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CANADIAN DEVELOPMENTS IN COAL COMBUSTION AND CARBONIZATION

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## CANADIAN DEVELOPMENTS IN COAL COMBUSTION AND CARBONIZATION

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### Abstract

Coal utilization R&D in Canada is aimed at expanding the use of both thermal and coking coals in domestic and export markets and at accelerating the commercialization of innovative technologies for efficiently and economically converting coal to clean energy. An extensive data base exists on the combustion and carbonization properties of Canada's coals in conventional industrial equipment and the performance of many of these coals has been demonstrated in emerging energy systems and processes. Ongoing programs are specifically structured to assist industrial clients in resolving particular problems related to coal behaviour and equipment reliability, in extrapolating research results to practical applications, and in implementing and evaluating full-scale trials with off-specification coals or unproved equipment.

## INTRODUCTION

Canadian research and development activities for the utilization of indigenous coals for combustion and carbonization in world markets are structured to effectively transfer technology between government agencies and industry, and to derive maximum benefit from participating in international programs.

Major combustion initiatives concentrate on clean coal burning technologies with emphasis on the commercialization of fluidized bed combustion technology, the development of low  $\text{NO}_x/\text{SO}_x$  burners for pulverized coal and the use of coal/water slurries as an alternative fuel in oil- designed furnaces. Carbonization projects, most of which are conducted under a cooperative arrangement with an industrial consortium, the Canadian Carbonization Research Association, are largely directed toward the use of Western Canadian coals in coking coal blends to reduce coke oven pressures, to increase hot coke strength and to reduce blast furnace coke consumption.

## COMBUSTION

Most of the bituminous thermal coals of Eastern Canada are burned locally whereas those of Western Canada are shipped to central Canadian and overseas markets. The lower rank subbituminous and lignitic coals of the plains region are burned in mine-mouth power stations.

Recent results from demonstration projects, which were in the early stages of implementation when overviewed at the 7th ICCR Conference, are described.

### Fluidized Bed Combustion

Fluidized bed combustion (FBC) is now viewed as an emerging technology for efficiently and cleanly burning coals of variable quality in industrial and utility furnaces. It is anticipated that atmospheric FBC systems, both bubbling and circulating, will be deployed during the 1990's to utilize high-sulphur coals in Eastern Canada and high-ash coal rejects in Western Canada.

Research in FBC has centred around the use of bench-scale and pilot-pilot plant facilities established at CANMET and in outside laboratories to characterize the combustion and sulphur capture properties of various coals and sorbents. Figure 1 shows the sulphur capture versus Ca/S ratio for high- and low-sulphur coal in a 0.4 m x 0.4 m bubbling bed. The data from this research have been used to design a mathematical model that has been validated by others and subsequently accepted as a "standard" procedure for countries in the International Energy Agency (IEA) Agreement on Fluidized Bed Combustion for predicting the combustion performance and gaseous emissions from bubbling beds. Figure 2 shows the close relationship between predicted and measured results for combustion efficiency and sulphur emissions for two FBC pilot plants in Europe.

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Circulating fluidized beds (CFB), because of their potential to burn a wider range of coals and to utilize sulphur sorbents more effectively than bubbling beds, are considered prime candidates for large-scale applications. Four pilot plants (capacities from 25 to 55 kg/h of coal) are either under construction or being commissioned.

Two demonstration projects have been funded by the Coal Utilization Program of Energy, Mines and Resources Canada to accelerate the commercialization of FBC systems. The first, a central heating plant equipped with two bubbling bed boilers, is located at Summerside, Prince Edward Island. As shown in Table 1, these boilers, which are designed to burn local coals containing up to 6% sulphur and 20% ash with 80% sulphur capture, have consistently met all performance requirements since being commissioned in 1984. Although the excess combustion air levels were higher than specified, the large radiant furnace readily generated the rated steam capacity.

During commissioning the following problems were identified and resolved:

- (a) severe in-bed tube erosion was arrested by studding and rodding the tube surfaces;
- (b) mechanical valve failures in the char reinjection system were eliminated by using modified "L-valves";
- (c) startup difficulties with a cold bed were eliminated by adding more bubble caps and by using a coarser, cheaper limestone than specified.

TABLE 1

## Acceptance Test Data

| Parameter                 | Design | Test  |
|---------------------------|--------|-------|
| Boiler efficiency, %      | 80     | 82.6  |
| Steam out/heat in, MJ/kg  | 308    | 345   |
| Ca/S, mol ratio           | 3:1    | 2.4:1 |
| Flue gas Emissions        |        |       |
| - O <sub>2</sub> , %      | 3.6    | 9.7   |
| - SO <sub>2</sub> , mg/MJ | 706    | 716   |
| Temperatures, °C          |        |       |
| - Furnace exit            | 600    | 586   |
| - Stack                   | 175    | 171   |

The second demonstration, a 22 MWe CFB for electricity generation at Chatham, New Brunswick, Figure 3, recently completed acceptance trials and successfully burned petroleum coke with 90% sulphur capture. It was designed to co-fire high-sulphur coal and oil shale with sulphur capture by calcium in the oil shale and by adding limestone. The facility is being used for contract studies to generate design criteria for 150 MWe CFB utility boilers and to demonstrate the feasibility of burning various low grade fuels for electricity production.

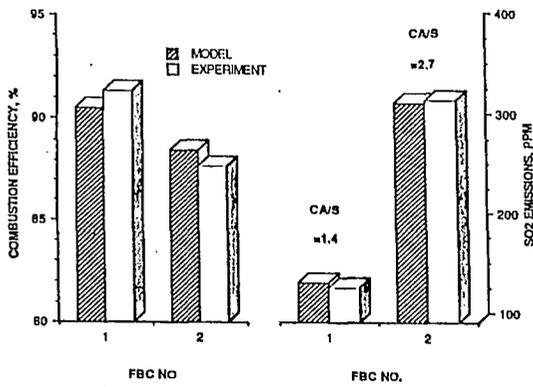


FIGURE 1 - Model and experimental FBC data

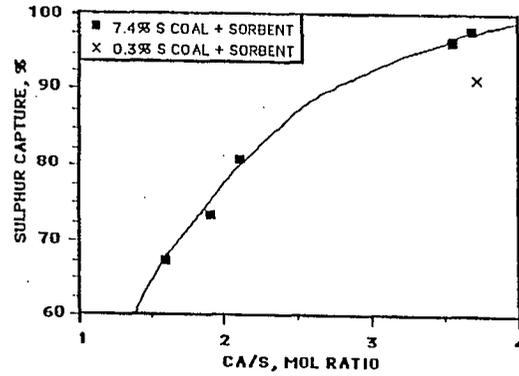


FIGURE 2 - Sulphur capture in FBC pilot plant tests

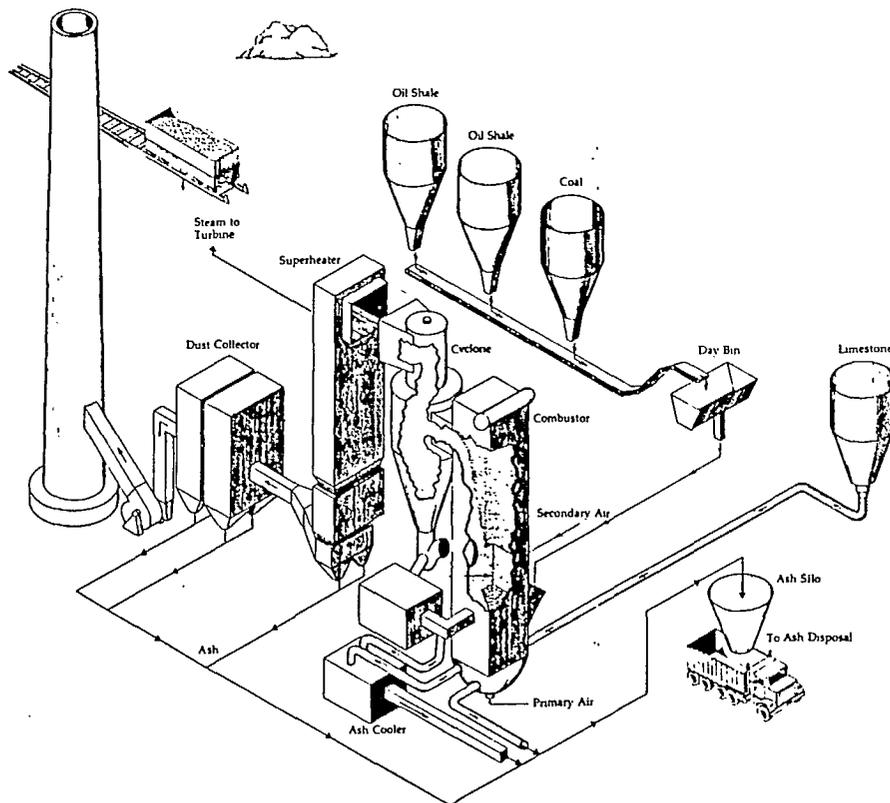


FIGURE 3 - Chatham circulating fluidized bed demonstration

In an associated study on carbon losses, it was found that the standard techniques for unburned carbon analyses are unsuitable for FBC residues. Errors in carbon losses above  $\pm 7\%$  can result from reaction of CaO with atmospheric humidity up to  $515^{\circ}\text{C}$  and from calcination of unreacted carbonates. This problem was overcome by removing carbonates and CaO by acid leaching prior to ashing.

### Coal-Water Slurries

Coal-water slurries (CWS) are potentially an excellent replacement for oil in compact furnace designs that cannot be readily converted to pulverized coal or FBC systems. However, widespread acceptance of CWS, which typically consist of 70% by weight pulverized coal suspended in water, has been severely hampered by excessive nozzle erosion, poor atomization, poor flame stability and poor combustion efficiency. These problems, which result from a generally accepted but incorrect perception that the atomization and burner aerodynamics for liquid fuels are applicable to CWS, can be overcome by applying concepts to accommodate the non-Newtonian behaviour of CWS.

Recent studies of twin fluid atomization of CWS(2) strongly indicate that aerodynamically induced wave disturbances on the surface of the slurry jet result in separation of the larger coal particles prior to the atomization of water droplets containing the finer coal. This proposed mechanism of CWS atomization is valid when the surface tension at the coal/water interface is greater than the combined effect of the surface tension and the viscous forces of the water. The apparent viscosity of the slurry appears to play only a secondary role in atomization, but a primary role in the fluid flow rates. The short length and rapid burn-out of the large scale CWS flames described later can be explained by this mechanism.

Figure 4 shows the influence of air/slurry mass flow ratios on the spray fineness from both swirled and unswirled atomizers rated at 3 MWt(3). At a constant slurry rate the spray quality improved when:

- (a) the airflow rate increased
- (b) the swirled atomization was changed to unswirled,
- (c) the air flow regime was sonic or higher.

Varying the slurry rate at a constant air rate caused the spray quality to deteriorate in the sonic airflow region.

Flame stabilization and fuel burn-out problems with CWS can be attributed to deficiencies in both residence times and convective heat transfer rates for droplet evaporation and particle devolatilization in the internal recirculation zone (IRZ) of the flame. The strength, size and shape of the IRZ, Figure 5, can be maximized by using air register and quarl designs that are compatible with the atomizer spray characteristics.

In a series of 2.5 MWt pilot-scale combustion trials with a CWS made from a high-volatile coal, it was demonstrated that burner quarls for CWS required wider angles and longer throats than for heavy oil to obtain comparable combustion performance, and that penetration of the IRZ by high momentum axial sprays resulted in flame instability. Figure 6 shows the radial temperature profiles for four CWS flames at different levels of combustion air swirl and different furnace chill rates. The maximum flame temperatures, which occurred when the fuel

spray angle coincided with the boundary of the IRZ, provided the best flame stability. High air swirl values and high chill rates resulted in flame temperatures below 1100°C and in poor flame stability(3). These data suggest that a reduction in swirl intensity will enhance flame stability with low-volatile coals, higher moisture slurries and coarser spray patterns. However, at swirl values below a critical minimum, an IRZ cannot be established and flame stability will again deteriorate.

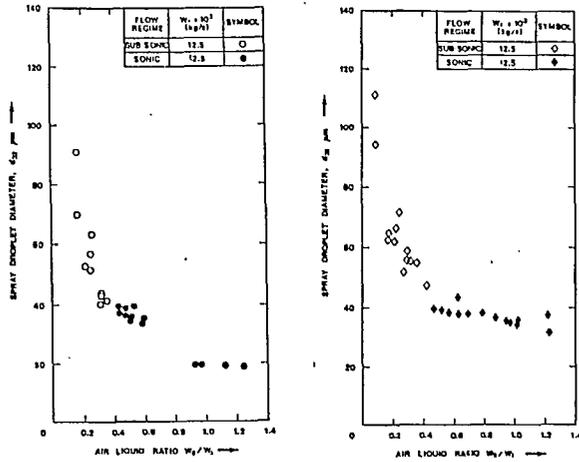
The pilot-scale research was applied to the development of an efficient, reliable industrial-scale burner specifically for CWS. CANMET subcontracted the fabrication of a ceramic atomizer, capable of spraying both CWS and heavy oil, to the National Research Council of Canada and then integrated the nozzle into a CANMET-designed combustion air register, fuel ignitor, burner management system and quartz assembly. A single prototype burner, rated at 12 Mwt, was co-fired with four heavy oil burners in a tightly-designed utility boiler for more than 150 h. During this test, the CWS flames were shorter than the equivalent heavy oil flames, ash sedimentation on the furnace floor and ash fouling of the convection passes were virtually non-existent, and NO<sub>x</sub> emissions were 30% less than for typical wall-fired, pulverized-coal flames. The flame stability was excellent and carbon conversion efficiencies were above 96% for firing rates from 9 Mwt to 16 Mwt. These results led to a decision to completely retrofit the boiler with five CWS burners and to conduct a series of demonstration trials during the fall of 1988.

A parallel demonstration, to start in May 1988, will be conducted on a single-burner, oil-designed package boiler which will provide 20 t/h of steam to a paper mill on a continuous basis for two years. The objective of this industrial demonstration is to generate baseline data on the long-term operational costs, technology reliability and boiler availability for CWS using the CANMET/NRC burner.

#### Acid Rain Abatement

Various techniques for in-furnace suppression of acid rain emissions from pulverized-fired boilers are being investigated extensively by both government agencies and industry. Most of this activity is directed at existing installations because only a few new Canadian thermal power plants will be built before the mid-1990's.

Under an IEA sponsored project, Canada, Denmark, Sweden and the USA co-funded a bench-scale study in which 50 world coals, including nine from Canada, were characterized for NO<sub>x</sub> generation and reduction potential. It was found that nitrogen, released as volatile matter, can be transformed to N<sub>2</sub> rather than NO<sub>x</sub> and that the conversion of fuel nitrogen to NO can be reduced from about 42% to 14% by providing a stoichiometry of less than 0.7 in the primary flame zone. This research led to the design of a 20 Mwt prototype wall-fired burner incorporating multiple air staging for NO control, with limestone injection through tertiary air ports for SO<sub>2</sub> control. Burner tests on



(a) Unswirled (b) Swirled

FIGURE 4 - Effect of air/liquid ratios on atomization

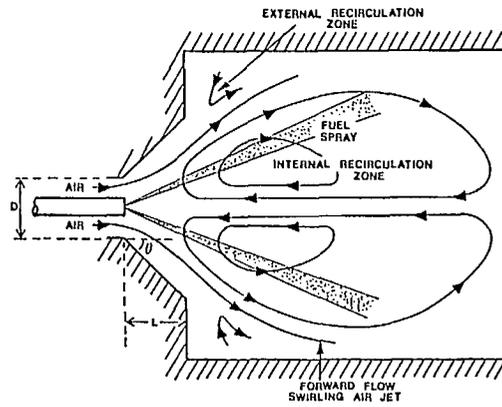


FIGURE 5 - Fuel spray into the flame recirculation zone

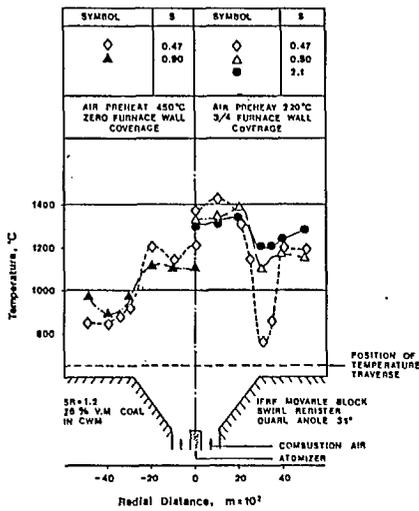


FIGURE 6 - Radial temperature profiles for CWS flames

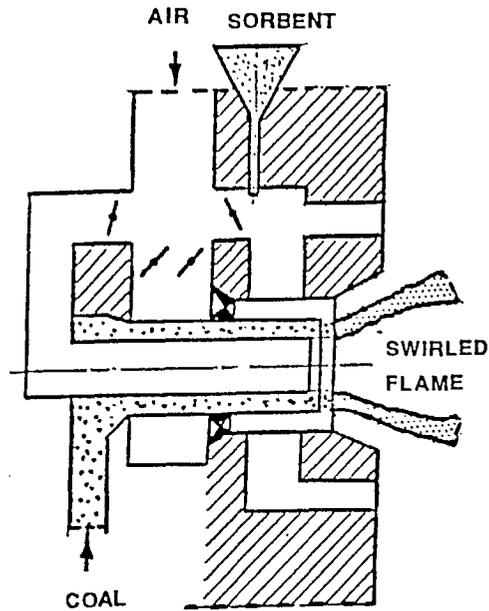


FIGURE 7 - Staged-mixing burner

a high-volatile Canadian coal at 120% total air showed that  $\text{NO}_x$  and  $\text{SO}_2$  emissions could both be reduced by over 50% with optimized air staging and a calcium/sulphur ratio of 3. The coal contained 2.6% sulphur, 1.2% total nitrogen and 0.7% volatile nitrogen. Calcium utilization was about 20% of the input.

The concepts developed in the IEA program led to collaborative full-scale demonstrations of in-furnace  $\text{NO}_x/\text{SO}_2$  control technologies in Denmark, Sweden and Canada. Three wall-fired boilers rated at 450, 150 and 20 Mwt, are being evaluated for  $\text{NO}_x$  and  $\text{SO}_2$  reductions using a common test plan and the same data reduction procedures, so that key parameters for the different boiler and burner sizes can be comparatively evaluated. Canada's demonstration is being conducted on a 20 Mwt high-temperature, hot water generator at Gagetown, New Brunswick. The generator is equipped with two low  $\text{NO}_x/\text{SO}_x$  burners, Figure 7, designed to burn a high-volatile bituminous coal containing up to 3% sulphur. Preliminary tests have yielded reductions in acid rain emissions ( $\text{SO}_2 + \text{NO}_x$ ) varying from about 65% at one-half load to 45% at full load and an increase in boiler efficiency of about 3% relative to the original burner installation.

In another demonstration, initiated by industry with government support, a 150  $\text{MW}_e$  lignite-fired boiler with a tangential burner array was modified to determine whether the normally low emissions of  $\text{NO}_x$  and  $\text{SO}_2$  from this unit could be further reduced by burner air staging and upper furnace sorbent injection(4). The boiler modifications, Figure 8, were designed to provide a lower furnace stoichiometry of about 1.0, an air rich zone above the fireball and the injection of sorbent into

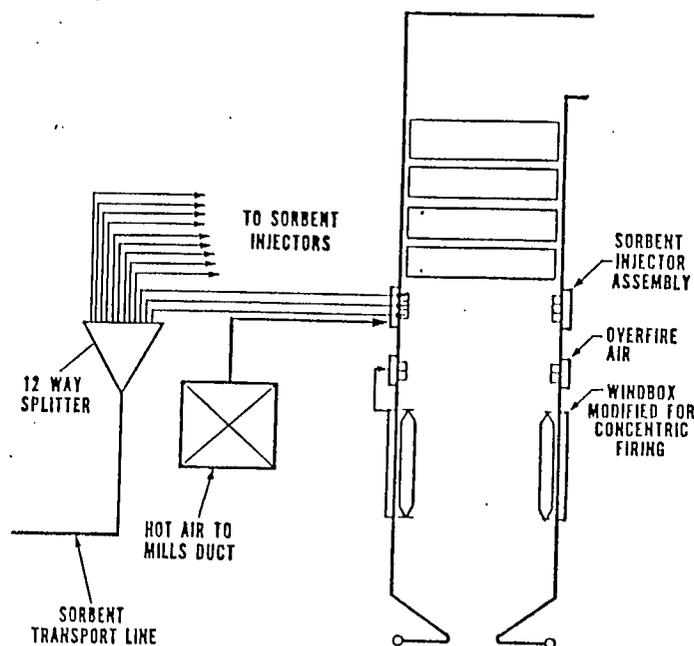


FIGURE 8 - Staged tangentially-fired furnace with sorbent injection

different temperature zones of the upper furnace. At full load with 3% O<sub>2</sub>, NO<sub>x</sub> and SO<sub>2</sub> levels each decreased by over 30% when calcium hydroxide was added to produce an input Ca/S ratio of 3.

These trials also identified a critical need for future research to elucidate the role of inherent sodium and calcium in ash on sulphur capture and to develop improved computer models for predicting local furnace conditions from coal properties, boiler heat transfer specifications and burner input data. The results generated from this demonstration are being processed to validate a three-dimensional furnace model which can then be used to optimize the various parameters for minimizing NO<sub>x</sub> and SO<sub>2</sub> from this low-sulphur coal.

### CARBONIZATION

The cretaceous coals of Western Canada generally yield fluidity and dilatation values below the accepted norm for quality cokes from carboniferous coals. However, carbonization research has shown that Western Canadian coals, either alone or in multicomponent blends, make excellent cokes. The carboniferous coals of Eastern Canada, which have low ash and high rheology properties, are ideal components for coking coal blends.

#### Coal Properties and Coke Quality

Three relationships to predict ambient coke strength properties are shown in Figure 9. The free swelling index/volatile matter (FSI/VM) plot although not as reliable as the fluidity/maximum average reflectance (R<sub>0</sub>) plots for predicting the quality of cokes for high FSI coals, gave the minimum standard error for all coals, presumably because low FSI values are a better indication of a poor coking coal than low fluidity or dilatation (d).

The fluidity/R<sub>0</sub> plots predict that strong cokes can be made from medium- to low-volatile Western Canadian coals with fluidities of 10 ddpm(4). Other coking studies have indicated that ash chemistry and coal rank must also be considered to predict accurately coke strength after reaction (CSR) properties for Western Canadian coals. CSR is the wt% of +10 mm coke remaining after 200 g of 20 mm coke reacts with CO<sub>2</sub> for 2 h and the product tumbled for 600 revolutions in a standard drum. The coke reactivity index (CRI) is the loss in wt% of coke during the test. By incorporating a modified basicity index (MBI) with (R<sub>0</sub>) and (d) into regression models to predict CSR, a formula derived from data on 33 Western Canadian and 22 Appalachian coals and blends showed that

$$\text{CSR} = 52.7 + 0.0822(d) - 6.73(\text{MBI})^2 + 14.6R_0$$

$$r = 0.94, \text{ SE} = 3.4, F = 134$$

This equation applies only to cokes made in a 460 mm wide test oven charged at a dry coal bulk density of about 820 kg/m<sup>3</sup>, using coking

times to 900°C of about 13.5 h and gross coking times of about 17.3 h. Figure 10 compares calculated versus actual CSR values for western and Appalachian coals.

To determine the role of ash chemistry on the resistance of coke to alkalis, nine cokes with similar ASTM stabilities but different coke textures and ash chemistry were prepared from component coals of different ranks and origins. Each coke was then impregnated with 0, 0.2, and 0.5% potassium by weight (5). As shown in Figure 11, both CRI and CSR values of all cokes deteriorated as the potassium levels increased indicating a progressive deterioration in coke quality. The alumina, silica, and titania contents in the cokes related inversely to deterioration in CRI and tended to minimize the effects of potassium on reactivity, perhaps by forming stable potassium compounds that do not catalyze the Boudouard reaction. In contrast, cokes containing kaolin, when impregnated with potassium carbonate in aqueous solution, are known to be less reactive to CO<sub>2</sub> and less susceptible to influences of potassium than those containing other types of minerals (6). Therefore, cokes made with Western Canadian coals which are rich in kaolinite and quartz should be more resistant to alkali deterioration.

#### Coal Preheating

To determine the benefits of preheating Western Canadian coking coals, three medium-volatile coals A, B, and C and an Eastern high volatile coal (E), Table 2, were carbonized under the following conditions:

1. Wet charge: coal with about 6% moisture to provide a low coal bulk density in the oven of 664-720 kg/m<sup>3</sup> (dry basis).
2. Air-dried charge: coal, air dried to 1.1-2.0% moisture, to provide a high coal bulk density of 803-912 kg/m<sup>3</sup>.
3. Preheated charge: coal, preheated to 180-210°C, to provide a high coal bulk density of 803-912 kg/m<sup>3</sup>.

Figure 12 shows that preheating the coals improved coke strength by increasing the bulk density of the charges. The ASTM stability of coke from the Western coals was much more sensitive to changes in coal bulk density than the Eastern coal, as shown by the slopes of the lines for the wet and air-dried charges. Since the preheated charges had similar bulk densities to the air dried charges, differences in their coke stability factors can be attributed solely to preheating. Preheating alone, shown by the dashed lines in Figure 12, was very beneficial for the Eastern coal and blends containing this coal, but unfavourable for Western coals when carbonized alone. A preheated blend containing 75% coal E with 25% coal A had an ASTM coke stability of 57.8. All blends had coking pressures well below accepted safety limits.

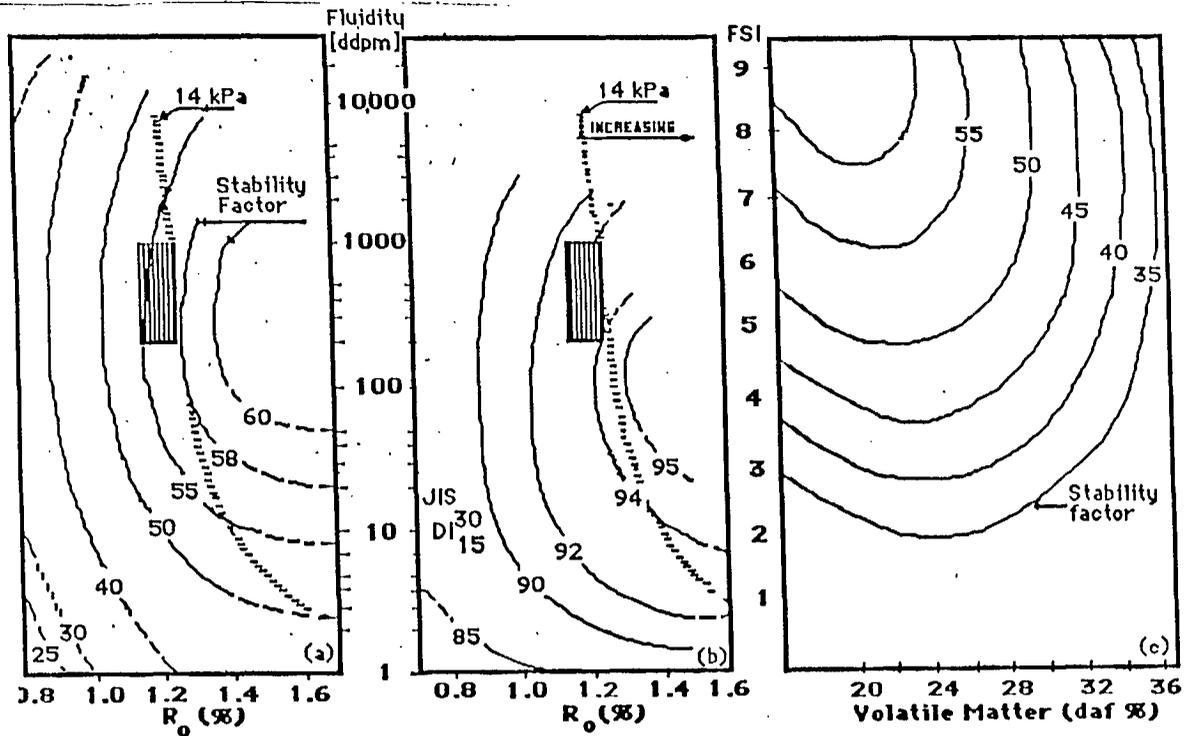


FIGURE 9-Influence of Western Canadian coal properties on coke strength

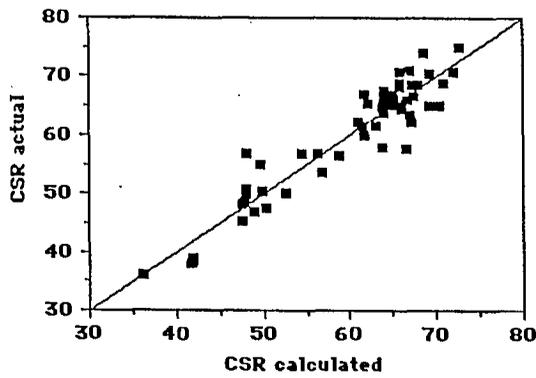


FIGURE 10 - Actual vs predicted CSR for Western Canadian and Appalachian coals and blends

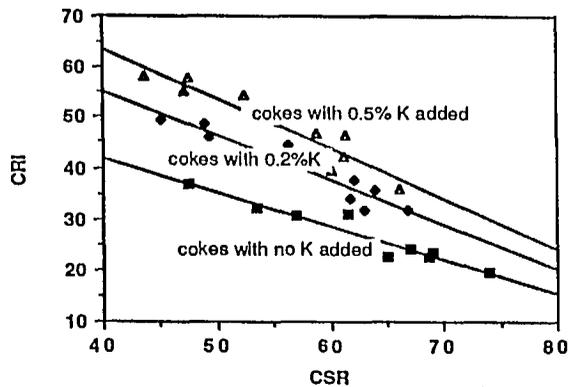


FIGURE 11 - Effect of alkali impregnation on CSR and CRI

TABLE 2  
Analyses of Component Coals

| Coal                            | A    | B    | C    | E    |
|---------------------------------|------|------|------|------|
| <u>Proximate Analysis (db)%</u> |      |      |      |      |
| Ash                             | 9.8  | 8.4  | 9.5  | 4.1  |
| Volatile matter                 | 21.8 | 23.5 | 25.5 | 33.9 |
| Fixed carbon                    | 68.4 | 68.1 | 65.0 | 62.0 |
| <u>Ultimate Analysis (db)%</u>  |      |      |      |      |
| Carbon                          | 80.9 | 82.0 | 84.1 | 82.3 |
| Hydrogen                        | 4.4  | 4.4  | 4.7  | 5.4  |
| Sulphur                         | 0.32 | 0.39 | 0.30 | 1.25 |
| Nitrogen                        | 1.3  | 1.4  | 1.0  | 1.7  |
| Ash                             | 9.8  | 8.4  | 9.5  | 4.1  |
| Oxygen (by difference)          | 3.3  | 3.4  | 0.4  | 5.2  |
| <u>Ash Analysis (db)%</u>       |      |      |      |      |
| SiO <sub>2</sub>                | 65.1 | 57.3 | 52.0 | 36.9 |
| Al <sub>2</sub> O <sub>3</sub>  | 28.4 | 33.2 | 25.9 | 21.4 |
| Fe <sub>2</sub> O <sub>3</sub>  | 2.3  | 5.8  | 3.7  | 35.2 |
| TiO <sub>2</sub>                | 1.7  | 1.8  | 1.5  | 0.9  |
| P <sub>2</sub> O <sub>5</sub>   | 0.5  | 1.0  | 0.8  | 0.1  |
| CaO                             | 1.1  | 1.4  | 6.1  | 1.8  |
| MgO                             | 0.6  | 0.5  | 1.5  | 1.4  |
| Na <sub>2</sub> O               | 0.1  | 0.1  | 1.4  | 0.5  |
| K <sub>2</sub> O                | 0.4  | 0.7  | 0.3  | 1.1  |

### Partial Briquetting

The quality of cokes produced from medium-volatile (mv) and low-volatile (lv) Western coals can be improved markedly by partial briquetting. However, high-volatile (hv) coals from Eastern and Western Canada were unaffected when carbonized with 30% briquets (7). Relative to a conventionally charged Western mv coal, the same coal containing 30% briquets yielded significantly higher CSR, ASTM stability and JIS drum indices. The partially briquetted charge increased oven wall pressures to 3.6 KPa, a level still considered safe by cokemakers.

Improvements to coke quality for the partially briquetted lv coal were even more pronounced than for the mv coal when compared with conventional charges. ASTM stability improved by 11-13 units and the amount of coke breeze from partially briquetted charges was greatly reduced. The finer pulverization of the coal in the briquets, the addition of the pitch binder, or the briquetting effect improved coke stability more than would be expected from increased bulk density alone, although higher oven wall pressures were generated at the higher bulk densities for the lv coal. The very large improvements to coke quality when carbonizing this coal with 30% briquets make it an excellent blending coal for partially briquetted charges.

To evaluate the effectiveness of coal rank and origin in partially briquetted charges, two Canadian and two US Appalachian hv coals were blended with a US Appalachian lv coal. The coals had the following properties:

- a) Appalachian, lv, high fluidity, good coking coal
- b) Appalachian, hv, high fluidity, good coking coal
- c) Appalachian, hv, low fluidity, poor coking coal
- d) Eastern Canadian hv, high fluidity, good coking coal
- e) Western Canadian hv, low fluidity, poor coking coal

Each of the hv coals was blended with the lv coal at hv:lv ratios of 75:25, 88:12, and 95:5 respectively. The three blends were carbonized conventionally and then 30% partially briquetted. Partial briquetting improved ASTM coke stability and hardness the most for blends containing the Western coal, and then for the blend containing the highest rank US hv coal. Maximum replacement of lv coal occurred by partially briquetting the blends containing the Western hv coal. Figure 13 shows that partially briquetting a blend containing 91% western Canadian hv and 9% Appalachian lv coal maintained coke quality at the base level.

#### Blending for Coke Strength

Industrial cokes are generally made from multicomponent coal blends to meet the  $R_0$ , rheological and impurity levels shown in Table 3. Most coal blends used by Canadian steel companies have similar overall properties and produce cokes with similar ASTM stabilities. However, components of these blends may have different rank and ash properties.

TABLE 3

#### Desirable Coking Coal Properties

|                    |       |                         |           |
|--------------------|-------|-------------------------|-----------|
| Ash, %             | 6-8   | Mean reflectance        | 1.10-1.25 |
| Volatile matter, % | 28-31 | Free swelling index     | 6         |
| Sulphur, %         | 0.8   | Gieseler fluidity, ddpm | 200-1000  |
| Alkali oxides, %   | 0.2   | Dilatation, %           | 50-140    |

To determine the effect of ash, inerts and texture on CSR properties of industrial strength cokes, cokes with the same stability but different component coal properties were prepared from two sets of binary blends. One set was made from reactive rich US coals whereas the second was made from high inert Western coals as summarized in Table 4. Each set of blends was prepared by combining the highest rank (reflectance) coal with the lowest; the second highest with the second lowest, etc. Blending ratios were adjusted to obtain an ASTM stability of  $58 \pm 1$ , the minimum value for North American industry. Carbonization conditions were kept constant by controlling bulk density and flue temperatures at  $825 \text{ kg/m}^3$  and  $1250^\circ\text{C}$  respectively. The stability requirement of  $58 \pm 1$  was met with both sets of coal blends even though

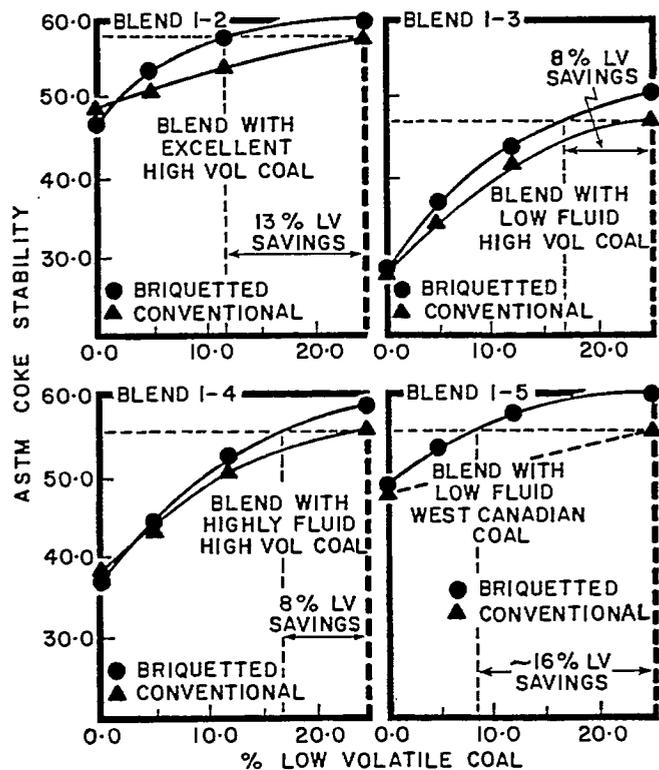


FIGURE 12 - Effect of coal preheating bulk density and coke stability

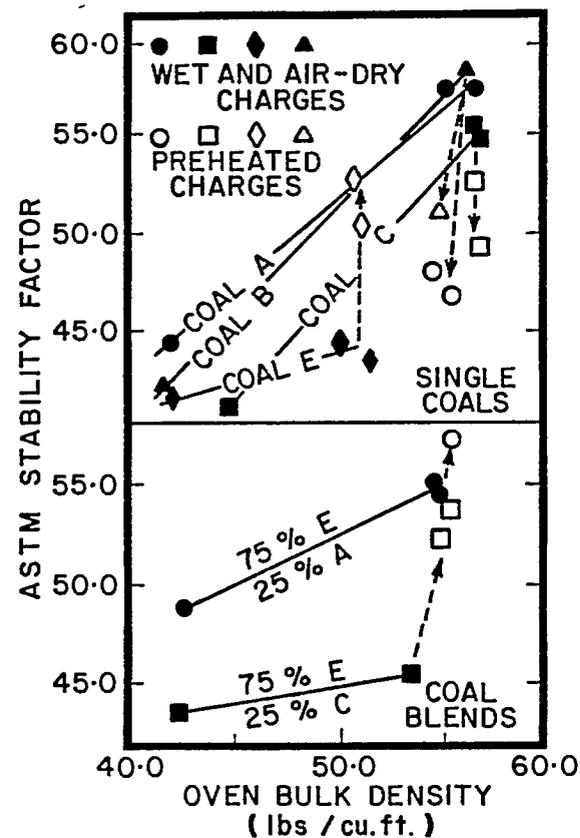


FIGURE 13 - Coke stability of binary blends carbonized conventionally and partially briquetted

fluidity and dilatation values for the US coals F,G,H, and I were much higher than those for the Western coals J,K, and L. Maximum wall pressure ranged from 7 to 9.5 kPa for the Western coals and from 7 to 27 kPa for the US coals. The Western blends displayed lower sulphur but slightly higher ash than the US blends.

Major differences occurred in the "hot strength properties" of the cokes from these coal blends. The CSR for the Western coals ranged from 65 to 69 whereas those for the Appalachian coals ranged from 48 to 62. These values were consistent with those obtained by Nippon Steel Corporation (8). This showed that CSR and CRI properties of industrial cokes with stabilities of 58 were influenced more by the ash chemistry of the blend than the rank of the components, coke texture, or inert content. CSR results related well to both the alkali content in the coal and the modified basicity index.

TABLE 4

Analyses of US and Western Canadian Binary Coal Blends and Their Cokes

| Coal properties                | US Blends |           |           |           | Western Canadian Blends |           |           |
|--------------------------------|-----------|-----------|-----------|-----------|-------------------------|-----------|-----------|
|                                | F         | G         | H         | I         | J                       | K         | L         |
| Ratio of components            | 72:28     | 70:30     | 75:25     | 93:7      | 65:35                   | 69:31     | 45:55     |
| Ro of components(a:b)          | 0.88:1.65 | 0.95:1.62 | 1.13:1.22 | 1.13:1.42 | 0.90:1.62               | 1.01:1.28 | 1.08:1.20 |
| Mean Ro                        | 1.06      | 1.22      | 1.17      | 1.16      | 1.13                    | 1.08      | 1.17      |
| Volatile matter, db %          | 32.9      | 28.7      | 28.2      | 29.0      | 26.9                    | 25.1      | 24.5      |
| Ash, db %                      | 6.2       | 6.2       | 6.0       | 5.3       | 6.5                     | 8.0       | 9.2       |
| Sulphur, db %                  | 0.9       | 0.8       | 0.7       | 0.6       | 0.39                    | 0.46      | 0.49      |
| Pulverization, % minus 3 mm    | 83        | 84        | 88        | 89        | 86                      | 92        | 90        |
| FSI                            | 7.0       | 7.5       | 7.5       | -         | 6                       | 7         | 7.5       |
| Gieseler plasticity, ddpm      | 570       | 4380      | 11090     | 6530      | 16.8                    | 12.0      | 12.5      |
| Total dilatation, %            | 44        | 134       | 242       | 248       | 13                      | 29        | 31        |
| Expansion/contraction, %       | -9.6      | -12.8     | -9.1      | -9.7      | -10.0                   | -12.6     | -8.2      |
| <u>Coal ash analyses, %</u>    |           |           |           |           |                         |           |           |
| SiO <sub>2</sub>               | 50.6      | 46.4      | 42.2      | 41.9      | 56.4                    | 57.1      | 58.9      |
| Al <sub>2</sub> O <sub>3</sub> | 29.1      | 28.5      | 27.5      | 26.9      | 27.2                    | 29.1      | 27.9      |
| TiO <sub>2</sub>               | 1.5       | 1.3       | 1.5       | 1.5       | 1.4                     | 1.8       | 1.9       |
| P <sub>2</sub> O <sub>5</sub>  | 0.2       | 0.2       | 0.5       | 0.4       | 1.2                     | 1.2       | 1.2       |
| Fe <sub>2</sub> O <sub>3</sub> | 9.8       | 11.5      | 10.9      | 11.2      | 6.0                     | 3.5       | 3.6       |
| CaO                            | 2.8       | 3.0       | 4.7       | 4.7       | 2.5                     | 2.2       | 1.5       |
| MgO                            | 0.9       | 1.7       | 1.9       | 2.1       | 0.7                     | 0.6       | 0.9       |
| Na <sub>2</sub> O              | 0.6       | 0.8       | 0.7       | 0.8       | 0.5                     | 0.1       | 0.1       |
| K <sub>2</sub> O               | 1.6       | 2.1       | 1.7       | 2.0       | 0.9                     | 0.7       | 0.9       |
| <u>Carbonization results</u>   |           |           |           |           |                         |           |           |
| Maximum wall pressure, kPa     | 12.5      | 7.0       | 6.8       | 26.8      | 7.3                     | 9.1       | 9.5       |
| <u>Coke properties, %</u>      |           |           |           |           |                         |           |           |
| Volatile matter                | 0.8       | 0.7       | 0.6       | 0.6       | 0.7                     | 0.8       | 0.6       |
| Sulphur                        | 0.6       | 0.7       | 0.6       | 0.6       | 0.4                     | 0.4       | 0.4       |
| ASTM stability                 | 58.9      | 58.1      | 57.6      | 57.9      | 58.4                    | 58.2      | 57.4      |
| JIS D130/15                    | 94.9      | 94.4      | 94.5      | 95.1      | 93.1                    | 93.0      | 93.6      |
| CSR                            | 61.6      | 47.5      | 56.9      | 53.6      | 67.0                    | 69.0      | 65.1      |
| CRI                            | 31.0      | 32.7      | 30.5      | 32.5      | 24.0                    | 23.3      | 22.6      |

In recent industrial trials at Algoma Steel Corporation, a mv Western Canadian coal was added to their normal hv/lv Appalachian coal blend. No coal handling, coke pushing, or other operational problems were encountered when the Western Canadian coal was used, and the company concluded that it reduced coking pressures and improved CSR properties while maintaining the stability of the original blend.

CLOSURE

A high-performance CWS burner has been developed and FBC systems for cleanly burning high-sulphur coals have been demonstrated. Staged burners with sorbent injection have reduced acid rain emissions by 50%. Excellent cokes can be made from Western Canadian coals by controlling bulk density, partial briquetting or coal preheating, and by finer pulverization. Unsafe oven pressures at high coking rates can be prevented by using these coals in multicomponent blends.

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