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IMPROVING COKE QUALITY WITH CANADIAN COALS

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## IMPROVING COKE QUALITY WITH CANADIAN COALS

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### ABSTRACT

Metallurgical coal deposits in Eastern Canada are Carboniferous while those in Western Canada are mainly Cretaceous in origin. The Cretaceous coals have undergone quite different coalification than the Carboniferous coals and have reduced pyrite but higher kaolinite, quartz and inerts contents. Western Canadian coals vary from high- to low-volatile in rank. They make strong blast furnace coke from conventional coke oven charges, either individually, or when blended with suitable foreign coals. Cokes made from blends with Western coals have excellent reactivity and coke strength after reaction (CSR) values because of the low basicity of their ash and coking pressures are generally low because of their high inert contents. Western coals are particularly suited to high density charging technologies such as partial briquetting because they demonstrate large improvements to coke quality and have low coking pressures. Nova Scotia coking coal, which is high volatile A bituminous has excellent caking properties and low inert and ash contents. It produces high quality coke in blends carbonized conventionally or preheated. Its ash, and caking properties complement most higher rank coals and it is ideally suited to blend with high inert low sulphur coals like those from Western Canada.

### INTRODUCTION

Canada, a major supplier of good coking coals, exported 22 million tonnes of coking coal in 1985. This represents about 81% of its coal exports and a 9% increase over 1984(1). Only about 3% of Canada's total coal production is used by the metallurgical industry because steel plants in central Canada are remote from the deposits and they import Appalachian coals from the United States (2). Bituminous metallurgical coal resources are estimated to be 2030 Mt of recoverable coal. The resources are found primarily in Nova Scotia, Alberta, and British Columbia where recoverable coal is estimated to be 133, 254, and 1643 Mt respectively (3).

The metallurgical coals from Atlantic Canada are of Carboniferous age, having formed 300 million years ago when the main coal deposition in Europe also took place. The

Sydney Coalfield forms part of the offshore Carboniferous basin which extends to Newfoundland and occupies about 36000 km<sup>2</sup>(4,5). Pyritic sulphur is removed in a coal preparation plant using heavy media cyclones and froth flotation cells. The lower specific gravity (S.G.) fractions (< 1.3) are combined to make a metallurgical coal with 3.0% ash and 1.2 % sulphur. The metallurgical coal is considered an excellent component in coking blends because of its low ash and high thermal rheological properties. Sydney is located on tide water, thus coal can be shipped easily to Ontario, Europe, and South America.

The Rocky Mountains and foothills of Alberta and British Columbia have Jurassic to early Tertiary high-rank coking coals stretching from the US border to the Yukon. These coals, having higher inertinite, kaolinite, and quartz with reduced volatile matter and pyrite contents, were generally formed in peat swamps under a non-marine cover that maintained an acidic bog with periodic oxidizing conditions(6). These coals were metamorphosed to ranks similar to the Carboniferous coking coals that are about 200 million years older; this is perhaps attributable to the effect of the Tertiary Laramide Orogeny. Shearing within coal seams has made the coal very friable, resulting in a fine particle size which contributes to difficulty in obtaining optimum wash yields and creates special handling, preparation, and drying problems. Cleaning of coal generally requires complex preparation plants using heavy media to treat coal coarser than 0.6 mm and both water-only washing cyclones and froth flotation cells to treat the fines.

Canada's coking coals have unique properties, advantages, and problems compared to coking coals from around the world . This paper describes results of carbonization research on Canadian coals sponsored by the Canada Centre for Mineral and Energy Technology (CANMET) and the Canadian Carbonization Research Association (CCRA)

## CONVENTIONAL COKEMAKING

### Results From Coking Canadian Coals

Table 1 gives results of coke oven tests done on the Eastern Canadian metallurgical coal and five typical Western Canadian coals from high-volatile A to low-volatile bituminous. Carbonization was conducted in a 460 mm wide oven with a coking time of about 13.5 h to 900 °C at coal charge bulk densities of 816 kg/m<sup>3</sup>.

The Nova Scotian coal produced coke with low strength and CSR properties probably

because of the coal's low rank and excessive caking properties. Chemically the coke has excessive sulphur. Its low ash and high fluid properties (27000 ddpm) allows it to be blended with most high-rank, low-volatile coals having high inerts and low sulphur contents to make good coke.

Table 1 - Analyses of coals and resultant cokes made from an Eastern high-volatile coal and five Western Canadian coals in CANMET pilot-scale test ovens

<u>Coal properties</u>	Nova Scotian		Western Canadian Coals			
	<u>hv</u>	<u>Coal A</u>	<u>Coal B</u>	<u>Coal C</u>	<u>Coal D</u>	<u>Coal E</u>
Mean Ro,	% 0.99	0.90	1.01	1.27	1.28	1.62
Volatile matter,	db% 36.0	31.9	26.5	21.7	21.6	17.4
Ash,	db% 3.0	6.1	7.1	9.6	9.3	7.2
Sulphur,	db% 1.25	0.48	0.50	0.28	0.40	0.38
Alkalies in coal	% 0.06	0.07	0.08	0.04	0.12	0.10
Pulverization %-3mm	81.0	84.5	93.4	90.1	91.1	82.0
Hardgrove index	65	66	89	84	89	92
<u>Caking properties</u>						
Free swelling index	8.5	8.	7.5	6.5	6.5	5.5
Gieseler plasticity(ddpm)27800	195	195	11.4	3.8	6.7	1.9
Dilatation (c+d)	% 226	66	30	0	7.0	0.
Expansion/contraction%	-15	--	-11.3	-13.5	-11.7	--
<u>Carbonization results</u>						
wall pressure,	kPa 2.1	3.7	7.2	2.1	5.8	16.1
<u>Coke properties</u>						
Ash	% 4.2	8.7	9.3	12.0	11.6	8.6
Volatile matter	% 0.9	0.8	0.8	0.7	0.8	0.6
Sulphur	% 1.04	0.37	0.38	0.27	0.36	0.32
ASTM stability	38.1	45.1	55.7	51.0	58.1	57.1
JIS DI30/15	-	92.1	-	90.8	94.6	93.2
CSR	37.0	62.1	64.0	61.4	73.9	68.3

Cokes made from most Western Canadian metallurgical coals have higher ash contents but generally meet most specifications of steel mills. Coal A is high-volatile bituminous and, like Nova Scotian coal, has a rank too low to make high-strength coke although its CSR of 62 is excellent. Coals of this nature, having low sulphur and alkali contents, having caking properties within the optimum range, and producing high CSR coke are very desirable components in coking blends. Coal B is a medium-volatile bituminous coal which produces cokes with good cold strength and CSR properties and has slightly lower ash levels than the other medium-volatile coals in Table 1. Coals C and D are typical of many medium volatile metallurgical coals from Western Canada. They can be

cleaned economically to about a 9.5% ash content to give cokes with 11-12% ash contents. The CSR values also range from very good to excellent. Coking pressures for these coals, like the high-volatile coals are low and present no danger in coke oven operation. Coal E, a low-volatile bituminous coal, produces coke with low ash, high strength and excellent CSR properties.

Table 2 -Analyses of three binary blends of Western Canadian coals and their cokes

		Western Canadian binary coal blends		
<u>Coal charge properties</u>		<u>Coal Blend 1</u>	<u>Coal Blend 2</u>	<u>Coal Blend 3</u>
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		1.13	1.08	1.17
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
<u>Ash analysis</u>	%			
SiO <sub>2</sub>		56.38	57.14	58.9
Al <sub>2</sub> O <sub>3</sub>		27.2	29.11	27.9
TiO <sub>2</sub>		1.45	1.76	1.87
P <sub>2</sub> O <sub>5</sub>		1.18	1.20	1.24
Fe <sub>2</sub> O <sub>3</sub>		6.0	3.47	3.61
CaO		2.52	2.24	1.53
MgO		0.68	0.58	0.91
Na <sub>2</sub> O		0.49	0.10	0.10
K <sub>2</sub> O		0.87	0.71	0.85
<u>Caking properties</u>				
Free swelling index		6	7	7.5
Gieseler plasticity	(ddpm)	16.8	12.0	12.5
Dilatation (c+d)	%	13.	29.	31.
Expansion/contraction	%	-10.0	-12.6	-8.2
<u>Carbonization results</u>				
Maximum wall pressure	kPa	7.3	9.1	9.5
<u>Coke Properties.</u>	%			
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 DI30/15		93.1	93.0	93.6
CSR		67.0	69.0	65.1
Coke reactivity index (CRI)		24.0	23.3	22.6

Table 3 - Properties of good coking Appalachian coal blends and their cokes

Coal Properties	Appalachian Binary Coal Blends				
	Blend 1	Blend 2	Blend 3	Blend 4	Blend 5
Ratio of components	72:28	70:30	75:25	93:7	65:35
Ro of components(a:b)	0.88:1.65	0.95:1.62	1.13:1.22	1.13:1.42	1.06:1.66
Mean Ro	1.06	1.22	1.17	1.17	1.26
Volatile matter, db%	32.9	28.7	28.2	29.0	26.8
Ash, db%	6.2	6.2	6.0	5.3	5.6
Sulphur, db%	0.89	0.81	0.72	0.62	0.72
Pulverization %-3mm	82.7	83.6	87.5	89.2	-
<u>Ash analyses</u> %					
SiO <sub>2</sub>	50.55	46.4	42.19	41.93	
Al <sub>2</sub> O <sub>3</sub>	29.1	28.5	27.54	26.92	
TiO <sub>2</sub>	1.47	1.3	1.53	1.50	
P <sub>2</sub> O <sub>5</sub>	0.18	0.24	0.46	0.38	
Fe <sub>2</sub> O <sub>3</sub>	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 <sub>2</sub> O	0.61	0.80	0.68	0.81	
K <sub>2</sub> O	1.55	2.06	1.72	1.96	
<u>Caking properties</u>					
Free swelling index	7.0	7.5	7.5	-	-
Gieseler plasticity (ddpm)	570	4380.	11090.	6530	2650.
Dilatation (c+d) %	44	134.	242.	248	122.
Expansion/contraction %	-9.6	-12.8	-9.1	-9.7	-
<u>Carbonization Results</u>					
Maximum wall pressure kPa	12.5	7.0	6.8	26.8	10.3
<u>Coke properties</u> %					
Ash	9.1	8.0	7.6	7.0	7.3
Volatile matter	0.8	0.7	0.6	0.6	0.8
Sulphur	0.63	0.74	0.64	0.62	0.64
Apparent specific gravity	0.894	0.945	0.897	0.885	0.899
ASTM stability	58.9	58.1	57.6	57.9	58.3
JIS DI30/15	94.9	94.4	94.5	95.1	-
CSR	61.6	47.5	56.9	53.6	57.4
CRI	31.0	32.7	30.5	32.5	27.0

Results From Coking Two-Component Blends of Western Canadian and Appalachian Coals

Table 2 gives pilot coke oven results showing that coke quality can be improved by blending Western Canadian coals in binary blends. Blend 1 is a two-component blend containing 65% hvb coal A and 35% lvb coal E (Table 1). Blends 2 and 3 are binary blends each containing two medium-volatile component coals from Western Canada; blend 2 contains 69% coal B and 31% coal C, whereas blend 3 contains 55% coal D (Table 1)

and 45% of another medium-volatile Western Canadian coal not listed in Table 1 but having a vitrinite reflectance of 1.08. Although total ash content may be somewhat high for some North American steel mills, coke specifications are generally good. ASTM stability and JIS drum indices are very good ( $58 \pm 1$  and  $94 \pm 1$  respectively) for these blends, better than would be predicted from their low plasticity and dilatation properties according to several coking models. CSR values are excellent as is the case for most Western Canadian coals. Coking pressures for these blends present no problems.

Table 3 shows five good coking Appalachian blends chosen to produce coke with the same ASTM stability ( $58 \pm 1$ ) as the Western Canadian blends shown in Table 2. They have much higher plasticity and dilatation properties than Western blends to produce cokes of equivalent strengths. Western Canadian coal blends have lower sulphur but higher ash contents. The CSR and CRI values of cokes produced from the Canadian blends are better than those of cokes from the Appalachian blends, consistent with the finding of Nippon Steel Corp(7). Many researchers have shown that optimum CSR and reactivity is achieved for coals at a vitrinite reflectance of 1.2-1.4 (8). Blend 1 of the Appalachian blends had component coals with Ro's deviating the most from the proposed optimum Ro, but its CSR result was better than those blends with components having Ro's nearer the optimum. The chemistry of the ash in good coking blends is a more important factor in coke reactivity and CSR than the rank of the components, coke texture, or ash quantity. The Western Canadian coals have a much lower content of basic compounds ( $\text{Fe}_2\text{O}_3$ , CaO, MgO,  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$ ) and higher contents of silica and alumina than the Appalachian coals. These parameters have been shown by CANMET and other investigators to be critical to coke reactivity and CSR (9).

#### Results From Coking Blends of Eastern And Western Canadian Coals

Nova Scotian coal was blended with each of four Western medium-volatile coals having Ro's of 1.06 to 1.38. Ash and sulphur levels can be optimized by using about 40% Western coal in the blends. Figure 1 shows that ASTM stability also attained acceptable levels for two of the blends (NS-F and NS-G) at this same blend ratio. These blends contained the higher rank coals F and G. Blends NS-H and NS-I containing the lower rank Western coals had insufficient overall rank to make high-strength coke. CSR values increased as higher levels of Western coals were incorporated into the blends. Coking pressures remained low, less than 4 kPa for all blends, throughout the study.

It can be concluded that high-strength coke with acceptable sulphur and ash levels can be made from blends of Eastern and Western Canadian coals provided the overall rank of the

blends fall within typical specifications, i.e., Ro of 1.10-1.25. The Sydney Steel Corporation has for many years made a low-ash, high-strength coke from a binary blend of Nova Scotian coal and low-volatile coal from Western Canada.

#### Cokemaking Using Appalachian Blends Containing Western Coal

Canadian steel producers typically make blast furnace coke from blends of one or more low-and high-volatile Appalachian coals. Coke quality can often be improved by adding a medium-volatile (i.e. a ternary blend) coal that bridges the fluid temperature ranges of the high and low volatile component coals.

Tests were done in CANMET's 460 mm wide test oven at flue temperatures of 1065°C and 1250°C to determine the effects on coke properties of incorporating medium volatile Western coal into high/low-volatile Appalachian blends carbonized at fast and slow coking rates. Coking times to a centre charge temperature of 900°C were about 20.4 and 14.7 h respectively for the slow and fast coking rates. The Appalachian hv coal, Ro of 1.05 and Gieseler fluidity of 23,000 ddpm, imparts excessive caking capacity in binary blends with Appalachian lv coal of Ro 1.66. The Western coal, (Ro 1.31) had low caking properties and at FSI 4 could be termed a weak coking coal.

Four separate blends were used containing hv:mv:lv ratios of: 65:0:35; 51:25:24; 36:50:14; and 18:82:0. The ratios were chosen to give a Ro of 1.26 for all blends. Figure 2 shows that 25-50% of the Western coal can be incorporated into the hv/lv blend before any significant deterioration in cold coke strength was observed at either fast or slow coking rates. CSR improved as the content of the mv coal in the blend increased and was significantly better at faster coking rates. Coke sulphur is reduced but ash content is increased with increased additions of the mv coal. Coking pressures were reduced by adding the mv coal to the blend and by coking at the slower heating rate.

#### Effects of Substituting Western and Appalachian Coals To An Industrial Blend

Three good coking medium-volatile coals (one Canadian and two Appalachian), were substituted for component coals in an industrial blend to compare their effects on coke quality, coking pressure, and per cent contraction in the sole heated oven. Table 4 shows that the cold coke strength varied according to mean Ro which was lowest for the Canadian blend. However, the CSR of the Canadian blend was 6-7 units higher. It had lower wall pressure and better contraction in the sole heated oven than the Appalachian blends, probably because of the combined effect of higher inert contents and lower Ro.



Table 4- Effects of substituting Western and Appalachian coals for components in an industrial coking blend

Coals	Ro	Dilatation	Blend Ratios			
			Reference Blend	1	2	3
U.S. lv	1.61	75.0	35.	28.	28.	28.
U.S. hv	0.95	150.0	65.	57.	57.	57.
U.S. mv - 1	1.39	77.0	-	15.	-	-
U.S. mv - 2	1.29	131.0	-	-	15.	-
Cdn. mv - 1	1.14	11.0	-	-	-	15.
Blend Ro			1.15	1.22	1.15	1.05
Dilatation		%	31	34.	38.	21.
Expansion/contraction		%	-4.8	-5.1	-5.5	-10.5
ASTM stability			57.2	62.3	58.9	55.7
CSR			61.0	60.0	60.9	67.0

#### Effect Of Mineral Matter On Coke Properties Made From Western Coals and Blends

Four coals were cleaned to different ash contents in a pilot plant to simulate industrial beneficiation by using heavy media cyclone for the +19 mm coal, water only cyclones for the -0.6 mm coal, and froth flotation circuits for the -0.2 mm material. Mean Ro, varied from 0.91 for the high-volatile coal C to 1.36 for the low-volatile coal D. Results showed that as ash content decreased, Gieseler fluidities, total dilatations, and melting ranges increased for all coals, whereas the reactive components in coals A and D increased moderately.

Cokes were made using the three washed products from each coal. Also, the different ash products for the two medium- and low-volatile coals (A, B, and D) were blended with Nova Scotian high-volatile coal E and an Appalachian low-volatile coal F (Table 5) and carbonized. Blends contained 37.5% E, 12.5% F and 50% of either coal A, B or D. Coal C, the high-volatile coal was blended with 25% low-volatile coal F.

Results of coking tests are summarized in Table 5. The strength of coke made in this oven improved as ash was removed from the four coals. CSR and CRI also improved as the ash was removed from the coals. Each 1% decrease in the ash of the parent coal improved the CSR factor by about 3.5-5% (Fig. 4). For coals A and D, the differences in ASTM stabilities (and perhaps CSR) of the coke caused by washing the coal can be attributed to changes in both inorganic and organic inert contents of the products. The relatively large improvement in coke strength for low-ash coal B is a result of the removal of coarse mineral matter during the washing process as well as the reduction of inorganic inerts.

For the cokes made from the blends of eastern Canadian/Appalachian coals with the washed Western Canadian coals, coke stability was higher for the blends containing the least ash but the differences are relatively small.

The results from this study indicated that coke strength and CSR properties would improve significantly by beneficiating Western Canadian coals to low ash levels but improvements are diminished when the coal is used in blends with other coals. Unfortunately, current beneficiation technology and market prices make beneficiation of Western Canadian coals to low ash levels uneconomical.

Table 5- Properties of cokes made from Western Canadian coals at different ash levels and in blends with Appalachian coals

		100% A			50.0% A 37.5% E 12.5% F		
Ash in coal A %		8.2	7.1	5.3	8.2	5.3	
Stability factor		50.6	50.7	56.2	56.9	58.5	
Hardness factor		63.0	61.1	68.9	68.7	69.7	
Mean coke size, mm		49.5	48.8	45.7	50.8	49.0	
Coking pressure, kPa		4.3	3.6	5.6	4.0	6.5	
		100% B			50.0% B 37.5% E 12.5% F		
Ash in coal B %		7.9	5.7	3.1	7.9	5.7	3.1
Stability factor		50.6	54.9	61.3	55.3	57.0	59.0
Hardness factor		71.1	71.5	72.3	69.3	68.0	68.5
Mean coke size, mm		54.4	49.5	45.7	51.1	50.8	50.3
Coking pressure, kPa		13.8	21.0	27.6	22.0	14.1	19.2
		100% C			75.0% C 25.0% F		
Ash in coal C %		9.6	6.6	5.1	9.6	6.6	5.1
Stability factor		43.1	48.7	46.7	55.4	57.8	57.8
Hardness factor		63.2	66.6	66.3	68.3	69.7	68.5
Mean coke size, mm		50.8	47.2	46.2	52.8	51.3	51.6
Coking pressure, kPa		4.9	6.4	5.9	10.5	14.9	13.4
		100% D			50.0% D 37.5% E 12.5% F		
Ash in coal D %		11.2	8.9	6.8	11.2	8.9	6.8
Stability factor		53.1	59.0	62.5	58.7	61.8	61.0
Hardness factor		67.6	69.4	72.9	69.5	69.5	71.1
Mean coke size, mm		61.0	55.9	52.1	54.9	53.3	51.3
Coking pressure, kPa		3.4	4.3	25.5	8.4	7.4	19.2

## THE USE OF ADDITIVES

The addition of refined petroleum pitches, coal tar pitches, and solvent refined coals to coke oven blends is being utilized commercially in Japan and has been the subject of considerable research throughout the world in recent years (10,11). Additives such as pitch and tar can be added to high inert low caking coals to improve the reactivities' content and caking properties of these coals during carbonization. Western Canadian coals that are generally high in inerts and low in caking properties might benefit from the addition of bitumen and pitch materials to bring their caking properties into the optimum coking range. An investigation into the advantages of adding several pitch materials at the 5% level to a typical steel company blend and to a blend containing 25% medium-volatile Western Canadian coal showed that the addition of certain pitches improved coke reactivity compared to that of conventional coke. However, no significant improvements to ASTM stability (about 57 for both blends) were found with the addition of pitches probably because the blends, even with high inert Western coal, had excellent caking and coking properties.

In another investigation, 7% of each of three commercially available pitch materials was added to each of three single poor-coking medium-volatile coals (Ro 1.07, 1.24, 1.42) from Western Canada(12). Figure 4 shows that the rank of the coal plays a major role in determining the coke strength improvement with pitch additives. Additions were most effective for the two higher rank coals producing cokes having physical properties considered acceptable by Canadian steel companies. Pitch additives had very little effect on microscopic texture of coke made from the lowest ranked coal but had interacted with the higher ranked coals to change coke textures. However, coke quality for all pitch/coal blends improved and is attributable to an enhancement of coke density caused by increased slumping of the coal in the coke oven. Coal contraction in the sole heated oven increased with the addition of the low melting pitches and correlated with the apparent specific gravity of the cokes made in the movable wall test oven. Not all of the improvements in coke quality can be attributed to increased coke density since the improvement in the strength of coke from the coal/pitch blends is greater than that of high density coke made from 100% coal at low moisture contents(Fig. 5).

The pitch having the best H donor ability, and the highest fixed carbon content was the most effective in modifying coal rheological properties and the mosaic textures of cokes. Coal-derived pitches (and hydrocracked petroleum) pitches seem to be more effective at improving CSR and CRI than normal petroleum derived pitches. Other less expensive additives such as decant oil proved to be almost as effective(13).

### Addition Of Chars To Nova Scotian Coking Coal

Coking coal from Nova Scotia has excessive caking properties and a rank too low to make strong coke and is usually blended by steelmakers with 20-25 % high inert low volatile coking coals. It was anticipated that coke quality could be improved by blending chars with the coal to reduce its volatile content, and reduce its caking properties.

Nova Scotian coal was charred at 400°C, 450°C, 500°C, and 700°C to determine if a suitable char could be made to blend with the fresh coal to make good coke. Volatile matters vary from 6.1 for the high-temperature char to 24.3 for the low-temperature char. Chars were crushed to about 80% minus 3 mm, then blended with the coal and charged to CANMET's 310 mm wide pilot test oven and carbonized under standard conditions. A coal to char ratio of 70:30 was chosen because dilatations (c+d) were between 50 and 100 for the different char blends.

Carbonization results in Table 6 indicate that coke quality improved most for the blends containing the chars made at lower temperatures. Coke stability for the blend containing the char made at 400°C improved about 12 units compared with that from the coal carbonized alone. Coking pressures were extremely low for all blends. Although results were encouraging, these additives did not improve coke quality enough to meet criteria of most blast furnace operators and a higher rank coal is needed in the blend to meet specification. Coke quality might be further improved by increasing the bulk density by partial briquetting or preheating these blends.

Table 6 - Carbonization Data for cokes made from Nova Scotia coal with four chars

<u>Carbonization Data</u>		Nova Scotia <u>coal</u>	NS Coal <u>400°char</u>	NS Coal <u>450°char</u>	NS Coal <u>500°char</u>	NS Coal <u>700°char</u>
Coal:char ratio		100:0	70:30	70:30	70:30	70:30
Moisture in charge	%	2.9	1.0	1.6	1.6	1.5
Coal bulk density(oven)	kg/m <sup>3</sup>	819	758	800	784	810
<u>Coke Results</u>						
Coke Yield	%	60.1	71.7	71.9	73.9	75.9
Mean Coke size	mm	47.9	49.0	45.5	42.7	91.9
+51 mm coke	%	39.2	43.4	32.7	24.9	85.7
-13 mm coke	%	4.2	4.0	3.6	3.8	4.9
ASTM stability		36.5	48.4	43.2	43.8	14.8
ASTM hardness		56.5	61.4	57.8	59.6	26.4
JIS DI150		76.4	78.8	77.7	76.6	41.0

## EFFECT OF PREHEATING

To determine the benefits of preheating Canadian coals, -three good coking Western Canadian mv coals and the Nova Scotian hv coal were carbonized under several different conditions:

1. Wet charge: coal contained about 6% moisture so the coal bulk density in the oven was low, 664-720 kg/m<sup>3</sup>(dry basis).
2. Air-dried charge: coal was air dried to 1.1-2.0% moisture so coal bulk density was high, 803-912 kg/m<sup>3</sup>.
3. Preheated charge: coal was preheated to 180-210°C and coal bulk density was 803-912 kg/m<sup>3</sup>.
4. Preheated and cooled in hopper under nitrogen before charging (Western coal A and NS E coal only) at two flue temperatures.

Figure 6 shows that preheating the coals improved coke strength and this is attributable to the higher bulk density of the preheated charges. The ASTM stability of coke from the Western coals is much more sensitive to changes in coal bulk density than the Eastern coal, as shown by the slopes of the lines for the wet and air-dried charges. Figure 6 also shows that preheated charges had similar bulk densities to air dried charges and differences in their coke stability factors are therefore attributed solely to a preheating effect. The preheating effect alone is represented by the dashed lines in Fig. 6. It shows this technology is very beneficial for the Nova Scotian hv coal and blends containing this coal but unfavourable for Western coals when carbonized alone. Preheated blends containing 75% Nova Scotian coal with 25% Western Canadian coal A had a very good ASTM stability of 57.8. Coking pressures were low for all blends tested in this investigation.

Figure 7 shows the effects of flue temperature on ASTM stability for air dried charges of the Nova Scotian coal E and Western coal A (a second set of coal samples were used). ASTM coke stability from the Western coal deteriorated for faster coking rates while it remained unchanged for the Nova Scotian coal. Coke from the preheated, then cooled, Nova Scotian coal had the same stability as the air-dried charge, precluding the possibility that significant oxidation during preheating improved the coke quality by decreasing the coal's reactives/inerts ratio(14).

## EFFECT OF PARTIALLY BRIQUETTING

Nova Scotian metallurgical coal, like most hvA bituminous coals of Appalachian age, did not improve conventional coke quality when carbonized in a charge containing 30% briquets(15). A Western hvA coal did show a small improvement in coke strength (about 1.7 stability units) when carbonized 30% partially briquetted. Carbonization of a 30% partially briquetted charge of medium-volatile Western Canadian coal having typical thermal rheological properties produced cokes of superior quality than from the same coal conventionally charged. CSR, ASTM stability, and the JIS drum indices all improved significantly by partial briquetting. Coke oven wall pressures increased to 3.6 kPa upon partial briquetting of the charge, a level considered safe by cokemakers.

Improvements to coke quality for the partially briquetted low-volatile coal were even more than for the medium-volatile coal when compared with conventional charges; ASTM stability improved by 11-13 units; the amount of coke breeze from partially briquetted charges was markedly improved. Figure 8 illustrates ASTM stability factors plotted as a function of bulk density and includes results obtained at different flue temperatures. It compares the improvement in ASTM stability caused by partially briquetting this lv coal with the improvement caused by adjustment of charge moisture to conventional charges. Thus, the finer pulverization of the coal in the briquettes, the addition of the pitch material, or, just the briquetting effect improved coke stability more than would be expected from increased bulk density alone. Relatively large coke oven wall pressures were generated at the higher bulk densities for the low-volatile coal. Although care must be taken to ensure safe wall pressures, the very large improvements to coke quality when carbonizing this coal with 30% briquettes suggested it should be an excellent blending coal for partially briquetted charges.

The effectiveness of high volatile Canadian coals in partially briquetted charges was also investigated at CANMET. Four different hv coals were used with the lv coal to determine which type of hv coal would be most effective for replacing lv coal in partially briquetted blends. The coals were:

1. Appalachian-lv, good coking coal
2. Appalachian-hv, high fluidity, good coking coal
3. Appalachian-hv, low fluidity, poor coking coal
4. Nova Scotian-hv, high fluidity, metallurgical coal
5. Western Canadian-hv, low fluidity.

The hv coals were each blended with the prime lv coal at hv:lv ratios of 75:25, 88:12, and 95:5, and these blends carbonized conventionally and then 30% partially briquetted.

Partial briquetting improved ASTM coke stability and hardness the most for the binary blends containing the low-fluidity Western Canadian coal, and then for the blend containing the highest rank Appalachian hv coal. Maximum replacement of lv coal occurred by partially briquetting the blends containing the Western Canadian hv coal. Figure 9 shows that partially briquetting a blend containing 91% Western Canadian hv and 9% Appalachian lv coal would maintain coke quality at the base level.

#### DISCUSSION AND SUMMARY

HvA coal from Nova Scotia has low ash content and a high vitrinite content after preparation, but has a rank too low to make strong coke on its own. It is an excellent coal for blending because it has high caking properties and low ash content, and can be blended with numerous coals that have higher rank but deficient reactives. It is ideal in blends with Western Canadian coking coals that have higher rank, higher inert contents, higher ash levels, and lower sulphur levels. CANMET investigations of partial briquetting and preheating of coke oven charges show that the Nova Scotian coal, when carbonized alone, is particularly suited for preheating technology. Little improvement in coke quality resulted from partially briquetting Nova Scotian coal alone but improvements were observed when blended with low-volatile coal. Large quantities of non-coking materials such as chars, semi-anthracites, and petroleum cokes could be included in conventional and partially briquetted charges containing Nova Scotian coals to improve coke quality. Nova Scotian hvA coal can be used very successfully as a binder coal for chars or non-coking coals in hot briquetting formed coke processes(16).

Coking coals from Western Canada vary in rank from high volatile bituminous to low volatile bituminous. The coals can be carbonized individually or in blends with other Western Canadian coals or foreign coals to meet the ambient coke strength specifications demanded by world cokemakers. The coals generally have ash contents that are consistent with blend averages of steel plants in Japan. Decreasing the ash content of coals gives a significant improvement to coke stability when the coals were carbonized individually but a somewhat lower improvement when carbonized in blends with Appalachian coals.

Coke strength after reaction (CSR) properties of the Western Canadian coals and blends are excellent, and CANMET studies comparing cokes made from blends of Western Canadian coals with blends made from U.S. Appalachian coals are consistent with results reported by the Nippon Steel Corporation (7). In spite of slightly higher ash contents, analysis of CANMET data shows that the very good CSR and CRI properties of Western Canadian coals are probably attributable to the low basicity and low concentrations of

elements such as Fe, Na, K, Mg, and Ca in the ash, which are known to catalyze coke reactivity and to be detrimental to coke quality (9). Also, the coals are mostly medium- to low-volatile In rank, considered optimum for CSR properties.

Nova Scotian and Appalachian coals generally have much larger Gieseler fluidities and Ruhr dilatation properties than the Cretaceous Western Canadian coals. Appalachian coals have more vitrinite, exinite, and micrinite but less semifusinite than the Western coals. Investigations have shown that differences in the dilatations of Appalachian and Western Canadian coals can not be attributed entirely to differences in particle size, coal maceral composition, and/or microlithotype composition and must be attributed in part to inherent differences in the vitrinite of the coal types. Although Western Canadian coals have less apparent caking properties, a microscopic study of the coal to coke transformation in a Western Canadian and Appalachian coal of the same rank showed the Western coal had a larger melting range than the Appalachian coal(17).

Carbonizing conditions have a significant influence on CSR and other coke properties for Canadian coals. Coke strength from Western Canadian good coking coals is particularly sensitive to changes in coal bulk density, and technologies such as partial briquetting and, to a lesser extent, preheating of coal charges are suited to these coals. Increased coking rate improves the CSR properties but is detrimental to ASTM stability (18). Finer pulverization of Western Canadian coal improved ASTM stability by about 2-4 units for every 10% increase in the amount of coal passing a 3 mm sieve (19).

Coking pressure created by coals during carbonization is also of critical concern to cokemakers around the world. With the policy of using fast coking rates in batteries higher than 5 m tall, the possibility of damage to oven walls caused by excessive carbonization pressure has become a reality. U.S. Steel, Inland Steel, Bethlehem Steel, and British Steel have all had batteries showing refractory failure (20). The Nova Scotian hv coal exhibits little or no coking pressures because of its low rank but many medium- and low-volatile Carboniferous coals can give high coking pressures. Coking investigations have shown that single coals or blends containing medium- or low-volatile Western Canadian coals generally have lower coking pressures than blends containing only Carboniferous coals. In a study reported elsewhere, the substitution of a Canadian mv coal for an Australian mv coal in an Australian (mv)/US (lv)/ U.K. (lv) blend reduced the coking pressures from an unacceptable to an acceptable value (20). The high inerts and lower caking vitrinite in the Western Canadian coals reduce coking pressures.



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## FIGURES

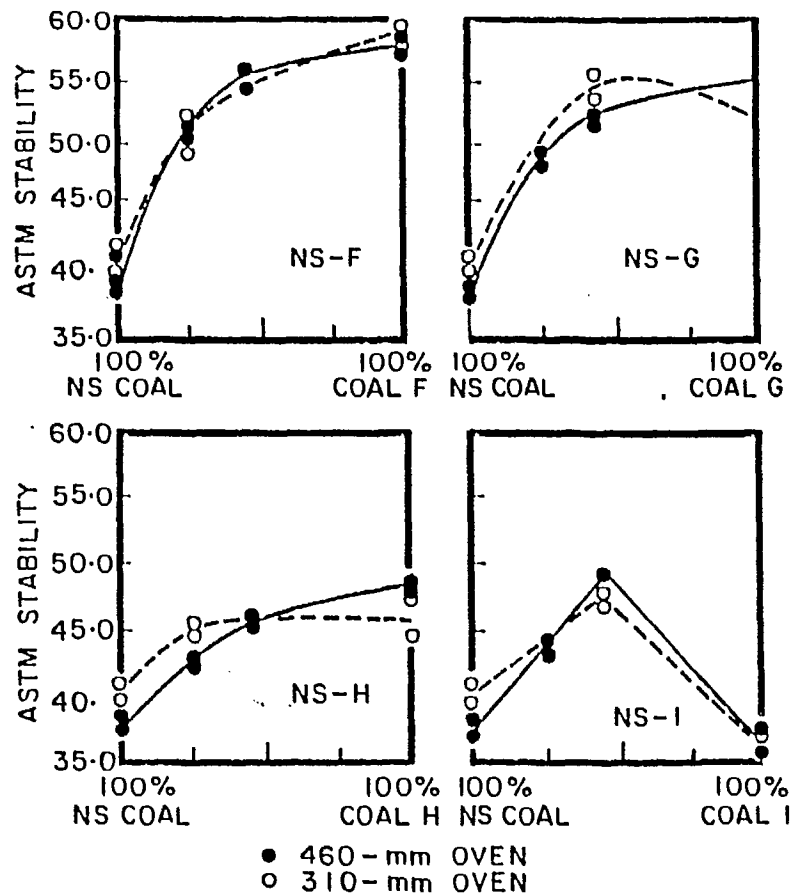


Fig. 1 - Relationship between stability factor and composition of Western Canadian/Nova Scotian coal blends

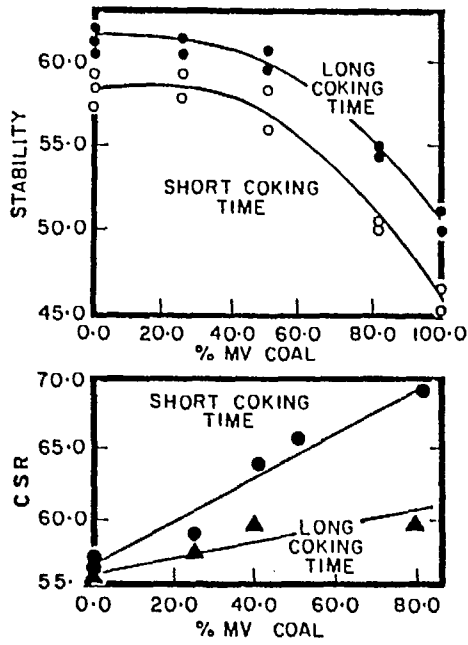


Fig. 2- Effects of heating rate and content of mv Western Canadian coal on ASTM coke stability and CSR from an Appalachian blend.

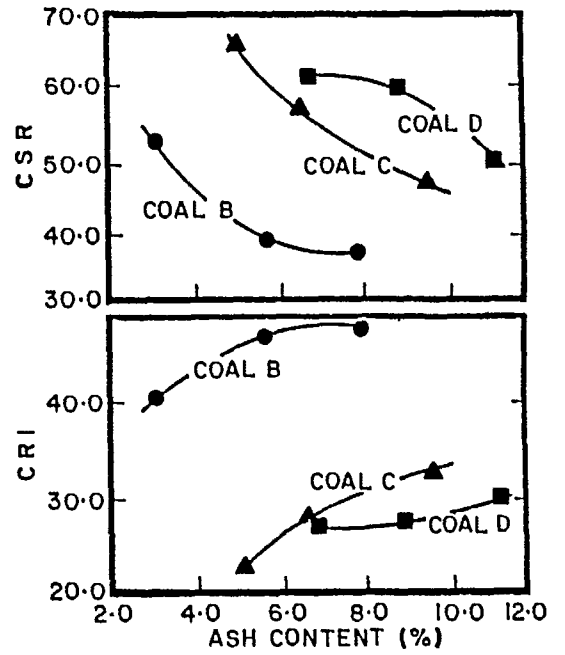


Fig. 3 - Ash content of Western Canadian coals versus CRI and CSR of their cokes

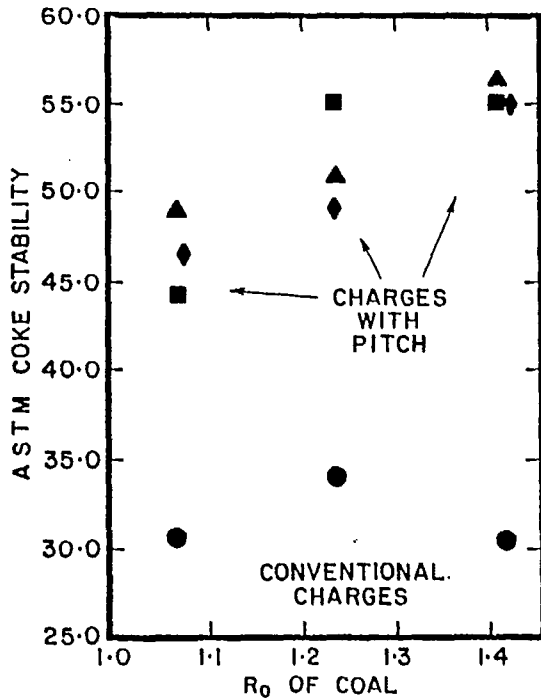


Fig. 4 Effect of coal rank on ASTM coke stability for coal/pitch blends

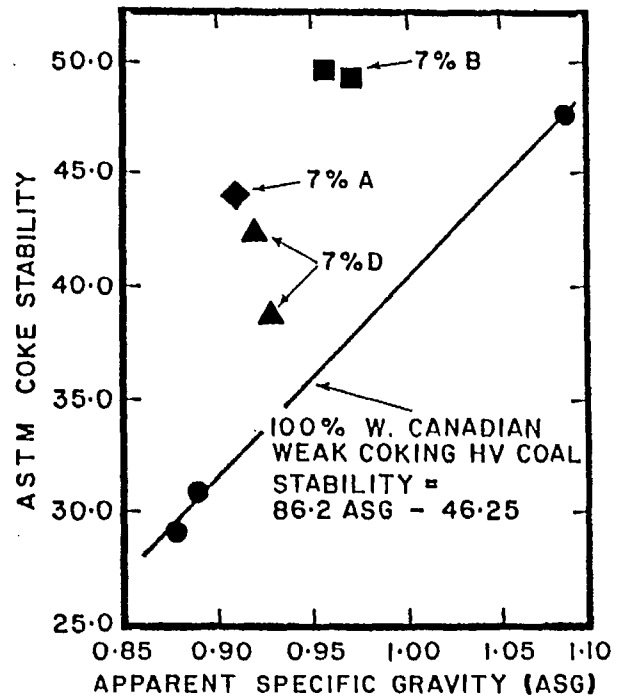


Fig. 5 - ASTM stability versus ASG for coke made from weak coking coal (Ro 1.07) with pitch additives.

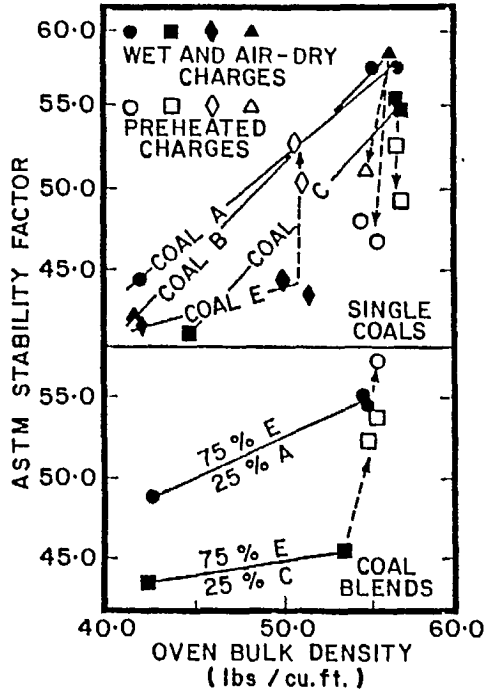


Fig.6 - ASTM stability factor versus coal bulk density for wet, air-dried, and preheated charges

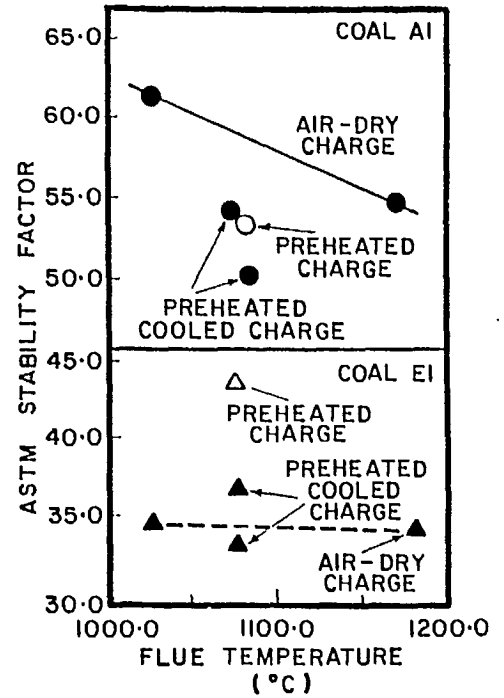


Fig. 7- ASTM stability versus oven flue temperature for preheated, preheated and cooled, and air-dried charges

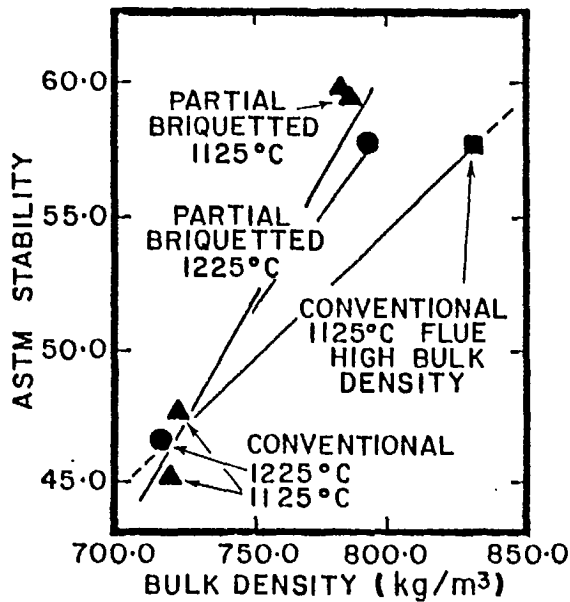


Fig. 8 - Effect of coal bulk density on the stability of cokes made from Canadian low-volatile coal

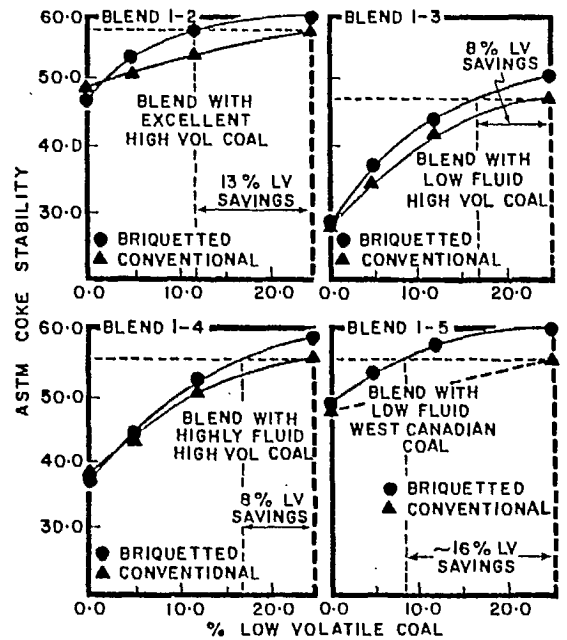


Fig. 9 - Coke stability of binary blends carbonized conventionally and partially briquetted