CANMET

REPORT 80-4E

Canada Centre for Mineral and Energy Technology

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

COKEMAKING WITH CANADIAN MEDIUM- AND HIGH-VOLATILE COMMERCIAL COKING COALS

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

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

JUNE 1979

Available in Canada through

Authorized Bookstore Agents
and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Hull, Quebec, Canada K1A 0S9

CANMET
Energy, Mines and Resources Canada,
555 Booth St.,
Ottawa, Canada K1A 0G1

or through your bookseller

Catalogue No. M38–13/80–4E
ISBN 0-660-10571-3

Canada: $2.25
Other countries: $2.70

Price subject to change without notice.

En vente au Canada par l'entremise de nos

agents libraires agréés
et autres librairies

ou par la poste au:

Centre d'édition du gouvernement du Canada
Approvisionnements et Services Canada
Hull, Québec, Canada K1A 0S9

CANMET
Énergie, Mines et Resources Canada,
555, rue Booth
Ottawa, Canada K1A 0G1

ou chez votre libraire.

N° de catalogue M38–13/80–4E
ISBN 0-660-10571-3

Canada: $2.25
Hors Canada: $2.70

Prix sujet à changement sans avis préalable.

COKEMAKING WITH CANADIAN MEDIUM- AND HIGH-VOLATILE COMMERCIAL COKING COALS

by

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

ABSTRACT

A strong export market has been established for Western Canadian coking coal and increasing quantities are also being used by the Central Canadian steel industry. Domestic coals provide a degree of diversification of supply for the companies which presently import most of their requirements from the United States.

In this report the quality of coke obtained from Western coking coals and from blends of Western and Eastern Canadian coking coals is investigated. Blending low ash, high sulphur Eastern coals with high ash, low sulphur Western coals produced cokes with chemical and physical properties suitable for the blast furnace. All blends carbonized in the 460-mm and 310-mm wide technical-scale coke ovens had low coking pressures and could be coked in industrial ovens.

The hot strengths of the cokes were measured by the Nippon Steel Corporation test and were found to vary with blend composition in a manner similar to the cold strength or stability factor.

Measured stability factors were compared with factors predicted from coal properties by three methods. The petrographic method gave accurate predictions of the strength of coals coked alone but was less accurate for blends of coals. The G-factor method was fairly accurate for all coals and blends except for Eastern Canadian coal. The third method was the most accurate and used a relationship between coke strength, mean maximum vitrinite reflectance and maximum Gieseler fluidity obtained by regression of CANMET data for 180 Western coals.

---

*Research Scientists, Coal Resource and Processing Laboratory, and **Manager, Western Research Laboratory (Edmonton), Energy Research Laboratories, Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada, Ottawa.

FABRICATION DU COKE A PARTIR DE CHARBONS COKEFIANTS MARCHANDS CANADIENS DE MOYENNE ET DE HAUTE VOLATILITE

par

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

RESUME

Un important marché d'exportation a été mis sur pied pour le charbon cokéfiant canadien de l'Ouest. De plus, l'industrie de l'acier du Canada central emploie des quantités de plus en plus abondantes. Les charbons domestiques offrent une certaine diversification d'approvisionnement pour les compagnies qui, en ce moment, importent la plupart de leurs besoins des Etats-Unis.

Le présent rapport étudie la qualité du coke provenant des charbons cokéfiants de l'Ouest et des mélanges de charbons cokéfiants de l'Est et de l'Ouest canadien. Le mélange des charbons de l'Est à basse teneur de cendres et haute teneur de soufre avec des charbons de l'Ouest à haute teneur de cendres et à basse teneur de soufre donne des cokes ayant des propriétés chimiques et physiques qui conviennent au haut-fourneau. Tous les mélanges ayant été carbonisés dans les fours à coke techniques de 460 mm et de 310 mm de largeur, avaient des basses pressions de cokéfaction et donc pouvaient être cokéfiés dans les fours industriels.

Les résistances à chaud des cokes ont été mesurées avec le test de Nippon Steel Corporation. Ce test a démontré que les résistances varient selon la composition du mélange et d'une façon semblable à la résistance à froid ou le facteur de stabilité.

Les facteurs de stabilité ainsi mesurés ont été comparés aux facteurs prédits par les trois méthodes qui suivent. Avec la méthode pétrographique on a obtenu de bonnes prédictions de la résistance des charbons cokefiés seuls mais elles étaient moins exactes pour les mélanges de charbon. La méthode du facteur-G était passablement bonne pour tous les charbons et les mélanges sauf le charbon de l'Est canadien. La troisième méthode était la plus précise et se servait du rapport entre la résistance du coke, la réflexion moyenne maximale de la vitrinite et la fluidité maximale de Gieseler obtenu par le traitement des données du CANMET sur 180 charbons de l'Ouest.

---

*Chercheurs scientifiques, Laboratoire des ressources et du traitement des charbons et **Gérant, Laboratoire de recherche de l'Ouest (Edmonton), Laboratoires de recherche énergétique, Centre canadien de la technologie des minéraux et de l'énergie, Energie, Mines et Ressources Canada, Ottawa.

CONTENTS

TABLES

FIGURES

CONTENTS (cont'd)

NOTE: This report replaces CANMET Report 79-36 (Catalogue No. M38-13/79-36) copies of which should be destroyed.

INTRODUCTION

About 90% of the eight million metric tons (8×10^6 t) of coking coal used annually by the three largest steel companies of Canada come from the Appalachian coalfields of the United States. Fifty-five per cent of this imported coal originates from mines totally or partly owned by the steel producers and the remainder is acquired by long- or medium-term purchase contracts (1). However, Canadian steel companies are showing increasing interest in obtaining coal supplies from within Canada because of rapidly escalating prices for imported coal caused by low productivity and because of some deterioration in quality at a time of moderate expansion. There is some concern about the future availability of the required quantities of premium quality coal. Low-volatile coking coal represents only 13% of the United States reserves and certain groups in that country have lobbyed for government monitoring of exports (2). The vulnerability of Central Canadian industry to any future U.S. restrictions on export has underlined its present heavy dependence on one source. Using more Canadian coals would diversify coal supply.

The work reported here investigates one extreme: the quality of coke produced from blends containing only medium- and high-volatile Canadian coals. The project was carried out by the Coal Resource and Processing Laboratory, CRPL, under the auspices of the Canadian Carbonization Research Association as a contribution to the federal government policy goal of achieving greater Canadian self-reliance in energy.

CANADIAN COKING COALS

Canada has large reserves of coking coals. Recoverable coal is defined as that portion of the coal resources that has been well delineated, can be mined with current technology and can be sold at competitive market prices. Recoverable coking coal in Western Canada totals 602×10^6 t and is a long-term potential source of low- and medium-volatile coal (3).

Coking coal deposits in Western Canada are mainly confined to the Inner Foothills belt, which parallels the eastern front of the Rocky Mountains (4). This narrow belt stretches 80 km from the U.S.A. border in Alberta and British Columbia through to the Peace River in northeastern British Columbia. Tectonic movements during the periods of mountain formation have affected the coal seams. They are often steeply inclined, truncated by faults, thickened or thinned and the coal is friable.

The Kootenay formation extends from the southern end of the belt to approximately Latitude 52°. The seams are Late Jurassic to Early Cretaceous in age and are mainly low- and medium-volatile bituminous in ASTM rank. High-volatile and semi-anthracite coals also occur in this region. The sulphur content of the coals is usually low at 0.2-0.65%, and the ash content moderately high at 7-10%.

From Latitude 52° to 57° the coal seams occur in the Luscar formation. The coking coals in this formation are Lower Cretaceous in age and fall into the low- and medium-volatile bituminous rank classification. The sulphur content is also low with less mineral matter than the coals of the Kootenay formation.

The five mining companies producing metallurgical coal in Western Canada are listed in Table 1 (1). In 1976 they exported about 11.7×10^6 t of which more than 90% was shipped to Japan.

The Sydney coalfield in Nova Scotia is the most important metallurgical coal deposit in Eastern Canada. The seams are Carboniferous in age and reserves of recoverable coal are 49×10^6 t (3). Two mines on the Harbour seam - No. 26 and Lingan - produce high-volatile coking coal (Table 1). Its ash content is very low at 3-4% but sulphur is moderately high at 0.8-1.5%, (5). A heavy-media type coal preparation plant that started operation in 1976 washes and blends the two coals to a product with about 3% ash and 1% sulphur (6).

The properties of coking coals from Western and Eastern Canada differ considerably.

Table 1 - Major Canadian metallurgical coal producers

Company	Location	Coal rank	1976 Production* (tonnes x 10^6)
Coleman Collieries Ltd.	Coleman, Alberta	mvb	0.91
Cardinal River Coal Ltd.	Luscar, Alberta	mvb	1.70
McIntyre Mines Ltd.	Grande Cache, Alberta	lvb	1.90
Kaiser Resources Ltd.	Sparwood, British Columbia	mvb	5.44
Fording Coal Ltd.	Fording Valley, British Columbia	mvb	1.81
Cape Breton Development Corp	Glace Bay and Lingan Nova Scotia	hvb hvb	0.73 1.12

*Estimated

Typical values for some properties are compared in Table 2.

Sydney Steel Corporation in Nova Scotia is the smallest of the four companies that operate coke ovens and is the only one that uses a coal blend composed of domestic coals exclusively. The blend consists of 80% high-volatile coal from Eastern Canada and 20% low-volatile coal from Western Canada. The other Canadian steel companies have been evaluating Canadian coals and learning how to incorporate them into their coal blends. For example, the Steel Company of Canada has used a Western coal as part of their low-volatile coal mix since 1973 and determined that some medium-volatile Western coal can be substituted for the high- and medium-volatile coals they currently use (1).

COKING TESTS

The five coal companies producing coking coal in Western Canada were asked to supply samples representative of the product they export. Four companies agreed to participate in the study. All the coals were medium-volatile in rank and identified in this report as A, B, C and D. Their chemical analyses and rheological properties are given in Appendix A.

Coking tests were carried out at CRPL in two movable-wall technical-scale coke ovens which have chamber widths of 460 and 310 mm and capacities of approximately 325 and 250 kg respectively. In the 460-mm oven the Western Canadian coals were coked alone and in two blends with coal E, a high-volatile Eastern Canadian coal. The blends con-

Table 2 - Comparison of Western and Eastern Canadian coking coals (4)

Property	Western Canada	Eastern Canada
Rank	Low- and medium-volatile bituminous, some high-volatile	High-volatile bituminous
Geological age	Late Jurassic to early Cretaceous	Carboniferous
Chemical analysis (dry basis)		
Ash %	7-10	2.5-4.5
Volatile matter %	18-24	34-36
Fixed carbon %	65-80	60-63
Sulphur %	0.2-0.65	1.0-1.3
Alkali oxides in coke	0.06-0.13	0.05-0.06
Rheological properties		
Free swelling index	3-8	6.5-9
Gieseler maximum fluidity, dial divisions/minute	0-2,000	20,000-30,000
Ruhr dilatometer		
contraction %	20-30	20-30
dilatation %	-25 to 50	150-250
Petrographic properties		
Total reactives %	50-70	80-85
Total inerts %	30-50	15-20
Mean reflectance %	1.0-1.5	0.9-1.0
Petrographic stability	45-65	38-44

tained 25 and 45% Western Canadian coal. Tests were done in duplicate and constituted the first large program carried out in the 460-mm oven since it was rebuilt with silica bricks and its performance evaluated (7). The Western coals were coked alone in the 310-mm oven and in blends with either 75 or 55% coal E. The standard coking conditions used for the two ovens are shown in Table 3. Because the heating walls of the ovens are constructed of different materials, different coking conditions are used to produced cokes of similar strength from a particular coal or blend. However, other coke properties may be dissimilar.

As the reserves of recoverable high-volatile coking coal in Eastern Canada at 49 x 10^6 t are small compared with the 8 x 10^6 t of coking coal used annually in Canada, widespread use of blends containing large percentages of this high-volatile coal, as in this study, is not possible. The objective of this study was to determine the behaviour of commercially available medium-volatile Western Canadian coals in blends

Table 3 - Standard coke oven operating conditions

	460-mm oven	310-mm oven
Coal moisture	6	3
Coal bulk density in oven, Kg/m^3 dry basis	745	817
Coal pulverization	80% minus 3.35 mm	80% minus 3.35 mm
Flue temperature	constant 1125°C	programmed 900-1066°C at 19.4°C/h

with a good high-volatile coal, rather than to demonstrate the technical feasibility of Canadian self-sufficiency by blending Western and Eastern coals. For commercial use, high-volatile coals would probably continue to come from traditional U.S.A. sources.

COKING TEST RESULTS

COKE STABILITY FACTOR

The coking test results are given in Appendix B. The most important coke quality parameter is strength which is measured in North America by tumbling a sized sample according to the ASTM standard. The percentage of coke remaining on a 25-mm sieve is defined as the coke stability factor. One Canadian steel company's analysis of the effect of coke strength on the blast furnace coke rate shows that for each decrease of one percentage point in the stability factor the coke rate increases by about 8 kg coke/t hot metal (8).

The average coke stability factor of coal E alone in the 460-mm oven was 38.0. Blends containing 25% of a Western Canadian coal and coal E had higher stability factors, and those for blends containing 45% were higher yet (Fig. 1). The stability factors of the Western coals coked alone were 58.1, 55.2, 48.1, and 37.1 for A, B, C, and D respectively, higher than those for any of their blends with coal E except for coal D.

The stability factors of coke produced in the 310-mm oven showed the same trends except for coal B, which in a 45% blend with coal E had a higher stability factor, 55.0, than when coked alone, 53.3. However, in general the stability factors measured in the two ovens were similar. For the Western Canadian coals coked alone, linear regression of the stability factors gives the following equation: Stability factor, 460-mm oven = 3.022 + 0.960 (stability factor, 310-mm oven). The correlation coefficient, R, is 0.961. The equation predicts that coals producing cokes with stability factors of 30 and 50 in the 310-mm oven would yield stabilities of 31.8 and 51.0 in the larger oven. The differences are reduced if the stability factors for the blends are included in the regression: stability factor, 460-mm oven = 1.889 + 0.965 (stability factor, 310-mm oven) R = 0.940. Then cokes made in the 310-mm oven and having stability factors of 30 and 50 are predicted to correspond to factors of 30.8 and 50.1 in the 460-mm oven.

COKE HARDNESS FACTOR

The coke hardness factor is the percentage of the coke sample remaining on the 6.3-mm sieve after the tumble test used to determine the

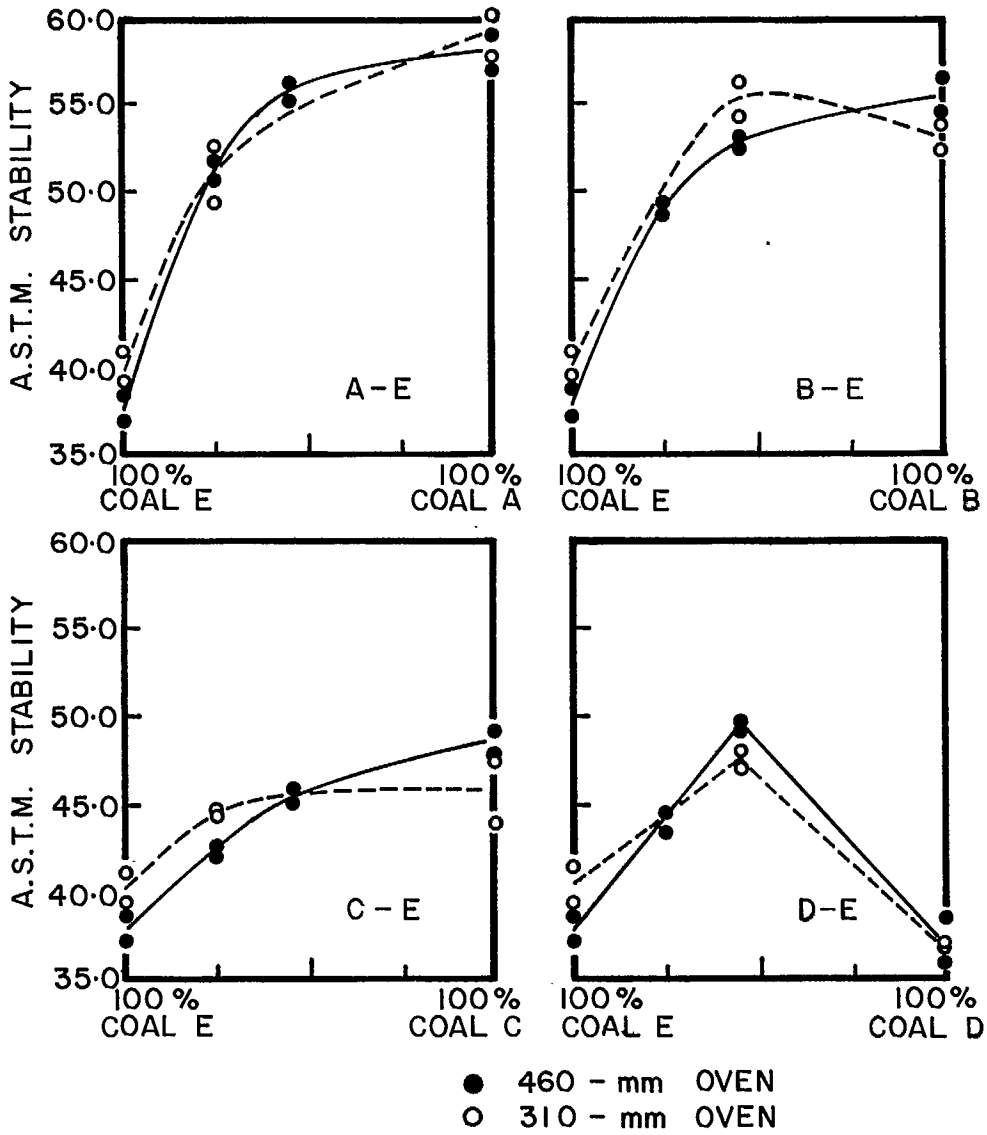

Fig. 1 - Relationship between stability factor and blend composition

stability factor. It is a measure of the abrasion resistance. Figure 2 shows that the hardness factor increased progressively as A and B coals were added to coal E. The trend was similar for coal C but the increases were smaller. In contrast, the hardness factor of coal D coked alone was less than that of coal E although blends of the two coals had factors slightly higher than coal E.

Figure 2 shows that the hardness factor of a coke made in the 460-mm oven was 5-7 percentage points lower than that produced from the same coal in the 310-mm oven. This difference is primarily caused by the lower coal bulk density used in the larger oven. Linear regression gives the following relationship: hardness factor, 460-mm oven = 1.147 (hardness factor, 310-mm oven) -15.57, R = 0.94

MEAN COKE SIZE

Figure 3 shows that the coke produced in the 310-mm oven had a smaller mean coke size than

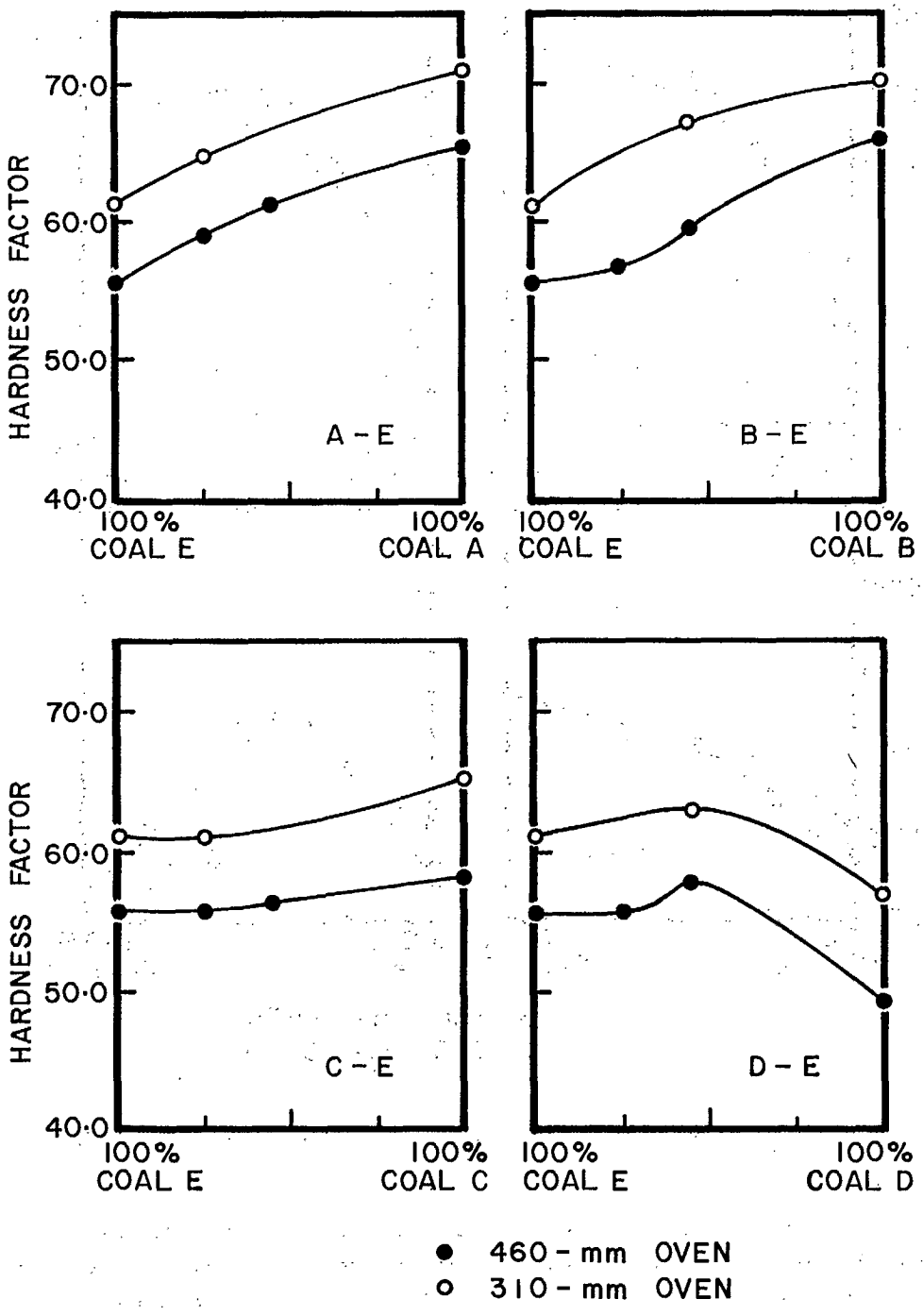

Fig. 2 - Relationship between hardness factor and blend composition

that produced in the larger oven. The difference was probably caused by oven size and the higher coking rate in the 310-mm oven which decreased the amount of large coke produced (7). Different trends in mean coke size occurred as the Western Canadian coals were added to the high-volatile coal (Fig. 3). Blends containing coals A and E or B and E had higher mean coke sizes than the

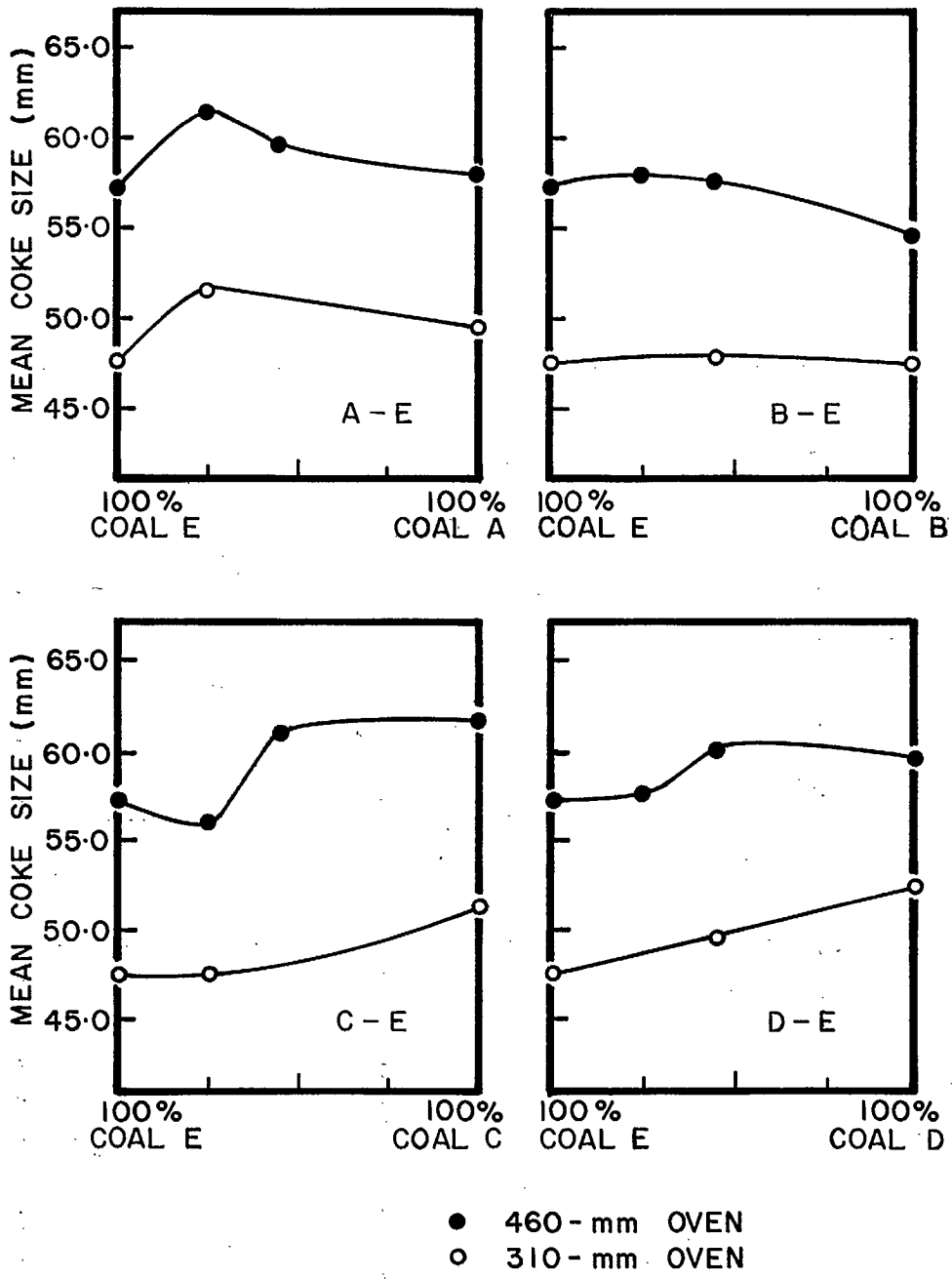

Fig. 3 - Relationship between mean coke size and blend composition

individual coals coked alone.

A series of blast furnace tests carried out in Germany showed that for good furnace productivity the mean coke size should be greater than 53 mm (9). This figure cannot be compared with the values reported here as it refers to the size after removal of the minus 25-mm coke. The preferred coke size range for the blast furnace is 63 x 19 mm according to one specification (10). All coals and coal blends except coal D produced between 3.3 and 5.6% minus 19-mm coke. Coal D produced an average of 13.6% minus 19-mm coke but

this decreased to 3.3% when this coal was blended with 55% coal E. How the sieve analysis of coke produced in the technical-scale ovens compared with coke made in industrial ovens is currently under investigation.

APPARENT SPECIFIC GRAVITY, ASG

The ASG of a coke is an inverse measure of its porosity. Previous work in the 460-mm oven showed that the ASG of coke made from a particular coal was mainly influenced by the coal bulk density and increased as the bulk density increased (7). Coke made in the 310-mm oven, which is operated at a bulk density of 817 kg/m^3, therefore has a higher ASG than coke made in the 460-mm oven which uses a bulk density of 745 kg/m^3. Figure 4 shows that the ASG of the coke increased as the Western Canadian coal formed larger propor-

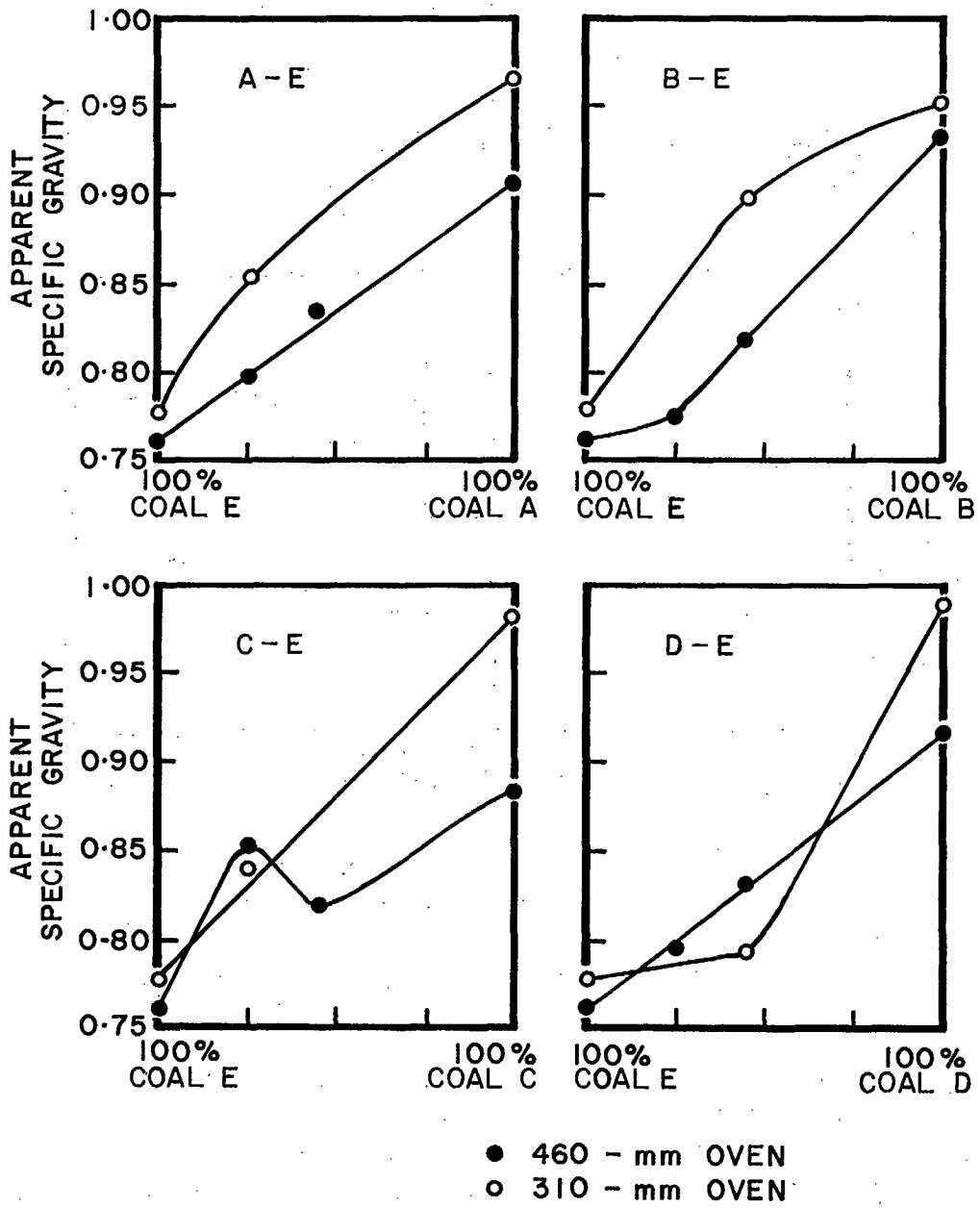

Fig. 4 - Relationship between apparent specific gravity and blend composition

tions of the blend and was highest when the Western coals were coked alone. This is caused by the increasing fixed carbon content of the oven charge. The preferred range of ASG for blast furnace coke is 0.87-0.91 (10).

MAXIMUM COKING PRESSURE

Because both ovens have movable walls connected to load cells, the pressure in the oven caused by gas evolution can be continuously recorded during the coking cycle. The coking pressure usually peaks when the two coal plastic layers, travelling from the heating walls, meet at the centre of the charge. This maximum pressure is plotted against blend composition in Fig. 5. Blends coked in industrial ovens should not develop maximum pressures above 14 kPa as oven wall damage may occur (11).

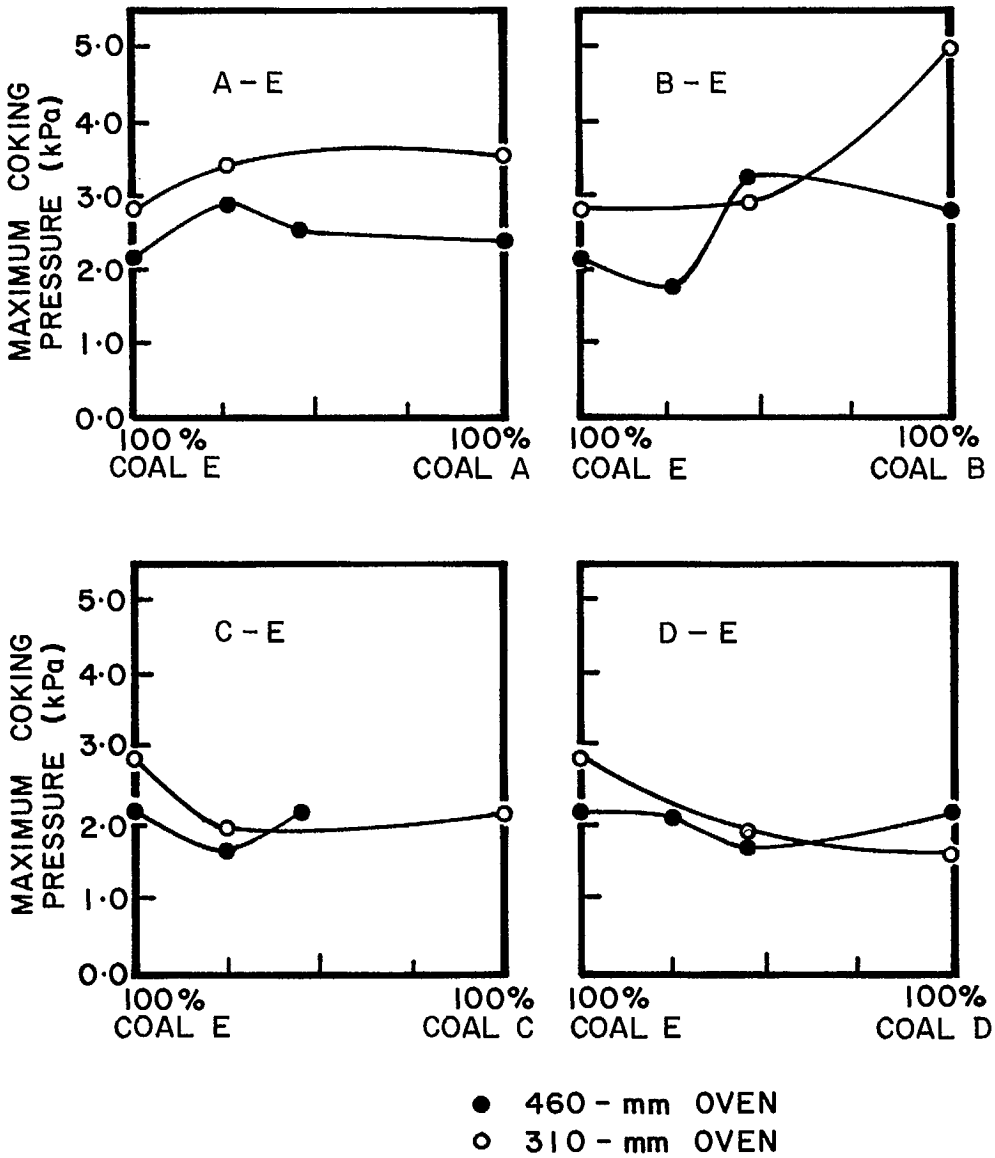

Fig. 5 - Relationship between maximum coking pressure and blend composition

All coals and coal blends used had maximum pressures less than 14 kPa. Moderate increases in coking pressure occurred as coals A or B were added to the high volatile coal. Coke stability factors were higher for these coals and blends than for coals C and D which produced, in general, decreasing coking pressure as they were blended with coal E. The higher bulk density and faster coking rate used in the 310-mm oven is believed responsible for the usually higher pressures developed in this oven. Oven size and geometry may also influence the pressure.

DISCUSSION OF COKE QUALITY

Blast furnace coke is manufactured from coal blends containing high-, medium- and low-volatile coals, although in some cases medium-volatile coal may be omitted. High-volatile coals give low coke yield, shrink excessively during carbonization and produce a friable coke with low stability factor. Low-volatile coals usually produce coke with a high stability factor and high coke yield, but their coking pressures often exceed values that are safe to use in slot-type coke ovens. Medium-volatile coals are "self-cokers" i.e., they produce coke of high strength with good coke yield and were used in beehive ovens now seldom used today (4). However, medium-volatile coals are not coked alone in slot-type ovens as their coking pressures are sensitive to ash content and such oven operating conditions as bulk density and coking rate and may exceed safe values (12). Proper blending of low-, medium- and high-volatile coals overcomes these problems so high strength cokes can be made safely in slot-type ovens. A typical blend composition in North America is 68% high-volatile coal, 12% medium-volatile coal and 20% low-volatile coal (13).

The cost of producing hot metal in the blast furnace is largely governed by coke cost. Good quality coke is needed to achieve low coke rates. The coke strength, as measured by the stability factor, and the coke ash and sulphur contents are the more important coke quality parameters. Table 4 lists the ideal and acceptable specifications for these coke parameters according to the Steel Company of Canada Ltd., together with the limits for coke alkali and phosphorus content and coke ASG. This company analyzed the effect of coke quality on the coke rate in their operation and found:

1. For each decrease of one percentage point in the coke stability factor, the coke rate increases by about 8 kg/t hot metal and furnace productivity decreases by 0.8%.
2. For each per cent increase in coke ash, the coke rate increases by about 15 kg/t hot metal and productivity decreases by 3%.
3. For each 0.1% increase in coke sulphur the coke rate increases by 4 kg/t hot metal and productivity decreases by 0.8% (8,10,11).

The sulphur and ash contents of the cokes made from Western Canadian coals and their blends with coal E are plotted in Fig. 6. For the purpose of discussion, the acceptable and ideal ash and sulphur limits from Table 4 are also shown. The

Table 4 - Blast furnace coke specifications (8,10,11)

Quality parameters	Coke specification	
	Ideal	Acceptable
Stability factor	55	53
Ash content, %	7.0 max	8.0 max
Sulphur content, %	0.6 max	0.7 max
Phosphorus content, %	minimal	0.12 max
Total alkali	minimal	0.20 max
Apparent specific gravity	0.87 - 0.91	

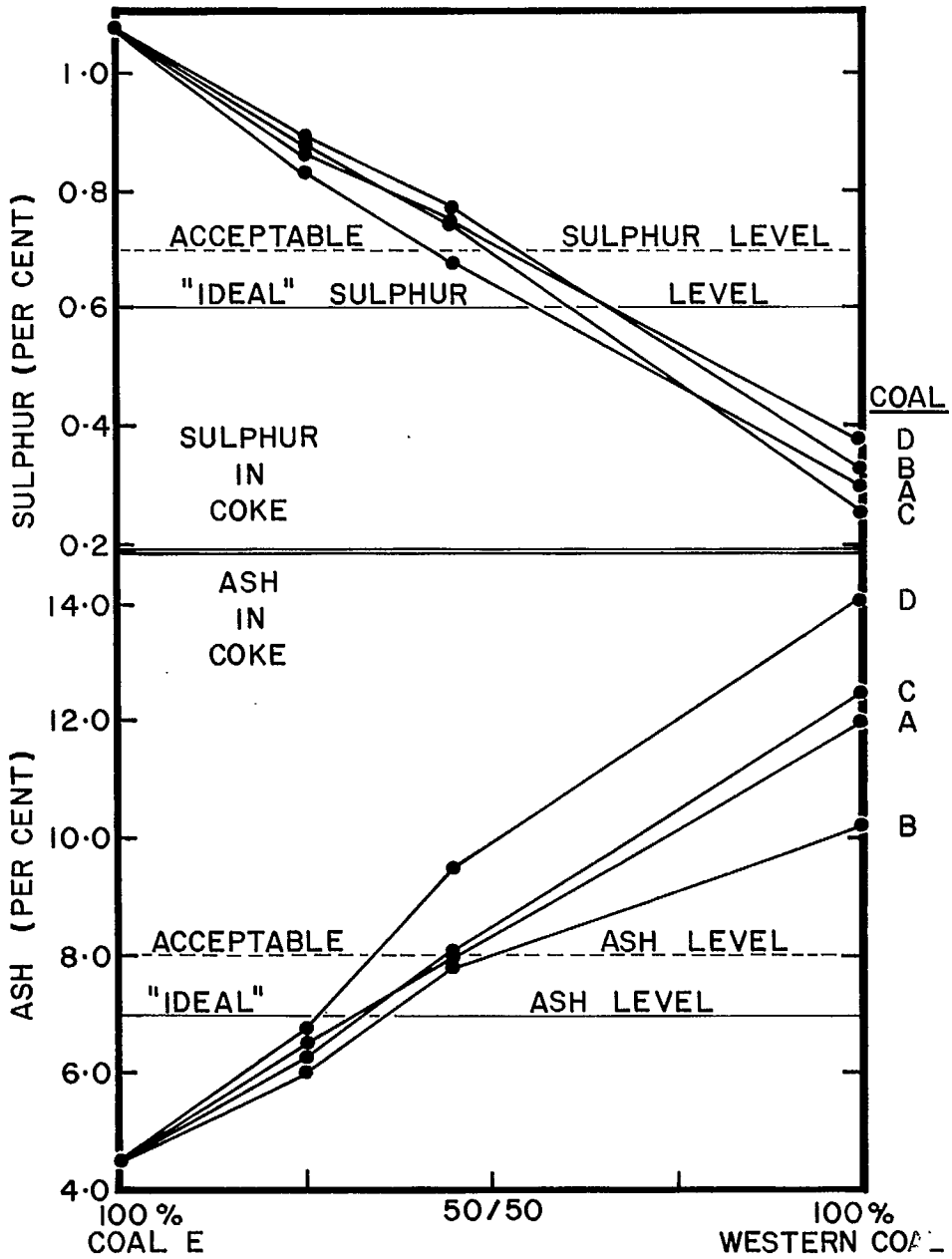

Fig. 6 - Relationship between sulphur and ash in coke and blend composition

coke ash content increases and the coke sulphur content decreases as the medium-volatile coals are added to the high-volatile coal. No blend of these coals can meet both the ideal ash content of 7% and the ideal sulphur content of 0.6%. A blend containing about 45% coal A and 55% coal E meets the acceptable specifications for ash and sulphur as would a blend containing 55% coal B and 45% coal E. Figure 1 shows that these blends have stability factors of about 55.7 and 53 and therefore meet the ideal and acceptable coke strength specifications of 55 and 53 respectively.

None of the blends of coal C or D with coal E had stability factors at or above the

acceptable value. The results for these coals illustrate that the value of a coal in a blend should not be judged solely by its coke strength when carbonized alone. The stability factor of coal C was 51 which is considerably higher than the 37 measured for coal D. However, when both are blended with 55% coal E the coal D blend had a stability factor of 49.2, higher than the coal C blend of 45.3.

The coke specifications in Table 4 have been used as landmarks in the field of coke quality. They are not absolute conditions that must be met: some steel producers use coke with stability factors between 40 and 50 or must cope with high sulphur or ash in their coke. Presumably similar coke rate increases to those outlined above would apply.

COKE HOT STRENGTH

The behaviour in the blast furnace of different cokes with similar cold-strength properties, such as stability and hardness factors, may not be identical. The coke structure and its inert, ash and alkali contents will affect its strength at the temperatures and reactive conditions present in the blast furnace. In 1978 the Canadian Carbonization Research Association expressed an interest in testing coke at high temperatures because of recent research (14). After reviewing different test methods, none of which are in widespread routine use, CRPL began using the After Reaction Strength test developed by Nippon Steel Corporation (15). Some cokes made in the present work were used to assess this testing method.

In the After Reaction Strength test, 200 g of 20-mm coke is gasified by 5 L/min of CO_2 for 2 h at 1100°C and the percentage weight loss is called the reaction per cent or RP. The coke remaining is tumbled for 30 min at 2.09 rad/s and the weight retained on a 10-mm screen is termed the After Reaction Strength, ARS.

The RP and ARS of cokes made from coals A, B, D and E is plotted against a measure of coal rank - the mean maximum vitrinite reflectance, R_o, in Fig. 7. The ARS increased and the RP decreased as R_o or the rank of the coal increased. The coke hot strength parameters were consistently better when the coal was coked in the smaller oven and this is attributed to the higher bulk density used in this oven.

Test results for coal blends carbonized in the 460-mm oven are also shown in Fig. 7. The ARS increased rapidly with increasing additions of Western Canadian coal to coal E. However, only blends containing coal D had better properties than the Western Canadian coals carbonized alone. The ARS-blend composition curves are similar to the stability factor-blend composition curves of Fig. 1.

PREDICTION OF COKE STRENGTH FROM COAL PROPERTIES

The use of laboratory-determined coal properties to predict coke strength is important as it avoids extensive technical-scale coking and because small samples such as drill cores can be assessed. The results from the four series of binary coal blends used in this study afford a good opportunity to examine the accuracy of predictive methods. Three methods of predicting the stability factor are examined and the results compared with the measured stability factors.

Petrography has proved useful in predicting coke strengths of U.S.A. Appalachian coals and is used extensively in North America (16). At CANMET the method of Schapiro and Gray is closely followed except that one half rather than one third of the semi-fusinite in Western Canadian coals with 20% or more of this maceral is considered reactive for the calculation of the stability factor. Previous work at CANMET has shown that the predicted coke strengths then agree better with measured coke strengths (17).

The G-factor method of predicting coke strength was developed in Germany by Simonis and Beck (18). The G-factor is calculated from data obtained from the Ruhr dilatomer:

$$G = \frac{E + V}{2} \cdot \frac{c + d}{cV + dE}$$

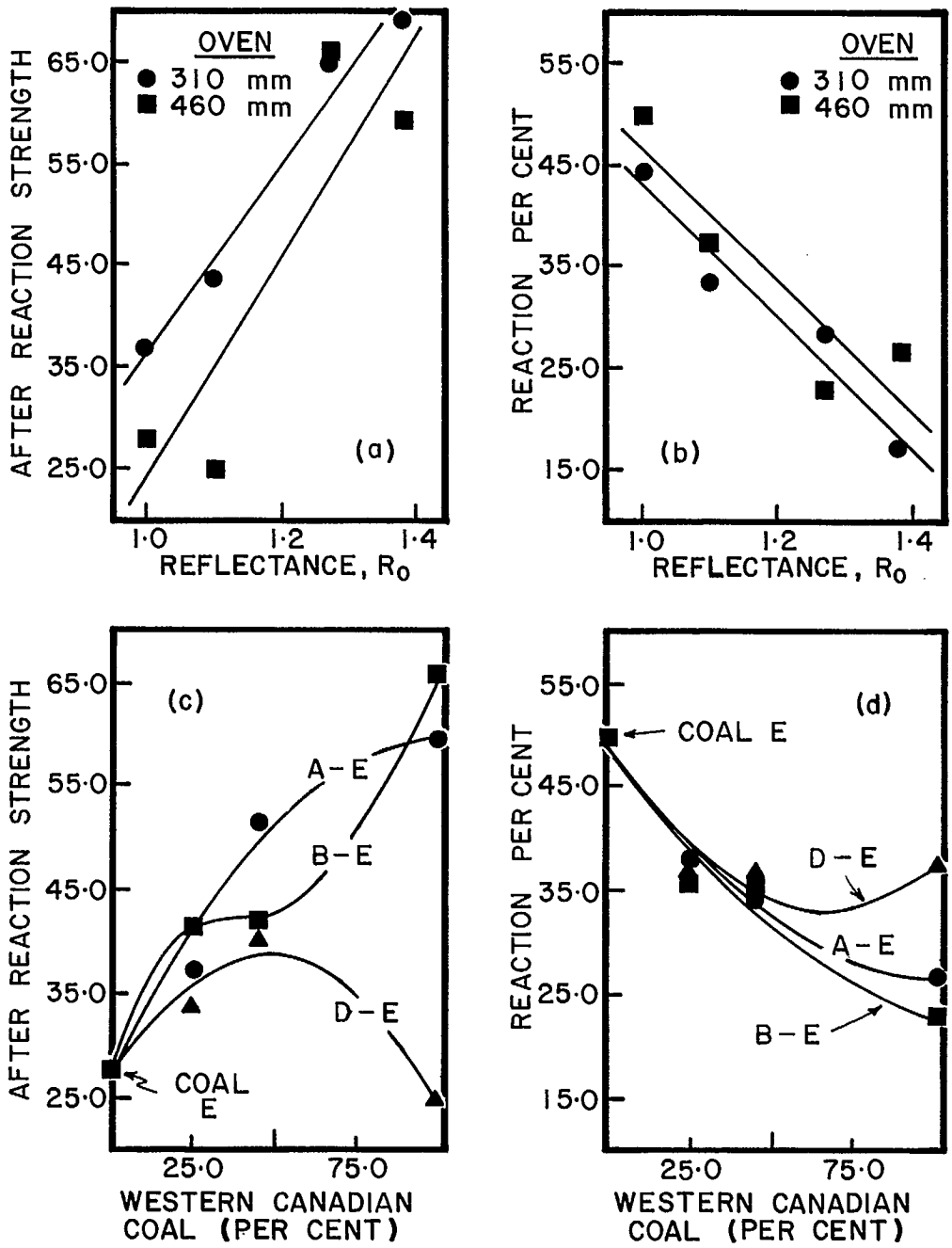

Fig. 7 - Relationship between - (a) after reaction strength and mean maximum vitrinite reflectance; (b) reaction per cent, RP and mean maximum vitrinite reflectance; (c) after reaction strength and blend composition; (d) reaction per cent RP and blend composition

where

E is the softening temperature of the coal, °C

V is the solidification temperature, °C

c is the percentage contraction

d is the percentage dilatation

Its usefulness is largely based on the fact it has been found to be additive for many coals; thus the G-factor for a binary coal blend containing coals A and B can be calculated from:

$$G_{blend} = \frac{G_A\ (\%A \text{ in blend}) + G_B\ (\%B \text{ in blend})}{100}$$

Other coal properties are often not additive. Total dilatation has been found to be additive for some coals providing their ranks, R_o are not too dissimilar (19). Table 5 compares the measured and predicted dilatations and G-factors and also their maximum fluidity, the logarithm of which has been assumed to be additive. The calculated G-factors are close to the measured values except for blends containing coal D, whereas calculated total dilatations and fluidities are in general significantly different from the measured values.

The G-factor can be used in a formula to predict coke strength directly. However, the formula involves volatile matter content and particle size measured by standard German (DIN) techniques rather than the ASTM methods used in this laboratory, and the coke strength is predicted in terms of the Micum index obtained from a tumble drum test which does not correlate well with the coke stability factor. Therefore, stability factors were predicted from Fig. 8, which was obtained previously by the writers from regression of the G-factor, R_o value and stability factors of 90 Western Canadian coals (20).

The third method of prediction examined also involves regression of data for Western Canadian coals. The relationship between maximum Gieseler fluidity, R_o, and stability factor seen in Fig. 9 was obtained using data for 180 coal samples tested by CANMET during the last

Table 5 - Comparison of measured and predicted coal rheological properties

Coal/coal blend	c+d measured	c+d* predicted	f measured	f** predicted	G-factor measured	G-factor predicted
100% A	39	-	20	-	0.98	-
45% A, 55% E	101	142	885	1064	1.05	1.05
25% A, 75% E	136	179	2100	4536	1.07	1.08
100% B	40	-	79	-	0.98	-
45% B, 55% E	91	142	383	2612	1.05	1.05
25% B, 75% E	153	179.5	1520	6374	1.08	1.08
100% C	72	-	435	-	1.04	-
45% C, 55% E	126	157	1225	4264	1.07	1.08
25% C, 75% E	153	187	1725	9800	1.09	1.09
100% D	0	-	6	-	0.93	-
45% D, 55% E	124	133	1065	621	1.05	1.03
25% D, 75% E	170	174	3250	3361	1.09	1.07
100% E	226	-	27800	-	1.11	-

c is percentage contraction in Ruhr dilatometer

d is percentage dilatation in Ruhr dilatometer

f is maximum fluidity in Gieseler plastometer

*assuming (c + d) is additive

**Assuming Ln (fluidity) is additive

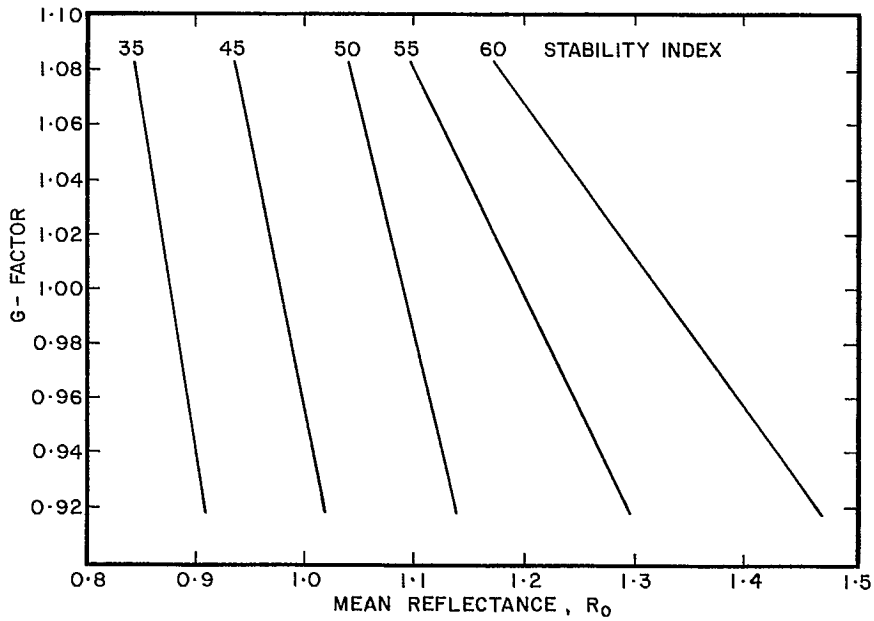

Fig. 8 - Relationship between the G-factor and mean maximum vitrinite reflectance for Western Canadian coals

ten years (21). This figure shows that the stability factor of low rank coals i.e., with low R_o depends largely on rank whereas for high rank coals it is governed by the coal's fluidity. The cross-hatched box is the target blending area used in Japan for making blast furnace coke.

Table 6 compares the predicted stability factors with stability factors measured on coke produced in the 460-mm oven. The standard deviations of the differences between predicted and measured values are for the petrographic, G-factor and R_o-fluidity methods respectively. The data in Table 6 are plotted in Fig. 10 to show the trends more clearly. The blends of coals A and C with coal E and the 45% B-55% E blend are predicted by the petrographic method to have coke strengths higher than the Western Canadian coals coked alone. This was not observed and is also contrary to the strengths predicted by the other two methods. The R_o-fluidity method predicts the measured stabilities most closely while the G-factor method predicts well except for coal E. Petrography predicts accurately the coke stability factors for Eastern and Western Canadian coals except for coal D.

The measured maximum fluidities and mean maximum vitrinite reflectance of the coals and coal blends are plotted in Fig. 9. Lines have been drawn for example between coal A, its blends and coal E. The fluidities of the Western coals increased as their rank decreased except for coal D which had a low fluidity, 6 dial divisions/minute (dd/min), and as seen in Fig. 9 a predicted stability factor of 45.2 which is somewhat larger than the measured factor of 37.2. Petrography predicted a stability factor of 51.4 for this coal and this position is marked on the diagram by an open circle and corresponds to a fluidity of about 200 dd/min. The large discrepancy between the measured and petrographic stability factors suggests this sample of coal D may have been partially oxidized. Two different samples obtained several months later had higher stability factors at 39.4 and 46.5

Figure 9 correctly predicts that, of the blends coked, only those of coal D should have stability factors higher than the Western coal coked alone. Two lines for further investigation are suggested by this figure. Carbonizing a blend of coals D and E with a fluidity between

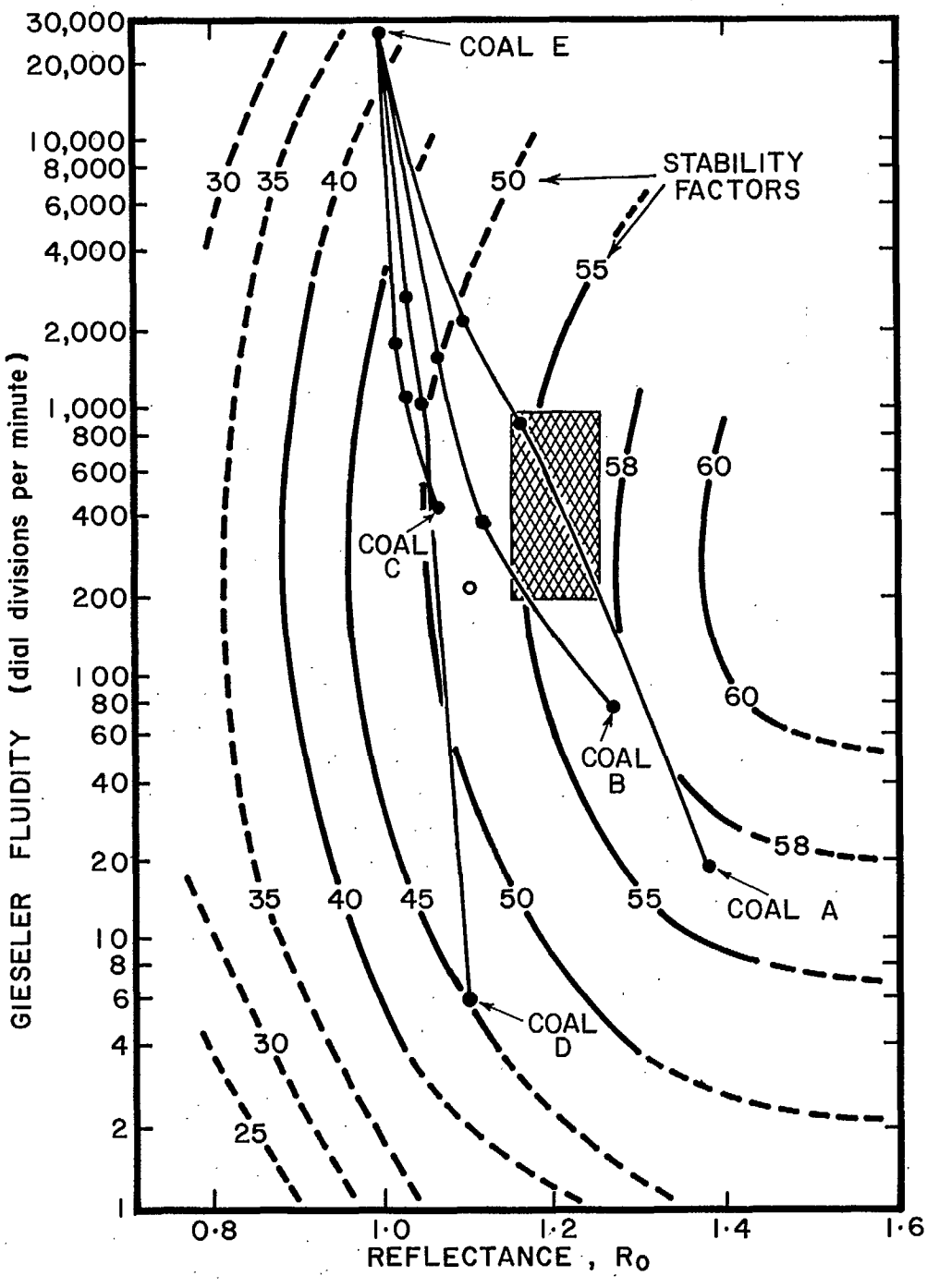

Fig. 9 - Relationship between stability factor, maximum Gieseler fluidity and mean maximum vitrinite reflectance for Western Canadian coals

Table 6 - Comparison of measured and predicted stability factors

Coal/coal blend	Measured stability factor, 460-mm oven	Predicted stability factor		
		R_o-fluidity	G-factor	Petrography
100% A	58.2	56.9	61.0	54.5
25% A, 75% E	51.6	50.2	53.0	57.9
45% A, 55% E	55.6	54.2	56.0	62.6
100% B	55.9	57.3	57.0	56.0
25% B, 75% E	49.6	49.3	52.0	53.4
45% B, 55% E	52.7	52.7	53.5	60.5
100% C	48.1	50.4	49.5	46.0
25% C, 75% E	42.3	46.6	49.0	47.3
45% C, 55% E	45.3	47.6	48.5	52.0
100% D	37.2	45.2	48.5	51.4
25% D, 75% E	44.4	45.9	49.0	48.9
45% D, 55% E	49.2	48.8	49.0	53.7
100% E	38.1	37.8	46.5	37.6
Standard deviation of difference between measured and predicted stability factor		2.69	3.45	4.77

about 100 and 400 dd/min should produce a 50-plus stability factor coke. This can be tested by measuring the fluidity of different blend compositions in the laboratory before carbonizing a suitable composition in a technical-scale oven. Secondly, the figure predicts that the stability factor of coal A will be increased slightly as small amounts of up to about 20% of coal E are added to it.

Figure 10 was constructed with data obtained from single coals. Therefore, although it predicts accurately the coke strength of blends used in the present work, it may not satisfactorily predict coke strength of all coal blends.

CONCLUSIONS

Coke with good chemical and physical properties for the blast furnace can be made by blending low ash, high sulphur Eastern Canadian coals with high ash, low sulphur Western Canadian coals. All blends carbonized had low coking pressures and could be coked in industrial ovens.

Coal blends were coked in CANMET's 460-mm and 310-mm technical-scale ovens. The strengths (stability factors) of the coke produced in the two ovens were similar, but other physical properties - coke hardness, apparent specific gravity and size distribution - differed considerably because of the difference in oven operating parameters.

The hot strengths of the cokes were measured by the Nippon Steel Corporation test. The trend of the results with blend composition was similar to that observed for the coke stability factors. The hot strengths were higher for coke made in the small oven probably because of its higher coal bulk density.

Three methods of predicting coke strength from coal properties were compared. In general the petrographic method predicted well

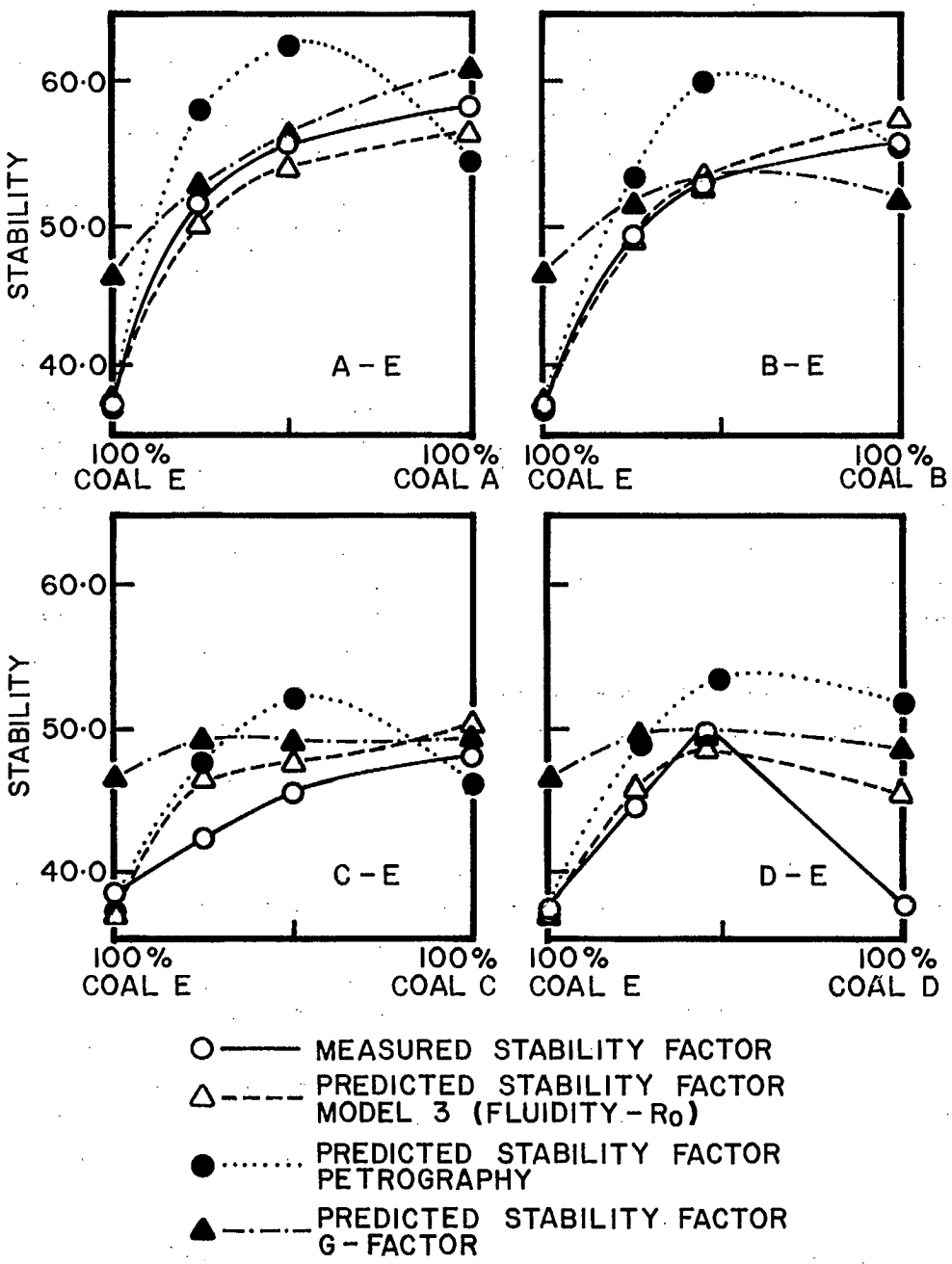

Fig. 10 - Relationship between predicted and measured stability factors and blend composition

the coke strength of coals coked alone but less accurately the strength of coke produced from coal blends. The G-factor method was fairly accurate for all coals and blends except for coal E coked alone. The most accurate method used the mean maximum reflectance of the vitrinite and the maximum fluidity of the coal or blend (Japanese MOF diagram). The predicted strengths were obtained from iso-stability lines drawn on the diagram that had been obtained previously by regression of data for 180 Western Canadian coals.

ACKNOWLEDGEMENTS

The authors thank members of the Coal Resource and Processing Laboratory for the coal and coke analyses and carbonization tests and especially J. Jorgensen for petrographic analysis.The authors are grateful to J.C. Botham, manager of CRPL for many helpful discussions and his advice. The Technical Committee of the Canadian Carbonization Research Association, especially A.W. Kay, helped plan the coke oven trials. The authors thank the coal companies that supplied samples representative of their production.

REFERENCES

1. Daneliak, N and Kay, A.W. "The use of Canadian coals in North American coal blends"; AIME Ironmaking Proc; 37:377-389; 1978.

2. Layt, G.H.G. "Canadian coal for the Canadian steel industry"; Proc 28th Can Conf Coal; 1976, Ottawa; 69-71; 1976.

3. "1976 assessment of Canada's coal resources and reserves"; Report EP 77-5; Energy, Mines and Resources Canada; 1977.

4. Botham, J.C. and Jorgensen, J.G. "Western Canadian coals for cokemaking"; AIME Ironmaking Proc; 33:347-371; 1974.

5. Botham, J.C. and Donaldson, J.R. "Coking coals of Eastern Canada"; North Min; 62:6; 1976.

6. MacLean, A.R. "Canadian coal mining underground - a viable necessity"; CIM Reporter; 3:1:12; 1977.

7. Gransden, J.F. and Leeder, W.R. "460-mm technical-scale coke oven: Influence of flue temperature and coal preparation on coke quality"; CANMET Report 79-18; CANMET, Energy, Mines and Resources Canada; 1979.

8. George, D.W.R. and Paulencu, H.N. "An approach to coke quality"; AIME Ironmaking Proc; 33:445-450; 1974.

9. Winzer, G. and Engel, K. "Influence of different coke sizes on blast furnace results"; In: "Coal, coke and the blast furnace"; London, Whitefriars Press; 29-35; 1978.

10. Fisher, A.D. "Metallurgical coals for the future"; Proc 23rd Can Conf Coal; 1971, Ottawa; 45-68; 1971.

11. Paulencu, H.N. and Readyhough, P.J. "Interpreting coal properties for utilization in commercial cokemaking"; In: "Symposium on coal evaluation"; Information Series 76; Alberta Research Council; 108-128; 1974.

12. Botham, J.C. "Cokemaking" paper presented at Blast furnace ironmaking conference; McMaster University, Hamilton, Ontario; June 1977.

13. Denton, G.H. "Coal selection for high quality coke"; Blast furnace ironmaking conference; McMaster University Press, Hamilton; 2:11:13; 1978.

14. Reeve, D.A., Price, J.T. and Gransden, J.F. "High-temperature behaviour of blast furnace coke - a review"; CANMET Report 77-60; CANMET, Energy, Mines and Resources Canada; 1977.

15. Murakami, S., Hara, Y. and Ishikawa, I. "New ideas about coke reactivity"; Coke Circular; 23:2:82-87; 1974.

16. Schapiro, N., Gray, R.J. and Eusner, G.R. "Recent developments in coal petrography"; Blast furnace, coke oven, raw materials committee Proc, AIME; 20:89-112; 1961.

17. Carr, A.J. and Jorgensen, J.G. "An estimation of the effective reactive/inert ratio of semi-fusinite in Western Canadian coals"; Division Report ERP/ERL 75-141; CANMET, Energy, Mines and Resources Canada; 1975.

18. Simonis, W. and Beck, K.G. "An approximate method of predicting coke strength"; Gluckauf Forschungshefte; 27:105-113; 1966.

19. Gregory, D.H. and Pierce, T.J. "U.K. views on blend composition and preparation"; In: "Coal, coke and the blast furnace"; London, Whitefriars Press; 107-116; 1978.

20. Gransden, J.F., Pierce, T.J. and Price, J.T. "The G-value: application to Western Canadian coals"; Division Report ERP/ERL 78-104; CANMET, Energy, Mines and Resources Canada; 1978.

21. Leeder, W.R., Gransden, J.F., Price, J.T. and Botham, J.C. "Prediction of coke quality with special reference to Canadian coals"; presented at 38th AIME Ironmaking Conf, Detroit; March 1979.

APPENDIX A - COAL PROPERTIES

Table A-1 - Chemical analyses of component coals

Identification						
Laboratory Number		3049-77	3335-77	2090-78	3083-77	3335-77
Coal		A	B	C	D	E
Classification						
Rank (ASTM)		mvb	mvb	mvb	mvb	hvAb
International system		433	433	533	421	635
Specific volatile index		195	190	182	177	172
Carbon (dmmfb)	%	90.7	90.4	93.9	88.2	86.3
Proximate Analysis (db)						
Ash	%	9.8	8.4	9.5	10.8	4.1
Volatile matter	%	21.8	23.5	25.5	24.8	33.9
Fixed carbon	%	68.4	68.1	65.0	64.4	62.0
Gross Calorific Value (db)						
Btu per pound		13,975	14,175	13,885	13,540	14,730
MJ/kg		32.5	33.0	32.3	31.5	34.2
Ultimate analysis (db)						
Carbon	%	80.9	82.0	84.1	77.7	82.3
Hydrogen	%	4.4	4.4	4.7	4.4	5.4
Sulphur	%	0.32	0.39	0.30	0.35	1.25
Nitrogen	%	1.3	1.4	1.0	1.2	1.7
Ash	%	9.8	8.4	9.5	10.8	4.1
Oxygen (by difference)	%	3.3	3.4	0.4	5.5	5.2
Ash Analysis (db)						
SiO_2	%	65.1	57.3	52.0	50.5	36.9
Al_2O_3	%	28.4	33.2	25.9	32.4	21.4
Fe_2O_3	%	2.3	5.8	3.7	2.5	35.2
TiO_2	%	1.7	1.8	1.5	2.5	0.9
P_2O_5	%	0.5	1.0	0.8	2.0	0.1
CaO	%	1.1	1.4	6.1	3.4	1.8
MgO	%	0.6	0.5	1.5	0.6	1.4
SO_3	%	0.7	0.7	4.3	2.3	2.0
Na_2O	%	0.1	0.1	1.4	0.3	0.5
K_2O	%	0.4	0.7	0.3	0.5	1.1

Table A-2 - Thermal rheological properties of component coals

Identification						
Laboratory number		3049-77	3336-77	2090-77	3083-77	3335-77
Coal		A	B	C	D	E
Gieseler Plasticity						
Start	°C	438	430	417	430	390
Fusion temp.	°C	455	446	429	445	403
Max. fluid temp.	°C	470	463	454	449	433
Final fluid temp.	°C	490	479	482	467	475
Solidification temp.	°C	493	484	486	473	477
Melting range	°C	52	49	65	37	85
Max. fluidity	dd/m	20	79	435	6	27,800
Torque	g.in.	40	40	40	40	40
Dilatation						
Ti - softening temp.	°C	397	392	377	397	349
Tii - max. contraction temp.	°C	454	442	427	453	406
Tiii - max. dilatation temp.	°C	485	472	461	-	449
Contraction	%	23	24	23	19	26
Dilatation	%	16	16	49	Nil	200
Free Swelling Index						
F.S.I.		7	7-1/2	5	4	8-1/2

Table A-3 - Petrographic analysis of component coals

Identification						
Laboratory Number		3049-77	3336-77	2090-78	3083-77	3335-77
Coal		A	B	C	D	E
Distribution of vitrinite types						
V-6	%					
V-7	%					
V-8	%					5.6
V-9	%			4.5	3.3	40.6
V-10	%		0.5	36.1	19.1	28.7
V-11	%		12.6	9.0	19.6	4.7
V-12	%	5.3	14.8	0.5	4.3	
V-13	%	27.0	24.7		1.4	
V-14	%	16.4	2.2			
V-15	%	4.3				
V-16	%					
V-17	%					
V-18	%					
Reactive components						
Total vitrinite	%	53.0	54.9	50.1	47.7	79.6
Reactive semi-fusinite	%	15.0	14.0	14.0	16.5	1.1
Exinite	%	0.0	0.3	0.1	2.4	5.3
Total	%	68.0	69.2	64.2	66.6	86.0
Inert components						
Inert semi-fusinite	%	15.1	14.0	14.0	16.5	2.3
Micrinite	%	3.4	2.1	7.5	2.3	3.2
Fusinite	%	8.0	10.0	9.0	8.5	6.0
Mineral matter	%	5.5	4.7	5.3	6.1	2.5
Total	%	32.0	30.8	35.8	33.4	14.0
Petrographic indices						
Mean reflectance	%	1.38	1.27	1.06	1.10	0.99
Balance index		2.78	1.93	1.53	1.31	0.41
Strength index		6.09	5.20	3.85	4.17	3.48
Stability Index		54.5	56.0	46.0	51.4	37.6

APPENDIX B - COKING TEST RESULTS

Table B-1 - Coke properties, 460-mm oven

Test No.	Coal blend composition	ASTM stability	ASTM hardness	Coke yield %	Apparent specific gravity	Screen analysis, cumulative %							Mean coke size mm	Coking pressure kPa
						+100mm	+75mm	+50mm	+38.1mm	+25mm	+19mm	+12.5mm		
245	100%A	57.3	65.1	76.3	0.906	2.6	16.7	60.2	81.6	93.3	94.6	95.5	57.1	2.3
246	100%A	59.0	66.0	77.1	0.904	5.6	18.4	60.8	83.5	94.1	95.1	95.7	58.7	2.5
256	25%A 75%E	51.9	58.8	71.3	0.803	1.8	18.3	63.4	84.0	95.0	96.2	97.0	62.2	1.9
257	25%A 75%E	51.2	58.6	71.2	0.790	3.4	20.1	67.4	87.2	95.1	96.1	97.0	60.7	3.9
254	45%A 55%E	55.3	61.1	72.1	0.831	1.0	15.1	66.3	86.8	95.3	96.2	97.0	58.4	2.5
255	45%A 55%E	56.2	62.1	72.2	0.833	2.6	19.0	66.4	87.3	95.7	96.7	97.4	60.2	2.5
247	100%D	38.2	50.2	73.4	0.912	8.8	27.4	59.0	74.5	82.4	83.7	84.7	57.4	2.1
248	100%D	36.1	47.8	73.4	0.919	13.5	33.2	63.1	77.1	84.3	85.4	88.2	62.0	2.1
249	25%D 75%E	44.0	54.8	68.9	0.777	2.0	15.9	60.2	84.0	94.1	95.6	96.6	57.4	2.1
250	25%D 75%E	54.8	56.3	68.7	0.808	3.2	18.2	59.7	84.2	94.4	96.0	96.7	57.9	2.1
251	45%D 55%E	49.1	59.0	69.8	0.828	1.3	16.4	58.2	81.9	93.7	95.1	96.3	56.4	1.7
252	45%D 55%E	49.3	56.6	71.1	0.831	3.1	21.2	64.3	84.8	94.3	95.5	96.3	64.8	1.7
258	100%B	55.9	65.6	76.8	0.920	1.1	9.3	48.9	77.7	94.3	95.7	96.6	56.1	2.3
259	100%B	54.5	65.6	75.3	0.940	2.6	11.3	46.3	76.0	93.5	94.9	96.2	52.3	3.4
260	25%B 75%E	49.6	57.1	70.1	0.774	1.0	14.1	61.0	84.9	94.6	96.0	96.9	56.9	1.8
261	25%B 75%E	49.0	56.7	70.1	0.769	0.9	16.9	66.7	88.2	95.4	96.4	97.2	59.2	1.7
267	45%B 55%E	52.6	59.4	71.0	0.814	3.0	12.1	60.8	85.8	94.6	95.6	96.4	56.9	3.8
268	45%B 55%E	52.7	59.4	71.0	0.822	2.6	15.2	63.6	86.0	95.0	96.2	97.1	58.2	2.9
277	100%C	49.0	59.9	72.3	0.880	6.6	25.2	66.0	84.8	94.0	95.3	96.3	62.0	-
278	100%C	47.2	57.1	70.8	0.884	6.4	25.0	64.0	84.2	93.0	94.4	96.2	61.2	-
280	25%C 75%E	42.1	57.1	67.3	0.850	0.4	12.3	57.6	80.9	92.6	94.4	95.6	54.9	-
281	25%C 75%E	42.4	54.3	66.7	0.854	1.4	15.4	63.3	84.2	93.7	95.2	96.2	57.4	1.2
282	45%C 55%E	45.2	57.0	70.2	0.819	4.4	18.5	61.4	82.0	93.1	94.5	95.7	58.2	2.1
283	45%C 55%E	45.3	56.1	69.8	0.818	7.6	27.6	71.0	86.6	94.4	95.6	96.6	64.0	2.1
262	100%E	38.9	54.3	64.0	0.762	3.4	16.6	61.3	88.3	93.4	94.8	96.4	57.9	-
263	100%E	37.2	56.9	65.1	0.757	2.1	14.8	60.7	82.0	93.0	95.0	96.4	56.4	2.1

Table B-2 - Coke properties, 310-mm oven

Test No.	Coal blend composition	ASTM stability	ASTM hardness	Coke yield %	Apparent specific gravity	Screen analysis, cumulative %							Mean coke size	Coking pressure kPa
						+100mm	+75mm	+50mm	+38.1mm	+25mm	+19mm	+12.5mm		
578	100%A	60.6	70.0	77.6	0.966	0	8.8	44.8	76.8	93.9	95.6	96.5	51.0	3.7
579	100%A	57.4	71.5	78.0	0.966	0	7.1	41.3	72.4	95.3	96.3	97.1	49.8	3.4
590	25%A 75%E	52.6	64.4	70.0	0.853	0	4.1	44.6	76.6	93.9	96.1	96.9	54.9	4.0
591	25%A 75%E	49.6	64.9	70.6	0.852	0	3.1	40.0	74.6	92.8	95.0	95.9	48.3	2.7
594	100%D	36.8	55.9	74.8	0.989	3.9	17.3	51.5	74.0	89.9	91.6	92.4	52.3	1.6
595	100%D	36.6	57.7	75.1	0.988	2.7	14.7	48.7	72.5	89.5	91.7	92.8	52.6	1.6
587	45%D 55%E	47.3	62.0	71.3	-	0	6.2	45.2	73.3	93.6	95.7	96.6	50.0	2.1
589	45%D 55%E	48.5	63.4	71.0	0.790	0.5	5.1	40.6	75.0	93.5	96.0	96.8	49.3	1.6
596	100%B	52.5	70.2	79.1	0.950	1.4	4.6	34.6	68.6	93.4	95.7	96.6	47.2	5.0
597	100%B	54.1	70.3	79.2	0.952	0	4.2	36.0	70.2	93.4	95.5	96.5	47.2	5.0
606	45%B 55%E	53.8	65.9	72.1	0.890	0	2.4	37.8	74.5	94.4	96.2	97.1	48.0	2.9
607	45%B 55%E	56.3	68.1	72.7	0.900	0	2.8	36.8	73.7	93.6	96.1	97.0	47.7	2.9
626	100%C	43.9	64.6	73.0	-	0.6	11.0	46.0	72.7	93.4	95.7	96.9	51.6	2.1
621	100%C	46.5	65.4	75.3	0.984	0.4	7.3	46.3	74.4	93.6	95.9	97.0	50.8	2.1
623	25%C 75%E	44.1	61.1	68.5	-	0	3.6	38.2	72.2	92.6	95.3	96.3	47.7	1.9
624	25%C 75%E	44.5	61.3	68.3	0.840	0	4.2	38.3	71.7	92.3	94.7	95.8	47.7	1.9
598	100%E	39.7	60.0	67.4	0.782	0	2.3	39.6	73.9	92.7	95.1	96.2	47.5	2.4
608	100%E	41.3	63.3	67.5	0.773	0	3.4	37.4	72.2	93.3	95.5	96.5	48.0	3.2

OPINION POLL

The opinion of concerned readers may influence the direction of future CANMET research.

We invite your assessment of this report — No. CM 79-36

Is it useful?	Yes_____	No_____
Is it pertinent to an industry problem?	Yes_____	No_____
Is the subject of high priority?	Yes_____	No_____

Comments_____

_____

_____

Please mail to: CANMET Editor, EMR, 555 Booth Street,
Ottawa, Ontario, K1A 0G1

A complimentary copy of the CANMET Review describing CANMET research activity will be sent on request.

CANMET REPORTS

Recent CANMET reports presently available or soon to be released through Printing and Publishing, Supply and Services, Canada (addresses on inside front cover), or from CANMET Publications Office, 555 Booth Street, Ottawa, Ontario, K1A 0G1:

Les récents rapports de CANMET, qui sont présentement disponibles ou qui ce seront bientôt peuvent être obtenus de la direction de l'Imprimerie et de l'Edition, Approvisionnements et Services, Canada (adresses au verso de la page couverture), ou du Bureau de Vente et distribution de CANMET, 555 rue Booth, Ottawa, Ontario, K1A 0G1:

79-1 Tantalum and niobium ore dressing investigations at CANMET; D. Raicevic and H.L. Noblitt;
Cat. No. M38-13/79-1, ISBN 0-660-10419-9; Price: $3.85 Canada, $4.65 other countries.

79-2 Synthesis and characterization of zirconia electrolytes for potential use in energy conversion systems; T.A. Wheat;
Cat. No. M38-13/79-2, ISBN 0-660-10405-9; Price: $1.75 Canada, $2.10 other countries.

79-6 Heat-affected-zone toughness of welded joints in micro-alloy steels; (Noranda Research) D.W.G. White and K. Winterton, editors;
Cat. No. M38-13/79-6, ISBN 0-660-10413-X; Price: $5.75 Canada, $6.90 other countries.

79-9 Construction and operation of a continuous ion exchange pilot plant using fluidized-bed columns; P. Prud'homme and B.H. Lucas;
Cat. No. M38-13/79-9, ISBN 0-660-10440-7; Price: $1.25 Canada, $1.50 other countries.

79-13 Liquid fuels from Canadian coals; G. Taylor;
Cat. No. M38-13/79-13, ISBN 0-660-10424-5; Price: $3.10 Canada, $3.75 other countries.

79-14 Zinc concentrate CZN-1 - A certified reference material; G.H. Faye, W.S. Bowman and R. Sutarno;
Cat. No. M38-13/79-14, ISBN 0-660-10270-6; Price: $2.00 Canada, $2.40 other countries.

79-15 Lead concentrate CPB-1 - A certified reference material; G.H. Faye, W.S. Bowman and R. Sutarno;
Cat. No. M38-13/79-15, ISBN 0-660-10287-0; Price: $2.00 Canada, $2.40 other countries.

79-16 Copper concentrate CCU-1 - A certified reference material; G.H. Faye, W.S. Bowman and R. Sutarno;
Cat. No. M38-13/79-16, ISBN 0-660-10288-9; Price $1.45 Canada, $1.75 other countries.

79-19 Test installation for studying erosion-corrosion of metals for coal washing plants; G.R. Hoey, W. Dingley and C.T. Wiles;
Cat. No. M38-13/79-19, ISBN 0-660-10420-2; Price: $1.10 Canada, $1.35 other countries.

79-21 Removal of radionuclides from process streams - A survey; I.J. Itzkovitch and G.M. Ritcey;
Cat. No. M38-13/79-21, ISBN 0-660-10409-1; Price: $8.00 Canada, $9.60 other countries.

79-22 Mineral waste resources of Canada report no. 3 - Mining wastes in British Columbia; R.K. Collings;
Cat. No. M38-13/79-22, ISBN 0-660-10407-5; Price: $2.00 Canada, $2.40 other countries.

79-24 A study and assessment of the technological capabilities of the Canadian foundry industry; (R. Shnay and Associates Ltd.) R.K. Buhr, editor;
Cat. No. M38-13/79-24, ISBN 0-660-10427-X; Price: $3.25 Canada, $3.90 other countries.

79-27 Mineralogy of samples from the Lac des Iles area, Ontario; L.J. Cabri and J.H.G. Laflamme;
Cat. No. M38-13/79-27, ISBN 0-660-104030-X; Price: $1.00 Canada, $1.20 other countries.