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SCANNING ELECTRON MICROSCOPE CHARACTERIZATION OF EIGHT COALS WITH PERFORMANCE COMPARISONS

Report prepared for

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INTRODUCTION

This report summarizes the results of characterization of eight coals. The report includes interpretations of ash behavior in the boiler and electrostatic precipitator.

The analyses used include determination of bulk ash composition, ash quantity, and mineral abundance and size. Mineral abundance and size were determined by computer-controlled scanning electron microscopy (CCSEM). Ash behavior issues evaluated in this project were erosion, abrasion, wall slagging, convective pass fouling, and ash resistivity.

APPROACH

The coals were received at MTI ground to 80% -200 mesh. Part of the sample was ashed and the bulk ash composition (mineral analysis) determined. The ground and dried coal was mounted in wax and allowed to harden. The mount was cross-sectioned and polished, coated with carbon, and placed in the computer-controlled scanning electron microscope (CCSEM) for analysis. The CCSEM is used to measure the size, composition, and abundance of mineral grains in the coal. CCSEM results, bulk ash composition, and ultimate analysis data were entered into MTI's Coal Quality Management System (CQMS) to calculate ash performance indices.

BACKGROUND: Description of CQMS Indices

MTI has developed a series of advanced indices that relate coal characteristics, as determined by CCSEM analysis and chemical fractionation, to ash behavior in a coal-fired utility boiler. Fuel performance is estimated in terms of slag flow behavior, abrasion and erosion wear, wall slagging, high temperature silicate-based convective pass fouling, and low temperature sulfate-based convective pass fouling. The following are descriptions of the indices used by MTI to assess the effects of ash behavior on utility boiler performance:

- Convective Pass Fouling

  Sulfation Index: Indicates the propensity of deposit to form in the convective pass of the utility boiler in the temperature range from 1000 to 1750 °F. This index is based on the availability of alkali (Na and K) and alkaline-earth elements (Ca and Mg) to react with SO_2 and SO_3 and form sulfates. Sulfates are the primary materials that cause particle-to-particle bonding in high-calcium coals. Sulfates are thermodynamically stable at temperatures below about 1650 °F. Index values range from 1-low to 10-severe. For high-sodium, lower-ranked fuels, the values are calculated on a log scale. Range is 1-low to 6-high.

Silicate Index: Indicates the propensity of deposits to form in at temperatures from 1600 to 2400 °F. This index is related to the formation of deposits in which the silicate material is the primary component that bonds the deposits together. The information used to derive the index includes: the size of the minerals such as quartz and clay minerals; the availability of alkali and alkaline earth elements; and the viscosity of the silicate liquid phase. Values range from 1-low to 200-severe.

- Water Wall Slagging

  Slagging Index: Indicates the propensity of deposits to form on the radiant walls at temperatures from 2000 to 3000 °F. The basis of the slagging index is the size of the minerals (especially the illite, quartz, and pyrite), association of the calcium (calcite can contribute to slagging), and the viscosity of the silicate-based liquid phase. Values range from 1 - low to 20 - severe.

- Wear Indices

Abrasion Index: This index indicates the potential for wear of fuel preparation and handling equipment. The amount of wear is related to the hardness of minerals in the coal. Quartz and pyrite are the primary minerals of concern. Values range from 0.1 - low to 10 - severe.

Erosion Index: This index indicates the potential for wear of boiler parts due to the impaction of fly ash particles. The erosion index is dependent upon the size of the ash/mineral particle and its velocity. Values range from 0.1 - low to 1.0 - severe.

- Deposit Strength:

  Strength Index: The strength index is based on the ability of the deposited material to develop strength. Strength development is primarily dependent upon the abundance and viscosity of the liquid phase components in the deposits. Values less than 0.25 indicate that the material will produce weak deposits, 0.25 to 0.34 weak-to-moderate strength deposits, 0.34-0.41 high-strength deposits, and >0.41 flowing slag.

- Resistivity Calculations:

  Resistivity: This calculation is based on Bickelhaupt's model of ash behavior. Resistivity is calculated for temperatures from 200 to 700 °F. The migration velocity of particles declines rapidly when the resistivity is higher than 2×10^{10} Ω-cm. The temperature at which the precipitator is operated and the chemical composition of the coal and resulting flue gas stream all have significant influences on resistivity. In order to obtain good precipitator performance, resistivity should be below 2×10^{10} Ω-cm.

RESULTS

Ash Composition

Bulk ash composition is summarized in Table 1. As-received ash contents range from 4.5 to 6.0%. The calcium oxide contents range from 18.7 to 26 %. The sodium oxide content ranges from 1.2 to 2.1 %. Sodium and calcium are the primary components that cause the formation of low melting point phases in boilers. These elements combine with silicates and aluminosilicates or sulfates to form liquid that bonds deposits together. Silicon dioxide content ranges from 30 to 36.8 %. Iron components in the ash may contribute to wall slagging and furnace exit ash deposition. The iron oxide content ranges from 4.5 to 8.6%.

Table 1. Ash composition analysis results for eight coals (expressed as wt % equivalent oxide, dry basis).

Coal:	A	B	C	D	E	F	G	H
% ash	5.80	4.59	4.50	5.90	5.01	5.17	5.35	5.99
SiO_2	34.16	30.00	32.84	31.16	34.18	36.84	37.73	35.87
Al_2O_3	10.98	13.68	12.99	14.88	12.27	15.17	15.07	16.18
Fe_2O_3	6.39	5.33	5.27	8.60	6.54	5.49	4.47	5.47
TiO_2	0.63	0.99	1.20	1.12	0.90	1.28	1.37	1.24
P_2O_5	0.66	0.54	0.69	1.87	0.50	0.65	0.90	1.45
CaO	18.73	26.21	23.30	23.79	24.13	22.55	20.81	19.49
MgO	4.43	6.06	4.96	4.31	5.65	3.89	3.67	3.49
Na_2O	1.17	1.72	2.12	1.62	1.40	1.57	1.37	1.26
K_2O	0.43	0.31	0.40	0.30	0.27	0.33	0.42	0.40
SO_3	21.18	16.58	17.18	13.58	13.92	13.18	11.52	16.15
BaO	0.49	0.56	0.58	0.83	0.60	0.67	0.55	0.59
MnO_2	0.10	0.06	0.02	0.06	0.03	0.03	0.07	0.02
SrO	0.36	0.43	0.28	0.45	0.38	0.36	0.39	0.41

CCSEM Coal Mineral Analysis

CCSEM analysis results are listed in Tables 2 - 9. The tables include abundance and size distribution of the minerals. Minerals of primary importance include quartz, kaolinite, pyrite, and Ca-Al-P. The highest level of quartz on a mineral basis was found in Coal G with 36%, followed by Coal C with 34%. The lowest level was found for Coal H at 21.2%. Coal A (29.5%), Coal B (28.0%), Coal D (28.2%), Coal E (32.6%), and Coal F (22.3%) have intermediate levels of quartz based on the coals tested. The kaolinite contents ranged from 27.1% for the Coal C and Coal G to 10.9% for Coal A. The pyrite contents ranged from 2.1 for Coal G to 22.9 for Coal B. The Ca-Al-P mineral (crandalite) ranged from 2.1 to 15 weight percent for Coal A to Coal D, respectively.

CCSEM results also provide the size distribution of the minerals. Sizes have an effect on the deposition potential of minerals in the coal. The larger the size the more prone to impact heat exchange surfaces causing the formation of massive deposits.

Particles greater than 10 micrometers in diameter have a higher potential to impact a convective pass heat transfer surface as compared to smaller particles. The smaller sizes also have the potential to produce smaller particles that may be difficult to collect in electrostatic precipitators. Coal F and Coal H have the highest levels of small particles (less than 10-micron diameter) with 71.8 % and 76.1 %, respectively. The Coal F also has an abundance of particles/mineral grains classified as unknowns in the 2.2 to 4.6 micrometer size fraction indicating the presence of mixtures of minerals types. Coal C has the lowest level of particles in the less-than-10-micron size fraction, at 52.7%.

Table 2. CCSEM analysis results for Coal A. All results are expressed as weight percentages on a mineral basis, normalized to 100%.

Size Bins, µm

	1.0 TO 2.2	2.2 TO 4.6	4.6 TO 10.0	10.0 TO 22.0	22.0 TO 46.0	46.0 TO 400.0	TOTALS
QUARTZ	4.8	6.7	5.4	6.5	4.7	1.5	29.5
IRON OXIDE	.1	.2	.0	.0	.5	.0	.9
PERICLASE	.0	.0	.0	.0	.0	.0	.0
RUTILE	.2	.0	.1	.0	.0	.0	.3
ALUMINA	.0	.2	.2	.8	.3	.0	1.6
CALCITE	.4	1.2	.5	.0	.3	.0	2.3
DOLOMITE	.1	.0	.1	.2	.3	.2	.8
ANKERITE	.1	.0	.0	.0	.3	.0	.4
KAOLINITE	1.6	1.8	2.8	3.3	1.1	.2	10.9
MONTMORILLONITE	.3	.4	.2	.0	.2	.0	1.0
K AL-SILICATE	.3	.3	.2	.5	.0	.0	1.4
FE AL-SILICATE	.0	.0	.2	.0	.0	.0	.2
CA AL-SILICATE	.3	.3	.2	.0	.0	.0	.8
NA AL-SILICATE	.0	.0	.0	.0	.0	.0	.0
ALUMINOSILICATE	.1	.0	.2	.0	.1	.0	.3
MIXED AL-SILICA	.2	.1	.0	.0	.0	.0	.3
FE SILICATE	.0	.0	.0	.0	.0	.0	.0
CA SILICATE	.0	.0	.0	.0	.0	.0	.0
CA ALUMINATE	.0	.0	.0	.0	.0	.0	.0
PYRITE	1.3	5.3	3.8	5.0	4.8	.5	20.8
PYRRHOTITE	.0	.0	.0	.0	.2	.0	.2
OXIDIZED PYRRHO	.0	.0	.0	.0	.3	.0	.3
GYPSUM	.1	.0	.1	.0	.0	.0	.2
BARITE	.1	.2	.2	.0	.1	.0	.6
APATITE	.0	.0	.1	.2	.0	.0	.3
CA AL-P	.4	1.2	.4	.0	.1	.0	2.1
KCL	.0	.0	.0	.0	.0	.0	.0
GYPSUM/BARITE	.1	.2	.0	.0	.0	.0	.3
GYPSUM/AL-SILIC	1.2	.7	.1	.0	.0	.0	1.9
SI-RICH	.6	.1	.3	.0	.0	.0	1.1
CA-RICH	.7	1.8	.1	.0	.1	.0	2.7
CA-SI RICH	.0	.0	.0	.0	.0	.0	.0
UNKNOWN	8.7	5.0	2.1	.5	1.5	1.1	18.9
TOTALS	21.7	25.8	17.1	17.0	14.9	3.5	100.0

Table 3. CCSEM analysis results for Coal B. All results are expressed as weight percentages on a mineral basis, normalized to 100%.

Size Bins, µm

	1.0 TO 2.2	2.2 TO 4.6	4.6 TO 10.0	10.0 TO 22.0	22.0 TO 46.0	46.0 TO 400.0	TOTALS
QUARTZ	1.9	6.5	7.1	6.6	5.0	1.0	28.0
IRON OXIDE	.0	.0	.2	.0	.0	.0	.2
PERICLASE	.0	.0	.0	.0	.0	.0	.0
RUTILE	.1	.0	.1	.0	.0	.0	.2
ALUMINA	.0	.0	.0	.0	.0	.0	.0
CALCITE	.2	.5	.1	.0	.0	.0	.7
DOLOMITE	.0	.0	.0	.0	.0	.0	.0
ANKERITE	.0	.0	.1	.0	.0	.0	.1
KAOLINITE	1.7	6.1	4.6	3.8	1.8	1.0	19.1
MONTMORILLONITE	.0	.6	.3	.0	.1	.0	1.0
K AL-SILICATE	.1	.0	.6	.0	.0	.0	.7
FE AL-SILICATE	.1	.0	.0	.0	.0	.0	.1
CA AL-SILICATE	.7	.7	.0	.0	.0	.0	1.4
NA AL-SILICATE	.0	.0	.0	.0	.0	.0	.0
ALUMINOSILICATE	.1	.0	.1	.0	.2	.0	.3
MIXED AL-SILICA	.0	.5	.1	.0	.0	.0	.6
FE SILICATE	.0	.0	.0	.0	.0	.0	.0
CA SILICATE	.0	.0	.0	.0	.0	.0	.0
CA ALUMINATE	.0	.0	.0	.0	.0	.0	.0
PYRITE	.6	5.1	3.0	8.5	4.5	1.2	22.9
PYRRHOTITE	.0	.0	.3	.0	.0	.0	.3
OXIDIZED PYRRHO	.0	.0	.0	.0	.0	.0	.0
GYPSUM	.1	.0	.1	.0	.0	.0	.2
BARITE	.3	1.5	.6	.8	.0	.0	3.2
APATITE	.0	.0	.0	.0	.0	.0	.0
CA AL-P	.7	3.0	1.0	.3	.0	.0	4.9
KCL	.0	.0	.0	.0	.0	.0	.0
GYPSUM/BARITE	.0	.4	.0	.0	.0	.0	.4
GYPSUM/AL-SILIC	.5	.8	.4	.0	.0	.0	1.7
SI-RICH	.2	.4	.0	.0	.0	.0	.6
CA-RICH	.2	.1	.0	.0	.0	.0	.3
CA-SI RICH	.0	.0	.0	.0	.0	.0	.0
UNKNOWN	3.5	7.7	.6	.7	.5	.3	13.2
TOTALS	10.9	33.7	19.2	20.8	12.0	3.4	100.0

Table 4. CCSEM analysis results for Coal C. All results are expressed as weight percentages on a mineral basis, normalized to 100%.

	Size Bins, µm						
	1.0 TO 2.2	2.2 TO 4.6	4.6 TO 10.0	10.0 TO 22.0	22.0 TO 46.0	46.0 TO 400.0	TOTALS
QUARTZ	5.2	4.8	4.7	6.6	6.4	6.3	34.0
IRON OXIDE	.0	.0	.1	.0	.0	.0	.1
PERICLASE	.0	.0	.0	.0	.0	.0	.0
RUTILE	.1	.5	.1	.4	.0	.0	1.1
ALUMINA	.0	.0	.0	.0	.0	.0	.0
CALCITE	.0	.2	.0	.0	.0	.0	.2
DOLOMITE	.0	.0	.0	.0	.0	.0	.0
ANKERITE	.0	.0	.0	.0	.0	.0	.0
KAOLINITE	2.5	5.2	3.1	7.6	5.0	3.8	27.1
MONTMORILLONITE	.4	1.6	.2	.5	.2	.0	2.8
K AL-SILICATE	.4	.1	.3	.3	.1	.0	1.2
FE AL-SILICATE	.0	.0	.0	.5	.0	.0	.5
CA AL-SILICATE	.7	.0	.0	.2	.5	.0	1.5
NA AL-SILICATE	.0	.0	.0	.0	.0	.0	.0
ALUMINOSILICATE	.1	.0	.3	.5	.8	.4	2.0
MIXED AL-SILICA	.2	.1	.2	.0	.0	.2	.7
FE SILICATE	.1	.0	.0	.0	.0	.0	.1
CA SILICATE	.0	.1	.0	.0	.1	.0	.3
CA ALUMINATE	.0	.0	.0	.0	.0	.0	.0
PYRITE	.8	.7	.0	.0	.7	2.1	4.2
PYRRHOTITE	.0	.0	.0	.0	.0	.0	.0
OXIDIZED PYRRHO	.0	.0	.0	.0	.0	.0	.0
GYPSUM	.0	.1	.0	.0	.0	.0	.2
BARITE	.1	.0	.0	.0	.0	.0	.1
APATITE	.0	.0	.0	.0	.0	.0	.0
CA AL-P	1.2	4.9	2.3	.0	.7	.2	9.4
KCL	.0	.0	.0	.0	.0	.0	.0
GYPSUM/BARITE	.0	.0	.0	.0	.0	.0	.0
GYPSUM/AL-SILIC	.3	.1	.0	.0	.2	.0	.7
SI-RICH	1.0	.6	.6	.2	.4	.3	3.1
CA-RICH	.1	.1	.0	.0	.1	.0	.3
CA-SI RICH	.0	.0	.0	.0	.0	.0	.0
UNKNOWN	3.5	4.5	.7	.6	.9	.5	10.6
TOTALS	16.7	23.5	12.5	17.2	16.2	13.8	100.0

Table 5. CCSEM analysis results for Coal D. All results are expressed as weight percentages on a mineral basis, normalized to 100%.

Size Bins, µm

	1.0 TO 2.2	2.2 TO 4.6	4.6 TO 10.0	10.0 TO 22.0	22.0 TO 46.0	46.0 TO 400.0	TOTALS
QUARTZ	4.7	5.0	5.6	5.5	6.1	1.3	28.2
IRON OXIDE	.0	.0	.1	.0	.1	.0	.1
PERICLASE	.0	.0	.0	.0	.0	.0	.0
RUTILE	.4	.8	.2	.3	.0	.0	1.8
ALUMINA	.0	.0	.0	.0	.0	.0	.0
CALCITE	.0	.5	.2	.0	.0	.0	.7
DOLOMITE	.0	.0	.0	.0	.0	.0	.0
ANKERITE	.0	.0	.0	.0	.1	.0	.1
KAOLINITE	3.4	3.1	3.1	2.8	2.8	.5	15.7
MONTMORILLONITE	.5	.3	.5	.4	.2	.0	1.9
K AL-SILICATE	.2	.0	.0	.0	.0	.0	.3
FE AL-SILICATE	.0	.0	.0	.0	.0	.0	.1
CA AL-SILICATE	1.2	.4	.4	.2	.0	.0	2.1
NA AL-SILICATE	.0	.0	.0	.0	.0	.0	.0
ALUMINOSILICATE	.0	.2	.1	.4	.5	.0	1.3
MIXED AL-SILICA	.0	.4	.1	.0	.1	.0	.6
FE SILICATE	.0	.0	.0	.0	.0	.0	.0
CA SILICATE	.0	.0	.0	.0	.0	.0	.0
CA ALUMINATE	.0	.0	.0	.0	.0	.0	.0
PYRITE	.7	.7	.6	1.0	2.5	.5	6.0
PYRRHOTITE	.0	.0	.0	.0	.0	.0	.0
OXIDIZED PYRRHO	.0	.0	.1	.0	.0	.0	.1
GYPSUM	.0	.0	.0	.0	.0	.0	.0
BARITE	.3	.3	.8	.7	.3	.0	2.5
APATITE	.4	.5	.1	.0	.0	.0	1.0
CA AL-P	3.3	6.1	3.6	1.8	.2	.0	15.0
KCL	.0	.0	.0	.0	.0	.0	.0
GYPSUM/BARITE	.1	.3	.0	.3	.0	.0	.7
GYPSUM/AL-SILIC	.8	.3	.1	.0	.2	.0	1.3
SI-RICH	.7	.3	.3	.0	.4	.0	1.7
CA-RICH	.0	.1	.1	.0	.0	.0	.3
CA-SI RICH	.0	.0	.0	.0	.0	.0	.0
UNKNOWN	6.2	4.9	3.8	1.8	1.5	.4	18.5
TOTALS	23.0	24.4	19.8	15.1	14.9	2.8	100.0

Table 6. CCSEM analysis results for Coal E. All results are expressed as weight percentages on a mineral basis, normalized to 100%.

Size Bins, µm

	1.0 TO 2.2	2.2 TO 4.6	4.6 TO 10.0	10.0 TO 22.0	22.0 TO 46.0	46.0 TO 100.0	TOTALS
QUARTZ	5.2	7.3	5.1	7.6	6.3	1.1	32.6
IRON OXIDE	.0	.3	.0	.0	.0	.0	.3
PERICLASE	.0	.0	.0	.0	.0	.0	.0
RUTILE	.5	.3	.1	.0	.0	.0	.9
ALUMINA	.0	.0	.0	.0	.0	.0	.0
CALCITE	.1	1.1	1.0	1.3	.5	.2	4.0
DOLOMITE	.1	.0	.0	.0	.0	.0	.1
ANKERITE	.0	.0	.1	.0	.0	.0	.1
KAOLINITE	5.0	5.1	4.6	4.7	2.5	.1	22.0
MONTMORILLONITE	1.0	1.2	.3	.1	.1	.0	2.8
K AL-SILICATE	.1	.0	.0	.0	.0	.2	.4
FE AL-SILICATE	.0	.0	.0	.0	.0	.0	.0
CA AL-SILICATE	.9	.3	.2	.5	.2	.0	2.1
NA AL-SILICATE	.1	.0	.0	.0	.0	.0	.1
ALUMINOSILICATE	.1	.0	.3	.6	.4	.0	1.4
MIXED AL-SILICA	.5	.2	.0	.0	.1	.0	.8
FE SILICATE	.1	.0	.0	.0	.0	.0	.1
CA SILICATE	.0	.1	.0	.0	.0	.0	.1
CA ALUMINATE	.0	.0	.0	.0	.0	.0	.0
PYRITE	2.3	1.4	1.6	1.4	2.7	.3	9.7
PYRRHOTITE	.1	.0	.0	.0	.0	.0	.1
OXIDIZED PYRRHO	.2	.0	.0	.0	.0	.0	.2
GYPSUM	.0	.0	.0	.0	.0	.0	.0
BARITE	.6	.9	1.0	2.5	.1	.0	5.1
APATITE	.0	.0	.0	.0	.0	.0	.0
CA AL-P	.9	1.6	.8	1.0	.0	.0	4.3
KCL	.0	.0	.0	.0	.0	.0	.0
GYPSUM/BARITE	.1	.0	.0	.0	.0	.0	.1
GYPSUM/AL-SILIC	.6	.2	.3	.0	.1	.0	1.2
SI-RICH	.5	.3	.2	1.4	.4	.0	2.8
CA-RICH	.1	.3	.1	.0	.0	.0	.5
CA-SI RICH	.0	.0	.1	.0	.0	.0	.1
UNKNOWN	4.0	1.8	1.2	.6	.3	.1	8.1
TOTALS	23.1	22.2	17.1	21.8	13.8	2.0	100.0

Table 7. CCSEM analysis results for Coal F. All results are expressed as weight percentages on a mineral basis, normalized to 100%.

Size Bins, µm

	1.0 TO 2.2	2.2 TO 4.6	4.6 TO 10.0	10.0 TO 22.0	22.0 TO 46.0	46.0 TO 400.0	TOTALS
QUARTZ	.9	3.6	5.0	8.5	3.8	.4	22.3
IRON OXIDE	.0	.0	.0	.0	.0	.0	.0
PERICLASE	.0	.0	.0	.0	.0	.0	.0
RUTILE	.0	.0	.2	.0	.0	.0	.2
ALUMINA	.0	.0	.0	.0	.0	.0	.0
CALCITE	.0	.0	.0	.0	.0	.0	.0
DOLOMITE	.0	.0	.0	.0	.0	.0	.0
ANKERITE	.0	.0	.0	.0	.0	.0	.0
KAOLINITE	1.4	3.6	3.8	3.4	2.0	.5	14.6
MONTMORILLONITE	.4	.0	.5	2.0	.4	.2	3.5
K AL-SILICATE	.0	1.1	.1	.0	.0	.0	1.2
FE AL-SILICATE	.0	.0	.0	.0	.1	.0	.1
CA AL-SILICATE	.6	.3	.4	.1	.1	.0	1.4
NA AL-SILICATE	.0	.0	.0	.0	.0	.0	.0
ALUMINOSILICATE	.0	.7	.3	.6	.4	.0	2.1
MIXED AL-SILICA	.3	.0	.2	.0	.0	.0	.5
FE SILICATE	.0	.0	.0	.0	.0	.0	.0
CA SILICATE	.0	.0	.0	.0	.0	.0	.0
CA ALUMINATE	.0	.0	.0	.0	.0	.0	.0
PYRITE	1.5	1.4	.5	1.1	.7	.0	5.2
PYRRHOTITE	.0	.0	.0	.0	.0	.0	.0
OXIDIZED PYRRHO	.0	.0	.0	.0	.1	.0	.1
GYPSUM	.3	.0	.0	.1	.0	.0	.4
BARITE	.0	.0	.0	.0	.0	.0	.0
APATITE	.0	.0	.0	.0	.0	.0	.0
CA AL-P	.4	1.9	1.4	.4	.2	.0	4.3
KCL	.0	.0	.0	.0	.0	.0	.0
GYPSUM/BARITE	.0	.0	.0	.0	.0	.0	.0
GYPSUM/AL-SILIC	1.6	4.2	.2	.0	.1	.0	6.2
SI-RICH	.3	.2	.3	1.1	.3	.0	2.2
CA-RICH	.0	.4	.1	.0	.0	.0	.5
CA-SI RICH	.0	.0	.0	.0	.0	.0	.0
UNKNOWN	6.8	25.5	1.3	1.1	.3	.1	35.1
TOTALS	14.4	43.0	14.4	18.5	8.5	1.2	100.0

Table 8. CCSEM analysis results for Coal G. All results are expressed as weight percentages on a mineral basis, normalized to 100%.

Size Bins, µm

	1.0 TO 2.2	2.2 TO 4.6	4.6 TO 10.0	10.0 TO 22.0	22.0 TO 46.0	46.0 TO 400.0	TOTALS
QUARTZ	2.1	6.1	7.0	10.6	8.3	2.5	36.6
IRON OXIDE	.0	.0	.2	.0	.0	.0	.2
PERICLASE	.0	.0	.0	.0	.0	.0	.0
RUTILE	.1	.0	.4	.0	.0	.0	.5
ALUMINA	.0	.0	.2	.0	.0	.0	.2
CALCITE	.0	.0	.0	.0	.0	.0	.0
DOLOMITE	.0	.0	.0	.0	.0	.0	.0
ANKERITE	.0	.0	.0	.0	.0	.0	.0
KAOLINITE	2.1	8.1	8.0	4.3	3.6	.9	27.0
MONTMORILLONITE	.7	.9	1.9	1.7	1.5	.2	7.0
K AL-SILICATE	.1	.1	.4	.0	.4	.0	1.1
FE AL-SILICATE	.0	.3	.0	.2	.2	.0	.7
CA AL-SILICATE	.3	.5	.5	.4	.3	.0	2.0
NA AL-SILICATE	.0	.0	.0	.0	.0	.0	.0
ALUMINOSILICATE	.1	.5	.5	.6	.3	.4	2.4
MIXED AL-SILICA	.1	.0	.0	.0	.2	.0	.3
FE SILICATE	.0	.0	.0	.0	.0	.0	.0
CA SILICATE	.0	.0	.0	.0	.0	.0	.0
CA ALUMINATE	.0	.0	.0	.0	.0	.0	.0
PYRITE	.6	.5	.2	.0	1.5	.0	2.9
PYRRHOTITE	.0	.0	.0	.0	.0	.0	.0
OXIDIZED PYRRHO	.0	.0	.0	.0	.0	.0	.0
GYPSUM	.0	.0	.0	.0	.0	.0	.0
BARITE	.0	.0	.0	.0	.0	.0	.0
APATITE	.0	.0	.1	.0	.0	.0	.1
CA AL-P	1.2	4.6	1.4	.6	.2	.0	8.0
KCL	.0	.0	.0	.0	.0	.0	.0
GYPSUM/BARITE	.1	.0	.0	.0	.0	.0	.1
GYPSUM/AL-SILIC	.2	.4	.0	.0	.0	.0	.7
SI-RICH	.1	.3	.3	.2	.3	.0	1.2
CA-RICH	.3	.6	.0	.6	.0	.0	1.5
CA-SI RICH	.0	.0	.1	.0	.0	.0	.1
UNKNOWN	2.4	3.6	.9	.2	.2	.0	7.3
TOTALS	10.6	26.4	22.3	19.7	17.0	4.0	100.0

Table 9. CCSEM analysis results for Coal H. All results are expressed as weight percentages on a mineral basis, normalized to 100%.

	Size Bins, µm						
	1.0 TO 2.2	2.2 TO 4.6	4.6 TO 10.0	10.0 TO 22.0	22.0 TO 46.0	46.0 TO 400.0	TOTALS
QUARTZ	4.4	4.5	4.9	2.2	4.6	.5	21.2
IRON OXIDE	.0	.0	.0	.0	.0	.0	.0
PERICLASE	.0	.0	.0	.0	.0	.0	.0
RUTILE	.4	.0	.0	.0	.1	.0	.5
ALUMINA	.0	.0	.0	.0	.0	.0	.0
CALCITE	.0	.4	.0	.0	.0	.0	.4
DOLOMITE	.0	.0	.0	.0	.0	.0	.0
ANKERITE	.0	.0	.0	.0	.0	.0	.0
KAOLINITE	5.3	4.8	5.5	3.1	2.2	.1	21.0
MONTMORILLONITE	.7	1.6	1.3	1.5	.5	.0	5.7
K AL-SILICATE	.1	.4	.1	.1	.1	.0	.8
FE AL-SILICATE	.1	.0	.1	.0	.0	.0	.2
CA AL-SILICATE	2.7	1.9	1.3	.3	.2	.0	6.4
NA AL-SILICATE	.0	.0	.0	.0	.0	.0	.0
ALUMINOSILICATE	.2	.3	.2	.5	.4	.0	1.6
MIXED AL-SILICA	.4	.6	.2	.0	.1	.0	1.3
FE SILICATE	.0	.0	.0	.0	.0	.0	.0
CA SILICATE	.0	.0	.0	.0	.0	.0	.0
CA ALUMINATE	.0	.0	.0	.0	.0	.0	.0
PYRITE	.8	.9	.7	.6	2.0	.5	5.6
PYRRHOTITE	.0	.0	.0	.0	.1	.0	.1
OXIDIZED PYRRHO	.0	.0	.0	.0	.0	.0	.0
GYPSUM	.0	.0	.0	.0	.0	.0	.0
BARITE	.1	.7	.3	.2	.0	.0	1.4
APATITE	.0	.0	.1	.0	.0	.0	.1
CA AL-P	2.0	3.8	2.2	1.0	.2	.0	9.1
KCL	.0	.0	.0	.0	.0	.0	.0
GYPSUM/BARITE	.1	.0	.0	.0	.0	.0	.1
GYPSUM/AL-SILIC	2.3	2.0	.4	.0	.1	.0	4.8
SI-RICH	.9	.4	.8	.2	.3	.0	2.4
CA-RICH	.0	.1	.0	.0	.0	.0	.1
CA-SI RICH	.0	.0	.0	.0	.0	.0	.0
UNKNOWN	7.5	4.8	2.7	1.3	.7	.0	17.0
TOTALS	28.0	27.2	20.9	11.0	11.6	1.2	100.0

Calculated Indices

Calculated ash behavior indices are listed in Table 10. Coals A, B, D, E, and F have similar erosion characteristics. Coal H has the lowest erosion index. Erosion index values for Coals C and G are slightly higher because of the higher quartz content in the coal as compare to the other coals. Abrasion index vales are highest for Coals E and F because of the higher levels of pyrite.

Ash deposition indices showed some differences for the coals characterized. The highest wall slagging index calculated was for Coal C followed by Coal B. Coal C and Coal B have high levels of calcium along with relatively large sized quartz, clay, pyrite and Ca-Al-P mineral grains. Various combinations of these minerals with calcium levels can contribute to wall slagging behavior. The Ca-Al-P mineral has been identified in the coals and is known to contribute to slagging. Convective pass fouling is calculated using two indices, the sulfate and silicate indices. These indices provide a ranking based on the potential for particles to accumulate. The sulfation index was found to be the lowest for Coal F because of the small size of the minerals. The smaller minerals have the potential to react with the calcium that contributes to the formation of deposits in the lower temperature regions of the boiler. The silicate-based fouling indices are the highest for Coals C and E. The high-temperature silicate indices are similar for Coals A, D, and H. Coals F and G have an intermediate silicate-fouling indices. The lowest silicate index was determined for Coal B.

Figure 1 illustrates the strength development curves calculated for the coal characterized. This index should be used in combination with the wall slagging and convective pass fouling indices to assess ash deposition potential. Ranking the coals from highest to lowest: Coal B > Coal D = Coal E = Coal C > Coal F > Coal A > Coal G = Coal H.

Predicted resistivity is illustrated in Figure 2. Coals A, H, and E had similarly high ash resistivity values. Coals C, F, G, D, and B had lower resistivity, decreasing in order listed. At the operating temperatures of up to 400 °F, the resistivity values of all the coals are below 2×10^{10} Ω-cm, the ESP should have good collection efficiency for the coal. Ash that exhibits higher resistivity will be more difficult to collect. Consideration of particle size of the resulting ash is also important. The smaller the size the more difficult it is to collect.

Table 10. Performance index values for eight coals.

Index	Coal A	Coal B	Coal C	Coal D	Coal E	Coal F	Coal G	Coal H
Erosion	0.17	0.18	0.21	0.18	0.18	0.16	0.21	0.15
Abrasion	1.90	1.28	1.59	1.51	2.46	2.54	1.55	1.55
Wall slagging	1.51	2.03	2.21	1.74	1.60	1.67	1.42	1.38
Convective pass sulfation	2.8	1.92	1.28	2.02	1.03	0.70	0.87	0.85
Convective pass silication	23.11	15.66	40.23	25.40	36.71	30.56	31.91	21.84
Strength (at 2250°F)	0.32	0.41	0.37	0.37	0.37	0.33	0.31	0.31

Notes on Table 10:

Erosion index indicates the potential for wear of boiler parts due to the impaction of fly ash particles. Ranges from 0.1 (low) to 1.0 (severe).
Abrasion index indicates the potential for wear of fuel preparation and handling equipment. Ranges from 0.1 (low) to 20 (severe).
Wall slagging index indicates the propensity of deposits to form on the radiant walls from 2000° to 3000°F. Ranges from 1 (low) to 20 (severe).
Convective pass sulfation index indicates the propensity of deposits to form in the convective pass at temperatures of 1000° to 1750°F. Ranges from 0.1 (low) to 10 (severe).
Convective pass silication index indicates the propensity of deposits to form in the convective pass at temperatures of 1600° to 2200°F. Ranges from 1 (low) to 200 (severe).
Strength index indicates the ability of the deposited material to develop strength. Values of less than 0.25 indicate weak deposits; values of 0.25 to 0.34 denote deposits of weak to moderate strength; and values of 0.34 to 0.41 indicate moderately strong deposits. Values of greater than 0.41 correspond to flowing slag.

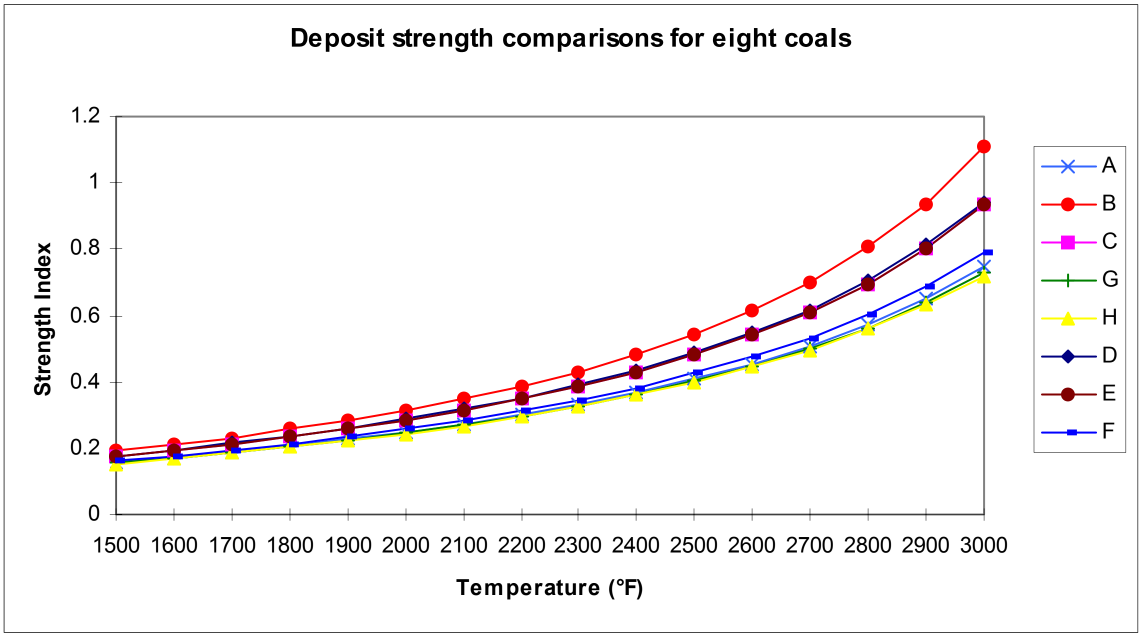

Figure 1. Deposit strength calculated using CCSEM data for eight coals.

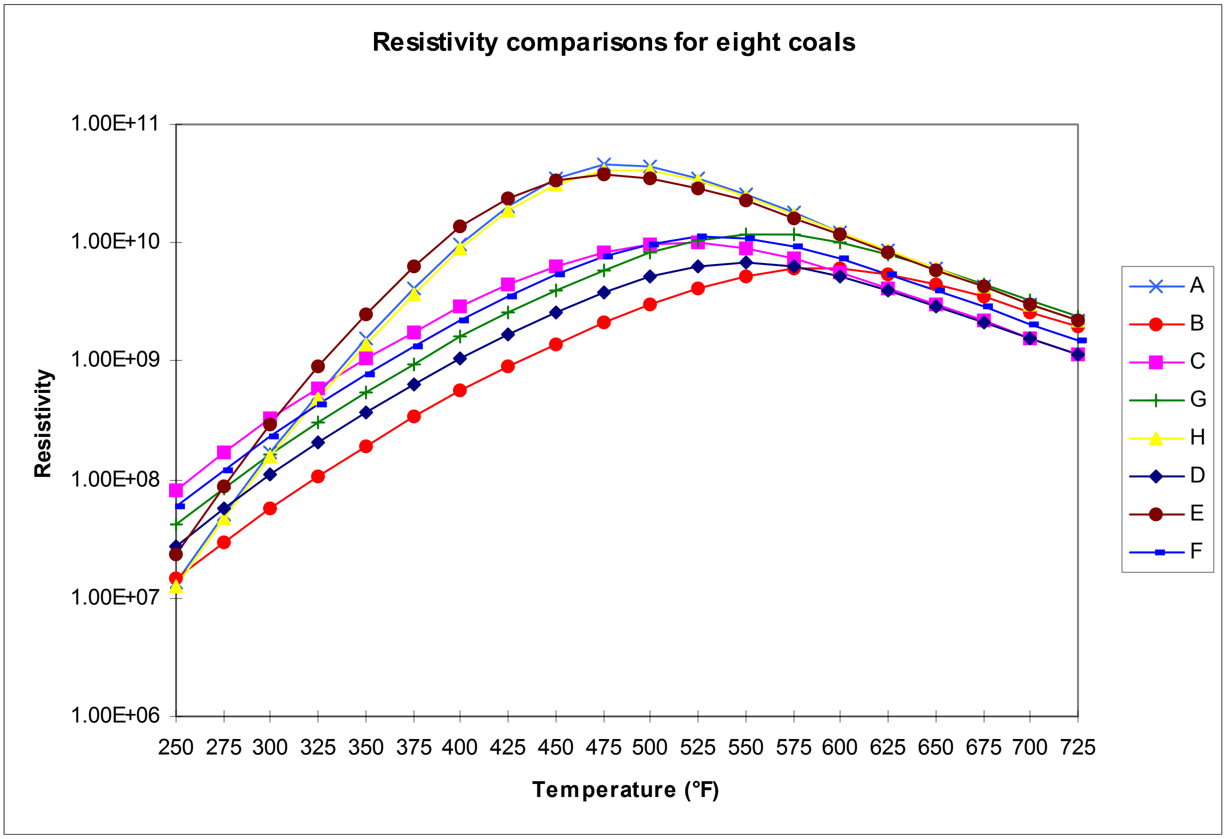

Figure 2. Resistivity calculated using CCSEM data for eight coals.

SUMMARY AND CONCLUSIONS

This project focused on determining the potential impacts of eight coals on boiler and electrostatic precipitator performance. Performance factors were based upon computer controlled scanning electron microscope (CCSEM) results and other data. Ash behavior issues evaluated in this project were erosion, abrasion, wall slagging, convective pass fouling, and ash resistivity.

The as-received ash contents of the eight coals range from 4.5 to 6.0%. The calcium oxide contents range from 18.7 to 26 %. The sodium oxide content ranges from 1.2 to 2.1 %. The sodium and the calcium are the primary components that cause the formation of low melting point phases in boilers. These elements combine with silicates and aluminosilicates or sulfates to form liquid that bonds deposits together. The silicon dioxide content of the ash ranges from 30 to 36.8 %. The iron components in the ash may contribute to wall slagging and furnace exit ash deposition. The iron oxide content ranges from 4.5 to 8.6%.

The minerals of primary importance to the eight coals include quartz, kaolinite, pyrite, and Ca-Al-P. The highest level of quartz on a mineral basis was Coal G with 36% followed by Coal C with 34%. The lowest level was found for Coal H at 21.2%. Coal A (29.5%), Coal B (28.0%), Coal D (28.2%), Coal E (32.6%), and Coal F (22.3%) have intermediate levels of quartz based on the coals tested. The kaolinite contents ranged from 27.1% for Coals C and G to 10.9% for Coal A. The pyrite contents ranged from 2.1 for Coal G to 22.9 for Coal B. The Ca-Al-P mineral (crandalite) ranged from 2.1 to 15 weight percent for Coal A to Coal D, respectively.

The CCSEM data also includes size distribution of the minerals. The sizes will have an effect on the deposition potential of minerals in the coal. The larger the size the more prone to impact heat exchange surfaces causing the formation of massive deposits. Particles greater than 10 micrometers in diameter have a higher potential to impact a convective pass heat transfer surface as compared to smaller particles. The smaller sizes also have the potential to produce smaller particles/minerals that may be difficult to collect in electrostatic precipitators. Coals F and H have the highest levels of small particles (less than 10 micrometers) with 71.8 % and 76.1 %, respectively. Coal F also has an abundance of particles/mineral grains classified as unknowns in the 2.2 to 4.6-micron size fraction indicating the presence of mixtures of minerals types. Coal C has the lowest level of particles in the less than 10-micron size fraction of 52.7%.

The ash behavior indices were determined using MTI's Coal Quality Management System (CQMS), which calculates predictions for erosion, abrasion, wall slagging, convective pass fouling, and ash resistivity. Results indicate Coals A, B, D, E and F have similar erosion characteristics. Coal H had the lowest erosion index. Erosion index values for Coal C and Coal G are slightly higher because of their relatively high quartz contents. Abrasion index values are highest for Coal E and Coal F because of their high levels of pyrite.

The highest wall slagging index values calculated were for Coal C, followed by Coal B. Coals C and B have high levels of calcium along with relatively large sized quartz, clay, pyrite and Ca-Al-P mineral grains. Various combinations of these minerals with calcium levels can contribute to wall slagging behavior. The Ca-Al-P mineral has been identified in the coals and is known to contribute to slagging.

Convective pass fouling is calculated using the sulfate and silicate indices. These indices provide a ranking based on the potential for particles to accumulate. The sulfation index was found to be the lowest for the Coal F because of the small size of the minerals. The smaller minerals have the potential to react with the calcium that contributes to the formation of deposits in the lower temperature regions of the boiler. The silicate-based fouling indices are the highest for Coals C and E. The high-temperature silicate indices are similar for Coals A, D, and H. Coals F and G have intermediate silicate-fouling indices. The lowest silicate index was determined for Coal B.

Deposit strength index curves were calculated as a function of temperature for the coal characterized. Ranking the coals from highest to lowest strength development potential: B > D = E = C > F > A > G = H.

Resistivity was calculated for the coals and plotted as a function of temperature. Coals A, H, and E had similarly high ash resistivity. Coals C, F, G, D, and B had lower resistivity, decreasing in the order listed. At the operating temperatures of up to 400 °F the resistivity of all the coals are below $2\text{x}10^{10}$ Ω-cm. Based on these findings, the ESP should have good collection efficiency for the coals.