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Investigation of Fuel and Ash Properties Of Popcorn Ash Formation

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Introduction

- *Large particle ash (LPA) has been shown to be detrimental to the operation of SCR systems*
- *Although LPA has been encountered for many years, little information exists as to:*
 - **Its method of formation**
 - **Chemical structure**
- *B&W carried out experiments to develop a method to predict the propensity of a coal or coal ash to generate LPA*



What is LPA

- *Ranges in consistency from extremely porous materials to ash deposit-like*
- *Agglomeration of particles that have high porosity*
- *Mostly low density and seem to be carried through the convective section with the flue gas*
- *Factors that appear to influence their formation appear to be:*
 - **Coal/ash characteristics**
 - **Boiler operating conditions**
 - **Boiler design**



Laboratory Testing

Overview:

- **Characterized three (3) coals for minerals that show the potential to form porous and sintered deposits**
 - Eastern bituminous, western subbituminous and 60% sub/e. bit. blend
 - Performed proximate, ultimate, ash composition analyses
 - Performed Computer Controlled Scanning Electron Microscopy (CCSEM)
 - CCSEM is used to determine size, composition and abundance of mineral grains in coal
- **Characterized four (4) samples of ash**
 - Economizer hopper (2), precipitator, and windbox
 - Performed chemical analysis
 - Used Morphological analysis
 - Scanning Electron Microscopy point count (SEMPC)
 - SEMPC provides a picture of the pore structure and composition of the selected features



Coal Analysis

- Proximate, ultimate and ash composition analysis
- Used CCSEM also to analyze the coal
 - It allows for up to 3,000 individual particles to be characterized in a single sample
- Coal minerals primarily responsible for the formation of cenospheres and highly porous ash deposits are *mixed layer clays*
- ❖ *Presence of sodium (Na), calcium (Ca) and iron (Fe) decreases the potential for cenosphere formation*



Ash Sample Testing

Used SEMPC to determine the abundance of phases in the particles:

- Economizer ash gray/tan in color
- Precipitator ash light gray, fine size
- Windbox ash light gray fine with some larger pinkish particles

- 300 points are acquired randomly
 - Chemical compositions are matched to known phases
 - Chemical composition of the liquid phases is used to calculate viscosity as a function of temperature

- It helps determine the temperatures and atmospheres present during the formation of the deposit

- ❖ ***Ash with high viscosity has higher potential of forming cenospheres and porous deposits***



Ash Performance Indices

- **Convective pass fouling**
 - **Sulfation index: Propensity to form low temperature deposits (1000 – 1750 °F)**
 - Based on availability of alkali (Na, K) and alkaline earth (Ca, Mg) to react with sulfur
 - Sulfates cause particle-to-particle bonding in high calcium coals and are stable at <1650 °F
 - **Silicate Index: Propensity to form deposits from 1600 – 2400 °F**
 - Silicates are the primary bonding material
 - Availability quartz, clay, alkali and alkaline earth along with the viscosity of the silicate liquid phase are used to derive it
 - **Strength Index**

❖ ***Coals with high higher silicate indices have a higher potential to form popcorn ash when the strength index in low***



Coal Analysis Results

Table 8. Proximate and ultimate analysis results for coals (as-received basis).

Analyte	C-23805	C-23806	C-23807
	60% Western (02-054)	100% Western (02-055)	100% Eastern (02-056)
<i>Proximate:</i>			
Total moisture, wt%	20.12	27.24	5.09
Ash, wt%	7.64	3.65	8.50
Volatile matter, wt%	31.29	31.71	33.18
Fixed carbon, wt%	40.95	37.40	53.23
BTU/lb	10082	8899	12872
Total sulfur, wt%	0.43	0.37	0.82
<i>Ultimate:</i>			
Ash, wt%	7.64	3.65	8.50
Carbon, wt%	58.14	51.79	73.18
Hydrogen, wt%	6.41	6.85	5.51
Nitrogen, wt%	0.90	0.65	1.36
Total sulfur, wt%	0.43	0.37	0.82
Oxygen, wt% (by difference)	26.48	36.69	10.63

Analyte	MTI 02-054	MTI 02-055	MTI 02-056
SiO ₂	45.12	21.90	59.65
Al ₂ O ₃	21.40	13.75	28.32
TiO ₂	1.31	1.89	1.49
Fe ₂ O ₃	4.04	8.89	3.19
CaO	9.48	22.78	1.11
MgO	2.60	4.78	1.09
K ₂ O	1.45	0.35	2.12
Na ₂ O	1.11	2.57	0.46
SO ₃	10.95	20.30	0.70
P ₂ O ₅	0.39	0.77	0.09
SrO	0.16	0.25	0.08
BaO	0.27	0.29	0.08
MnO ₂	0.02	0.02	0.01



Coal Analysis Summary

60% Western blend:

- Kaolinite 20%
- Mixed layer clays 36%
- Quartz 21%
- Pyrite 2%

Western coal:

- Kaolinite 19%
- Mixed layer clays 10%
- Quartz 22%
- Pyrrhotite 2%
- Barite 5%

Eastern coal:

- Kaolinite 23%
- Mixed layer clays 36%
- Quartz 15%



Ash Composition Results

Economizer ash sample:

- Consisted mainly of Al, Si, K, Ca, and O
- Main ingredients Al and Si
- Some evidence of LPA like structure
- Cenospheres ingredients mainly Al, Si, and O with small amounts of K, Ca, Ti, and Fe

Windbox ash sample:

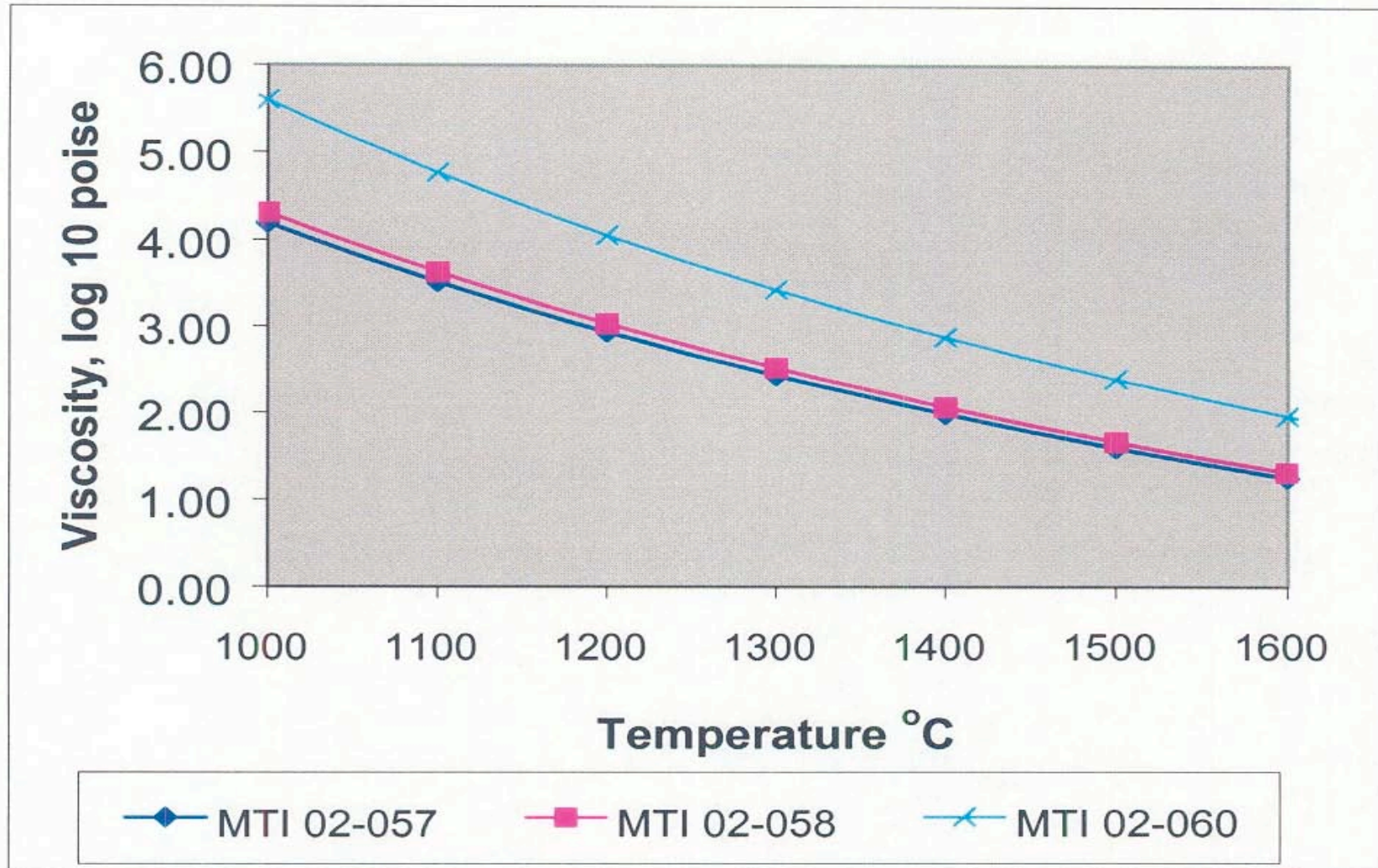
- Similar in chemical composition as the economizer ash sample

Table 7. SEMPC ash composition analysis (wt % expressed as equivalent oxide).

MTI 02-057, Economizer Ash M-56599													
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	CaO	MgO	Na ₂ O	K ₂ O	SO ₃	BaO	Cr ₂ O ₃	ClO
BULK	34.2	49.3	1.7	.6	1.3	2.4	3.9	3.6	.8	1.1	.7	.0	.5
AMORP.	45.4	39.9	1.1	.5	1.4	3.6	2.6	4.1	1.0	.0	.4	.0	.0
MTI 02-058, Economizer Ash M-59600													
BULK	36.1	50.3	1.8	.6	1.2	2.8	3.0	1.9	.7	.8	.5	.0	.3
AMORP.	46.3	37.9	2.8	1.1	1.9	2.8	2.5	3.0	1.3	.0	.5	.0	.0
MTI 02-060, Windbox Ash M-59611													
BULK	47.2	28.8	2.7	.6	1.2	3.1	2.1	2.3	2.0	9.4	.3	.0	.3
AMORP.	47.3	37.4	3.4	.8	1.3	1.8	2.5	2.8	2.5	.0	.3	.0	.0



Viscosity Results



Results

- **The formation of crystalline deposits provides information on:**
 - Age of deposit
 - Composition of the liquid
 - Temperature it was exposed
- **High degree of unclassified phases does not provide any match for any coal minerals due to high melting and interaction**

Phase	Economizer Ash M-59599 (MTI 02-057)	Economizer Ash M-59600 (MTI 02-058)	Windbox Ash M-59611 (MTI 02-060)
<i>Crystallization Products</i>			
% AKERMANITE	.0	.0	.0
% GEHLENITE	.0	.3	.0
% ANORTHITE	.4	1.0	.0
% ALBITE	.0	.0	.0
% SPINEL	.0	2.0	.0
% CALCIUM TITANATE	.0	.0	.0
<i>Oxides and sulfates</i>			
% QUARTZ	3.0	5.7	10.6
% IRON OXIDE	.0	.0	.0
% CALCIUM OXIDE	.0	.0	.0
% MAGNESIUM OXIDE	.0	.0	.0
% ANKERITE (CA,MG,FE)CO ₃	.0	.0	.0
% ALUMINUM OXIDE	3.0	9.4	.0
% RUTILE	.0	.0	.0
% DOLOMITE	.0	.0	.0
% BARITE	.0	.0	.0
% ANHYDRITE	.0	.0	2.0
<i>Amorphous Glass and Derived</i>			
% UNCLASSIFIED	88.2	71.9	60.9
% PURE KAOLINITE (AMORP)	2.2	1.3	9.9
% KAOLINITE DERIVED	3.3	7.0	15.2
% ILLITE (AMORP)	.0	1.0	.7
% MONTMORILLONITE (AMORP)	.0	.3	.3
% APATITE	.0	.0	.0



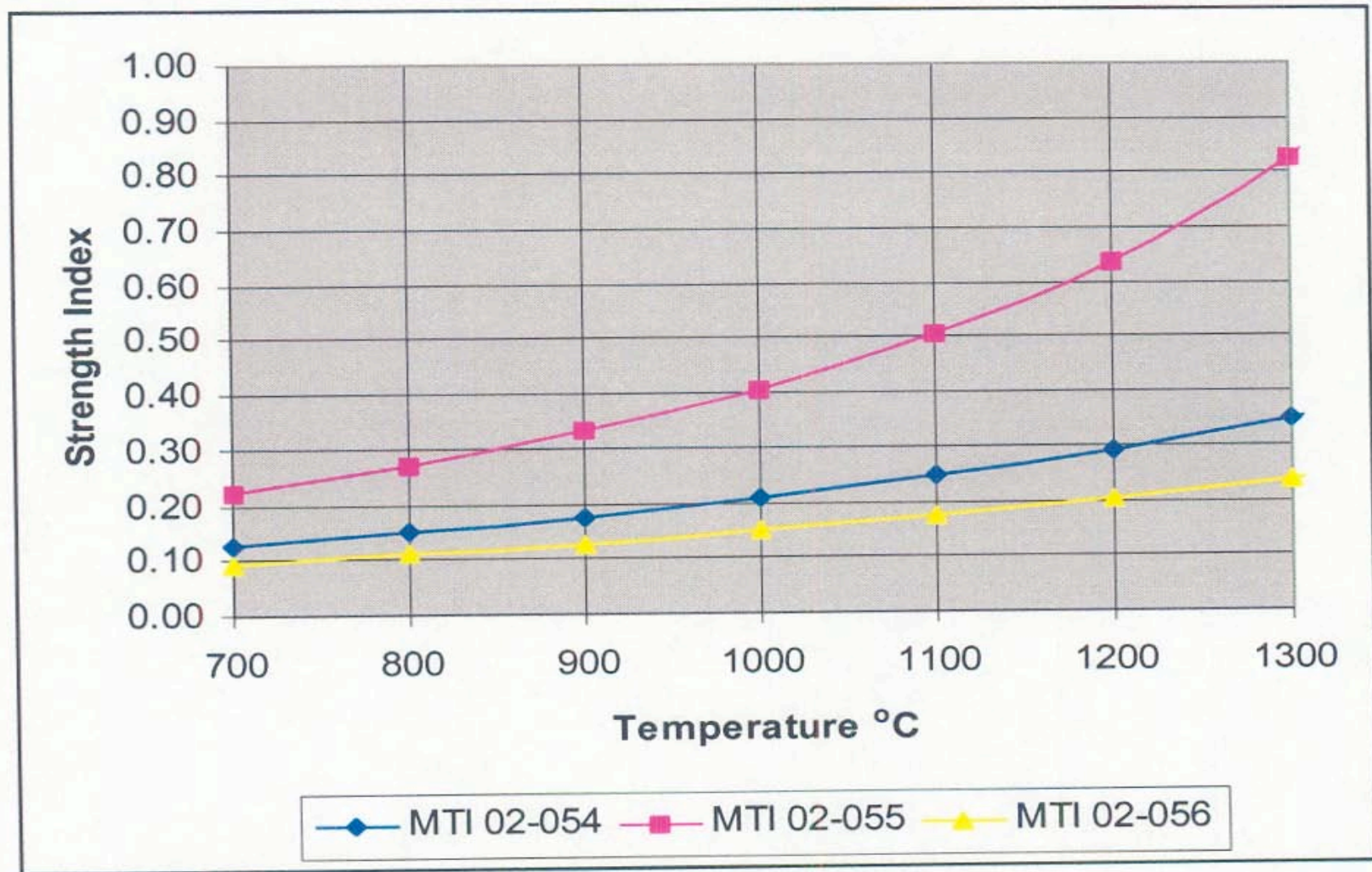
Predictive Indices of the Coals Tested

Table 11. Predictive indices for coals, calculated using CCSEM and bulk analysis results.

MTI #	Source	Abrasion	Erosion	Wall Slagging	Silication	Sulfation	Deposit Strength	T ₂₅₀ , °F	T ₂₅₀ , °C
02-054	60% Western	0.68	0.17	1.22	8.81	0.10	0.24	2813	1545
02-055	Western	0.69	0.19	2.84	9.22	1.72	0.5	2095	1146
02-056	Eastern	2.25	0.14	0.64	14.54	0	0.22	2930	1610



Coal Deposit Strength Index



Conclusions

- ***Analysis of the ash and agglomerated particles indicates the presence of popcorn ash***
- ***Deposits appear to have formed in the upper radiant and/or convective sections***
 - Material have either shed or sootblown to the back passes with the bulk gas flow
 - Absence of sulfur indicates formation at 1800+ °F
 - Silicate liquid phases are holding them together
- ***Cenospheres appear to have formed in the flame***
 - Cenospheres form primarily from mixed layer clays in the coal
 - Composition in mainly Si and Al
 - Most likely coal is eastern bituminous
 - High viscosity (4.5 – 5 log₁₀ poise)
 - High levels of Ca, Na, Fe, and Mg lower viscosity
- ***Eastern coal has higher potential to form porous low density deposits***



Summary

- ***Analytical methods exist that can provide predictions on the ability of a coal to form:***
 - Agglomerating ash particles
 - Cenospheres
 - Low density particles
- ***Predicting the severity of LPA formation is difficult due:***
 - Uncertainty of sampling used in the analysis
 - Complexity of the process





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