CHARACTERISTICS OF CANADIAN METALLURGICAL COALS

Harry S. Stellmach
Manager Marketing and Technology
Crows Nest Resources Limited

INTRODUCTION

I have been asked to speak about the characteristics of Canadian coals and about the potential for Canadian weak coking coals. While I will briefly discuss the coals from eastern Canada, my main emphasis will be on those from western Canada. However, before addressing these points, I would like to provide a brief overview of the Canadian coal industry, its size, its infrastructure and its market distribution.

Canada's coal resource base is vast and greatly exceeds all anticipated domestic and export requirements. It offers to export markets a reliable, high quality coal supply at competitive prices.

Even though the western Canadian coal industry operates in one of the most demanding geographic and climatic environments in the world, it has emerged as the most reliable coal supplier in world trade. This has been achieved by the coordinated development of high productivity, state of the art mines and supporting infrastructure as well as by a stable labour environment and supportive government policies. Thus, Canada's large, well run coal mines, its sophisticated rail transportation system and large specialized coal loading ports have become its main strengths and are crucial to Canada's continued success in the highly competitive world markets.

The two major Canadian railways (the Canadian Pacific and the Canadian National) have pioneered and developed efficient unit train movements; each train moving about 10,000 tonnes of coal, through 1,100 kilometers of mountainous terrain between the mines and coal ports. The unit cost of these movements is among the lowest in the world. Nevertheless, rail transport is a major component of the total product cost.

Three coal terminals provide Western Canada with highly efficient shipping capability. Roberts Bank, Vancouver has been the cornerstone of the export coal industry to date, and has an annual capability of 22 million tonnes. Neptune Terminals, Vancouver also serves as a major coal terminal, having annual throughput capacity of 6-7 million tonnes. The new coal superport at Prince Rupert adds a further 12 million tonnes of throughput annually.

In eastern Canada, the Sydney coal field is located on tidewater, and coal is shipped via the International Pier.

Canada has generally experienced stable labour relations in its coal chain and the Canadian coal mining industry is not likely to experience industry-wide shutdowns as different mines have different contract dates and different unions. Contract differences are normally resolved in a reasonable time frame and contracts run smoothly over their entire term.

Both provincial and federal governments actively encourage private sector coal development and have been strongly supportive of coal exports. Their non-involvement in marketing, export pricing and export taxation is much appreciated by the industry.

In 1986 the Canadian coal industry produced 57.8 million tonnes of coal (down from 60.8 million tonnes in 1985). Of this total, 26 million tonnes were exported and 31.8 million tonnes were consumed domestically, primarily for electric power generation. Exports consisted of 21.5 million tonnes of metallurgical coal and 4.5 million tonnes of thermal product. The 1986 metallurgical coal production by province and the principal coking coal export mines are shown on Figure 1.

As a result of the great distances between the coalfields in the west and the industrial centre in Ontario (some 3500 km), coal movement to the east in 1986 was limited to 0.095 and 2.82 million tonnes of metallurgical and thermal coal respectively. Canadian steel mills have traditionally imported their coal requirements from the nearby U.S.A. coal fields. Exports to the U.S.A. were 0.26 and 0.08 million tonnes metallurgical and thermal coal respectively while imports from the U.S.A. to Ontario in 1986 were 5.84 million tonnes of coking coal and 7.28 million tonnes of thermal coal.

The movements of coking coal from western Canada east to Ontario and the U.S.A. although small, are a very significant development for the western Canadian coal industry. The movements have been made possible, in part by the prevailing competitive market environment; but primarily, these coal shipments have occurred in recognition by the eastern steel mills of the technical benefits which the western Canadian coal can provide to the U.S.A. coal blends. Increased coal sales to eastern Canada and the U.S.A. are anticipated as these steel mills develop greater familiarity with western Canadian coals.

The western Canadian coal export industry was developed over a period of about 15 years, from the late 1960's to the early 1980's. Mine developments, infrastructure, railways and ports were put in place primarily in response to metallurgical coal demand from Japan and Korea. As a result, the current export capacity of the industry is about 40 million tonnes, 30 million tonnes metallurgical and 10 million tonnes thermal coal. As noted earlier, total exports unfortunately are only 26.0 million tonnes.

Figure 2 shows Canadian metallurgical coal exports by destination. The Japanese market is by far the largest one representing about 73% of total sales in 1986. The figure also illustrates the changing trade pattern which has developed over the past 12 years. Greater emphasis is now being given to coal movements to Latin America, Korea, Taiwan and Europe in an effort by the coal industry to diversify its markets.

Western Canadian coal is produced mainly by open pit methods; only Smoky River Holdings extracts some 300,000 tonnes per year by underground methods. In the east, the Cape Breton Development Corporation operation, which will produce 1.1 million tonnes of metallurgical coal (plus 2.9 million thermal) in 1987, is entirely underground and mostly under the ocean.

GEOLOGICAL SETTING

The characteristics of the western Canadian and eastern North American coals are distinctly different. These differences appear to be the result of the geological histories of the regions as the coal depositional environment is a very important influence on maceral proportions, sulphur content, ash content and ash chemistry of coals.

The coals from Atlantic Canada and U.S. Appalachia are of Carboniferous age, about 300 million years old. As a generalization, these coals were formed in fairly stable coastal swamps that experienced occasional flooding by salt water. The resulting coals are characterized by low inherent ash, high vitrinite, high sulphur and high alkali content.

The coals of western Canada were formed during the Cretaceous age, some 100 million years ago, in delta plain swamps which were generally smaller and less stable than the Carboniferous swamps. This has resulted in the formation of coals that in general have less vitrinite, less sulphur, lower alkalies and more inherent ash than Carboniferous coals.

After deposition, the western coal measures were buried by several thousand meters of sedimentary material and subsequently were brought back to the surface by the mountain building process. This resulted in folded, faulted and steeply dipping seams. Stressing of the coal seams resulted in the friable nature of the coal.

TECHNICAL CHARACTERISTICS

Canadian metallurgical coals have proven themselves in international markets to be of excellent quality. While many of the brands produce very good coke when carbonized alone, the coals perform best when carbonized in well balanced blends.

Nova Scotian Coal

Nova Scotian metallurgical coal is of high volatile 'A' bituminous rank. It is very low in ash and high in vitrinite and exinite. As a result, it displays high coking properties which makes it an excellent blend component with coals of higher rank, particularly those with high inertinites.

Nova Scotian High Vol	
Moisture (ar)	8.0%
Ash (db)	3.5%
Volatile Matter (db)	36.5%
Sulphur (db)	1.2%
Chlorine	0.1%
Phosphorous	0.01%
FSI	7.5
Maximum Fluidity	30,000 ddpm
Total Dilatation (c+d)	275%
Mean Reflectance	0.98%
HGI	65%
Size, minus 38 mm	100%
minus 0.6 mm	23%

Western Canadian Coals

Western Canadian metallurgical coals range in rank from high volatile bituminous to low volatile bituminous. However, most western Canadian coals are typically in the medium volatile category.

As outlined earlier, western Canadian coals were created under a different depositional environment from the Carboniferous coals of eastern North America and Europe. As a result, the western coals have a number of different characteristics which for the most part can be advantageously applied in modern coke making practices.

Typical quality ranges for western Canadian coals are given below.

Western Canadian Coals

Moisture (ar)	8%
Ash (db)	6 to 9.5%
Volatile (db)	17 to 32 %
Sulphur	0.25 to 0.50
FSI	5.5 to 8
Mean Reflectance	0.9 to 1.65
HGI	65 to 90
Size, minus 50mm	100%
minus 0.6mm	30 to 40%

Rheological Properties

Coke strength, as measured by various drum indices at ambient temperatures, is the single most important parameter for assessing coke performance in the blast furnace. The preparation of coke for testing involves either industrial scale or at least pilot scale coke oven operations, is very expensive and requires large coal samples. Therefore, reliable methods of predicting coke strength from coal properties as determined in the laboratory, are very valuable. The most successful and most frequently used methods attempt to define the optimum balance between two parameters. One is a measure of the coals' caking property and the other of the coals' rank. Thus, we have models of total dilation (or G-factor) versus volatile matter, fluidity versus mean maximum reflectance, and composition balance versus strength (rank) index. These models were developed primarily for carboniferous coals.

Most western Canadian coking coals exhibit lower caking properties than other internationally traded coals of similar rank and similar coke strength. Thus calculation models tend to underestimate the strength of coke made from western Canadian coal.

The Canada Centre for Mineral and Energy Technology (CANMET) sponsored research which examined the thermal rheological, petrographic and analytical differences between western Canadian and U.S. Appalachian coals (1). The study explored the effect of particle size, heating rates and petrographic composition on the standard rheological properties.

Even though the rheology of the western Canadian coal could be increased by raising the top size and increasing the heating rate, total dilatation remained significantly lower than that measured for the U.S. Appalachian coals of similar rank and reactives content. This is illustrated in Figure 3. The difference in total dilatation increased as the vitrinite content of the two coals was increased by using specific gravity fractions with mean max reflectance of 1.22. Geiseler fluidity showed similar trends; the western Canadian values ranged from 10 to 200 ddpm compared with 200 to 10,000 ddpm for U.S. Appalachian coals of similar vitrinite content. FSI responded differently. FSI values were similar for the two types of coal if rank and maceral content were similar.

Petrographic analyses of various size and specific gravity fractions showed that for a given percent vitrinite western Canadian coals had slightly higher ash, fusinite and semi fusinite and U.S. Appalachian coals had higher micrinite and exinite.

While petrographic maceral composition, particle size and effective heating rate contribute to the rheology differences between western Canadian and U.S. Appalachian coals, the main cause appears to lie in the chemical make-up of the vitrinite itself. This difference may also be reflected in the lower volatile content of western Canadian coals as compared to U.S. Appalachian coals - Figure 4. Therefore, it is important to be cognizant of the shortcomings of the laboratory rheology test results when using them to assess the carbonization potential of western Canadian coking coals.

Coke Quality

In view of the rheological behaviour of western Canadian coals described above, the most reliable way to assess the carbonization potential of these coals (short of industrial trials) is by using pilot scale e.g. 250 kg coke oven tests. These tests simulate the charging and operating condition of industrial ovens and produce coke very close to industrial quality. This has been confirmed for the CANMET pilot scale ovens in coke quality comparisons with both Canadian and Japanese steelmakers.

A test program was undertaken by the CANMET laboratory (2) to:

- evaluate five western Canadian coals typical of the full range of production,
- evaluate binary blends of the above western Canadian coals, and
- compare the above western Canadian binary blends with binary blends of U.S. Appalachian coals of similar rank.

Coke Quality of Single western Canadian Coals

Table 1 summarizes the coal and coke properties of the individual western Canadian coals. All coals were carbonized under similar conditions in a 460 mm wide oven with a coal charge bulk density of 816 kg/m^3 and a gross coking time of 18 hours.

The coals in Table 1 cover a full range in rank (Romax 0.90 to 1.64) and have low sulphur and alkalies. Considering the low rank of two of the coals (A and B), cold coke strengths are excellent. Coke strength after reaction (CSR) also ranges from very good to excellent. Maximum wall pressure is low when compared to similar rank U.S. Appalachian coals. (Wall pressure will be discussed further in a later section). Specific attention must again be drawn to the G. fluidity and dilatation. These values are far below levels normally deemed acceptable for coke making; yet, in keeping with the discussions on rheology, coke quality is much better than would be predicted by normal rheology based models. A review of the fluidity numbers however does suggest that some oxidation of the small laboratory samples may have occurred due to delays between sampling and analysis. This subject will also be discussed later.

Table 1 - Coals and resultant cokes made from five western Canadian coals in CANMET pilot-scale test ovens.

Coal Charge Properties	CoalA (hv)	CoalB (mv)	CoalC (mv)	CoalD (mv)	CoalE (lv)
Mean reflectance Ro, %	0.90	1.01	1.27	1.28	1.64
Volatile matter, db .... %	31.9	26.5	21.7	21.6	17.4
Ash, db .... %	6.10	7.1	9.6	9.3	7.2
Sulphur, db .... %	0.48	0.50	0.28	0.40	0.38
Alkalies in coal .... %	0.07	0.08	0.04	0.12	0.10
Pulverization ...(%-3mm)	84.5	93.4	90.1	91.1	82.0
Hardgrove index	66.	89.	84.	89.	92.
Caking Properties					
Free swelling index	8.	7.5	6.5	6.5	5.5
Gieseler plasticity (ddpm)	195.	11.4	3.8	6.7	1.9
Dilatation (c+d) .... %	66.	30.	0.	7.0	0.
Expansion/contraction .. %	-	-11.3	-13.5	-11.7	-
Carbonization results					
Maximum wall pressure,kPa	3.7	7.2	2.1	5.8	16.1
Coke Properties					
Ash .... %	8.7	9.3	12.0	11.6	8.6
Volatile matter .... %	0.8	0.8	0.7	0.8	0.6
Sulphur .... %	0.37	0.38	0.27	0.36	0.32
ASTM stability	45.1	55.7	51.0	58.1	57.1
JIS D1 30/15	92.1	-	90.8	94.6	93.2
CSR (Nippon Steel procedure)	62.1	64.0	61.4	73.9	68.3

Table 2 - Analyses of binary blends of western Canadian coals and their resultant cokes.

	BLEND PROPERTIES		
Coal Charge Properties	CoalBlend 1	CoalBlend 2	CoalBlend 3
Ratio of components	65:35	69:31	45:55
Reflectances of components(a:b)	0.90:1.62	1.01:1.28	1.08:1.27
Mean reflectance Ro	1.14	1.08	1.16
Inertinite macerals ....%	29	39	32.3
Volatile Matter, db ....%	26.9	25.1	24.5
Ash, db ....%	6.5	8.0	9.2
Sulphur, db ....%	0.39	0.46	0.49
Alkalies in ash ....%	0.09	0.08	0.1
Pulverization ....(%-3mm)	86.1	92.4	90.3
Ash Analysis ....%			
SiO_2	56.38	57.14	58.9
Al_2O_3	27.2	29.11	27.9
TiO_2	1.45	1.76	1.87
P_2O_5	1.18	1.20	1.24
Fe_2P_3	6.0	3.47	3.61
CaO	2.52	2.24	1.53
MgO	0.68	0.58	0.91
Na_2O	0.49	0.10	0.10
K_2O	0.87	0.71	0.85
Caking Properties			
Free Swelling index	6	7	7.5
Gieseler platicity ....(ddpm)	16.8	12.0	12.5
Dilatation (c+d) ....%	13.	29.	31.
Expansion/contraction ....%	-10.0	-12.6	-8.2
Carbonization Results			
Maximum wall pressure ....kPa	7.3	9.1	9.5
Coke Properties ....%			
Ash	8.5	10.3	11.5
Volatile Matter	0.7	0.8	0.6
Sulphur	0.37	0.35	0.43
ASTM stability	58.4	58.2	57.4
JIS D1 30/15	93.1	93.0	93.6
CSR	67.0	69.0	65.1
CRI	24.0	23.3	22.6

Table 3 - Analyses of binary blends of Appalachian coals and their resultant cokes.

	BLEND PROPERTIES			
	CoalBlend	CoalBlend	CoalBlend	CoalBlend
Coal Charge Properties	1	2	3	4
Ratio of components	72:28	70:30	75:25	93:7
Reflectances of components(a:b)	0.88:1.65	0.95:1.62	1.13:1.22	1.13:1.42
Mean reflectance Ro	1.09	1.22	1.15	1.17
Inertinite Macerals, ...%	21	26.6	25.3	17.5
Volatile matter, db ....%	32.9	28.7	28.2	29.0
Ash, db ....%	6.2	6.2	6.0	5.3
Sulphur, db ....%	0.89	0.81	0.72	0.62
Pulverization (%-3mm)	82.7	83.6	87.5	89.2
Ash Analyses ....%				
SiO_2	50.55	46.4	42.19	41.93
Al_2O_3	29.1	28.5	27.54	26.92
TiO_2	1.47	1.3	1.53	1.50
P_2O_5	0.18	0.24	0.46	0.38
Fe_2O_3	9.8	11.53	10.92	11.18
CaO	2.81	2.95	4.74	4.70
MgO	0.92	1.73	1.89	2.05
Na_2O	0.61	0.80	0.68	0.81
K_2O	1.55	2.06	1.72	1.96
Caking Properties				
Free swelling index	7.	7.5	7.5	
Gieseler plasticity(ddpm)	570.	4380.	11090.	6530.
Dilatation (c+d) ....%	44.	134.	242.	248.
Expansion/contraction ....%	-9.6	-12.8	-9.1	-9.7
Carbonization Results				
Maximum wall pressure .....kPa	12.5	7.0	6.8	26.8
Coke Properties ....%				
Ash	9.1	8.0	7.6	7.0
Volatile matter	0.8	0.7	0.6	0.6
Sulphur	0.63	0.74	0.64	0.62
Apparent specific gravity	0.894	0.945	0.897	0.885
ASTM stability	58.9	58.1	57.6	57.9
JIS Dl 30/15	94.9	94.4	94.5	95.1
CSR	61.6	48.6	56.9	53.6
CRI	31.0	36.4	30.5	32.5

Coke Quality from western Canadian and U.S. Appalachian Binary Blends

As follow-up to the work on single coals in Table 1, a number of two-component blends were prepared from the western Canadian coals as summarized in Table 2. A similar set of two-component blends was also prepared for U.S. Appalachian coals as summarized in Table 3. The reflectance ranges of the two sets of coals were similar. The blends were prepared by combining the highest rank (reflectance) coal with the lowest rank coal; the second highest with the second lowest, etc. Blending ratios were adjusted by trial and error to obtain a cold coke strength suitable for use in modern blast furnaces, i.e. an ASTM stability of 58±1. Carbonization conditions in the 460 mm CANMET oven were maintained as constant as possible with bulk densities at about 825 kg/m^3 and flue temperatures at 1250°C. The properties of the western Canadian and U.S. Appalachian coal blends and cokes were then compared.

The ASTM stability requirement of 58±1 could be met with both sets of coals. The fluidity and dilatation of the western Canadian blends are much lower than those for U.S. Appalachian coals producing equivalent strength coke. Maximum wall pressure ranged from 7 to 9.5 kPa (1.02 to 1.39 psi) for the western Canadian coals and from 6.8 to 27 kPA (0.99 to 3.94 psi) for the U.S. Appalachian coal; the latter value being unacceptably high. The western Canadian blends displayed lower sulphur but slightly higher ash then the U.S. Appalachian blends.

Substantial differences also occurred in the "hot strength properties" and these parameters were explored further to determine their dependence on other coal/coke quality parameters when ASTM stability was kept constant.

The CSR for the western Canadian coals ranged from 65 to 69 while those for the U.S. Appalachian coals ranged from 48 to 62.

CANMET scientists examined the relationships between the key carbonization parameters by regression analysis (3). The results of their findings are plotted on Figures 5a to 5c. The trend between reflectance and CSR on Figure 5a, showing a decrease in CSR with increasing rank, is opposite to that normally expected. This may suggest that rank is a secondary influence. The CSR and CRI (coke reactivity index) parameters appear to be mainly influenced by the chemistry of the coal/coke ash. The basicity index used in Figure 5c is (Fe_2O_3 + CaO + MgO + Na_2O + K_2O)/(SiO_2 + Al_2O_3). Although coke texture was also examined, it did not show an obvious relationship to CSR or CRI in this test series.

The above blend comparison clearly shows that the western Canadian and U.S.Appalachian coals complement one another in terms of caking properties, ash, ash chemistry, sulphur and coking pressure.

Blends of Western Canadian and U.S.Appalachian Coals - Effect of Longer Coking Times

To examine the complementary characteristics of the cretaceous and carboniferous coals CANMET, developed a blend test program using the three coals described in Table 4.

Table 4 - Properties of Coals used in Western Canadian/Appalachian coal blends.

	Appalachian Coals		W.Canadian Coal
Properties	hv Coal Blend	lv Coal Blend	mv Coal
Ro	1.05	1.66	1.31
Ash (db) ....%	5.7	5.4	9.9
Volatile matter, db .%	31.8	17.4	20.9
Sulphur,db ....%	0.75	0.67	0.41
Gieseler fluidity(ddpm)	23100.	10.7	1.8
Ruhr dilatation(c+d)	276.	56.	0.
FSI	6.	7.	4.

The intent of the study was to take advantage of the excess fluid properties of the U.S. Appalachian high vol coal by adding a weakly caking western Canadian medium volatile coal. Blending ratios were selected to maintain a constant mean (max) vitrinite reflectance of 1.26. The blend properties are summarized in Table 5 below.

Table 5 - Blend Properties of U.S.Appalachian and western Canadian Coals

% hv:mv:lv	65:0:35	51:25:24	36:50:14	18:82:0	0:100:0
Ro	1.26	1.26	1.26	1.26	1.31
Gieseler Fluidity	2650.	610.	138.	10.1	1.8
Dilatation (c+d)	122.	78.	58.	23.0	0.

The blends were carbonized at flue gas temperatures of 1250°C and 1065°C to establish the effect of longer coking times on coke strength. The results are illustrated in Figures 6a to 6e. Up to about 50% of the western Canadian coal could be added to the blend before the lower blend fluidity resulted in a reduction in cold coke strength (ASTM stability). The CSR and CRI continued to improve with the addition of western Canadian coal. Longer coking time improved coke cold strength (stability) but reduced hardness, hot strength (CSR) and maximum wall pressure. Other CANMET coking rate studies have shown similar trends. The opposing effects of heating rates on cold and hot coke strength are obviously a subject for blast furnace optimization.

Coking Pressure

The pressure exerted on the coke oven walls during the carbonization cycle is of critical concern in coke-making operations. Figure 7 shows schematically the directions of influence of the main variables on maximum wall pressure. Charge bulk density and blend composition are the most important means of controlling pressure (4). Efforts by several operators to improve productivity by using higher coking rates and/or bulk densities have resulted in oven deterioration. This concern is particularly valid for ovens over 5 m tall. For these ovens, sizeable local variations in charge bulk density can occur during the charging process (5).

The studies described earlier have already shown the favorable coking pressure characteristics of western Canadian coals. However, a project sponsored with BCRA demonstrates the pressure moderating properties of a western Canadian coal even more clearly. The program included four international coals which were carbonized in various blends in a 250 kg moveable wall oven at dry bulk density of at least 830 kg/m^3 and a coking rate of 25 mm/h. The blend make-up and results are summarized in Table 6 and are illustrated in Figures 8a to 8c.

Table 6 BCRA 250 KG Moveable Wall Oven Tests

Blend Components, %				Blend	Blend	Max Wall
USA	Australian	W.Cdn.	U.K.	v.m.	Romax	Pressure
(lv)	(mv)	(mv)	(hv)	(% db)	(%)	(psi)
100	-	-	-	17.1	1.68	7.00+
-	100	-	-	21.2	1.41	3.38
-	-	100	-	19.7	1.34	1.20
-	-	-	100	35.0	.92	1.20
20	10	0	70	29.3	1.12	0.80
20	15	0	65	28.9	1.15	2.70
20	15	15	50	27.0	1.21	1.39
20	30	0	50	26.8	1.22	3.39
20	30	15	35	23.9	1.28	3.02
20	30	30	20	22.5	1.35	1.20

The western Canadian coal reduced the maximum wall pressure while actually increasing the rank (Romax) of the blend. The inclusion of the western Canadian coal results in a safer oven operation while improving coke yield and productivity; improving hot coke strength and maintaining cold coke strength.

Effect of Storage Time on Western Canadian Coal Samples

As discussed earlier, western Canadian coking coals generally display lower thermal rheological properties than carboniferous coals. Thus any deterioration in these properties due to delays and faulty handling of samples could evoke a negative response from customers. As small samples age more rapidly than coal in large stockpiles, a test program was developed by CANMET to determine the effect on such samples kept over time in bags or drums.

Twelve drums of western Canadian medium volatile coal with good rheological properties were divided into four parts. Three parts (samples) were stored at ambient conditions and the fourth was refrigerated. Thermal rheological and coke properties were determined from time to time over a 20 week period as illustrated on Figures 9a to 9c.

The change in the coal's thermal rheological properties with time is shown in Figure 9a. The FSI showed no deterioration with time for either the refrigerated coal or coal stored at ambient temperature. In fact. FSI appeared to improve after six to eight weeks storage. However, the total dilatation (c+d) properties dropped quite quickly during the first eight weeks from 100% to about 75%. Thereafter, c+d declined at a much slower rate to about 54% after 27 weeks. The c+d of the refrigerated sample had deteriorated slightly less than that of the sample stored at ambient temperature. The reduction in Gieseler fluidity with time is even greater than the dilatation. Fluidity declined rapidly from 360 ddpm at time of coal delivery to about 120 ddpm after about eight weeks. Fluidity declined at a much slower rate from 8 to 27 weeks. Again, the refrigerated sample showed only slightly better fluidity than the corresponding sample stored at ambient temperature.

Results from carbonization showed that cold coke strength may have improved very slightly with time as shown in Figure 9b. Increased length of storage had very little effect on ASTM hardness but appeared to improve stability and both JIS drum indices. The refrigerated sample gave equivalent coke strength to the non-refrigerated samples.

Figure 9c shows that coke strength after reaction (CSR) and the coke reactivity index (CRI) deteriorated with coal storage time. Coke reactivity increased and coke strength after reaction decreased after 20 weeks storage of the coal. The CRI from the sample stored under refrigeration was slightly better than the sample stored at ambient temperatures.

Quality of Canadian Weak Coking Coal

Western Canadian weak coking coals perform well in blends with internationally traded coals of good fluidity. Typical western Canadian weak coking coals tend to be of good rank (Romax 1 to 1.3) and generally contain high levels of inerts (fusinite and semi-fusinite) and some partially oxidized macerals. As a result, thermal rheology tends to be low.

A typical western Canadian weak coking coal was evaluated by pilot scale (250 kg) carbonization (at BCRA) to assess its performance as a component in blends with Polish medium volatile and American high volatile coals.

Three carbonizations were run with the weak coking coal added at two levels to the base blend which contained equal parts of medium and high volatile coal. The properties of the individual coals and blend charges are shown in Tables 7 and 8.

Table 7 Weak Coking Coal Blend Trials

	Polish M.V.	American H.V.	W.Cdn. Weak
Ash, d.b.	7.2	7.7	11.9
Volatile Matter, d.b.	26.7	30.8	20.5
Sulphur, d.b.	0.7	0.94	0.34
FSI	8	8.5	2
Dilatation, (c+d) %	126	157	-22
Fluidity, ddpm	480	4400	None
RoMax, %	1.11	0.99	1.24
Total Inerts, %	21	10.7	36

From Table 8 it can be seen that the western Canadian weak coking coal is an effective blend coal. The base blend of equal proportions of Polish and American HV produced a high quality coke with micum indices of the required levels for use in large modern blast furnaces. These micum indices were maintained when 10 and 20 percent of the weak coking coal was added to the base blend. No evidence of any trend indicating a deteriorating influence attributable to the additions of the weak coking coal was detected. It has been shown that at least 20 percent of weak coking coal could be included in blends of higher volatile American and Polish metallurgical coals to produce cokes of strength indices suitable for large modern blast furnaces. The key to successfully incorporating the weak coking coal was the good caking capacity of the parent blend.

Table 8 Weak Coking Coal Blend Trial - Properties of Charges

Coals				
Polish	%	50	45	40
American HV	%	50	45	40
Western Canadian Weak	%	0	10	20
Properties of charges				
Total moisture	%	3.9	4.5	4.4
Size 3.35 mm	%	14.9	15.4	15.4
Ash, d.b.	%	7.3	7.9	8.5
Volatile matter, d.b.	%	28.9	27.9	27.4
Sulphur, d.b.	%	0.87	0.83	0.80
FSI		8	8	8
Calculated Ro Max.		1.05	1.07	1.09
Calculated total inerts		15.8	17.8	19.8
Conditions of carbonization				
Charge bulk density, d.b.	kg/m^3	767	761	767
Final charge-centre temperature	°C	1000	1010	1000
Carbonizing time	h	17.4	17.5	17.4
Coke characteristics				
Ash, d.b.	%	10.5	11.1	11.4
Sulphur, d.b.	%	0.81	0.75	0.71
Mean size, mm		82	82	81
Micum indices				
M40		80.9	81.2	80.1
M10		7.9	7.7	8.0

POTENTIAL FOR THE USE OF CANADIAN WEAK COKING COAL

The thrust for the greater use of weak coking coal has originated in Japan and carries with it a strong commercial element. In the late 1970's and early 1980's projections of future world steel and coal demand were very high. Japanese steel mills had real concerns that sufficient quantities of prime coking coal would not be available in future to satisfy their requirements. As a result, they initiated the development of a number of new mines, primarily in Australia and Canada. In addition, they developed technologies and facilities which would allow them to replace prime coking coal with weak or non-coking coal (6). Some of these methods for prime coking coal replacement are as follows:

1. Straight additions to the blend. This is possible if the balance of the blend is "rich" in caking properties and would otherwise produce coke of unnecessarily high quality. The addition of weak coking coal in this way must be based on a detailed optimization of the blast furnace. Lower coke strength will increase the coke rate and reduce blast furnace productivity. The effect of weak coking coal on both the cold and hot strength of the coke complicates this evaluation further. The optimization, of course, is much easier for a steel mill faced with production cutbacks than for one trying to increase production.

2. Briquetting. The bulk density of a coal charge can be significantly increased by briquetting part of the charge. It appears that maximum density is achieved with some 30% of the charge briquetted. This improvement allows some 15% to 20% of weak coking coal to be incorporated although it seems to be unimportant whether it is included in the briquettes alone or throughout the blend. A special

binder is required to produce the briquettes and this also contributes to the quality of the coke produced. However, this binder must have special properties and is consequently expensive. This factor and operating costs make briquetting unattractive and the equipment, only installed in Japan and Korea, currently is not fully utilized.

3. Pre-heating. By drying and heating the coal blend prior to charging, bulk density and hence coke quality can be improved. Productivity is increased by the reduced coking time. Weak coking coal can then be added at the rate of 5 to 20%, depending on the level of heating, to achieve the same coke quality. Some level of drying only may be economical today.

4. Differential crushing. Normal practice is to combine the different coals forming the blend and crushing them together. However, the different physical properties of the individual coals can result in harder coals being insufficiently crushed, with consequent deleterious effects on coke quality. Differential crushing prevents this by crushing selected blend components separately to the desired size range. (Western Canadian prime coking coals respond very well to this practice.) Any improvement can then be offset by adding weak coking coal.

5. Dry quenching of coke. Coke is usually quenched with water which causes a severe thermal shock to the coke and reduces its strength by creating microscopic cracks. Dry quenching with gas reduces the thermal shock and improves coke strength. It also is an environmentally clean process. For the same coke quality 2% - 5% weak coking coal can be added. At present there are few dry quenching plants but, despite their high capital cost, they are likely to be popular in environmentally sensitive areas when coke ovens must be replaced in future.

6. Formed coke. This technology seeks to produce metallurgical coke from primarily non-coking coals. It has been demonstrated on a pilot scale that several process routes can produce acceptable coke. As the name suggests, the process involves the formation of a briquette of coal or char which is then devolatilised as a unit. There is as yet no evidence that this will emerge as a commercially significant process route.

7. Pulverized/crushed coal injection (PCI). The foregoing processes have all allowed direct substitution of weak for prime coking coal. PCI is effectively a substitute for coke. Coal is injected into the blast furnace and provides a source of carbon which replaces a quantity of coke. There is a limit to the amount of coke that can be replaced because, as well as being a source of carbon, coke is required to maintain permeability in the burden. Injection rates as high as 250 kgs/tonne of hot metal have been reported, mainly from China. European furnaces have reached 150 kgs/tonne of HM but most areas only regularly use up to 100 kgs/tonne HM. This level will replace about 90 kgs of coke per tonne of HM. British Steel Corporation has used western Canadian coal very successfully in this application.

In today's market environment, with the exception of PCI and straight blend addition, increased use of weak coking coal can only be justified to the extent that facilities described above are already in place. In December, 1986 the Japanese steel mills had 38 blast furnaces in operation and 16 idle. With this overcapacity, optimum coke oven and blast furnace practice is totally different to that of a country where plans for expansion are being made. The increased use of weak coking coal is therefore less attractive to the newly industrialized countries where productivity is critical and steel production is still increasing.

CONCLUSIONS

- Canada produces a full range of excellent metallurgical coals. Eastern coals are of carboniferous age while those in the west are of cretaceous origin.

- Eastern Canada produces only high volatile coal which is very low in ash, has high fluidity and moderately high sulphur. It is an excellent blend component for coals with higher rank and higher inerts.

- Western Canadian coals range from high volatile bituminous to low volatile bituminous rank. The coals are higher in semifusinite and ash and lower in vitrinite, exinite and micrinite and sulphur than coals from Eastern North America.

- Vitrinite from western Canadian cretaceous coals is inherently different than vitrinite from carboniferous coals. This difference is to a large degree responsible for the lower thermal rheological properties of the coals. Maceral composition and particle size difference also contribute to the lower rheology levels. Standard coke quality prediction models tend to underrate these coals.

- Western Canadian coals carbonized alone or in blends make coke of very good cold strength and of excellent CSR (coke strength after reaction) and CRI (reactivity).

- Western Canadian coals make very good cokes at fluidity levels well below the traditionally accepted limits. As a result, these coals have a wide blending range.

- Western Canadian coals carbonized alone or in blends generate lower coking pressure than other blends of comparable rank. Some brands can be used effectively as pressure moderating agents for highly expanding blends.

- Oxidation of small western Canadian coal samples can have a significant effect on the measured thermal rheological properties. Care must be taken to minimize delays between sample extraction and sample analysis.

- Western Canadian weak coking coals perform well in both densified and conventional charge application.

Acknowledgments

Most of the studies reported here were conducted or sponsored by the Energy Research Laboratories of the Canada Centre for Mineral and Energy Technology in conjunction with the Canadian Carbonization Research Association. The author would like to express his thanks and appreciation to these organizations and particularly to Drs. J. T. Price and J. F. Gransden for their excellent work on these projects.

References

(1) J. T. Price, J. F. Gransden, CANMET, Energy, Mines and Resources Canada, Ottawa
P. J. Readyhough, A. Newman, P. Ramachandran, Dept. of Chemical Engineering, University of Waterloo, Waterloo, Ont., Canada.
"Factors Affecting the Rheology of Cretaceous Coals".

(2) J. T. Price, J. F. Gransden, "Metallurgical Coals in Canada: Resources, Research, and Utilization"
CANMET Report ERP/ERL 86-40 (R) (R)
Energy Mines and Resources Canada, Ottawa.

(3) J. T. Price, J. F. Gransden, "Effect of Component Coal Properties on Strength After Reaction Properties of Cokes Made From Binary Blends", Internal Report, Energy Research Laboratories, CANMET, Ottawa.

(4) L. G. Benedict, R.R. Thompson, Research Department, Bethlehem Steel Corporation. "Selection of Coals and Coal Mixes to Avoid Excessive Coking Pressure".

(5) G. Nashan, "Adaptation of the Coking Industry to Present and Future Demands" Yearbook of the Coke Oven Managers Association, pp. 237-270, 1985.

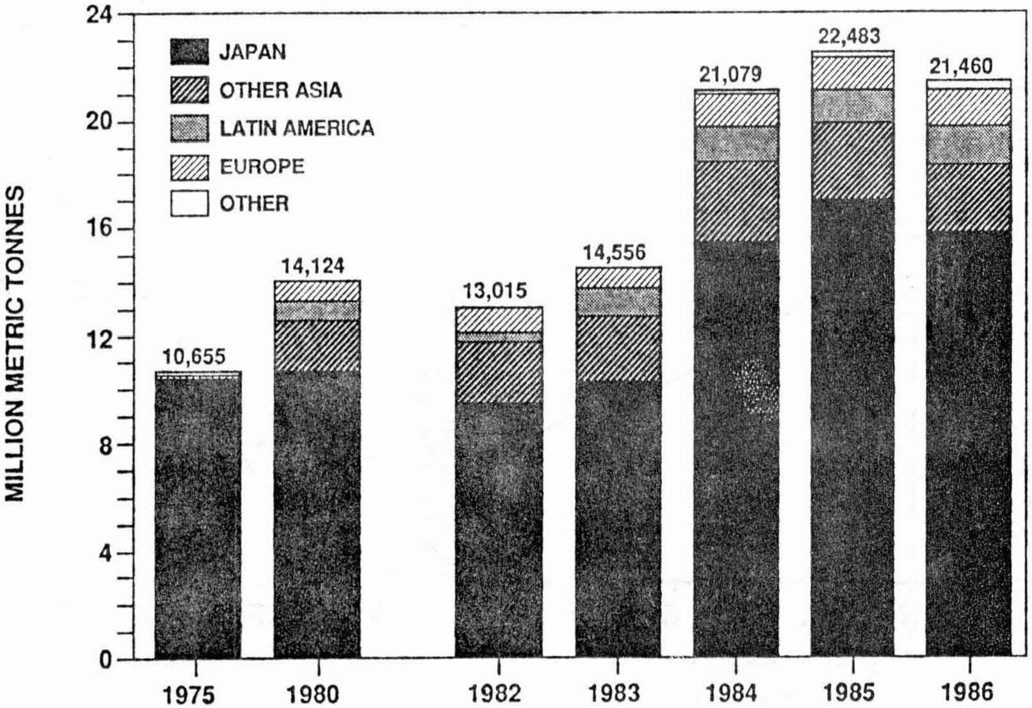
(6) T. Yamada, "Current Development of Coking Coal Utilization Technology in the Japanese Steel Industry", The 10th Japan - Australia Coal Conference, October 1986.

Figure 1
PRINCIPAL CANADIAN COKING COAL EXPORT MINES

Mine	Company	Mine	Company
Balmer	Westar Mining	Line Creek	Crows Nest Resources
Bullmoose	Teck Corporation	Lingan	Cape Breton Develop.
Coal Mountain	Esso Resources	Luscar	Luscar Ltd.
Fording River	Fording Coal	Prince	Cape Breton Develop.
Greenhills	Westar Mining	Quintette	Denison Mines
Gregg River	Gregg River Resources	Smoky River	Smoky River Holdings

Figure 2

CANADIAN METALLURGICAL COAL EXPORTS



Source: Stats Canada/EMR

Figure 3
EFFECT OF A CHANGE IN VITRINITE CONTENT ON THE TOTAL DILATATION OF A WESTERN CANADIAN AND AN APPALACHIAN COAL OF THE SAME RANK

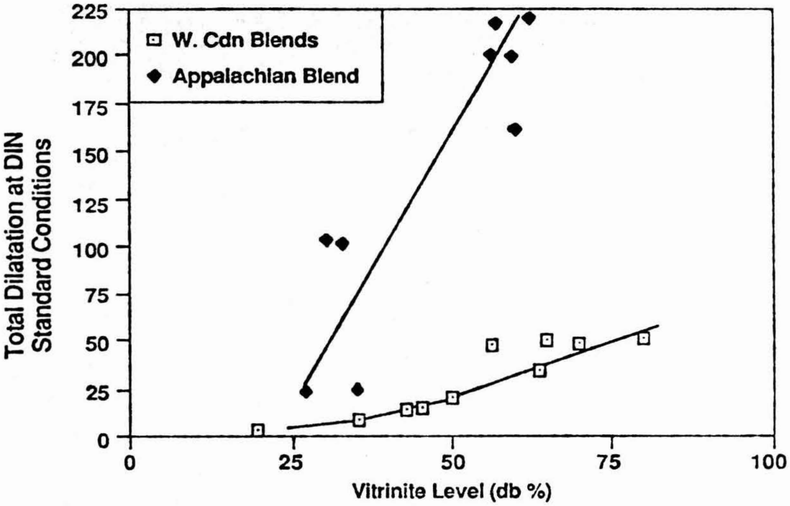


Figure 4
VOLATILE MATTER VERSUS MEAN REFLECTANCE WESTERN CANADIAN AND U.S. APPALACHIAN COALS

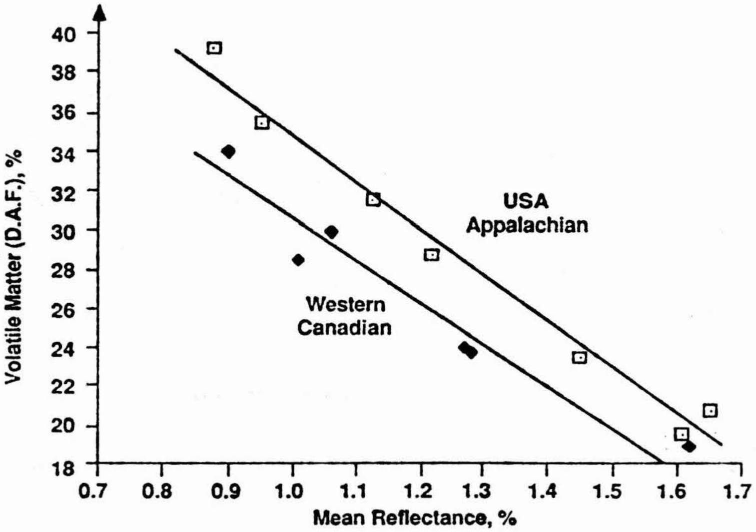


Figure 5a
CSR OF WESTERN CANADIAN AND APPALACHIAN COAL BLENDS PLOTTED AGAINST MEAN BLEND RANK

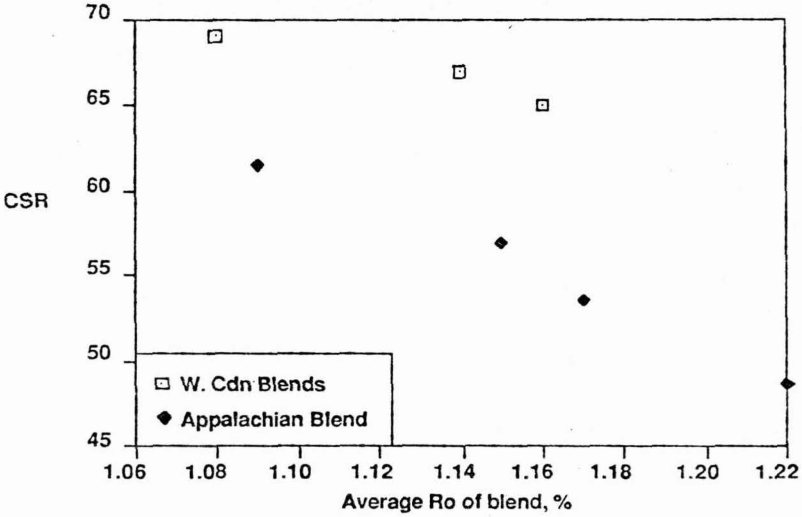


Figure 5b
EFFECT OF TOTAL ALKALIS IN BLEND ON THE CSR PROPERTIES OF THE COKE

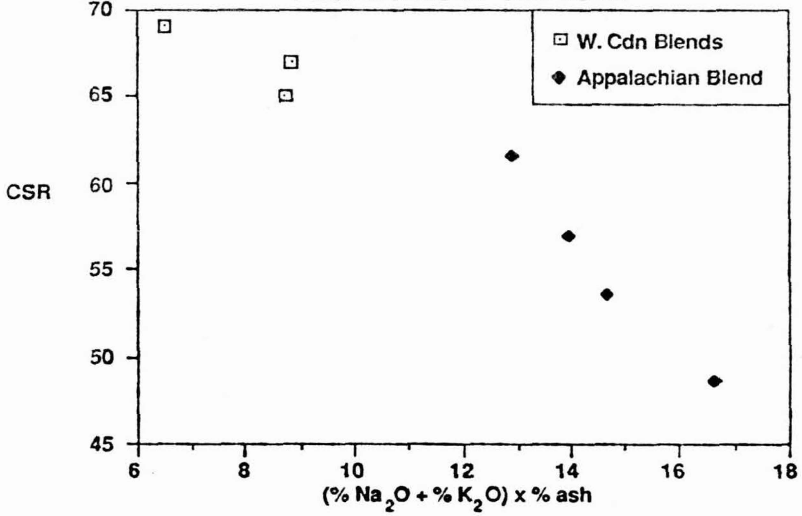


Figure 5c
EFFECT OF ASH TIMES THE BASICITY INDEX ON THE CSR PROPERTIES OF THE COKE

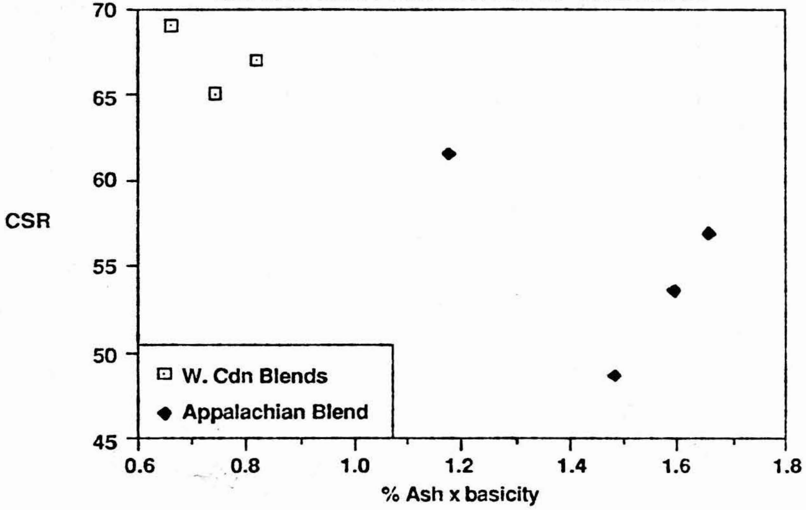


Figure 6a
EFFECT OF ADDING WESTERN CANADIAN M. VOL. COAL TO AN APPALACHIAN BINARY BLEND

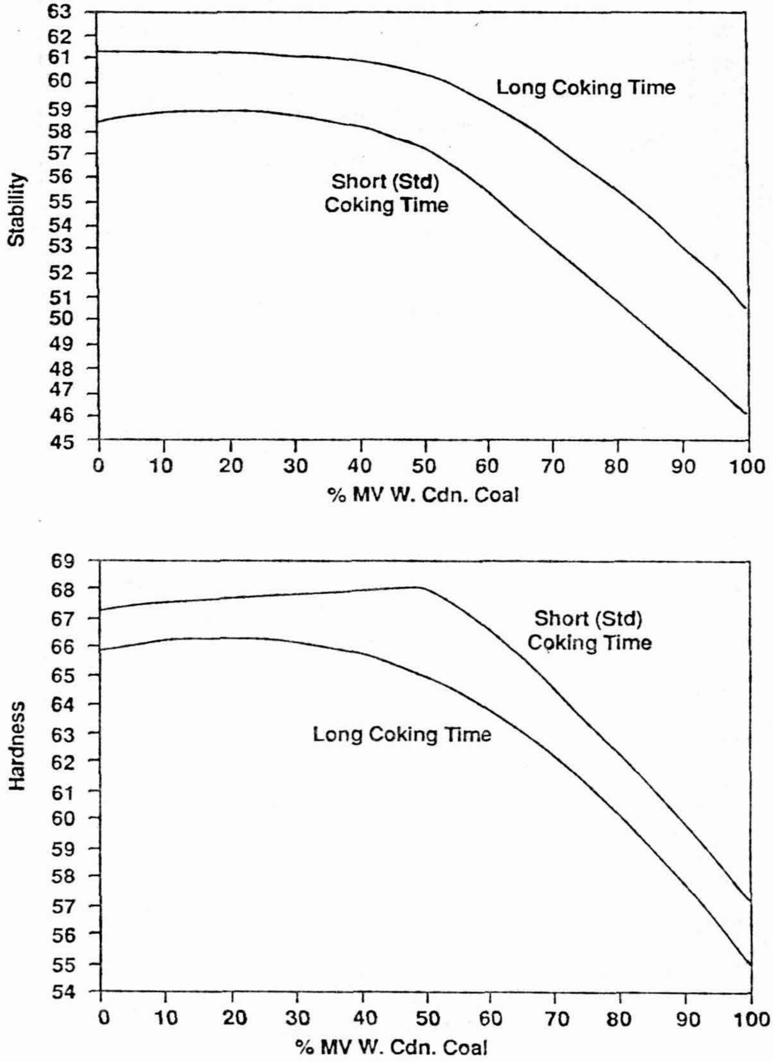


Figure 6b
EFFECT OF ADDING WESTERN CANADIAN M. VOL. COAL
TO AN APPALACHIAN BINARY BLEND

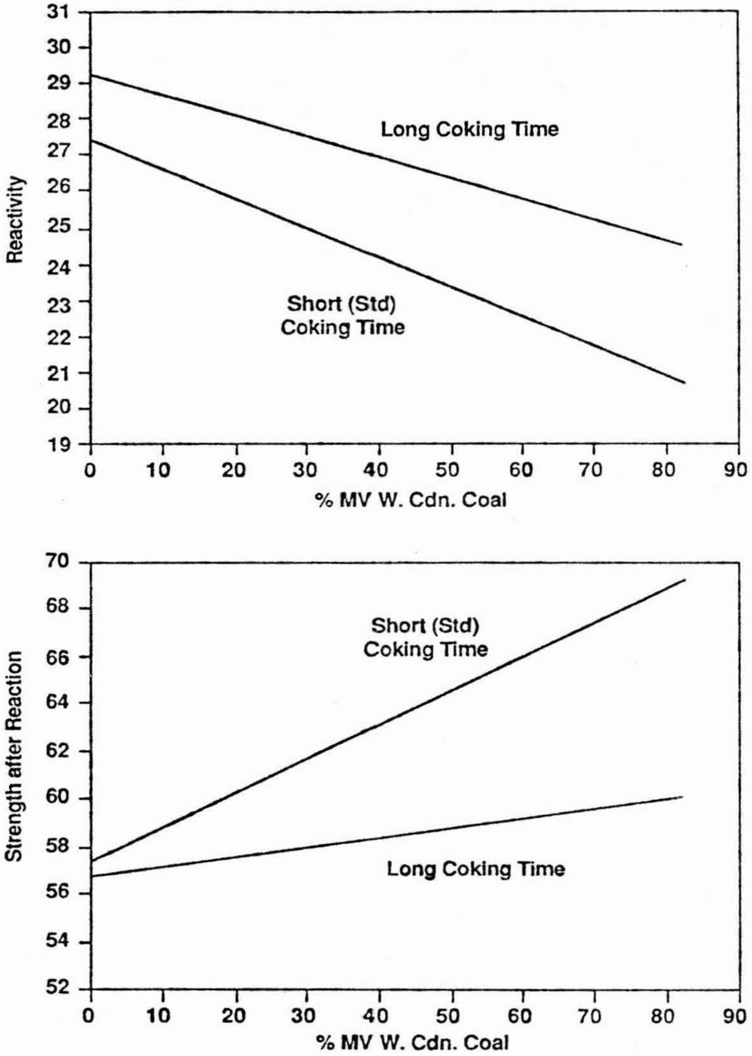


Figure 6c
EFFECT OF ADDING WESTERN CANADIAN M. VOL. COAL TO AN APPALACHIAN BINARY BLEND

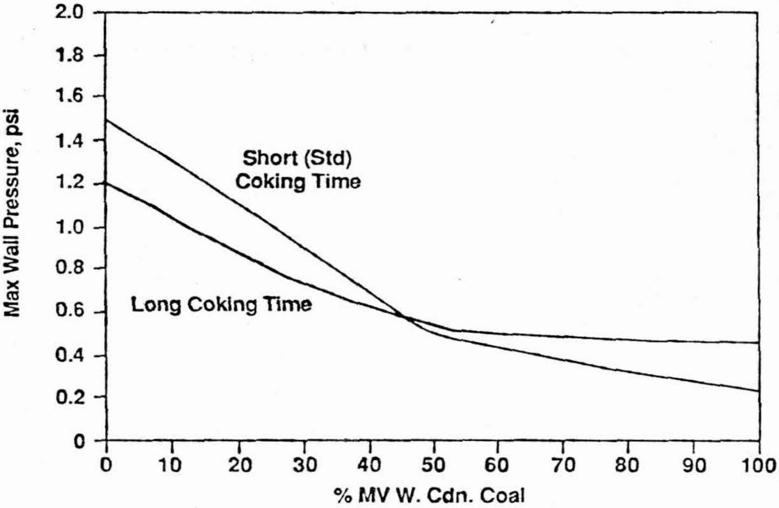


Figure 7
INFLUENCE OF KEY VARIABLES ON COKING PRESSURE

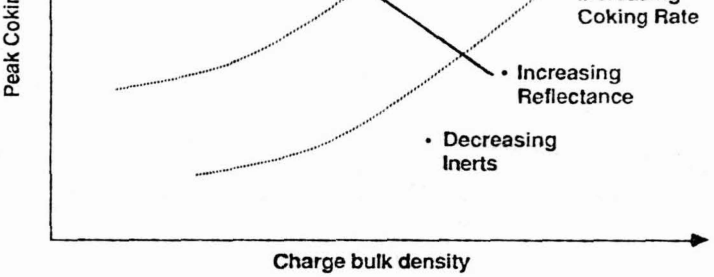


Figure 8a
COKING PRESSURES DEVELOPED BY FOUR SINGLE COALS

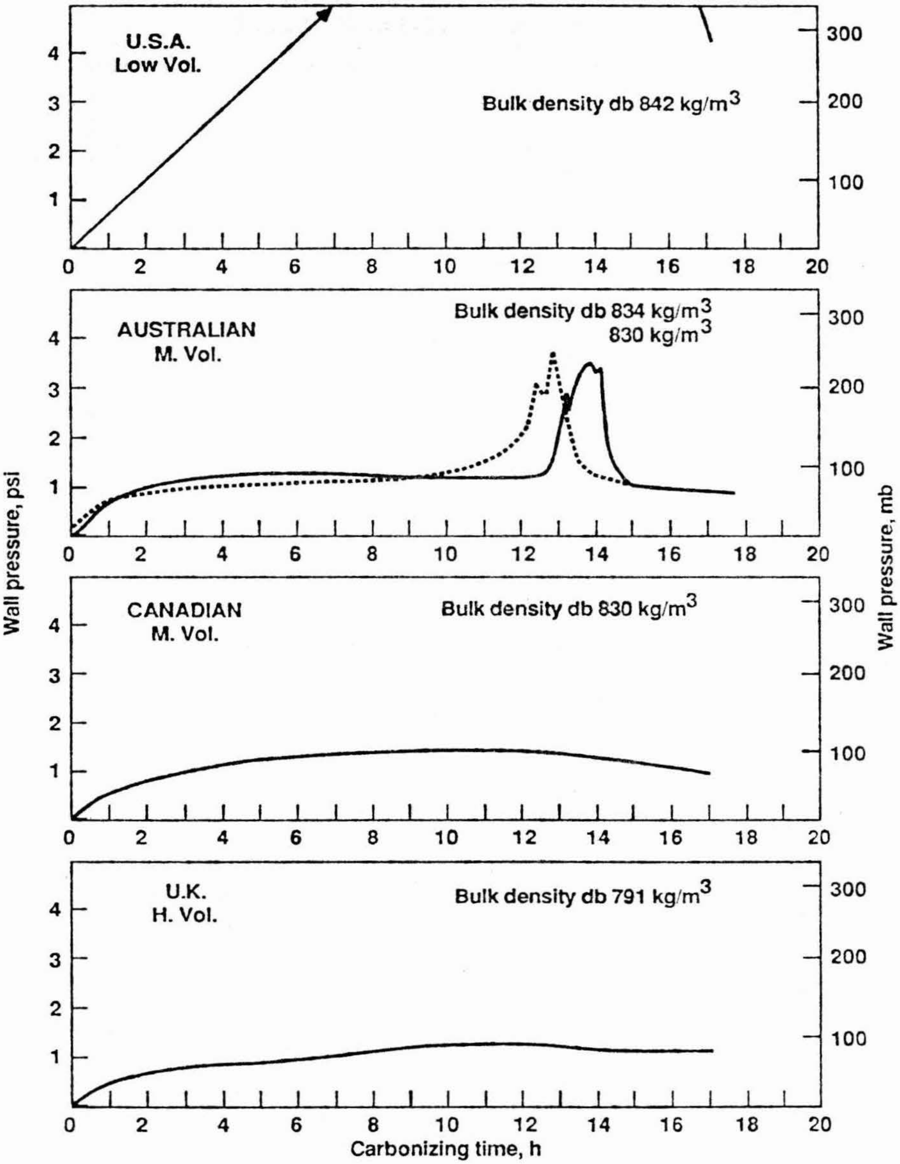


Figure 8b
COKING PRESSURES DEVELOPED BY BLENDS
- EFFECT OF ADDING WESTERN CANADIAN MEDIUM VOLATILE COAL

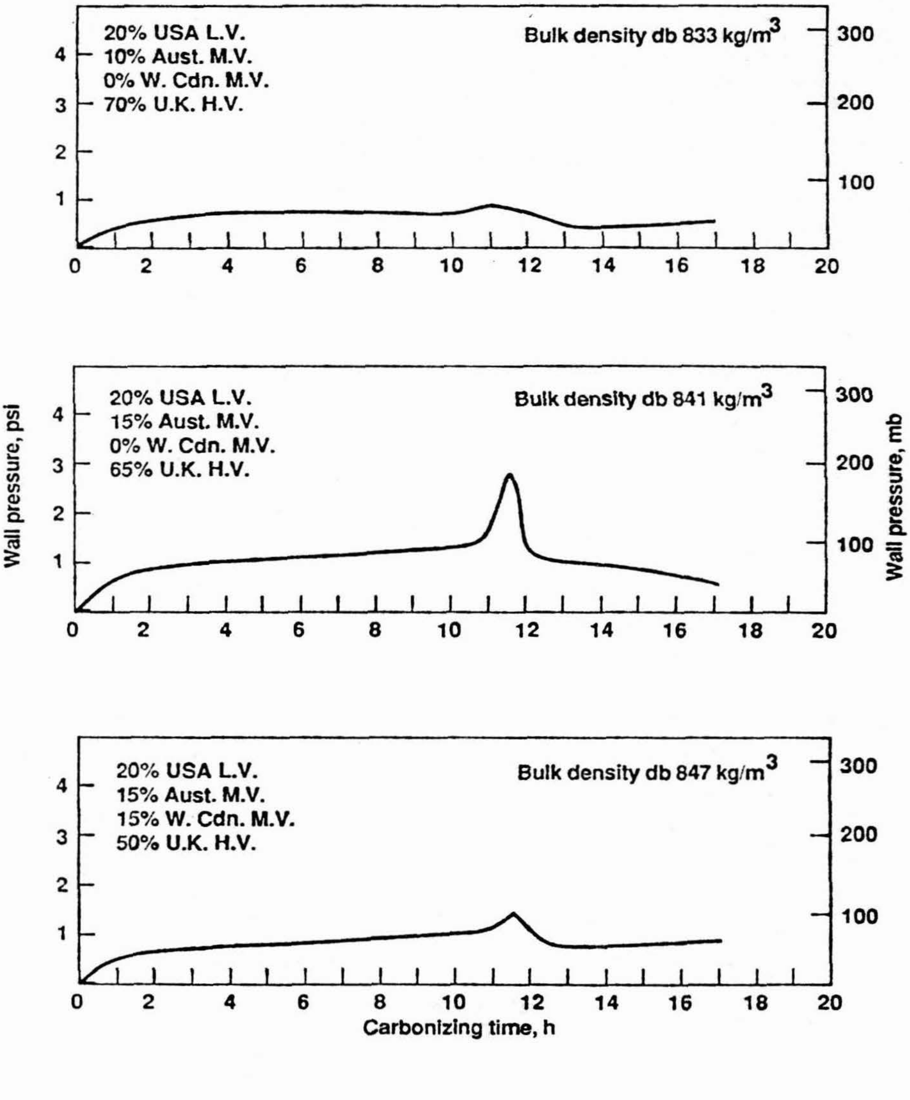


Figure 8c
COKING PRESSURES DEVELOPED BY BLENDS
- EFFECT OF ADDING WESTERN CANADIAN MEDIUM VOLATILE COAL

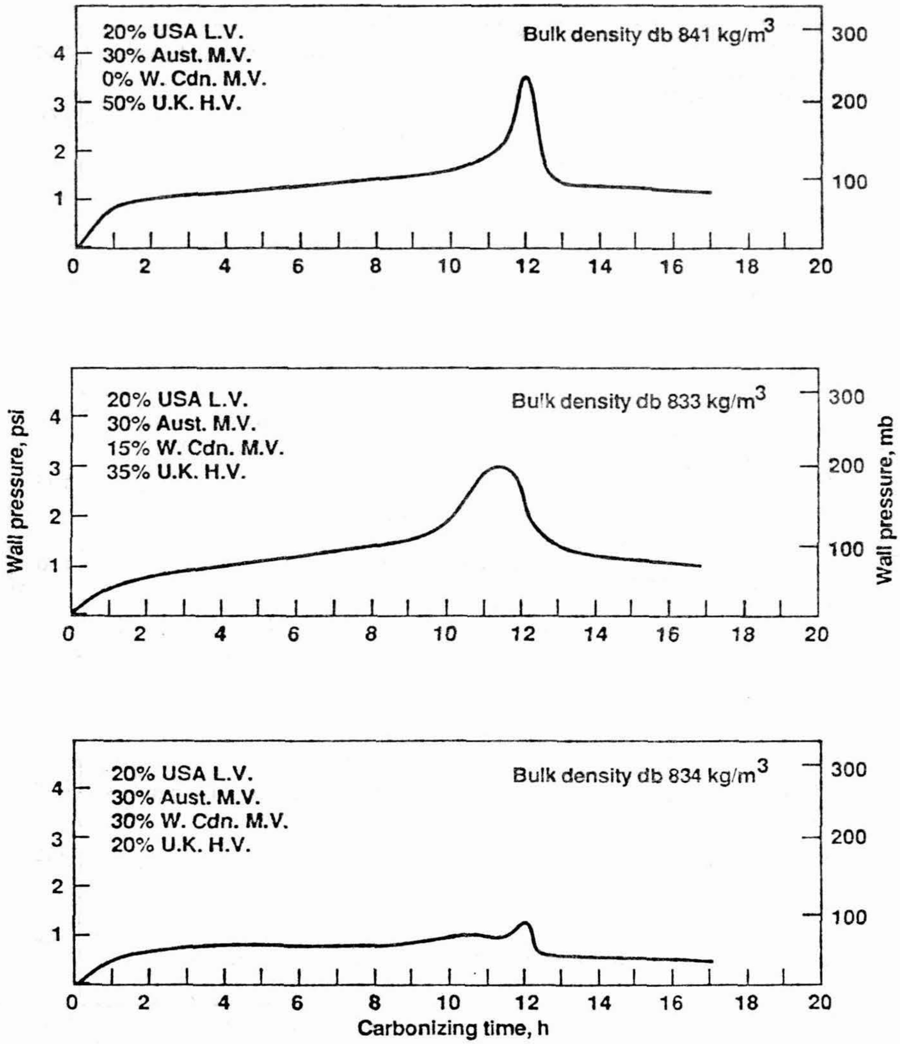


Figure 9a
THERMAL RHEOLOGICAL PROPERTIES OF COAL VERSUS STORAGE TIME

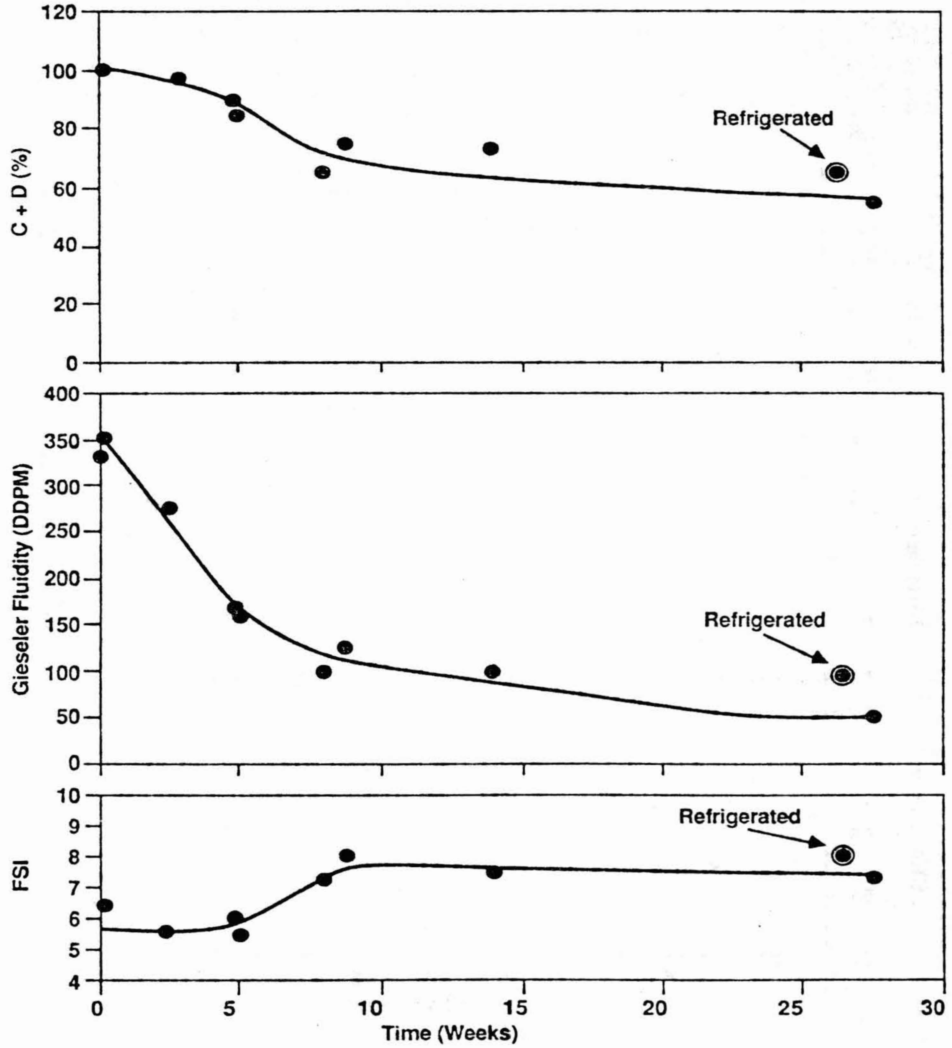


Figure 9b
COKE STRENGTH PARAMETERS VERSUS COAL STORAGE TIME

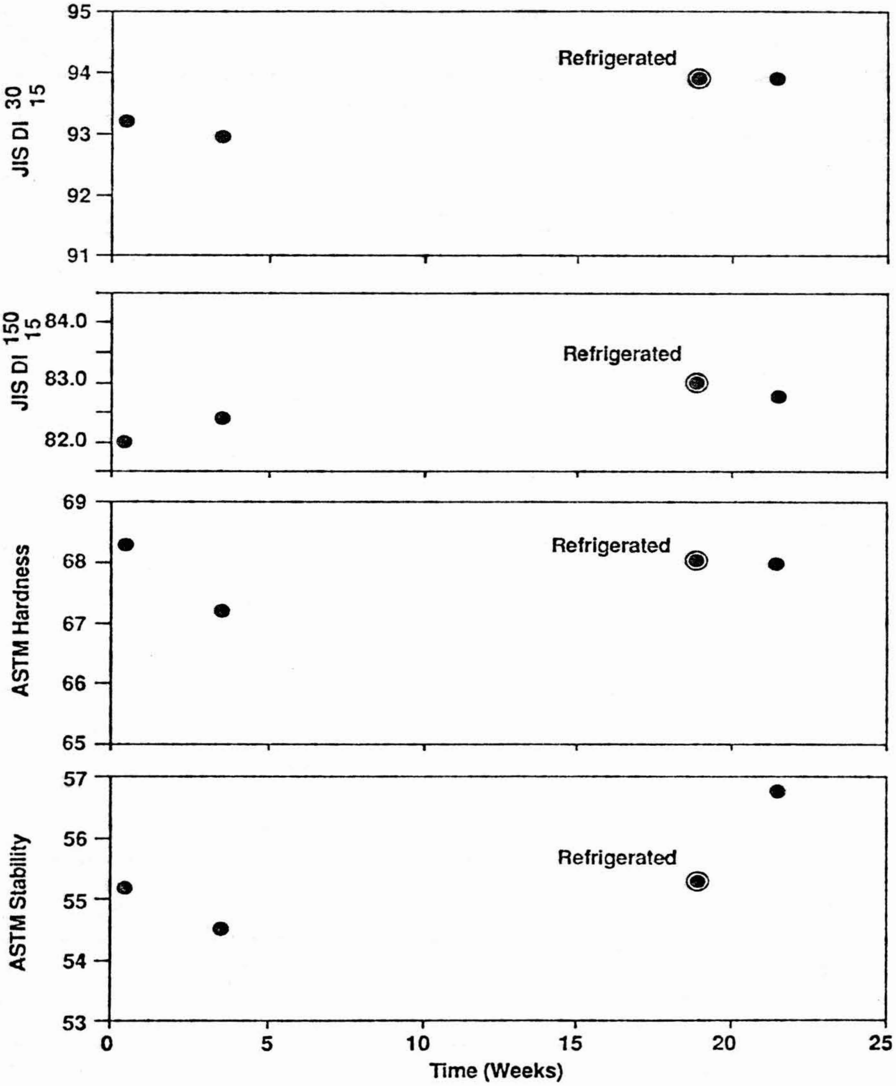


Figure 9c
REACTIVITY AND STRENGTH AFTER REACTION OF COKE VERSUS COAL STORAGE TIME