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Centre canadien de la technologie des minéraux et de l'énergie

REPORT 82-8E

CANADIAN R&D STUDIES OF PARTIALLY BRIQUETTED COKE OVEN CHARGES

J.T. PRICE, J.F. GRANSDEN AND W.R. LEEDER

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R-D CANADIENNE SUR L'AGGLOMÉRATION PARTIELLE DES CHARGES DE FOUR À COKE

J.T. Price*, J.F. Gransden** et W.R. Leeder**

RÉSUMÉ

L'agglomération partielle est une technique abondamment utilisée au Japon, qui améliore la qualité du coke. Elle consiste à agglomérer une partie de la charge d'un four à coke, à mélanger uniformément les briquettes obtenues à un gâteau de charbon et à enfourner le mélange dans un four à chambres classique. Les chercheurs de CANMET ont étudié cette technologie en carbonisant des charbons et des mélanges provenant des industries canadiennes de la sidérurgie et du charbon dans un four à coke pilote d'une capacité de 325 kg. L'agglomération partielle (à 30 p. 100) de quatre mélanges de cokéfaction commerciaux utilisés au Canada a permis d'augmenter la qualité du coke de 2,6 à 6,7 unités de stabilité ASTM, par rapport à celle obtenue au moyen des méthodes traditionnelles, sans élévation de la pression des parois ni modification de la productivité du four à coke. Afin de déterminer la quantité minimale de charbon à faible teneur en matières volatiles qu'il faut dans un mélange de charbons très volatils et peu volatils, les chercheurs ont mélangé quatre charbons différents à haute teneur en matières volatiles à du charbon peu volatil, dans des proportions différentes dans chaque cas. Ils les ont carbonisés de la façon habituelle et en ont aggloméré partiellement 30 p. 100. Dans le cas du charbon très volatil de l'Ouest canadien et dans le cas des meilleurs mélanges très volatils des Appalaches, la proportion nécessaire de charbon à faible teneur en matières volatiles est passée de 25 p. 100 dans une charge classique à environ 10 p. 100 dans une charge partiellement agglomérée, sans baisse de qualité. Des recherches ont également été faites sur l'addition de charbon thermique très volatil, de semi-anthracite, de poussier de coke et de coke de pétrole uniquement dans la partie agglomérée d'un mélange de charbons peu volatils et très volatils (partiellement aggloméré dans une proportion de 30 p. 100). On s'est rendu compte que l'on pouvait utiliser dans les briquettes entre 70 et 80 p. 100 de coke de pétrole ou de charbon thermique avant que la qualité du coke ne soit ramenée à celle d'une charge habituelle. On peut aussi ajouter du poussier de coke, mais en faibles quantités, et on doit alors le mélanger aux briquettes et au gâteau de charbon. Des résultats comparables ont été obtenus avec des mélanges industriels canadiens. Ces additions ont généralement pour effet de diminuer les pressions de cokéfaction. Le coke de pétrole s'est avéré un additif excellent, mais il ne pourrait remplacer entièrement le charbon peu volatil et conserver au coke sa résistance, même si 50 p. 100 de la charge était agglomérée. Selon des essais techniques exécutés sur plusieurs variables du procédé, une diminution du calibre des briquettes et une augmentation du volume de brai de 6 à 10 p. 100 donnent un coke de meilleure qualité par rapport aux charges classiques.

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CANADIAN R&D STUDIES OF PARTIALLY BRIQUETTED COKE OVEN CHARGES

by

J.T. Price*, J.F. Gransden* and W.R. Leeder**

ABSTRACT

Partial briquetting, a technology used extensively in Japan, improves coke quality by briquetting a portion of a coke oven charge and blending the briquets uniformly with matrix coal before charging the mixture to conventional slot-type coke ovens. This technology has been investigated at CANMET by carbonizing coals and blends from the Canadian steel and coal industries in a 325-kg capacity pilot-scale coke oven. Partially briquetting (30%) four commercial coking blends used in Canada improved coke quality by 2.6 to 6.7 ASTM coke stability units compared with that produced conventionally with no excessive wall pressures, and no change in coke oven productivity. To determine the minimum amount of lv coal required in binary hv-lv blends, four different hv coals were each blended with lv coal at several ratios, carbonized conventionally, and 30% partially briquetted. For both the Western Canadian hv and the best coking Appalachian hv blends the amount of lv coal required to maintain coke quality dropped from 25% in a conventionally charged blend to about 10% in partially briquetted charges. Additions of thermal hv coal, semi-anthracite, coke breeze, and petroleum coke to only the briquetted portion of a binary hv-lv (30% partially briquetted) blend were studied. About 70-80% petroleum coke or thermal coal could be substituted into the briquets before coke quality deteriorated to that of the conventionally charged base blend. Coke breeze could be added in only small amounts and should be blended into briquets and matrix coal. Similar results were obtained for Canadian industrial blends. Such additions generally decreased coking pressures. Petroleum coke proved to be an excellent additive but could not replace the lv coal completely and maintain coke strength, even if 50% of the charge was briquetted. Technical scale testing of several briquetting variables indicated finer crushing of the briquetted coal and increasing pitch levels from 6 to 10% further improved coke quality compared with that of conventional charges.

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INTRODUCTION

Partial briquetting of coke oven charges is one of several methods to improve coke quality by increasing the coal bulk density in coke ovens. Other methods include oiling, preheating, drying and mechanical densifying of the coal charge. Partial briquetting involves briquetting a coal or coal blend and uniformly mixing the briquets with a loose coal blend before dropping into the coke ovens. Microscopic examination of cokes and semi-cokes from partially briquetted charges has attributed improved coke strength to a denser coke which has contracted less and has a better continuity of cell walls than conventional coke made from the same coals (1,2). Alternatively, partial briquetting can be used to maintain coke quality while using significant amounts of cheaper, poorer quality coals or non-coking materials.

PARTIAL BRIQUETTING METHODS

Briquetting is the most common agglomeration method used to increase coal bulk density in coke ovens and investigations throughout the world have resulted in establishing commercial operations in both Germany and Japan. Three procedures are basically followed:

1. A 30% portion of the blend (coking and non-coking materials) is briquetted and the briquets mixed with the non-briquetted blend to make up the oven charge (3,4). This method is used by Nippon Kokan Keihin Corporation (NKK) and Nippon Steel Corporation (NSC).
2. The non-coking coal or material is included only in the briquets, whereas the matrix blend contains mainly good coking coals (5,6,7). This method is used by the Sumikin Coke Company.
3. The entire coal charge is briquetted using no binder and relies upon breakage during handling to form the fine coal matrix (8,9). This method is used by the Roechling-Burbach Steel Works.

SELECTING PROPORTION OF BLEND TO BRIQUET

Laboratory investigations showed that the bulk density of partially briquetted charges in a coke oven is a function of briquet density and size and the proportion of briquets in the coal charge (1,10-14). To achieve large bulk densities, care must be taken to avoid segregation of briquets from matrix coal. In general, larger briquets result in higher bulk densities of the overall charge and maximum bulk density is attained using 50% briquet addition and 50-mm diam briquets. Other investigations showed maximum bulk density was achieved between 50 and 70% briquet addition (2,15-20). However, increased bulk densities of the oven charge increased coking pressures. Japanese experiments in a Koppers test oven showed wall pressures increased with increasing briquet addition and reached an unsatisfactorily high value of 10.7 kPa when the coal charge bulk density was 825 kg/m^3, at 40% briquet addition. As a result Japanese coke producers do not exceed 30% briquet additions to avoid excessive coke oven wall pressures.

CANMET movable wall oven tests on a good coking hv-lv coking blend indicated that excessive wall pressures would be created at the higher charge bulk densities (Fig. 1) (21). Both charge bulk density and ASTM coke stability increased as more briquets were used (Fig. 2). Based on Koppers test oven experience where the maximum acceptable coking pressure is 14.0 kPa, oven bulk densities above 840 kg/m^3 must be avoided for this blend. Since wall pressures increased so rapidly past the 30% partial briquet level and the rate of increase in the coke stability decreased, the 30% addition level was generally maintained.

BRIQUET PREPARATION VARIABLES

Briquet preparation is most important for assuring good coke quality and includes such variables as binder level and composition, fineness of blend grind, briquetting pressure, etc. Many have used finer coal in the briquets than in the matrix blend (19,22,23). One study found about 6% binder was optimum for briquetting but exact amounts depended on the type of binder and the grain size of the coal (20). Others have found optimum binder levels for briquetting ranged from 1 to 6% depending on the properties of the constituent coals (12). The Sumikin Coke Company

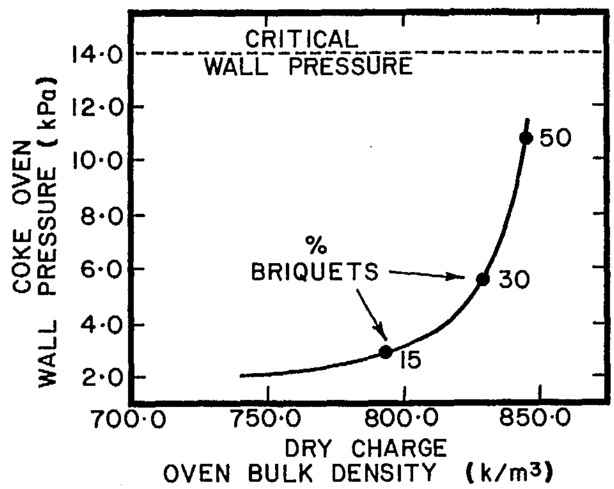

Fig. 1 - Effect of partial briquetting on dry charge bulk density and coke oven wall pressure

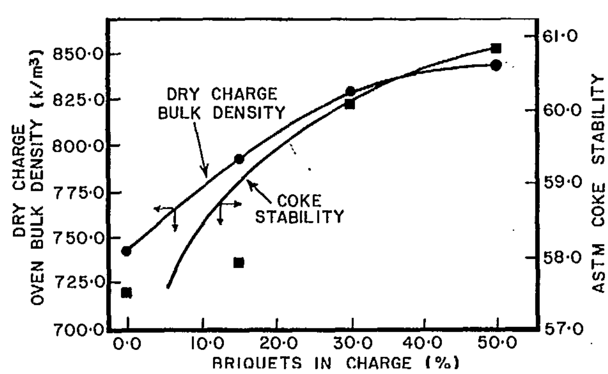

Fig. 2 - Effect of partial briquetting on dry charge bulk density and ASTM coke stability

has added special caking materials dissolved in coal tar to bind their briquets and the properties of this material allow larger amounts of non-caking coal to be added to their coal blends. Moisture contents of coal blends to be briquetted are generally held at about 7% although some investigations dried coal prior to briquetting to improve coke oven productivity (8,20). Briquetting pressures varied from 400 to 1000 kg/cm. Bulk densities of briquetted coal materials were between 1100 and 1250 kg/m^3.

USE OF POORER NON-COKING MATERIALS

Partial briquetting processes can produce good metallurgical coke from less expensive blends containing coals having poorer caking and lower rank properties. Small-scale testing at CANMET indicated that up to 20% noncoking oxidized medium volatile coal could be added to the briquetted portion of a 30% partially briquetted charge without affecting coke strength (25). Other investigations have shown that blend-caking properties as measured by plastic layer thickness, roga index, caking index, and Gieseler plasticity can be reduced significantly by partial briquetting (3,12,19, 24). For example, NKK estimates that 30% partial briquetting allows the Gieseler fluidities and rank of their blends to be extended as low as 70 ddpm with a mean maximum reflectance of vitrinite of about 1.0 to 1.05% as shown in Fig. 3 (3). The Sumi process, which uses a special caking substance in the briquet, allows up to 20% noncoking coal in their blends. However, for coals with excessive caking properties, partial briquetting is unsuitable as it does not increase coke density or improve coke strength (5,11,12). It may therefore be concluded that North American high-caking coals are unsuitable for partial briquetting.

OBJECTIVES

This report primarily discusses the application of coals and blends used in Canadian cokemaking operations to typical partial briquetting technologies used in Japan. Our investigations attempted to evaluate partial briquetting as a means of:

- increasing the strength of coke produced from Canadian commercial blends;
- reducing the amount of lv coal required to produce good metallurgical coke from these blends;
- replacing coking coal with less expensive non-coking coals in the blend, while maintaining coke quality; and
- improving coke strength by optimizing variables associated with the partial briquetting process.

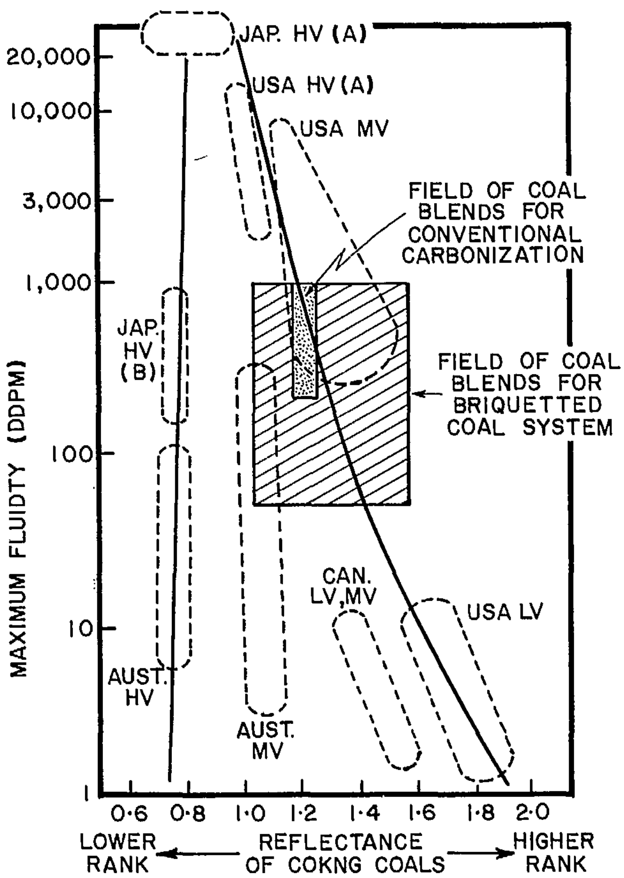

Fig. 3 - Fluidity of bituminous coals versus rank showing acceptable range of coking coal properties for conventional and 30% partially briquetted charges, Ref. (3)

EXPERIMENTAL PROCEDURES AND CONDITIONS

Carbonization tests were conducted in a CANMET movable wall test oven which has a coking chamber 457 mm wide, 914 mm long, 914 mm high to the coal levelling door sill, and a charge capacity of 325 kg. The oven flue temperature is maintained at 1125°C by electrically heated globars and the heat is transferred to the coal charge through high density silica bricks similar to those used industrially. Standard procedure is to charge the oven with coal containing 6% moisture and a nominal pulverization level of 80 ± 5% minus 3 mm, resulting in a coal bulk density in the oven of about 744 kg/m^3 (dry basis). About 18 h is required to carbonize the charge to a centre temperature of 1000°C.

The matrix coal for 30% partially briquetted charges was prepared identically to that for conventional charging and was sampled for rheological and petrographic analyses. The coal or blend for briquetting was pulverized nominally to 90% minus 1 mm, mixed with 6% roofing asphalt (softening point 77°C) in a double-arm kneader-mixer heated to 100°C, and then briquetted in a double roll press which produced 30 x 30 x 18-mm pillow-shaped briquets. Briquet moisture at the time of charging was 1.2- 1.8%. A flow diagram of CANMET's partial briquetting procedures is shown in Fig. 4.

Segregation of the loose coal from the briquets must be avoided during charging and matrix coal and briquets were layered into a charging hopper and dropped into the test oven (7,19,24). The briquet distribution in the oven resulting from this charging technique was examined by charging a wooden box, the size of the coking chamber with a blend of matrix coal containing 30% briquets. The amount of coal and briquets in the left and right halves of the box appeared to be equivalent. However, bulk densities generally increased from the top to bottom quarters of the box with the amount of briquets increasing from about 20% in the top section to about 33% at the bottom. Although these percentages indicated the charges had greater briquet density at the bottom of the oven, the briquets were considered to be well distributed within the matrix coal.

After carbonization the coke was pushed from the oven, water quenched, dropped 3 m to simulate commercial coke handling, dried, screened, and tested for coke strength according to ASTM and JIS tumbler methods (26,27). Strength after reaction (SAR) tests were made on selected cokes (28).

CANADIAN STEEL INDUSTRY COAL BLENDS

Canadian cokemaking blends differ from Japanese blends in having higher fluidity and low reflectances (Table 1). The Japanese, in develop-

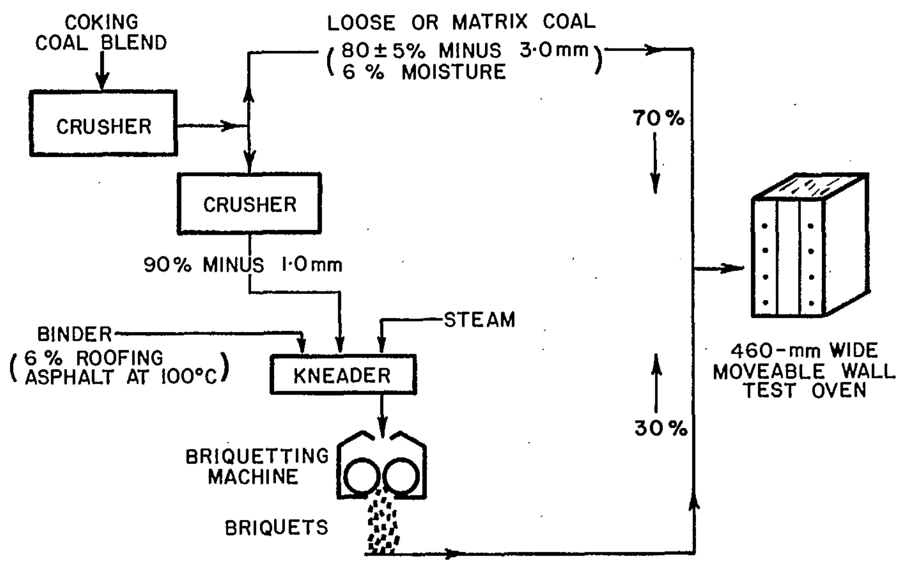

Fig. 4 - Flow diagram of CANMET's partial briquetting procedure

ing the partial briquetting process, did not test Canadian-type coal blends and even suggested that partial briquetting would not improve the strength of the coke produced from them (29). Since little was published about the influence of partial briquetting on Canadian types of coking blends, an independent study was made.

Four reference production coal blends were supplied by the major steel producers in Canada - Algoma Steel Corporation, Dominion Foundry and Steel Corporation, Steel Company of Canada Ltd. and Sydney Steel Corporation. Detailed analyses of the four commercial blends are given in Table 2. Carbonization tests were done on the blends as received, with 30% of the blend briquetted. To determine the effects of binder and finer grinding used for producing the briquets that would normally improve coke strength, additional carbonization tests were done on loose blends of matrix coal and briquets, i.e., crushed to 90% minus 1 mm.

CONVENTIONALLY CHARGED BLENDS

Averaged results from two or more carbonization tests on the four Canadian commercial blends are given in Table 3. Conventional charging of these blends gave coke strengths as measured by ASTM stability ranging from 55.2 for blend D to 48.7% for blend B. The low result for blend B was attributed to its coarser particle size.

Table 1 - Comparison of typical Canadian and Japanese coal blends

Coal blend properties	Canadian	Japanese
Chemical analysis, (db) %		
Volatile matter	27 - 30	26 - 28
Ash	4 - 7.5	8 - 9
Fixed carbon	63 - 68	68 - 65
Gieseler maximum fluidity, ddpm	700 - 2500	180 - 300
Mean maximum reflectance, Ro, %	1.07 - 1.17	1.16 - 1.25

Table 2 - Detailed analyses of Canadian commercial blends

Reference	Properties								
coal	VM(db)	Ash	Ro	%P	TD	FI	FT	ST	FSI
A	26.9	7.1	1.17	86.4	87	715	420	483	8.5
B	29.4	7.4	1.17	71.8	77	1230	416	483	8.0
C	30.2	4.0	1.07	83.2	127	2075	413	482	7.0
D	30.2	6.1	1.08	80.3	68	2500	414	479	7.0

VM = volatile matter; Ro = mean maximum reflectance; %P = blend pulverization level, % less than 3 mm in tests; TD = total dilatation (contraction plus dilatation); FI, FT, ST = Gieseler plastometer maximum fluidity, fusion temperature and solidification temperature, respectively; FSI = free swelling index.

Table 3 - Results of carbonization tests using commercial blends

		Coal blend						
		A				B		
Type of charge		ℓ	b	c	c_1	ℓ	b	c
Moisture in charge	(%)	5.7	4.4	6.0	4.2	5.8	5.0	6.2
Bulk density in oven (db)	(kg/m^3)	753.6	824	773	814	779	834	790
Coking time to 900°C	(h:min)	15:48	17:07	16:10	17:03	16:48	18:08	17:03
Coke yield	(%)	74.6	73.9	72.9	73.9	72.7	71.3	71.1
Mean coke size	(mm)	72.9	73.4	71.8	71.6	60.1	58.9	59.9
+50-mm coke	(%)	78.3	79.3	78.7	78.7	63.2	60.8	62.7
-12.7-mm coke	(%)	2.9	2.6	3.0	2.9	3.8	3.1	3.8
Max. wall pressure	(kPa)	1.7	2.6	1.3	2.8	1.5	4.3	3.3
ASG		0.86	0.90	0.86	0.88	0.85	0.88	0.82
ASTM stability	(%)	54.5	61.2	57.0	58.4	48.8	53.2	50.6
hardness	(%)	60.9	66.3	62.7	63.4	63.9	66.4	64.3
JIS DI_{15}^{30}	(%)	93.1	95.0	94.9	94.7	92.2	93.2	92.5
JIS DI_{15}^{150}	(%)	79.4	84.2	82.5	83.6	78.7	80.7	79.5
Strength after reaction	(%)	28.0	33.6	-	-	36.8	38.6	-
Reaction	(%)	42.0	39.1	-	-	40.9	41.3	-

ℓ is conventional charge, b is 30% partially briquetted charge, c is crushed-briquetted charge at 6% moisture, c_1 is crushed-briquetted charge at 4% moisture

Table 3 (cont'd)

Type of charge		Coal blend						
		C				D		
		ℓ	b	c	c_1	ℓ	b	c
Moisture in charge	(%)	6.3	4.7	6.0	4.3	6.0	4.5	6.2
Bulk density in oven (db)	(kg/m^3)	754	811	779	830	730	826	723
Coking time to 900°C	(h:min)	18:00	18:32	17:00	18:05	15:25	17:31	16:00
Coke yield	(%)	69.2	70.4	69.4	69.1	71.0	71.8	69.0
Mean coke size	(mm)	59.4	58.1	59.2	59.2	64.0	63.2	62.7
+50-mm coke	(%)	62.5	61.2	64.6	65.2	67.8	65.5	65.5
-12.7-mm coke	(%)	3.4	2.8	2.7	2.9	3.4	2.8	3.5
Max. wall pressure	(kPa)	2.7	4.6	2.1	4.7	4.0	3.0	1.7
ASG		0.78	0.81	0.80	0.83	0.80	0.85	0.80
ASTM stability	(%)	52.5	58.4	54.8	57.2	55.2	58.0	55.3
ASTM hardness	(%)	60.0	65.5	62.6	65.4	65.1	67.6	64.3
JIS DI^{30}_{15}	(%)	93.8	94.6	94.1	94.3	94.0	94.2	94.1
JIS DI^{150}_{15}	(%)	80.9	83.7	82.9	82.9	82.4	83.6	82.7
Strength after reaction	(%)	38.7	51.3	-	-	-	53.1	48.1
Reaction	(%)	38.6	33.5	-	-	-	33.5	33.1

ℓ conventional charge, b is 30% partially briquetted charge, c is crushed-briquetted charge at 6% moisture, c_1 is crushed-briquetted charge at 4% moisture

PARTIALLY BRIQUETTED CHARGES

Partially briquetting 30% of the reference coal blends improved the strength properties of all resultant cokes, i.e., ASTM stability increased by an average of 4.2 units as indicated in Table 3. Compared with the conventional charge the ASTM stability factor for the partially briquetted blend A improved the most, at 6.7 units whereas blend D improved the least, at 2.6. Results were similar for both the JIS and ASTM hardness indices. Blend A had the highest rank and lowest fluidity of the reference blends, whereas blend D made the strongest conventional coke and had high fluidity. The small improvement of blend D is consistent with Japanese findings for highly fluid good coking coals (5,19).

The strength after reaction (SAR) results also showed partial briquetting improved coke quality for commercial blends - the SAR values increased by an average of 6 units. Coke from partially briquetted blend C improved the most according to SAR results; however, the order of coke quality for the partially briquetted blends was D>C>B>A. Thus blend A, producing the best coke according to tumbler testing, gave the poorest coke according to SAR testing. (Cokes from technical scale oven tests have lower SAR values than commercial coke previously tested (29); this is attributed to the smaller ASG of cokes made in the 460-mm oven).

The higher bulk density of the partially briquetted blends produced cokes with apparent specific gravities (ASG) about 0.04 units higher than the conventional charge and caused oven wall pressures to increase to values between 2.6 and 5.0 kPa, well below the critical pressure of 14 kPa. Coke size decreased on partial briquetting by an average of 1.0 mm (2%) for three of the reference blends but increased slightly for blend A.

CRUSHED-BRIQUETTED BLENDS

The commercial blends containing 30% crushed briquets (90% minus 1.0 mm) were carbonized to determine the effects of binder and finer coal in the briquets on coke quality. All crushed-briquetted blends charged at 6% moisture produced stronger cokes according to ASTM and JIS tumbler indices than those made from conventional charges at the same moisture level but weaker than the cokes made from partially briquetted charges. The addition of pitch and finer crushing of coal improved the stability factor by an average of 1.7 units compared with that of the conventionally charged blends. The actual improvement attributed solely to briquetting was 2.0 units as determined from results of briquetted and crushed briquetted charges containing 4.3% moisture. Coke ASG, size, and coke-oven-wall pressures were similar for conventional and 30% crushed-briquetted charges. The SAR of coke made from a crushed-briquetted charge of blend D, the only charge of this type tested, was poorer than that for coke from the same briquetted charge.

COKE PRODUCTIVITY

Figure 5 shows a plot of coke oven centre temperature as a function of time for two conventional, three partially briquetted, and two crushed-briquetted charges of blend A. This figure is typical for all blends tested and shows that although there were differences for individual charges, the coking times for partially-briquetted charges were longer than for conventional or crushed-briquetted charges.

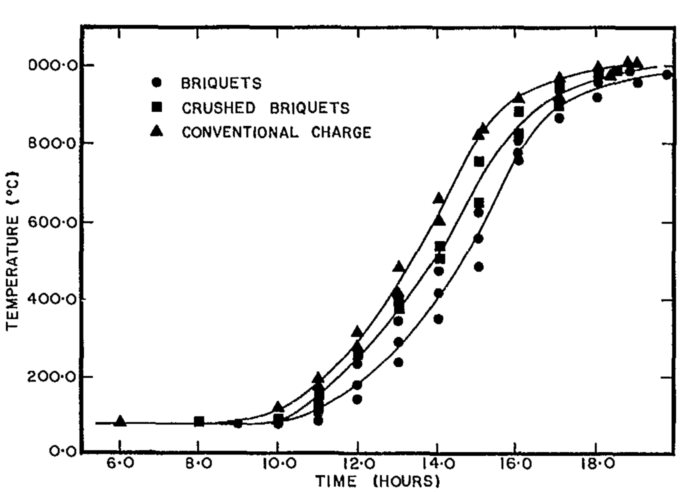

Fig. 5 - Average coking times for conventional, partially briquetted and crushed-briquetted blend of Company A

Although it is difficult to determine productivity differences from coking times and throughputs of pilot-scale test ovens, coal and coke throughputs per unit time were estimated for each blend by averaging test results. The productivity ratio, R, of briquetted to conventional charges:

$$R_x = \frac{w_b/t_b}{w_l/t_l}$$

where w_b and w_l are weights of briquetted and conventional charges, and t_b and t_l are coking times to 900°C plus 2 h for briquetted and conventional charges, was used as an indication of the influence of partial briquetting upon coke oven productivity. The per cent change in productivity was calculated as 100 (R_x-1). The same type of productivity comparison can be made based on coke outputs per unit time using the above formula but in this case w_b and w_l represent weights of coke from briquetted and conventional charges respectively; R_y would represent the productivity ratio based on coke.

Table 4 shows ratios for briquetted and crushed-briquetted charges compared with conventional charges. Although the reliability of these ratios for any one of the blends may be doubtful because of errors associated with small scale testing, sufficient tests, 31 in all, were made on all blends to give the overall ratios some significance. The effects of partiallybriquetted or crushed-briquetted charges on coke oven productivity is on the average negligible if based on coal throughput and decreased slightly if based on coke outputs. The latter decrease in productivity may be associated with a slight overall decrease in coke yields caused by the higher VM content of the pitch binder used in the briquets.

Table 4 - Ratios for productivities of 30% partially briquetted blends relative to conventional charges

Reference coal	Production briquetted vs R_x	Ratios for conventional R_y	Production crushed briquets vs R_x	Ratios for conventional R_y
A	1.037	1.027	1.027	0.984
B	1.001	0.985	1.004	0.983
C	0.945	0.962	0.979	0.980
D	1.006	0.983	1.007	0.968
Average	0.998	0.989	1.004	0.979
Average productivity increase (%)	nil	-1.1	nil	-2.1

R_x is based on coal throughput for test oven

R_y is based on coke output from test oven

REDUCTION IN LOW-VOLATILE COAL REQUIREMENTS

One of the objectives of partial briquetting is to reduce the expensive lv portion of conventional Canadian hv-lv coking blends while maintaining coke quality. Binary hv-lv coal blends were partially briquetted and carbonized to determine the amount of lv coal that could be replaced by hv coal while maintaining coke quality of the conventionally charged base blend (75% hv:25% lv). One prime coking U.S. lv coal was used in all blends. 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. They were:

1. U.S. - lv, good coking
2. U.S. - hv, high fluidity, good coking
3. U.S. - hv, low fluidity, poor coking
4. Eastern Canadian - hv, high fluidity, poor coking
5. Western Canadian - hv, low fluidity.

Complete coal properties are listed in Table 5.

The hv coals were each blended with the prime lv coal at hv:lv ratios of 75:25, 88:12, and 95:5, carbonized conventionally and then 30% partially briquetted. Results in Table 6 are the mean of duplicate tests.

Table 5 - Properties of coals

Coal	Properties* VM	Ash	Ro	%P	TD	FI	FT	ST	FSI
1	18.8	7.0	1.67	90.0	33	10.4	437	501	7.5
2	32.9	6.0	1.05	85.1	111	1900	414	474	8.0
3	34.4	7.2	0.92	84.8	40	327	416	461	3.5
4	32.8	3.1	1.00	83.5	157	4700	410	480	8.0
5	32.0	5.4	0.94	84.6	37	339	28	478	-

*See Table 2 for explanation of symbols

Table 6 - Carbonization results from conventional and partially briquetted binary blends

		Blends of coals 1-2 (highly fluid-good coking hv)									
hv:lv ratio:		75:25		88:12		95:5		100% 2		100% 1	
Type of charge		ℓ	b	ℓ	b	ℓ	b	ℓ	b	ℓ	b
Moisture in charge	(%)	6.0	4.5	5.8	4.6	5.9	4.6	6.1	4.6	6.2	4.6
Bulk density in oven (db)	(kg/m^3)	734	826	726	837	728	813	731	749	747	826
Coking time to 900°C	(h:min)	15:20	16:33	14:55	16:38	14:40	18:33	16:22	17:32	18:10	-
Coke yield	(%)	73.0	70.9	70.9	70.0	69.3	70.8	69.7	69.8	76.5	73.8
Mean coke size	(mm)	60.5	60.2	59.7	59.4	60.5	59.4	63.2	59.9	62.0	56.9
+50-mm coke	(%)	63.8	61.5	62.8	60.7	63.1	62.2	68.1	60.7	65.4	58.3
-12.7-mm coke	(%)	3.7	3.1	3.7	3.0	3.5	3.4	3.5	3.3	7.6	5.9
Max. wall pressure	(kPa)	2.6	3.6	-	2.6	3.4	1.9	-	1.7	>140	>142
ASG		0.83	0.83	0.80	0.83	0.82	0.85	0.82	0.85	-	-
ASTM stability	(%)	57.3	60.4	53.5	57.7	50.4	53.3	49.4	46.8	57.8	56.0
hardness	(%)	65.5	67.2	62.2	66.5	60.7	64.6	61.8	62.7	63.7	63.6
DI_{15}^{30}	(%)	95.0	94.7	93.5	94.4	93.3	93.4	92.4	92.4	93.2	93.6
JIS DI_{15}^{150}	(%)	83.6	84.7	81.1	83.7	79.5	82.0	78.0	78.8	80.1	81.3

ℓ is conventional charge

b is briquetted charge

Table 6 (cont'd)

		Blends of coals 1-3 (low fluid-poor coking hv)							
hv:lv ratio:		75:25		88:12		95:5		100% 3	
Type of charge		ℓ	b	ℓ	b	ℓ	b	ℓ	b
Moisture in charge	(%)	6.1	4.6	5.4	4.6	5.4	4.6	6.0	4.6
Bulk density in oven (db)	(kg/m^3)	754	829	749	829	746	806	723	814
Coking time to 900°C	(h:min)	17:42	18:42	17:22	18:00	17:33	18:15	17:27	18:10
Coke yield	(%)	71.1	71.1	70.0	69.4	69.3	70.1	68.7	66.6
Mean coke size	(mm)	65.5	61.7	60.5	61.0	56.6	56.1	56.9	54.9
+51-mm coke	(%)	64.0	63.1	63.0	62.7	58.8	58.0	57.2	56.1
-12.7-mm coke	(%)	5.6	4.6	5.7	4.6	5.9	5.5	6.4	5.0
Max. wall pressure	(kPa)	1.3	2.4	2.2	-	1.72	2.1	-	-
ASG		0.82	0.87	0.80	0.86	0.80	0.83	0.80	0.85
ASTM stability	(%)	47.9	50.2	41.4	43.5	34.0	36.5	28.0	28.0
hardness	(%)	60.9	65.7	60.0	63.6	59.4	63.7	58.9	61.7
DI_{15}^{30}	(%)	91.7	92.7	88.7	91.0	88.0	88.9	85.7	86.0
JIS DI_{15}^{150}	(%)	77.5	79.9	74.0	75.5	69.5	70.5	66.3	66.5

ℓ is conventional charge,

b is briquetted charge

Table 6 (cont'd)

		Blends of coals 1-4 (highly fluid-poor coking hv)							
hv:lv ratio:		75:25		88:12		95:5		100% 4	
Type of charge		ℓ	b	ℓ	b	ℓ	b	ℓ	b
Moisture in charge	(%)	5.8	4.7	6.0	4.6	5.8	4.6	6.0	6.0
Bulk density in oven (db)	(kg/m^3)	734	811	734	797	739	797	738	792
Coking time to 900°C	(h:min)	15:51	17:33	16:00	17:05	16:05	17:21	14:50	16:12
Coke yield	(%)	70.0	67.6	68.1	69.0	65.2	67.3	64.6	67.2
Mean coke size	(mm)	62.4	60.7	61.7	57.4	57.4	55.9	57.2	52.1
+50-mm coke	(%)	71.0	66.6	65.0	61.2	61.5	56.5	61.0	49.8
-12.7-mm coke	(%)	3.4	2.9	3.4	3.3	3.6	3.4	3.6	3.6
Max. wall pressure	(kPa)	3.7	4.7	3.3	2.7	1.9	1.9	2.1	3.2
ASG		0.77	0.79	0.76	0.80	0.74	0.80	0.76	0.77
ASTM stability	(%)	56.3	58.5	50.8	52.3	42.7	44.6	38.1	36.5
hardness	(%)	61.7	64.9	58.6	64.3	57.9	63.2	55.8	60.6
JIS DI^{30}_{15}	(%)	94.6	94.8	92.9	94.1	91.1	91.8	91.7	91.6
JIS DI^{150}_{15}	(%)	82.2	83.5	78.6	81.7	75.5	77.4	75.2	74.7

ℓ is conventional charge

b is briquetted charge

Table 6 (cont'd)

		Blends of coals 1-5 (W. Cdn. low fluid hv)					
hv:lv ratio:		75:25		88:12	95:5	100% 5	
Type of charge		ℓ	b	b	b	ℓ	b
Moisture in charge	(%)	6.0	4.8	4.8	4.8	6.0	4.8
Bulk density in oven (db)	(kg/m^3)	752	800	795	797	727	803
Coking time to 900°C	(h:min)	16:35	17:00	17:05	16:50	16:15	18:15
Coke yield	(%)	70.1	70.8	70.7	69.8	67.4	69.5
Mean coke size	(mm)	60.1	57.0	54.0	54.5	56.6	58.4
+51-mm coke	(%)	64.9	56.7	53.1	52.2	58.6	56.7
-12.7-mm coke	(%)	4.0	3.2	3.4	3.3	4.1	3.3
Max. wall pressure	(kPa)	1.79	3.41	1.9	1.6	1.8	1.72
ASG		0.84	0.89	0.88	0.88	0.81	0.86
ASTM stability	(%)	56.2	60.6	57.3	52.6	45.9	47.6
hardness	(%)	63.3	68.4	67.1	66.6	58.8	62.1
JIS DI^{30}_{15}	(%)	94.4	94.4	94.0	92.5	90.6	92.5
JIS DI^{150}_{15}	(%)	84.1	83.9	83.2	80.9	78.3	79.2

ℓ is conventional charge

b is briquetted charge

CONVENTIONAL CARBONIZATION OF BINARY BLENDS

Conventional carbonization showed coke quality for blends 1-2, 1-3, and 1-4 was substantially different as indicated by ASTM stabilities in Fig. 6. The Western Canadian blend 1-5 was similar to blend 1-2 which gave the best coke stability results.

COKE QUALITY FROM 30% PARTIALLY BRIQUETTED CHARGES OF BINARY BLENDS

Coke strength indices of all partially briquetted binary blends were better than those of the corresponding conventional charge (Fig. 7). Improvements were generally smaller than for the commercial blends. Partial briquetting improved ASTM coke stability and hardness the most for the binary blend containing the low-fluidity Western Canadian coal, and then for the blend containing the good coking U.S. hv coal - about 4 ASTM stability units. Partially briquetting the blends containing poor coking hv coals only increased ASTM stability by about 2 units. Thus, maximum benefits from partial briquetting occurred for blends 1-2 and 1-5, containing the better coking hv coals (Fig. 6,7). These blends could reduce the lv coal requirements to about 10% with no decrease in coke quality from the non-briquetted base blend (75% hv:25% lv).

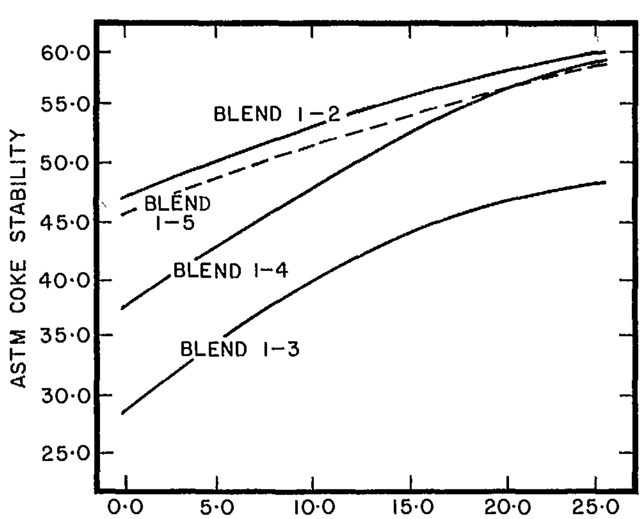

Fig. 6 - Dependence of coke strength on amount of lv coal for conventionally charged binary blends

Coke ASG increased for the partially briquetted binary blends reflecting the increased bulk density of coal in the oven compared with conventional charges. Table 6 also shows a decrease in coke size and coke breeze for briquetted charges compared with that of conventional charges. Coke yields lessened, as expected, with decreased amounts of lv coal in the blends but did not change significantly from conventional- to partially-briquetted charges. Coking pressures remained low.

PARTIAL BRIQUETTING OF SINGLE COALS

Table 6 and Fig. 7 show that carbonizing 30% partially briquetted single coal charges alone increased the ASTM coke stability for only one of the five coals tested. Figure 8 shows the decline in coke stability when the high fluidity Eastern Canadian hv coal was carbonized with 0%, 30% and 50% of the blend briquetted. Only the low-fluidity high-inert Western Canadian hv coal showed any improvement in coke stability when partially briquetted. The ASTM coke hardness factor, the JIS drum indices, and the amount of coke breeze generally improved for all coals after partial briquetting.

ADDITION OF NON-COKING COALS AND ADDITIVES

Another possible use of partial briquetting is to replace coking coals with cheaper, poorer coking coals, non-coking coals or additives. Conventional carbonization of coking coal blended with non-coking coal decreases coke strength as seen in Fig. 9 (15). Workers at Sumikin Coke Company have indicated that partial briquetting enables replacing 15 to 20% of the conventional coal charge with non-coking coals while maintaining the original coke strength (15). Small-scale coking tests at CANMET indicated that at least 10% oxidized bituminous coal could be added to the briquetted portion of a 30% partially-briquetted charge without deteriorating coke quality (25).

Tests were conducted at CANMET to determine the maximum amount of additive or noncoking coal that could be substituted for a good coking

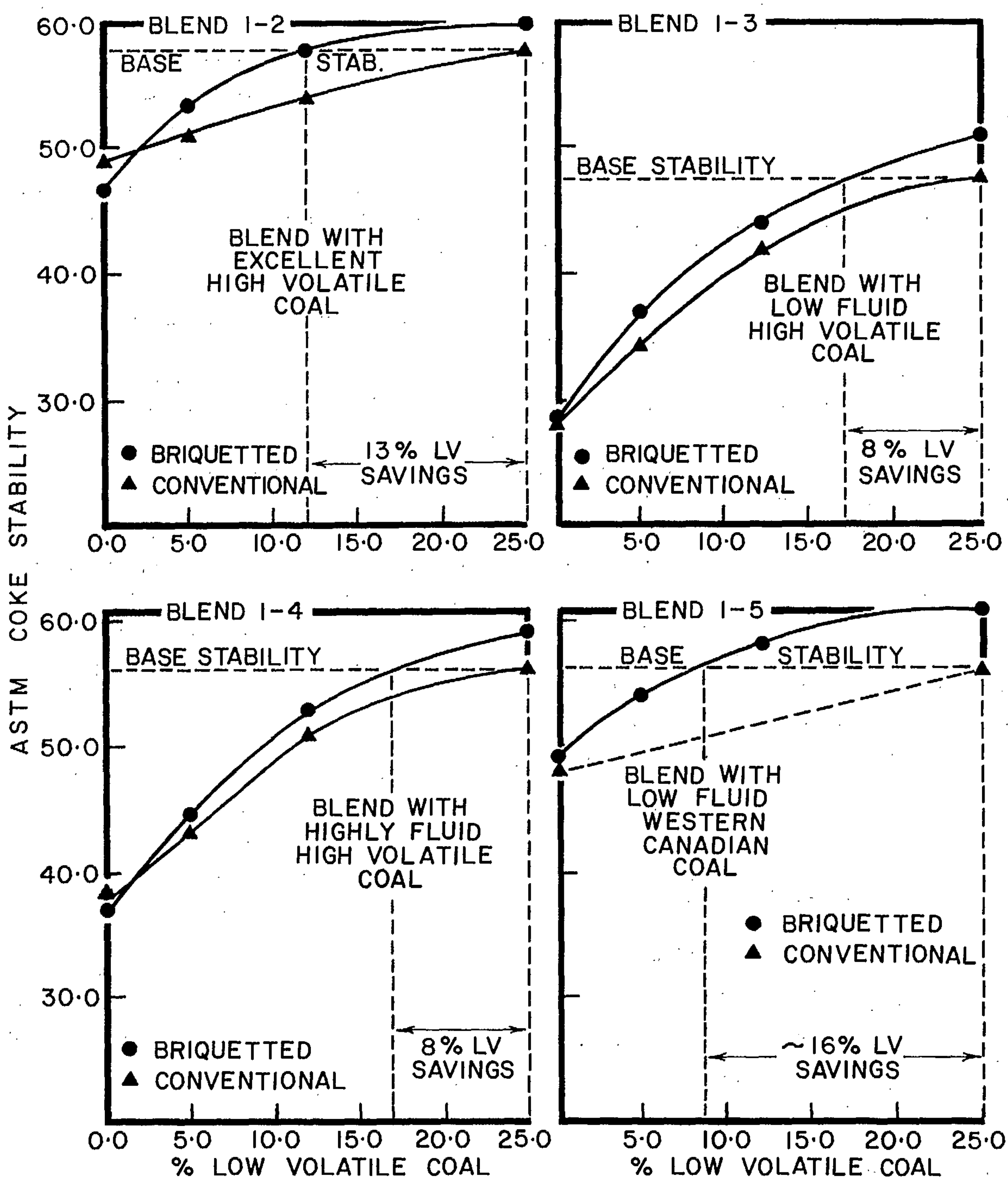

Fig. 7 - Coke stability of binary blends carbonized conventionally and partially briquetted

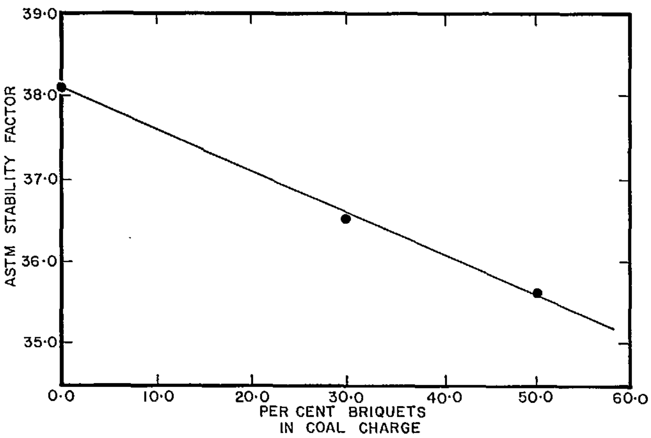

Fig. 8 - Decline in coke stability of Eastern Canadian·hv coal upon partial briquetting

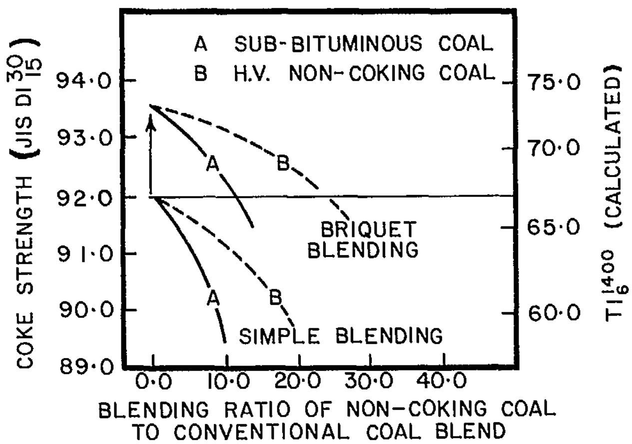

Fig. 9 - Influence of non-coking coal additions and partial briquetting on coke quality (Ref. 15)

coal blend (75% hv:25% lv) while maintaining coke stability. The additives and non-coking coals were:

- Canadian hvA bituminous, high-ash, thermal coal (coal 6)
- Canadian semi-anthracite coal (coal 7)
- coke breeze
- petroleum coke.

Details of coal properties are listed in Table 7.

The non-coking materials replaced the blend on a 1:1 basis in the briquetted portion of the blend. The briquets also contained 6% asphalt binder and the coke oven charge was comprised of 30% briquets, 70% good coking blend.

Table 7 - Properties of coking and non-coking materials used in partial briquetting with additives

	Properties*									
Coking coals	VM	Ash	S	Ro	%P	TD	FI	FT	ST	FSI
Coal 4'	36.2	2.7	1.2	1.01	85.5	198	23,407	408	483	8.5
Coal 1'	19.1	6.6	-	1.71	90.4	52	22.3	463	501	8.0
Non-coking additives										
Coal 6	36.2	15.7	2.54	0.73	100	0	5.3	424	441	5
Coal 7	12.5	9.5	-	2.15	100	-	-	-	-	0.5
Petroleum coke	18.2	0.0	4.27	-	-	-	-	-	-	-
Coke breeze	-	-	-	-	-	-	-	-	-	-

*See Table 2 for explanation of symbols

Coals 4' and 1' are separate shipments of coals 1 and 4 used earlier - see Table 5

Coal 6 is thermal hvA

Coal 7 is semi-anthracite

ADDITION OF POOR COKING THERMAL HVA COAL TO BRIQUETS

The Eastern Canadian thermal hvA coal 6 which has poor caking properties as measured by a Gieseler maximum fluidity of 5 ddpm was added to the briquetted portion of a good coking blend (75% coal 4':25% coal 1'). Table 8 compares carbonization results from the good coking blend tested conventionally, 30% partially briquetted, and with 17, 33, 67 and 100% coal 6 substituted into the briquets. Results are averages of duplicate tests. Partial briquetting of the good coking blend increased dry coal bulk density in the oven from 747 to 838 kg/m^3, oven wall pressure from 2.0 to 4.3 kPa, and improved coke strength.

Figure 10 shows the addition of coal 6 to the briquetted blend decreased the ASTM coke stability from 59.6 for the partially-briquetted base blend to 50.2 for those tests in which the briquets contained only coal 6. It also shows that about 60-65% of coal 6 could be substituted into the briquets before coke strength deteriorated to below that of the non-briquetted good coking blend. A similar result was obtained from the JIS tumbler indices. Figure 8 shows that the additions had little effect upon ASTM hardness factor, ASG, coke size, coke yield, or coking times; the amount of coke breeze produced increased only slightly. Coking pressures of partially briquetted charges decreased with increased addition of poor coking coal as shown in Fig. 11.

ADDITION OF NON-COKING SEMI-ANTHRACITE COAL TO BRIQUETS

The Canadian semi-anthracite coal 7 had no thermal rheological properties. Table 9 compares carbonization results from the good coking blend (75% 4' and 25% 1') tested conventionally and partially briquetted with coal 7 added to the briquets.

Figure 12(a) shows that semi-anthracite additions to the briquets did not deteriorate ASTM coke stability until the additions exceeded about

Table 8 - Carbonization results from the addition of thermal hvA coal 6 to the 30% briquetted portion of charges containing base blend 75% coal 4' and 25% coal 1'

		Oven charges					
		Conventionally charged base blend	Partially briquetted charges % of coal 6 in briquets				
			0	17	33	67	100
Moisture in charge	(%)	6.0	4.6	4.8	4.6	5.1	5.1
Bulk density (db)	(kg/m^3)	747	838	840	840	835	842
Coking time to 900°C	(h:min)	16:20	19:20	19:25	19:37	19:20	19:22
Coke yield	(%)	69.8	71.5	71.6	71.2	72.0	72.4
Mean coke size	(mm)	61.5	61.0	63.0	62.5	63.0	62.7
+51-mm coke	(%)	70.7	70.2	72.4	71.9	71.0	67.8
-12.7-mm coke	(%)	2.7	2.4	2.4	2.5	2.8	3.0
Max. wall pressure	(kPa)	2.96	5.2	3.8	3.5	3.1	2.3
ASG		0.77	0.84	0.83	0.86	0.86	0.86
ASTM stability	(%)	56.6	59.6	58.3	58.7	56.5	50.2
hardness	(%)	61.3	64.9	63.4	65.8	65.6	64.2
JIS DI_{15}^{30}	(%)	93.3	95.3	94.2	94.7	93.8	92.8
JIS DI_{15}^{150}	(%)	81.1	84.8	84.2	84.6	82.4	78.3

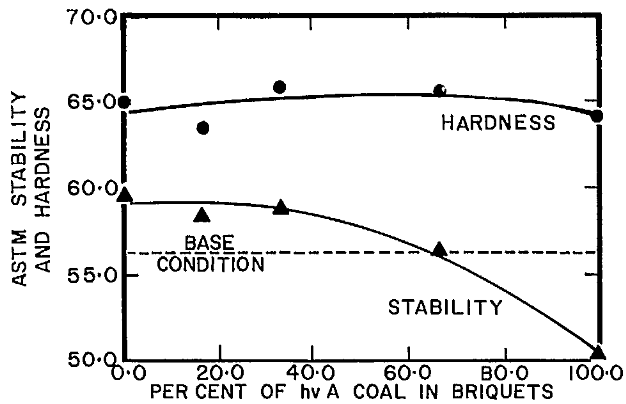

Fig. 10 - Effects of adding hvA thermal coal to briquets on coke quality of a coking blend 30% partially briquetted

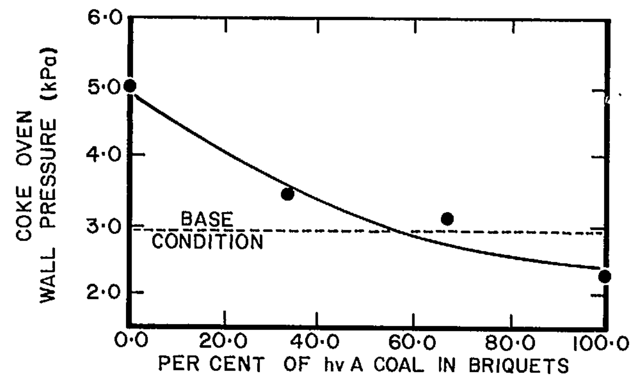

Fig. 11 - Effects of adding hvA thermal coal to briquets on coke oven wall pressures for a coking blend 30% partially briquetted

Table 9 - Carbonization results from the addition of semi-anthracite coal 7 to briquets of partially briquetted charges 75% coal 4' and 25% coal 1'

		Oven charges						
		Conventionally charged base blend	Partially briquetted charges % of coal 7 in briquets					
			0	17	33	50	66	100
Moisture in charge	(%)	6.2	4.8	4.9	4.9	4.8	4.9	4.8
Bulk density (db)	(kg/m^3)	728	819	819	819	810	824	816
Coking time to 900°C	(h:min)	16:40	18:05	18:00	17:50	18:50	18:22	18:42
Coke yield	(%)	70.4	70.0	71.8	71.4	71.4	72.8	74.2
Mean coke size	(mm)	63.0	58.4	59.9	62.0	61.7	62.5	55.9
+51-mm coke	(%)	73.0	64.7	67.2	70.4	66.6	69.4	57.9
-12.7-mm coke	(%)	2.7	3.0	3.2	3.2	3.0	3.6	8.2
Max. wall pressure	(kPa)	2.1	4.3	3.7	2.8	2.9	2.1	2.1
ASG		0.77	0.82	0.84	0.86	0.87	0.88	0.88
ASTM stability	(%)	55.8	57.8	58.6	57.4	53.4	52.2	39.1
hardness	(%)	60.5	64.6	64.4	63.2	61.5	61.7	49.3
JIS DI^{30}_{15}	(%)	94.1	94.3	94.0	94.2	93.4	94.0	82.8
JIS DI^{150}_{15}	(%)	82.5	83.1	81.9	82.1	80.2	81.0	64.3

33% of the briquet (10% of blend); and the stability of the partially-briquetted charges exceeded that of the conventionally charged base until the briquets contained more than 45% semi-anthracite. Strength indices from JIS tumbler tests also decreased quickly after substitutions of more than 33% semi-anthracite.

Semi-anthracite additions to the briquets of 30% partially-briquetted charges increased coke yield and ASG which can be attributed to the lower VM content of this coal (Fig. 12(b),(c)). The semi-anthracite also decreased coking pressures and behaved as an antifissurant causing coke size to increase until excessive amounts (100% in the briquets) were added as shown in Fig. 13. The percentage of coke breeze increased only slightly when semi-anthracite additions were increased; these results were similar to those for the poor coking thermal coal.

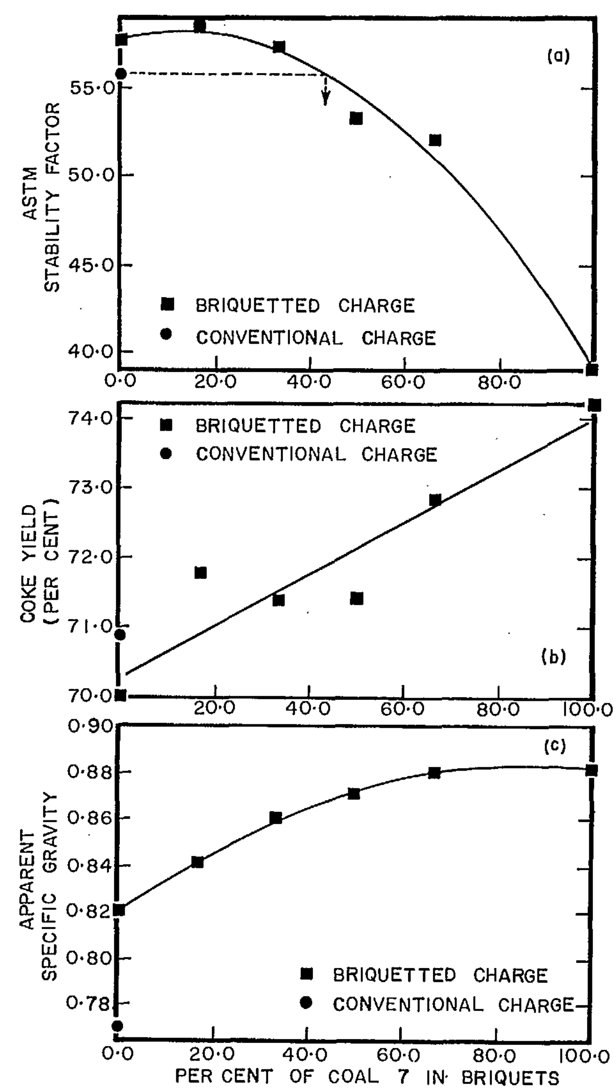

Fig. 12 - ASTM stability, yields, and apparent specific gravities of cokes made from partially briquetted charges with semi-anthracite added to the briquets

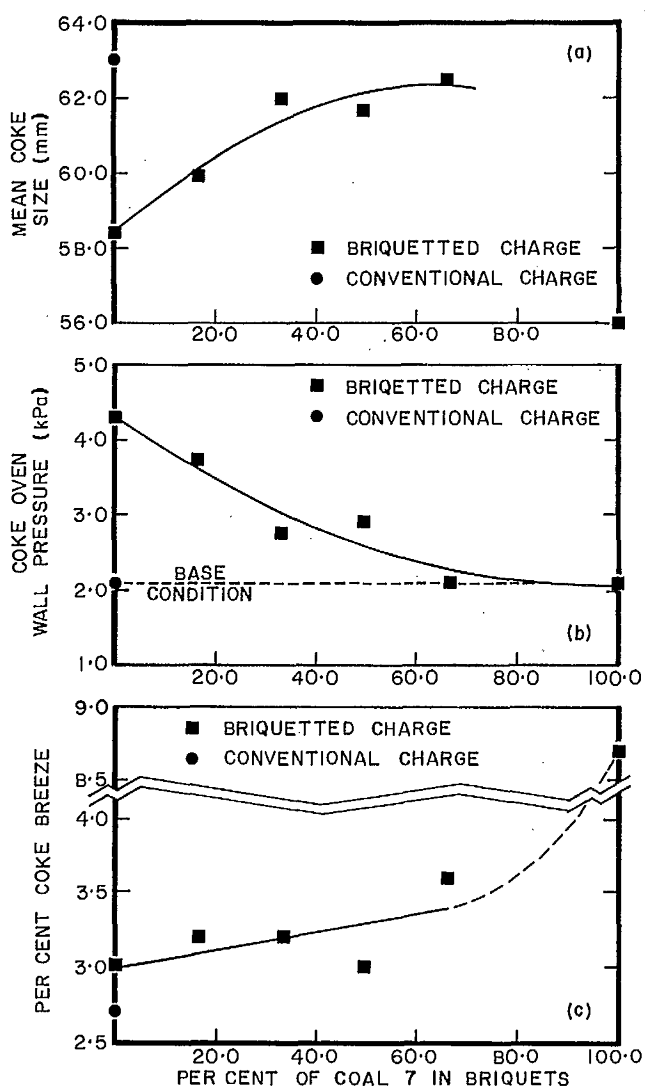

Fig. 13 - (a) Mean coke size (b) oven wall pressures and (c) amount of coke breeze from 30% partially briquetted charges with semi-anthracite added to the briquets

ADDITION OF COKE BREEZE TO PARTIALLY-BRIQUETTED CHARGES

Metallurgical coke breeze was added to the briquetted portion of a 75% hv:25% lv blend of a new shipment of coals 4"-1". Properties of the new coal samples are listed in Table 10. Two sizes of coke breeze were used to determine if larger sizes could be included in partially-briquetted coke oven charges. Earlier investigations indicated up to 7% of finely pulverized coke breeze could be added to conventionally charged Canadian blends (30). For this study, coke breeze designated as "fine" was pulverized to 80% minus 250 µm. The coarse coke breeze was between 1.0 and 4.76 mm. The addition of fine coke breeze decreased ASTM coke stability, from 60.0% for the 30% briquetted base coal blend to 26.7% for a charge with briquets containing 33% coke breeze (10% of the charge) (Fig. 14).

Only 14% fine coke breeze can be incorporated into the briquetted portion of partially-briquetted charges if coke stability is to be maintained at that of the base condition representing only 4-5% of the total coal charge. This is less than can be accommodated in loose charges, e.g., 7-10%. The thermal rheology also suggested coke quality would deteriorate quickly with greater than 10% additions of coke breeze (Fig. 15).

Additions of fine coke breeze decreased coking pressure and behaved as an antifissurant causing coke size to increase with increased additions until excessive amounts were added as shown in Fig. 16.

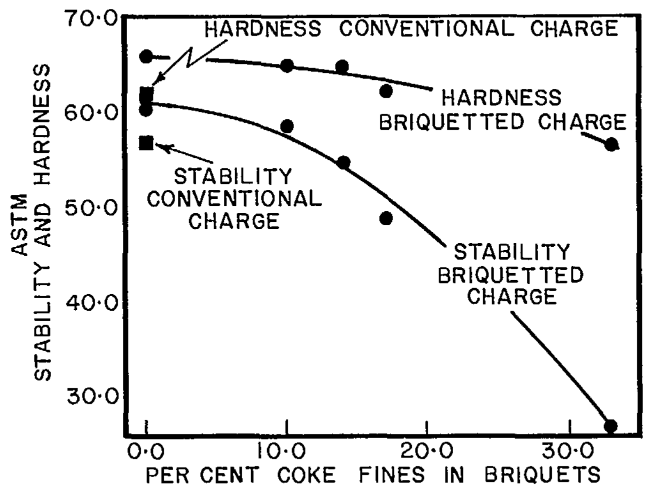

Fig. 14 - Effects of adding coke breeze to briquets on the quality of coke from partially briquetted charges

Carbonization results shown in Table 11 indicate additions of coarse coke breeze decreased coke stability even more rapidly than for the fine additions and only about 3-4% of the coarse coke breeze could be added to the briquets and maintain the stability of the base condition.

Further tests in which small amounts of fine coke breeze were substituted into both matrix coal and briquets are summarized in Table 12. Coke of good quality can be maintained by distributing up to 10% coke breeze uniformly throughout the partially-briquetted charge.

By adding coke breeze to partially-briquetted charges the differences in shrinkage

Table 10 - Properties of coals used when coke breeze was added to briquets of partially briquetted charges

	Properties*									
Coal	VM	Ash	S	Ro	%P	TD	FI	FT	ST	FSI
1"	17.9	6.4	0.73	1.71	90.4	66	40	461	499	8.5
4"	35.5	2.7	1.28	0.97	85.8	171	7537	409	481	8

*See Table 2 for explanation of symbols.

Coals 1" and 4" represent new batches of the same coal used previously.

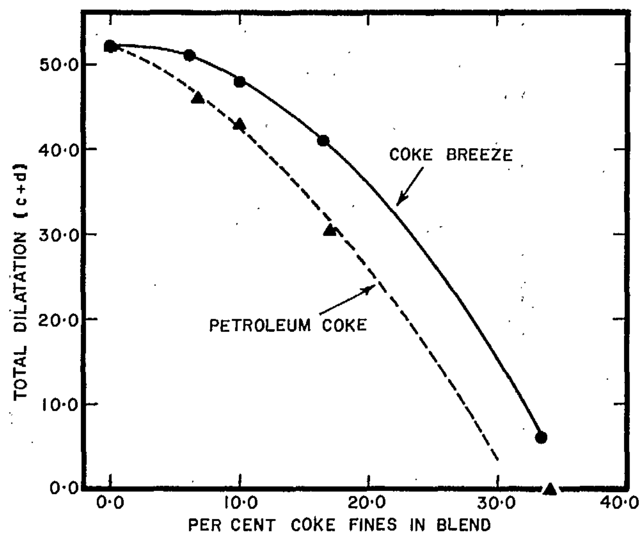

Fig. 15 - Effects of adding metallurgical and petroleum coke fines on the total dilatation of coking blend 1-4

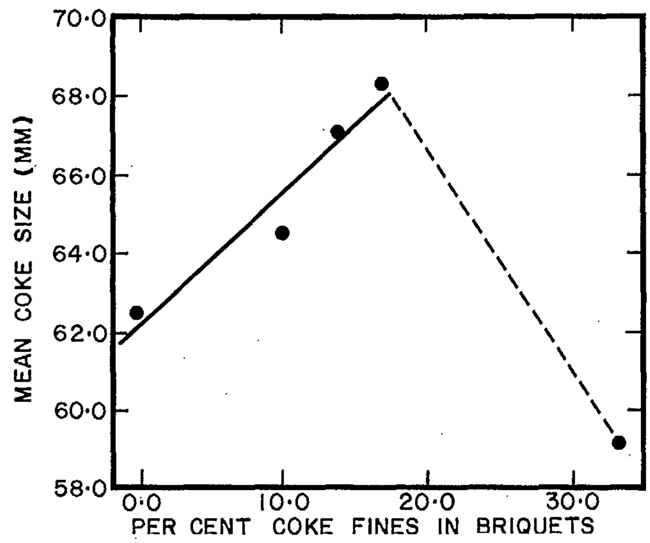

Fig. 16 - Effects of adding fine metallurgical coke breeze to briquets of partially briquetted charges on the mean size of the resultant coke

between the coking matrix and the coke breeze during carbonization may control the size and strength of the resultant coke. Therefore, in partially-briquetted charges coke breeze should be:

- added in small quantities (about 10%);
- pulverized to a fine level;
- homogeneously distributed throughout the briquet and matrix coal.

ADDITION OF PETROLEUM COKE TO BRIQUETS

A delayed petroleum coke was substituted into the briquetted portion of the base coal blend 4"-1" used for coke breeze additions. Although Fig. 15 shows the total dilatation of this blend deteriorates more quickly with petroleum coke additions than with metallurgical coke breeze additions, carbonization results shown in Table 13 indicate this material is an excellent additive for cokemaking. The ASTM coke stability factor improved from 60.0 for coke from the partially-briquetted base blend to 62.5 for the partially-briquetted charges with briquets containing 33% petroleum coke. Extrapolation of results indicated that as much as 70% petroleum coke could be added to the briquets of 30% partially-briquetted coke oven charges and coke strength would be maintained at that of the conventionally charged base blend. Petroleum coke additions decreased coking times and with its low VM content petroleum coke should also improve coke yield, hence oven productivity. Oven wall pressures remained low for all tests with petroleum coke additions.

The high sulphur contents of this and most other delayed petroleum cokes would prohibit large additions; the charge made with 20% petroleum coke (66% of the briquet) had a coke sulphur content of 1.6% compared with 1.0% for the base blend.

COMPARISON OF ADDITIVE EFFECTS ON COKE QUALITY

Figure 17 compares ASTM coke stabilities from all tests of partially-briquetted charges with poor and non-coking materials added to the briquetted portion of the blend. For this study petroleum coke was the best additive, then poor-coking hvA coal, semi-anthracite, and finally coke breeze. Generally all additives decreased coke oven wall pressures. The coke breeze and semi-anthracite behaved as antifissurants.

Table 11 - Carbonization results from the addition of coke breeze to the 30% briquetted charges containing base blend 75% coal 4" and 25% coal 1"

		Conventionally charged base blend	30% Partially briquetted charges							
			Base blend 30% briquetted		Briquets with					
					10% Coke fines	14% Coke fines	17% Coke fines	33% Coke fines	7% Coarse coke breeze	10% Coarse coke breeze
Moisture in charge	(%)	6.1	5.4	4.7	4.5	4.8	4.7	4.7	4.8	4.8
Bulk density (db)	(kg/m^3)	728	822	816	821	830	826	822	821	814
Coking time to 900°C	(h:min)	16:15	18:30	18:15	18:00	17:45	17:45	19:45	18:40	18:45
Coke yield	(%)	74.6	70.4	69.7	71.2	71.0	70.7	74.4	72.2	71.0
Mean coke size	(mm)	60.2	62.5	62.2	64.5	67.0	68.3	59.2	50.2	45.7
+51-mm coke	(%)	64.9	70.2	71.7	74.1	74.3	74.0	53.7	46.8	38.8
Coke breeze	(%)	2.6	2.4	2.9	2.8	3.4	2.7	5.7	5.9	7.4
Max. wall pressure	(kPa)	1.7	3.2	3.6	4.07	3.9	2.8	1.9	3.2	1.9
ASG		0.78	0.83	0.83	0.82	0.86	0.85	0.82	0.86	0.82
ASTM stability	(%)	56.8	60.3	59.8	58.6	54.9	48.9	26.7	51.9	47.9
Hardness	(%)	61.5	65.6	65.3	64.8	64.7	62.1	56.5	63.9	62.3
JIS DI_{15}^{30}	(%)	94.7	94.6	95.2	94.4	93.9	92.2	83.1	91.6	89.0
JIS DI_{15}^{150}	(%)	83.0	84.5	86.5	83.2	82.4	80.2	61.3	77.2	76.1

Table 12 - Carbonization results from addition of coke breeze to briquets and matrix coal of 30% partially briquetted charges

Components in loose coal		93% BB + 7% Coke fines	93% BB + 7% Coke fines	93% BB + 7% Coke fines	93% BB + 7% Coke fines	90% BB + 10% Coke fines
Components in briquetted coal		93% BB + 7% Coke fines	90% BB + 10% Coke fines	86% BB + 14% Coke fines	80% BB + 20% Coke fines	90% BB + 10% Coke fines
Moisture in charge	(%)	4.5	4.8	4.8	4.8	4.8
Bulk density (db)	(kg/m^3)	814	827	822	816	830
Coking time to 900°C	(h:min)	17:00	18:00	18:40	17:30	17:00
Coke yield	(%)	70.6	71.6	71.0	71.5	71.1
Mean coke size	(mm)	66.8	79.0	81.5	83.1	83.8
+50-mm coke	(%)	81.0	86.2	85.8	84.9	87.8
Coke breeze	(%)	2.7	3.3	2.6	3.20	2.8
Max. wall pressure	(kPa)	2.9	3.3	2.9	2.9	2.9
ASG		0.871	0.857	0.869	0.846	0.864
ASTM stability	(%)	58.9	59.9	56.6	51.1	58.1
hardness	(%)	64.0	63.3	61.0	56.5	61.1
JIS DI^{30}_{15}	(%)	94.6	94.2	94.3	93.4	94.4
JIS DI^{150}_{15}	(%)	83.5	83.1	82.3	78.2	83.2

BB is base blend of 75% coal 4" and 25% coal 1"

Table 13 - Carbonization results from addition of petroleum coke to briquets of 30% partially briquetted charges containing base blend 75% coal 4" and 25% coal 1"

		Conventional charge	30% Partially briquetted charges				
					Petroleum coke added		
Composition of charge		Base blend	Base blend only		Briquets with 10% pet. coke (-10 mesh)	Briquets with 33% pet. coke	Briquets with 66% pet. coke
Moisture in charge	(%)	6.1	5.4	4.7	5.1	4.8	5.8
Bulk density (db)	(kg/m^3)	728	822	816	824	821	808
Coking time to 900°C	(h:min)	16:15	18:30	18:15	17:40	17:00	17:00
Coke yield	(%)	74.6	70.4	69.7	70.5	70.0	72.4
Mean coke size	(mm)	60.2	62.5	62.2	62.0	61.7	61.7
+50-mm coke	(%)	64.9	70.2	71.7	70.4	68.1	67.7
Coke breeze	(%)	2.6	2.4	2.9	2.4	2.5	3.0
Max. wall pressure	(kPa)	1.7	3.2	3.7	3.9	2.1	2.22
ASG		0.78	0.83	0.83	0.86	0.88	0.92
ASTM stability	(%)	56.8	60.3	59.8	62.4	62.5	59.5
hardness	(%)	61.5	65.6	65.3	67.4	67.0	66.3
JIS DI^{30}_{15}	(%)	94.7	94.6	95.2	95.0	95.0	93.7
JIS DI^{150}_{15}	(%)	83.0	84.5	86.5	86.2	86.2	82.7

TOTAL REPLACEMENT OF LV COAL BY PETROLEUM COKE IN BINARY BLENDS

As mentioned, petroleum coke proved to be an excellent substitute for a good coking coal blend in partially-briquetted charges and was used in this study to determine if it could replace totally the lv coal used in blends with Eastern Canadian hvA coal 4. Delayed petroleum cokes have VM contents (13-18%) similar to that of lv coals and their high-inert contents would lower the excessive caking properties of coal 4 as shown in Fig. 18.

Adding 20% petroleum coke to coal 4 coked conventionally improved coke stability from 38 for the coal alone to 46.0 as shown in Table 14 but this is still substantially lower than the 56 stability obtained from the hv-lv blend (Fig. 17). For the petroleum coke-coal 4 blend, 50% of the charge was partially briquetted in an attempt to achieve acceptable coke strengths and because previous tests gave low coke oven wall pressures. Partially briquetting 50% of the 20% petroleum coke-coal 4 blend improved ASTM coke stability

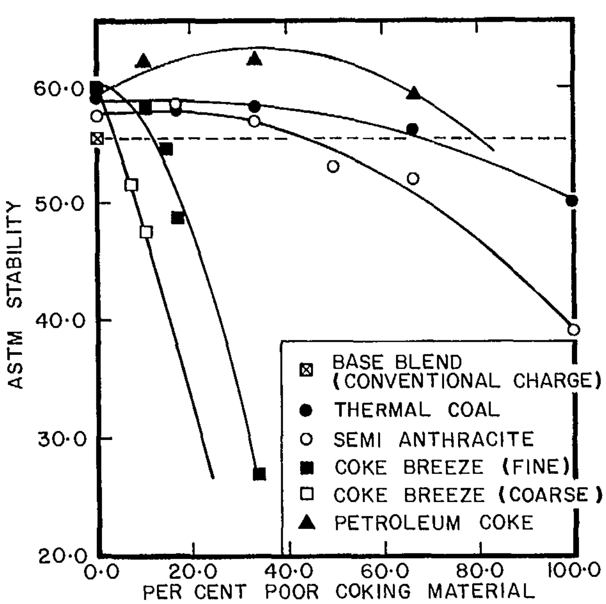

Fig. 17 - Effects of adding various materials to briquets of 30% partially briquetted coke oven charges upon ASTM coke quality

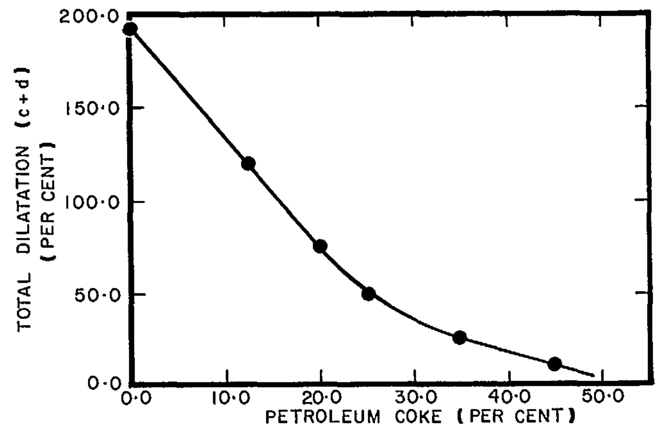

Fig. 18 - Effect of the amount of petroleum coke upon the total dilatation properties of hv Eastern Canadian coal

and hardness to 48.5 and 56.2, respectively. Further improvements to coke strengths occurred when larger amounts of petroleum coke were added to the briquetted portion of the charge. The best ASTM coke stability at 51.2 occurred for the 50% partially-briquetted charge in which the briquets contained 59% coal 4, 35% petroleum coke, and 6% binder; the matrix blend contained 20% petroleum coke. Cokes of this strength may be sufficient for small blast furnaces. However, the above results indicate that petroleum coke, although a good additive to briquetted blends, cannot totally replace prime lv coal in binary hv-lv blends even when the charges are 50% partially briquetted.

Benefits from including petroleum coke in partially-briquetted charges are improved coke yields because of the low VM of petroleum coke and improved coke oven productivity (shorter coking times) presumably caused by the better thermal conductivity of petroleum coke compared with coal.

ASSESSMENT OF PARTIAL BRIQUETTING VARIABLES

SMALL-SCALE PRELIMINARY TESTING

Five briquetting variables were previously investigated in a 2^5 factorally designed experiment in which 20 cylindrical canisters, 76 mm diam x 305 mm, were charged with different

Table 14 - Carbonization results from conventional and partially briquetted binary blends of hv coal and petroleum coke

		Types of blends					
		Conventional charges		50% Partially briquetted charges			
		Coal 4	80%C4-20%PC	m(80%C4-20%PC) b(70%C4-20%PC)	m(100%-C4) b(47%C4-47%PC-6%Br)	m(80%C4-20%PC) b(47%C4-47%PC-6%Br)	m(80%C4-20%PC) b(35%PC-59%C4-6%Br)
Bulk density in (db)	(kg/m^3)	738	723	782	782	792	798
Gross coking time to 900°C	(h:min)	18:00	15:45	17:00	16:35	15:40	17:30
Coke yield	(%)	64.5	71.5	71.0	73.6	75.6	69.7
Mean coke size	(mm)	57.9	58.9	54.4	57.6	53.6	54.1
Coke breeze	(%)	3.6	4.3	3.5	3.2	3.9	3.3
ASG	(%)	0.76	0.83	-	-	-	0.88
Max. oven pressure	(kPa)	2.1	2.1	2.5	2.8	2.1	2.5
ASTM stability	(%)	38.0	46.0	48.5	45.7	49.6	51.2
hardness	(%)	55.1	52.1	56.2	56.2	59.7	60.0
SAR	(%)	27.6	-	39.0	-	37.4	34.7
Reaction	(%)	50.0	-	33.5	-	44.8	43.1

C4 - coal 4

PC - petroleum coke

m - matrix coal content

b - briquet content

Br - binder

30% briquet/good coking coal mixtures (23). The canisters were placed in a good matrix coal within a wooden box and side-charged into CANMET's 310-mm wide movable wall oven. The variables and levels are given in Table 15. The carbonized contents of the canisters were sectioned, analyzed visually and then shattered in CANMET's shatter test to obtain a relative measure of coke strength and hardness values (Fig. 19) (31).

Detailed results described previously indicated partial briquetting improved coke quality compared with that of non-briquetted charges for all variables tested (23,32). However, in tests of this scale, changes in the level of any of the first order briquetting variables had no statistically significant effect upon coke quality. Analysis of variance indicated interactions between variables may be important.

TECHNICAL-SCALE TESTS USING A BINARY BLEND

CANMET's small scale investigations showing partial-briquetting variables had no significant effect on coke quality contrasted with results found elsewhere. It was evident that technical-scale tests were required to determine the effects of such variables when coals used by the Canadian steel industry were partially briquetted and carbonized.

To reduce the number of coke oven tests only the four variables shown in Table 16 were investigated.

Table 15 - Briquetting variables investigated

Variable	Levels
Coal size (mm)	minus 1.2
	minus 3.3
Briquetting pressure (kPa)	40,000
	100,000
Briquet shape (g)	Flat (10)
	Cylindrical (20)
Binder content (%)	7
	10
Non-coking coal (%)	0
	20

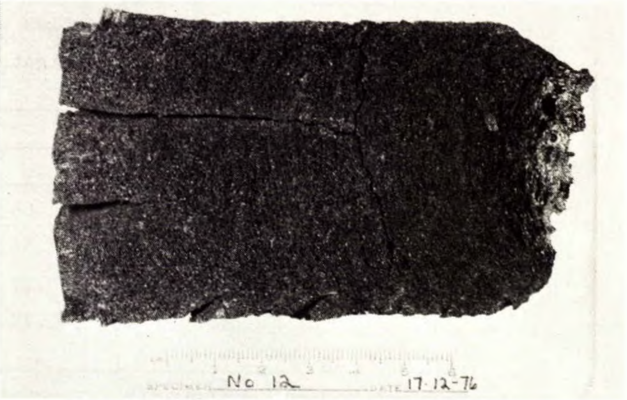

Fig. 19 - Coke section from carbonization test in which cannister was charged with coal containing 30% cylindrical briquets

The coal blends for this investigation were made from the same coal types as the study involving additions of non-coking materials although new samples were used. Their properties are listed in Table 17. A base blend of 75% hv coal 4 and 25% lv coal 1 was used as the matrix coal. The 30% briquetted portion of a charge was made from one of three blends:

70% thermal coal 6 + 30% base blend (1-4)

50% semi-anthracite coal 7 + 50% base blend (1-4)

70% petroleum coke + 30% base blend (1-4)

These blends were chosen for carbonization because earlier work showed they contained the maximum amounts of non-coking material that would produce acceptable coke. Six per cent pitch was added to the coal for briquetting (Table 18). To minimize testing only the best pitch material

Table 16 - Briquetting variables investigated in technical scale tests

	Variable	Levels
1.	Type of binder	PDA, asphalt, decanter tar sludge
2.	Amount of binder	6 and 10%
3.	Grain size	Minus 1 and minus 3 mm
4.	Caking additive	5% SRC added to briquet

Table 17 - Properties of coals used in blends to investigate briquetting variables

Sample	Properties* VM	Ash	Ro	%P	TD	FI	FT	ST	FSI
Coal 1**	17.8	6.5	1.66	92.4	51	14.8	466	502	8.5
Coal 4**	34.8	2.5	1.00	81.5	264	27,500	405	487	8
Coal 6**	33.6	10.7	0.77	89.8	44	464	406	462	5.5
Coal 7	12.5	9.5	2.15	90.4	-	-	-	-	0.5
Petroleum coke	18.2	0.0	-	100.0	-	-	-	-	-

*See Table 2 for explanation of symbols

**New samples of coals 1, 4, 6 from those used previously

Table 18 - Properties of pitches and additives used in partial briquetting

	Properties									
	Softening		Ultimate analysis							
Material	°C	Ash	C	H	N	S	PI	TI	CI	%AROM. C
Asphalt	80	0.04	85.0	10.1	0.51	3.6	34.7	0.18	0.18	37.3
PDA	68	0.02	87.4	10.0	0.81	1.4	15.0	0.62	0.57	40.8
Sludge	<5	1.86	80.8	3.7	0.92	0.40	78.9	45.2	40.3	-
SRC	>198	0.2	86.7	6.0	2.46	0.54	98.9	64.0	40.2	100% of solubles

PI = pentane insolubles; TI = toluene insolubles; CI = chloroform insolubles

as determined at the 6% level was used in subsequent tests. Thus, only one pitch was used to determine the effects on coke quality of: 10% pitch added to briquets; pulverization of coal for briquetting; and the use of SRC as an additive.

Carbonization results confirm Japanese findings and showed that finer pulverization of briquetted coals improved coke quality for all blends (Tables 19,20,21) (Fig. 20). ASTM coke stabilities and hardnesses would suggest PDA was the best binder at the 6% level; however, the small improvements in coke quality for this binder are within the limits of experimental error for the test. Addition of 10% PDA to the briquet gave further improvements to ASTM coke stability factors for all partially-briquetted blends. Using 5% SRC as a caking additive in the briquets was not particularly effective in the blends tested; larger amounts of SRC in other blends may be more effective.

Overall, best coke quality resulted from partially-briquetted blends in which the briquets contained petroleum coke, 10% PDA binder, and the briquetted coal pulverized to a fine level. However, the effects of pulverization, binder, and caking additives on coke quality are relatively minor.

TECHNICAL-SCALE TEST USING COMMERCIAL BASE BLENDS

Commercial blends from the four Canadian steel companies were carbonized conventionally and 30% partially briquetted using a PDA binder and 50% semi-anthracite coal 7 to determine if similar levels of non-coking materials could be added to commercial blends as for binary blend

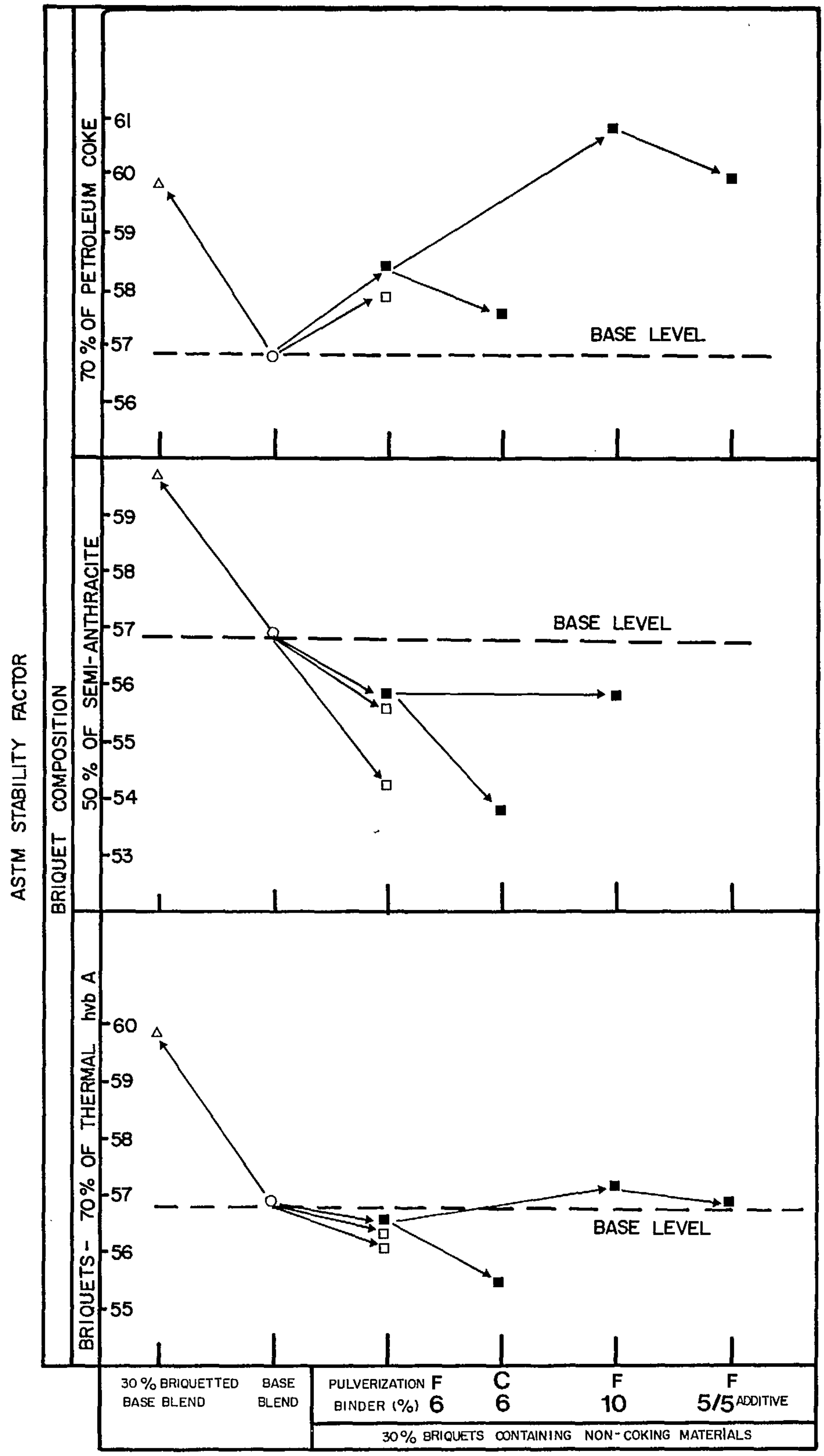

Fig. 20 - Effects on type and amount of binder, and coal pulverization in briquets on the ASTM stability of coke from partially briquetted charges containing 3 types of non-coking materials

Table 19 - Effect of partial briquetting variables on carbonization results of the hv-lv base blend with briquets containing 70% coal 6

		Conv. charge	30% Partially briquetted charges with matrix of 75% coal 4-25% coal 1						
				With briquets containing 70% coal 6					
		Base blend 75% coal 4 25% coal 1	Base blend	FP 6% Asphalt	FP 6% PDA	FP 6% Sludge	CP 6% PDA	FP 10% PDA	FP 5% SRC-5% PDA
Moisture in charge	(%)	6.1	4.7	4.8	4.4	5.1	4.8	4.7	5.0
Bulk density (db)	(kg/m^3)	728	816	787	797	786	772	797	781
Coking time to 900°C	(h:min)	16:15	18:15	16:45	17:15	17:45	17:20	17:00	17:10
Coke yield	(%)	74.6	69.7	70.6	69.6	71.2	71.1	70.2	69.3
Mean coke size	(mm)	60.2	62.3	64.0	63.0	63.5	64.0	62.5	65.3
+51-mm coke	(%)	64.9	71.7	71.7	70.9	71.9	72.0	69.4	73.9
Coke breeze	(%)	2.6	2.9	2.6	3.4	3.0	2.4	2.7	2.7
Max. wall pressure	(kPa)	1.7	3.7	2.3	3.3	2.6	3.0	2.6	3.2
ASG		0.78	-	0.86	0.87	0.88	0.87	0.89	-
ASTM stability	(%)	56.8	59.8	56.1	56.5	56.4	55.5	57.2	56.8
hardness	(%)	61.5	65.3	63.6	64.9	63.7	64.8	65.3	64.6
JIS DI_{15}^{30}	(%)	94.7	95.2	94.0	94.8	94.1	93.9	94.0	94.0
JIS DI_{15}^{150}	(%)	83.0	86.5	81.4	82.2	81.7	82.0	82.8	81.9

FP - Fine pulverization of briquetted material - 90% minus 1 mm

CP - Coarse pulverization of briquetted material - 85% minus 3 mm

Table 20 - Effect of partial briquetting variables on carbonization results of the hv-lv base blend with briquets containing 50% coal 7

		Conv. charge	30% Partially briquetted charges with matrix of 75% coal 4-25% coal 1					
				With briquets containing 50% coal 7				
		Base blend 75% coal 4 25% coal 1	Base blend	FP 6% Asphalt	FP 6% PDA	FP 6% Sludge	CP 6% PDA	FP 10% PDA
Moisture in charge	(%)	6.1	4.7	4.8	5.1	4.5	5.0	4.5
Bulk density (db)	(kg/m^3)	728	816	792	803	794	765	768
Coking time to 900°C	(h:min)	16:15	18:15	17:20	17:30	16:15	17:20	16:35
Coke yield	(%)	74.6	69.7	73.1	72.5	73.6	73.0	72.7
Mean coke size	(mm)	60.2	62.3	62.5	63.5	61.7	63.8	62.5
+51-mm coke	(%)	64.9	71.7	71.6	70.1	68.4	72.9	69.6
Coke breeze	(%)	2.6	2.9	2.5	2.6	2.5	2.8	2.5
Max. wall pressure	(kPa)	1.7	3.7	2.4	3.0	3.2		
ASG		0.78	-	0.91	0.92	0.91	0.89	0.90
ASTM stability	(%)	56.8	59.8	55.7	55.9	54.3	53.8	55.9
hardness	(%)	61.5	65.3	63.5	64.7	63.6	62.0	63.8
DI_{15}^{30}	(%)	94.7	95.2	94.8	94.4	93.6	93.4	94.4
JIS								
DI_{15}^{150}	(%)	83.0	86.5	82.4	82.1	81.2	80.9	83.5

FP - Fine pulverization of briquetted material - 90% minus 1 mm

CP - Coarse pulverization of briquetted material - 85% minus 3 mm

Table 21 - Effect of partial briquetting variables on carbonization results of the hv-lv base blend with briquets containing 70% petroleum coke

		Conv. charge	30% Partially briquetted charges with matrix of 75% coal 4-25% coal 1						
				With briquets containing 70% petroleum coke					
		Base blend 75% coal 4 25% coal 1	Base blend	FP 6% Asphalt	FP 6% PDA	FP 6% Sludge	CP 6% PDA	FP 10% PDA	FP 5% SRC-5% PDA
Moisture in charge	(%)	6.1	4.7	4.7	4.9	4.5	4.9	4.4	4.6
Bulk density (db)	(kg/m^3)	728	816	795	779	798	774	795	782
Coking time to 900°C	(h:min)	16:15	18:15	16:45	18:30	17:35	16:25	17:15	-
Coke yield	(%)	74.6	69.7	72.3	74.5	73.3	71.9	73.4	72.1
Mean coke size	(mm)	60.2	62.3	62.2	65.5	63.2	62.7	61.0	61.2
+51-mm coke	(%)	64.9	71.7	72.4	76.5	71.0	71.1	67.0	69.2
Coke breeze	(%)	2.6	2.9	2.3	2.1	2.3	2.6	2.3	2.8
Max. wall pressure	(kPa)	1.7	3.7	1.7	3.9	3.2	2.2	2.4	0.83
ASG		0.78	-	0.92	0.95	0.91	0.95	0.96	-
ASTM stability	(%)	56.8	59.8	57.8	58.4	57.8	57.6	60.9	60.0
hardness	(%)	61.5	65.3	65.5	63.8	64.8	65.2	67.7	66.4
DI^{30}_{15}	(%)	94.7	95.2	94.3	94.9	93.6	93.8	94.0	94.3
JIS									
DI^{150}_{15}	(%)	83.0	86.5	83.0	82.8	82.0	81.8	82.6	83.9

FP - Fine pulverization of briquetted material - 90% minus 1 mm

CP - Coarse pulverization of briquetted material - 85% minus 3 mm

1-4. Properties are listed in Table 22. Carbonization results indicated that non-coking coal could be added to briquets of 30% partially-briquetted blends of A, B and C and that coke quality would be maintained or improved from that of the conventionally charged base blend (Table 23). The difference in ASTM stabilities between conventional and partially-briquetted blends with additives relates to the fluidity of the commercial blends. Those blends with larger fluidities apparently incorporated the non-coking coal more readily and produced the stronger cokes as shown by ASTM stability factors.

Table 22 - Properties of commercial blends used in the partial briquetting study with non-coking coal

	Properties*								
Reference	VM	Ash	Ro	%P	TD	FI	FT	ST	FSI
A**	26.4	5.7	1.19	77.7	134	1642	425	495	8
B	31.2	5.7	1.18	75.7	64	1433	418	481	8
C	32.0	4.2	1.07	86.4	139	2268	415	486	8
D	29.8	6.8	1.16	84.4	35	461	422	480	6

*See Table 2 for explanation of symbols

**Blends A, B, C and D are new samples of blends used previously

Table 23 - Carbonization results from partially briquetted commercial blends containing non-coking coals

		Blends							
		A*	A+	B*	B+	C*	C+	D*	D+
Moisture in charge	(%)	5.9	4.5	6.2	4.5	6.1	4.5	5.8	4.5
Bulk density (db)	(kg/m^3)	750	824	725	781	710	792	717	797
Coking time to 900°C	(h:min)	17:45	18:52	16:40	18:20	16:10	18:30	16:15	18:20
Coke yield	(%)	74.1	76.2	70.5	72.4	68.8	73.4	71.3	73.8
Mean coke size	(mm)	70.9	68.8	64.0	61.7	58.4	73.7	64.8	65.3
+51-mm coke	(%)	80.1	76.4	69.3	64.7	66.1	73.8	70.6	69.0
Coke breeze	(%)	2.5	2.4	3.7	3.3	3.4	2.9	4.2	3.8
Max. wall pressure	(kPa)	3.2	3.4	2.1	4.1	1.3	2.8	2.5	3.5
ASG		0.83	0.94	0.80	0.90	0.84	0.91	0.84	0.88
ASTM stability	(%)	55.5	58.6	53.0	55.4	51.1	55.3	56.1	53.9
hardness	(%)	60.2	66.2	61.8	65.3	58.3	64.4	64.3	64.5
DI^{30}_{15}	(%)	94.2	94.3	92.3	93.1	92.5	93.5	92.8	93.0
JIS									
DI^{150}_{15}	(%)	83.1	82.7	80.0	81.0	78.0	81.5	80.6	81.9

*Conventionally charged commercial blend; +30% partially briquetted charges with briquets containing 50% semi-anthracite-50% matrix coal; 6% PDA binder

SUMMARY

The applicability of partial briquetting technology to North American coals, particularly Canadian steel industry blends, was examined. Coal blends of the four major steel producers in Canada, considered to have excessive caking properties by Japanese cokemakers, were carbonized conventionally with 30% of the charge briquetted. Results showed this method:

- increases bulk density of coal in the oven and ASG of resultant coke;
- increases coke stability from Canadian blends by 2.8 to 6.7 units; the blend having lowest fluidity and highest rank improved most;
- maintains coke oven productivity;
- increases coke oven wall pressure but not above the critical level if briquets made up 30% or less of the blend;
- improves coke SAR for all Canadian blends, most improvement was for the blend of lowest rank.

Binary blends of lv coal with each of four types of hv coals were carbonized conventionally and partially briquetted at different lv:hv ratios. Partial briquetting tests gave results similar to those for commercial blends. Also, partial briquetting of these blends indicated:

- coke quality could be maintained at the base level of a conventional charge with significant reductions in lv coal content;
- maximum lv coal replacement was found for blends containing highly inert, low-fluid Western Canadian coal; generally, replacement levels were higher for the blends containing the better coking hv coals.

Semi-anthracite, hv thermal coal, coke breeze and petroleum coke were added at several concentrations to the briquetted portion of a partially-briquetted binary blend. Coking results indicated:

- poor and non-coking additives could be substituted, to different extents, into briquets for coking blend and maintain the base coke strength of the normal charge; the order of substitution, from best to worst, is petroleum coke - about 22% of total charge, thermal coal, semi-anthracite, coke breeze (about 10% of charge);
- additions decreased coke oven wall pressures from that of the partially-briquetted base blend; briquetting of larger portions, e.g., 50% of the blend should be possible with additions of non-coking materials;
- coke breeze and semi-anthracite behave as antifissurants in briquetted charges; coke breeze should be finely pulverized and homogeneously distributed throughout both briquets and matrix coal to maximize coke strength.

To maintain high coke strength, the lv coal in partially-briquetted binary hv-lv blends must not be completely replaced by petroleum coke even though it had the correct VM content and proved to be an excellent additive to briquetted charges. Petroleum coke additions to briquetted charges containing a hv-lv blend enhanced coke oven productivity through higher coke oven yields and faster coking rates. Sulphur contents may restrict the use of petroleum coke as an additive to partially-briquetted coke oven charges.

Although preliminary small-scale testing of partial-briquetting variables proved inconclusive, technical-scale coking tests on a binary blend with briquets having three different additives indicated coke quality improved by:

- finer pulverization for briquetted coal;
- increasing pitch levels from 6 to 10%.

Effects of pitch type and caking additives on coke quality were marginal.

Generally, coke strengths from partially-briquetted single coals did not improve from conventional charging; this agrees with results from Japanese and Soviet workers (5,11,12). Of the four hv coals carbonized only the highly inert, low-fluid Western Canadian coal showed slight improvements in coke quality. Further study of partial briquetting of other highly inert Western Canadian coals and blends is warranted.

Partial briquetting did not change coke oven productivity; however, further experiments are planned to determine the effects of increased coking rates on coke quality, oven wall pressures and coke oven productivity.

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