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May 1981

For presentation to 64th Conference, Chemical Institute of Canada, Halifax, May 31 - June 3, 1981.

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
DIVISION REPORT ERP/ERL 81-42 (J)(OP)

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ABSTRACT

This report discusses some of the findings of CANMET studies to assess Canadian coking coal qulaity and their use in newer cokemaking technologies. The use of Canadian coking coals in commercial types of coal blends has been investigated and the results have been good. Empirical predictions of the coke quality for individual Canadian coals, based on laboratory scale results, have been shown to be often limited, particularly for methods developed in other countries. The definitive coal evaluation method for Canadian coals remains pilot-scale coke oven testing.

Cleaning of given western Canadian coking coals to different mineral matter (e.g. ash) levels changed the resulting coke quality. An example is given that can be explained by changes in the petrographic composition of the coal, but the influence of other factors such as coarser sized mineral matter is still under investigation. Canadian coals were effectively used in studies of new coking technologies such as partial briquetting, preheating and pitch additions.

It is concluded that Canadian coking coals can be excellent coking blend components or most satisfactorily used in new coking technologies.

Keywords Canadian coking coals; partial briquetting;blending; testing: pitch additives; preheating.

INTRODUCTION

The majority of Canadian coking coal resources are found at opposite ends of the country - Nova Scotia and the Rocky Mountains - whereas the majority of coking coal users are found in central Canada and use U.S. coals that are geographically closer. Most Canadian coking coal production is exported, particularly to the Pacific rim area. Canadian coking coals cover a wide range of coal characteristics. Eastern coking coals are classified as ASTM high volatile bituminous and have lower inerts content, higher sulphur, lower mineral matter and higher caking properties than their Western counterparts, which cover the entire ASTM bituminous coal range (low, medium and high volatile bituminous; lvb, mvb, and hvb, respectively).

Commercial cokemaking operators normally mix two or more coals to produce a blend that will give specific coke and carbonization quality characteristics. The desired characteristics inclued:

- specified (low) coke sulphur, ash, alkali and phosphorus content - these influence blast furnace productivity and slag and metal characteritics;
- specified (high) coke strength such as ASTM coke stability factor - influences blast furnace productivity and coke used per ton of hot metal produced;
- a low coking pressure produced by the blend during carbonization - excessive pressure can damage coke oven walls causing expensive repairs.

The levels set for these quality specifications vary from plant to plant depending upon coke oven design, operation and technology, and the coke quality desired for the blast furnace. The use of single coals is sometimes possible, but most often the quality criteria cannot be satisfied by single coals. Cokemakers are also reluctant to become dependent upon a single source of supply.

This paper will consider the quality of Canadian coking coals as it relates to use in blends, as substitutes for U.S. coals, and in new cokemaking technologies. The information has been gathered from a number of studies conducted by CANMET, often in conjunction with the Canadian Carbonization Research Association* (CCRA), to assess the quality of the Canadian coking coal resources and to contribute to the federal government policy goal of achieving greater Canadian self-reliance in Energy.

TESTING METHODS AND QUALITY CRITERIA

At CANMET coking coals are studied both in the laboratory and in pilot-scale equipment. Routine laboratory testing of coals and blends follow the American Society for Testing and Materials (ASTM) or the International Standard Organization (ISO)

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*A Research organization whose members include Canadian cokemakers and coal exploration and production companies. CANMET acts as secretariat.

standards. No standards exist for the method of operation of the pilot-scale coke ovens, but the quality of the coke produced by them is evaluated with the standarized tests used commercially.

Coke samples are analyzed using chemical, physical, caking and microscopic techniques in the laboratory. Table 1 lists some of these tests together with ranges of values found for coking coals and values required for commercial coking blends. Chemical analysis includes coal moisture, proximate analysis, ultimate analysis and ash analysis. Physical tests include size consist, Hardgrove grindability and ash fusion. The following caking tests are undertaken: Free Swelling Index (FSI); Gieseler plasticity; and Ruhr dilatation. As well, pilot-plant testing in the USBM sole-heated oven is conducted to obtain expansion/contraction values of coal during coking. Petrography produces a maceral analysis which together with the mean maximum reflectance of vitrinite maceral is used to predict a coke strength and to assist in the selection of coals for a coke oven blend.

The most definitive test work to evaluate the quality of a coking coal sample is conducted in pilot-scale coke ovens. Oven tests have assumed particular importance for Western Canadian coals since frequently laboratory analysis of these coals suggest they may produce poorer quality coke, based on predictive methods developed from non-Canadian coals. In fact many such Western coals are found to produce good to excellent quality coke in the pilot-scale ovens. Consequently an empirical model was produced for Canadian coals based on the accumulated experience of over 2 decades of testing at CANMET (1).

CANMET operates four pilot-scale ovens with coal capacities of 450 - 800 lbs, all of which have movable-walls that allow the measurement of the coking (or expansion) pressure of the coal or blend during carbonization. The ovens are operated under standardized conditions, see Table 2, that produce cokes of a quality similar to commercial-scale equipment.

Coke test results include coke yield, size of coke produced, specific gravity of coke produced, pressure produced by the coal or blend during coking, coke chemical analysis and coke strength parameters, a summary of which appears in Table 3. CANMET is equipped to evaluate the strength of coke, the most important coke quality parameter, using ASTM, ISO or Japanese Industrial Standard (JIS) tests. These tests tumble a sample of coke in the drum and measure its degradation. The normal results determined are the ASTM stability and hardness factors, and the JIS DI^{30}_{15} and DI^{150}_{15} indices. The stability factor is considered the prime coke quality parameter in North America.

BLENDING WITH CANADIAN COALS

Many pilot-scale coking tests and laboratory assessments of individual Canadian coals have been conducted by CANMET. During the last 15 years hundreds of exploration and production samples have been studies. Coke quality results have varied widely and have depended on a number of variables associated with the individual coals. These variables have included rank, method and extent of washing to remove undesirable mineral matter, inert maceral content, extent of weathering (often an influence of sampling location), etc. Use of the quality assessments without specific reference to a coking blend is often misleading. This section will review studies when Canadian coals were blended together or substituted for/added to a U.S. Appalachian blend.

All-Canadian Blend

In normal commercial blending practice in Canada mixtures of lvb and hvb coals are used. In one study an Eastern Canadian highly caking hvb was blended in a ratio of 80/20 with a Western poorly caking lvb coal and carbonized. The results appear in Table 4. Neither coal had particularly good coke strength when carbonized alone, yet produced a reasonable quality coke when carbonized together in the blend. Coking pressures for the blend were lower than when the lvb coal was carbonized alone. The blend was selected using Fig. 1, based on the empirical predictive method developed by CANMET from its accumulated experience with Canadian coals. Actual test results correlated well with predicted values (Table 4).

A study was undertaken to consider different blends of 4 Western Canadian mvb coals with an Eastern Canadian hvb coal (2). The chemical and caking properties of the coal appeared complimentary and specific information was sought on their coking behaviour. A summary of the analyses of the coals appears in Table 5. The blend compositions was compared to changes in the resulting coke ASTM stabilities (Fig. 2), sulphur and ash content (Fig. 3) and coking pressures. The results show that two of the mvb-hvb blends could produce a coke of acceptable strength and quality for blast furnace use. The sulphur and ash criteria were achieved in all blends the coking pressures was low. The results indicate that acceptable coke could be produced from a two-way blend of Canadian Western mvb and Eastern hvb coals.

Substitution of Canadian Coals in a U.S. Appalachian Blend

A study was undertaken to determine if Western Canadian lvb and mvb coals could be added to advantage in a U.S. hvb/lvb blend. Blends were selected using guidance from a commercial cokemaker and empirical predictive methods based on petrography and the CANMET approach in Fig. 1 which also includes the predicted results for the blends. The resulting coke strength values are compared in Table 6, to the predicted results. It was concluded from Table 6 that improved stability factors could be obtained when a Canadian lvb coal was substituted for a U.S. Appalachian lvb coal in a U.S. Appalachian blend, and also when a Canadian mvb coal was added to the blend. The test results showed that the predictive method (Fig. 1) worked reasonably well for blending with both the Canadian and U.S. coals. Although not shown in Table 6, other coking test results such as coking pressures, were also acceptable.

COAL WASHING

The amount and the type of mineral matter (e.g. ash) in a coal is known to influence the quality of the coke produced from it. Earlier preliminary studies conducted at CANMET on two Western Canadian coals, cleaned to two different ash levels, showed significant changes in coke strength (3). A recent continuation of the studies investigated the changes in coking quality of five Western coals cleaned in a pilot plant consisting of heavy media cyclones, water only cyclones and flotation, to yield products at three different ash levels for each coal. Fig. 4 shows the results for one coal where the coke stability factor increased as the ash content decreased. The changes in coke strength were accurately predicted by CANMET petrography, and as it was surmised that the observed change in coke strength was due to changes in the ratios of the reactive coal macerals to the inerts present in the coal. CANMET petrography, was not accurate for all coals however, and it is believed that in some of the samples investigated coarse mineral particles may also have influenced coke strength. Coarse mineral matter may help to explain large errors in predictions noted for single coals when Fig. 1 was derived (1).

The coal of Fig. 4 is mvb in rank and would not normally constitute the larger part of a blend used for commercial cokemaking. It was decided to determine if the influence of coal samples prepared at different ash levels would carry over into a commercial type blend. Each blend consisted of 50% of the washed coals, 37.5% of a Canadian hvb coking coal and 12.5% of a U.S. lvb coal. The results in Fig. 4 show that the influence of the washed samples on blend coke quality was far less since a change of 2-3 stability units occurred as compared to 9.4 units for the mvb by itself.

CANADIAN COALS IN NEW COKING TECHNOLOGIES

The use of Canadian coals in new technological advances in cokemaking such as partial briquetting, preheating and addition of pitches have been studied by CANMET. This section discusses selected results from these studies.

Preheating of Canadian Coals

Preheating of the coal blend before charging to coke ovens is an established technology, but it is not currently used in Canada. Preheating improves coke oven productivity by 25-40% and usually improves coke strength or, alternatively, allows the use of poorer quality coking coals. Tests were conducted to assess the application of preheating to Canadian coals and to try to shed some light on the reasons why preheating improves coke strength (4). Tests with coals and blends of A,B,C and E in Table 4 showed that preheating usually increased the coke stability factor as compared to charging at standard conditions (e.g. 6% moisture), Table 7. Much of this increase was attributed to the higher bulk density of the charge in the oven as a result of preheating. To determine if bulk density was the only factor influencing the change in coke strengths coals were dry-charged i.e., with only 1% moisture so that the bulk densities were similar to those of the preheated charges. The resulting coke stabilities indicated that other factors must be taken into account: the Eastern high-volatile coal E, dry-charged, had a stability factor 8 points lower, whereas the three Western medium-volatile coals had stability factors 4-10 points higher than the preheated charge. Further batches of coals A and E were obtained and additional tests carried out. The coals were coked preheated, at different coking rates and after cooling the preheated coal. From these results and from the results of rheological testing of the coals after preheating, it was concluded that preheating caused a deterioration in the caking behaviour of the medium-volatile but not of the high-volatile coal, and that the temperature history of the coal in the oven must also be a contributory factor to the improved coke strength of the high-volatile coal.

Blends containing 75% E and 25% A or C had superior coke strength after preheating and test oven productivities were increased by 26-30%.

It was concluded that preheating of hvb/mvb blends containing Canadian coals leads to significant increases in coke strength and oven productivity. Several factors including increased coal bulk density of the preheated blend and the oven temperature history contributed to the improved coke strength.

Partial Briquetting with Canadian Coals

Partial briquetting is a new cokemaking technology in which part of the coke oven charge consists of briquettes that are mixed into the coking blend. Usually this technology will improve coke quality, or permit the use of poorer quality coals without reduction in strength. However, partial briquetting increases coke oven charge densities which contribute to excessive coking pressure, so careful selection of coals for the loose charge and briquettes is necessary. Replacement of lvb coal by hvb in partially briquetted blends, was studied at CANMET. Two Canadian and two U.S. hvb coals were blended with a U.S. lvb coal at levels of 25, 12, 5 and 0 percent levels of the lvb coal. Thirty percent of the blend mixture was briquetted using 6% petroleum pitch binder and the briquettes mixed with the loose coal blend. Test results in Fig. 5 show that the Canadian hvb coals were as good as their U.S. counterparts in blends with lvb. The dotted lines in Fig. 5 also indicate that using partially briquetted blends, the percentage of lvb can be reduced from 25% to 10-20% without loss in coke quality. Although not shown, coking pressures for all tests were low and there was no indication of excessive pressures were found in the study.

Additions of Pitch to Coke-Oven Charges

Western Canadian coals tend to be characterized by higher levels of inert and semi-inert macerals. Large amounts of these macerals reduce the coal's caking ability as measured by the Geiseler plastometer or Ruhr dilatometer. Oxidation or partial oxidation can also result in poorer caking properties of coking coals. To improve the coal's caking properties and possibly increase coke strength, CANMET studied the additions of asphalt, coal tar pitches, solvent refined coal and other heavy oil materials to a low fluidity Western Canadian mvb coal. A number of pilot-scale coke oven tests were conducted along with measurement of the coal and pitch blend caking properties (5).

Additions of these pitch-like materials to the Western Canadian coal sample led to an increase in their Geiseler fluidity. The increase in fluidity, for the coal pitch blends was linear when plotted against percentage of pitch, up to 14% pitch additions.

The percentage of pitch added varied from 2-14% of the blend. All pitches produced increases in the coke stability factor range from 3 to 14 stability units. The apparent Gieseler fluidities of the coal-pitch mixtures were relatively high and could not be used to correctly predict coke strength from Fig. 1.

CONCLUSIONS

The results of a long history of CANMET assessment of the quality of Canadian coals in blends, washed to various ash levels and in new cokemaking technologies has shown that Canadian coking coals are good for blending and effective in new technologies. Methods developed in other countries do not always work for predicting coke strength of Canadian coals. However, a predictive method developed from CANMET experience appears to work reasonably well for Canadian coals and is applicable in the case of substitution of Canadian coals into U.S. Blends. Washing of Canadian coals to lower mineral matter levels resulted in improved coke strength. This improvement can be partly explained by changes in the petrographic composition of the coal, and possible reductions in the coarse mineral matter in the coals. Canadian coal was found to behave well in blends in new cokemaking technologies such as preheating, partial briquetting and addition of pitches. Canadian coals appear to be good for conventional cokemaking blends of Canadian and U.S. Appalachian coals.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge the considerable contributions of time and effort so freely given to the many programs discussed in this paper by members of the CCRA Technical committee and Board of Directors and their member companies, and by the staff of the CANMET carbonization and laboratory analysis groups.

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TABLE 1: Coal and Blend Quality Criteria

Test Criteria	Standard	Typical Range For Coking Coals	Typical Commercial Coking Blend Range
MOISTURE	ASTM D3173-73	2 - 20	6 - 12
Proximate Analysis (db)	ASTM D3172-73		
Ash..........................%	ASTM D3174-73	3 - 15	5 - 10
Volatile Matter..............%	ASTM D3175-77	14 - 40	25 - 33
Ultimate Analysis (db)	ASTM D3176-74		
Sulphur......................%		0.2 - 2	≤ 0.6
Ash Analysis (db)	ASTM D3682-78		
P_2O_5........................%		0.01 - 0.5	≤ 0.1
Na_2O........................%		0.01 - 0.5	≤ 0.1
K_2O.........................%		0.01 - 0.5	≤ 0.1
Linear Expansion	ASTM D2014-71		
Bd 52 lb/ft^3 at 2% moisture..%		+30 to -30	-8
Gieseler Plasticity	ASTM D2639-74		
Max. Fluidity............dd/m		1 to 28,000$^+$	50 - 2000
Dilatation	DIN 51739/1951		
Contraction.................%			
Dilatation..................%		-20to+300	50 - 140
Free Swelling Index			
F.S.I........................	ASTM D720-67	0 - 9	> 4
Petrography	ASTM D2796-78		
Reactives....................		50 - 95	75 + 10
Inerts.......................		5 - 50	25 + 10
Mean Max. Reflectance.........		0.8 - 1.8	1.1 - 1.3

TABLE 2: CANMET Pilot Scale Ovens

Design Basis	Eastern Coal Associates	Bethleham/CANMET (rebuilt 1976)	Koppers	Carbolite
Location	Ottawa	Ottawa	Edmonton	Edmonton
Date Installed	1971	1970	1973	1979
Oven Construction:				
Movable Wall	yes	yes	yes	yes
Coking chamber width, in.........	12.5	18.4	12.0	Variable;12-18"
Coking chamber refractories ...	Silicon carbide	High Density Silica	Alcor	Silicon Carbide
Heating Method	Glow Bars	Glow Bars	Natural Gas	Glow Bars
Standard Oven Test Conditions:				
Charge Weight, lbs	500	800	450	750-800
Charge Pulverization, %-6 mesh .	80 ± 5	80 ± 5	80 ± 5	80 ± 5
Target Charge Moisture, %	2.0	6.0	2.0	2.0
Dry Bulk Density, lb/ft^3	51 ± 1	46.5 ± 1	51 ± 1	50 ± 1
Flue Temperature Control	900 to 1070°C @ 19.44°C/hr.	constant 1125°C	constant 1950°F	875 to 1130 @ 15°C/min.
Charge Push Method*	0.5 hr. after C_T = 1010°C	0.5 hr. after C_T = 1000°C	0.5 hr. after C_T = 1010°C	3.0 hr. after C_T = 950°C
Normal Push Time, hr.	9	18	8	18

*C_T = Charge Centre Temperature

TABLE 3: Coke Quality Criteria

Test Criteria	Standard	Typical Range For Cokes From Single Coals	Typical Commercial Coke Criteria
Proximate Analysis (db)	ASTM D3172-73		
Ash..........................%		4 - 15	< 7
Volatile Matter..............%		16 - 34	< 1
Sulphur (db)...................%	ASTM D3177-75	0.2 - 2	< 0.6
Maximum Wall Pressure......lb/in^2		0 - 20^+	< 1
Coke Yield Actual..............%		60 - 86	70 - 75
Mean Coke Size.................in		1.5 - 2.5	> 2
Apparent Specific Gravity.........	ASTM D167-73	0.6 - 1.2	0.9
Screen Analysis of Coke (Cumulative percentage retained on)	ASTM D293-69		
2 inch sieve..................		0 - 80	20 - 60
Tumbler Test (ASTM)	ASTM D3402		
Stability Factor..............		15 - 65	> 55
Hardness Factor...............		50 - 80	> 68/70
Japanese Drum Test (JIS) (Cumulative percentage retained on	JIS K2151-72		
50 mm sieve...................			
25 mm sieve...................			
15 mm sieve...................	30 rev	30 - 95	> 92
	150 rev	30 - 90	> 82

TABLE 4: All-Canadian hvb/lvb Blend

Coal or blend	lvb	hvb	hvb/lvb: 80/20
R_o mean max. reflectance. Gieseler max. Fluidity (ddpm)	1.66 0.9	0.99 27000	1.12^+ 3516^+
ASTM Stability	43.2	39	50.6
Predicted Stability*	45	39	52

*From Figure 1

+Calculated

TABLE 5: Analyses of Component Coals

Identification						
Coal		A	B	C	D	E
Classification						
Rank		mvb	mvb	mvb	mvb	hvAb
International System		433	433	533	421	635
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
Gieseler Plasticity						
Max. Fluidity	dd/m	20	79	435	6	27800
Dilatation						
Contraction	%	23	24	23	19	26
Dilatation	%	16	16	49	-	200
Free Swelling Index						
F.S.I.		7	7-1/2	5	4	8-1/2
		PETROGRAPHY				
Reactive Components						
Total	%	68.0	69.2	64.2	66.6	86.0
Inert Components						
Mineral Matter	%	5.5	4.7	5.3	6.1	2.5
Total Inerts	%	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
Predicted Stability Index		54.5	56.0	46.0	51.4	37.6

TABLE 6: Substitution/Addition of Canadian Coals in a U.S. Appalachian Blend

Blend	U.S. hvb/ U.S. lvb	U.S. hvb/ Can. lvb	U.S. hvb/ Can. mvb/lvb
Coal Ratios	75:25	75:25	55:30:15
ASTM Stability	51.1	53.1	53.1
Predicted Stability*	47.5	51.0	52

*Figure 1

TABLE 7: Preheating Results - Canadian Coals

Coal or Blend	ASTM Stability Factor		Productivity, lb/min	
	Conventional	Preheated	Conventional	Preheated
A	44.3	47.5	.604	.773
B	41.9	50.3	.610	.765
C	41.1	51.2	.650	.804
E	41.2	51.8	.679	.865
25%A/75% E	48.6	57.6	.658	.833
25%C/75% E	43.5	53.0	.672	.877

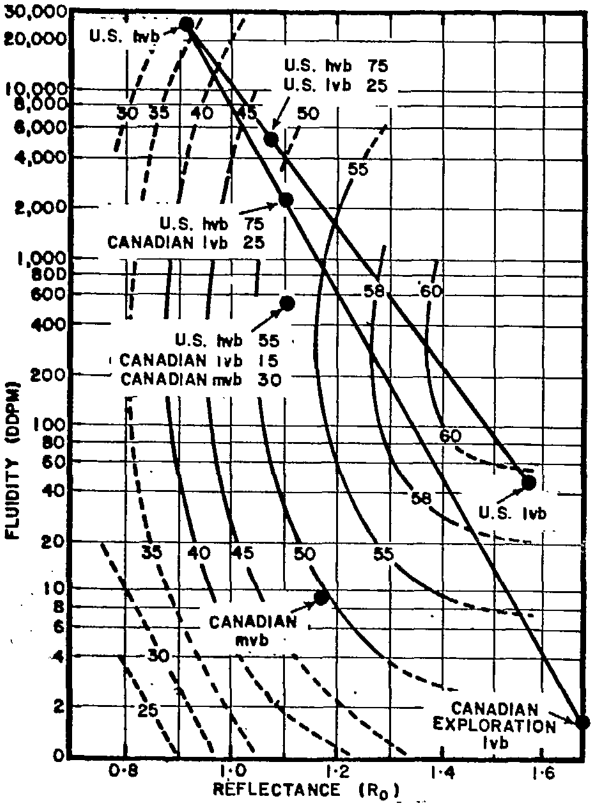

Fig. 1. Prediction of Coke Stability Factors.
- Regression Results from CANMET Data on Western Canadian Coals.

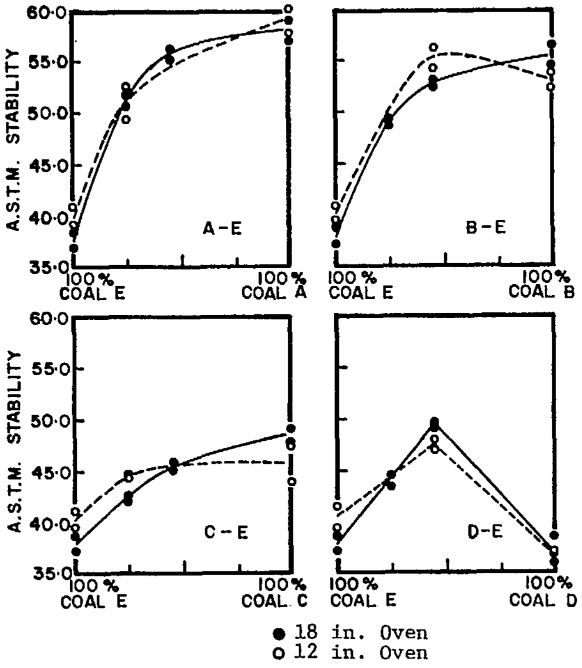

Fig. 2. Relationship Between Stability Factor and Blend Composition.

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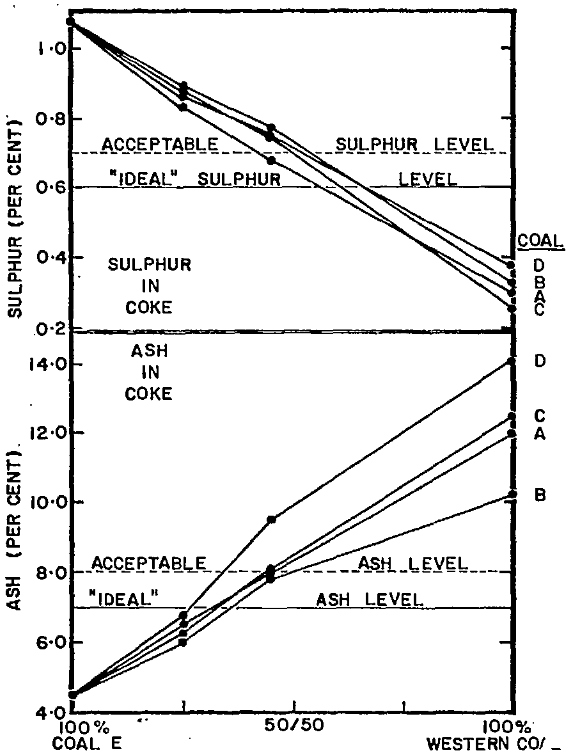

Fig. 3. Relationship Between Sulphur and Ash in Coke and Blend Composition.

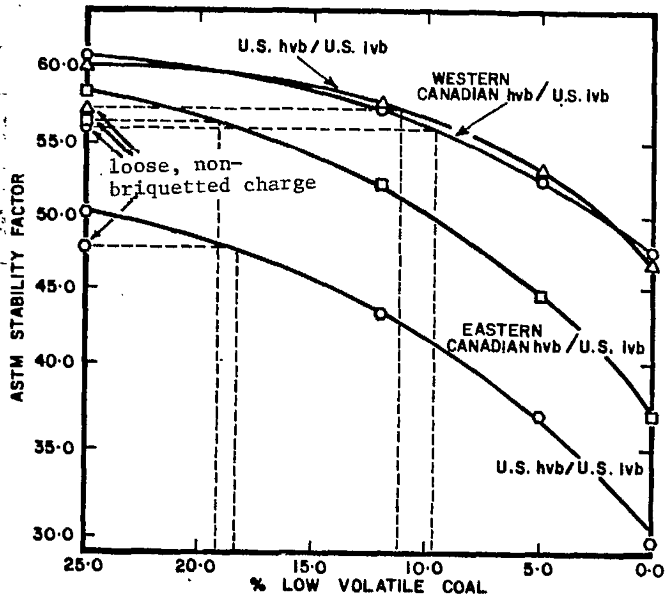

Fig. 5. Influence of Replacement of U.S. lvb Coal with U.S. and Canadian hvb Coals for 30% Briquetted Blends.

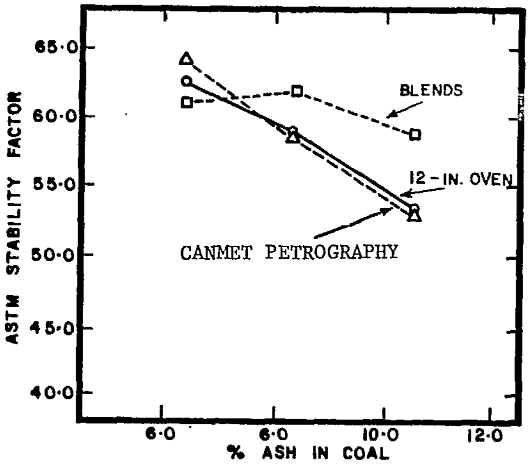

Fig. 4. Change in Coke Stability Factor for A mvb Coal Wahsed to Different Ash Levels.