

## DEPOSITION OF BEULAH ASH IN A DROP-TUBE FURNACE UNDER SLAGGING CONDITIONS

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### INTRODUCTION

The deposition characteristics of coal ash in combustors is a major operational parameter when considering the applicability of a fuel for utilization in a given system. Recent research has shown that drop-tube combustion and deposition experiments can be effectively used to study ash-formation and deposition furnace behavior of coal under carefully controlled conditions (1,2,3). The drop-tube experiment has many advantages over the usual pilot-scale combustion system with respect to deposition studies. A small quantity of coal (400 grams) is needed to perform many tests and the coal feed rate can be carefully controlled. The flow pattern of the fly ash and products of combustion over the ash deposition surface can also be controlled as well as the temperature of the gases and the substrate, gas composition, and residence time. In order to best understand the processes involved in coal ash deposition detailed knowledge of the coal characteristics, combustion conditions, and temperature history of ash particles and deposit surfaces must be obtained. Furthermore, a detailed knowledge of the mineralogy of the various species within the coal allows comparison of the mineralogy of the ashes and deposits formed during combustion. This comparison can give valuable insight into the mechanism of ash formation and the processes involved in the growth and development of strength which lead to the problem of hard-bonded deposits on heat transfer surfaces in the boiler.

The coal chosen for study in this paper is a Beulah, North Dakota lignite. The lignite has been well-studied by a number of researchers and is considered to be somewhat characteristic of the Northern Plains lignite coal. The lignite has high moisture, low ash fusion temperatures, and high alkali - alkaline earth elements present in the ash. A benefit of the coal is the lower sulfur content on a sulfur per million Btu basis compared to eastern coals and high reactivity. The deposition characteristics of the coal are of particular interest as the fuel is known to cause heavy fouling deposits in utility boilers. Indeed, the boilers designed to burn the lignite are about 50% larger than comparable boilers designed to burn high ash-fusion eastern coals. The Beulah lignite is also of importance in ash deposition studies as the coal contains inorganic species both in the mineral phase as well as within the organic matrix of the coal. Extensive research at the University of North Dakota Energy and Minerals Research Center has shown the importance of the organically-bound species on the deposition characteristics in pilot-scale combustion testing (4). Techniques have been developed which can quantify the relative amount of an element which is organically bound or mineral bound. In general, the technique, called chemical fractionation, determines the amount of an inorganic species present in a series of leachates using water, ammonium acetate, and hydrochloric acid (5). The water removes the inorganic species which was loosely associated with the carbonaceous matrix. The ammonium acetate removes a portion of the inorganic constituents, by ion exchange; these constituents are chemically associated with the coal matrix, usually in the form of salts of carboxylic acids. The

hydrochloric acid dissolves the acid-soluble mineral grains such as carbonates, some oxides as well as sulfates and organically coordinated inorganic elements. By comparing the amount of inorganic constituents removed from the coal with the original composition, the amount of inorganics present as insoluble material can be calculated. The insoluble material usually includes inorganic elements associated with acid-insoluble discrete mineral phases such as quartz, pyrite, and clays. In the case of Beulah lignite, chemical fractionation shows that the bulk of the sodium and a large fraction of the calcium is organically bound. These data contrast with eastern coals, where most of the inorganic constituents tend to be associated with the acid-insoluble fraction.

The fate and behavior of the organically bound elements and their reactions with the mineral bound species are of great interest in relation to the deposition characteristics of the coal. Therefore, a detailed understanding of the processes that affect the deposition characteristics of Beulah lignite will give valuable insight into the fundamental aspects of coal ash deposition.

TABLE 1  
DROP-TUBE FURNACE RUN CONDITIONS USED TO PRODUCE  
INTERMEDIATE ASH FROM BEULAH COAL

Coal Size, $\mu\text{m}$	53-74
Coal Feed Rate, g/min	0.314
Primary Air, L/min	1.0
Secondary Air, L/min	3.0
Quench Gas, L/min	3.0
Temperature, $^{\circ}\text{C}$	
Secondary Air	930
Furnace Tube skin	1500
Gas Temperature at Inlet to Quench Probe	1450

#### EXPERIMENTAL PROCEDURE

A sample of Beulah lignite was characterized using chemical fractionation and computer controlled scanning electron microscopy (CCSEM). The latter technique provides the identification and size distribution of the coal minerals. Details of the technique can be found elsewhere (6). Pulverized coal samples were then burned under a range of combustion and deposition conditions in the EMRC drop-tube furnace facility. Details of the drop-tube facility can be found in other publications (1). However, for the purpose of this study, it is important to note that the drop tube furnace has the capability of studying the formation of ash intermediates as

TABLE 2  
 DROP-TUBE FURNACE RUN CONDITIONS USED TO PRODUCE ASH DEPOSITS  
 BEULAH DEPOSIT RUN

Feed Rate, g/min	0.272
Coal Size, $\mu\text{m}$	53-74
Primary Air, L/min	1.0
Secondary Air, L/min	3.0
Quench Air, L/min	8.0
Temperature, $^{\circ}\text{C}$	
Secondary Air	1000
Furnace Tube Skin	1501
Gas Temperature at Constrictor	1478
Substrate	475

• Distance from tip of injector

well as the formation of deposits over a wide range of temperature and residence times. In this study, the determination of intermediate species (entrained ash) and deposits formed under slagging ( $1450^{\circ}\text{C}$ ) conditions was defined by the gas temperature at the region of the probe and residence time (0.6 to 0.8 sec). The intermediate ash species were cooled with a gas quenching probe and collected using a six-stage multicyclone. Ash deposits were produced by accelerating the fly ash and products of combustion through a ceramic nozzle and impinged on an oxidized boiler steel substrate. In all cases where deposition was studied, the substrate consisted of pre-oxidized carbon steel and was controlled at a given temperature. The conditions used to produce the intermediate ash and deposits are summarized in Table 1 and 2, respectively.

In all cases the intermediate ash from each stage of the multicyclone and deposits were analyzed by x-ray diffraction, scanning electron microscopy and scanning electron microscopy point count (SEMP) techniques. The SEMPC technique was developed at the EMRC to quantify the various phases present in an ash sample. The technique involves the analysis of about 240 points on a polished section of a deposit or a dispersion of ash on cello tape using the electron microprobe facility of the electron microscope with a thin window energy dispersive detector. The compositions of each of the points are transferred to a Lotus<sup>®</sup> spreadsheet which classifies each analyzed point based on chemical composition. The range of classification includes a total of about 30 phases including coal mineral phases, derived mineral phases, crystalline phases, amorphous phases and unclassified phases. Full details of the technique can be found elsewhere (7). Major advantages of the technique include: quantification of the phases, chemical composition of the phases and chemical composition of the point analyzed. The latter is particularly useful for studies where there is insufficient material for bulk chemical analysis. Another important advantage is the ability to determine physical characteristics of each point based

on the chemical composition. For heterogeneous samples such as deposits and fly ash, the chemical composition of the points will be different. However, using the Urbain model of viscosity recently improved by Kalmanovitch and Frank (8), the chemical composition can be used to calculate the viscosity at a given temperature. From these calculations a distribution or population frequency of the viscosity can be determined. This has two advantages. The first is that it describes the heterogeneity of the sample with respect to a key parameter in the deposition process, namely the viscosity of the liquid phase. Second, it allows comparison of the viscosity distribution of specific areas with other areas from the same sample or other samples.

## RESULTS AND DISCUSSION

### Characterization of Coal

The chemical fractionation results for the coal, Table 3, shows that the bulk of the sodium, magnesium, and calcium are organically bound. The elements removed by HCl include significant amounts of aluminum, calcium, and iron. The extractability with HCl suggests that these elements are associated in the coal as carbonates, acid soluble oxides and organically coordinated elements. The elements remaining after the water, ammonia acetate, and HCl extractions consisted of portions of the aluminum, iron and most of the silicon. The aluminum is likely associated with clay minerals, the silicon with clay minerals and quartz, and the iron is associated as pyrite.

The mineral grains present in the 53-74 $\mu$ m sized fractions of coal were sized consistently with the multicyclone particle size controls. The results of the CCSEM mineralogical analysis of the 53-74 $\mu$ m sized fraction coal are listed in Table 4. The data shows that the major mineral phase present was aluminosilicate. The aluminosilicate is defined in the technique as mineral grains which contain predominantly Si and Al with no significant presence of another element. Oxygen is not detected by this technique. The aluminosilicate is found to be predominantly in the less than 11 micrometer size range. Only about 30 wt% of the mineral was observed to be larger than 11 microns. There was very little aluminosilicate observed in the size ranges below 2.1 microns. Quartz was also observed in the coal. The bulk of the quartz was in the 4.4-8.0 micron size range. There was very little quartz in the smaller size fractions (less than 2.1 microns) and little quartz above 11 microns. There was very little Fe-aluminosilicate or K-aluminosilicate detected in the coal sample. However, some Ca-aluminosilicate, that is mineral grains containing Si, Al, and Ca, was observed in the sample. The bulk of this phase was present in size ranges less than 4.4 microns. The other mineral phases which were observed in significant quantities were pyrite (Fe and S rich grains), barite (Ba and S rich grains), and gypsum (Ca and S rich grains). The pyrite was present in size ranges below 11.0 microns with the bulk observed in the 8.0-11.0 micron range. The barite was present in the sample both in the large size fractions, above 11.0 microns, and the smaller size fractions, between 1.2 and 8.0 microns. The gypsum was present in significant quantities between 2.1 and 11.0 microns. An important aspect of the mineralogy is that there was no mineral phase observed which contained sodium even though this element is present in the coal ash. Furthermore, the level of calcium present in the various mineral phases does not account for the total amount of calcium present in the coal ash. This data confirms the chemical fractionation data.

TABLE 3  
CHEMICAL FRACTIONATION RESULTS FOR BEULAH (6.2% Ash)

	Initial ( $\mu\text{g/g}$ mf coal)	Removed by $\text{H}_2\text{O}$ (%)	Removed by $\text{NH}_4\text{OAc}$ (%)	Removed by $\text{HCl}$ (%)	Remaining (%)
Sodium	5,700	42	57	1	0
Magnesium	2,600	1	97	2	0
Aluminum	3,500	0	0	32	68
Silicon	7,230	1	4	2	93
Potassium	100	65	26	9	0
Calcium	9,700	0	74	26	0
Iron	3,500	0	2	83	15

TABLE 4  
BEULAH CCSEM MINERAL COMPOSITION AND DISTRIBUTION  
(Results expressed as wt% minerals)

Mineral types	SIZE CATEGORIES (MICRONS)						TOTAL WT. % TOTAL WT. %	
	<1.2	1.2-2.1	2.1-4.4	4.4-8.0	8.0-11.0	>11.0	MINERALS	MINERALS (Coal Basis)
QUARTZ	5.7	7.7	14.5	21.7	29.0	19.1	19.5	1.17
KAOLINITE	41.5	39.5	42.1	53.6	38.1	71.7	51.6	3.11
FE-ALUMINOSILICATE	2.4	1.3	0.3	0.7	0.0	0.0	0.4	0.03
K-ALUMINOSILICATE	0.0	0.0	2.3	0.0	0.0	0.0	0.5	0.03
CA-ALUMINOSILICATE	20.9	24.7	16.4	2.2	0.0	0.0	6.3	0.38
IRON OXIDE	3.6	0.5	0.7	3.9	0.0	0.0	1.6	0.09
PYRITE	4.4	2.1	7.2	1.1	15.3	0.0	4.5	0.26
GYPSUM/BARITE	1.5	5.4	0.4	0.0	0.0	0.0	0.5	0.03
CALCITE	0.0	0.0	0.7	0.0	0.0	0.0	0.1	0.01
BARITE	2.3	7.1	6.1	7.4	0.0	9.2	6.3	0.38
GYPSUM	0.0	0.5	2.8	6.6	12.4	0.0	4.5	0.28
UNKNOWN	17.7	10.5	6.5	2.8	5.2	0.0	4.1	0.24

#### Characterization of Intermediates

Table 5 lists the results of the SEMPC analysis of the various multicyclone fractions quenched at a gas temperature of  $1450^\circ\text{C}$  during the drop-tube combustion of the 53-74 $\mu\text{m}$  Beulah lignite. The first five multicyclones contained various quantities of anorthite,  $(\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot(\text{SiO}_2)_2)$ , quartz, melilite (a solid solution series between akermanite,  $(\text{CaO})_2\text{MgO}\cdot(\text{SiO}_2)_2$  and gehlenite,  $2\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{SiO}_2$ ), and kaolinite derived material. The anorthite and melilite are products of high temperature

recrystallization from a melt phase. The quartz is a residual coal mineral phase. The kaolinite derived material is defined as a point which has a Si/Al molar ratio corresponding to that of kaolinite but has extraneous elements associated with it. The kaolinite derived material and the unclassified material are assumed in our interpretation to be amorphous. In all cases where x-ray diffraction was performed on the same sample as analyzed by SEMPC the latter technique found more crystalline phases than the x-ray diffraction. The points which are overlaps of two adjacent phases may be unclassified. However, these are statistically rare and would not be expected to affect the interpretation of the data as amorphous phases. In general, the SEMPC data shows that the size fractions above 1.2 microns tend to aluminosilicate phases with little sulfate present. The presence of kaolinite derived, anorthite, and melilite phases, shows that there was significant melting and interaction between the Ca, derived from the organic matrix, and the aluminosilicate mineral phase (kaolinite). The relative amounts of quartz in the different size fractions follows the same trend as observed in the CCSEM analysis of the coal. The chemical composition of the material collected in the first five multicyclone filters contained very little sodium. The material in the final filter contained predominantly sodium-calcium sulfate, 76%. The data shows that the sodium and sulfate species tend to be present in, or associated with, the finely dispersed phase, that is, the phase below 1.2 microns.

TABLE 5  
SEMPC RESULTS FOR BEULAH MULTICYCLONE SIZE FRACTIONS  
(Results expressed as number %)

STAGE #	1	2	3	4	5	6
SIZE, $\mu\text{m}$	>11.0	8.0-11.0	4.4-8.0	2.1-4.4	1.2-2.1	<1.2
MASS, %	76.2	4.8	7.5	4.2	3.6	3.7
<hr/>						
Phase						
CaO	3	0	0	0	0	0
Fe-oxides	7.2	2.3	0	0.6	0	0
Kaolinite*	36.2	50.4	63.5	60.2	60.1	10
Anhydrite	0.4	0	0	0	0	5
Anorthite	5.1	3.1	2.9	6.4	1.2	0
Quartz	4.7	2.3	0.7	1.2	0.4	0
Melilite	1.7	2.3	5.8	1.2	1.2	0
Na-Ca-Sulfate	0	0	0	0	0	76
Unclassified	41.7	35.7	34.3	33.9	36.6	8

\* kaolinite-derived

#### Characterization of Deposits

Figure 1 shows the general view of the slag droplet formed on the probe plate. There are two distinct regions, the sintered material near the base and the glassy droplet on the surface of the sintered material. The sintering material at the base of the deposit and slag droplet were each analyzed by the SEMPC technique. Table 6 compares the SEMPC data for the two samples.

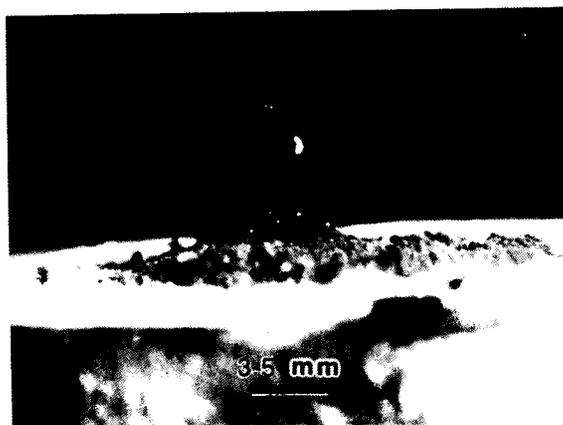


Figure 1. General view of slag formation on the probe plate.

TABLE 6

SEMPC DATA FOR SINTERED AND SLAG SAMPLES OF BEULAH ASH (1450°C)

PHASE, percent	SINTERED	SLAG
Calcium oxide	2.0	0.0
Montmorillonite-derived	0.5	1.3
Calcium silicate	1.0	0.0
Iron oxide	10.4	18.9
Kaolinite-derived	12.4	10.6
Anhydrite	1.5	0.4
Anorthite	1.5	1.3
Quartz	7.9	7.5
Melilite	0.5	0.0
Dicalcium silicate	0.5	0.0
Calcium derived	6.0	0.9
Unclassified	56.1	58.6

The results of the SEMPC analysis indicates that there are different phases present in the base of the deposit than in the slag at the top of the deposit. The SEMPC analysis of the base of the deposit corresponds very well with the analysis of the first stage of the multicyclone. All the phases observed in the first multicyclone stage were observed in the base of the deposit and the relative proportion of the phases are very similar. However, there was more calcium derived and less kaolinite derived material in the deposit base than was observed in the multicyclone. This is presumably due to the effect of residence time, milliseconds for the multicyclone sample compared to minutes for the deposit.

The slag deposit had similar phases to the base deposits. However, there were some significant differences. There was only one calcium aluminosilicate phase, that of anorthite, observed in the slag samples. This contrasts with the base where calcium silicate, dicalcium silicate, and melilite were observed in the base as well as the multicyclone samples. No calcium oxide was observed and the level of calcium-derived material was much lower in the slag as compared to the deposit base. The data indicates that the sample was approaching thermal equilibrium due to the long residence time and the higher temperature, approaching 1450°C. The composition of the material excluding quartz and iron oxide phases, would give a predominantly calcium aluminum silicate system. The normalized CaO-FeO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> composition when plotted on the equilibrium phase diagram show that the composition lies in the primary phase of anorthite with a liquidus temperature of about 1400°C.

The SEMPC also gives data on the chemical composition of the sample studied. Table 7 compares the chemical composition of the sample base and slag deposit. Also included in Table 7 is the Si/Al molar ratio and the chemical composition of the unclassified points and the silicate phases observed in the two samples. The latter data is obtained by deleting the compositions of the quartz, iron oxide, calcium derived and anhydrite points from the data base and recalculating the average chemical composition.

The composition of the base was very different than the slag. Most notable differences were with the levels of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, CaO, and SO<sub>3</sub>. The base had less SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> and greater CaO and SO<sub>3</sub> than the slag. This confirms the earlier observation that the initial deposit adhesion and growth is via a sulfate mechanism whereas the slag is via a silicate based matrix (9,10). The Si/Al molar ratio for the base and slag are relatively similar. This indicates that there is little change in the transport of silicate and aluminosilicate species to both types of deposit. The higher levels of CaO and SO<sub>3</sub> in the base of the deposit would suggest that there is a preferential deposition of the calcium-rich species on deposit surfaces still cooled by the probe. The level of SO<sub>3</sub> tends to indicate that the sulfation of the calcium occurred after the deposition of the calcium rich grains.

The CCSEM data on the coal and the chemical fractionation data indicated that there was relatively limited mineral bound calcium in the coal, the bulk was organically bound. This would tend to indicate that the transport of calcium would be as finely dispersed calcium oxide/calcium sulfate particles. However, the SEMPC data on the multicyclone samples indicate that significant calcium was associated with the large size fractions which were also rich in aluminum and silicon. It was also noted that the SEMPC data for the first multicyclone was very similar to the SEMPC data for the base of the deposit. This indicates that the major mass transport to the deposition probe is via the large size fractions. The presence of such a high level of calcium

TABLE 7  
CHEMICAL COMPOSITION OF DEPOSITS (SEMPC)

<u>Wt. %</u>	<u>Base</u>	<u>Slag</u>
SiO <sub>2</sub>	25.5	39.8
Al <sub>2</sub> O <sub>3</sub>	10.0	16.5
Fe <sub>2</sub> O <sub>3</sub>	21.0	30.7
TiO <sub>2</sub>	0.7	0.4
P <sub>2</sub> O <sub>5</sub>	0.0	0.0
CaO	31.3	9.8
MgO	2.0	0.3
Na <sub>2</sub> O	0.2	0.8
K <sub>2</sub> O	0.1	0.3
SO <sub>3</sub>	8.8	1.3
Si/Al molar ratio	2.05	2.17

CHEMICAL COMPOSITION OF UNCLASSIFIED AND SILICATE PHASES

<u>Wt. %</u>	<u>Base</u>	<u>Slag</u>
SiO <sub>2</sub>	24.9	50.6
Al <sub>2</sub> O <sub>3</sub>	13.5	24.9
Fe <sub>2</sub> O <sub>3</sub>	10.7	11.3
TiO <sub>2</sub>	1.0	0.6
P <sub>2</sub> O <sub>5</sub>	0.0	0.0
CaO	37.6	13.1
MgO	2.6	0.4
Na <sub>2</sub> O	0.1	1.1
K <sub>2</sub> O	0.2	0.4
SO <sub>3</sub>	9.1	1.3

associated with the aluminosilicate species indicates that melting and assimilation occurred at the relatively high temperatures. The entrained ash would not be expected to see a temperature below the gas temperature of 1450°C. These high temperatures and relatively short residence times preclude the formation of sulfate species. However, calcium aluminosilicate phases, both liquid and crystalline, are stable at these temperatures. The reaction of calcium with the aluminosilicate

phases is evidenced by the presence of phases such as melilite, anorthite, calcium silicate, and dicalcium silicate in the multicyclone fractions. These phases are not the product of thermal decomposition of mineral phases but are products of recrystallization from a calcium rich melt phase.

The level of calcium in the multicyclone fractions precludes total reaction with the aluminosilicate phases, and once deposited, the calcium rich material will tend to react with sulfate at lower temperatures. This leads to the low level of calcium in the slag deposit. This process can be understood if one considers that the material which will form a melt phase at these temperatures will be the elements intimately associated with the aluminosilicate phases. Refractory oxides such as calcium oxide which have not reacted to any extent with the aluminosilicate will not be associated with the phase forming the liquid drop and will tend to be expelled from the surface of the droplet and removed by the scrubbing action of the gas stream. Substantiation of this process can be seen with the analysis of the relative levels of sodium in the two samples. The sodium was observed to be present predominantly in the final filter of the multicyclone along with calcium sulfate. The stability of sodium sulfate is less than that of calcium sulfate at 1450°C. Therefore, the low level of sodium in the base deposit is due to the fact that it was not transported along with the aluminosilicate phases. The relative enrichment in the slag is due to thermal dissociation of the sulfate species and reaction with the aluminosilicate phase. Sodium has a greater affinity for aluminosilicate melt phase than calcium at 1450°C. A large proportion of the sodium is present in the very small size fractions. Under the conditions used the bulk of the sodium must have been carried past the deposit probe along with the gaseous products of combustion. This shows why sodium is such a problem in the cooler regions of the boiler, i.e. the convective pass where conditions tend to increase the stability of sodium sulfate and other alkali-rich species.

## CONCLUSIONS

The detailed analysis of a Beulah lignite sample and the deposits formed from the fuel in a drop tube furnace at a gas temperature of 1450°C has given valuable insight in the mechanisms of mass transport and deposit initiation and growth. The coal was shown by chemical fractionation and computer controlled scanning electron microscopy (CCSEM) to contain aluminosilicate species and organically bound calcium and sodium. The entrained ash, as sampled using a multicyclone, was shown, by using a novel technique called scanning electron microscopy point count (SEMPC), to contain high temperature calcium silicate and calcium aluminosilicate phases in the size fractions above 1.2 microns and calcium and sodium-calcium sulfate in the less than 1.2 micron range. The deposit formed from the coal ash with a probe surface temperature of 350°C and gas temperature of 1450°C was comprised of a small sintered base with a molten slag droplet on the surface; both sections were characterized using SEMPC. This technique showed that the deposit base had a similar chemical composition and phase assemblage as the largest multicyclone fraction, i.e. above 11.0 microns. The slag deposit however, had lower CaO and SO<sub>3</sub> than the base of the deposit and the calcium aluminosilicate phase observed was consistent with that expected for the melt phase from thermal equilibrium phase diagrams. Further analysis of the SEMPC data showed that the bulk of the material was transported to the probe surface with the aluminosilicate fraction. The different levels of CaO in the two sections of the deposit were consistent with the observed association of calcium with the aluminosilicate phases in the multicyclone samples and the known relative thermal stability of calcium aluminosilicates over calcium sulfate at 1450°C. The level of sodium was low in both samples of the deposit, and low in all multicyclone

samples except the final filter material. The low level of sodium in the deposit is consistent with the sodium being present in a finely dispersed form which was carried past the deposit with the combustion gases.

The study has shown the importance of detailed analysis of the coal, intermediates, and deposits in understanding the mechanisms and processes which affect deposit formation and growth in a drop-tube furnace. The results of this study can be summarized as follows:

- o Organically bound calcium will react with clay species to form calcium-rich aluminosilicates at short residence times.
- o The bulk of the calcium is transported via these calcium-rich aluminosilicates.
- o Sodium (organically bound) as sodium calcium sulfate was formed in the smallest size fractions.
- o The mass transport to the cooled metal surface tends to be that of the largest size fraction of the multicyclone (above 11 microns).
- o Sulfation of the calcium tends to occur after deposition and only in the cooler regions of the deposit (nearest the metal surface).
- o The matrix in the slag section of the deposit is predominantly calcium aluminosilicate and tends to approach thermal equilibrium.
- o The similarity in Si/Al molar ratio in the base and slag sections of the deposit indicates similar transport mechanisms throughout the deposit growth cycle.
- o Relatively low concentrations of Ca in the slag was indicated to be due to the poor assimilation of refractory calcium oxide rich regions into the melt phase.
- o Sodium enrichment in the slag relative to the base was consistent with the great affinity of sodium in silicate melts.
- o The low level of sodium in the deposit indicates that the sodium was entrained in the gas phase and passed over the probe and deposit under then slagging conditions.

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