarly, best Boron removals are achieved with the Militant fly ash samples collected under full power and with the Deep Hollow fly ashes collected under minimum power.

In the case of the low fusion fly ashes, boiler temperatures appears to influence Boron removal. The Blend, and Wellmore Cactus #1 fly ashes which were collected in the #11 boiler show some Boron removals, whereas, their counter parts produced in the #12 boiler exhibits no Boron removals at all (see Table 41). These fly ashes were produced in the #11 boiler where the fly ashes encountered high temperatures for longer periods of time than the #12 boiler. Although the size of the fly ash particles collected from the #11 and #12 precipitators were found to differ. This difference does not appear to be a factor in the ability of the #11 fly ash particles to remove more Boron than the #12 fly ash particles. This reasoning is based upon the finding that the size of the fly ash particles collected from the #11 precipitator are larger than the fly ash particles collected from the #12 precipitator. If size were a factor, the smaller particles collected from the #12 precipitator would be expected to provide greater Boron removals because the ash pond samples would encounter greater fly ash surfaces for a given weight with the smaller fly ash particles.

Tin Removal

The Tin sorbent characteristics exhibited by the fly ashes produced from the twelve test coals under different boiler conditions were investigated. The results of the analysis of the concentration of Tin remaining after treatment of 1500 ml of ash pond Sample A revealed that the Mine Mouth D fly ash

exhibits the best Tin removal collected followed by the Blend #11 fly ash, the Mine Mouth D fly ash, the Wellmore Cactus #1 #11 fly ash, the Blend #12 fly ash, the Wellmore Cactus #1 #12 fly ash, respectively. The fly ashes reduced the Tin concentration in Sample A from 0.90 ppm to 0.05 ppm, 0.08 ppm, 0.10 ppm, 0.20 ppm, 0.30 ppm and 0.50 ppm, respectively (see Table 42). These values correspond to Tin removals of 94%, 91%, 89%, 78%, 67% and 44%.

The results of the analysis of the concentration of Tin remaining in the effluent after 1500 ml, 3000 ml and 4000 ml of ash pond Sample B had been treated with the Deep Hollow fly ashes reveal significant leaching of Tin. In all cases, the concentration of Tin in the treated effluent was above the 0.07 ppm concentrations present in the untreated ash pond Sample B (see Table 42).

The results of the treatment of ash pond Sample C with the Militant, Upshur, Badger, Nora, Wellmore Cactus #2, Ellsworth and Wellmore Ackiss fly ashes provided reductions in the Tin concentration in the treated ash pond samples. Analysis of the Tin concentrations remaining in the effluent after 1500 ml of ash pond Sample C was treated shows a reduction in Tin concentration from 1.01 ppm to 0.50 ppm, 0.50 ppm and 0.69 ppm, respectively. Breakthrough of Tin as evidenced by Tin concentrations in the treated effluent being equal or greater than the concentration of Tin present in the ash pond sample, occur in the case of the #11 Nora fly ash at a treated volume of ash pond sample that lies between 3000 ml and 4000 ml; whereas, for both Ellsworth fly ashes, breakthrough occurs before 3000 ml of ash pond sample had been treated (see Table 42).

An examination of the Tin removal results for the high fusion Militant, Deep Hollow, Upshur and Badger fly ashes produced in the Boiler A reveal no reduction in Tin concentrations; whereas, four of the six low fusion fly ashes produced in the Boiler B that is both the Blends #11, Wellmore Cactus #1 #11, Nora and Ellsworth #11 fly ashes, as well as the Mine Mouth C and Mine Mouth D fly ashes all achieved greater than 50% Tin reduction in the treated ash pond effluents. These findings indicate that melting of the ash within boilers favors the formation of fly ash with Tin removal properties.

In addition, the period of time a fly ash remains in the molten state appears to influence Tin removals. The Blend, Wellmore Cactus #1, Nora and Ellsworth fly ashes produced in the #11 of Boiler B encountered high temperature for longer periods of time than the fly ash produced in the #12 boiler. All of these fly ashes exhibited better Tin removal properties than their respective fly ashes produced in the #12 boiler (see Table 42).

Molybdenum Removal

The results of the analysis for Molybdenum in the treated ash pond samples reveals that of the twelve different fly ashes examined only the Mine Mouth D, Blend, Wellmore Cactus #1 and Deep Hollow fly ashes removed Molybdenum from the ash pond samples. The #12 Blend fly ash followed in decreasing order by the #11 Wellmore Cactus #1 fly ash, #11 Blend fly ash, #12 Wellmore Cactus #1 and Mine Mouth D fly ash, respectively, reduced the Molybdenum in ash pond Sample A from 3.0 ppm to 1.7 ppm, 2.0 ppm, 2.4 ppm, 2.4 ppm and 2.8 ppm, correspondingly, after treatment of 1500 ml of ash pond samples (see Table 43). These results indicate

Molybdenum removals of 43%, 33%, 20%, 20% and 7%, respectively. The Mine Mouth C fly ash which was also evaluated using ash pond Sample A did not provide any Molybdenum removals. Its treated effluent contained the same concentration of Molybdenum (3.0 ppm) as present in ash pond Sample A (3.0 ppm).

The Deep Hollow fly ashes collected from the front precipitator under full, intermediate power generation and from both the front and back precipitators under minimum power generation were observed to remove some Molybdenum. These fly ash samples reduced the concentration of Molybdenum in ash pond Sample B from 2.7 ppm to 2.6 ppm, 2.6 ppm, 2.1 ppm and 2.5 ppm, respectively. These Molybdenum reductions in the ash pond sample amounts to removals of less than 22 percent after treatment of 1500 ml of ash pond sample.

The results of the analysis for Molybdenum in the treated ash pond Sample C using the #11 and #12 Wellmore Cactus #2 fly ash, the #11 and #12 Wellmore Ackiss fly ashes generated under full and minimum power, the #11 and #12 Nora fly ashes, the #11 and #12 Ellsworth fly ashes, Badger fly ashes, Upshur fly ash and the Militant fly ashes generated under full, intermediate and minimum power generation indicate no removals of Molybdenum. In fact, the concentration of Molybdenum in the ash pond samples treated with the above fly ashes is found to be significantly greater than the 0.41 mg/l present in the original untreated ash pond sample (see Table 43). However, the decrease in the concentration of Molybdenum upon the addition of 3000 ml and 4000 ml of ash pond sample, in general, suggests that the Molybdenum may cease to leach at some point beyond the addition.

of 4000 ml of ash pond sample. Perhaps at this point, some of these fly ashes may begin to remove some Molybdenum from the ash pond sample.

A comparison of the amount of Molybdenum remaining in the various treated samples upon the treatment of 1500 ml, 3000 ml and 4000 ml of ash pond samples suggest that these fly ash samples will continue to leach Molybdenum. No decrease in the Molybdenum concentration in the treated samples is observed with increasing amounts of treated ash pond sample for these fly ash samples (see Table 43). The relationship between particle size and power reduction on the removal of Molybdenum by the high fusion fly ashes could not be examined because of the poor Molybdenum removal achieved with these fly ashes. Only one of the Deep Hollow fly ashes provided a Molybdenum removal of 22 percent. The rest of the Deep Hollow fly ashes provided removals of less than 10 percent. In addition, the Badger, Upshur and Militant fly ashes not only show no Molybdenum removals, but they continued to leach Molybdenum even after 4000 ml of ash pond sample had been passed through these fly ash samples.

In the case of the low fusion fly ashes which provided removals of 43 percent, boiler temperatures nor ash fusion appears to be a factor in Molybdenum removals. The #12 Blend fly ash produced at lower temperatures in the #12 boiler exhibited better removals than the #11 Blend fly ash (43% versus 20%); whereas, the #11 Wellmore Cactus #1 fly ash provided greater Molybdenum removals than the #12 Wellmore Cactus #1 fly ash (33% versus 20%).

Nickel Removal

The Nickel leaching and sorbent characteristics exhibited by the fly ashes generated from the twelve test coals were investigated.

The analysis of the concentration of Nickel remaining in the ash pond Sample A after treatment reveal that the Mine Mouth C, Mine Mouth D, Blend, and Wellmore Cactus #1 fly ashes exhibit significant Nickel removals. The Mine Mouth C, Mine Mouth D, Boiler B Blend #11 and #12, and Wellmore Cactus #1 #11 and #12 fly ashes reduced the Nickel concentration in the effluent after treatment of 1500 ml of ash pond sample from 0.26 ppm to 0.01 ppm, 0.01 ppm, 0.01 ppm, 0.05 ppm, 0.08 ppm and 0.09 ppm, respectively. These reductions amount to Molybdenum removals in ash pond Sample A of 96%, 80%, 69% and 58%, respectively.

The Deep Hollow fly ashes collected from the front and back precipitators under full power and minimum power generation were observed to provide Nickel removals from ash pond Sample B. These Deep Hollow fly ashes reduce the Nickel concentration in the ash pond Sample B after treatment of 1500 ml of sample from 0.11 ppm to 0.07 ppm, 0.03 ppm, 0.07 ppm and 0.06 ppm, respectively. These values correspond to Nickel reductions of 36%, 73%, 36% and 45%.

The results of treatment of ash pond Sample C using the Militant, Upshur, Badger, Nora, Wellmore Cactus #2, Ellsworth and Wellmore Ackiss fly ashes reveal that the Nora fly ashes, Wellmore Cactus #2 fly ashes, Wellmore Ackiss fly ashes produced under full and minimum power, the Upshur fly ash and the Badger fly ashes indicate Nickel removals. The #11 Nora, #11 Wellmore Cactus #2, and #11 Wellmore Ackiss fly ashes produced under full and minimum power provided the best removals of Nickel followed by the #12 Wellmore Cactus #2 and #12 Nora fly ashes, the #12 Wellmore Ackiss fly ashes produced under full and minimum power, the

Badger fly ash collected from the front precipitator and the Upshur fly ashes, in decreasing order. These fly ashes reduced the concentration of Nickel in ash pond Sample C after treatment of 1500 ml of sample from 0.09 ppm to 0.02 ppm, 0.03 ppm, 0.04 ppm, 0.06 ppm, and 0.08 ppm, respectively (see Table 32). These reductions in Nickel concentrations represent Nickel removals of 77%, 67%, 56%, 44% and 11%, correspondingly. These removals should be considered significant in view of the fact that the concentration of Nickel present in ash pond Sample C was only 0.09 ppm.

No removal of Nickel from the ash pond Sample C is essentially achieved with Ellsworth fly ashes as well as the Militant fly ashes produced under full, intermediate and minimum power generations (see Table 44. The only exception to these results is the Nickel removals achieved with the Militant fly ash samples collected from the front electrostatic precipitator under full power generation. This fly ash reduced the Nickel concentration in ash pond Sample C from 0.09 ppm to 0.03 ppm. The reason for this fly ash sample removing Nickel from the ash pond effluent is unclear because the results obtained with the three other Militant fly ash samples, which were also collected during full power generation showed no Nickel removals.

A comparison of the Nickel removals results achieved with the high fusion Militant, Deep Hollow, Upshur and Badger fly ashes with the Blend, Wellmore Cactus #1, Mine Mouth C, Mine Mouth D, Nora, Wellmore Cactus #2, Ellsworth and Wellmore Ackiss fly ashes which underwent fusion, reveals that the majority of the latter fly ashes exhibit better Nickel removals than the ashes that did not undergo fusion. Even though the Mine Mouth C

and Mine Mouth D fly ashes are considered high fusion fly ashes, boiler temperatures encountered in their respective boilers were high enough to cause these fly ashes to undergo fusion. Length of time in the fusion state also appears to be a factor in generating fly ash with Nickel removal properties. In all cases, the fly ashes produced in the #11 boilers which encountered elevated temperatures in the molten state for longer periods of time than the #12 boilers provided greater Nickel removals than their counterparts produced in the #12 boiler.

Particle size does not appear to be a factor in the Nickel removals achieved with the Militant, Deep Hollow and Badger fly ashes. No consistent differences in Nickel removals is observed between the larger fly ash particles collected from the front precipitator and the smaller particles collected from the back precipitators. For example, the only significant difference in removals between the fly ash particles collected from the front and back precipitators is achieved with the Deep Hollow fly ashes produced under full power. Here, the fly ash particles collected from the back precipitator exhibit better Nickel removals than the fly ash collected from the front precipitators (see Table 44). In comparison, the Badger fly ash samples collected from the front precipitator exhibit better Nickel removals than the particles collected from the back precipitator.

A comparison of the results of the Nickel removals achieved with the Deep Hollow fly ashes under different power generation shows no correlation between power generation and Nickel removal exhibited by the fly ashes. An examination of the results in Table 32 reveals that the Deep Hollow fly ash samples produced under intermediate power generation exhibits the poorest Nickel removals.

Lead Removals

Lead removals in ash pond effluents samples were achieved with the fly ashes generated under different power levels from the majority of the coals.

The Mine Mouth C and Mine Mouth D fly ashes were observed to exhibit the greatest removals of Lead from the Sample A ash pond effluent, followed by the Blend and Wellmore Cactus #1 fly ashes in decreasing order. The Lead concentration in the initial 1500 ml of treated effluent was reduced from 1.8 mg/l to 0.38 ppm, 0.42 ppm, 0.47 ppm, 0.88 ppm, 1.02 ppm and 1.38 ppm using the Mine Mouth C, Mine Mouth D, #11 Blend, #11 Wellmore Cactus #1, #12 Blend and #12 Wellmore Cactus #1 fly ashes, respectively. These concentrations in the treated samples indicate Lead removals of 79%, 77%, 74%, 51%, 43% and 23%, correspondingly.

The results obtained with the Deep Hollow fly ashes generated under minimum, intermediate and full generation do not show Lead removals. The results of the analysis show a Lead concentration of 0.35 ppm or greater in the treated effluents after 1500 ml of ash pond samples was passed through the fly ashes. This 0.35 ppm is the same concentration as that present in the original ash pond sample (see Table 45).

Treatment of the ash pond Sample C with the high fusion Militant, Badger and Upshur fly ashes reveal that a Militant fly ash exhibits the best Lead removals followed by the Badger and Upshur fly ash. The Militant fly ash collected from the front precipitator under minimum power, intermediate and full power generation, the Badger fly ash collected from the back precipitator and the Upshur fly ash reduced the concentration of Lead in the ash pond Sample C after treatment of 1500 ml of ash pond sample

from 0.62 ppm to 0.24 ppm, 0.44 ppm, 0.55 ppm, 0.41 ppm and 0.50 ppm, respectively. These concentrations represent Lead removals of 61%, 29%, 11%, 34% and 19%, correspondingly.

In the case of the low fusion fly ashes, the #11 Wellmore Ackiss fly ash generated under full power followed by the #12 Wellmore Cactus #2 fly ash generated under full power provided the only Lead removals after treatment of 1500 ml of ash pond sample. These two fly ashes reduced the Lead concentration in ash pond Sample C from 0.62 ppm to 0.49 ppm and 0.55 ppm, respectively. The concentration remaining in the treated ash pond samples represent removals of 21% and 11%, respectively.

The #11 Wellmore Cactus #2, the #11 Wellmore Ackiss fly ash produced under minimum power, the #11 and #12 Nora fly ashes and the #11 and #12 Ellsworth fly ashes continued to leach Lead after passage of 1500 ml of ash pond Sample C through these fly ashes (see Table 47).

A comparison of the Lead removals achieved with the high fusion Militant, Badger and Upshur fly ashes with the low fusion Wellmore Ackiss and Wellmore Cactus #2 indicate that the high fusion fly ashes exhibits better Lead removals than the low fusion fly ashes. Also, the larger fly ash particles collected from the front precipitators provide consistently better Lead removals than the smaller fly ash particles collected from the back precipitators.

The reason for the larger fly ash particles exhibiting better Lead removals than the smaller fly ash particles is not clear. Normally, it would be expected that the smaller particles should exhibit better removals because of their greater surface areas.

Reduction in boiler temperatures as represented by a reduction in power generation also appears to favor the formation of fly ash with Lead removal properties. The Militant fly ash particles collected from the front precipitation under minimum power exhibited the best Lead removals followed by the front fly ash particles produced under intermediate and full power generation, respectively (see Table 33).

The lower boiler temperature and larger particle size also appears to favor Lead removals for one of the low fusion fly ashes. The Wellmore Cactus #2 fly ash produced in the #12 boiler provided better Lead removals than the fly ash produced in the #11 boilers. The Wellmore Cactus #2 fly ash produced in the #12 boilers differ from its counterpart produced in the #11 boiler in that it was generated at lower boiler temperatures and it consists of larger particles.

Copper Removal

The effectiveness of the Mine Mouth C, Mine Mouth D, Blend, Wellmore Cactus #1 and Deep Hollow fly ashes for the removal of Copper ion in ash pond Sample A and ash pond Sample B are not clear because the concentration of Copper encountered in these ash pond samples is very low (0.01 ppm).

An evaluation of the results of Copper removal in ash pond Sample C after 1500 ml of sample had been treated indicate that the #11 Nora fly ash is the most effective for Copper removal, followed by #11 Wellmore Ackiss fly ash produced under full power, the #11 Wellmore Ackiss produced under minimum power, both the Ellsworth and Wellmore Cactus #2 fly ashes, and the #12 Nora fly ash, respectively. These fly ashes reduced the Copper concentration in the ash pond Sample C from 0.09 ppm to 0.02 ppm, 0.03 ppm, 0.04 ppm, and 0.05 ppm, respectively (see Table 46). The Copper concentrations remaining in the treated ash pond represent Copper removals of 78%, 67%, 56% and 44%, correspondingly.

No Copper removals from ash pond Sample C were achieved with the #12 Wellmore Ackiss fly ashes or the Militant fly ashes. In fact, the Militant fly ashes continued to exhibit leaching even after 4000 ml of ash pond sample were passed through these fly ashes (see Table 46).

An examination of the limited results obtained with only one ash pond sample reveals that the low fusion fly ashes exhibited better Copper removals than the high fusion fly ashes. The #11 Nora and #11 Wellmore Ackiss fly ashes produced under full power generation exhibited better Copper removals than Badger or Upshur fly ashes. Also, it appears that the conditions encountered in the #11 boiler leads to the formation of fly ashes with better Copper removal characteristics. The Nora, and Wellmore Ackiss fly ashes produced in the #11 boiler exhibited better Copper removals than the fly ash samples produced in the #12 boilers.

The effect of particle size or reductions in power generation levels on the high fusion fly ashes removal of Copper from the ash pond samples could not be determined. The ash pond Sample B treated with Deep Hollow fly ash was too low in Copper concentration to provide meaningful results and Militant fly ashes exhibited no removal of Copper.

Chromium Removal

The fly ash samples collected from the Mine Mouth C and Mine Mouth D boiler were found to be the most effective for Chromium removal followed by the Blend and Wellmore Cactus #1 fly ashes. The Mine Mouth C and Mine Mouth D reduced the Chromium concentration after treatment of 1500 ml of ash pond Sample A from 0.48 ppm to 0.19 ppm and 0.30 ppm, respectively (see Table 47). These values represent Chromium removals of 60% and 38%, correspondingly. No differences in Chromium removals were observed

between the Blend and Wellmore Cactus #1 fly ashes produced in the #11 and #12 boilers.

The treatment of ash pond Sample B with the Deep Hollow fly ashes under different power generation levels show no Chromium removal. The concentration of Chromium in the treated sample after treatment of 1500 ml of ash pond sample was 80 ppm which corresponds to the concentration of Chromium in the ash pond Sample B.

The treatment of ash pond Sample C with the Badger, Upshur, and the Wellmore Ackiss fly ashes generated at full and minimum power, fly ashes showed removals of the Chromium even though the Chromium concentration in the ash pond sample was only 0.09 mg/l. The results of the analysis of Chromium remaining after treatment of 1500 ml of ash pond sample with the high fusion Badger fly ash collected from the back precipitator and the high fusion Militant fly ashes collected from the front and back precipitators under intermediate and minimum power generation, respectively, show Chromium concentration reductions from 0.09 ppm to less than detectable concentrations levels (see Table 47). The high fusion Upshur fly ash, and one of the high fusion Militant fly ashes collected from the back precipitator under full power followed by the other Militant fly ashes collected from the front and back precipitator under full power and from the back precipitator under minimum power reduced the Chromium concentration from 0.09 ppm to 0.02 ppm and 0.05 ppm, respectively.

Only the low fusion #11 Wellmore Ackiss fly ashes produced under full power was found to reduce the Chromium concentration after treatment of 1500 ml of ash pond Sample C to values below 0.09 ppm. The other Wellmore Ackiss fly ashes and one of the Wellmore Cactus #2 fly ashes only showed Chromium removals after 3000 ml of ash pond Sample C was passed through these fly ashes. At this point, the Wellmore Ackiss and Wellmore Cactus #2 fly ashes reduced the Chromium concentration from 0.09 ppm to about 0.02 ppm and 0.07 ppm, respectively (see Table 47). Apparently, the initial washing of these fly ashes with 4 liters of water was not adequate to provide a fly ash with Chromium removal properties.

No Chromium removals were achieved from the ash pond samples using the Nora and Ellsworth fly ashes collected from the #11 and #12 precipitators. In fact, the analysis for the Chromium remaining in the treated ash pond samples revealed in general that all of these fly ashes contain Chromium concentration in excess of that present in the original ash pond sample (see Table 47). The Ellsworth fly ash was observed to exhibit the greatest amount of leaching. The concentration of Chromium in the treated ash pond sample averaged about 0.80 mg/l which is some eight times the 0.09 mg/l concentration of Chromium present in the original ash pond sample (see Figure 47).

A comparison of the Chromium removal results obtained with the high fusion and low fusion fly ashes indicate that the high fusion fly ashes provide better Chromium removals than the low fusion fly ashes. Also, the Chromium removal differences exhibited by the high fusion fly ashes collected

from the front and back precipitators indicates that the smaller fly ash particles provide better removals. Four of the five Badger and Militant fly ash samples collected from the back precipitator yielded effluent with lower Chromium concentration than those collected from the front precipitator in the corresponding fly ashes.

Reduction in power level generation does not appear to be a factor in providing fly ash with Chromium removal properties. No trend was observed between power generation reduction and Chromium removal. The Militant fly ashes produced at intermediate and minimum power reduction exhibited similar Chromium removals (see Table 47).

Zinc Removals

The Wellmore Cactus #1, Blend and Mine Mouth D were found to remove Zinc from ash pond Sample A. The #11 Wellmore Cactus #1 fly ash followed by the Mine Mouth D fly ash, the #11 Blend fly ash, #12 Blend fly ash and the #12 Wellmore Cactus #1 fly ash reduced the Zinc concentration in the treated sample after 1500 ml of ash pond sample was passed through these fly ashes from 0.16 ppm to 0.015 ppm, 0.06 ppm, 0.075 ppm and 0.10 ppm, respectively to undetectable levels. The Mine Mouth fly ash not only provided no Zinc removal from ash pond Sample A but leached Zinc into the treated ash pond sample to levels that were some three times the Zinc concentration present in the original ash pond Sample A (see Table 48).

The Deep Hollow fly ashes produced under maximum, intermediate and minimum power generation were found to leach rather than remove Zinc from ash pond Sample B. The samples treated with the Deep Hollow fly ashes were found to contain Zinc concentrations that range from twice to some six times that present in the ash pond Sample B (0.06 ppm) after 1500 ml of ash pond sample was passed through these fly ashes.

The high fusion Militant, Badger and Upshur fly ashes were observed to remove Zinc from ash pond Sample C. Best Zinc removals were observed using the Militant fly ash collected from the front precipitator under full power generation. The next best removals were achieved using the Militant fly ash collected from the back precipitator under full power followed by the Badger fly ash, the Militant fly ash collected under minimum power, the Militant fly ashes collected from front and back precipitators under intermediate power and Upshur fly ash, in decreasing order, respectively. These fly ashes reduce the Zinc concentration in the ash pond Sample C after treatment of 1500 ml of sample from 1.48 ppm to 0.05 ppm, 0.14 ppm, 0.18 ppm, 0.30 ppm, 0.35 ppm and 0.43 ppm, correspondingly.

The #11 Nora followed by the #11 Ellsworth low fusion fly ashes were observed to provide the best removals of Zinc in comparison to the other low fusion fly ashes used to treat ash pond Sample C. The next best removals were achieved with the #11 Wellmore Ackiss fly ashes produced under full power and minimum power, followed by the #11 and #12 Wellmore Cactus #2 fly ashes, the #12 Wellmore Ackiss fly ash produced under full power, the #12 Ellsworth fly ash, the #12 Nora fly ash and the #12 Wellmore Ackiss fly ash produced under minimum power. The above low fusion fly ashes reduced the Zinc in the ash pond Sample C after treatment of 1500 ml from 1.48 ppm to 0.02 ppm, 0.03 ppm, 0.05 ppm, 0.06 ppm, 0.12 ppm and 0.44 ppm, correspondingly (see Table 48).

A comparison of the Zinc removal results achieved with the high fusion fly ashes and the low fusion fly ashes reveal that the low ash fusion fly ashes provide significantly better removals of Zinc than the high fusion fly ashes. Boiler conditions encountered in the #11 boiler also favor the formation of fly ash with Zinc removal properties. All of the fly ashes,

Blend, Wellmore Cactus #1, Nora, Wellmore Ackiss, and Ellsworth, produced in the #11 boiler with the exception of the Wellmore Cactus #2 showed significantly greater Zinc concentration reductions in the treated ash pond samples than the fly ashes produced in the #12 boiler.

Neither the effect of size or reductions in power generation on the removal of Zinc by the high fusion Militant, Badger and Upshur fly ashes appears to be a factor. The larger particle size Militant fly ash collected from the front precipitator under full power exhibited better Zinc removal than its counterpart collected from the back precipitation; whereas, the reverse was true for the Militant fly ashes collected under minimum power generation. Here, the fly ashes collected from the back precipitator exhibited slightly better Zinc removal properties than the fly ash collected from the front precipitator. In addition, the Militant fly ashes produced under full power exhibited better Zinc removals than the Militant fly ashes produced under intermediate and minimum power generation. However, the Militant fly ashes collected under minimum power generation provide better removals than the Militant fly ashes obtained under intermediate power generation (see Table 48).

Manganese Removals

The results of the analysis for Manganese concentration remaining in the treated ash pond Sample A indicate that the Mine Mouth C, Mine Mouth D, Blend, and Wellmore Cactus #1 fly ashes remove Manganese from ash pond effluent. The Mine Mouth C, Mine Mouth D and #11 Wellmore Cactus #1 fly ashes provided the best Manganese removals followed by the #11 Blend fly ash, #12 Blend fly ash and #12 Wellmore Cactus #1 fly ash. These fly ashes reduced the Manganese

concentration in ash pond Sample A after treatment of 1500 ml of sample from 0.24 ppm to 0.02 ppm, 0.03 ppm and 0.05 ppm, correspondingly (see Table 49).

The treatment of ash pond Sample B with the Deep Hollow high fusion fly ashes produced under full, intermediate and minimum power generation show that all these Deep Hollow fly ashes with the exception of the samples collected from the front and back precipitators under intermediate power provide Manganese removals. Analysis of the Manganese remaining in the treated ash pond sample show that the sample collected from the back precipitator under full power provided the best Manganese removal followed by both samples collected from the front and back precipitator under minimum power and the sample collected from the front precipitator under full power in decrease order, respectively. These fly ashes reduced the concentration of Manganese in the ash pond sample after treatment of 1500 ml of sample from 0.24 ppm to 0.05 ppm, 0.07 ppm and 0.17 ppm, correspondingly. The Deep Hollow fly ashes collected from both the front and back precipitators under intermediate power generation provide no removals of Manganese from ash pond Sample B. Manganese concentration of 0.24 ppm found in the treated ash pond sample corresponds to the Manganese concentration found in the untreated ash pond sample (see Table 49).

The results of the treatment of ash pond Sample C with the high fusion Badger, Upshur and Militant fly ashes in general show no removals of Manganese. An examination of the concentration remaining in the treated ash pond sample after passage of 1500 ml of sample through these fly ashes show Manganese concentrations comparable or larger than that present in the untreated ash pond sample. Only one of the Militant fly ash samples collected from the front precipitator under full power showed significant removals of Manganese. This sample reduced the Manganese concentration in the ash pond Sample C from 0.40 to 0.02 ppm.

The reason that one of the Militant fly ashes remove Manganese from the ash pond Sample C may be due to the initial washing of this ash sample with 4000 ml of H_2O during the leaching studies which was adequate to provide a fly ash sample with Manganese removal properties. A comparison of the concentration of Manganese remaining in the treated ash pond samples after treatment of 3000 ml and 4000 ml of ash pond sample show a significant reduction in the Manganese concentration for all Militant fly ashes. In fact, all Militant fly ash samples exhibit Manganese removal after treatment of 4000 ml of ash pond sample (see Table 49).

An examination of the Manganese concentrations in the treated effluent using ash pond Sample C shows that all of the low fusion fly ashes with the exception of the #12 Nora fly ashes are able to reduce the Manganese concentration to safe levels. The #12 Nora fly ash exhibited Manganese leaching (see Table 49). The largest reduction in Manganese concentration in the treated effluent was achieved with the #11 Nora fly ash and the #11 Wellmore Ackiss fly ashes produced under full and minimum power generation, followed by the #11 Wellmore Cactus #2 fly ash, #12 Wellmore Ackiss fly ash produced under full power, #12 Wellmore Cactus #2 fly ash, #11 Ellsworth fly ash, #12 Ellsworth fly ash and #12 Wellmore Ackiss produced under minimum power, in decreasing order, respectively. These low fusion fly ashes reduced the concentration in ash pond Sample C after treatment of 1500 ml of sample from 0.40 ppm to 0.02 ppm, 0.03 ppm, 0.04 ppm, 0.12 ppm, 0.19 ppm, 0.22 ppm and 0.34 ppm, correspondingly (see Table 49).

A comparison of the Manganese removal results achieved with the high fusion ashes and the low fusion ashes reveal that the low fusion ashes which have undergone fusion exhibited the better Manganese removals. The high fusion sample of Mine Mouth C and Mine Mouth D ashes which provided comparable Manganese removals to the low fusion fly ashes are considered part of the low fusion fly ashes because of boiler temperatures. The boiler

temperatures encountered during the generation of the Mine Mouth C and Mine Mouth D fly ashes were adequate to fuse the ash. In addition, boiler condition encountered by the fly ashes in the #11 boiler favor the generation of fly ashes with Manganese removal properties. In all cases for the low fusion fly ashes, the fly ashes produced in the #11 boiler provided better Manganese removals than the fly ashes produced in the #12 boiler.

A comparison of the Manganese results obtained with the high fusion fly ashes indicate that particle size and reduction in power generation do not appear to be a factor in Manganese removal. In the cases where the high fusion fly ashes exhibited Manganese removals, there is no correlation between either particle size or a reduction in power generation and the Manganese removal results exhibited by these fly ashes. The larger and smaller particle size Deep Hollow fly ashes collected from the front and back precipitators, respectively, under intermediate and minimum power generations provided the same level of treatment. The concentration of Manganese remaining in the ash pond sample treated with these four fly ash samples were the same (see Table 49). Similarly, the best Manganese treatment was achieved with a Deep Hollow fly ash produced under full power. If power reduction were a factor in providing fly ash with Manganese removal properties, then, the next best Manganese removal would be observed with the Deep Hollow fly ashes produced under intermediate power generation. However, this was not the case. The next best Manganese treatment was achieved with the Deep Hollow fly ashes produced under minimum power.

Iron Removal

The treatment of ash pond Sample A using the Mine Mouth C, Mine Mouth D Blend and Wellmore Cactus #1 fly ashes indicate that all these fly ashes exhibit Iron removals. The #11 Blend fly ash, provided the best treatment

followed by the Mine Mouth D, #11 Wellmore Cactus #1 fly ash, #12 Blend fly ash, #12 Wellmore Cactus #1 and the Mine Mouth C fly ash in decreasing order, respectively. These fly ashes reduced the Iron concentration in the ash pond Sample A after treatment of 1500 ml of sample from 0.22 ppm to 0.01 ppm, 0.03 ppm, 0.06 ppm, 0.08 ppm, 0.10 ppm and 0.18 ppm, correspondingly (see Table 50).

Only the Deep Hollow fly ashes collected from the front precipitator under intermediate and minimum power generation provide a reduction in the Iron concentration in the treated ash pond Sample B. Analysis of the Iron concentration remaining after treatment of 1500 ml of ash pond Sample B shows that the above Deep Hollow fly ash samples reduced the Iron concentration from 0.05 ppm to 0.03 ppm and 0.04 ppm, respectively. An examination of Table 62 shows that the rest of the Deep Hollow fly ashes did not exhibit any Iron removals. The Iron concentration present in the treated ash pond samples were found to be the same or larger than the Iron concentration present in the untreated ash pond Sample B.

The treatment of ash pond Sample C with the high fusion Badger, Upshur and Militant fly ashes all showed reductions in the Iron concentration. The Militant fly ashes collected from the front precipitator under full and intermediate power generation were found to give the greatest reduction in iron concentration in the treated ash pond sample using the high fusion fly ashes. The next best treatment was achieved with the Badger and Militant fly ash collected from the back and front precipitator under full, intermediate and minimum power, respectively, followed by the Militant fly ashes, collected from the front and back precipitator during the two separate full power generation, the Upshur fly ash and the Militant fly ashes, collected from the back precipitator and under full power, in decreasing order, respectively. The analysis of the concentration of Iron remaining in the treated ash pond sample after passage of 1500 ml of sample through these fly

ashes showed reduction in the Iron concentrations from 0.10 ppm to 0.05 ppm, 0.06 ppm, 0.07 ppm, 0.08 ppm and 0.09 ppm, correspondingly. Only four of the ten low fusion fly ashes collected provided Iron removals in ash pond Sample C. The #11 Nora fly ash exhibited the best treatment followed by the #11 Wellmore Ackiss produced under minimum power and the #12 Nora fly ash in decreasing order, respectively. The corresponding concentrations of Iron remaining in the liquid collected after treatment of 1500 ml of ash pond sample showed a reduction in Iron concentration from 0.10 ppm to 0.04 ppm, 0.05 ppm, 0.07 ppm and 0.08 ppm, respectively. The rest of the ash pond samples treated with the low fusion fly ashes contained Iron in concentrations comparable or larger than the untreated ash pond samples (see Table 50).

A comparison of the amounts remaining in the ash pond samples after treatment with the high fusion fly ashes and low fusion fly ashes reveal that the low fusion fly ashes provide greater reductions in iron concentration than the high fusion fly ashes. Boiler temperatures which lead to the fusion of the fly ashes favor the generation of fly ashes with Iron removal properties. The Mine Mouth D fly ash which is considered a high fusion ash encountered high enough boiler temperatures to cause fusion of this ash. The reduction in Iron concentration achieved after a treatment of 1500 ml of ash pond sample was second only to that obtained in the #11 Blend fly ash. Also, a comparison of the Iron treatment achieved with the #11 and #12 low fusion fly ashes show that the #11 fly ashes provide greater reductions in the Iron concentration in the treated samples than their corresponding fly ashes generated in the #12 boiler. This result can be either due to the higher temperatures encountered in the #11 boiler or the fact that the #11 fly ash particle were in general larger in size than the fly ash particles collected from the #12 precipitator. However, higher boiler temperatures must be a factor in the differences in Iron removals observed between the #11 and #12 fly ashes because the #11 and #12 Wellmore Ackiss fly ashes produced

under full power were observed to be comparable in size. Yet, the #11 Wellmore Ackiss fly ash produced at higher boiler temperatures exhibited better treatment than its #12 counterpart fly ash.

The larger size fly ash particles appear to favor the removal of Iron. A comparison of the concentration of Iron remaining in the ash pond samples after treatment with the high fusion ashes collected from the front and back precipitator show that the fly ashes collected from the front precipitator provide better Iron treatment. In all cases of the high fusion Militant and Deep Hollow fly ashes where Iron removals were observed, the concentration of Iron remaining in the ash pond samples after treatment with the fly ash samples collected from the front precipitator were consistently lower than the Iron concentration in the samples treated with the fly ashes collected from the back precipitator.

These results are opposite to what would be expected. Normally, the smaller size particles would be expected to provide better treatment than the larger particles because of their greater surface area for a given weight of sample. The reason for these results can not be explained at this time.

Arsenic Removal

The fly ashes produced from the twelve test coals under the boiler conditions described earlier have been evaluated for Arsenic removal using these ash pond samples, Sample A, Sample B, Sample C which contained 0.16 ppm, 0.13 ppm and 0.13 ppm, respectively. Investigation of the fly ashes produced from the combustion of high ash fusion temperature coal under a variety of boiler conditions showed only that one of the Badger fly ash of removing Arsenic from the ash pond effluent. This fly ash collected from the back precipitator reduced the concentration of Arsenic in the ash pond sample after treatment of 1500 ml of sample from 0.13 ppm to 0.12 ppm, respectively (see Table 52). No removals of Arsenic from the ash pond effluent

Table 52. Arsenic Removal

Fly Ash	Source	Power	Influent	Treatment, ug/ml		
			conc. ug/ml	1500ml	3000ml	4000ml
Mine Mouth C		Full	0.16	0.170	0.165	0.165
Mine Mouth D		Full	0.16	0.148	0.135	0.130
Blend	No. 11	Full	0.16	0.70	0.040	
	No. 12	Full	0.16	0.102	0.095	0.095
Wellmore	No. 11	Full	0.16	0.090	0.075	0.068
Cactus (1)	No. 12	Full	0.16	0.158	0.137	0.131
Badger	Front	Full	0.13	0.145	0.138	0.130
	Back	Full	0.13	0.129	0.120	0.115
Upshur	Back	Full	0.13	0.150	0.150	0.150
Militant	Front	Full	0.13	0.180	0.156	0.145
	Back	Full	0.13	0.167	0.157	0.150
	Front	Int.	0.13	0.186	0.168	0.155
	Back	Int.	0.13	0.170	0.157	0.150
	Front	Min.	0.13	0.186	0.167	0.160
	Back	Min.	0.13	0.178	0.167	0.165
	Front	Full	0.13	0.216	0.190	0.176
	Back	Full	0.13	0.226	0.205	0.194
Deep Hollow	Front	Int.	0.13	0.216	0.185	0.168
	Back	Int.	0.13	0.200	0.164	0.152
	Front	Min.	0.13	0.210	0.190	0.173
	Back	Min.	0.13	0.230	0.195	0.180
Nora	No. 11	Full	0.13	0.10	0.070	0.060
	No. 12	Full	0.13	0.10	0.020	0.060
Wellmore	No. 11	Full	0.13	0.090	0.065	0.060
Ackiss	No. 12	Full	0.13	0.109	0.080	0.069
	No. 11	Min.	0.13	0.120	0.080	0.080
	No. 12	Min.	0.13	0.128	0.102	
Ellsworth	No. 11	Full	0.13	0.135	0.122	
	No. 12	Full	0.13	0.150	0.150	0.150
Wellmore	No. 11	Full	0.13	0.113	0.105	
Cactus (2)	No. 12	Full	0.13	0.132	0.125	0.115

were observed using the Militant, Deep Hollow and Upshur fly ashes. None of these fly ashes produced at different power outputs or the different size fly ashes collected from the front and back precipitators which are operated in series exhibited any arsenic removals. The concentration of arsenic in the aliquot taken after 1500 ml of ash pond sample had been treated using these fly ashes, is equal to or greater than the concentration of arsenic present in the untreated ash pond effluent (see Table 52).

In the case of the Mine Mouth C and Mine Mouth D fly ashes, the fly ashes produced from the high ash fusion temperature coal burned in the Boiler D showed some removal of arsenic (see Table 52). The fly ash produced in the Boiler C shows no removals of arsenic. The concentration of arsenic in the leachate treated with the Mine Mouth C fly ash is greater than that originally present in the ash pond effluent.

On the other hand, all of the fly ashes produced from the low ash fusion temperature coal burned in the Boiler B showed removals of arsenic from the ash pond effluent with the exception of the #12 Wellmore Cactus #2 and the Ellsworth fly ashes. The #11 fly ashes produced by the #11 Boiler operated at some 400°F higher in the ash than the similarly designed #12 Boiler operated in parallel exhibited greater arsenic removals than the #12 fly ashes produced by the #12 Boiler (see Table 52). The only exception is the Nora fly ashes. Both the Nora inlet and outlet fly ashes exhibited the same removal. In addition, the higher temperatures encountered in the Boilers B during the combustion of Wellmore Ackiss coal at full power output produced a #11 fly ash which exhibited better arsenic removals than the #11 fly ash produced at minimum power. The inlet fly ashes produced at full power reduced the arsenic in the ash pond effluent after treatment of 1500 ml of Ackiss pond sample from 0.13 ppm to about 0.09 ppm whereas the fly ash produced at minimum power reduced the arsenic to about 0.12 ppm (see Table 52).

The #11 fly ashes produced from the Blend, Wellmore Cactus #1, Wellmore Ackiss and Nora under full power generation coals exhibited the most significant removals of Arsenic from the ash pond effluent. In general, the arsenic concentration in the aliquot after treatment of 1500 ml of ash pond sample was reduced from 0.13 ppm to 0.070 ppm, 0.090 ppm and 0.100 ppm, respectively (see Table 52). The #11 fly ash produced from Wellmore Cactus #2 exhibited the next best removals of arsenic. The arsenic concentration remaining in the aliquot taken after treatment of 1500 ml of ash pond sample with these fly ashes were reduced from 0.13 ppm to 0.113 ppm (see Table 52).

DISCUSSION OF FACTORS INFLUENCING FLY ASH SORBATE CHARACTERISTICS

Specific fly ashes have been identified which provide the best removals of Cadmium, Boron, Tin, Molybdenum, Nickel, Lead, Copper, Chromium, Zinc, Manganese, Iron, and arsenic from actual ash pond effluent (see Table 53). Comparisons of the treatment results with the maximum allowable primary and secondary concentration of those elements designated show that the fly ashes have reduced these elements in the ash pond samples to levels significantly below the maximum allowable concentration for drinking water with the exceptions of Lead and Arsenic. Although, the Militant and #11 Blend fly ash exhibit Lead and Arsenic removals of 61% and 75%, respectively, the concentration of Lead and Arsenic remaining in the ash pond samples treated with these fly ashes were 0.24 mg/l and 0.04 mg/l correspondingly (see Table 53). The maximum allowable concentration level for Lead and Arsenic for drinking water is 0.05 mg/l.

A comparison of the number of elements that are best treated with the high fusion fly ashes and those fly ashes which have undergone fusion during their generation reveals that the low fusion fly ashes provide the best treatment

Table 53. Evaluation of Treatment Results for Each Element -
Fly Ash with Best Sorbate Characteristics

Element	Fly Ash	Ash Pond conc. mg/l	Conc. Remaining after Treatment mg/l	Removal	Primary and Secondary Drinking Water Standards** mg/l
Cadmium	Militant, Nora, No. 11 Wellmore Cactus No. 2, No. 11 Wellmore Ackiss (Full, Min.)	0.02	N.D.*		0.01
Boron	Militant	2.80	2.20	21%	
Tin	Mine Mouth D	.90	0.05	94%	
Molybdenum	No. 12 Blend	3.00	1.70	43%	
Nickel	Mine Mouth C, Mine Mouth D No. 11 Blend	0.26	0.01	96%	
Lead	Militant	0.62	0.24	61%	0.05
Copper	No. 11 Nora	0.09	0.02	78%	1
Chromium	Militant	0.09	N.D.		0.05
Zinc	No. 11 Nora	1.48	0.02	97%	5
Manganese	No. 11 Nora, No. 11 Wellmore Ackiss (Full & Min.)	0.40	0.02	95%	0.05
Iron	No. 11 Blend	0.22	0.01	95%	0.3
Arsenic	No. 11 Blend	0.16	0.04	75%	0.05

* N.D. - below measurable limits

** National Interim Primary and Secondary Drinking Water Regulations,
used for comparative purposes only. Materials are considered
non-hazardous unless their leachate exceeds one hundred times
(100 x) these concentrations

for the greatest number of elements. The high fusion Militant fly ash provided the best treatment for Boron, Lead and Chromium; whereas, the Mine Mouth D, Blend, Nora and Wellmore Ackiss (full and minimum) fly ashes which underwent fusion provided the best treatment for Tin, Molybdenum, Nickel, Copper, Zinc, Manganese, Iron and Arsenic. In addition, a comparison of the pairs of low fusion fly ashes, produced at the same time from the same coal in the #11 and #12 boilers, shows that the fly ashes which remained in the fused state in the #11 boiler for a longer period of time exhibits better sorbate characteristics than the fly ashes generated in the #12 boiler. Only the treatment of Molybdenum was best achieved with the #12 Blend fly ash (see Table 43).

The above results indicate that the fly ashes which have undergone fusion and remained in the fused state for the longest period of time provide the best treatment for most of the elements examined. Apparently, at high temperature physical or chemical changes are occurring in the fused state that lead to the formation of fly ash particles with suitable sorbate characteristics. However, the nature of these changes have not been identified.

A comparison of the results of treatment of ash pond Sample A and ash pond Sample C reveal that the Mine Mouth D and #11 Mercer fly ashes exhibited better sorbate characteristics than the Mine Mouth C and #11 Wellmore Cactus #1, the low fusion #11 Nora and #11 Wellmore Ackiss fly ashes exhibit better treatment than the Badger and Upshur fly ashes.

Variation in the amounts of Ti, Cd, Sn, Ni, Pb, Mo, Cu, Cr, Zn, Mn, Fe, Ba and V in the fly ashes bulk composition do not appear to influence their sorbate characteristics. No correlation was observed between the amounts of any of the above elements in the fly ash and the ability of the

fly ash to remove these elements from ash pond effluents. As an example, the #11 Wellmore Ackiss fly ash (full) contained the largest amount of Tl followed by the #11 Wellmore Cactus #2, #11 Ellsworth, and #11 Nora fly ashes (see Table 11) in decreasing order, respectively. This order of its reverse order does not compare to the findings that the Nora and Ellsworth inlet fly ashes exhibited the best and poorest sorbate characteristics for the treatment of ash pond Sample C. Examination of the other elements in Table 12 through Table 22 in the same manner were found to provide similar results.

No correlation was observed between the treatment ability of fly ash and the amounts of silicon, aluminum, sulfur and calcium on the fly ash surface in all cases for the (1) Wellmore Cactus #1 and Blend, Ellsworth and Nora inlet fly ashes, produced in the same Boiler B; (2) Militant, Upshur, and Badger fly ashes produced in the same Boiler A; and (3) the Mine Mouth C and Mine Mouth D fly ashes produced in the same type of boiler.

The leaching and removal results obtained with Power Stations A, B, C and D fly ashes revealed that even though all of these fly ashes initially leached Cadmium, Boron, Tin, Molybdenum, Nickel, Lead, Copper, Chromium, Zinc, Manganese and Iron, most of these fly ash samples were capable of removing these elements from the ash pond samples after approximately 4000 ml of water was initially passed through these ashes. This contradiction may be explained by the fact that these ions which were initially leached from the fly ash may be contained within a water soluble component whose removal improves the sorbent quality of the fly ash. Similar results have been reported by the work of Pagenkopf and Connolly ⁽¹³⁾ where they concluded that the washing process with water could condition the fly ash to become a sorbent for Boron.

There also, appears to be some correlation between the fly ash fusion temperatures and the sorbate characteristics of the fly ash. Low fluid temperatures appear to favor the sorbate characteristics of the fly ashes. A comparison of the number of elements removed from the ash pond Sample C by the fly ashes produced at the Boiler B indicates that the #11 fly ash from the Nora coal exhibits the best sorbate characteristics. The #11 Nora fly ash exhibits the lowest fluid temperature (see Table 39).

In view of the above finding, the fluid temperatures exhibited by the Blend and Wellmore Cactus #1 fly ashes indicate that the #11 Wellmore Cactus fly ashes should remove more elements from the ash pond Sample A than the #11 Blend fly ash. The ash softening temperatures for the #11 Wellmore Cactus #1 fly ash occurs approximately 95°F lower than the #11 Blend fly ash (see Table 39). However, it should be noted that the temperatures measured at the arch during the formation of the #11 Blend and #11 Wellmore Cactus #1 fly ashes show the Blend fly ashes encountering temperatures some 200°F higher than the Wellmore Cactus #1 fly ashes. The higher boiler temperatures encountered by the #11 Blend probably accounts for its fly ash exhibiting better sorbate characteristics than the #11 Wellmore Cactus #1 fly ash.

Parameters that Determine Quantity of Fly Ash Required for Treatment

The quantity of fly ash required to provide adequate treatment of ash pond leachate depends on the sorbate capacity of the fly ash for a specific pollutant and the contact time between the fly ash and the ash pond leachate required to achieve removal. The sorbate capacity identifies the amount of

fly ash required to remove a given amount of pollutant and the contact time defines the time of the ash pond leachate must remain in contact with the fly ash in the treatment system for a specific volumetric flow to achieve the maximum pollutant removals.

Sorbate capacity of the fly ashes for specific pollutants can be determined by continuous addition of ash pond leachate to the fly ash placed in a lysimeter until breakthrough of the specific pollutant occurs. The amount of pollutant removed from the ash pond leachate until breakthrough by a specific amount of fly ash represents the capacity of the fly ash for that specific pollutants. However, since the pH of the ash pond leachate will change upon contact with the fly ash, depending upon acidity or alkalinity of the fly ash, the fly ash will encounter different concentration of a specific element in the ash pond leachate over a period of time under field conditions, factors such as the changes in pH or pollutant concentration which may influence the removal of the pollutant must also be considered.

The washed #11 Blend fly ash, #11 Nora fly ash, Mine Mouth D fly ash and Militant fly ashes which was collected from the back precipitator, all generated under full power generation, were used to generate the above information for the removal of Cadmium, Copper, Lead, Zinc, Arsenic and organics as represented by the Chemical Oxygen Demand (COD) in actual ash pond leachate. The above fly ashes were selected because they in general exhibited the best sorbate characteristics of the fly ashes evaluated. Prior to their use, these fly ashes were washed until leaching of the Cadmium, Copper, Lead and Zinc ceased because it was shown earlier that washing the fly ashes provided fly ashes with the capacity to remove these elements.

A different ash pond sample was used for this part of the investigation because Sample A, Sample B and Sample C were found to contain high concentrations of chloride which interfere with the Chemical Oxygen Demand measurements. The analysis of the ash pond Sample D is presented below.

TABLE 54 ANALYSIS OF ASH POND SAMPLE D

<u>Element</u>	<u>Original Conc., mg/l</u>	<u>Initial Conc.,mg/l</u>
Cd	0.02	0.52
Cu	0.07	0.52
Pb	0.30	0.30
Zn	0.56	0.56
As	0.10	0.10
COD	12.8	12.8
pH	6.4	

In order to determine the sorbate capacity of the selected fly ashes for the above elements without being required to treat large volumes of ash pond leachate before breakthrough occurs, due to the low concentration of Cadmium and Copper present in this leachate, sufficient Copper and Cadmium were added to the ash pond sample to raise their concentration to 0.52 mg/l. The analysis of ash pond Sample D added to the selected Blend, Nora, Mine Mouth D and Militant fly ashes is presented in Table 54 under the column designated initial concentrations.

The concentration of Cd, Cu, Pb, Zn, As and COD remaining in ash pond Sample D after treatment with the selected Blend, Nora, Mine Mouth D and Militant fly ashes have been determined. In some cases up to 36 liters of ash pond Sample D was added to the fly ash samples before breakthrough occurred.

Cadmium Removal

A comparison of the Cadmium treatment results show that each of the fly ashes reduced the Cadmium from 0.52 mg/l to non-detectable concentration levels in the initial treatment of about 12 liters of ash pond sample (see Figures 14 through 17). Beyond the 12 liters, even though the concentration of Cadmium in the ash pond sample was increased as indicated by the dotted influent concentration line until breakthrough occurred, the Militant, Blend, Nora and Mine Mouth D fly ashes still reduced the Cadmium concentration in the treated ash pond to non-detectable levels.

The concentration of the Cadmium in the ash pond sample was increased to determine whether the Cadmium removed is influenced by changes in the Cadmium concentration in the influent. The treatment results show that increasing the Cadmium concentration from 0.52 mg/l to 2.1 mg/l, 0.80 mg/l, 0.80 mg/l and 1.8 mg/l for the ash pond samples treated by the Militant, Blend, Nora and Mine Mouth D fly ashes, respectively, had no measurable influence on the concentration of Cadmium remaining in the treated ash pond samples (see Figures 14 through 17). The Cadmium concentration in the treated samples remained below measurable levels until breakthrough begins to occur. This occurred for the Militant, Blend, Nora and Mine Mouth D after 16 liters, 28 liters, 32 liters and 22 liters, of ash pond samples had been treated by those fly ashes, respectively (see Figures 14 through 17).

Similarly, observed changes in pH during the course of treatment also does not appear to influence the concentration of Cadmium remaining in the treated ash pond sample. The range of pH changes encountered in the ash pond samples treated with the Militant, Blend, Nora and Mine Mouth D fly ash until breakthrough of Cadmium occurred were 7.0 - 5.8 (see Figure 18), 9.0 - 6.5 (see Figure 19), 10 - 6.5 (see Figure 20) and 11.5 - 6.5 (see Figure 21),

Fig. 14. Concentration of Cadmium Remaining After Treatment with Militant Fly Ash, 500 grams

Fig. 15. Concentration of Cadmium Remaining After Treatment with Blend Fly Ash, 500 grams

Figure 16 Concentration of Cadmium Remaining After Treatment With Nora Fly Ash, 500 grams

Fig. 17. Concentration of Cadmium Remaining After Treatment with Mine Mouth D Fly Ash, 500 grams

Fig. 18. pH of Treated Ash Pond Sample Using Militant Fly Ash, 500 grams

Fig. 19. pH of Treated Ash Pond Using Blend Fly Ash, 500 grams

Figure 20 pH of Treated Ash Pond Sample Using Nora Fly Ash

Fig. 21 pH of Treated Ash Pond Sample Using Mine Mouth D Fly Ash, 500 grams

respectively. In spite of these pH changes, the Cadmium concentration in the treated ash pond sample was unaffected and remained below measurable levels until breakthrough occurred.

The determination of the Cadmium sorbate capacity of two of the fly ashes, Blend and Mine Mouth D, over the pH range from 5 to 10, under batch conditions, reveals that at pH's above 6.5, the batch Cadmium sorbate capacity exhibited by these two fly ashes remain constant, whereas, a significant drop in sorbate capacity occurs at pH's below 6.5 (see Figure 23). The ratio of ash pond sample to fly ash used in these batch studies was 80 ml/gm with the concentration of Cadmium in the ash pond sample represented in Figure 22. Since these results indicate the sorbate capacity for Cadmium is independent of pH in the range from 6.5 to 10, the Cadmium removals exhibited by the Blend and Mine Mouth fly ashes (see Figure 15 and Figure 17) should not be influenced by the changes in pH encountered in the treated ash pond samples.

The interaction between the Militant, Blend, Nora and Mine Mouth D fly ashes and the ash pond sample appears to be a significant factor in Cadmium removals achieved with these fly ashes. Removals of Cadmium due to precipitation or other factors that may be related to pH changes has not occurred. The relationship between the Cadmium solubility in the ash pond sample and pH shows that the concentrations of Cadmium used in the ash pond Sample C over the pH ranges encountered, (see Figure 18 through Figure 21) in evaluations of the selected fly ashes, are below the 0.60 mg/l and 3.0 mg/l maximum Cadmium solubility observed for basic (pH - 10) and acidic (pH - 6) conditions (see Figure 22).

Copper Removals

A comparison of the Copper treatment results reveal that the Militant, Blend, Nora and Mine Mouth D fly ashes provide Copper removals that are

Fig. 22. pH Effect on Cadmium, Copper, Lead and Zinc Solubility in Ash Pond Sample D,

Fig. 23. pH Effect on Cd - Removal Capacity Under Batch Conditions

similar to Cadmium removals. These selected fly ashes reduced the Copper in the ash pond sample from 0.52 mg/l to non-detectable concentration levels in the treatment of about the first 12 liters of ash pond sample. Subsequent addition of ash pond sample with increasing amounts of Copper, as indicated by the dotted line, shows a continual reduction in Copper to non-detectable levels until breakthrough begins to occur. The concentration of Copper remaining in the treated ash pond effluent begins to increase toward breakthrough after 16 liters, 31 liters, 33 liters and 26 liters of ash pond samples have been treated by the Militant, Blend, Nora and Mine Mouth D fly ashes, respectively (see Figures 24 through Figure 27). The Copper concentration in the ash pond samples treated by the Militant, Blend, Nora and Mine Mouth D increased from 0.52 mg/l to 3.0 mg/l, 3.5 mg/l, 2.8 mg/l and 2.8mg/l, respectively, did not effect the concentration of Copper remaining in the treated ash pond. In order to avoid the precipitation which can respond to portions of Copper removal, and is a function of pH, the concentrations of Copper on the ash pond samples were maintained below the solubility of the Copper at different pH's (see Figure 22).

pH changes in treated ash pond samples also do not affect the amount of Copper removal. The above results were obtained even though the pH in the ash pond samples treated with the Militant, Blend, Nora and Mine Mouth D decreased from 7.0 - 5.9, 9.0 - 5.2, 10.0 - 6.0 and 11.5 - 6.0, respectively. Again, the batch sorbate capacity exhibited by the Blend and Mine Mouth D fly ashes for Copper and for Cadmium remained fairly constant over the pH range from 5 to 10 (see Figure 28).

The Copper treatment achieved during the earlier screening of the #11 Blend, #11 Nora and Mine Mouth D fly ashes also show reductions to non-detectable concentration or very low concentration of Copper. The Militant fly ash collected from the back precipitator under full power on the other hand,

Fig. 24. Concentration of Copper Remaining After Treatment with Militant Fly Ash, 500 grams

Fig. 25. Concentration of Copper Remaining After Treatment with Blend Fly Ash, 500 grams

Figure 26 Concentration of Copper Remaining After Treatment With Nora Fly Ash, 500 grams

Fig. 27. Concentration of Copper Remaining After Treatment with Mine Mouth D Fly Ash, 500 grams

Fig. 28. pH Effect on Copper Removal Capacity Under Batch Conditions

did not exhibit any removals (see Table 46). These findings do not agree with the results presented in Figure 24, where it can be seen that the Militant fly ash reduced the Copper to non-detectable levels. This removal rate may be explained by the fact that the earlier results show that the concentration of Copper remaining in the treated ash pond sample was decreasing upon addition of ash pond sample. Apparently, the washing of the selected fly ashes with water in this part of the investigation, until the leaching of the Cadmium, Copper, Lead and Zinc ceased, probably produced Nora and Militant fly ashes with better Copper sorbate properties than that indicated from the earlier screening results.

Lead Removals

Exceptional Lead treatment results were achieved with the Militant, Blend, Nora and Militant fly ashes. The concentration of Lead remaining in the treated ash pond samples was observed to remain below detectable levels with no indication of breakthrough even after treatment of 36 liters of ash pond sample. These removals were achieved even though the concentration of Lead was increased to 3.0 mg/l (see dotted influent concentration Figure 29 through Figure 32). The maximum allowable primary drinking standard for Lead is 0.05 mg/l. Apparently, the extensive washing of these fly ashes provided fly ashes with exceptional Lead sorbate characteristics. The time constraints of this investigation did not allow us to go beyond the addition of 36 liters of ash pond samples to the Blend, Nora and Mine Mouth D fly ash samples. This exceptional treatment was not the results of precipitation or other pH factors that may lead to removal of Lead since the concentration of Lead in the ash pond samples were kept below the maximum solubility of the Lead measured as a function of pH (see Figure 22).

The dependence of the batch sorbate capacity for Lead on pH could not be determined for the Blend and Mine Mouth D fly ashes as was the case for Cadmium and Copper because the ratio of ash pond samples to fly ash sample

Fig. 29. Concentration of Lead Remaining After Treatment with Militant Fly Ash
500 grams

Fig. 30. Concentration of Lead Remaining After Treatment with Blend Fly Ash, 500 grams

Fig. 31. Concentration of Lead Remaining After Treatment with Nora Fly Ash, 500 grams

Fig. 32. Concentration of Lead Remaining After Treatment with Mine Mouth D Fly Ash
500 grams

that would insure saturation of the fly ash with Lead could not be defined because of the absence of Lead breakthrough. However, since the change in pH for the ash pond samples treated with the Militant, Blend, Nora and Mine Mouth D fly ashes ranged from 7.0 - 4.0, 9.0 - 5.0, 10.0 - 6.0 and 11.5 - 3.5, respectively (see Figure 18 through Figure 21), and the concentration of the Lead remaining in the treated ash pond samples did not change, it is assumed that the sorbate capacity of the selected fly ashes for Lead, as was the case for Cadmium and Copper, is independent of pH in the above ranges.

Zinc Removals

The treatment of ash pond Sample D using the Militant, Blend, Nora and Mine Mouth D fly ashes for Zinc removal provided removal results, in general, that were similar to that obtained for Cadmium and Copper. The Blend, Nora, and Mine Mouth D fly ashes reduced the Zinc in the ash pond samples to below measurable levels until breakthrough occurred after treatment of 25 liters, 32 liters and 21 liters, respectively (see Figure 33 through Figure 35). The Militant fly ash on the other hand only reduced the Zinc concentration in the ash pond sample from 0.56 mg/l to an average concentration of about 0.25 mg/l, with breakthrough beginning to occur after the treatment of 15 liters of ash pond sample (see Figure 36). Breakthrough of the Zinc from the Blend, Nora and Mine Mouth D occurs at a pH of about 6. The lack of change in the concentration of Zinc remaining in the ash pond with pH is again due to the fact that sorbate capacity of the fly ashes are independent of pH in the range from about 7 up to 10 (see Figure 37).

The above treatment results are similar to our earlier screening results obtained with the #11 Blend, #11 Nora, Mine Mouth D and Militant fly ash, collected from the back precipitator, all under full power generation. The Blend, Nora and Mine Mouth D fly ashes all reduced the Zinc to low but measurable concentration, whereas, the Militant was not as effective in reducing the

Fig. 33. Concentration of Zinc Remaining After Treatment with Blend Fly Ash, 500 grams

Figure 34 Concentration of Zinc Remaining After Treatment With Nora Fly Ash, 500 grams

Fig. 35. Concentration Remaining After Treatment with Mine Mouth Fly Ash, 500 grams

Fig. 36. Concentration of Zinc Remaining After Treatment with Militant Fly Ash, 500 grams

Fig. 37. pH Effect on Zn Removal Capacity with Batch Conditions

Zinc concentration (see Table 48). Again, extensive washing of the fly ashes probably improved the fly ashes sorbate characteristics for the removal of Zinc in the ash pond sample, as was the case for Copper and Lead removals.

Arsenic Removals

Arsenic removals from the ash pond sample were achieved with the Blend, Nora and Mine Mouth D fly ash. The Blend, Nora and Mine Mouth fly ashes reduced the arsenic from 0.10 mg/l to about 0.03 mg/l, 0.04 mg/l and 0.04 mg/l, respectively (see Figure 38 through Figure 40). Breakthrough of the arsenic occurs after 37 liters, 34 liters and 28 liters of ash pond sample is passed through the Blend, Nora and Mine Mouth D fly ashes, respectively.

An examination of the results achieved with the Nora and Mine Mouth D fly ashes suggest that these fly ashes may be able to reduce the arsenic concentration to levels below 0.04 mg/l. The Nora and Mine Mouth D fly ashes do not provide reductions in the arsenic concentration of 0.04 mg/l until after 8 liters and 16 liters of ash pond sample has been treated, respectively (see Figure 39 through Figure 40). These results suggest that the extensive washing of these fly ashes until the Cadmium, Copper, Lead and Zinc had ceased was not adequate to prepare the Nora and Mine Mouth D fly ashes for arsenic removal. Further washing of those fly ashes may lead to the fly ashes with sorbate properties that could reduce the level of arsenic concentration in ash pond to the primary allowable drinking water concentration of 0.05 mg/l.

Virtually no arsenic removals were achieved with the Militant fly ash. This fly ash only reduced the arsenic from 0.10 mg/l to about 0.08 mg/l. However, it should be noted, as was the case for the Nora and Mine Mouth D that the Militant may provide better arsenic removals than observed. Twelve

Fig. 38. Concentration of Arsenic Remaining After Treatment with Blend Fly Ash, 500 grams

Figure 39 Concentration of Arsenic Remaining After Treatment With Nora Fly Ash, 500 grams

Fig. 40. Concentration of Arsenic Remaining After Treatment with Mine Mouth D Fly Ash
500 grams

Fig. 41. Concentration of Arsenic Remaining After Treatment with Militant Fly Ash, 500 grams

liters of ash pond sample was treated by this fly ash before it reduced arsenic concentration in the ash pond sample to 0.08 mg/l. Further washing of the arsenic beyond what was carried out in this experiment may lead to a Militant fly ash with better sorbate characteristics.

Organic Removals

The results of treatment of organics as represented by the Chemical Oxygen Demand (COD) in ash pond leachate using the #11 Militant, #11 Blend, #11 Nora and Mine Mouth D fly ashes shows a reduction in the concentration of COD from 12.8 mg/l to an average of about 2 mg/l in the treated ash pond samples. This treatment represents a reduction in COD of about 85 percent.

The results of the analysis of COD remaining in the ash pond Sample D after treatment with the Militant shows the COD concentration to remain constant at 2.0 mg/l through the treatment of 12 liters of ash pond sample (see Figure 42). After 12 liters of ash pond had been treated with the Militant fly ash, the concentration of COD remaining in the ash pond sample begins to increase toward breakthrough. Projection of the data points indicates that breakthrough will occur after treatment of 32 liters of ash pond sample with 500 grams of Militant fly ash.

A comparison of the COD treatment results achieved with the Blend, Nora and Mine Mouth D fly ashes, all of which have undergone fusion during their generation, show that the Mine Mouth D fly ash provides the best removals of COD followed by the Blend and Nora fly ashes in decreasing order, respectively. The Mine Mouth D and Blend fly ashes reduced the COD from 12.8 mg/l to an average of about 1.8 mg/l in 22 liters and 18 liters of treated ash pond sample, correspondingly (see Figure 43 and Figure 45). Projection of the data points indicated that breakthrough of the organics from 500 grams of Mine Mouth D and Blend fly ashes will occur at some point after treatment of

Figure 42 Concentration of COD Remaining After Treatment With Militant Fly Ash (500 grams)

Figure 43 Concentration of COD Remaining After Treatment With Mine Mouth D Fly Ash (500 grams)

Figure 44 Concentration of COD Remaining After Treatment With Blend Fly Ash (500 grams)

Figure 45 Concentration of COD Remaining After Treatment With Nora Fly Ash (500 grams)

40 liters of ash pond sample. Five hundred grams of Nora fly ash, on the other hand, reduced the COD concentration in the ash pond sample from 12.8 mg/l to an average of about 2.4 mg/l with breakthrough occurring after the treatment of 36 liters of ash pond sample (see Figure 45).

The amount of Carbon remaining in the fly ashes which have undergone fusion appears to be a factor in COD removal. The amount of Carbon remaining in the Mine Mouth D, Blend and Nora fly ashes on a dry basis was found to be 2.5%, 1.8% and 1.0%, respectively. The decreasing amounts of Carbon remaining in the fly ashes correlated with the removal of COD achieved with the Mine Mouth D, Blend and Nora fly ashes. Apparently, the high boiler temperatures encountered by these fly ashes in the molten state may lead to activation of the carbon present in the fly ash. Activated Carbon is regularly used for the removal of organics from waste streams. Increasing carbon content in fly ashes was reported by Johnson, et al.⁽¹⁴⁾ and Mancy, et al.⁽¹⁵⁾ that fly ashes with high organic contents are better absorbers.

Sorbate Capacity

The Sorbate capacity of the Militant, Blend, Nora and Mine Mouth D fly ashes were determined for the removal of Cadmium, Copper, Lead, Zinc, arsenic and organics from ash pond Sample D. The results of these determinations are presented in Table 55. The values represent the amount of a specific element that can be removed by one gram of fly ash under dynamic conditions. The sorbate capacity for Lead is not included in this table because breakthrough with these fly ashes was not achieved within the volume of ash pond sample treated.

TABLE 55. Sorbate Capacities Obtained Under Dynamic Conditions

Fly Ash	Cd	Removal Capacity ug/gm				COD
		Cu	Pb	Zn	As	
Militant	41	34		51	0	530
Blend	66	83		86	3.26	680
Nora	56	70		60	3.4	560
Mine Mouth D	53	41		76	3.0	692

A comparison of the sorbate capacity for the Militant, Blend, Nora and Mine Mouth D fly ashes reveal that the latter three fly ashes, which encountered higher boiler temperatures, underwent fusion during their formation and exhibit significantly larger sorbate capacities than the high fusion Militant fly ash. In addition, the sorbate capacity of the Mine Mouth D ash for organic removal was the largest, followed by the Blend, Nora and Militant fly ashes in decreasing order, respectively. As was discussed earlier, the Mine Mouth fly ashes also had the highest carbon content.

Contact Time

The contact time between the ash pond sample and the Blend and Mine Mouth D fly ashes required to achieve maximum removals of Cadmium, Copper and Zinc were determined. The Blend fly ash reduced the Cadmium, Copper and Zinc in six hours contact time to approximately 0.10 mg/l, 0.20 mg/l and 0.10 mg/l, respectively. If these Cadmium, Copper and Zinc concentrations remaining in the ash pond are the minimum concentrations that can be obtained using a ratio of 80 ml of ash pond sample to a gram of fly ash under batch conditions, the Blend fly ash was able to provide Cadmium, Copper and Zinc removals of 77%, 76% and 85% within 15 minutes (see Figure 46, Figure 47 and Figure 48).

The above results indicate that contact time of at least 15 minutes between the ash pond samples and the fly ash should be considered for preliminary design of a treatment system to remove Cadmium, Copper and Zinc from an ash pond effluent. However, the time limitations imposed upon this investigation did not allow for the determination of the contact time required for removal of the cations, arsenic or organics. If the removal of these pollutants are of concern in the design of treatment systems, the contact time required for maximum removal of these pollutants should be determined. The longest contact time needed to remove a specific element would define the detention time of the ash pond leachate required in the treatment system to remove the desired pollutants.

Figure 46 Contact Time for Cadmium Removal

Figure 47 Contact Time for Copper Removal

Figure 48 Contact Time for Zinc Removal

MÖSSBAUER STUDY OF COAL ASH

In a study of the leaching of trace elements from fly ash it is desired to determine the exact state of each hazardous element as a function of boiler conditions and the source of the original coal. The conditions which would minimize the leaching of trace elements from the coal ash can be determined. However, there are few available experimental techniques which are capable of providing this information for any of the trace elements in coal ash. Therefore, it was decided to use a probe, iron, and Mössbauer spectroscopy to study the effect of boiler conditions on the environment from this element. This choice of probes proved to be indeed fortunate because the iron content of the coal is important in determining the leaching properties of all elements.

It became evident in the early phases of this project ⁽¹⁶⁾ that the degree which the fly ash fused together was important in the encapsulation of many elements in the coal ash. Evidence will be presented which indicates that this encapsulation of the metal ions can occur at temperatures below the initial deformation temperature of the coal burned.

Coal ash does not consist of a single compound and, therefore, does not undergo a phase change at one single temperature. The changing of coal ash from a solid, where compounds are local regions, to a liquid is characterized by four temperatures called "fusion temperatures":

1. ID: Initial Deformation Temperature
2. ST: Softing Temperature (spherical), height = width
3. HT: Hemispherical Temperature, height = 1/2 width
4. FT: Fluid Temperature

The methods used to determine these temperatures are reviewed by Winegartner.⁽¹⁷⁾ These temperatures cover the range where the coal ash begins to melt, the initial deformation temperature, to the temperatures at which the coal ash is in a liquid state, the fluid temperature.

The effect of heating coal ash on the iron atoms in the coal ash can be seen in Figure 49. In the coal the iron can be in several compounds, pyrite, siderite, illite, jarosite, etc.. For example, in a typical coal obtained at the Mercer boiler, where the bottom ash is removed as a slag, the coal contains pyrite and illite. This can be seen in the Mössbauer spectra of coal as two doublets with peak overlap on the left as shown in Figure 49a. When this coal is ashes at a relatively low temperature (600°C), the pyrite is oxidized to hematite, Fe_2O_3 , and possibly magnetite, Fe_3O_4 . These compounds are the predominate iron species in the ashed coals ashed at 600°C, as seen in the Mössbauer patterns given in Figure 49b. At the higher temperatures present in a boiler, the iron becomes encapsulated in a alumina-silica matrix as seen in the Mössbauer spectra of fly ash (see Figure 49c). The quadrupole doublets are due to the presence of iron in the assymetric charge distribution present in the alumina-silica matrix, and the magnetic pattern is from the iron oxides. In the alumina-silicate matrix iron has been analyzed in terms of one iron (III) species and up to three iron (II) species. It was not possible to obtain a consistant set of isomer shifts and quadrupole splitting for each iron species in all the same samples studied. However, if a particular sample was reduced or oxidized, the isomer shifts and quadrupole splittings are fairly consistant and only the intensities change. After the coal ash has become a liquid in a reducing environment, such as bottom ash (see Figure 49d), most of the iron exists as iron (II) species.

Coal Analysis

The fusion temperature of the coals, fly ash, and bottom ash derived from the burning of the coals in commercial boilers, are reported in Table 39. These coals are grouped according to the type of boiler in which they were burned. The coals which were burned in a non-slugging boiler are given first, followed by the coals burned in a slugging boiler. The fusion temperatures of the coals ashed in the boiler varied somewhat with where they were collected, but these variances, in general, are small. Therefore, only the average fusion temperatures are given here.

The Mössbauer data indicated the presence of three iron compounds in the coals: pyrite ($\delta = 0.30$ mm/sec, $\epsilon = 0.61$ mm/sec), jarosite ($\delta = 0.36$ mm/sec, $\epsilon = 1.08$ mm/sec), and a Fe(II) clay ($\delta = 1.12$ mm/sec, $\epsilon = 2.65$ mm/sec), probably illite. For the coal sample from the Nora mine siderite ($\delta = 1.04$ mm/sec, $\epsilon = 2.09$ mm/sec) was also present. The Mössbauer analysis for all the coal samples is given in Table 56. The Mössbauer spectra and computer generated fit of the data for the twelve coals studied are given in Figures 50 and 51. In Figure 69, the Mössbauer spectra for the coals burned in the non-slugging boiler are given. Each spectra consists of two lines which are almost equal in height characteristics of pyrite. The computer analysis indicated that an additional quadrupole doublet was present in some coals. The quadrupole splitting and isomer shift of this second doublet is consistent with the presences of jarosite, resulting from the slow oxidation of pyrite. The absence of any substantial peak at 2.4 mm/sec indicates that little of the iron present in these coals was in the clay as iron(II) illite. In Figure 51, the Mössbauer spectra for the coals burned in the slugging boiler are given. There are three easily recognized lines in the Mössbauer spectra

for the coals from the Wellmore Cactus mine, the Wellmore Ackiss mine, the Nora mine, and from the Blend. This result is interpreted as two doublets with the left line of each doublet nearly coincidental, one doublet from the pyrite and the other doublet from an Fe(II) clay (illite). The Mössbauer spectra in Figures 50 and 51 were obtained within a few months of the time the coal samples were collected. The Mössbauer spectra obtained a few months later were substantially different for many of the coals from the slagging boiler. In Figure 52 the Mössbauer spectra of the non-slagging boiler after a few months after collection, usually seven, are given. The analysis indicated that the amount of jarosite in the sample increased with aging.

For all the coals from the non-slagging boiler, the iron in the coal is predominately in the pyrite form or the product of slowly oxidized pyrite, jarosite. There is only a small amount of iron in the Fe(II) state incorporated in the clay. For the coals burned in the slagging boiler there is, in general, a substantial portion of the iron in the Fe(II) state which is incorporated into the alumina-silicate matrix (clay). The Ellsworth coal was the only coal burned in the slagging boiler which contained almost no iron in a clay matrix. Note that the coal ash from this mine contains over five percent CaO, which is a good fluxing agent.

The relative compositions of the iron compounds in the ash for the twelve coals studied are given in Table 5. It is assumed that the recoil free fraction of all the iron compounds are approximately equal at room temperature. The relative composition was calculated using the relative area under each of the Lorentzian curves used to fit the data.

Coal Ash Analysis

In order to investigate the effect of the elevated temperature on the iron compounds in the ash, a few coals were ashed at 600°C using ASTM method number 3683. The Mössbauer spectra for the resulting ash are given in Figure 53. The iron oxide, hematite, was the prevalent form of iron in the ash obtained for the coals from the Militant and Wellmore Ackiss mines (Figure 53a, 53d, and 53b). The coals from which these samples were derived contained only a small amount of iron(II) clay as determined by Mössbauer spectroscopy. However, there was a large fraction of iron(III) alumina-silica in the ashes from Wellmore Cactus coal as can be seen by the presence of a quadrupole doublet with an isomer shift of 0.35 mm/sec and a splitting of 0.89 mm/sec. The coals from the Wellmore Cactus mine contained almost 50% Fe(II) in clay.

Then a series of five coals received direct from various mines where ashed at 800°C according to ASTM method 1857 and their fusion temperatures determined (see Table 57). The Mössbauer spectra of these coals and the ashed coals are given in Figures 54 and 55. In general, the amount of iron in the alumina-silica matrix in the ashed coals is proportional to the amount of iron(II) clays in the coal samples. However, there are exceptions, such as the coal from the Turner mine (Figures 54c and 55c) where pyrite is the predominate form in the coal, but the iron(III) in the alumina-silica is the predominate form of iron in the ashed coal. It should be noted that this coal ash contained the most calcium oxide (5.9%).

To investigate the possibility that a phase change occurs in the inorganic portion of the coal when it is burned at 800°C, the sample from the Bostic mine was placed in concentrated hydrochloric acid for

twenty-four hours in order to remove all the hematite present. This sample was then reduced in carbon monoxide at 400°C for eight hours. The effect of this treatment of the coal ash on the iron compounds in the sample can be seen in Figure 56. The reduced sample had a Mössbauer spectra very close to a typical bottom ash sample. This will be discussed later. The iron in the sample was found to consist of one iron(III) and three iron(II) species. Neither of these iron(II) quadrupole doublets were the same as the doublet due to the Fe(II) in clay of the original coal. This indicated that there is some phase transition of the inorganic portion when the coal is burned at this temperature. Also, although the amount of the various iron species changed with the oxidation and reduction of the sample, the isomer shifts and the quadrupole splittings of each iron species remained fairly constant.

Fly Ash Analysis

The Mössbauer patterns for the twelve fly ash samples used in this study are presented in Figures 57 and 58. The Mössbauer spectra of the fly ash from coals which were burned at the non-slagging boilers, Hudson, Boiler C, and Boiler D are given in Figure 5. All these fly ash samples were obtained from coals which had a fluid temperature above the average boiler flame temperature at the time of burning. The Mössbauer spectra of the fly ash from coals which were burned at the slagging boiler, Mercer, are given in Figure 58. All these fly ash samples are for coals which had fluid temperatures below the average flame temperatures in the boiler at the time of burning. It can be seen that the peak at around +5 mm/sec., which corresponds to the iron oxides hematite and magnetite, were the strongest for the fly ash samples which were burned in the non-slagging boiler where the flame temperature is below the respective fluid

temperatures of the coals burned (Figure 57). It should also be noted that the average flame temperature in Boiler A (1410 ° C) was well below the ID temperature of the coals from the Badger (ID = 1500+) and the Upshur (1500+) mines, but a large portion of the fly ash was still incorporated into the alumina-silica matrix. This indicates that the iron dissolved in the alumina-silica matrix was well below the initial deformation temperature of the coal. Also, it should be noted that the coal burned in the slagging boiler contains simple iron oxides even though the flame temperature in the boiler was well above the fluid temperature of the coals being burned. It can be seen from Table 59, that the amount of iron in the alumina-silicate matrix is greatest for the coals from the slagging boiler.

In order to interpret the effect of the iron on the fusion of the coal ash, it is important to differentiate between two general types of iron compounds, the iron oxides hematite and magnetite, and the iron substituted in the alumina-silicate matrix. Since both of these types of iron compounds contribute to the Mössbauer pattern in the low velocity range, it is helpful to remove the iron oxides from the sample before analyzing the iron in the alumina-silica matrix. Two methods were found to accomplish this task, one chemical and the other physical. The iron oxides could be removed from the coal ash by placing the sample in concentrated hydrochloric acid for 24 hours as seen in Figure 59. Also, the iron oxides can be removed using a permanent magnet to attract the iron oxides (Figure 60). Since only the magnetite (Figure 61a) is attracted to the magnet, the fact that most of the hematite comes along, indicates that they are physically associated with each other. The iron oxide removed by the magnet contains around 20% hematite as analyzed by the area

under the appropriate Mössbauer lines (Table 60). This analysis was checked using physical mixtures of hematite and magnetite (Figure 61). It should be noted that little or no iron in a alumina-silica lattice was attached to the portion removed by the magnet. This indicates there are few particles in which the iron was partially incorporated into the alumina-silica matrix. Also, the higher temperatures used in the slagging boiler produced less hematite than in the non-slagging boiler as expected with the greater stability of the magnetite at higher temperatures. In addition, the Mössbauer spectra of the magnetic component can be fitted by assuming only magnetite and hematite is present. The iron which had been incorporated into the alumina-silica matrix was not attracted to the magnet (see Figure 62). The Mössbauer spectra of these iron compounds can be interpreted in terms of the similar quadrupole doublets present in the oxidized and reduced coal ashes. The use of constraints was checked by only constraining the dominate species, the iron(III) to have equal height and equal line width for the portion of the fly ash not attracted to a magnet. The analysis of the Mössbauer data was similar to that obtained for the iron species in the alumina-silica matrix in the coal ash. The Mössbauer parameters, the isomer shift and the quadrupole splitting, were fairly consistent for the oxidized and reduced species from the same sample.

Selected fly ashes were also reduced using hydrogen. The Mössbauer spectra of one sample is given in Figure 63. When the samples were reduced, the quadrupole splitting for the iron(III) decreased somewhat and a third iron(II) species was present. However, it was not possible to completely reduce or oxidize the iron in the samples under the conditions used in this study.

Analysis of Bottom Ash

As seen by the Mössbauer spectra of selected bottom ashes (see Figure 63), the iron in the bottom ashes is in a highly reduced state. This reduced state of the iron is more stable in the bottom ashes than in fly ash or ashed coals. Pure oxygen at 550°C for 21 hours was not enough to oxidize the iron to any appreciable extent (see Figure 64). The difficulties in oxidizing the bottom ashes from the slagging boiler indicates that there is a stabilization of the reduced state when the coal ashes have been in a liquid state.

Conclusion

The iron in the coal ash can be divided into two general categories, the simple iron oxides Fe_2O_3 and Fe_3O_4 , and the iron encapsulated in the alumina-silica matrix. However, other iron compounds have been reported in coal ash literature. The simple iron oxides exhibit some type of magnetic phenomena. These oxides can be easily distinguished from the iron in the alumina-silicate matrix using Mössbauer spectroscopy. The iron in the alumina-silicate matrix contributes quadrupole doublets to the Mössbauer pattern of coal ash.

Hydrochloric acid can be used to leach all the material which exhibit magnetism. No quantitative study was done on the iron so it is not known how much, if any, of the iron encapsulated in the alumina-silica matrix was removed during this leaching process. Since the intensity of the Mössbauer spectra obtained before and after the leaching are comparable, it is probable that little of the iron was removed from the alumina-silica matrix during this process.

The method which the iron becomes encapsulated is not known. Many clays have some iron already in a clay matrix. When these coals are

burned the iron remains in an alumina-silica matrix. At some temperature the remainder of the iron is encapsulated. Reducing the iron in the coal ash at 800°C using hydrogen or carbon monoxide does not produce a iron species with a quadrupole splitting as large as that present in the coal. This is probably due to the removal of chemically bound water from the clay matrix.

The Mössbauer parameters for the iron species in the alumina-silicate matrix were similar for the coals ashed below 800°C, the fly ash, and the bottom ash. However, there are probably more than one iron species contributing to each Mössbauer doublet. Huffman, et al.⁽¹⁸⁾ have reported that the quadrupole double ($\epsilon = 1.50$) with an isomer shift of 1.0 mm/sec is a mixture of a ferrous glass and hercynite (FeAl_2O_4). Only a low temperature Mössbauer spectra can distinguish how much of each is present. This problem can be seen in the oxidation-reduction studies done in this work. The coal ash is relatively easy to oxidize while the fly ash is harder to completely oxidize. The bottom ash is oxidized very little under the conditions used in this study. Yet, the Mössbauer parameters for all of these ashed coal samples are similar.

CONCLUSIONS

The use of fly ash is feasible for the treatment of Cadmium, Boron, Tin, Molybdenum, Nickel, Lead, Copper, Chromium, Zinc, Manganese, Iron, arsenic and organics at levels typical of actual ash pond effluents. Removals of greater than 75 percent were achieved for all of the above elements with the exception of Boron and Molybdenum. Boron and Molybdenum removals of 21% and 43% were achieved. The fly ashes were capable of reducing the concentrations of Cadmium, Lead, Copper, Chromium, Zinc, Manganese, Iron and arsenic to concentration below the maximum allowable concentrations set for these elements under the National Interim Primary and Secondary Drinking Water Regulations. This is far below RCRA requirements of 100x the drinking water standard.

The general sorbate characteristics of the fly ashes are favored by low fly ash fusion temperatures, combustion temperatures that favor the fusion of fly ash during formation and the time that the fly ashes remain in the fused state. No correlation could be established between the sorbate characteristics of the fly ashes and their bulk major, minor and trace elemental compositions nor with their major and minor elemental surface compositions. Only the carbon content of the fly ash could be related to its organic removal properties. High temperature chemical or physical changes which have not been identified must be occurring within the fly ash during the combustion process to favor the sorbate characteristics of the fly ashes.

No correlation could be established between the treatment achieved with the fly ashes and the surface area of the fly ash particles. In the

cases where different removals could be observed between different size distributions of fly ashes, generated from the same coal at the same time, Iron, Zinc and Lead were best removed by the larger sizes; whereas, Manganese and Chromium were best removed by the smaller sizes.

The sorbate capacities of the fly ashes, identified in this investigation to provide the best treatment, average about 80 ug/gm for Cadmium, Copper and Zinc, 3.4 ug/gm for Arsenic and 700 ug/gm for the organics. However, the sorbate capacity for Arsenic may be increased with further washing of the fly ashes. These capacities were found to be independent of pH in the range from about 6 to 10. Also, the removals of Cadmium, Copper, Lead and Zinc were observed to be independent of their concentrations in the ash pond sample in the ranges from 0.52 mg/l to 2.0 mg/l, 0.52 mg/l to 3.5 mg/l, 0.30 mg/l to 3.0 mg/l and 0.56 mg/l to 4.0 mg/l, respectively. Greater than 75 percent of the Cadmium, Copper and Zinc present in the ash pond samples were achieved within a 15 minute contact time between the fly ash and ash pond sample.

The removals of Cadmium, Boron, Tin, Molybdenum, Nickel, Lead, Copper, Chromium, Zinc, Manganese and Iron were achieved even though the fly ashes initially leached these elements. These leachable elements are apparently contained to some extent within a water soluble component whose removal through washing leads to a fly ash with sorbate characteristics. The leachable amounts of each element can be in general related to 1) the amount of this element present in the fly ash provided that a major portion of the element is located at the surface, 2) the surface area of the fly ash particles and 3) the boiler temperatures encountered by the fly ashes during their formation. The smaller fly ash

particles exhibited the greatest amount of leaching. Also the fly ashes produced at lower boiler temperatures leached the greatest quantities of each of the above elements. High boiler temperatures apparently lead to some fixation of the above elements in the non-leachable portion of the fly ash particle.

The results of the investigation indicates that the leaching associated with the fly ashes should not pose a danger to the environment. Removals of Cadmium, Boron, Tin, Molybdenum, Nickel, Lead, Copper, Chromium, Zinc, Manganese and Iron from actual ash pond samples occurred after these elements cease to leach from the fly ash. The experimental results show that fly ash may be used to clean its own leachage.

The Mossbauer patterns for the fly ash obtained from coal burned in boilers (wet bottom) with flame temperatures above the fusion temperatures of the coals were almost the same as the Mossbauer patterns for the fly ash from coal burned in boiler (dry bottom) with flame temperatures below the fusion temperatures of the coal burned. In addition, there was less hematite and magnetite in the coals burned in a wet bottom boiler, but not to the degree expected. Apparently the conditions in the wet bottom boiler did not provide for the particle contact necessary to completely incorporate the separate iron oxide particles into the alumina-silica matrix of other particles even though the boiler temperatures were above the ash fusion temperatures. Since the fly ash particles separated using a magnet contained the iron oxides as the principle component, it is reasonable to assume that these particles existed as individual particles in the boiler. This lack of adequate particle contact could also occur for particles containing other metal oxides. Thus,

not only is boiler temperature a factor in determining the incorporation of the elements in an insoluble matrix which controls the sorption and desorption of these elements, but also the particle contact history in the boiler may play a role in regulating the sorption and desorption processes. Also, Mossbauer analysis indicates that the type of coal and the distribution of the compounds in the individual fly ash particles play a significant role in determining the sorbate characteristic of the fly ash.

RECOMMENDATIONS

Since a number of factors have been identified that lead to the formation of fly ash which can provide effective treatment of ash pond leachate, a pilot scale investigation on an actual site should be undertaken to generate the engineering data required for scale up to actual treatment size. Two possible treatment approaches are recommended. One approach would be to treat the ash pond leachate in a fly ash bed operated in an up-flow expanded bed mode to overcome the low permeability exhibited by a fly ash bed when operated under gravity flow. The fly ash would be washed to expose the sorbate properties of the fly ash prior to its use in the bed. The amount of fly ash needed in the bed will be dependent upon the sorbate capacity of the fly ashes for the elements that will be treated, the concentration of the elements in the ash pond, and the volumetric flow. The second approach would be to identify the contact time and volume of wash required to remove the water soluble portion of the fly ash so that the pre-washing and the treatment can be carried out in situ during the time the ash is being transported to the ash pond. If adequate time is allotted for the washing process and treatment processes by reducing the rate of pumping of the ash slurry to the ash pond, the trace elements in the water soluble component of the fly ashes would be treated by the fly ash during transport. In essence, the fly ash could be used to clean up its own act. This approach would be applicable if the boiler is being operated under conditions conducive to the formation of fly ashes with suitable sorbate characteristics.

In order to identify the factors that lead to the formation of the water soluble fly ash component, minimize the leaching and maximize the

sorbate characteristics of the fly ashes, studies of the physical and chemical changes that occur in the fly ash at elevated temperatures, must be carried out. The results of these high temperature studies would identify the physical and chemical process that are occurring at elevated temperatures and improve the sorbate capacity of a fly ash for the treatment of specific elements. This information is necessary to permit the results, generated during the pilot scale study, to be used at a number of sites where boiler conditions are different from those encountered during this study.

Figure 49. Mossbauer spectra of coal and coal ash from the Wellmore Ackiss mine: a) coal, b) coal ashed at 600 °C, c) fly ash, c) bottom ash.

TABLE 56. Mossbauer parameters for coal samples.

sample	pyrite			illite			siderite			jarosite		
	δ	ϵ	Γ	δ	ϵ	Γ	δ	ϵ	Γ	δ	ϵ	Γ
NON SLAGGING BOILER												
MILITANT	0.27	0.56	69	1.06	2.68	9	--	--	--	0.34	0.93	22
DEEP HOLLOW	0.26	0.59	76	--	--	--	--	--	--	0.32	1.15	24
UPSHUR	0.31	0.55	47	1.24	2.32	26	--	--	--	0.36	0.98	28
BADGER	0.31	0.58	60	1.25	2.31	24	--	--	--	0.34	1.04	15
Boiler C	0.31	0.59	84	1.11	2.57	16	--	--	--	--	--	--
Boiler D	0.30	0.59	87	1.12	2.55	13	--	--	--	--	--	--
SLAGGING BOILERS (NON-AGED)												
BLEND	0.31	0.56	57	1.14	2.56	43	--	--	--	--	--	--
WELLMORE CACTUS 1	0.30	0.56	50	1.08	2.48	50	--	--	--	--	--	--
ELLSWORTH	0.32	0.60	92	0.78	3.25	8	--	--	--	--	--	--
WELLMORE ACKISS	0.33	0.57	49	1.16	2.61	24	1.04	1.90	7	0.40	1.09	19
NORA	0.31	0.63	50	1.15	2.72	5	1.15	2.11	45	--	--	--
SLAGGING BOILER (AGED)												
BLEND	0.29	0.57	28	1.07	2.43	36	--	--	--	0.32	1.07	36
WELLMORE CACTUS 1	0.34	0.57	39	1.06	2.53	34	--	--	--	0.34	1.04	26
ELLSWORTH	0.27	0.57	93	--	--	--	--	--	--	0.34	1.10	7
WELLMORE ACKISS	0.32	0.58	47	1.12	2.63	12	1.07	2.13	16	0.42	1.11	25
NORA	0.27	0.57	49	1.06	2.58	12	1.01	2.02	39	--	--	--
WELLMORE CACTUS 2	0.34	0.65	45	1.12	2.55	51	--	--	--	0.59	0.96	4
COAL DIRECT FROM MINE												
Benedict	0.32	0.61	86	1.13	2.52	14	--	--	--	--	--	--
Americoal	--	--	--	1.11	2.57	66	1.22	1.75	34	--	--	--
Turner	0.35	0.62	70	1.09	2.57	23	1.12	1.96	7	--	--	--
Bostic	0.33	0.65	40	1.12	2.58	41	1.22	1.70	19	--	--	--
Primary Energy	0.33	0.64	47	1.12	2.65	46	1.08	2.10	7	--	--	--

Figure 50. Mössbauer spectra of coals burned in nonslagging boilers: (a) Militant, (b) Deep Hollow, (c) Upshur, (d) Badger, (e) Boiler C (f) Boiler D

Figure 51. Mossbauer spectra of coals burned in slagging boilers:
(a) Blend, (b) Wellmore Cactus #1, (c) Ellsworth, (d) Wellmore Ackiss
(e) Nora

Figure 52. Mössbauer spectra of coals after aging: (a) Militant, (b) Deep Hollow, (c) Upshur, (d) Badger, (e) Boiler C (f) Boiler D

Figure 53. Mössbauer spectra of coals ashed at 600°C according to ASTM method #d3683: (a) Militant, (b) Wellmore Ackiss, (c) Wellmore Cactus 1.

Figure 54. Mössbauer spectra of coal samples from: (a) Benedict Mine, (b) Americoal Mine, (c) Turner Mine, (d) Bostic Mine, (e) Primary Energy Mine.

Figure 55. Mössbauer spectra of coals ashed at 800 C: (a) Benedict Mine, (b) Americoal Mine, (c) Turner Mine, (d) Bostic Mine, (e) Primary Energy Mine.

Figure 56. Coal ashed at 800° C after the iron oxides were removed with HCl: (a) leached, (b) reduced at 400° C for 4hrs, (c) reduced for 8 hrs, (d) oxidized at 400°C for 8hrs.

TABLE 57. Fusion Temperatures and Compositions of Various Coal Ashes

Source Mine	IE	ST	HT	FT	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	K ₂ O	TiO ₂	So ₃
Benedict	1135	1145	1180	1365	29.0	19.	46.8	2.0	2.7	0.7	2.2
Americoal	1330	1350	1420	1475	29.1	26.0	16.1	3.8	1.2	1.5	4.6
Turner	1240	1265	1285	1305	43.4	26.5	12.4	5.9	2.9	1.5	9.7
Bostic	1255	1305	1360	1405	53.1	26.2	10.2	2.7	5.2	1.0	3.9
Primary Energy	1480	1480	1480	1480	54.0	29.3	5.8	1.3	3.6	1.5	1.0

Table 58. Mössbauer parameters of coal ashes

sample	iron(II)			iron(II)			iron(II)			iron(III)		
	δ	ϵ	%	δ	ϵ	%	δ	ϵ	%	δ	ϵ	%
Wellaore Ackiss Fly Ash												
leached	-	-	0.0	-	-	0.0	1.02	2.0	25	0.33	1.09	75
reduced	1.02	1.57	30	1.05	2.9	10	1.05	2.3	36	0.38	0.84	24
oxidized	0.85	1.31	15	0.96	2.9	9	0.98	2.0	25	0.30	1.07	51
Ellsworth fly ash												
leached	1.04	0.94	6	1.17	2.48	10	1.04	1.93	22	0.32	1.17	62
reduced	1.01	1.48	42	1.14	2.62	14	1.08	2.11	31	0.42	0.72	13
oxidized (8hrs)	0.97	1.68	41	1.02	2.47	31	1.34	2.41	3	0.38	0.88	37
oxidized (25hrs)	0.84	1.68	33	0.85	2.85	10	--	--	--	0.32	0.99	57
Upshur fly ash												
leached	--	--	--	0.38	2.10	8	1.01	2.09	39	0.31	0.98	54
reduced	0.98	1.63	39	1.24	2.64	4	1.08	2.21	25	0.26	1.06	32
Wellaore Ackiss Bottom Ash												
bottom ash	1.00	1.52	19	1.07	2.63	20	1.05	2.07	33	0.43	1.18	28
oxidized 8hrs.	1.03	1.62	26	1.04	2.79	12	1.05	2.22	24	0.44	1.19	38
oxidized 21hrs.	0.98	1.65	29	1.01	2.82	14	1.06	2.12	24	0.40	1.09	29
BOTTOM ASHES												
Blend	0.98	1.53	26	1.23	2.24	17	0.94	2.21	39	0.50	1.04	18
Ellsworth	0.96	1.53	16	1.13	2.42	25	0.93	2.21	26	0.47	0.81	16
Nora	0.86	1.69	25	1.16	2.31	22	0.92	2.18	27	0.34	0.49	26
Bostic ashed coals												
leached	0.91	1.23	35	0.83	2.15	10	1.03	2.39	11	0.31	0.67	44
reduced (4hrs)	0.88	1.41	52	0.84	2.17	10	1.15	2.19	6	0.29	0.65	32
reduced (8hrs)	0.88	1.35	51	--	--	--	0.98	2.04	28	0.26	0.66	21
oxidized	1.05	2.02	3	0.99	2.71	1	0.62	2.02	16	0.26	0.76	80
Non Magnetic fly ash												
Wellaore Ackiss	--	--	--	0.85	2.65	7	0.57	2.14	26	0.33	0.94	67
Nora	--	--	--	0.85	2.72	5	0.58	2.17	30	0.34	0.93	65
Badger	--	--	--	0.87	2.52	20	0.65	2.06	27	0.41	0.07	53
Militant	--	--	--	0.80	2.67	8	0.54	2.11	28	0.34	0.97	64

Figure 57. Mossbauer spectra from fly ash obtained at nonslagging boilers: (a) Militant, (b) Deep Hollow, (c) Upshur, (d) Badger, (e) Boiler D, (f) Boiler C

Figure 58. Mossbauer spectra of fly ash obtained from slagging boilers: (a) Blend, (b) Wellmore Cactus 1, (c) Ellsworth, (d) Wellmore Ackiss, (e) Nora, (f) Wellmore Cactus 2.

TABLE 59. Percent Iron Composition, Magnetic vs. Non-magnetic,
of Fly Ash and Coal Ash

Sample	Magnetic	Non-Magnetic
Militant	60	40
Deep Hollow	60	40
Upshur	51	49
Badger	59	41
Boiler D	61	39
Boiler C	56	44
Blend	47	53
Wellmore Cactus 1	40	60
Ellsworth	46	54
Wellmore Ackiss	47	53
Nora	38	62
Wellmore Cactus 2	41	59
Benedict	91	9
Americoal	57	43
Turner	45	55
Bostic	63	37
Primary Energy	50	50

Figure 59. Mossbauer spectra of: (a) Fly ash from the Deep Hollow coal, (b) Deep Hollow fly ash leached 24 hrs. with HCl.

Figure 60. Mössbauer spectra of (a) Magnetite (Fe_3O_4), (b) Hematite (Fe_2O_3), (c) 60% Magnetite/ 40% Hematite, (d) 80% Magnetite/ 20% Hematite.

Figure 61. Mössbauer Spectra of the Magnetic Portion of the Fly Ash for (a) Wellmore Ackiss, (b) Nora, (c) Badger, (d) Milita

Figure 62. Mössbauer Spectra for the Non-Magnetic Portion of the Fly Ash for (a) Wellmore Ackiss, (b) Nora, (c) Badger, (d) Militant

TABLE 60. Composition of the Magnetic Fraction of the Fly Ash Samples.

Sample	Magnetite (Fe_3O_4)		Hematite (Fe_2O_3)	
	I%	A%	I%	A%
1. Militant	63	79	37	21
2. Badger	62	78	38	22
3. Nora	75	87	25	13
4. Wellmore Ackiss	77	85	23	15
5. 80% Magnetite/ 20% Hematite	74	77	26	23
6. 60% Magnetite/ 40% Hematite	58	64	42	36

I% - percent composition based on peak intensity

A% - percent composition based on peak area

NOTE: Compositions are based on moles percents. Samples 5 and 6 were used as standards to test the accuracy of Mossbauer spectroscopy in predicting these compositions.

Figure 63. Bottom Ash from a) Blend, b) Ellsworth, c) Wellmore Ackiss, d) Nora

Figure 64. Bottom Ash. from Wellmore Ackiss mine: a) as collected, b) Oxidized 8 hrs. at 400 C in O_2 , c) Oxidized at 550 for 21 hrs. in O_2

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