

ERP/ERL 77-67(OP) c. 2



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THE EFFECT OF PARTIAL AGGLOMERATION OF COKE-OVEN CHARGES
UPON COKE QUALITY

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AUGUST 1977

For presentation at the International Briquetting Association Conference,
Montreal, August 22 - 25, 1977

Preprint subject to revision before publication

ENERGY RESEARCH PROGRAM

Energy Research Laboratories
Report ERP/ERL 77-67 (OP)

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01-0003544 c. 2

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by

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ABSTRACT

Previous investigations at CANMET into the partial agglomeration of coke-oven charges have recently been renewed at ERL. Evidence from these and other investigations indicates that this approach can improve coke quality and can extend the coking coal range to include less expensive coals. This report surveys such investigations and discusses the effects of such influences as briquet preparation and oven bulk density upon coke quality.

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INTRODUCTION

Metallurgical coke is a strong, porous carbonaceous material which is conventionally produced from the destructive distillation of crushed coking coals in refractory chambers called coke ovens. Ninety per cent of world's coke production is consumed during the manufacturing of primary iron by the blast furnace process. Coke is the main source of heat and reductant in the blast furnace. It must have sufficient strength to support the iron oxide burden and be of a limited size range to allow for unimpeded flow of gases, molten iron and burden materials. Coke strength has become particularly important with the advent of very large blast furnaces that require a more consistent and higher strength coke than the older smaller blast furnaces. The strength of iron blast furnace coke is represented by a strength index calculated from the mechanical breakdown of coke at ambient temperatures in a tumble drum (1,2) although other tests are being considered (3) which simulate the chemical and thermal conditions in blast furnaces. The tumbler tests most extensively used at CANMET on coke produced from technical oven tests are the ASTM* (American Society for Testing and Materials) and the JIS* (Japanese Industrial Standard) methods (1,2), the key coke strength indices being the ASTM stability factor and the JIS DI_{15}^{30} and DI_{15}^{150} indices (see Appendix).

Metallurgical coke-making has evolved from simple beginnings to its present position as a highly technical, though empirical, operation involving the blending of coals into conventional slot-type by-product coke ovens. Conventional slot-type coke-oven practice is restricted in the types of coals it can use to produce metallurgical coke suitable for the iron blast furnace. These coals are normally bituminous in rank and must possess certain thermal rheological properties, e.g., melt in the range of 300-500°C.

Bituminous coals are classified according to fluidity*, reflectivity in visible light*, and proportion of volatile matter*. Coal fluid properties are measured as a function of temperature using a Gieseler plastometer, with maximum fluidity reported in dial divisions per minute (ddpm). Coke strength

*Appendix

is predicted from these properties and several methods have been formulated for blending coals (5, 6, 7) that will yield coke of high strength. For example, the small rectangular box in Figure 1 represents the range of fluidities and rank properties of blends that, empirically, have been found to produce good metallurgical coke (7). The blend should have a fluidity of 200 - 1000 ddpm, and a reflectance of 1.2 - 1.3. The volatile matter should be in the range of 30 - 33 per cent. The majority of the world's bituminous coals (Figure 1) do not lie in these ranges and therefore coal blending is essential to conventional metallurgical cokemaking.

High volatile (hvb) and low volatile (lvb) bituminous coals are normally blended before coking to maximize coke strength, to minimize sulfur and ash content and to avoid excessive swelling of the coke which can damage the oven walls. Hvb usually makes up the bulk of the blend but, if used alone, produces coke that lacks strength and generally contains a high sulfur content. Although lvb coal swells during carbonization and causes increased coke oven wall pressures, it is the prime blending material that gives metallurgical coke high strength and that dilutes the coke's sulfur content. Consequently, the demand for lvb coals makes them expensive and coke makers are looking to replace the lvb portion of the blend with poor- or non-coking coals. This can be done in part by substituting part of the lvb portion of the blend with coke breeze, or pitch and poorer coking coals (8, 9). Pitch can improve the caking properties of certain coal blends while coke breeze decreases coke shrinkage during the latter stages of carbonization. However, only small amounts of lvb can be replaced.

Increases in the bulk density of the charge in conventional coke ovens have long been known to improve coke strength and several methods have been developed, although this approach must be used with caution because large bulk densities often exert unacceptably high pressures on coke oven walls. Oiling of the oven charge is a simple method of increasing bulk density, but increases are small. Mechanical densifying, pre-heating (e.g., to ca 180°C) or partial agglomeration of oven charges are more elaborate methods to significantly increase bulk density and improve coke strength. Alternatively, these techniques can achieve required coke strengths and yet use poorer quality and less expensive coking coals. By partial briquetting of coke oven charges it is possible to use significant amounts of non-coking coals in blends that contain little or no lvb coal.

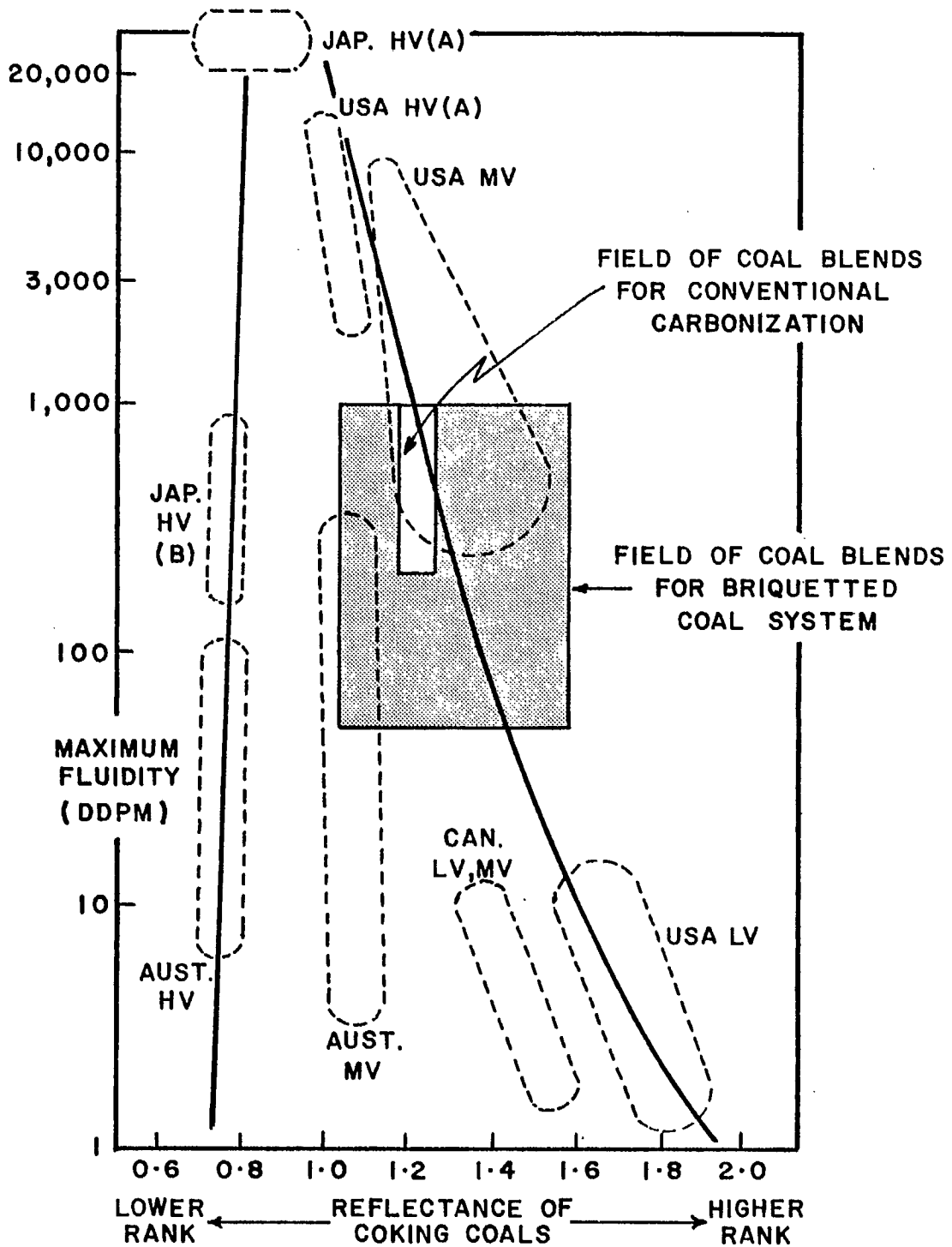


FIGURE 1 Fluidity of Bituminous Coals vs Rank Showing Acceptable Range of Coking Coal Properties for Conventional and 30 Per Cent Partially Briquetted Charges

After NKK Technical Paper (33)

The objective of this paper is to review the current state of development of partial agglomeration of coke oven charges and to discuss work carried out in CANMET laboratories.

LITERATURE REVIEW

Partial Briquetting Processes

Although several methods of agglomerating coke oven charges have been used to increase oven bulk density, briquetting has been the most common and studies on partially briquetted charges have been made in the USSR (10 - 15), Canada (16), Australia (17), South Africa (18), Japan (19 - 22) and several European countries (23 - 29). Although techniques varied with the investigation, the briquets were generally pitch-bound, made from coking and non-coking coals, and varied in dimensions from 9 x 30 x 34 mm to 22 x 55 x 122 mm. Three procedures have been employed for the use of poor or non-coking coal. In one procedure, non-coking coal is included in the briquets which are blended with good coking coal as the matrix of the coke oven charge. In a second procedure, non-coking coal is briquetted and small amounts of non-coking coals are added to the matrix coal. In a third procedure, a portion of the coal blend (coking and non-coking) is briquetted and the briquets mixed with the non-briquetted blend to make up the oven charge. In the Sumi process (20 - 22), for example, part of the regular coke oven charge is blended with non-coking coal, briquetted, and then mixed (30:70, briquet: coal ratio) with the remaining coal charge (Figure 2). The non-coking coal is usually incorporated in the briquets although at the Wakayama Works small additions of non-coking coals (1 - 4 per cent) are being made to the matrix coal without affecting coke quality.

Effect of Partial Briquetting on Oven Bulk Density

As mentioned previously, increased coke oven charge bulk density generally improves coke quality. The effects of briquet density, size and proportion in the oven charge on oven bulk density have been extensively studied.

Laboratory investigations in the Soviet Union (10 - 15) have shown that the bulk density of partially briquetted charges is a function of briquet

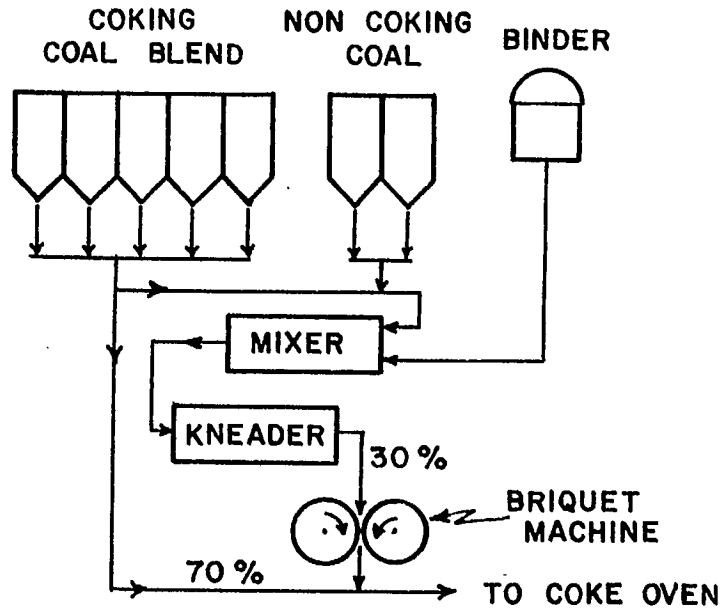


FIGURE 2 Briquet Charging Method of Sumitomo Metal Industries

After "Sumi Coal. System" (20)

density, briquet size, and the proportion of briquets in the coal charge. Figure 3 shows the bulk densities obtained from various coal briquet ratios as a function of briquet size. In general, coal charges using larger briquets result in higher bulk densities of the overall charge. For example, the highest bulk density was attained using 50 per cent briquet addition and briquets of 50 mm dia. However, coke quality did not necessarily improve with increased bulk density of the charge, if the mixture did not have the correct rheological characteristics (11, 12).

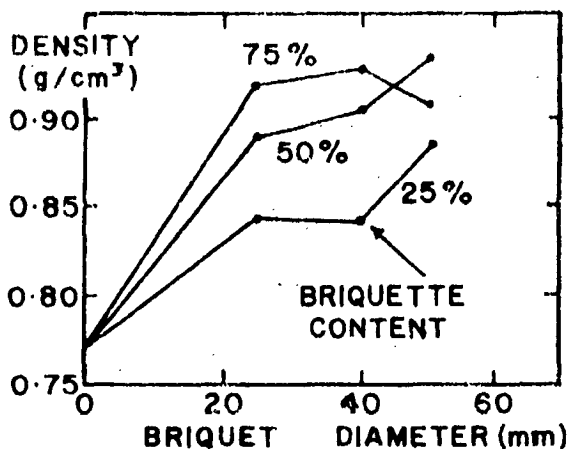


FIGURE 3 Relationship between Bulk Density, Briquet Content, and Briquet Size

After Taitz and Pokrovskaya (12)

Several investigations in other countries have also indicated that partial briquetting procedures enhanced coke oven bulk densities (23 - 32). For example, Czechoslovakian researchers (23, 24) found coke quality improved when bulk densities of coke oven charges were increased from 4 to 8 per cent by mixing coal and pelletized coal-wash-plant flotation concentrates. More detailed investigations (25, 26) have been made in Germany in a model coke chamber to determine the relationships between moisture content, briquet ratio, and oven bulk density. Maximum density was attained at 60 - 70 per cent briquet addition for the three types of coals studied. This was somewhat higher than Japanese results (9, 30 - 32) that indicated maximum bulk density was achieved when 51 x 51 x 31 mm briquets made up 50 to 60 per cent of the charge. Results (30, 31) showed however that in most coal blends the amount of improvement in coke strength diminished when the briquet ratio exceeded 30 per cent. In a Koppers oven test, wall pressure increased with increasing briquet addition and reached an unsatisfactorily high value of 0.12 kg cm^{-2} with 40 per cent briquet addition (32). The bulk density was (825 kg m^{-3}) 52.8 lb ft^{-3} . The resistance to discharge as measured by pushing current in the commercial oven test also increased with briquet loading. As a result

most Japanese coke producers consider that to avoid excessive coke wall pressures 30 per cent briquet addition should not be exceeded.

Increasing oven bulk densities from 750 to 1000 kg cm⁻³ by partially briquetting the charge was found (33) to raise pyrolysis temperatures from 400 to 550°C and gas pressures from 300 to 1100 mm H₂O. Microscopic examination indicated (14, 32) that the voids between the coal particles in compacted charges were smaller and upon carbonization the semi-coke was much denser, had contracted less, and had a better continuity of cell walls than semi-coke made by conventional means. This would account qualitatively for improved coke quality. The denser coke made by the partial briquetting procedure was found to be slightly less reactive to CO₂ than conventional coke (31, 32) suggesting the carbon solution loss reaction occurring in the blast furnace stack would decrease and possibly decrease coke consumption.

Effect of Mixing Briquetted and Non-Briquetted Coal

Homogeneous coke produced from partial briquetting procedures is best attained by eliminating segregation of the briquets and matrix coal, and by ensuring low moisture content of the mixture. Various techniques have been used to mix briquets and loose coal. They include the Japanese method (31) of feeding coal and briquets from separate bunkers onto belts which load the charge car and a German method (26) of blending briquets and coal into a model coke oven from a two compartment hopper. Briquet shape plays an important role in the mixing. For example, mixing difficulties were overcome in a Hungarian study (34) by using small lamella shaped briquets weighing 10 g and having dimensions of 9 x 30 x 34 mm. These briquets are not easily separated after mixing with matrix coal. Of considerable interest is the observation that swelling pressures in the oven using the flat briquets were much less than for other shapes tested. This result was attributed to the briquet swelling component being taken up by the matrix coal over a greater surface area. The lamella shape also facilitated drying of the briquets.

Effect of Briquet Preparation

In partial briquetting, briquet preparation is most important for assuring good coke quality. Important variables to be adjusted to the particular coal blend include: degree of coal pulverization; moisture content; selection and amount of binder; and briquetting pressures. British (27), Japanese (31), and Hungarian (35) workers used finer coal in the briquets than in the matrix blend. Nippon Steel Corporation (NSC) used 90 per cent < 1 mm coal in their briquets and 80 per cent < 3 mm coal for the matrix (31). Most investigations held the moisture content of the coal blend to be briquetted between 7 and 10 per cent. The NSC process maintains about 7.0 to 7.5 per cent moisture content for the briquets and matrix coal (31). To increase productivity, Hungarian investigators (34) allowed the briquets to dry prior to charging the coke ovens to obtain a moisture content of 5 per cent for the total charge. According to Soviet studies (12), the amount of pitch added to the blend to be briquetted depended upon the blend's constituent coals and from 1 to 6 per cent pitch was added. Hungarian workers (34, 35) used from 3 to 6 per cent pitch (34, 35), while the Nippon, Kokan, Keihin Corporation (NKK) and NSC processes (31, 33) used from 6 to 8 per cent pitch. The bulk densities of the briquetted coal materials were between 1.1 and 1.25 g cm⁻³ for the studies reviewed here but briquetting pressures varied from 400 - 500 kg cm⁻² in a Soviet study (14) to 1000 kg cm⁻² in a German investigation (29).

Extension of Coking-coal Requirements to Include Less Expensive Coals

Although the partial briquetting process can be used to improve coke quality by increasing coke oven bulk density, the current interest in this procedure is in the possibility of producing metallurgical coke of acceptable quality by using less expensive coal blends made with poor- or non-coking coals. As early as 1957 coke oven charges containing 15 per cent briquets made from brown coals were studied (36) as means of diminishing requirements for expensive coking coals. Continuations of this Hungarian work have involved charges containing from 30 to 70 per cent coal briquets made from coals of low coking potential (34, 37) or from coal fines and flotation concentrates from coal washeries (35). Results of this work

indicated that the Roga number* (an index of a coal blend's coking ability) could be reduced from 65 to 52 without decreasing coke friability or coke strength.

Soviet workers (12), who measure the coking ability of coal blends by their plastic layer thickness during carbonization found that good metallurgical cokes could be made by partially agglomerating inferior coal blends that have relatively thin plastic layers. The results showing coke strengths for eight different briquetted and non-briquetted coal blends appear in Figure 4. The plastic layer thickness (coking ability) of the blend can be reduced, for example, from 12 mm to 8 mm by partial briquetting while maintaining a coke strength of 55. Similar results have been found by Japanese investigators (31) who can predict coke strength from the coal's volatile matter and caking index*. Figure 5 (31) shows the caking index of the blend can be lowered from about 87.5 to 84.5 to maintain coke strength at 81 - 82. The dotted area in Figure 1 (33) shows the field of coal blends that can be used for 30 per cent briquetted coal systems according to Japanese blending criteria. As a result, partial briquetting has made it possible to replace, in the Sumi - process for example, 20 - 25 per cent of the conventional coal charge with non-coking coal.

Metallurgical cokes of high quality have been produced by briquetting 30 per cent of the total coal blend even when the amounts of good coking coals have been reduced significantly. In one test period at the Tobata Works of NSC, a partially briquetted blend of 65 per cent good coking coal and 35 per cent weakly-coking coal produced coke of good quality. Blast furnace trials with such cokes have been good (31) and their blast furnaces are currently operating at the same level of productivity, fuel rate, and bed permeability as for conventional coke.

Effect of Partial Briquetting on Oven Productivity

Results from industrial coke oven trials in Hungary (34) found the charge bulk density on a dry basis increased from 730 kg m⁻³ for normal coal charges to 810 - 860 kg m⁻³ for charges with 50 per cent briquet additions.

* Appendix

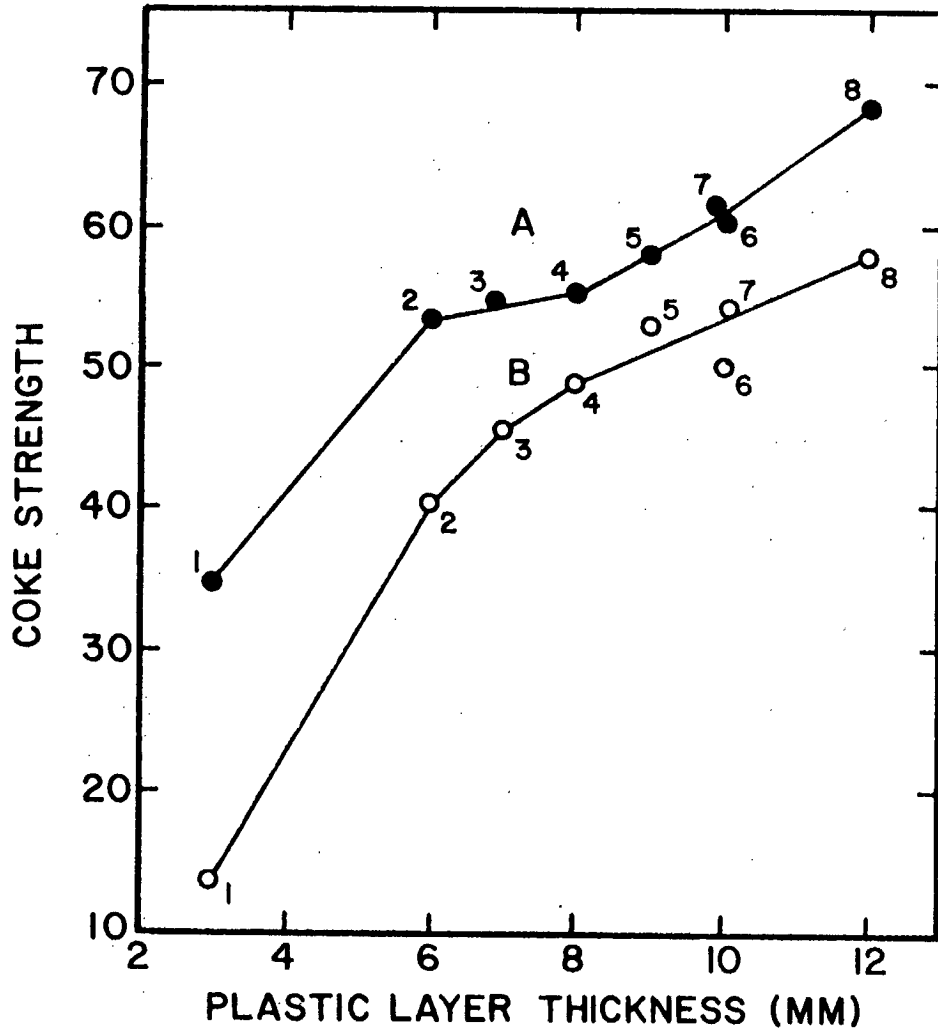


FIGURE 4 Plastic Layer Thickness vs Coke Strength for Eight Briquetted (A) and Non-Briquetted (B) Coal Blends

After Tait's and Pokrovskaya (12)

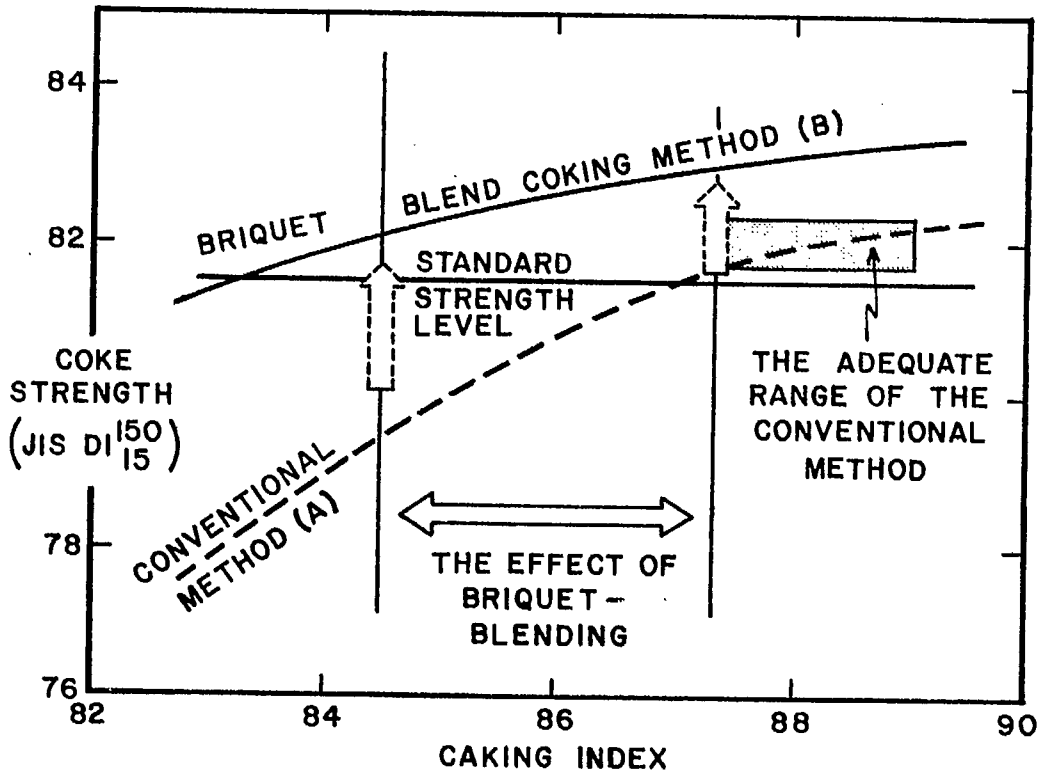


FIGURE 5 Effect of Caking Index of Coal Blend on Coke Strength of Conventional and Briquetted Coal Charges

After Yoshinaga et al (31)

Although the coking time increased approximately 4 per cent over conventional charges, an average increase of 15 per cent in output was achieved. However, in Japanese work (30) using the 30 per cent briquetting procedure only a small increase in productivity was achieved. The amount of coal in the coke-oven charges could be increased by 8.1 per cent but resulted in an increased coking time of 7.1 per cent. Thus, the chief advantage was not the slightly improved ($\approx 1\%$) oven productivity but the extended lifetime of the coke ovens due to less frequent pushing (coke discharging).

CANMET INVESTIGATIONS

CANMET initiated investigations into the agglomeration of coke oven charges in 1966 but after preliminary results, work was soon discontinued because the Canadian steel industry's sources of good coking coals made such a study of little interest to them. Recently however, the industry has become interested in partial agglomeration of coke oven charges because of increased prices of coking coals and the successes of European and Japanese investigators. CANMET has undertaken a study with the objective of determining the qualities of cokes that can be produced from Canadian coal blends when part of the charge is agglomerated. While much of the early CANMET work was concentrated on trying to improve coke quality by increasing oven charge bulk density, the current studies are concentrated on using poor- or non-coking Canadian coals in partially briquetted blends.

Spherical Agglomeration

The spherical agglomeration product from a process designed to clean and agglomerate fine coal was added to coke oven-charges to determine if satisfactory metallurgical coke could be produced (38). The agglomerate was balled from fine (minus 1.4 mm) hvb coal to form a pellet of suitable size for conventional coke making (approximately 80 per cent minus 3.2 mm.). The agglomerates were prepared on a laboratory scale using varying amounts of tar binder (8 - 14 per cent). Carbonization results appear in Table 1. It is noteworthy that the small spherical agglomerates did not significantly increase oven bulk densities or coking pressures but did increase the coke strength (ASTM stability). However, spherical agglomeration of half of a hvb charge did not increase the coke stability sufficiently to permit completely omitting the lvb component from the blend. The potential of this agglomerating and coking technique is in the production of high quality coke from beneficiated coals which had limited use in the coking industry because of their fine size, high ash, and high sulfur contents.

TABLE 1

Spherical Agglomeration of Coke Oven Charges

Test No.	1	2	3	4	5	6	7
Number of Repeats	2	3	2	4			
<u>Test Coke Oven</u>	1	1	1	1	2	2	2
<u>Blend Used</u>							
Coal no. 1 (lvb) %	25	25	-	-	25	-	
Coal no. 2 (hvb) %	75	37.5	100	50	37.5	100	50
% Coal no. 2 agglomerated %	-	37.5	-	50	37.5	-	50
<u>Test Results</u>							
Oven charge bulk density (d.b.) ^a lb ft ⁻³	46.8 ^b	46.8 ^b	46.8 ^b	46.8	48.5	50.3	48.4
Max-carbonization pressure psi	-	-	-	-	0.9	0.4	0.6
Coke apparent specific gravity	-	-	-	-	0.886	0.865	0.891
Coke ASTM stability %	45.7	48.4	36.1	41.5	51.6	38.7	40.7

^a dry basis^b estimated wet bulk density

Addition of Coal Extrusions

Preliminary CANMET investigations studied several methods of increasing coke oven bulk densities to determine the resulting effects upon carbonization. Hot-formed coal extrusions (18 mm dia x 60 mm l) when making up 40 per cent of the oven charge (Test No. 3, Table 2) resulted in increased bulk density, ASTM coke stability, and oven productivity over the normal coal charge (Test No. 1) that was charged at 6 per cent moisture. A regular charge of unusually high bulk density, prepared by air drying, was carbonized (Test No. 2) to determine if bulk density was the only factor that affected coke quality. The regular charge high bulk density test had an unacceptably high maximum carbonization pressure and a lower coke stability than the coal extrusion test. The pressure in the test with 40 per cent additions of coal extrusions was surprisingly low (0.7 psi) and the improvement in coke quality over test No. 2 could not be attributed to differences in oven bulk densities. The results from this preliminary evidence suggest that the addition of coal extrusions to coke oven charges may be an excellent method of increasing oven bulk densities, productivity, and coke quality. Further studies are warranted.

TABLE 2

Comparison of Effects of Briquet and Coal Extrusion Additions on Oven Bulk Densities and Coking Conditions

Blend no.	Hot-extrusions			Briquet (30x30x18 mm)	
	1	2	3	4	5
Test no.	1	2	3	4	5
Agglomerate addition %	0	0	40	0	40
<u>Test Results</u>					
Oven bulk density (d.b.) ^a (lb ft ⁻³)	41.5	54.1	52.5	51.0	56
Maximum carbonization pressure (psi)	0.4	4.4	0.7	1.2	3.3
Coke oven productivity (d.b.) (lb hr ⁻¹)	34.2	37.1	37.3	-	-
Coke apparent specific gravity	0.771	0.929	0.960	0.893	0.945
Coke ASTM Stability %	45.7	52.9	58	54.9	54.0

^a d.b. = dry basis

Partially Briquetted Charges

Preliminary CANMET investigations to study the effects of increased coke oven bulk densities upon carbonization parameters included a partially briquetted coal charge; its carbonization results are included in Table 1. Forty per cent addition of briquets (30 x 30 x 18 mm) prepared from coals heated to 232°C resulted in an increased oven bulk density over the normal charge bulk density. Partial briquetting did not improve ASTM coke stability and caused unacceptably high carbonization pressures. The lack of improvement in coke quality is probably attributed to the high quality coal blend used. Japanese work (35) depicted in Figure 5, indicated partial briquetting of good blends produced smaller improvements in coke quality than did poorer coking blends (i.e., note convergence of lines A and B in Figure 5).

In more recent studies at CANMET, briquets were made at 100°C with 8 per cent asphalt as binder. The briquetted portion of several Canadian blends was reduced to 30 per cent and the resulting carbonization pressures were found to be acceptable (≤ 1.1 psi). The improvement in ASTM coke stability for these charges over normal charges is plotted against the blend fluidity in Figure 6. In general, coke quality improved more for partially briquetted blends (relative to the non-briquetted blends) having fluidities greater than the 1000 ddpn preferred for conventional coke-making (7) than for blends having acceptable fluidities.

Other studies have been conducted on a smaller scale to incorporate non-coking oxidized mvb coal into 30 per cent briquetted coke oven charges. Matrix coal and 10 (or 20) g hand pressed cylindrical briquets were manually charged into 75 mm dia x 240 mm 1 cylindrical canisters which were evenly distributed within the 500 lb oven and held by a matrix of good coking coal. This method permitted several coking variables and duplicate samples to be investigated in one technical scale oven test. Figure 7 shows longitudinal and sectional views of canister coke from a 30 per cent partially briquetted charge. The coke had a similar homogeneous appearance in all canisters and showed no evidence of briquets having been present in the original charges. The quality of coke in each canister was determined using a canister disintegration test*, devised at ERL. The averaged results from

* Appendix

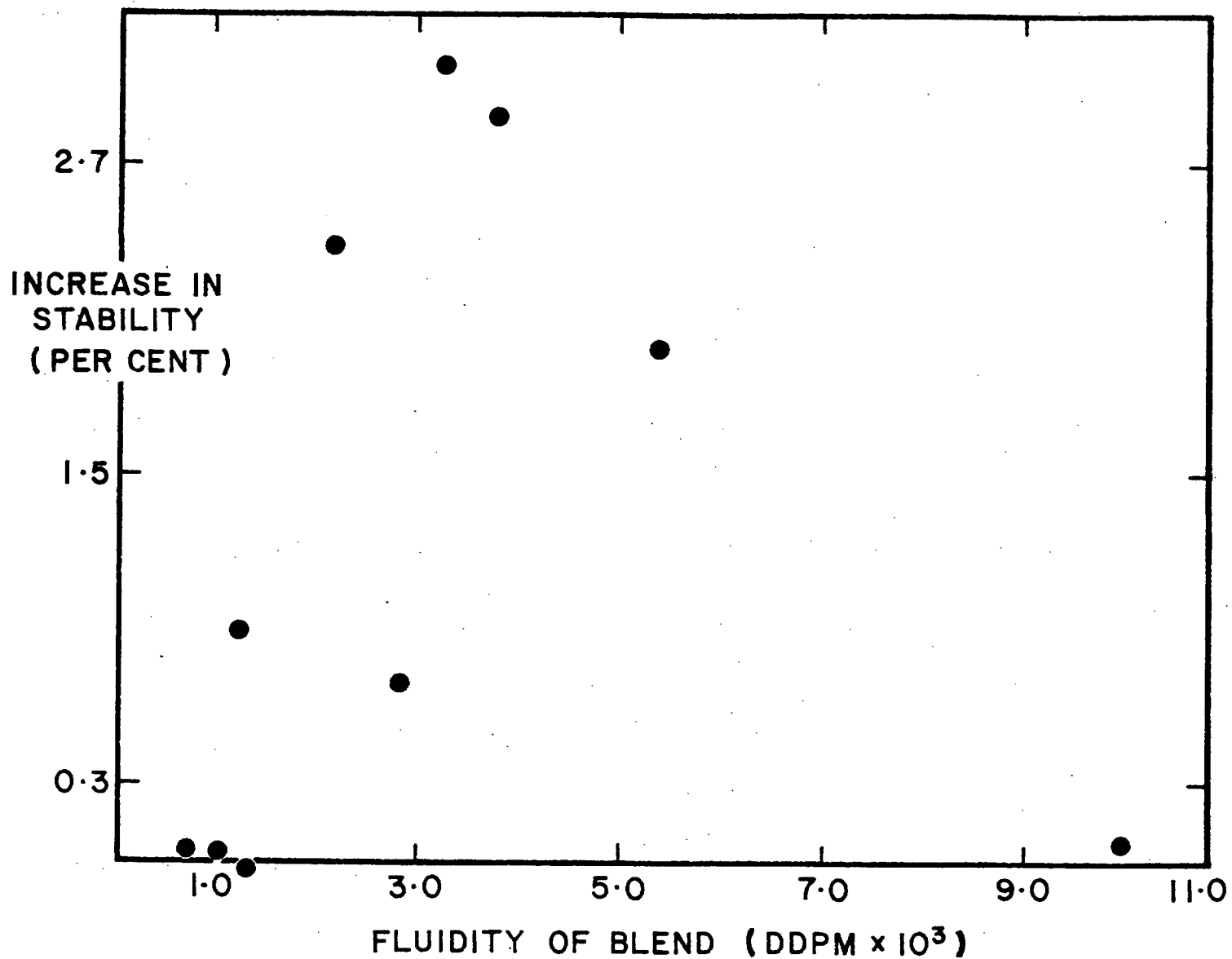


FIGURE 6 Fluidity vs Increased Coke Stability of 30 Per Cent
Briquetted Charges over Conventional Charges



No. 7 22-18-76

a) Photograph of Half Canister Coke.



No. 7 22-18-76

b) Photograph of the Longitudinal Section of same Coke.

FIGURE 7

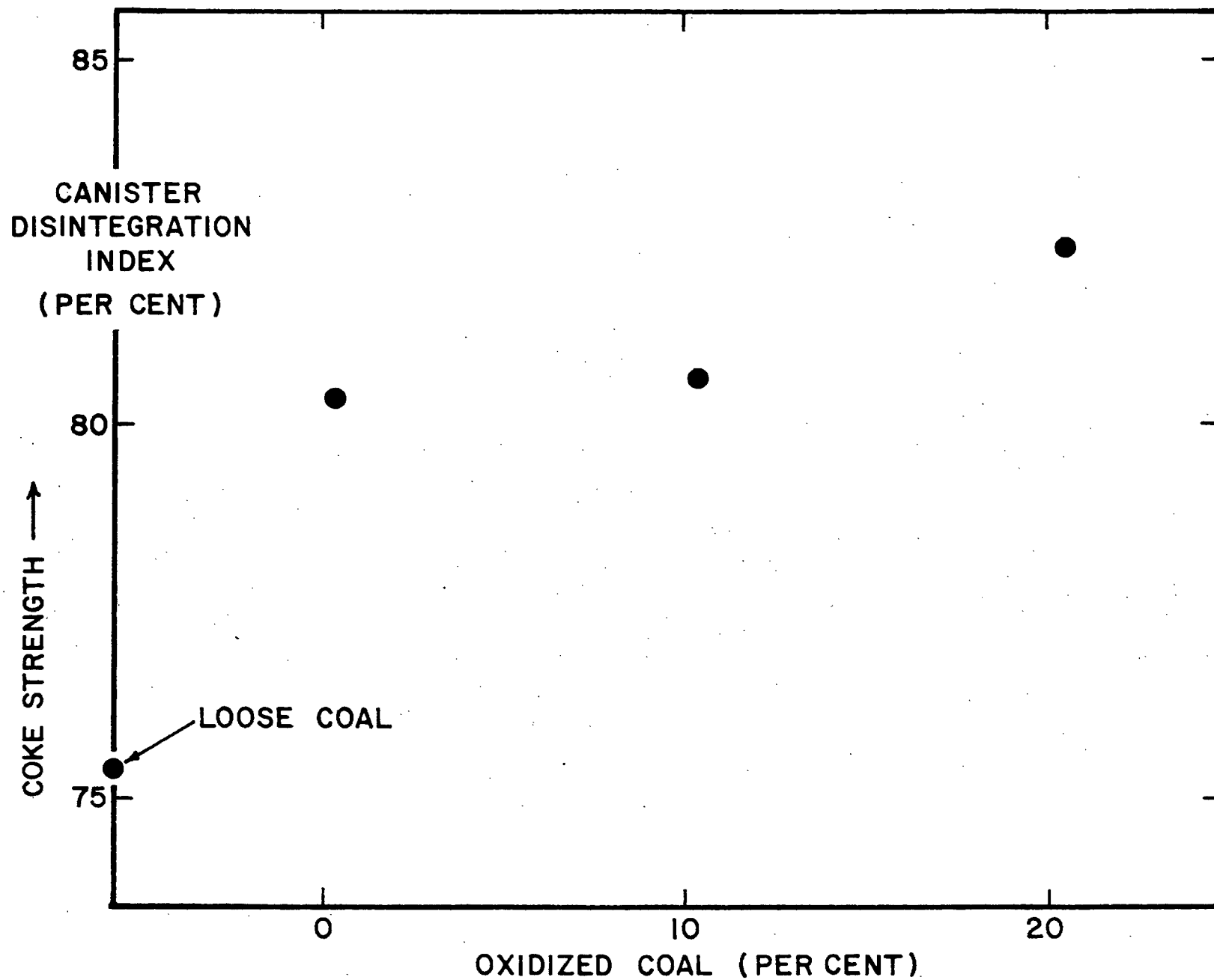


FIGURE 8 Effect of Proportion of Oxidized Coal in Coal Briquets upon Resulting Coke Strength

multiple canister tests appear in Figure 8. Coke quality improved significantly from an average canister disintegration index of 75.5 for normal charges to an average value of 80.4 for briquetted charges. Additions of 10 or 20 per cent non-coking oxidized coal to the briquets had no adverse effects and yielded similar canister disintegration values as the partially briquetted good coking coal charges.

SUMMARY AND CONCLUSIONS

CANMET investigations of partially agglomerated coke oven charges provide evidence that briquets, spherical agglomerates, and hot formed coal extrusions all improved coke quality. When compared to conventional coke-making, coke quality from partially briquetted charges improved more for inferior coking blends than for good coke blends. With the coals used in our studies the briquetted portion of the blend should be limited to 30 per cent to avoid large coke oven wall pressures. The addition of small (~ 3 mm) spherical agglomerates to oven charges improved coke quality without increasing oven bulk density. Addition of 40 per cent coal extrusions enhanced bulk density and coke quality without unduly increasing coke oven wall pressures.

Other investigations have indicated that briquets and loose coal should not be allowed to segregate during handling. It has been suggested that this problem can be simply overcome by using lamella shaped briquets. Grinding the coal used in the briquets to a finer size (90 per cent < 1 mm) improves coke quality. A large range (1 to 8 per cent) of binder has been used in briquets and suggests that the type and amount of binder must be regulated according to the rheological properties of the particular coal blend.

Significant economic benefits may be derived from the partial agglomeration practices; the major benefits include the utilization of non-coking coals to replace the expensive lvb coals in coking coal blends; and the ability to carbonize fine sizes of coking coals that would otherwise be unsuitable in coke oven charges. The briquetted portions of the charge can also be pre-dried to lower moisture levels to increase coke productivity without creating dust problems during coal handling. As a result, several

steel companies (including NKK, NSC, and Sumitomo Metal Industries) now have partial briquetting facilities operating commercially in a few of their coke plants and additional facilities are being considered.

ACKNOWLEDGEMENTS

The authors are indebted to Dr. B.J.P. Whalley for suggestions and assistance during the final preparation of this paper, and to Mr. T.A. Lloyd, Mr. K.F. Hampel, and to Mr. P. Couturier for the preparation of coal and briquet samples.

REFERENCES

1. American Society for Testing and Materials Book of ASTM Standards; Standard method of tumbler test for coke; Part 26, D 294-64, pp 41-42; 1974.
2. Japanese testing method for coke strength; Japanese Industrial Standard JIS K2151-1972; Translation by Y. Okuyama, Nippon Kokan K.K., Technical Research Center, Kawasaki, Japan.
3. Miyazu, T., Yanagiuchi, M., Muroya, M. and Okuyama, Y. Coke strength at 1500°C; Iron and Steel Institute of Japan 91st Meeting; p S27; April 1976.
4. American Society for Testing and Materials Book of ASTM Standards; Plastic properties of coal by the constant-torque Gieseler plastometer; Part 26, D 2639-74, pp 512-518; 1974.
5. Gibson, J. and Gregory, D.H. Selection of coals and blend preparation for optimum coke quality; Joint meeting of Institute of Fuel and Coke-Oven Managers Association, Chesterfield, U.K.; 10.3; 1977.
6. Schariro, N. and Gray, B.S. The use of coal petrography in coke-making; J. Institute of Fuel; vol. 37, no. 281, pp 234-242; 1964.
7. Miyazu, T., Okuyama, Y., Fukuyama, T. and Sugimura, H. Petrographic study on coal and its application for cokemaking; Nippon Kokan Technical Report - Overseas; pp 15-22; December 1971.
8. Grainger, L. Blending techniques for the use of low quality coking coal in coke production; ILAFA - Coal Conference, Mexico City; July 1976.
9. Nakamura, N., Yuji, T. and Takeki, A. The philosophy of blending coals and coke-making technology in Japan; Coal, coke and the blast furnace, Middlesbrough, U.K.; no. 10; June 1977.
10. Turchenko, P.I. Stal; no. 2, 1952.
11. Pokrovskaya, F.I. Bulk density of briquetted coal charges and the mechanism of fissure formation during their coking; Akad. Nauk SSSR, IGI, Moscow, pp 130-138, 1964.
12. Taits, E.M. and Pokrovskaya, F.I. The carbonization of briquetted charges; Coke and Chem.; no. 9, pp 15-19, 1964.
13. Taits, E.M. et al. Use of lignites for coking, Tr. Inst. Goryuch. Iskop, Moscow; vol. 25, no. 1, pp 64-73, 1970.
14. Taits, E.M. et al. Charge compaction prior to carbonization; Coke and Chem. USSR; no. 8, pp 17-21, 1972.
15. Ivleva, A.S. Densification of coal charges by partial pelletization; Khimiya tverd. Topl.; no. 6, pp 195-196, 1968.

16. Botham, J.C., Walsh, J.C., and Whalley, B.J.P. Investigation of the carbonization characteristics of spherically agglomerated coal; Department of Energy, Mines & Resources, Fuel Research Centre, Canada; Report FD 67/148 CG, 1967.
17. Gregory, J.A. Metallurgical coal for the Iron & Steel Industry; SEASIS Quarterly; pp 23-32; April 1975.
18. Anon. Iscor produces form-coke; Iscor News; September 1969.
19. Anon. Construction of plants to produce coke using partly briquettes in Japan, runs its course; The Japan Daily Echo; vol. 15, no. 3585, p 4, December 1976.
20. Anon. Sumi-Coal System; Sumitomo Metal Ind. Ltd.; Sumitomo Shoji America, Inc., New York, N.Y.; pp 1-14, July 1976.
21. Ikeshima, T., Sugasawa, K., Akamatsu, K. Developments in producing metallurgical coke and their application to Latin American coals; The 1975 Latin American Iron and Steel Congress; ILAFO-16, pp 1-20, 1975.
22. Akamatsu, K., Nire, H., Miyazaki, T. and Nishioka, K. Influence of non-coking coal on the quality of metallurgical coke; Coal, coke and the blast furnace, Middlesbrough, U.K.; no. 6; June 1977.
23. Holub, J. and Koliha, J. Increasing the bulk density of coking blends by means of pelletizing; Uhlí; vol. 21, no. 6, pp 231-233, June 1973.
24. Holub, J. and Koliha, J. Increasing the bulk density of coking blends by pelletizing; Sbornik Prace UVP; no. 28, pp 43-73; 1974.
25. Schmidt, J. and Hanke E. Coking of pit coal with bitumen and coal briquettes, Part I; Institut fur Energetik 22, pp 77-87, 1960.
26. Schmidt, J. and Hanke, E. Coking of pit coal with bitumen and coal briquette additions; Part II; Institut fur Energetik 23, pp 155-171, 1960.
27. Anon. Report of 10 Ton Oven and Commercial Oven Investigations into the Effects of Partially and Wholly Briquetting Coke Oven Blends on behalf of the National Carbonizing Co. Ltd.; British Coke Research Assn., no. 8210, October 1971.
28. Centre National de Recherches Metallurgique; Metallurgical Coke; Belg. 816,995 (Cl.C10b) pp 1-5, December 1974.
29. Strunz, D. (Stahlwerke Roehling-Burbach G.m.b.H.); Blast Furnace Coke; Ger. Offen. 2,332,376 (Cl.c10b); pp 1-7, January 1975.
30. Inoue, M. et al. Development of the improvement process of coking properties; J. Fuel Soc. Jap; vol. 53, no. 565, pp 315-324, 1974.

31. Yoshinaga, H. et al. Industrialization of the briquette-blend coking process; presented at the Ironmaking Conference of the AIME, St. Louis, 1976.
32. Ida, J. et al. Coke production with mixtures of preheated briquetted coal (I); Coke Circ., vol. 22, no. 3, pp 197-211, 1973.
33. Paper presented by NKK at the first NKK-CCRA Technical meeting, Stelco Research Centre, Hamilton, Canada, March 10, 1976.
34. Takacs, P., Jako, L., and Nagy, F. Blast furnace coke production by mixed feeding; Publications of the Hungarian Mining Research Institute; no. 13, pp 235-241, 1970.
35. Takacs, P. et al. Improvement of the quality of a mixture of fines for a coking blend by agglomeration with a binder; Industrie Minerale, Serie Mine, no. 2, pp 131-140, 1973.
36. Jako, L., Takacs, P., Voszatko, K. Tentative production of formed coke in Hungary; Koks, Smola, Gas; no. 2, pp 299-302, 1957.
37. Jako, L. Mixed-charge coking; Nehezvegyipari Kutato Intezet Kozlemenyei; no. 1, 217-221 (1959).
38. Walsh, J.H., Whalley, B.J.P. and Botham, J.C. Upgrading coking coals and coke production; U.S. Patent no. 3,367,464; January 1972; Cdn. Patent no. 841584; May 1970.

APPENDIX

DESCRIPTIONS OF TESTS

ASTM tumbler test for coke is a relative measure of the resistance of coke to degradation by impact and abrasion. 10 kg of coke, 50 to 75 mm, is placed in a circular steel drum (914 mm dia x 457 mm l), tumbled at $24 \pm$ rpm for 1400 revolutions, and then screened through 25 mm and 6.3 mm square mesh sieves. ASTM coke stability is the percentage of coke retained on the 25 mm sieve.

Caking index is obtained by crushing 1 g of coal to minus 0.21 mm and 9 g of coke to 0.21 - 0.30 mm in a crucible and heating in an electric furnace at $950 \pm 20^{\circ}\text{C}$ for 7 minutes. The percentage of carbonized material remaining on a + 0.30 mm sieve after screening is the coal's caking index.

Canister disintegration index is calculated from the results of a shatter test in which 300 ± 10 g of canister coke is shattered by twice dropping a 15 kg weight down a pipe (13.3 cm dia x 91.4 cm l), and screened through 3.8, 2.5, 1.9, 1.3, 0.64 and 0.42 cm sieves. The mass and number of pieces of coke on each sieve is recorded, then this material is placed in a shatter box (30.5 x 17.8 x 22.9 cm) and shattered again for 20 min (720 cycles per min) using a paint shaker. The resultant coke is again screened and the mass and number of pieces on each screen recorded. The disintegration index is given by the ratio of the mean coke lump diameter (plus 0.42 cm material) after shattering to the mean lump diameter before shattering. The index gives a measure of coke strength.

Fluidity of coal is determined using a Gieseler plastometer and gives a relative measure of the plastic behaviour of coals. A steel stirrer having four rabble arms is immersed in a 5 g coal sample within a heating crucible. The crucible and stirrer is placed in a furnace and the stirrer attached to the plastometer head which applies a 46 g in. torque to the sample. The sample temperature is increased from 300°C at a rate of 3 degrees/min and the maximum fluidity is recorded in ddpn (100 ddpn = 1 revolution).

Japanese industrial standard coke tumble tests specify that 22 lb of plus 2-in. coke be tumbled for 30 or 150 revolutions at 15 ± 5 revolutions per min in a 1.5-m diameter by 1.5-m long cylindrical drum equipped with six equispaced 0.25-m wide lifters set 90 degrees to the drum wall. The coke, tumbled for 2 minutes (30 revolutions), is screened over square-mesh sieves having hole diameters of 50, 25 and 15 mm. The cumulative percentage remaining on the 15-mm sieve after 30 revolutions is known as the JIS DI_{15}^{30} index. In a recent test modification, the coke sample is reconstituted and tumbled for an additional 8 minutes for a total of 150 revolutions, after which it is screened again. The cumulative percentage retained on the 15-mm screen after 150 revolutions is known as the JIS DI_{15}^{150} index.

Reflectivity is measured using plane polarized light source and a microscope that can project an image to a photomultiplier tube. Reflectivity is reported as the mean of readings of maximum reflectance of a specified coal component (usually vitrinite), as per cent reflectance in immersion oil.

Roga number is derived from an agglutination test in which 1 g of coal (0.2 mm) and 5 g of anthracite (0.3 - 0.4 mm) is compacted, heated to 850° (in 15 min, and material > 1 mm is tumbled) in a drum (20 cm dia) for three periods of 5 minutes.

$$\text{Roga number} = \frac{a + d + b + c}{2} \times \frac{100}{Q}$$

Where: Q = weight of coke button
A = wt of > 1 mm material place in drum
b,c,d = wt of > 1 mm after successive 5 min intervals.

Volatile matter is determined by establishing the loss in weight resulting from heating 1 g of coal or coke to $950 \pm 20^{\circ}\text{C}$ for 7 minutes. The measured weight loss corrected for moisture establishes the volatile matter.