

The Effects of Advanced Physical Coal Cleaning on
Mineral Matter and Ash Composition and its Relationship
to Boiler Slagging and Fouling Potential

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INTRODUCTION

Recent progress in cleaning medium to high-sulfur coals from the Illinois Basin by advanced flotation methods (Read et al., 1987a) has led to the need to evaluate changes in the ash fusion temperatures of deep cleaned coal. Because the alumina- and silica-rich clay minerals and coarse pyrite are more easily removed during coal cleaning than finely disseminated pyrite, it is believed that deeply cleaned coal products may have lower ash fusion temperatures because of altered composition of the remaining ash.

To investigate this question a suite of six coals, cleaned to various degrees, were analyzed for ash chemistry (ASTM method on 750°C Ash), ash fusion temperatures, petrographic variation and mineralogic composition. The samples include the two major mined seams in the Illinois Basin, the Herrin (No. 6) and Springfield (No. 5) Coal Members, as well as the widely used Pittsburgh seam. In this abbreviated paper results for ash chemistry and ash fusion analysis are reported and evaluated.

The coals tested contain a variety of minerals. For a run-of-mine (ROM) or channel sample the typical mineral suite listed in decreasing abundance order is: various clay minerals (kaolinite, illite and expandables), pyrite/marcasite, quartz, calcite and other minerals.

As these coals are cleaned certain components are more easily removed, such as the free clay and quartz (largely from floor and roof materials) and coarse pyrite/marcasite and calcite from the coal seam. While some of the mineral matter can be liberated with minimum crushing and removed by gravity separation without significant Btu loss, the finely dispersed (framboidal) pyrite requires extensive grinding to achieve significant liberation levels (Read et al., 1987B).

Ash minerals remaining in the flotation concentrates are predominantly clay, quartz, and pyrite/marcasite, with only traces of calcite remaining. Ash values for the six samples examined at various stages of cleaning are shown in Table 1. Particle size for the wet tabling step was 6M x 0. The table concentrate was ground to 80% passing 400M for the flotation step. Grinding time was 5 minutes in a stirred ball mill; mean particle size fell between 15 and 20 μ m based on particle size analysis. Flotation was not optimized for ash rejection, but was maintained at acceptable (>75%) Btu recoveries.

ASH FUSION TEMPERATURES AND ANALYSIS

Coal cleaning causes significant changes in ash fusion temperature (Table 1). Taking first the changes from the ROM sample to the tabled samples, most temperatures under reducing condition stayed the same or dropped slightly (most less than 50°C) with the largest changes in the initial deformation temperature (IDT) and lesser changes through the fluid temperature (FT). Exceptions to this were the Herrin-SC1 where the IDT dropped 75°, and the Herrin-SW where the FT dropped 75°.

From the ROM sample to tabled sample most temperatures under oxidizing conditions changed only slightly, dropping by less than 50°F; largest changes generally occurred in the FT (Table 1). Exceptions to this are the Springfield-SE sample where the FT increased 60°F and the Herrin-SW samples where the FT increased 115°F.

Examination of the changes between ROM samples and the flotation concentrates points to a wider variation. In general, the reducing temperature increased for the Springfield-SE, but decreased for the three Herrin samples. The Herrin sample with the largest drop (210°F) was the Herrin-SC2. Changes between ROM and flotation concentrate samples in a reducing environment varied considerably; for the Springfield-SE from +45°F to +95°F, for the Herrin-SC1 sample little change (+35°F to -30°F), and for Herrin-SC2 and Herrin-SW significant drops (-65°F to -205°F and +30°F to -180°F, respectively).

For the two samples received as preparation plant products (Herrin-SC3 and Pittsburgh) the flotation concentrate generally had low to moderate increases in ash fusion temperature. Under reducing conditions the Herrin-SC3 increased from +130°F for the IDT to +80°F for the FT. Similarly, the Pittsburgh coal increased 60°F for the IDT and +35°F for the FT. Under oxidizing conditions the IDT for the Herrin-SC3 was increased 210°F while the FT went up only 30°F. The Pittsburgh sample under oxidizing conditions was hardly changed; the IDT was decreased by 5°F and the FT increased 50°F.

No consistent patterns in the changes of ash fusion temperatures emerged from this data, and it was anticipated that chemistry of the ash would also be needed to gain understanding of the variations. Using the work of Winegartner and Rhodes (1975) as a model, statistical correlation analysis for 16 cases was performed. Significant correlations between a set of variables including various oxide abundance data and derived ratios (See Table 3 for equations) and various ash fusion temperatures and temperature ranges, significant at the 99% confidence level, are reported in Table 2.

For the prediction of reducing ash fusion temperature (reducing), factors involving CaO and base % plus indices involving SiO₂ and Al₂O₃ values had high correlation coefficients (Table 2; Table 3). Best predictors for the initial deformation temperature were FeO*CaO ($r = -.91$) and the R-250 ratio ($r = .90$). Best predictors of the softening temperature were the slagging factor ($r = -.88$) and FeO*CaO ($r = -.78$). Likewise, the best predictors of the hemispherical temperature were the slagging factor ($r = -.91$) and FeO*CaO ($r = -.81$). The fluid temperature was best predicted by the slagging factor ($r = -.91$) and CaO ($r = -.81$). The temperature spread between IT and FT in reducing conditions was less strongly correlated with these variables; the highest correlation ($r = -.84$) was with FeO*Al₂O₃. In general, the slagging factor was the strongest single variable, and it has an inverse relationship with the ash fusion temperature. The second strongest variable for prediction of these ash fusion temperatures is FeO*CaO and it also varies in inverse relationship with the temperature.

The prediction of ash fusion temperature under oxidizing conditions is not as clear cut as those found for the reducing temperatures. The correlation coefficients are generally lower, indicating less precise matches of variation. Best predictors of initial deformation temp. were the base/acid ratio and % base, both inversely correlated ($r = -.72$). Best predictors of the softening temperature are the slagging factor ($r = -.75$) and the base/acid ratio ($r = -.68$). The hemispherical temperature was best predicted by the slagging factor ($r = -.78$) and the Al₂O₃ value ($r = .70$). The fluid temperature was best predicted by the slagging factor ($r = -.80$) and the FeO*CaO value ($r = -.68$). The temperature spread between IT and FT in oxidizing conditions is not well predicted by any of the variables; signifi-

cant but weak positive correlations exist only with the fouling factor ($r = .60$) and the MgO value ($r = .57$).

Discussion and Conclusions

In comparing these correlation coefficients to the discussion of coefficients reported in Winegartner and Rhodes (1975) for their eastern data set (which was dominated by Herrin Coal samples) many similarities exist. CaO, % base and the base/acid ratio generally had strong negative correlations with both the reducing and oxidizing ash fusion temperatures in the two studies. The dolomite ratio had a strong correlation ($-.72$) in our study only with the reducing temperature spread, not with both reducing and oxidizing temperatures as they found.

Winegartner and Rhodes (1975) expected to find FeO well correlated with ash fusion temperature, but were disappointed. In contrast, in our data set FeO*CaO had strong negative correlations with both reducing and oxidizing temperatures, and FeO was also correlated with the initial deformation temperature under reducing conditions. In our data set Al₂O₃ was positively correlated with the ST, HT and FT but not with the RT (Table 2).

Silica ratio values for these 16 samples varied between .76 and .89 and this suggests that high viscosity slags (400 poise) would be produced by this ash (Gibbs and Hill, Inc. 1978). In 4 of 6 cases the flotation concentrates had lower silica ratios than parent feeds, suggesting higher slag viscosities would result. Base/acid ratios for these coals all fell in the 0.13 to 0.28 range, making these coals suitable for dry-bottom furnaces, but unsuitable for slag-tap furnaces.

Analysis of this data set is continuing. We have presented only empirical data on a limited set of coals; broadening of the sample set and running actual combustion tests on selected samples would be most useful.

Bibliography

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Table 1. Changes in Ash Fusion Temperatures as a Function of Progressive Ash Reduction

Coal	Condition*	Reducing (°F)**			Oxidizing (°F)**			750°C Ash (wt.%)
		IDT	ST	HT	IDT	ST	HT	
Springfield-SE	ROM	1985	2095	2205	2325	2395	2455	30.8
	Tabled	1970	2150	2250	2295	2385	2485	12.0
	AF Conc	2040	2245	2360	2370	2455	2525	7.3
Herrin-SC1	ROM	2325	2445	2565	2475	2565	2660	27.7
	Tabled	2250	2390	2520	2480	2550	2620	10.4
	AF Conc	2230	2420	2520	2510	2575	2630	5.4
Herrin-SC2	ROM	2220	2335	2440	2340	2510	2590	25.5
	Tabled	2210	2330	2440	2365	2465	2560	8.7
	AF Conc	2010	2210	2330	2135	2365	2490	2.5
Herrin-SC3	PPP	2040	2220	2350	2305	2450	2530	5.5
	AF Conc.	2170	2365	2460	2515	2555	2605	4.8
Herrin-SW	ROM	2020	2165	2305	2285	2355	2425	38.6
	Tabled	2045	2140	2270	2285	2370	2460	17.0
	AF Conc	1970	2125	2260	2105	2345	2445	6.4
Pittsburgh	PPP	2015	2345	2445	2490	2550	2610	6.5
	AF Conc	2075	2375	2480	2485	2560	2615	3.8

* ROM = run of mine; PPP = prep. plant product; AF conc = Aggregate Flotation concentrate
 ** IDT = initial deformation temp; ST = softening temp.; HT = hemispherical temp.; FT = fluid temp.

Table 2 Correlation matrix of most significant coefficients

Ash Variables	Reducing Temp. (°F)				Temp. Spread	Oxidizing Temp. (°F)				Temp. Sread
	IDT	ST	HT	FT		IDT	ST	HT	FT	
SiO ₂					-.73					
Al ₂ O ₃		.67	.65	.67		.67	.70	.68		
FeO	-.73				.74					
CaO		-.76	-.79	-.81			-.66	-.66	-.67	
MgO						-.60				.57
K ₂ O										
Na ₂ O										
TiO ₂										
FeO*SiO ₂	-.78				.68					
FeO*Al ₂ O ₃					.84	-.61				
FeO*CaO	-.91	-.78	-.81	-.79		-.72	-.65	-.67	-.68	
% Base	-.87	-.75	-.76	-.68		-.72	-.67	-.67	-.64	
Base/Acid	-.86	-.74	-.76	-.67		.57	-.68	-.67	-.64	
Silica ratio	.86	.61	.64	.58						
Dolomite r.					-.72					
R-250 ratio	.90	.67	.70	.66		.59		.58		
B & W - SF	-.75	-.88	-.91	-.91		-.62	-.75	-.78	-.80	
B & W - FF						.58				.60

* Spread is FT minus IT in °F.

Table 3 Equations for indices*

1.	$\text{FeO} \cdot \text{SiO}_2$	=	$(\text{FeO})(\text{SiO}_2)$
2.	$\text{FeO} \cdot \text{Al}_2\text{O}_3$	=	$(\text{FeO})(\text{Al}_2\text{O}_3)$
3.	$\text{FeO} \cdot \text{CaO}$	=	$(\text{FeO})(\text{CaO})$
4.	% base	=	Sum of FeO, CaO, MgO, K ₂ O and Na ₂ O
5.	Base/acid ratio	=	$\frac{\% \text{ Base}}{100 - \% \text{ Base}}$
6.	Silica value	=	$\frac{\text{SiO}_2}{\text{SiO}_2 + \text{FeO} + \text{CaO} + \text{MgO}}$
7.	Dolomite ratio	=	$\frac{\text{CaO} + \text{MgO}}{\text{FeO} + \text{CaO} + \text{MgO} + \text{K}_2\text{O} + \text{Na}_2\text{O}}$
8.	R-250 value	=	$\frac{\text{SiO}_2 + \text{Al}_2\text{O}_3}{\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{FeO} + \text{CaO}}$
9.	Babcock-Wilcox Slagging Factor	=	$\frac{\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{Fe}_2\text{O}_3 + \text{CaO} + \text{MgO}}{\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{TiO}_2} \times \text{TS}\%$
10.	Babcock-Wilcox Fouling Factor	=	$\frac{\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{Fe}_2\text{O}_3 + \text{CaO} + \text{MgO}}{\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{TiO}_2} \times \text{Na}_2\text{O}$

* oxides are expressed as mole percent with iron as FeO, normalized to SO₃ - free basis