



THE EFFECT OF COAL PREPARATION ON THE QUALITY OF CLEAN COAL AND COKE

By Barry Ryan (B.C. Geological Survey Branch), Ross Leeder (Industrial Leader - Canadian Carbonization Research Association and Teck) and John T. Price and John F. Gransden (CETC, CANMET Energy Technology Centre)

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INTRODUCTION

Coal preparation plants are designed to control clean coal quality to meet contract quality specifications and normally focus on ash, sulphur, calorific value, size and moisture contents of the clean coal. The coking quality of clean metallurgical coal is evaluated, but generally only limited attempts are made to influence it by changing operating conditions in the plant.

Plants size the feed coal into different fractions, which are processed in individual circuits before being combined into the final clean coal. In western Canada, the coarsest (+0.6mm) coal is cleaned in combinations of heavy media vessels, drums and cyclones, while the finer coal (-0.6mm by 0.0mm) is cleaned using water-only-cyclones (WOC), spirals and/or froth flotation (FF) (Romaniuk, 1986). These processes are chosen to maximize the recovery of clean coal and for ease of control. Run-of-mine coal delivered to a plant is more complex than a mixture of three uniform materials (coal, rock and water). The coal is composed of a mixture of macerals and the rock a mixture of minerals with different chemical compositions. The type of association of the minerals and macerals, and the ability of each to be liberated by crushing, influences the size fraction and therefore the circuit into which they are concentrated. It is possible to adjust coal recovery from individual circuits to decrease ash content, and improve maceral composition and/or ash chemistry in the clean coal product. Whether this is economic depends in part on the characteristics of the run-of-mine coal and on the washing circuits available in the plant.

BACKGROUND

In the mid 1970's, the Canadian Carbonization Research Association (CCRA) undertook laboratory-scale coal washing (float/sink) tests of Canadian metallurgical coals to investigate changes in coal quality and petrographic and thermal rheological properties at varying ash concentrations for clean coal (Price and Gransden, 1987). It was found that as ash content decreased, the reactivities content of the coal increased and thermal rheological properties improved. However, it has been known for some time that using laboratory scale results to predict the coking quality of western Canadian coals is difficult (Gransden *et al.*, 1980). Four bulk samples of western Canadian coals were subsequently washed in a pilot plant and both the coal and coke quality determined for clean coals with varying ash contents (Gransden and Price, 1982). The results were similar to the earlier laboratory scale studies and there was a general improvement in coke quality. Generally finer sized coal produced from the pilot scale tests had higher reactivities content and better thermal rheological properties than coarser clean coal fractions, however, their relative influence on the coking quality of the coal was not investigated.

Following these two programs, the CCRA initiated the a detailed investigation of the performance of several coal preparation plants belonging to member companies. The objectives of the program were:

- ♦ to determine if it is technically possible to improve the coking characteristics of the over-all product coals;
- ♦ to determine if general trends occurred that would assist coal preparation engineers design or modify plant methods of operations to improve the clean coal coking characteristics.

This paper presents and discusses the results

of the CCRA study.

VARIATIONS IN COAL QUALITY AND ASH CHEMISTRY IN PLANT CIRCUITS

Maceral trends in wash plants

If all circuits in a plant recover all the coal, then the product coal will have the maceral composition of the run-of-mine coal but will be accompanied by less ash. However, if there is some coal loss, then it is possible to influence the maceral composition of the clean coal. Vitrinite is more friable than inert coal macerals and concentrates in the finer sizes. Therefore feed for coarse circuits is enriched in inert macerals compared to run-of-mine coal and feed to fine coal circuits is progressively enriched in vitrinite. Coarse circuits are generally not good at retaining vitrinite in clean coal. It appears that in these circuits some vitrinite is present in fine vitrain bands associated with in-seam splits. There is therefore a tendency for it to be lost in the rejects and the vitrinite content of the clean coal is less than that of the feed coal.

Vitrinite is less dense than the inert macerals, and once liberated in the feed coal, concentrates in the clean coal from the finer circuits, which use density separation. Bustin (1982) found that the maceral composition of washed coal varies based on the specific gravity (SG) of the split (Figure 1). The inert macerals tend to concentrate in the intermediate SG splits and the vitrinite in the lower SG splits. In detail there is a weak tendency in plants for vitrinite to concentrate in the clean 0.6 to 0.15 mm size fraction, and a stronger tendency for it to concentrate in the clean minus 0.15 mm material compared to the amount in the feed coal to these circuits (Table 1, Figure 2). In contrast the inert macerals concentrate in the clean coal from coarse circuits. It is therefore possible to influence the maceral composition of the clean coal by varying the cut points in the various circuits.

When documenting maceral trends, data can be presented as macerals in the total sample, which can be misleading because of varying ash content, or as maceral content as a percentage of the coal only part of the sample (mineral matter free basis). This second method is more representative of maceral changes in the various prod-

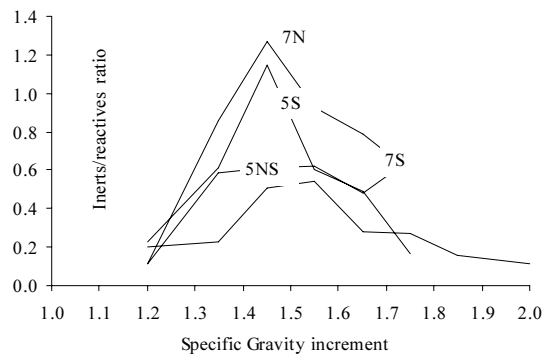


Figure 1. Variation of the reactivities/inerts ratio with specific gravity split for a number of Mist Mountain Formation coals. Numbers refer to specific seams (data from Bustin, 1982).

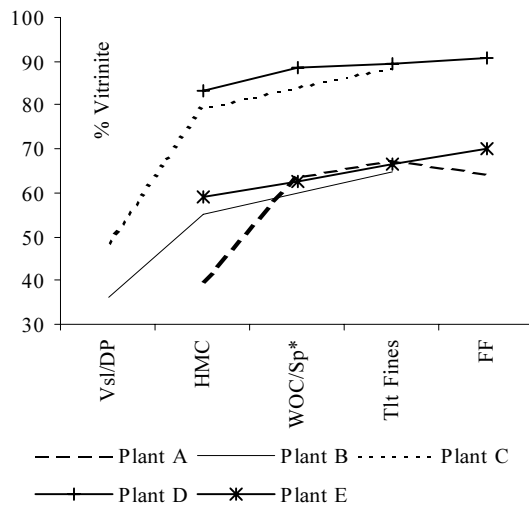


Figure 2. Variations in vitrinite content (total sample) in clean coal from the various circuits of the 5 plants studied, VsVDP=heavy medium vessels and drums, HMC=heavy medium cyclones, WOCSP=water only cyclones and spirals, Tlt Fines=total fines, FF=froth floatation.

ucts. Also it is possible to track vitrinite as the main reactive maceral or to track vitrinite plus reactive semifusinite as the total reactivities in the sample. The later method requires an assumption on how to divide the semifusinite into reactive and non-reactive components.

Controls on ash chemistry in wash plants

Coal wash plants cannot reduce the ash content of the clean coal to zero, there is therefore, always the possibility of improving the ash chemistry of the clean coal. Ash chemistry has

Table 1. Petrography and ash chemistry; Plant A.

<u>FEED COAL</u>				
Size mm	50x0.0	50x0.6	.6x0.15	0.15x0
percentage	100	66	18	16
	FEED	CLEAN	REJECT	
<u>HEAVY MEDIUM 50x0.6 mm</u>				
% Weight	100	68	32	
Ash%	29	10.5	68	
total reactives	68	65.5	70	
base/acid ratio	0.098	0.082	0.09	
Al ₂ O ₃ /SiO ₂	0.44	0.55	0.43	
S%	0.2	0.36	0.09	
coal rec%	-	90	-	
<u>WOC 0.6x0.15 mm</u>				
% Weight	100	69	31	
Ash%	18.7	8.3	41.5	
total reactives	79.5	79.6	73.3	
base/acid ratio	0.081	0.048	0.106	
Al ₂ O ₃ /SiO ₂	0.49	0.5	0.46	
S%	0.37	0.33	0.4	
coal rec%	-	80	-	
<u>WOC + Floatation 0.15x0.0 mm⁽¹⁾</u>				
% Weight	100	64	36	
Ash%	21.3	8.5	43.9	
total reactives	76.7	84.9	78.2	
base acid ratio	0.099	0.038	0.23	
Al ₂ O ₃ /SiO ₂	0.46	0.51	0.37	
S%	0.52	0.4	0.74	
coal rec%	-	76	-	
WOC =water only cyclones				
(1) data calculated from 0.6 by 0.0mm and 0.6 by 0.15mm material				
total reactives =% of organic material				
coal rec= ratio coal recovered / coal in raw sample				

always been an important parameter for thermal coals but it is also becoming an important parameter for metallurgical coals. This is because ash chemistry influences coke reactivity and

coke strength at high temperatures. The coke strength after reaction (CSR) test is used to evaluate coke strength at high temperatures and is used to assess the coking quality of hard coking coals, with ranks in the range 1.0% to 1.7% Rmax. In fact as PCI replaces coke in the blast furnace even more emphasis is likely to be placed on CSR values. A number of authors (Goscinski *et al*, 1985, Price *et al.*, 1988) have illustrated that CSR is strongly influenced by ash chemistry measured as alkalinity, base/acid ratio (B/A) or the modified basicity index (MBI) (Table 2).

There are a number of empirical equations, many listed in Coin (1995), that use only coal quality parameters to predict CSR. Generally the equations use rank, coal ash chemistry, rheology, and petrography, in that rough order of significance. It is important to recognize that rheology and petrography are in fact not independent variables and that CSR has a non linear relationship to rank, decreasing at high and low ranks and reaching a maximum value in the range Rmax%=1.35-1.43% (Coin, 1995). There appears to be an optimum amount of inerts, at a given rank, for maximum CSR and this amount increases as rank increases (Gill, 1982). This means that any linear regression of CSR against rheology, petrography and rank can only be effective over a limited range. CSR probably has a better linear correlation to ash basicity than any other factor, depending on how it is defined. Todoschuk *et. al.* (1998) uses coke basicity and other coke derived properties to predict CSR over a wide range of rank.

Table 2. Abbreviations for plant data.

<u>Gieseler Plastometer</u>	
startC° =temp of softening, fusC°=temp of fusion, max C°=temp of max fluidity, finalC°=temp at end of fluidity	
solidC°=temp at solidification, maxC°= fluid temp range, ddpm= max fluidity	
<u>Dilatometer</u>	
sf TC°= temperature of start of fusion in a dilatometer, max C C° = temperature at maximum contraction,	
max D C° = temperature at maximum dilatation, C=maximum contraction, D=maximum dilatation,	
<u>Ash Chemistry</u>	
B/A=base/acid ratio = (CaO+MgO+Fe ₂ O ₃ +Na ₂ O+K ₂ O)/(SiO ₂ +Al ₂ O ₃ +TiO ₂), MBI=B/A x Ash/ (100-MV) x 100	
Alkalinity=base/acid ratio x Ash/100	
<u>Petrography</u>	
vit =vitrinite, ex=exinite, SF=semifusinite, Mic=micrinite, Fus=Fusinite, MM=Mineral Matter, TR=total reactives	
<u>Plant</u>	
cl=clean, hm=heavy medium, sb=sieve bend, sbo=sieve bend oversize, bp=bird product, woc=water only cyclone, m=mesh	
Carbonization	
H ₂ O=moisture of charge, ASTM BD=bulk density of charge kg/m ³ , Max w l P kPa=max wall pressure, SI=Stability Index	

There have been a number of studies investigating the relationship of CSR to ash chemistry. Some studies have attempted to differentiate alkalis in terms of their ability to effect CSR and to determine whether mineral form influences the ability of an alkali element to effect CSR. Price *et al.*, (1992) found that additions of pyrite (FeS_2), siderite (FeCO_3) or calcite (CaCO_3) to coal samples decreased CSR in proportion to the amount they increased MBI. Goscinski and Patalsky (1989) emphasize the importance of Fe_2O_3 and CaO contents. When these oxides are present in eutectic proportions the ash fusion temperature is lowered and the catalytic effect of the ash on coke reactivity is enhanced.

The oxides CaO and Fe_2O_3 may be released by the dissociation of carbonates or pyrite in the coke oven. If the carbonates are finely dispersed in coal macerals the resulting oxides will be highly reactive. A plot of the concentration of Fe_2O_3 versus CaO in the total samples for 3 of the suits of medium-volatile coals studied in this paper (Figure 3) illustrates the devastating effects of iron and calcium on CSR and the tendency of CaO to be more harmful than Fe_2O_3 . Suite B contains increased concentrations of CaO, probably occurring as calcite (CaCO_3) on cleats in vitrinite. The Fe_2O_3 total sample concentrations in coals A, B and C do not correlate with sulphur (Table 3) and many of the samples plot above the pyrite line (Figure 4) indicating that the iron is probably present as siderite not as pyrite. Microscope work has identified siderite (FeCO_3) dispersed as oolites through the coal. Apparently the dispersion of calcite in vitrinite

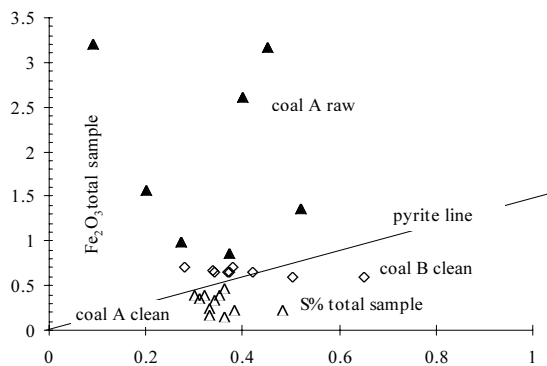


Figure 3. Fe_2O_3 total sample versus S% for plants A, B illustrating lack of relationship; plot indicates a siderite origin for most of the iron and an organic origin for the sulphur. Samples containing only pyrite plot on pyrite line.

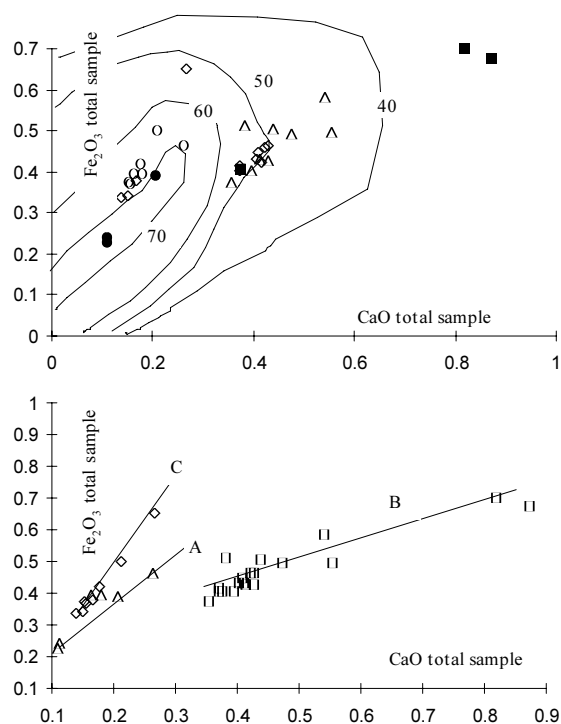


Figure 4. Fe_2O_3 and CaO data for plants A, B and C illustrating relative effect of oxides on CSR. CSR values are divided as follows Squares<40,triangles 40-50, diamonds 50-60, circles 60-70 solid circles>70. Plant B ash contains calcite plant C ash contains siderite.

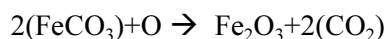
has increased the reactivity of CaO over that of Fe_2O_3 , which is not as finely dispersed in the coal macerals.

It is possible using a CSR predictive equation to illustrate the effects on CSR of additions of small amounts of calcite or siderite. The equation derived by Price *et al.* (1988) is a relatively consistent empirical approach to estimating CSR

Table 3. Linear correlation matrix for clean coal data, Plant C, illustrating effect of Fe_2O_3 on base/acid ratio (B/A).

×	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	B/A	K_2O	Ash	CSR
SiO_2	1.0										
Al_2O_3	-.51	1.0									
Fe_2O_3	-.19	-.33	1.0								
TiO_2	-.11	.56	-.93	1.0							
P_2O_5	-.50	.04	.69	-.60	1.0						
CaO	-.21	-.29	.98	-.92	.78	1.0					
MgO	.42	.01	-.94	.79	-.80	-.94	1.0				
B/A	-.24	-.42	.98	-.89	.64	.96	-.88	1.0			
K_2O	.31	.14	-.97	.87	-.81	-.98	.98	-.92	1.0		
Ash	.61	-.93	.34	-.58	-.19	.28	-.04	.40	-.14	1.0	
CSR	-.70	.35	-.39	.54	-.03	-.38	.28	-.24	.40	-.52	1.0

values, though it tends to predict on the high side (Coin, 1995). The equation emphasizes the sensitivity of CSR to changes in ash chemistry. It can be used to illustrate the effect of adding 1% calcite to a raw coal. If the original sample has values of 10% ash, 50 ddpmm fluidity, base/acid ratio 0.07 and a rank of $R_{max}=1.3\%$ then the calculated CSR is 67. The CSR value drops to 49 and the base/acid ratio changes to 0.13 after addition of 1 weight % calcite. The 1% addition of calcite added about 0.56% CaO to the sample but all of this is concentrated into the 10% ash changing the CaO % in ash from 1.4% to 6.6%. It is not uncommon to find 1% calcite in coal either along cleat surfaces in vitrain bands or in cells in semifusinite. The situation is even more extreme if siderite ($FeCO_3$) is added to the sample, because this will report to the ash as Fe_2O_3 and requires addition of oxygen because it is present in calcite as Fe+2 but is oxidized to Fe+3 in the ash:



This means that 1 gram of siderite in the samples adds 0.7 grams of Fe_2O_3 to the ash producing an increase in the percentage of Fe_2O_3 in the ash of over 7%. Or conversely surprisingly high Fe_2O_3 concentrations in ash result from quite small concentrations of siderite in the total sample.

It is important to know what minerals are influencing the ash chemistry and where they are located in the coal, before attempting, in a plant, to change the ash chemistry of the product coal. Coals with no marine influence generally contain high proportions of kaolinite and quartz; coals with some marine influence contain less degraded clays and more pyrite. Most of the Cretaceous coals in western Canada have kaolinite based ash, which ensures low base/acid ratios, unless there have been syngenetic or epigenetic additions of carbonate minerals. Scanning electron microscope work indicates that there are three primary locations for difficult to remove mineral matter in coal.

- ♦ Finely dispersed mineral matter occurs in desmocollinite (vitrinite B). In western Canadian coals this appears to be kaolinite rich though quartz and sometimes crandillite (aluminum phosphate) occur. If pyrite is pre-

sent it is often finely dispersed in reactive macerals (Ryan and Ledda, 1998) because it usually forms by bacterial reduction of SO_4 in moderate pH anaerobic conditions favourable to the preservation of vitrinite.

- ♦ A number of minerals (kaolinite, carbonates and sometimes apatite) fill the cell voids in semifusinite and fusinite. In some coals with high macrinite contents the amount of inherent mineral matter is low because these sites are not available.
- ♦ Some minerals are external to maceral grains but are too finely dispersed to be easily liberated by crushing. Calcite and other carbonates sometimes coat cleat and microfracture surfaces in vitrain bands. Calcite can be unexpectedly difficult to remove because it impregnates the vitrinite along microfractures associated with cleats. Oolites of siderite can occur randomly dispersed in the coal. Siderite can also coat cleat surfaces.

It is important to realize that these minerals are associated with the coal and not with the in-seam rock splits.

Calcite is one of the most important minerals influencing the ash chemistry of British Columbia coals. It is deposited on cleats and in the cell structure of semifusinite. The deposition of calcite into semifusinite cells must occur as the coal is forming and before compaction closes the cell openings. It has been suggested that fires in the coal swamps form charred vegetation, latter to form semifusinite and at the same time increase the pH of the swamp water, probably by deposition of soluble ash (Lamberson and Bustin, 1996). The higher pH causes calcite to precipitate into the porous semifusinite. This often effects upper parts of seams, producing a hard dull looking coal in outcrop. The occurrence of calcite-rich semifusinite will vary based upon depositional features. Once filled with calcite the semifusinite cells are protected from compaction and deformation and provide a location, from which it is almost impossible to remove the calcite. A similar problem can occur in some coals where apatite fills semifusinite cells.

If the calcite coats the surfaces of cleats, it must have been deposited after the coal was sufficiently indurated to fracture. Probably calcium rich water percolated down through the coal

from marine strata higher in the section. In this case the calcium will be associated with the bright vitrinite rich bands in the coal and may, on the regional scale, vary based on the extent of cleat development related to folding. Crushing the coal to a finer size may help to liberate some of the calcite.

Based on the association of minerals with coal and the type of minerals present, the base/acid ratio of ash changes with the size consist of raw coal and by specific gravity of wash fractions. This leads to the possibility of changing the ash chemistry of the clean coal. Coals that have carbonates on cleats and micro fracture surfaces have higher base/acid ratios in coarser sized coal, caused by increased contents of calcium, iron and magnesium associated with the minerals calcite (CaCO_3), dolomite (CaMgCO_3), ankerite (CaMgFeCO_3) and siderite (FeCO_3). These minerals are associated with coal rather than in-seam rock splits. They report to SG splits based on the average SG of the coal plus mineral matter plus carbonate mixture. The maximum amount of carbonate can occur in any SG split when it is associated only with pure coal. As the inherent mineral matter content increases in the sample the carbonate content has to decrease to maintain the same SG. In coals with high inherent ash contents, the carbonate is forced into the higher SG splits and tends to be removed with the rejects. In coals with low inherent mineral matter contents it can occur in lower SG splits and end up in the product coal.

A previous study looked at the distribution of calcite in a high-volatile bituminous coal (Ryan, 1994). Using washability data it is possible to convert analyses of CaO content by SG increment into approximate concentrations of calcite in the total sample (Table 4). Estimated contents of calcite increased to the range 10% to 20% in SG splits 1.45 to 1.7. These high concentrations were achieved because this coal has a low inherent mineral matter content. The reported ash concentrations include the CaO from the calcite, which has to be removed before calculating the content of non calcite derived ash in the coal. It should be noted that when carbonate concentrations are high, ash values are very deceptive because of the loss of CO_2 from carbonate component of the non coal part of the sample during ashing. In fact in the calcite distribution study (Ryan, 1994) the reported ash

Table 4. Calcite distribution by size and SG increment. Data from a high-volatile bituminous coal (Ryan, 1994).

SIZE mm	100-25	25-10	10-0.5	0.5-0.15
Weight%	23.5	24.3	40.2	4.5
Ash%	32.8	32.6	31.3	21.4
CaO% Ash	8.8	4.9	5.9	15.0
Wt% calcite	4.6	2.3	2.7	5.4
Vol% calcite	2.4	1.2	1.4	2.8

S.G.	wt% calcite		wt% calcite		wt% calcite		wt% calcite	
	Ash%	wt% calcite	Ash%	wt% calcite	Ash%	wt% calcite	Ash%	wt% calcite
1-1.3	6.0	0.9	4.0	1.0	4.8	1.1	4.2	0.5
1.3-1.35	6.4	2.6	5.7	2.0	5.5	1.2	6.2	0.6
1.35-1.4	10.5	6.5	9.9	5.6	9.9	2.6	7.7	0.9
1.4-1.45	14.4	9.7	15.0	6.4	14.3	4.4	10.4	1.0
1.45-1.5	17.7	12.7	18.7	10.0	18.4	7.1	15.1	1.5
1.5-1.6	21.8	16.3	24.2	13.9	23.4	9.5	19.4	2.1
1.6-1.7	30.8	9.7	33.7	10.5	30.7	10.6	28.2	3.1
1.7-1.8	44.4	9.9	45.3	5.8	38.9	13.5	36.8	5.4
1.8-2.0	51.2	3.3	53.9	1.0	51.8	9.3	47.9	8.1
2.0-2.17	65.9	0.5	66.8	2.7	61.5	10.6	58.9	11.9
2.17-2.5	80.5	0.0	80.9	-0.5	81.4	1.0	79.3	21.3

concentrations for intermediate SG values and coarse size fractions are 23% and 36%; these values are actually closer to 30% and 42% mineral matter when the oxides are reconstituted to make carbonates.

It is also possible to estimate the SG of the material in each split by assigning densities to coal, mineral matter and calcite. When this is done in the study (Ryan, 1994), it is found that in order to derive an average SG for the material in each SG split that is bracketed by the SG increment range, a low density for calcite has to be used in the calculations. It is difficult to derive an accurate number but the effective density of the calcite appears to be low by about 20%. It appears that the actual density for carbonates on cleats and micro fractures may be less than the ideal density of the pure minerals. Possibly larger coal fragments (i.e. >5 mm), which contain microfractures have increased porosity, which is only partially filled by carbonate material. This could help explain the difficulty in removing carbonate material from coal, unless it is crushed to a fine (<1 mm) size. Obviously it is easier to remove calcite from finer sized coal, as more calcite is liberated. Also because the grains are smaller more of them contain higher amounts of

included calcite so that the calcite occurs in higher SG splits (Table 4).

Variations in ash chemistry are very important and can only be fully understood in the context of the mineralogy of the mineral matter in the coal. A powerful and cost effective way of doing this is to use a linear correlation matrix of oxide data. This is illustrated using data from a detailed study, which analyzed all major oxides in a bulk sample by size and SG increment. Data from this study are used to infer the mineralogy of the ash in each increment (Table 5). It should be noted that because Al_2O_3 and SiO_2 are major components of the ash they will always tend to be negatively correlated and this does not necessarily reflect changes in mineralogy. Calcium, iron and magnesium are concen-

trated in the coarser sizes and in these sizes they correlate with each other and not with SiO_2 or Al_2O_3 indicating that they are present as carbonates. In the fine size, concentrations of these elements decrease; CaO correlates with P_2O_5 indicating an apatite connection; MgO correlates with ash and not with Fe_2O_3 or CaO indicating a clay connection; Fe_2O_3 does not correlate with CaO, MgO or ash indicating a probable pyrite connection. Maximum carbonate content of the samples can be estimated by combining the oxides of Ca, Mg and Fe with CO_2 and recalculating the weights as carbonates (XCO_2). This indicates that in the coarser sizes carbonate contents are in the range 1 to 15% but in the fine size, contents decrease to less than 3% except in the plus 2.17 SG split.

Table 5. Linear correlation matrix for ash chemistry and petrographic data for incremental wash samples from 3 size ranges; TR=total reactivities.

x	Ash	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	SO_3	Na_2O	K_2O	TR
Ash	1.0											
SiO_2	-.90	1.0										
Al_2O_3	-.07	.45	1.0				plus 12.5 mm					
Fe_2O_3	.62	-.86	-.57	1.0								
TiO_2	.63	-.33	.25	-.18	1.0							
P_2O_5	.59	-.53	.31	.60	-.04	1.0						
CaO	.72	-.91	-.74	.78	.29	.14	1.0					
MgO	.56	-.86	-.78	.95	-.12	.34	.90	1.0				
SO_3	.72	-.51	.49	.41	.31	.93	.12	.16	1.0			
Na_2O	.38	-.07	.83	-.03	.26	.77	-.34	-.30	.88	1.0		
K_2O	-.96	.90	.03	-.73	-.43	-.78	-.65	-.61	-.83	-.49	1.0	
TR	-.76	.75	.15	-.77	-.13	-.70	-.57	-.63	-.69	-.31	.81	1.0
Ash	1.0											
SiO_2	.88	1.0										
Al_2O_3	-.85	-.86	1.0				12.5 - 0.6 mm					
Fe_2O_3	-.79	-.96	.72	1.0								
TiO_2	-.91	-.99	.91	.92	1.0							
P_2O_5	-.84	-.78	.91	.72	.83	1.0						
CaO	-.62	-.84	.48	.87	.78	.35	1.0					
MgO	.09	-.12	-.39	.29	.02	-.41	.62	1.0				
SO_3	-.82	-.90	.59	.95	.85	.64	.86	.40	1.0			
Na_2O	-.65	-.63	.89	.54	.69	.93	.13	-.64	.38	1.0		
K_2O	.88	.99	-.89	-.96	-.99	-.85	-.78	-.05	-.88	-.71	1.0	
TR	.52	.73	-.30	-.85	-.66	-.31	-.93	-.74	-.88	-.04	.70	1.0
Ash	1.0											
SiO_2	.81	1.0										
Al_2O_3	-.86	-.97	1.0				0.6 - 0.15 mm					
Fe_2O_3	-.68	-.55	.73	1.0								
TiO_2	-.71	-.92	.83	.25	1.0							
P_2O_5	-.81	-.98	.92	.42	.96	1.0						
CaO	-.47	-.65	.54	.04	.85	.68	1.0					
MgO	.84	1.0	-.98	-.59	-.91	-.98	-.65	1.0				
SO_3	-.41	-.29	.16	-.31	.59	.42	.73	-.29	1.0			
Na_2O	-.80	-.98	.94	.50	.90	.98	.58	-.98	.29	1.0		
K_2O	.86	.95	-.99	-.78	-.76	-.89	-.44	.95	-.06	-.92	1.0	
TR	.13	.14	-.27	-.60	.24	-.04	.64	.14	.80	-.19	.39	1.0

It is obvious, that for the coal represented in Table 5 the base/acid ratio is controlled by carbonate material on cleats. It is not easily liberated because a lot of the carbonate material is contained in particles with SG values in the middlings range. Small increases in the cut point of the coarse circuit or crushing the coal to a finer size may remove more carbonate material, reduce the base/acid ratio of the clean coal and improve the CSR values, with out a major decrease in plant yield.

In coals that do not contain carbonates on cleats, carbonate material can occur as cell filling in fusinite and semifusinite; though the amount present will be much less than in cleated

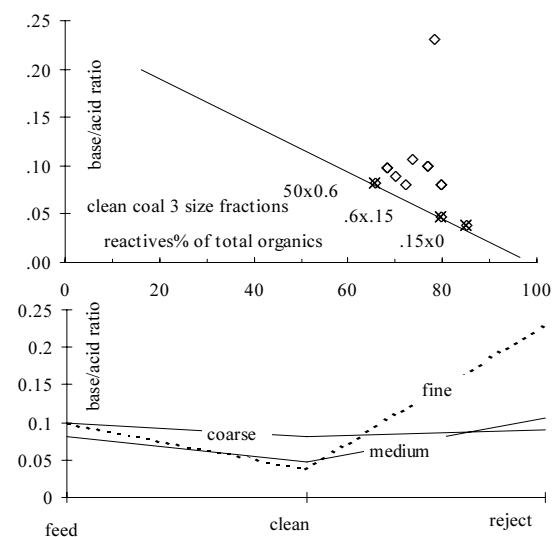


Figure 5. Relationship of base/acid ratio to size, clean, raw or reject coal and petrography in plant A. Diamonds are raw and reject samples.

coals. In these coals base/acid ratios have a negative correlation with reactive maceral contents and also decrease in the fine circuits because coal in these circuits tends to be enriched in reactive macerals (Table 1). A plot of reactivities content (mineral matter free basis) versus base/acid ratio for clean coal from a number of circuits (Figure 5) provides a good negative correlation indicating a zero base/acid ratio for reactivities and a ratio of about 0.2 to 0.25 for the organic inerts plus ash. A zero base/acid ratio suggests a mineralogy of kaolinite and quartz in the vitrinite. The ratio can be decreased by adjusting the cut point of coarse circuits to retain less inertinite.

CCRA PLANT EVALUATION PROGRAM

Coal was sampled from five Canadian coal preparation plants. The size fractions treated in the individual circuits of these five plants are summarized in Table 6. The sampling program varied at each plant because of somewhat different objectives and varying plant design and as the program unfolded the sampling program at each plant tended to become more detailed as information from the previous plants became available. Attempts were made to sample product coal, coal from each circuit as well as a number of blends of material from different circuits at each plant. Sampling at each plant occurred over a relatively short period and therefore quality does not necessarily reflect average product coal quality. It should also be noted that this CCRA project has been on going for a number of years and product quality from the plants has changed considerably since the project started.

Table 6. Coal sizes treated in the five plant circuits.

Plant	Plant Circuits			
	Heavy Media		Fines	
	Vessels or Drum	Cyclones	WOC/Sp*	Froth Flotation
A	-	50x0.6	0.6x0.15	0.15x0
B	50x16	16x0.65	0.65x0.15	0.15x0
C	40x10	10x0.65	0.65x0.15	0.15x0
D	-	50x0.65	0.65x0.15	0.15x0
E	-	40x0.65	-	0.65x0

*Water-only-cyclones (WOC) and/or Spirals (Sp)

Each of the bulk samples taken from the plants was evaluated for both coal and coke quality, and the impact of the coal produced from individual circuits on the coking quality of the overall clean coal was also evaluated. Testing of samples for coal and coking quality was conducted in the laboratories and pilot scale coke ovens at the CANMET laboratories (Ottawa). Because of differences in the sampling programs, the detailed results for each plant vary somewhat and are discussed separately. All the abbreviations used in tables containing the plant results are in Table 2.

Plant A

Basic analytical data for Plant A (Tables 7,8) indicate the distribution of ash and variations in petrography between the three size circuits in the plant. The coal is screened to 50mm by 0.6 mm and 0.6mm by 0.0mm. The coarse size is washed in heavy medium cyclones. The finer coal is partially cleaned in water only cyclones then screened to 0.6 by 0.15 mm and 0.15 mm by 0.0 mm. The 0.6 mm by 0.15 mm material goes to clean coal and 0.15 by 0 mm material is cleaned in floatation cells.

Some general comments can be made about the plant. Raw coal ash concentration is minimum in the 0.6 mm by 0.15 mm size; sulphur and reactive macerals concentrate in the finer sizes. Ash chemistry varies little with size, though there seems to be a concentration of kaolinite, probably associated with vitrinite, in the fine coal. The cleaning efficiency of the circuits decreases as the size decreases and this provides some flexibility to influence the petrography of the clean coal. The 0.15 mm by 0.0 mm clean coal, which is a combination of material from water only cyclones and floatation is enriched in vitrinite, possibly because these circuits reject about 25% of the feed coal. Consequently the reject coal must be enriched in inertinite.

Base/acid ratios are generally low and decrease as coal size decreases and as the amount of vitrinite increases (Figure 5). They tend to increase as the amount of inertinite or ash increase in the sample Figure 6. An indication of the ability of a plant to effect the base/acid ratio of the product coal is given by the percent-

	plant feed	hm feed	woc feed 0.15 x 0	hm reject	bird reject 0.6 x 0.15	bp reject 0.15x0.0	cl coal #1	cl coal #2	hm prod	sbo 0.6 x 0.15	bird prod 0.6 x 0	bird prop 0 x 0.15	cl c 0x0.15 only	new cl c 0x0.15 only	90%hm+10%sb	75%hm+25%sb	85%nci+15%bp 0x.15	bird -100m n dried	cl -100m thru drier	nci -100m thru drier
Ash%	23.5	29	18.7	21.3	68	41.5	43.9	10.1	10	10.5	8.3	9.6	9.1	10.6	10.3	9.9	9.9			
S%	0.27	0.2	0.37	0.52	0.09	0.4	0.4	0.32	0.33	0.36	0.36	0.48	0.34	0.31	0.3	0.35	0.38			
VM%	18.8	18.3	20.5	19.8	13.3	17.6	17.1	20.5	21.1	20.2	21.8	21.4	21.7	21.4	20.2	20.2	20.8			
VM%daf	24.58	25.77	25.22	25.16	41.56	30.09	30.48	22.8	23.44	22.57	23.77	23.9	23.87	23.94	22.52	22.42	23.09			
FC%	57.7	52.7	60.8	58.9	18.7	40.9	39	69.4	68.9	69.3	69.9	69.4	69	69.2	69.2	69.5	69.3			
H%	3.5	3.3	3.8	3.7	1.6	2.7	2.6	3.9	4.2	3.9	4.2	4.1	4.3	4.3						
O%	4.2	4.6	4.5	4	5.5	5.7	5.4	4.3	3.8	3.7	4.1	4.1	4	3.6						
FSI	2.5	1.5	7.5	4	0.5	1		3.5	7	3	8	7.5	8	7.5	3	3.5	7	7.5	8	7.5
startC°	455	450	434	437				453	445	457	433	443	445	441	451	452	446	444	445	441
fusC°			450	467				463	463	449	459			464	464	465	465	470	469	464
max C°	470	467	471	469				467	472	468	470	470	469	471	468	468	470	470	469	471
final C°	479	477	492	482				476	484	479	486	483	481	486	480	478	484	483	481	486
solid C°	488	483	495	486				485	490	489	492	490	487	491	486	486	490	490	487	491
range C°	24	27	58	45				23	39	22	60	43	39	45	29	26	38	39	36	45
ddpm	1.8	1.9	39	5.4				2.1	9.2	1.6	14.4	4.4	3.8	7.5	1.3	2.1	5.4	4.4	3.8	7.5
sf TC°	426	429	416	417				416	411	422	410	417	416	417	423	422	419	417	416	417
max C C°	492		467	474				483	469	485	459	467	469	466	483	483	474	469	467	466
max D C°			491	483				490	490		489	491	492	493	491	490	490	492	493	491
C	20	17	28	23				27	28	21	30	25	28	24	25	25	27	28	28	24
D	-20	-17	-1	-22				-27	-7	-21	19	6	-7	5	-25	-25	-19	-7	-8	5
vit%	46	38.5	58.4	55.4	23.8	41.7	46.8	42.5	50	39.6	63.6	67.4	64.2	65.8	47	49.8	58.5	64.2	65.8	71.8
SF%	32	34.6	24.8	23	15.4	22.4	16	37.4	36	44.2	24.6	20.8	21.6	21.2	37.2	37	27	21.6	21.2	17.5
Mie%	3.3	4.4	3.7	3.7	1.7	3.1	2.7	5.2	3.7	4.7	3.8	2.4	3.9	3.2	4.8	3.2	4.1	3.9	3.2	2.2
Fus%	4.6	4.6	2.2	5.2	4.1	5	4.6	9.3	4.7	5.6	3.4	4.5	4.9	4.7	5.2	4.5	4.9	4.9	4.7	2.6
MM%	14.1	17.9	10.9	12.7	55	27.8	29.9	5.6	5.6	5.9	4.6	4.9	5.4	5.1	5.8	5.5	5.5	5.4	5.1	5.9
Rmax%	1.34	1.34	1.36	1.35	1.32	1.35	1.34	1.35	1.34	1.35	1.35	1.33	1.33	1.33	1.37	1.34	1.33	1.33	1.33	1.33
TR%	62	55.8	70.8	66.9	31.5	52.9	54.8	61.2	68	61.7	75.9	77.8	75	76.4	65.6	68.3	72	75	76.4	80.55

Table 7. Proximate, ultimate, rheological and petrographic data for Plant A.

	plant feed	hm feed	woc feed .6x.15	woc feed .15x0	hm reject	bp reject .6x.15	bp reject .15x0	cl coal #1	new cl c #2	hm prod	sbo 0.6 x 0.15	bird prod (bp) 0.6 x 0.0	bird prop 0x.15	c cl 0x0.15 only	new c cl 0x0.15 only	90%hnm+10%sb	75%hnm+2.5%sb	85%ancl+15%bp 0x.15
<u>Proximate and ash chemistry</u>																		
Ash	24	29	19	21	68	42	44	10	10	11	8.3	8.8	9.6	9.1	11	10	9.9	9.9
S%	0.3	0.2	0.4	0.5	0.1	0.4	0.5	0.3	0.3	0.4	0.3	0.4	0.5	0.3	0.3	0.3	0.4	0.4
S% in Ash	1.15	0.69	1.98	2.44	0.13	0.96	1.03	3.17	3.30	3.43	3.98	4.09	5.00	3.74	2.92	2.91	3.5	3.8
SiO ₂	62	62	60	61	64	60	60	59	60	58	61	61	61	60	61	57	58.7	61.3
Al ₂ O ₃	27	27	29	28	28	27	25	31	31	32	31	31	31	30	29	31	31.5	31.4
Fe ₂ O ₃	4.2	5.4	4.6	6.4	4.7	6.3	7.2	3.9	2.4	4.4	2	1.7	2.4	3.7	3.3	3.8	4.0	2.3
TiO ₂	1.3	1.2	1.5	1.5	1.1	1.1	1	2.1	1.8	1.5	2.2	2.3	2.3	2.3	2	1.5	1.2	1.9
P ₂ O ₅	0.5	0.6	0.6	0.6	0.4	0.3	0.4	1.1	1	1.6	1	0.9	0.9	0.8	0.3	1.5	1.4	0.9
CaO	0.8	0.9	0.9	0.7	0.6	0.7	0.9	1.6	1.1	2.5	1.4	1.2	1.3	1.3	0.6	2	1.8	1.1
MgO	0.6	0.7	0.5	0.5	0.7	0.6	0.5	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.1	0.2	0.3
SO ₃		0.1			0.1		0.3	0.1	0.1	0.3				0.2	0.5			
Na ₂ O						0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1		
K ₂ O	1.7	1.8	1.4	1.4	2.3	1.7	1.6	0.8	0.8	0.3	0.8	0.9	1	1	1.3	0.3	0.4	0.8
BaO				0.1		0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
LOF	0.5	1.4	1.6	0.9		0.8	1.6	1.2	0.5	0.2		2.1		0.6		3.8		0.2
B/A	0.08	0.10	0.08	0.10	0.09	0.11	0.13	0.07	0.05	0.09	0.05	0.04	0.06	0.07	0.07	0.07	0.07	0.05
<u>Carbonization results</u>																		
H ₂ O								3.4	3.5	3.3						3.1	3.1	3.4
wt charge								271	267	268						272	270	263
ASTM BD								777	775	777						778	778	777
Max wl P kPa								4.7	3.8	2.1						1.9	2.8	4.1
coke yld%								79	80	79						79	79	78
mean coke size mm								50	48	52						50	47	48
coke ash%								12	12	13						13	12	12
coke VM%								1	0.8	0.8						0.9	1.1	0.8
coke S%								0.3	0.3	0.3						0.3	0.3	0.3
Stability								43	56	38						43	47	53
hardness								63	70	61						64	65	69
CSR								68	75	66						70	68	72
CRI								23	19	24						22	24	22
<u>Coke Petrography</u>																		
mosaic								19	18	19						21	21	20
flow								15	12	11						15	22	19
domain								13	12	17						12	17	14
total inerts								53	58	53						52	40	47

Table 8. Ash chemistry and carbonization data for Plant A.

age spread in base/acid ratios defined as:

$(baC-baF)/bacoal \times 100$: Where baC is base/acid ratio of product from the coarse circuit, baF is ratio for fine circuit and bacoal is the ratio for product coal.

The value for Plant A is about 70%. This is quite high though in general the ratios are low for all circuits. The ratios correlate strongly with the presence of Fe_2O_3 and are high in the coarse circuit because of the presence of siderite, which is inferred from the lack of correlation of Fe_2O_3 with Al_2O_3 , SiO_2 or sulphur (Table 9). Siderite is removed by crushing but probably does not have a strong maceral association in the coal and therefore may not be concentrated with the inert macerals in the intermediate SG splits.

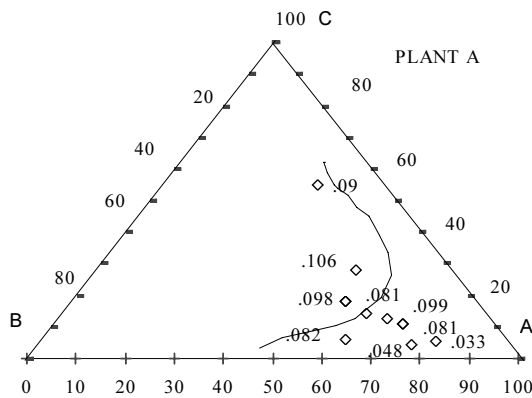


Figure 6. Triangular plot for Plant A data illustrating that base elements tend to be associated with mineral matter and inert macerals. Posted values are base/Acid ratios. A=reactives%, B=inerts%, C=ash%.

x	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	CaO	MgO	B/A	K_2O	Ash	S/ash
SiO_2	1.									
Al_2O_3	-.42	1.								
Fe_2O_3	-.02	-.77	1.							
P_2O_5	-.59	.85	-.55	1.						
CaO	-.70	.68	-.35	.94	1.					
MgO	.61	-.82	.69	-.82	-.70	1.				
B/A	-.02	-.79	.99	-.53	-.29	.70	1.			
K_2O	.76	-.83	.55	-.91	-.84	.94	.56	1.		
Ash	.55	-.73	.60	-.71	-.56	.78	.65	.85	1.	
S/ash	-.53	.84	-.72	.78	.63	-.96	-.75	-.92	-.86	1.

Table 9. Linear correlation matrix for ash chemistry data, Plant A.

Phosphorus contents in coals from Plant A are moderately high and have an ambiguous association with ash. At high ash concentrations there is some correlation with ash contents, but at low ash concentrations phosphorus content is not related to ash content. Phosphorus is concentrated in the coarse size fraction and is in part removed with the ash from this fraction. In the finer fractions it is not removed by washing and in the clean coal its concentration correlates with the fusinite plus semifusinite content (Figure 7). Most of the phosphorus is in these macerals and very little is associated with reactive macerals or ash. This means that phosphorus will concentrate in the intermediate SG splits (Figure 1) and in the coarser size fractions tracking the inertinite concentrations in the coal.

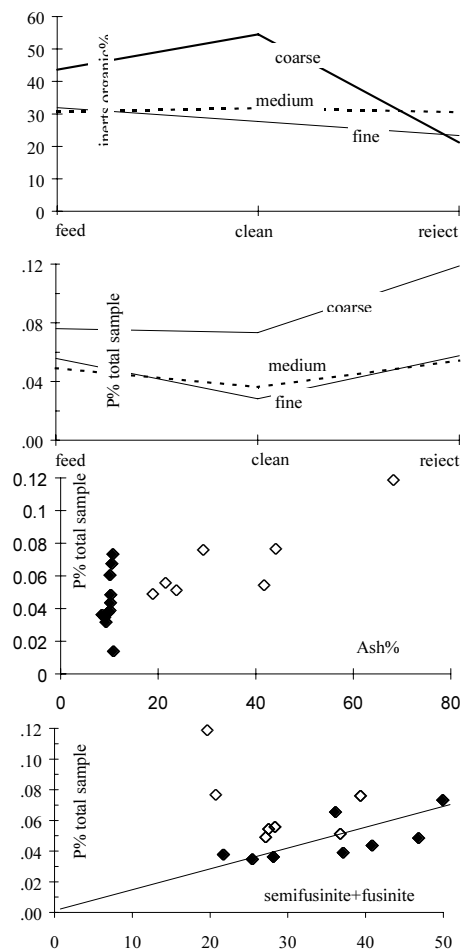


Figure 7. Phosphorus in Plant A. Phosphorus and inerts distribution by circuit and phosphorus relationship to ash and semifusinite+fusinite. Solid points are clean coal samples.

Fluidity and FSI values for the product 0.6 mm by 0.15 mm and 0.15 mm by 0.0 mm material are generally better than for the 50 mm by 0.6 mm material. This is to be expected based on the increased vitrinite content of this material (Figure 8). However on closer inspection it appears that fluidity and to a lesser extent FSI values of the 0.6 mm by 0.0 mm material are less than anticipated based on the high total reactivities content (Figure 8). This is important because it had been assumed that the fine coal with its increased reactivities content was important in maintaining and improving the coking quality of the product coal.

A partial explanation may relate to the fine size of the coal particles. A number of papers have indicated that fluidity and to a lesser extent FSI values are decreased if the coal is crushed to a finer size (Price and Gransden, 1987). It also appears that vitrinite in the fine coal forms a different population in terms of oxygen content than vitrinite in the product and coarse coal. The oxygen content of macerals increases from semifusinite to vitrinite and possibly from desmocolinite to tellinite (Mastalerz and Bustin, 1993). The fine coal samples plot to the left of a line of positive slope drawn through the product samples in the vitrinite versus oxygen plot implying that these samples are deficient in oxygen based on their vitrinite content. One would

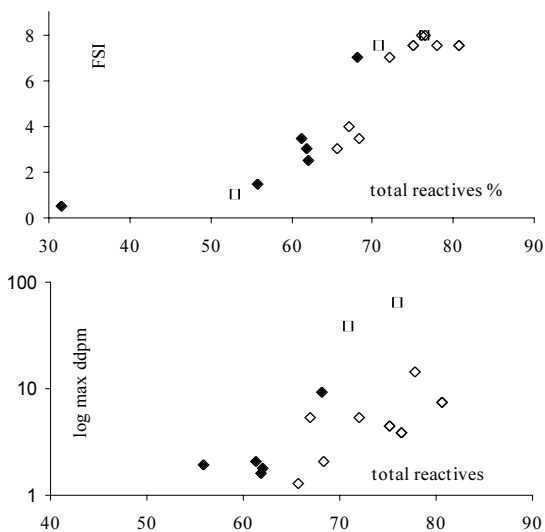


Figure 8. Relationship of FSI and fluidity to total reactivities content for Plant A. Solid diamonds = total product or 50 by 0.6 mm material, open diamonds = samples with all or some additional 0.15 mm material, open squares = 0.6 by 0.15 material.

expect the opposite trend because tellinite is more friable and contains more oxygen than desmocolinite. If the fine coal samples are deficient in oxygen, then probably some of the fine vitrinite is more inert than coarse vitrinite. This may be because it experienced shearing, which increased its friability and decreased its reactivity, or it may be of higher rank. The effect is not related to the thermal drier because the samples were collected before the drier, nor is it related to ash because the effect is apparent in samples of similar ash content. The differences must therefore originate in the raw coal.

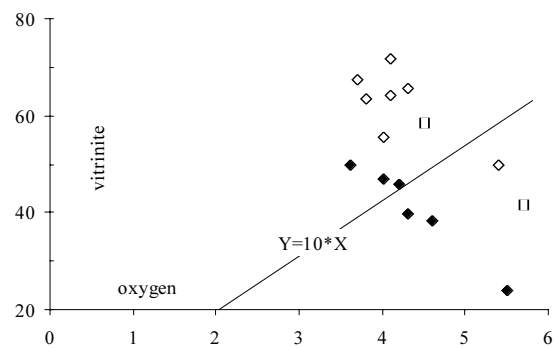


Figure 9. Oxygen versus vitrinite relationship.

When coal is coked there are some changes in the mineralogy of the mineral matter, which result in a volume decrease, but the main effect is loss of volatile matter, mostly from the reactive macerals. This has the effect of decreasing the relative percentage of reactive macerals in the coke compared to the coal. The effect is greater for coals with high inertinite contents and decreases to zero as the reactive maceral content approaches 100%. In the mid range it can account for a 5% to 10% increase in the inertinite content in coke compared to coal. For plant A, a comparison of coke and coal petrography indicates that when 15% 0.15 mm by 0.0 mm material is added to the clean coal, the coal reactivities maceral content increases but decreases in the coke (solid arrow in Figure 10) whereas when 0.6 by 0.15 mm material was added to heavy medium coal and coke reactivities increased (dashed arrow). Obviously petrography of fine samples is miss leading. It appears that the fine size and lower (?) oxygen content of vitrinite in the fine circuits makes it, in part, act like an inert coke maceral.

In an attempt to determine the contributions

of each size fraction to coke quality, additional fine coal was added to product coal and to product 50 by 0.6 mm coal. Despite increased vitrinite content, stability factor values appear to reach a maximum and then decrease as additional fine coal is added to the blend (Figure 10). This is not unexpected based on predictions by Schapiro and Gray, (1964) and Pearson (1980), who indicate that for a rank of about $R_{max}=1.35\%$ the optimum amount of reactive macerals is about 85%. Coin (1995) suggests the stability factor maximum occurs over a broader range of inerts content at constant rank. The

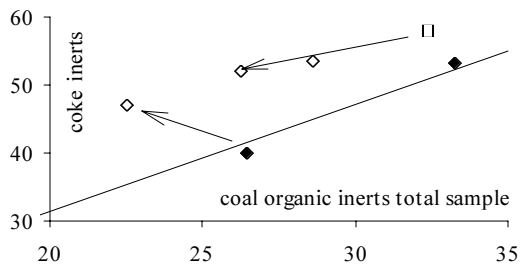


Figure 10. Relationship between coke and coal inerts for Plant A data. Open square=coarse fraction, solid diamond=clean coal, open diamond=additional fines.

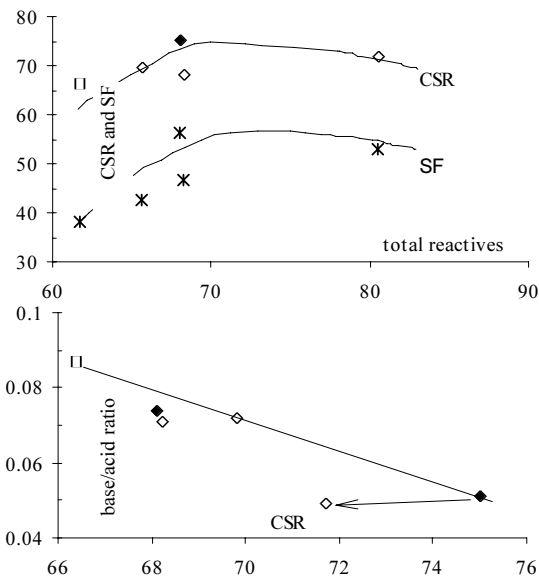


Figure 11. Relationship of coke strength and stability factor to total reactives and relationship of CSR to base/acid ratio. Plant A data, data symbols same as in Figure 10.

value of 85% reactives was not reached in blends of coal A and the stability factor maximum may occur in part because the vitrinite added was fine and therefore not as reactive as coarse vitrinite. CSR values also decrease as additional fines are added to product coal and the effect is not related to increasing base/acid ratios (Figure 11).

Plant B

Plant B uses wemco heavy medium drums to wash the 150 mm by 8 mm material, heavy medium cyclones to wash the 8 mm by 0.6 mm material, water only cyclones to wash the 0.6 mm by 0.15 mm material and froth floatation to wash the 0.15 mm by 0.0 mm material. Analytical data are in Table 10 and 11. In this plant emphasis was placed on sampling clean coal from the various circuits and recombining material from different circuits to make a number of new blends. Most of the samples therefore have similar ash contents of about 10% +/- 1%.

As with plant A, the vitrinite content increases in the clean coal in the fine circuits (Figure 12), however FSI and fluidity values increase less than predicted based on the increased vitrinite content. This may be because vitrinite in the fine circuits contains less oxygen and is less reactive than that in coarse circuits. A plot of oxygen *versus* vitrinite content indicates a weak tendency for the fine samples to contain less oxygen (Figure 12). Coke petrography provides an alternate estimate of the inert maceral content of the coal. In general it appears that coal petrography provides similar estimates of inert material in the various sizes as coke petrography though coke inerts are consistently higher (Figure 13).

Stability factor values for blends of coal from Plant B increase as the reactive contents increase, though there is a suggestion that values for the reactive rich bird product are lower than expected. Based on rank of about $R_{max}=1.35\%$ the maximum stability factor should occur at about 85% reactives, which was not reached in blends of coal B (Figure 14). When increasing vitrinite content is achieved by adding fine coal it is difficult to distinguish the effect of optimum vitrinite content from the decreased rheology of fine vitrinite additions. Additions of drum, heavy medium and belt press

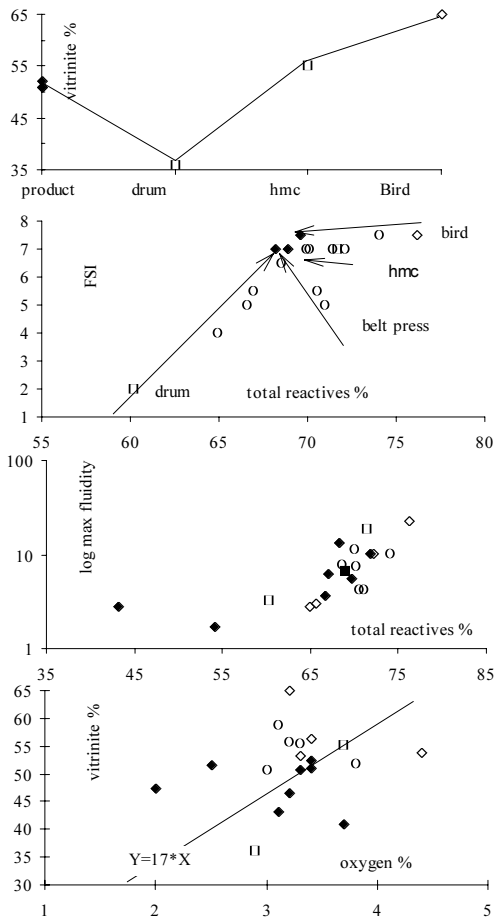


Figure 12 . Plant B, vitrinite content versus size, FSI, maximum fluidity and Oxygen content for clean coal and clean coal blends. Solid diamonds=product coal, open circles=blends, open diamond=fine coal and open square=coarse coal.

clean material to product coal decreased Stability Factor, only additions of bird product increased it.

Base/acid ratios decrease as size decreases (Figure 14). A correlation analysis of oxide data for all samples (Table 12) indicates that base/acid ratios correlate with the oxides CaO, MgO and Fe₂O₃. These oxides correlate with each other and not with SiO₂ or Al₂O₃. They probably occur in carbonates in the coarse coal, but are more likely associated with ash minerals in the fine coal, where individual oxide concentrations are lower. Carbonate minerals on fractures increase the base/acid ratios in the coarse material, but in the finer sized samples carbonate material is liberated and washed out so that base/acid ratios are lower. An indication of the ability of a plant to effect the base/acid ratio of the product coal is given by the percentage

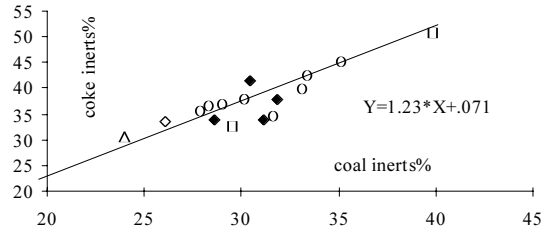


Figure 13. Coal inerts versus coke inerts for Plant B.

spread in base/acid ratios, defined previously, which is about 70% for Plant B.

CSR values are strongly correlated to ash chemistry and have a good negative correlation to modified basicity index (MBI) (Figure 14). Despite the lower base/acid ratio of the bird product its MBI value is higher and its CSR value lower than that of product coal because the bird product has a higher ash content. Also Additions of product from drum, heavy medium, bird or belt press material to product coal generally do not improve CSR (Figure 14). Only the heavy medium material has similar CSR values to product coal. In fact despite similar base/acid ratio and lower reactivities content it has a better CSR value than the bird product, probably because of the better rheology of coarser vitrinite.

The CSR values of coal from plant B are mainly limited by the base/acid ratio of the drum product (Figure 14). Removal of drum product from the product coal, or washing techniques that increase the removal of carbonate material from this circuit will lead to a decrease in base/acid ratio and improved CSR values of the product. Carbonates can be removed by crushing to a finer size with additional liberation or by washing to a lower cut point in the drum circuit. Washing to a lower cut point will reduce ash content and yield; these effects can be countered by increasing the cut point in the heavy medium circuit. This will have the effect of adding back ash with a lower base/acid ratio and increasing the yield. The effect on the product coal quality of over washing in the drum circuit and under-washing in the heavy medium circuit will be to reduce the base/acid ratio, probably cause a minor decrease in yield and have a marginal effect on ash content.

Phosphorus concentrations are not high in coal from Plant B. An association of phospho-

Table 10. Proximate, ash chemistry and rheological data for Plant B.

	test/clean prod coal #1	clean prod coal #2	75% clean coal+25% drum	75% cl coal+25%hmc	100% drum plant	100% hmc	75%cl coal+25%bird	100% bird	5%bltp+20%cl+d+25%b+50%hmc	75% cl coal+25% belt P	100% clean	100% clean	100% drum	100% hmc	100% bird	50% clean+50% drum	50% clean+50% hmc	50% clean+50% drum	50% clean+50% bird	60% clean+40% belt	5%b+25%brd+50%hmc+20%	100% clean	100% raw coal fines	100% raw coal	75% clean+25%raw fines	100% clean	
Ash%	9.7	9.8	10.4	9.6	10.9	8.8	10.1	11.2	10.3	11.2	9.7	9.8	10.8	9.1	11.2	10.4	9.4	9.7	10.4	11.9	9.9	9.9	9.6	23	38.2	13.2	9.8
VM%	21.2	21.5	21.4	19.7	18.4	21.3	21.1	22	21.5	21.4	21.8	20.9	20	21.6	22.2	20.6	22	19.9	20.8	20.9	21.6	21.7	19.2	16.4	20.9	21.2	
FC%	69.1	68.7	68.2	70.7	69.9	68.3	66.8	68.2	67.4	68.5	69.3	69.2	69.3	69.3	66.6	69	65.6	70.4	68.8	67.2	68.5	68.7	57.8	45.4	65.9	69	
H%	4.1	4.2	4.1	4.1	4.1	4.3	4.3	4.2	4.3	4.1	4.3					4.2	4.4	4.2	4.3	4.1	4.2	4.2	3.7	2.9	4.1		
S%	0.37	0.36	0.33	0.39	0.29	0.41	0.41	0.47	0.4	0.4	0.39	0.38	0.34	0.39	0.45	0.33	0.38	0.38	0.41	0.4	0.41	0.39	0.44	0.34	0.39		
O%	3.4	2.5	2	3.4	2.9	3.7	3.3	3.2	3	4.4	2.5					3.1	3.2	3.2	3.1	3.3	3.8	3.3	3.4	3.7	3.5		
SiO ₂	59.5	60	58.1	59.9	56.7	59	61.1	62.2	58.5	59	58.6					57.1	58.6	56.9	60	60.3	59.9	59.2	64.1	67.3	61		
Al ₂ O ₃	21.7	22	20.6	22.2	17.8	22.9	22.3	22.6	21.3	21.9	21.4					19.8	22.5	20.9	22.2	23.8	23.2	21.6	20.9	18.6	21.1		
Fe ₂ O ₃	4.8	4.7	5.6	4.5	6.2	4.6	4.2	3.7	4.8	4.5	4.6					5.3	4.4	5.1	3.6	4.3	4.3	4.2	3.2	3.1	3.9		
TiO ₂	1.3	1.3	1.2	1.2	1	1.2	1.3	1.4	1.2	1.2	1.2					1.1	1.2	1.2	1.3	1.3	1.2	1.2	1	0.9	1.1		
P ₂ O ₅	0.6	0.7	0.6	0.6	0.8	0.7	0.5	0.4	0.6	0.5	0.6					0.7	0.6	0.9	0.4	0.3	0.6	0.6	0.3	0.3	0.4		
CaO	4.4	4.3	5.2	4.2	8	4.2	4.1	3.3	4.6	3.9	4.2					6.2	4.2	5.7	3.4	3.2	4.3	4.1	3.1	2.6	3.6		
MgO	1.3	1.3	1.4	1.2	2	1.1	1.3	1.2	1.4	1.4	1.3					1.7	1.2	1.6	1.2	1.4	1.5	1.3	1.3	1.4	1.3		
SO ₃	3.5	3.1	3.5	2.9	3.8	3.1	2.9	2.4	3.7	2.9	3.2					4.8	3.8	4.6	3.1	2.4	2.7	4.1	2.4	1.6	3.1		
Na ₂ O	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.5	0.6	0.5	0.6					0.6	0.6	0.6	0.6	0.5	0.6	0.6	0.4	0.3	0.4		
K ₂ O	1	1	0.9	0.9	0.5	0.8	1.2	1.7	1.1	1.4	0.9					0.7	0.9	0.8	1.3	1.7	1.2	1	2.2	2.3	1.5		
BaO	0.6	0.6	0.6	0.6	0.5	0.7	0.6	0.6	0.6	0.6	0.6					0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.5	0.3	0.5		
B/A	0.16	0.15	0.18	0.15	0.24	0.15	0.14	0.13	0.16	0.15	0.15					0.2	0.15	0.19	0.13	0.14	0.15	0.15	0.13	0.12	0.14		
start C°	435	436	436	429	449	429	432	432	433	435	435	434	439	432	430	441	431	436	432	441	433	433	438	440	435	432	
fusion C°	451	451	455	452	447	449	447	447	453	453	453	452	452	449	447	48	48	450	450	450	453	456	453	451	451		
max C°	462	462	461	463	459	465	462	462	460	463	463	459	458	462	461	460	480	458	462	461	458	460	459	455	459	459	
final C°	483	483	478	481	471	483	480	481	477	475	479	478	469	480	481	473	478	478	479	475	476	477	472	466	475	477	
solid C°	489	486	483	488	480	486	485	485	482	484	483	483	478	486	485	482	486	482	485	479	486	483	481	475	480	483	
range	48	47	42	52	22	54	48	49	44	40	44	44	30	48	51	32	47	41	47	34	43	44	43	26	40	45	
ddpm	13.5	10.3	6.2	11.6	3.3	19	10.2	22.8	7.9	4.4	5.6	8.7	2.2	11.4	16.4	2.8	10.3	3.7	10.1	4.2	7.6	6.8	3	1.7	5.1	7.5	
soft T	402	412	415	411	421	406	401	401	402	399	399	411	399	399	411	405	399	405	402	408	411	405	406	416	428	404	
max C C°	452	457	458	452	479	447	454	448	455	454	456	454	473	452	449	470	454	464	456	457	458	456	479	500	465	456	
max D C°	481	481	482	479	481	479	479	479	477	477	479	480	476	476	478	480	478	480	479	482	481	481	483	480	483	480	
C	28	24	25	26	21	27	29	29	26	29	27	30	27	29	29	26	28	26	26	28	27	28	22	6	26	30	
D	-3	-8	-16	-1	0	7	-4	8	-11	-12	-8	-5	0	-7	5	0	-5	-25	-3	-10	-11	-7	0	0	-21	-10	
FSI	7	7	5.5	7	2	7	7	7.5	6.5	5	7.5	7	2.5	7	7.5	4	7	5	7.5	5.5	7	7	4	0	0	-10	

Table 11. Coal and coke petrography and carbonization data for Plant B.

	test clean prod coal #1	clean prod coal #2	75% clean coal+25% drum	75% cl coal+25%hmc	100% drum plant	100% hmc	75%cl coal+25%bird	100% bird	5% belt+20%drum+25%bird+50%hm	75% cl coal+25% belt P	100% clean	100% clean	100% drum	100% hmc	100% bird	50% clean+50% drum	50% clean+50% hmc	50% clean+50% drum	50% clean+50% bird	60% clean+40% belt	5%belt+25% bird+50%hm+20% drum	100% clean	100% raw coal fines	100% raw coal	75% clean+25%raw fines	100% clean			
Vit% ex%	51	47	52	36	33	33	56	65	51	54	52	52	43	56	46	59	53	52	51	53	52	51	56	41	41	51	56	41	
SF%	34	0	39	35	48	33	33	22	36	34	36	36	43	32	40	30	34	36	36	34	36	36	24	26	36	36	24	26	
Mic%	7.9	5.8	4.5	7.7	5.4	3.2	4.8	5.2	3.7	5.1	5.1	5.1	5.1	5	4.6	3.6	3.8	4.4	5	4.6	4.4	5	4.6	6	5	4.6	6	5	
Fus%	1.3	2	2.6	1.9	2	2.5	1.5	2.6	1.9	1.7	1.7	1.7	2.5	2.1	3.1	1.5	1.7	1.7	2.6	0.7	1.7	2.6	0.7	1.3	2.6	0.7	1.3	2.6	
MM%	5.5	5.8	5.4	6.1	4.9	5.7	6.4	5.8	6.3	5.5	5.5	5.5	5.8	5.3	5.5	5.9	6.8	5.6	5.4	14	25	5.4	14	25	5.4	14	25	5.4	
Rmax%	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	
TR%	68	67	70	60	71	72	76	69	71	70	70	70	65	72	67	74	71	70	69	66	66	66	66	66	66	66	66	66	66
SI	55	54	57	45	58	59	62	55	57	57	57	57	52	58	54	61	57	57	56	57	57	56	55	54	56	55	54	54	
	Coal petrography																												
	Carbonization results																												
H ₂ O	2.7	2.7	2.7	2.9	2.8	3.3	2	2.7	2.1	2.8	2.9	2.5	2.8	1.8	3	2.8	3	2	2	2	2	2	2.6	2.6	2.6	2.6	2.6	2.6	
ASTM BD	782	782	783	782	782	783	783	778	783	785	782	780	778	782	782	777	778	778	778	778	778	778	778	778	778	778	778	778	778
max wall Kpa	2.9	1.6	2.1	3.8	1.9	3.1	2.9	2.6	3.5	3.5	3.4	2.9	1.9	2.4	4.8	1	2.3	2.8	3.7	3.8	3.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
max gas Kpa	3.4	9	1.7	7.6	0.7	3.4	2.8	3.6	7.9	2.6	2.6	2.6	2.2	6.9	1	0.3	5.5	2.4	2.4	2.4	2.4	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
coke yld	78	78	80	78	79	79	78	78	78	78	80	78	76	79	78	78	78	77	77	77	77	77	77	77	77	77	77	77	77
Ash%	12	12	12	13	11	12	14	13	14	12	12	12	13	11	14	13	12	12	13	15	13	12	12	12	12	12	12	12	12
VM%	0.5	0.6	0.8	0.8	1.1	0.7	0.7	0.5	0.6	0.7	0.7	0.6	0.9	0.7	0.7	0.6	0.6	0.6	0.7	0.7	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
S%	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
mean coke size	54	52	57	56	64	57	54	49	56	53	55	54	64	58	50	60	58	61	51	54	56	55	55	55	55	55	55	55	55
Stability	52	53	43	51	29	48	50	61	46	46	53	52	25	43	60	33	47	46	53	44	46	48	48	48	48	48	48	48	48
hardness	69	69	65	69	54	64	69	70	66	62	69	67	53	62	70	53	64	68	68	64	66	62	62	62	62	62	62	62	62
CRI	30	30	34	30	40	29	32	32	32	35	31	40	30	34	34	36	31	35	33	36	34	31	31	31	31	31	31	31	31
CSR	56	56	44	53	27	56	53	51	47	42	52	21	55	49	35	49	42	48	41	44	44	49	49	49	49	49	49	49	49
	Coke petrography																												
mosaic	26	20	29	17	27	36	43	36	40	29	27	32	29	39	46	32	29	39	46	32	29	39	46	32	29	39	46	32	29
flow	25	17	20	10	23	13	15	15	12	19	12	20	18	14	8	20	18	14	8	20	18	14	8	20	18	14	8	20	18
domain	11	23	13	23	16	16	12	15	12	11	16	12	12	13	14	14	12	12	13	14	14	14	14	14	14	14	14	14	14
inerts	38	40	38	51	34	36	31	35	37	41	45	37	43	33	32	34	43	33	32	34	43	33	32	34	43	33	32	34	43

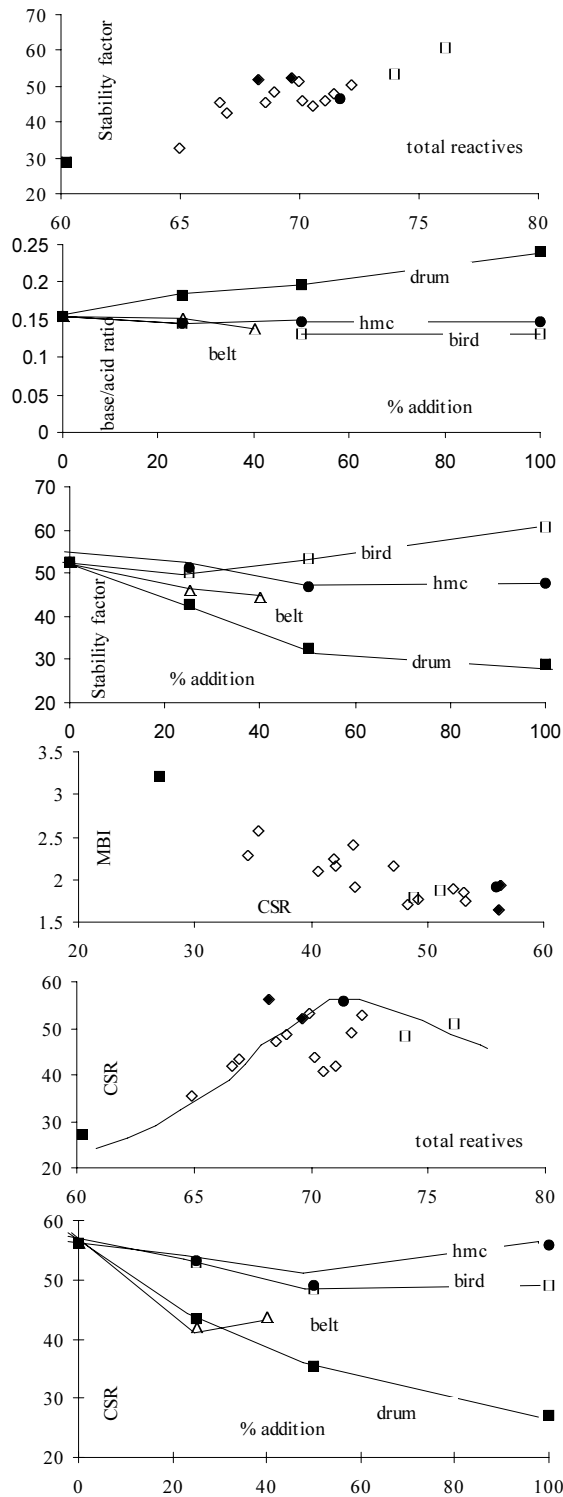


Figure 14. Stability Factor and CSR versus total reactivities and MBI, CSR, B/A and SF versus additions to clean coal of material from different circuits; Plant B. Drum=solid square, bird=open square, hmc=solid circle, belt press=open triangle, blend=open diamond, clean coal=solid diamond.

Table 12. Linear correlation matrix for clean coal ash chemistry, Plant B.

x	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	B/A
SiO ₂	1.0										
Al ₂ O ₃	.81	1.0									
Fe ₂ O ₃	-.76	-.95	1.0								
TiO ₂	.64	.89	-.77	1.0							
P ₂ O ₅	-.73	-.46	.42	-.37	1.0						
CaO	-.85	-.98	.92	-.91	.60	1.0					
MgO	-.89	-.97	.88	-.86	.62	.98	1.0				
SO ₃	-.82	-.47	.33	-.31	.57	.50	.62	1.0			
Na ₂ O	-.49	-.78	.74	-.88	.38	.82	.73	.01	1.0		
K ₂ O	.70	.83	-.74	.95	-.59	-.91	-.85	-.35	-.86	1.0	
B/A	-.86	-.99	.95	-.88	.56	.99	.98	.49	.80	-.87	1.0

rus with semifusinite plus fusinite in the clean coal is apparent (Figure 15). The high phosphorus contents in two raw samples (star and cross) indicate that there is some easy to remove phosphorus in the ash but in the clean samples the phosphorus correlates positively with semifusinite+fusiinite and negatively with ash. Therefore concentrations are higher in coarse and intermediate sized fractions and in intermediate SG splits where the inert macerals tend to concentrate, and lower in the fine coal and low SG splits.

Plant C

Plant C uses a tromp bath to wash the plus 10 mm material and heavy medium cyclones for

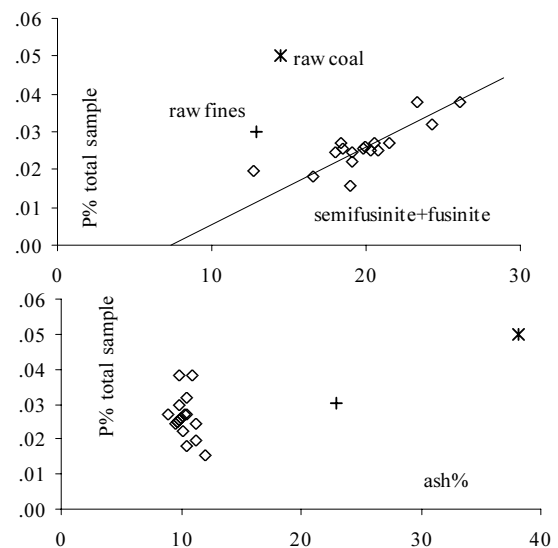


Figure 15. Relationship of phosphorus to ash and inerts content of coal, Plant B. Most of the samples are cleaned to about 10%.

Table 13. Coal quality, ash chemistry, rheology and carbonization data for plant C. A=clean coal, B=tromp clean coal, C=heavy medium cyclones clean coal, D=filter cake.

	A	85%A+15%D	50%A+50%D	85%A+15%B	50%A+50%B	A	C	B	D	50%C+50%B	50%C+50%D
Ash%	6.9	6.8	7.2	7	7.5	6.7	6.1	8.8	7.5		
VM%	29.6	29.8	29.4	28.6	28.1	29.2	29.5	27.3	28.9		
VMdaf	31.79	31.97	31.68	30.75	30.38	31.30	31.42	29.93	31.24		
FC%	63.5	63.4	63.4	64.4	64.4	64.1	64.4	63.9	63.6		
H%	4.9	4.9	4.9	4.9	4.9	5	5	4.7	4.9		
S%	0.65	0.66	0.67	0.65	0.6	0.66	0.7	0.59	0.71		
O%	3.9	4.2	3.8	4.2	4.3	4	4.1	4.1	4.4		
SiO ₂	59.4	58.9	61.5	60.1	60.4	56.4	58.6	61.1	62.3		
Al ₂ O ₃	23.9	23.8	24.1	23.6	23.1	24	24.8	22.5	23.3		
Fe ₂ O ₃	5.4	5	4.7	6	6.7	5.5	6.2	7.4	3.7		
TiO ₂	1.7	1.8	1.9	1.6	1.3	1.8	1.5	1	1.9		
P ₂ O ₅	2	1.9	0.7	2.1	2.2	1.9	2.6	2.1	1.3		
CaO	2.2	2.2	1.9	2.5	2.8	2.3	2.7	3	1.7		
MgO	0.5	0.6	0.7	0.5	0.4	0.5	0.3	0.3	0.9		
SO ₃	0.8	0.7	0.5	0.5	0.5	0.7	0.7	1	0.9		
Na ₂ O		0.1	0.1								
K ₂ O	1.3	1.4	1.9	1	0.7	1.3	0.5	0.3	2.4		
BaO	0.3	0.3	0.3	0.3	0.2	0.3	0.4	0.2	0.3		
B/A	0.114	0.114	0.110	0.121	0.127	0.120	0.119	0.132	0.103		
start C°	411	408	412	409	412	409	402	413	413	412	409
fus C°	422	421	425	422	424	421	420	426	427	425	424
max C°	448	445	451	447	448	447	446	450	450	448	449
final C°	478	477	481	475	474	477	478	474	451	474	477
solid C°	481	480	484	478	477	481	482	478	486	478	480
range C°	67	69	69	66	62	68	76	61	68	62	68
ddpm	690	760	660	530	410	580	915	190	430	225	365
FSI	9	9	9	8.5	8.5	8.5	8.5	6	9	8	9
sf TC°	375	377	380	378	383	378	371	384	378	377	376
max C C°	424	426	426	427	431	427	425	436	425	434	428
max D C°	467	470	468	468	466	468	466	467	465	464	465
C	32	31	32	31	27	31	30	28	29	33	31
D	148	139	146	109	62	127	137	10	145	50	109
Vit%	77.4	77.3	81.9	75.6	67	73.8	79.2	48.4	88.7	63.6	79.4
ex%	1.9	0.9	0.8	1.1	1.1	2.2	1.6	1.5	1	1.1	1.2
SF%	13.5	13.8	10.1	15.3	22.6	15.2	12.5	36	4.3	25.6	11.7
Mic%	1.4	1.9	1.9	1.4	2	2.3	1.4	2.8	1	3	1.7
Fus%	1.9	2.2	1.2	2.6	3.1	2.7	1.8	6.3	0.7	2.6	2.2
MM%	3.9	3.9	4.1	4	4.2	3.8	3.5	5	4.3	4.1	3.8
Rmax%	1.06	1.06	1.05	1.06	1.06	1.06	1.06	1.04	1.05	1.05	1.04
SI	49.2	50.4	43.3	52.2	53.2	51.5	47.7	51	34.4	54.1	46
H ₂ O	3.5	3	2.8	3.2	3	3.4	2.8	2.7		2.8	2.9
ASTM BD	778.4	776.8	776.8	780	780	775.4	781.6	778.4		778.4	778.4
max wall Kpa	7.86	7.72	7.72	6.14	4.48	7.65	6.27	1.59		5.24	10.55
coke yld	73.1	72.4	73.9	73.9	74	72.8	72.7	74.3		73.9	73
Ash%	9.1	9.2	9.7	9.5	10.2	9.1	8			1.03	9.8
VM%	0.5	0.5	0.5	0.4	0.2	0.3	0.5			0.5	0.5
S%	0.55	0.55	0.55	0.55	0.52	0.55	0.44			0.6	0.59
mean coke size	55.6	53.2	53.9	54	50.3	51.6	52.3	53.3		50.5	53.1
Stability	54.3	54.4	53.3	55.6	55	55.6	52.8	46.4		52.3	52.1
hardness	64.8	65.2	63.1	65.2	64.8	65.9	63	65.8		66.8	65.6
CRI	21.4	23.1	22.3	22.8	22.4	19.3	22.2	28.3		24.4	22
CSR	62.1	58.9	59.4	60.6	62	67.2	58.8	54.6		61.9	61.4

the 10.0 mm by 0.6 mm material. The 0.6 mm by 0.0 mm material is classified using water only cyclones and the 0.15 mm by 0.0 mm material is washed in flotation cells. Spirals are also used to clean the fine coal. The sampling program was similar to that at plant B. Product coal, clean coal from the various circuits, and several combinations of product coal and coal from various circuits were analyzed (Table 13).

The reactive maceral content of the clean coal increases and base/acid ratios decreases as the size decreases and consequently base/acid ratios have a good negative correlation with reactive maceral content (Figure 16). This is not because of an association of alkali rich minerals with inert macerals, but rather because the vitrinite concentrates in the fine circuits and the base/acid ratio is influenced by the probable presence of siderite and ankerite occurring in the coarse clean coal. This is inferred from the strong correlation of Fe_2O_3 with CaO and lack of correlation with ash (Table 3).

The stability factor reaches a maximum at about 80% reactives and despite additions of fine coal that increase the reactive content, it then decreases as reactive content increases (Figure 17). In fact the best stability factor appears to be achieved with the present mix of material from

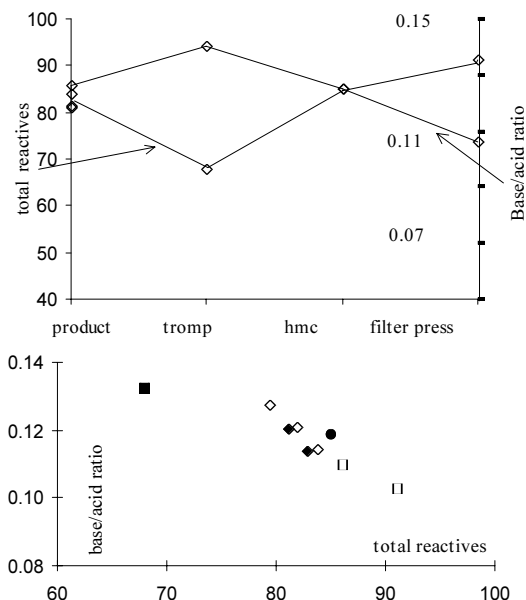


Figure 16. Plant C; Variation of petrography and base/acid ratio with size. Solid diamond=clean coal, solid circle=hmc, open square=fines or additional fines, solid square=drum, open diamond=additional coarse coal.

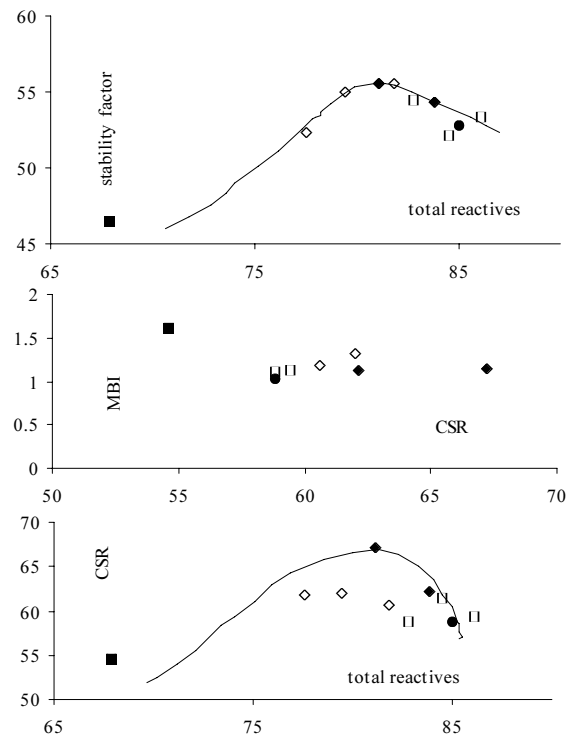


Figure 17. Stability Factor and CSR versus total reactives and CSR versus MBI for coal from Plant C. Solid diamond=clean coal, solid circle=hmc, open square=fines or additional fines, solid square=drum, open diamond=additional coarse coal.

the various circuits. It is not clear if this is because 80% is the optimum amount of reactives or the fine vitrinite has poor rheology. The vitrinite versus oxygen relationship is ambiguous and there is no clear evidence that the fine vitrinite contains less oxygen than the coarse vitrinite. Removal of drum product from the clean coal may increase stability factor by increasing the reactives content of the product but it is possible that at about 80% reactives the coal is close to the optimum reactives content for maximum stability factor.

Decrease in base/acid ratio in the fine coal (Figure 17) does not translate into a noticeable improvement in CSR, probably because the percentage spread in base/acid ratios is only 25% and also in part because the main oxide effecting MBI values is Fe_2O_3 , which may be less detrimental to CSR than CaO. CSR values are more sensitive to changes in ash content than ash chemistry (Table 3) and ash content in the clean coal is not correlated to base/acid ratio. This means that a noticeable improvement in CSR values may be achieved by reducing the ash content of the clean coal. Indications are that a 1%

decrease in ash content could increase of CSR values of up to 5.

Phosphorus correlates with the inert maceral content of the clean coal and is therefore concentrated in the coarse and intermediate sizes (Figure 18). Because phosphorus minerals (mainly apatite) occur in cells in the inert macerals, crushing the coarse coal to a finer size will not liberate much apatite. Over washing the coarse material and underwashing the fine material may reduce the phosphorus content. Based on the calculated distribution of phosphorus between inerts, reactives and ash in similar coals (Ryan and Grieve, 1995) and the variation of the reactives/inerts ratio by SG (Figure 1), it is possible to model the distribution of phosphorus by size and SG and compare the results to the actual phosphorus versus inerts distribution (Figure 18). The model washability data predicts a similar phosphorus distribution to that seen and can therefore be used to estimate the effect of over washing the coarse circuit. The predicted product coal has 7.1% ash, 0.062% phosphorus and a yield of 66%. If the SG in the coarse circuit is lowered the new product is predicted to have 6.6% ash, 0.059% phosphorus and a yield of 47%

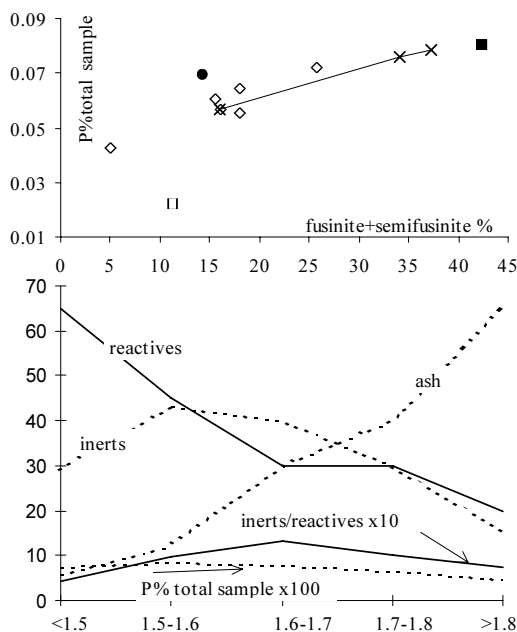


Figure 18. Phosphorus versus fusinite+semifusinite for Plant C, with model washability data and calculated theoretical phosphorus contents for three circuits (solid line and crosses). Symbols same as Figure 17.

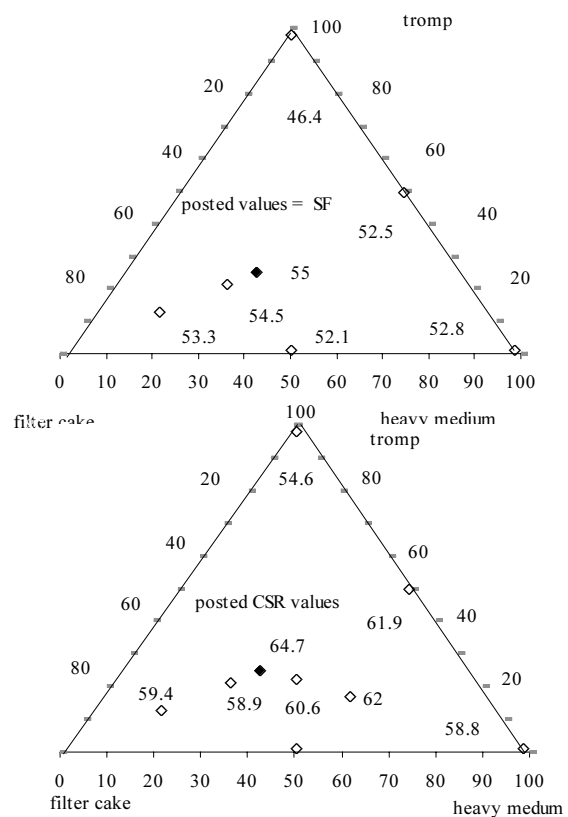


Figure 19. Variations of Stability Factor and CSR for blends of material from different circuits, Plant C.

59%. These numbers are based on modeling ash, phosphorus and inerts distributions and therefore only reflect trends. It appears that phosphorus can only be reduced a little by changing cut points in circuits, which incurs a yield penalty.

The various blends of product, tromp, heavy medium and filter cake coals are displayed in a triangular plot (Figure 19) from which it is apparent that the best quality is obtained from a mixture of all three components (the plotted position of the product coal is approximate).

Plant D

Plant D uses heavy medium cyclones, water only cyclones and froth flotation to produce thermal and metallurgical grade products by washing medium-volatile bituminous coal from two mines (coal A and coal B). The plant operating strategy is to produce acceptably low sulphur metallurgical and thermal coal products by blending the products from the various plant circuits and the two source coals, which generally

Table 14. Coal quality, ash chemistry, petrography and rheological data for Plant D. ASCF=secondary cyclone feed, SCOF=screen over flow, TP=thermal product, FT=float tails, FC=filter cake, PC=primary cyclone.

	RAW COAL				PC feed	MET PRODUCT				SCF 50x0.07	Coarse reject	TP				SCOF 0.07x.015	FC <0.015	FT <0.015
	size mm 50x0	25x12.5	12.5x3.35	<3.35		50x0.7	50x6.3	6.3x0.2	10x0.2			50x0.07	50x6.3	6.3x0.2	0.2x0.0			
Ash%	28.9	36.8	20.6	14.5	32.7	2.2	2.7	2	2.1	67.1	89.3	7.7	9	7.1	6	6.4	4.7	65.7
VM%	28.4	26.5	31.5	32.4	27	37	37.7	37.4	36.2	17.1	8	35.2	35.4	35.6	35.5	35.3	34.4	16.7
FC%	42.7	36.7	47.9	53.1	40.3	60.8	59.6	60.6	61.7	15.8	2.7	57.1	55.6	57.3	58.5	58.3	60.9	17.6
H%	3.9	3.4	4.4	4.6	3.7	5.3	5.3	5.4	5.3	2.1	0.7	5.2	5.1	5.2	5.2	5.1	5.2	2.1
S%	1.85	2.14	2.11	2	2.1	1.32	1.65	1.19	1.18	2.32	1.66	3.53	3.82	3.5	2.89	1.67	1.51	1.35
O%	3.4	3.6	4.1	3.9	3	5	4.5	4.7	4.6	1.8	3.9	3.7	3.3	3.5	3.9	4.3	4.5	3.3
SiO ₂	60.9	53	55.2	49.4	56.1	25.9	22.8	27	26.1	53.9	60.4	27.3	29.8	24.8	25.8	40.4	35.3	52.1
Al ₂ O ₃	21.6	24.1	23.5	23.3	24.1	17.4	14.6	19.2	16.9	23.2	22.7	15.9	16.3	14.8	16	20.1	18.3	23
Fe ₂ O ₃	10.5	10.4	14.1	16.8	10.9	49.5	58.5	48	49	16.4	6.9	49.4	48.1	54.2	52	28.9	31.7	13.3
TiO ₂	0.9	0.9	0.9	0.9	1	0.9	0.8	0.9	0.9	1.2	0.9	0.7	0.8	0.6	0.6	0.9	1	1.2
P ₂ O ₅	0.1	0.1	0.1	0.2	0.1	0.4	0.4	0.3	0.4	0.1	0.1	0.3	0.5	0.4	0.4	0.2	0.3	0.1
P%	.013	.016	.009	.013	.014	.004	.005	.003	.004	.029	.039	.010	.020	.012	.010	.006	.006	.029
CaO	0.3	0.1	0.4	1.2	0.4	1.2	0.9	0.2	1.8	0.2	0.1	1	0.9	1.1	1.6	2.2	3.4	1.8
MgO	1.4	1.4	1.3	1.3	1.3	0.6	0.5	0.6	0.7	1.3	1.4	0.5	0.4	0.4	0.5	1.1	1.2	1.3
SO ₃	0.5	0.4	0.6	1.2	0.6	0.8	0.8	0.9	1.3	0.6	0.4	1.3	0.8	1.3	1.3	1.2	2.6	2.3
Na ₂ O	0.5	0.4	0.5	0.8	0.6	0.8	0.5	0.8	1.3	0.3	0.4	0.3	0.3	0.3	0.6	1.4	2.2	0.9
K ₂ O	3.2	3.5	3.4	3.1	3.5	0.6	0.4	0.6	0.7	3.4	3.5	0.8	0.8	0.8	0.9	2.1	1.8	3.3
B/A	0.19	0.20	0.25	0.32	0.21	1.19	1.59	1.07	1.22	0.28	0.15	1.18	1.08	1.41	1.31	0.58	0.74	0.27
Vit%	78.5	75.2	81.9	85.5	81.9	82.3	76.8	80.1	83.3	73.4		78.3	68.2	78.6	83.7	85.6	88.5	78.0
ex%	5.4	5.2	4.0	3.9	4.6	5.5	7.1	5.3	4.2	7.2		5.2	8.8	4.7	3.5	3.3	2.8	4.2
SF%	8	9	6.1	3.7	5.9	5.2	7.2	6.8	4	8.6		9.6	12.3	7.6	4.9	5	2.6	6.2
Mic%	5.6	8	5.1	4	4.9	4.5	5.8	5.4	4.9	6.2		3.5	7	5.8	4.6	2.9	4	4
Fus%	2.5	2.6	2.9	2.9	2.7	2.5	3.1	2.4	3.6	4.6		3.4	3.7	3.3	3.3	3.2	2.1	7.7
TR%	87.9	84.9	89.0	91.3	89.5	90.4	87.5	88.8	89.5	84.9		88.3	83.2	87.1	89.7	91.4	92.6	85.3
Rmax%	0.96	0.95	0.98	0.98	0.95	0.97	0.96	0.95	0.98	0.94		0.96	0.94	0.96	0.95	0.98	0.96	0.95
SI	48.5	35	48.8	42.4	45.7	32.1	38.3	34	34			41.1	46.1	41.9	36.3	35.3	28.9	
startC°	386	384	383	389		379	377	380	379			379	379	381	383	381	387	
fusC°	400	400	399	402		398	395	397	397			397	396	398	399	398	404	
max C°	438	440	437	435		436	436	437	436			438	436	439	436	438	438	
final C°	475	474	480	479		477	480	480	479			478	478	479	479	480	480	
solid C°	478	477	483	482		480	483	483	482			481	481	482	482	483	483	
range C°	89	90	97	90		98	103	103	103			102	99	98	96	102	93	
ddpm	21300	20300	28000	23800		28000	28000	28000	28000			28000	28000	28000	28000	28000	28000	
sf TC°	354	368	356	356	366	348	344	351	351			347	347	345	350	348	351	
max C C°	414	419	408	409	417	398	398	398	398			402	404	402	402	402	403	
max D C°	464	462	463	462	462	465	463	467	465			461	461	461	463	464	462	
C	27	24	29	28	25	28	30	26	26			28	28	28	28	25	26	
D	118	42	198	203	76	270	290	274	265			246	247	252	249	259	238	
FSI	4.5	3	4	7	4.5	7.5	7	7	7.5			6.5	5.5	7	8	8	7.5	

have quite high run of mine sulphur contents. The sampling program was comprehensive involving sampling of raw coal, feed coal and product coal from the circuits. Samples were taken while the plant was washing the two source coals (A and B) separately. This enabled different qualities and washing characteristics of the two coals to be determined. Previously it was assumed that the two coals had similar washing characteristics, but data from this study revealed a number of differences. The analytical data for coals A and B and the coal quality and carbonization data for blends are in Tables 14, 15.

The petrography of the two coals is slightly

different both are vitrinite rich, but coal A contains less vitrinite and more micrinite than coal B and consequently has a lower reactive maceral content. Though both coals contain about the same amount of exinite in the raw feed, coal A retains more exinite in the various component clean coals and this partially explains the higher fluidity. Most samples of coal A have maximum fluidities over 28 000 ddpm (Table 14). Fluidity for coal B is generally lower and values correlate with total reactivities content, though the vitrinite enriched finer coals tend to have lower than expected fluidities.

Raw coal A contains slightly less sulphur than

Table 15. Coal quality, ash chemistry, petrography and rheological data for Plant D. BSCF=secondary cyclone feed, SCOF=screen over flow, P=thermal product, FT=float tails, FC=filter cake, PC=primary cyclone

size mm	RAW COAL			PC	MET PRODUCT			SCF	Coarse	TP			FC	FT			
	50x0	25x12.5	12.5x3.35		50x0.7	50x6.3	6.3x0.2			10x0.2	50x0.7	50x0.7			50x6.3	6.3x0.2	0.2x0.0
Ash%	40.9	48	35.3	26.6	40.9	2.5	3.5	2.2	2.5	90.3	8.1	12.8	8.4	7.1	9.9	13.1	90.4
VM%	23.4	21.5	25.4	27.4	23.3	35.1	35.5	36	34.9	7.7	33.3	33.6	33.7	33.7	32.7	30	9.6
FC	35.7	30.5	39.3	46	35.8	62.4	61	61.8	62.6	13.7	2	58.6	58	59.2	57.4	56.9	0
H%	3.1	3	3.5	3.9	3.1	5.3	5.3	5.3	5.2	0.6	4.9	4.7	4.9	4.9	4.7	4.4	0.7
S%	2.05	1.78	1.81	2.09	1.7	1.2	1.21	1.13	1.19	1.66	3.15	3.82	3.35	3.03	1.94	2.04	0.7
O%	4.6	4.3	4.2	4.3	3.8	6.9	6.1	6.6	6.1	4	5.5	4.2	5.5	5.3	6.5	4.8	3.3
SiO ₂	59	61.2	59.5	54	60	41.1	52.4	46.1	41.2	56.6	61.1	34	34.6	32.5	45.8	45.3	55.9
Al ₂ O ₃	22.6	22.9	22.8	21.9	22.6	18.1	19.9	19.8	17.7	21.5	23	14.9	16.6	15.1	19.2	19.3	22
Fe ₂ O ₃	9.9	8.4	9.6	11.6	8.9	26.5	20.2	23.6	29.3	12.6	7.3	40.3	34	41.8	43.3	19.8	8.9
TiO ₂	1	1	1	1	1.1	1.2	1.2	1.2	1.4	1.2	1	0.9	1.1	0.9	0.8	0.9	1.1
P ₂ O ₅	0.2	0.4	0.2	0.3	0.2	0.5	0.4	0.5	0.5	0.2	0.1	0.5	0.6	0.5	0.6	0.3	0.2
P%	.036	.084	.031	.035	.036	.005	.006	.005	.005	.063	.039	.018	.034	.018	.019	.013	.039
CaO	1	0.6	0.8	2.5	0.7	3.9	2.2	3.8	4.4	0.5	0.4	2.6	1.9	2	3.1	4.6	3.2
MgO	1.7	1.7	1.7	1.6	1.7	0.7	0.9	0.7	0.8	1.6	1.7	0.5	0.6	0.5	0.6	1.2	1.6
SO ₃	1.4	0.9	0.9	3.1	1	3.2	1.2	2	2.4	1	1.2	3.3	1.9	1.9	3.4	4.1	2.2
Na ₂ O	0.5	0.4	0.5	0.7	0.5	1.2	0.8	1.1	1.3	0.4	0.4	0.5	0.3	0.5	0.6	1	0.7
K ₂ O	3.8	3.7	3.8	3.4	3.7	1.3	1.9	1.4	1.3	3.6	3.9	1.2	1.5	1.2	2.5	2.6	3.5
B/A	0.21	0.18	0.20	0.26	0.19	0.57	0.36	0.46	0.63	0.24	0.16	0.92	0.64	0.93	1.03	0.44	0.23
Vit%	85.5	82.7	84.6	87.3	87.4	88.2	86.6	86.9	89.8	80.4	77	78.3	67	79.3	83.1	87.3	88.4
ex%	5.3	4.4	4.7	2.4	2.6	2.2	3.8	3.9	1.8	4.6	7	4.5	8	4.7	2.3	3.5	1.6
SP%	4.6	6.3	4.9	4.6	5.1	3.9	4.7	3.1	3.7	8.2	9	10.2	13	7.4	6.5	2.7	3
Mic%	2.3	2.7	3.1	3.3	2.1	2.5	1.3	2.4	2.7	3.2	6.0	2.0	5.4	2.7	3.0	3.9	5.1
Fus%	2.3	3.9	2.7	2.4	2.8	3.2	3.6	3.7	2	3.6	1	5	6.6	5.9	5.1	2.6	1.9
TR%	93.1	90.3	91.8	92.0	92.6	92.4	92.8	92.4	93.5	89.1	88.5	87.9	81.5	87.7	88.7	92.2	91.5
Rmax%	0.94	0.94	0.95	0.97	0.96	0.97	0.95	0.96	0.97	0.96	0.96	0.94	0.94	0.95	0.94	0.97	0.96
SI	41.6	24.4	47.1	49.6	43.7	26.7	24.8	23.8	21.2	21.2	42.2	47	41.7	38.6	37.1	39	39
startC°	398	398	397	403	398	393	391	395	393	393	394	396	393	394	388	403	403
fusC°	407	407	406	413	408	405	403	403	407	407	407	409	404	405	402	413	413
max C°	436	436	435	440	437	438	432	432	438	438	437	437	438	436	438	439	439
final C°	465	466	467	468	467	473	473	474	472	472	467	468	468	469	471	466	466
solid C°	468	469	470	471	470	476	476	477	475	475	470	471	471	472	474	469	469
range C°	67	68	70	65	69	80	82	79	79	79	73	72	75	75	83	63	63
ddpm	900	1110	1510	690	1120	6640	15590	12150	4300	1680	2120	2120	2750	1810	3450	400	400
sfTC°	390	408	387	383	399	369	369	368	371	362	366	363	363	363	369	372	372
max C C°	438	444	424	424	438	409	408	410	411	411	417	413	413	411	414	423	423
max D C°	447	448	448	454	447	449	452	449	449	450	450	450	449	449	452	455	455
C	18	13	24	27	17	31	28	30	30	30	32	31	29	30	29	30	30
D	-13	0	6	18	-11	151	174	167	144	144	73	28	71	78	110	33	33
FSI						8	8	8	8.5	8.5	8	8	8	8	8.5	8	8

coal B, but washes to a slightly higher sulphur content and contains much more Fe₂O₃ than coal B. The Fe₂O₃ probably occurs in the mineral siderite. Sulphur is liberated somewhat into the fine feed but less than half is removed by washing, producing product metallurgical coals with sulphur contents in the range of 1% to 1.5% and thermal coals in the range 3% to 4%. Plots of S%

versus Fe₂O₃ % in total sample (Figure 20) provide some indication of how much of the iron and sulphur are combined as pyrite, how much excess iron exists as siderite and the concentration of organic sulphur. The slope of the line in Figure 20 (1.245) is that of the ratio of Fe/S in pyrite (FeS₂), taking into account that the Y axis is Fe₂O₃ and not Fe. The band, defined by the two lines, inter-

sects the X axis from 0.0% sulphur to about 0.6% sulphur and encloses samples containing pyrite and 0.0% to 0.6% organic sulphur. Points to the left and above this band contain excess Fe_2O_3 , which probably occurs as siderite, because Fe_2O_3 does not correlate with Al_2O_3 or SiO_2 (Table 16). The raw coal B appears to contain more siderite than A, though siderite tends to be removed by all circuits and is concentrated in the coarse and fine reject material (square symbols). Clean blends of each coal are represented by crosses and feed coal by solid symbols.

Coking tests were performed on number of blends each composed of one of the coals but made from different combinations of size fractions (Table 17). Maximum wall pressure was distinctly higher for blends using coal B. The blend composition, rank and bulk density were the same for the two coals, though the charge moisture for coal B was about 1% higher and the ash about 2% absolute higher. Usually a higher ash content will reduce pressure. In this case various sizes of washed coal A, which produced less

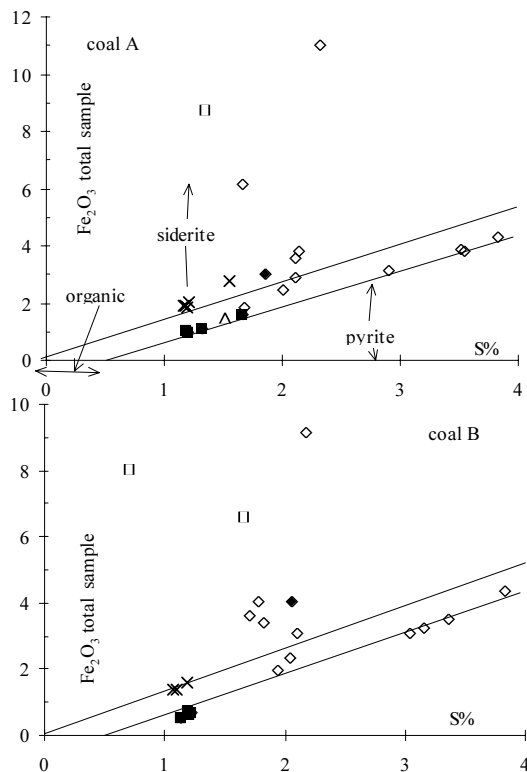


Figure 20. Approximate distribution of sulphur and iron between siderite, pyrite and organic sulphur. Coals A and B plant D. Open squares= reject material, solid diamonds=raw coal, open points =individual circuits, x= blend of sizes, solid squares=metalurgical coal.

Table 16. Linear correlation matrix for ash chemistry and CSR data, blend coals A and B from Plant D.

x	SiO_2	Al_2O_3	Fe_2O_3	Ash	P_2O_5	CaO	MgO	SO_3	Na_2O	K_2O	A	SA	CSR
SiO_2	1.0												
Al_2O_3	.97	1.0											
Fe_2O_3	-.7	-.6	1.0										
Ash	.92	.96	-.37	1.0									
P_2O_5	.80	.89	-.55	.84	1.0								
CaO	.95	.87	-.70	.81	.61	1.0							
MgO	.90	.82	-.62	.77	.55	.96	1.0						
SO_3	.96	.89	-.74	.81	.69	.97	.96	1.0					
Na_2O	.88	.88	-.59	.82	.68	.84	.89	.86	1.0				
K_2O	.91	.83	-.64	.77	.55	.97	.99	.97	.87	1.0			
A	.39	.47	.41	.68	.30	.32	.37	.27	.36	.36	1.0		
SA	.97	.93	-.61	.89	.68	.98	.95	.95	.90	.96	.45	1.0	
CSR	-.9	-.8	.9	-.6	-.6	-.9	-.9	-.9	-.8	-.9	.0	-.9	1.0

Note A=alkalinity (base/acid ratio*ash/100)

Note SA= Sum($\text{K}_2\text{O}+\text{MgO}+\text{CaO}+\text{Na}_2\text{O}$)*ash/100

pressure, contain more exinite and less vitrinite than coal B and this has the effect of increasing the VMdaf value for coal A by 1.5% absolute (VMdaf 37.5% for coal A and 36% for coal B). Increased vitrinite content increases pressure, whereas exinite reduces pressure and because of its very high volatile content will decrease coke yield. The exinite contents of the raw coals are similar and it appears that more exinite is lost from coal B during washing, possibly indicating a fundamental difference in the lithotypes. Exinite in both coals tends to concentrate in the coarser size fractions. The exinite content of high-volatile coals probably plays an important role in reducing maximum wall pressure. In this study a small average increase in the exinite content of the washed blends of coal A seems to be responsible for a pressure decrease from 7.3 kPa for blends of coal B to 1.1 kPa for blends of coal A.

Generally CSR has a negative correlation to the alkalinity of samples, but in this case there is a positive correlation between MBI and CSR (Figure 21). Compared to coal B, Coal A has higher CSR values associated with higher concentrations of Fe_2O_3 and lower concentrations of Ca, Mg Na and K. The Fe_2O_3 probably occurs as pyrite and it appears that in this form it is less damaging to CSR than the other alkalis especially CaO, which dominates Mg, Na and K in the chemistry of coals A and B and probably occurs as calcite on cleats in vitrinite. In experiments additions of pyrite to coals produced the same relative decrease in CSR as additions of calcite on a CSR versus MBI plot (Price *et al.*, 1992) so it appears that the association of these

Table 17. Plant D, Coal quality, ash chemistry, rheology, carbonization and coke texture data for blends of coals A and B. HV= high volatile blend coal, E=coal from Plant E.

size mm	A	A	A	A	A	B	B	B	B	HV	HV+E
3.8x0.07	75	75	65	85	56.25	75	75	65	85		
0.07x0.015	15	10	21	9	11.25	15	10	21	9		
0.015x0.0	10	15	14	6	7.5	10	15	14	6		
middlings 3.8x0.07					2.5						
Ash%	3.2	2.9	3.6	2.9	4.3	4.4	4.4	5.2	3.8	4.3	5.2
VM%	37.1	36.4	36.2	36.2	36	34.1	34.2	33.9	34.7	35.2	30.5
FC%	59.7	60.7	60.2	60.9	59.7	61.5	61.4	60.9	61.5	60.5	64.3
S%	1.41	1.4	1.45	1.44	1.97	1.29	1.3	1.36	1.23	1.34	1.08
SiO ₂	31.5	29.6	32.5	28.7	28.8	43	43.2	44.3	44.4	41.6	47
Al ₂ O ₃	18.5	17.6	18.3	17.5	16.7	18.8	19.4	19.3	18.9	19.2	22.6
Fe ₂ O ₃	43.2	45.6	40.9	47.2	49.1	21.7	22	21.1	23.2	25.3	16.8
TiO ₂	0.9	0.9	0.9	0.9	0.8	0.9	1	1	1	0.9	1.1
P ₂ O ₅	0.3	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.6
CaO	2.1	2.1	2.2	1.9	1.7	4.7	4.5	4.6	4.2	3.5	3.6
MgO	0.9	0.7	0.9	0.7	0.6	1.1	1.1	1.1	1	1.1	0.8
SO ₃	1	0.8	2.1	1.1	0.8	4	4.2	3.9	3.6	3.9	3.4
Na ₂ O	1.3	1	1.2	1	0.8	1	1	1	1	1	1
K ₂ O	1.3	1	1.4	1	0.9	1.9	2.1	2.1	1.9	1.9	1.4
LOF	0.6	2	0.6	0.5	1.4	2	2.2	2.1	0.8	2.2	2.3
startC°	384	385	382	382	378	395	395	396	394	392	397
fusC°	399	401	399	400	398	407	407	406	405	405	409
max C°	440	438	440	439	436	437	439	437	437	439	438
final C°	480	481	480	480	478	470	469	468	468	474	471
solid C°	483	484	483	483	481	473	472	469	471	477	474
range C°	96	96	98	98	100	75	74	70	74	82	74
ddpm	28000	28000	28000	28000	28000	2900	1970	1995	2460	6150	880
FSI	7.5	7.5	7	7.5	8	8	8.5	8.5	8	8.5	8
sf TC°	348	350	354	353	356	369	363	363	363	360	374
max C C°	402	402	404	402	403	404	401	400	401	404	420
max D C°	465	465	464	464	464	455	446	449	479	454	467
C	28	30	29	32	32	30	39	29	31	29	27
D	257	256	252	254	233	132	129	129	128	151	47
Coke Ash%	4.3	4.2	5	4	5.7	6.4	6.4	7.5	5.5	6	6.8
VM%	0.7	0.8	0.9	0.8	0.7	0.9	0.7	0.9	0.9	0.8	1
S%	1.2	1.18	1.21	1.17	1.55	1.1	1.07	1.18	0.98	1.07	0.83
H ₂ O	2.3	2.4	2.1	2.3	2.3	3.2	3.4	3.3	3.4	2.9	3.2
ASTM BD	776.8	776.8	776.8	778.4	776.8	778.4	780	778.4	776.8	780	778.4
linear expn	-25	-22.3	-25	-24.8	-23.8	-1.5	-7.2	-3	-4.7	-13.1	-8.1
max wall Kpa	1.24	1.24	1.24	0.62	1.02	8.3	9.41	5.5	6.1	3.4	9.6
max gas Kpa	0.69	1.18	1.38	0.62	0	19.3	11.4	13.8	18.1	6.3	18.3
coke yld	68	69.7	69.5	69.1	68.9	72.9	72.1	70.7	70.6	69.9	74.3
mean coke size	49.4	47.36	47.11	47.17	46.18	44.65	44.65	45.13	44.14	46.3	49.79
stability	34.3	36.1	38.6	32.7	38.9	33.8	16.9	39.8	33.1	40.2	57.1
hardness	62	62.1	61	63	62.6	68.9	34.2	68.8	68.5	68	68.7
CRI	40.3	38	38.8	38	40.5	53.8	55.5	55.1	50.6	50.9	45.7
CSR	33.7	39.1	35.5	38.3	45.1	21.5	24.2	22.8	28	26.3	26.1
mosaic	69.7	67	73.2	75.6	78	80.7	84.1	86.3	88		
flow	14.9	15.7	11.1	9.3	5.5	7.8	4.5	2.7	1.7		
domain	0.4	0.5	0.1	0.1	1	0	0	0	0		
inerts	15	16.8	15.6	15	15.5	11.5	11.4	11	10.3		

minerals in the natural samples influences how they effect CSR. The empirical rule seems to be that iron minerals are less destructive to CSR than calcite.

The best correlation for CSR is with SO_3 (Table 16, Figure 21), probably because SO_3 represents the formation of sulphates in the ash from organic sulphur and alkalis as they are released during the destruction of carbonates and other minerals. Obviously this is an approximate measure of the more mobile alkali components in the ash. For this particular plant it might offer the best way of estimating the CSR values of possible production blends. A similar though not as well defined trend is apparent in coals from the other plants (Figure 21).

Plant E

Plant E washes a low-volatile coal using 2 circuits, a heavy medium cyclone circuit to process the plus 0.6 mm material and froth floatation to process the minus 0.6 mm material. Product coal and a number of blends of product coal with coal from individual plant circuits were analyzed (Table 18).

Vitrinite is concentrated in the clean coal and fine coal feed (Figure 22). Despite the mod-

erate enrichment of vitrinite in the froth floatation feed and product, adding 10% product froth material to clean coal did not increase vitrinite content and did no improve stability factor (Figure 22). It appears that the best improvement in stability can be achieved by removing the inert rich plus 20 mm material from the clean coal, which accounts for about 5% of product.

The coal washes to a low ash (6% to 7%). Some blends were constructed to see what effect increased product ash content would have on coke quality. Blends composed of product coal plus additional feed or reject material were analyzed to see if ash content and yield could be increased without causing a major decrease in coke quality. It appears that a 2% increase in ash content reduces stability factor by about 20 points (Figure 23). Obviously at this rank ($R_{max} = 1.6\%$) coking properties are easily destroyed by the addition of inert material.

The maximum wall pressure of the product coal is quite high, as expected based on the high rank of the coal, but additions of small amounts of clean fine coal decrease pressure substantially while having only a minor negative effect on stability factor (Figure 23). In terms of pressure this is probably a good compromise but the increased fines content will make the coal more

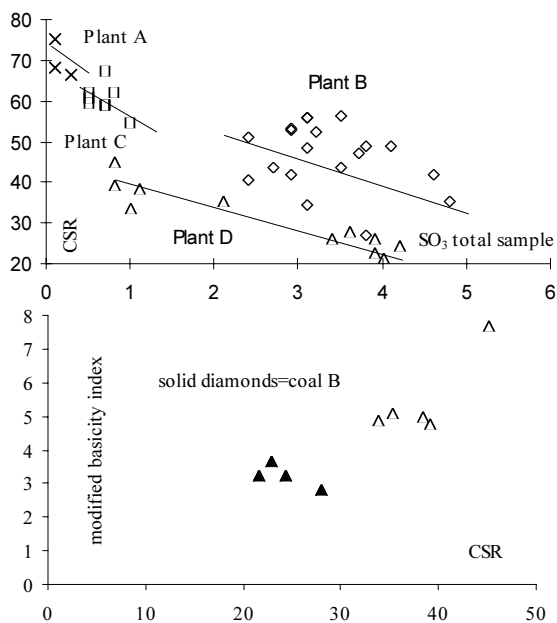


Figure 21. Relationship of CSR to SO_3 for different coals with different sulphur contents from plants A,B, C and D and relationship of CSR to MBI for coals A and B from Plant D.

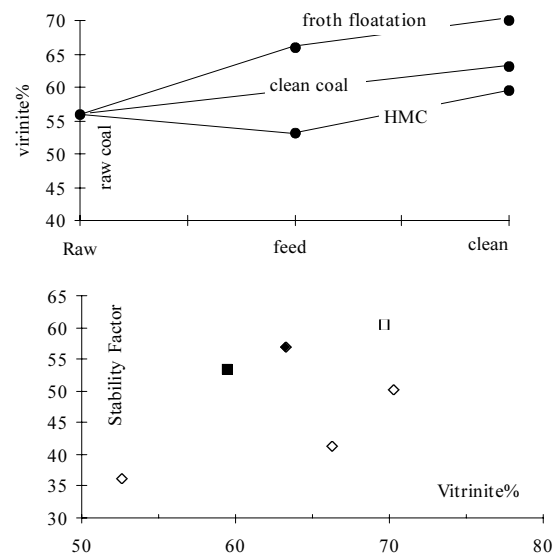


Figure 22. Vitrinite versus size and raw, feed and clean coal. Vitrinite versus stability factors, open diamonds=blends, open square=clean coal with plus 20 mm material removed, solid diamond=clean coal, solid square=clean coal with additional fines. Data from Plant E.

Table 18. Coal quality, rheology, petrography and carbonization data, Plant E.

	raw coal	cl coal	cl < 20 mm	hm prod	hm feed	hm reject	float prod	float feed	float reject	breaker reject	90% cl+10% cl fines	95% cl+5% reject	80% cl+20% feed	90% cl+10% rj fines	30% feed E+70% HV	24% E cl+6% E feed + 70%HV	30% cl E +70% HV
Ash%	19.4	6.7	6.4	6.6	19.1	61.7	7.4	14.5	29.6	78.3	6.8	10.7	8.9	7.5	10	7.2	6.4
VM%	16.3	17.4	17.5	17.3	16.6	13.3	17.5	16.8	15.6	14.2	17.6	17.5	17.5	17.8	29.4	29.8	29.9
S%	0.42	0.35	0.35	0.32	0.32	0.40	0.34	0.35	0.40	0.22	0.35	0.21	0.26	0.45	0.57	0.50	0.58
FSI	4	6.5	7	7	4		7.5	5.5			6.5	6	6.5	7.5	7.5	7.5	8
start C°		467	460	463	466		472	478			466	474	469	466	402	403	402
max C°	478	474	478	478	475		479	480			475	479	474	478	440	441	439
final C°		482	489	487	483		483	487			483	486	483	488	478	477	478
solid C°	496	493	497	493	492		498	495			492	497	496	501	481	481	481
range C°		15	29	24	17		11	9			17	12	8	22	76	73	76
ddpm	0.8	1.3	2.8	2	1.4		1.3	1.2			1.5	1.3	1.2	1.6	2150	2140	2520
sf TC°	441	438	429	434	437		432	441			435	437	434	435	363	363	362
max C C°		486	480	484			481	486			483	491	493	483	427	428	427
max D C°		495	498	495			497							495	466	468	468
C	16	24	26	24	22		23	23			24	26	27	24	27	27	26
D	0	-23	-13	-21	0		-19	0			0	0	0	-21	49	49	49
Vit%	56	63.2	69.7	59.4	52.6		70.2	66.2			61.5	62	61	61.5	65.3	65	63.7
ex%	0	0	0	0	0		0	0			0	0	0	0	5.5	4.4	5.8
SF%	22.4	24.8	17.8	26.8	24.6		16.6	17.2			12.8	23.8	25.2	22.8	11.5	17.4	16.2
Mic%	3.6	5.3	4.1	5.7	6		6.6	5			7	4.1	2.9	7	7.4	5.9	7.4
Fus%	6.6	3	4.9	4.5	5.6		2.5	3.3			4.9	4.1	5.9	4.9	4.6	3.2	3.3
MM%	11.4	3.7	3.5	3.6	11.2		4.1	8.3			3.8	6	5	3.8	5.7	4.1	3.6
Rmax%	1.63	1.63	1.62	1.65	1.64		1.64	1.64			1.62	1.63	1.63	1.62	1.1	1.13	1.08
H ₂ O coke		3.4	3.4								3.4	3.6	3.4	3.6	3	3	3.1
ASTM BD		784	790								784	778	782	787	781	786	783
max wall Kpa		30.8	42.1								8.8	3.8	4.7	4.07	2.41	4.55	4.9
coke yld		76.6	79.4								74.4	74.1	70.6	72.9	74.7	74.3	75.1
Coke Ash		8	7.6								7.9	11.7	9.7	7.8	11.8	9.1	8.3
VM%		0.8	0.9								1	0.9	0.8	1	0.9	1	0.8
S%		0.25	0.35								0.35	0.21	0.26	0.31	0.57	0.52	0.56
Stability		56.8	60.4								53.5	36.3	39.6	50.3	41.2	57.6	60.2
Hardness		63.7	67.2								62.3	49.6	52.3	59	62.4	68.4	69.1
CRI		24.2	21.3								24.5	31.8	28		29.4	28.8	27.5
CSR		66.8	70								65.2	40.9	47.9		47.9	56.1	58.9

hm = heavy medium, cl = clean, rj = reject, HV = high-volatile blend coal

difficult to transport and handle.

CONCLUSIONS

Generally economics dictate that plants have to maximize yield at a given specified clean ash content. Plants can not remove all the ash from the clean coal. This means that if the ash chemistry varies by size consist or specific gravity, then there is the possibility of changing the ash chemistry of product coal while at the same time having only a marginal effect on ash content and

yield. Before this is attempted it is important to know what minerals are effecting the ash chemistry and where they hide in the coal matrix. This can be achieved using standard microscope techniques, but the process is helped by using linear correlation matrixes of oxide data. In some coals, carbonates in the clean coal increase the base/acid ratio and decrease CSR values. A better understanding of the coal plus carbonate association with regards to size and SG splits gives the plant operator some flexibility to reduce base/acid ratios without incurring a major loss of yield and

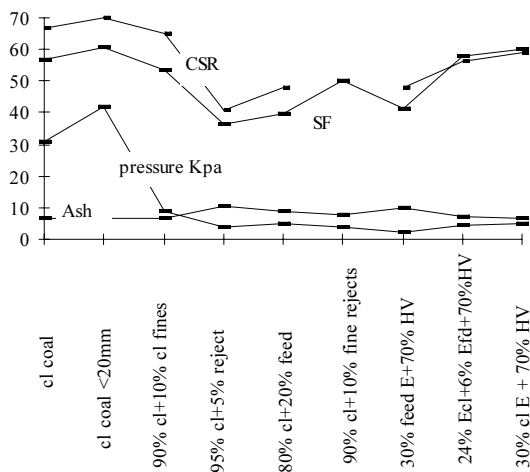


Figure 23. Variation of Stability Factor, CSR, ash and pressure (Kpa) for different blends of coal from plant E.

this has the potential to improve CSR values.

Coal macerals fractionate in plants in at least two ways. Firstly the vitrinite tends to concentrate in the finer sizes and secondly if the macerals are separated by crushing and washed using density separation, then the inert macerals tend to concentrate in the intermediate SG fractions and the vitrinite in the low density fractions. This pattern is confused in the coarser coal by incomplete liberation of the macerals and it is suspected that vitrinite tends to remain attached to in-seam rock material while the inert macerals tend to be liberated. Fine coal is washed by froth floatation using a wetting principle and it is not clear how this effects concentration of vitrinite into the clean coal. It appears that compared to fine feed coal there is an enrichment of vitrinite in the fine clean coal.

Plants are becoming very efficient at recovering coal from the various circuits and it is therefore difficult to influence the maceral composition of the clean coal. However it may be possible to increase the recovery of vitrinite rich coal from the fine circuit while decreasing the recovery in the more inert rich coarse circuit. This will probably require accepting a lower yield and it appears that increasing the content of fine vitrinite in the clean coal does not necessarily improve coke quality. Vitrinite enriched coal from fine circuits does not have the coke making properties that one would expect based on its reactive content. The problem does not seem to relate to the predicted optimum amount of reac-

tives in a sample because most of the coals studied are inert rich. Part of the effect may be size related but there may also be a chemical component to the problem. It is possible that altered non reactive vitrinite is concentrating in the fine material. There is some indication that fine vitrinite is oxygen deficient and may have experienced devolatilization or increase in rank caused by shearing or other geological process.

The size consist or Hardgrove Index of run of mine coal may indicate quality problems not apparent in proximate or petrographic analyses. Handling may not be the only problem associated with sheared coal. Shearing may increase the friability of vitrinite and decrease the rheology of some fine vitrinite grains. This is not unlike what is seen in artificial oxidation or alteration in underground mines where there have been fires. Over production of fines at the mine site may degrade coke quality by separating reactive and non reactive vitrinite, with the non reactive vitrinite concentrating in the fine coal. Addition of fine vitrinite rich coal is not guaranteed to increase coke quality despite the fact that it improves FSI and possibly fluidity of the product.

In addition to the above general conclusions, a number of other more coal specific insights were gained during the study.

Phosphorus is associated with the inert coal macerals in the coarse and intermediate sized circuits. Unfortunately the fractionation of phosphorus into the inert macerals is not complete and it is difficult to alter the washing characteristics of the various circuits to effect a decrease in phosphorus contents with out causing a substantial decrease in yield.

Sulphur content is a concern in some high-volatile coals studied. Washing these coals separately illustrates what each coal is contributing to the clean coal blend and by changing blend proportions possibly reduce the sulphur content. The sulphur is associated with high iron concentrations indicating the presence of siderite.

In most coals there is a good negative correlation between base/acid ratio and CSR. However in coals rich in Fe_2O_3 this is not true because high iron concentrations in the ash, have a positive correlation with CSR. In fact in these coals the SO_3 content in the sample is the best indicator of the CSR value.

The low-volatile coal washes to a low ash

content, and yield could be improved if a higher ash product were produced. Unfortunately coke properties decrease markedly when the ash content of the clean coal increases. Coke oven wall pressure is reduced with only small decreases in stability factor values when small quantities of clean fine coal are added to the product coal.

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