

Chemical Variation of Feed Coal and Coal Combustion Products from an Indiana Power Plant Utilizing Low Sulfur Powder River Basin Coal

By

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INTRODUCTION

The U.S. Geological Survey and the University of Kentucky Center for Applied Energy Research, in collaboration with an Indiana utility, are studying a coal-fired power plant burning Powder River Basin coal. This preliminary investigation involves a systematic study of the chemical and mineralogical characteristics of feed coal and coal combustion products (CCPs) from a 1300 megawatt (MW) power unit. The main goals of this study are to characterize the temporal chemical variability of the feed coal, fly ash and bottom ash by looking at the major-, minor-, and trace-element compositions. Emphasis is placed on the abundance and modes of occurrence of elements of potential environmental concern that may affect the utilization of these CCPs and coals.

METHODS

The Indiana power plant in this study exclusively utilizes subbituminous coal (mean = 8,220 Btu/lb), that has low sulfur content (mean = 0.48 percent) and low ash yield (mean = 6.2 percent). The feed coal is from the Wyodak-Anderson bed which is mined from three separate locations in the Powder River Region of Montana and Wyoming. In order to evaluate chemical and mineralogical compositional variability, samples were first collected daily (15 samples), then weekly (14 samples), and finally monthly (9 samples). Most feed coal and fly ash samples were collected in the plant by means of automated sampling devices while the bottom ash samples were collected manually by power plant personnel. During the one year study, fly ash samples were routinely collected from four sites for every sampling period. One sample was collected manually from a site closest to the furnace (EFA), two from automated fly ash collectors designated as NFA and OFA, and one sample was obtained from the truck silo (TFA), which is a composite of the NFA and OFA. This preliminary report primarily discusses the samples collected during the daily sampling period, with minor emphasis on samples from the weekly and monthly collection periods. Because of access problems and power plant maintenance schedules, some individual samples from the sample sites in the plant could not be collected during this study.

ANALYTICAL TECHNIQUES

Determination of ash yields and analysis of major-, minor-, and trace-element contents were conducted by the U.S. Geological Survey (Energy Team laboratories). Feed coal samples were ashed at 525° C prior to analysis and results are reported on an as-determined ash basis except for mercury which is analyzed on the raw unashed coal and reported on a whole coal basis. Most elements were determined by inductively coupled plasma mass spectroscopy (ICP-MS, 17 elements) or inductively coupled plasma atomic emission spectroscopy (ICP-AES, 25 elements). Mercury was analyzed by cold vapor atomic absorption spectroscopy (CV-AAS). For mineralogical study, feed coals were ashed by a low-temperature gas plasma ashing unit (LTA) using compressed oxygen at temperatures below 150° C. The mineralogy of the LTA, fly ash and bottom ash was primarily determined using X-ray diffraction (XRD). Microprobe and scanning electron microscope (SEM) methods were used to aid the mineralogical identification. For detailed descriptions of U.S. Geological Survey analytical methods see Swanson and Huffman 1976; Baedecker, 1987 ; and Golightly and Simon, 1989.

RESULTS AND DISCUSSION

The mean contents of major and minor oxides and selected trace elements for the feed coal, fly ash, and bottom ash samples for the first three weeks of our study are shown in tables 1 and 2. Variations were observed for all of the sample types and these variations basically reflect the composition of the feed coal (figures 1-4). Shipments of the feed coal can vary chemically and are reflected in samples separated by several weeks to months. Ash content did not vary significantly, but did change slightly (from 5.3% to 7.8%) as new shipments of coal were used at the plant. This variation had only a minor effect on the element distributions. These variations may also reflect complex changes in plant operation, such as changes in the feed rate of coal into the furnaces that may have ultimately affected our sample collection process.

Although most of the feed coal originates from a single coal bed, there is always a certain amount of variation in the trace element chemistry. This can be seen in figures 1-4 which shows the mean contents of MgO, CaO, As, and Pb for feed coal, fly ash, and bottom ash and also shows the range of values for these elements during the first three weeks of our sampling period. This variation is to be expected as coal composition can differ vertically and laterally within the same coal bed. The change in composition probably corresponds to the mineralogical variation (including various volcanic ash partings) that occurs vertically within the thick (up to 140 feet) Wyodak-Anderson coal bed. These minor variations also can be observed in the fly and bottom ash composition.

Some samples where the feed coal shows higher concentrations of selected elements may be the result of various volcanic partings within the coal. The nature of these partings can be identified by the various mineral phases detected in the feed coal. One observation from our study is the correlation of Ca, Sr, Ba, and P in the coal, that is in part reflected in several of the fly ashes as well (Brownfield and others, 1999a). The association of these elements together can be related to the presence of volcanic ash partings found within the coal. These associations probably resulted from the alteration of apatite-bearing air fall tuffs that were deposited into the reducing environment of the peat swamps. X-ray diffraction, SEM and chemical analysis indicates the

Table 1. Mean contents of major and minor oxides in the laboratory ash from the feed coal, fly ash (EFA, NFA, OFA, and TFA), and bottom ash. All values are in percent and are presented on an as-determined ash basis.

Oxide	Feed	Fly Ash				Bottom
	Coal mean n=15	EFA Mean n=15	NFA mean n=9	OFA mean n=11	TFA mean n=11	Ash mean n=15
Ash	6.2	--	--	--	--	--
SiO ₂	30	37	38	37	34	43
Al ₂ O ₃	15	17	19	19	19	18
CaO	23	24	27	27	29	22
MgO	5.1	5.6	5.9	6.0	6.0	4.7
Na ₂ O	2.0	2.0	2.2	2.3	2.4	1.7
K ₂ O	.29	.29	.36	.35	.36	.30
Fe ₂ O ₃	5.2	5.7	6.2	6.1	6.3	6.1
TiO ₂	1.3	1.5	1.5	1.5	1.6	1.5
P ₂ O ₅	.96	.82	1.1	1.1	1.2	.73

Table 2. Mean contents of selected elements from the feed coal, fly ash (EFA, NFA, OFA, and TFA), and bottom ash. All elements are in parts per million and are presented on the as-determined ash basis. Mercury content in the feed coal is on a whole coal basis.

Element	Feed	Fly Ash				Bottom
	Coal mean n=15	EFA mean n=15	NFA mean n=9	OFA mean n=11	TFA mean n=11	Ash mean n=15
As	17	11	14	12	17	6.8
Be	4.3	4.4	4.4	4.5	4.9	4.0
Cd	1.1	1.4	1.0	1.1	1.0	.4
Co	27	28	27	27	31	26
Cr	90	110	84	86	95	65
Hg	.07	.01	.01	.01	.01	.02
Mn	200	200	180	180	220	190
Ni	56	62	51	58	75	70
Pb	19	21	40	37	42	20
Sb	1.4	2.1	3.0	2.9	3.1	1.3
Th	22	29	27	26	28	27
U	8.9	8.7	9.1	8.5	9.0	8.2

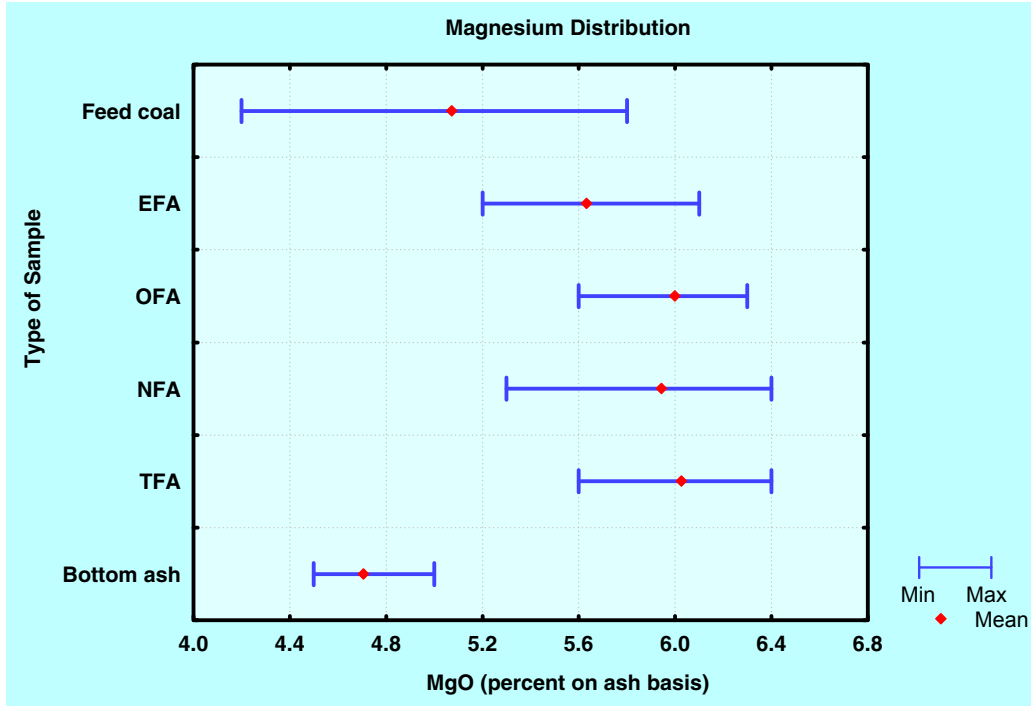


Figure 1. The variation of MgO content during the first three week sampling period. Range plot showing the mean, minimum, and maximum values from the feed coal, EFA, OFA, NFA, TFA, and bottom ash.

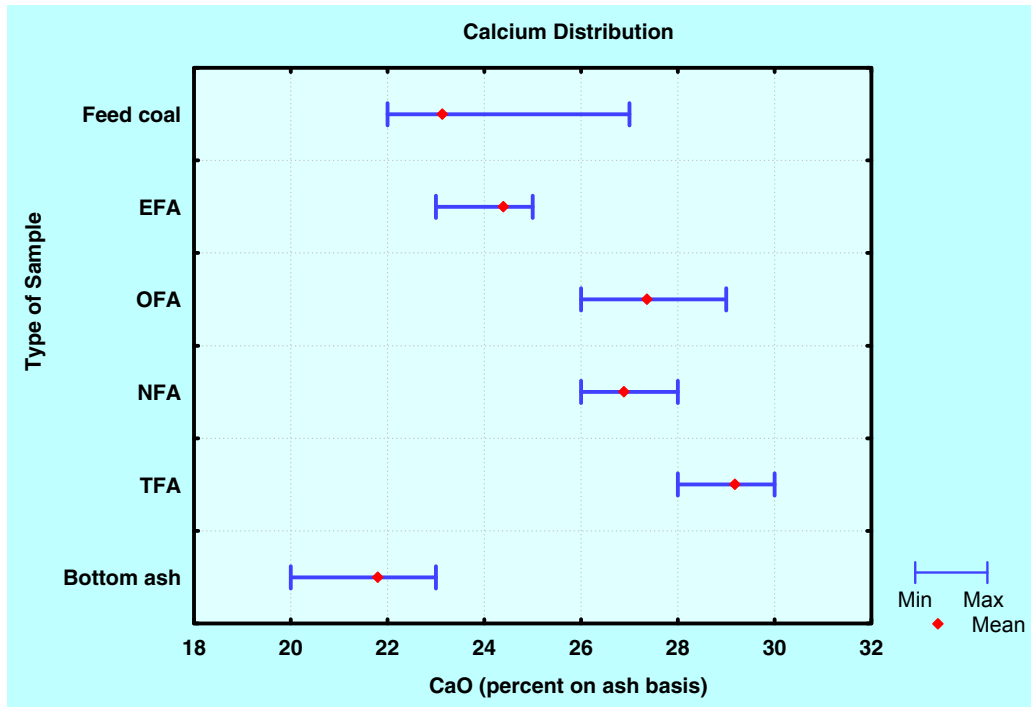


Figure 2. The variation of CaO content during the first three week sampling period. Range plot showing the mean, minimum, and maximum values from the feed coal, EFA, OFA, NFA, TFA, and bottom ash.

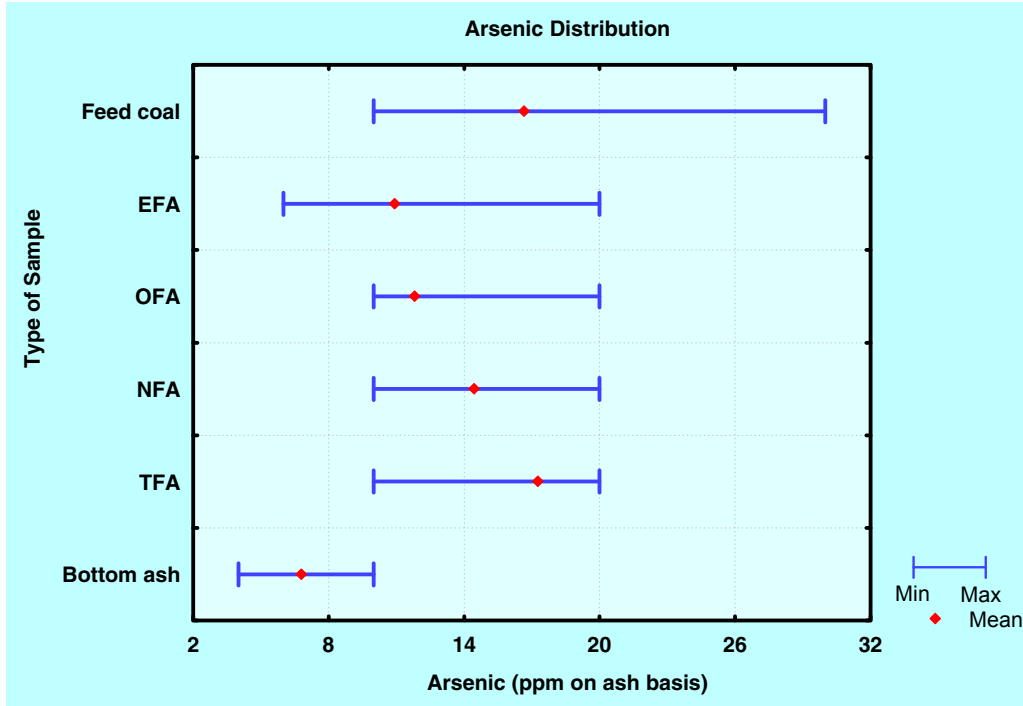


Figure 3. The variation of As content during the first three week sampling period. Range plot showing the mean, minimum, and maximum values from the feed coal, EFA, OFA, NFA, TFA, and bottom ash.

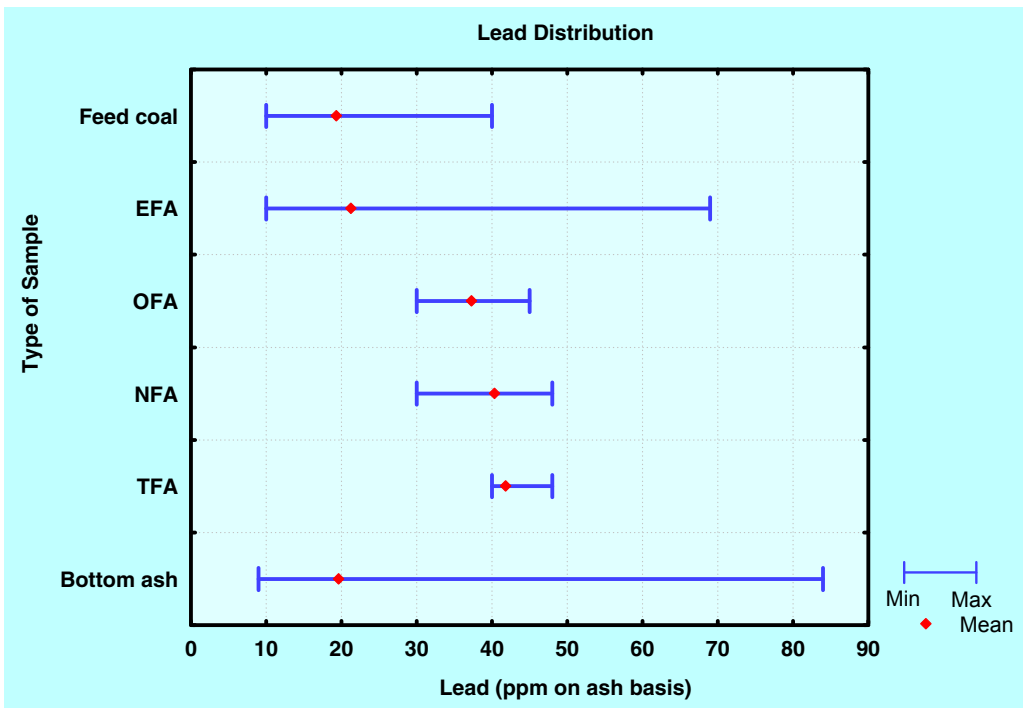


Figure 4. The variation of Pb content during the first three week sampling period. Range plot showing the mean, minimum, and maximum values from the feed coal, EFA, OFA, NFA, TFA, and bottom ash.

presence of hydrated aluminum-phosphate minerals of the crandallite group. These minerals formed during early diagenesis in the peat swamps, and are localized in and near kaolinitic altered volcanic-ash partings. For a detailed discussion of the effects of dispersed volcanic ash on the feed coal and CCPs see Brownfield and others, 1999b this volume.

The mineralogical evaluation indicates that the LTA for feed coals contains quartz (SiO_2), kaolinite ($\text{Al}_4\text{Si}_4\text{O}_{10}(\text{OH})_8$), calcite (CaCO_3), and hydrated alumino-phosphate minerals containing Ba, Ca, and Sr (crandallite group). Fly ash samples contained glass, quartz, perovskite (CaTiO_3), lime (CaO), periclase (MgO), gehlenite ($\text{Ca}_2\text{Al}(\text{Al},\text{Si})\text{O}_7$) and anhydrite (CaSO_4). Bottom ash contained quartz, anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$), rhodonite (Mn,SiO_3), and augite ($(\text{Ca},\text{Na})(\text{Mg},\text{Fe},\text{Al},\text{Ti})(\text{Si},\text{Al})_2\text{O}_6$) (Brownfield and others, 1999a). The abundant calcium mineral phases in the fly ash can probably be attributed to the presence of carbonate, clay, and various alumino-phosphate minerals in the original feed coal. Although a variety of minerals can be identified in the coal and fly ash, the mineral content of most feed coal and fly ash appears to be consistent during our sampling period. The consistent mineral content suggests that a feed coal from a single bed will produce less variation of element and mineralogical content in both the fly ash and bottom ash when compared to studies where the feed coal is from multiple sources (Affolter and others, 1997).

One feed coal sample showed some variation in one of the daily samples with anomalous contents of As, Cu, Hg, Mn, Mo, Ni, Pb, and Sb. The nature of this anomaly has not been identified but is observed in several of the associated fly ash samples (EFA, OFA, and NFA) for that same collection period. These higher values may be the result of some form of contamination.

Generally, the mean element content of the various fly ashes (EFA, OFA, NFA, and TFA) appears to be similar, with the TFA being slightly higher and the EFA slightly lower for some elements and oxides. The variation in element content does not appear to vary significantly for the daily collection periods (figures 1-4). This is in contrast to other studies (Affolter and others, 1997) where the supply of feed coal to a single power plant comes from numerous mines and different coal beds. This can produce a fly ash that represents several types of coals. Multiple sources of feed coal from different beds can greatly affect the range of contents of elements in CCPs increasing the variation over any sampling period to far greater than was seen in this study. Because this power plant is utilizing feed coal from a single source we generally will have relatively similar shape, fineness, particle-size distribution, and density within the OFA and NFA which have a fine particle size. These characteristics may cause similar adsorption of selected elements on the fly ash particles resulting in a more homogenous composition than from feed coal from multiple sources. The EFA has a variety of particle sizes (coarse to fine) and the TFA has properties of the NFA and OFA fly ash samples since it is a composite.

The bottom ash is the least valuable in the evaluation of element variability. These samples consist not only of bottom ash, but also of boiler slag, EFA, and char (unburned coal), as well as pulverizer discards that bypass the furnace. These discards may include small bolts, gears, and nails. In addition, bottom ash samples are manually collected from the sludge pond and are probably not very representative of the feed coal. Also, some high Pb contents observed in the

bottom ash (figure 4) may be attributed to plant procedures used to remove boiler slag deposits and may mask variations in some of the bottom ash samples.

SUMMARY

Preliminary results from this study indicate that the chemical variation based on daily sampling within this Indiana power plant is small. The overall chemical variation is much less than seen in other studies of feed coals from multiple sources (Affolter and others, 1997). This is mainly the result of a single source feed coal. This study is continuing and when finished will include over 200 samples collected during the study period. The additional power plant samples will help to evaluate the chemical and mineralogical variation between daily, weekly, and monthly sampling schemes, and will aid in evaluating power plants using single source coal versus those using multiple coal sources.

REFERENCES

- Affolter, R.H., Brownfield, M.E., and Breit, G.N. 1997, Temporal Variations in the Chemistry of Feed Coal, Fly Ash, and Bottom Ash from a Coal-Fired Power Plant, Proceedings of the 1997 International Ash Utilization Symposium, Pushing the Envelope, (Lexington, Kentucky) pp 757-764.
- Baedecker, P.A., ed., 1987, Methods for geochemical analysis: U.S. Geological Survey Bulletin 1700, p. 1n1-1n3.
- Brownfield, M.E., Affolter, R.H., and Cathcart, J.D., 1999a, Characterization of Feed coal and Coal Combustion Products from Power Plants in Indiana and Kentucky, in Proceedings of the 24th International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, Florida March 8-11, 1999, Coal Slurry Technology Association, Washington D.C., pp 989-1000.
- Brownfield, M.E., Affolter, R.H., Brownfield, I.K., Hower, J.C., and Stricker, G.D., 1999b, Dispersed Volcanic Ash in Feed Coal and its Influence on Coal Combustion Products, in Proceedings of the 1999 International Ash Utilization Symposium, Materials for the Next Millenium, (Lexington, Kentucky) this volume.
- Golightly, D.W., and Simon, F.O., 1989, Methods for sampling and inorganic analysis of coal: U.S. Geological Survey Bulletin 1823, 72 p.
- Swanson, V.E., and Huffman, Claude, Jr., 1976, Guideline for sample collecting and analytical methods used in the U.S. Geological Survey for determining chemical composition of coal: U.S. Geological Survey Circular 735, 11 p.