

INFLUENCE OF COKING VARIABLES ON THE QUALITY OF COKE PRODUCED IN A TECHNICAL SCALE COKE OVEN

by J.F. Gransden, W.R. Leeder, J.C. Botham and
B.J.P. Whalley, Coal Resource and Processing
Laboratory, Energy Research Laboratories, CANMET,
Department of Energy, Mines & Resources, Ottawa,
Canada.

ABSTRACT

The Coal Resource and Processing Laboratory evaluates coking coals by numerous techniques. Coking in technical scale slot-type ovens of 500 and 700 lb capacity, that simulate carbonization in industrial ovens, is the ultimate laboratory test of a coking coal or coal blend and is the subject of this paper. The effect of carbonization variables on the properties of coke made from one industrial coking coal blend using a re-built 18-inch width oven is presented. This study was conducted to determine, for this oven, the influence of coking variables on each other and on coke quality. The results were used to choose standard test oven operating conditions felt to simulate industrial practice. Cokes produced from the same blend in industrial and technical scale ovens are compared.

INTRODUCTION

Coke is one of the most important materials used by industrial nations such as Canada, because it is the chief chemical reductant and energy source for the iron blast furnace, the basis of current steel production. Coke is of vital economic importance to a steel producer since it is the highest single cost item in steelmaking and its properties can have dramatic effects on blast furnace performance. There is little public awareness of the role of metallurgical coke in our society, as it is usually produced and used "in-house" by large integrated steel plants.

Metallurgical coke is produced almost exclusively by carbonization (heating in the absence of oxygen) of blends of coking coals in slot-type ovens. Presently about 8 million tons per annum of coking coal is used by Canadian coke makers. The coal comes primarily from the Appalachian fields of the U.S.A., although smaller quantities of eastern and western Canadian coals are also used. Interestingly, about 11 million tons of coking coal is presently exported from western Canada to a variety of locations such as Japan, Korea, Brazil and Europe. Western Canadian coking coals are not used in substantial quantities by Canadian coke makers because of higher costs associated with their use as compared to their American counterparts, notwithstanding the present difference in value of the Canadian and American dollars. Higher costs result mainly

from higher transportation costs and coal ash contents, and increased handling problems. As well, about 45 per cent of the coking coal imported from the U.S.A. is from mines owned by Canadian coke makers. Consequently American coals still remain the main source for Canadian coke makers.

The results of technical scale oven tests are required for realistic interpretation of coking properties of coals or blends, particularly when there has been no prior history of their use for the manufacture of conventional metallurgical coke. Therefore, the use of such equipment is essential in coking coal resource evaluation, in choosing new blends of coals for industrial use, and in research and development in the field of carbonization. CANMET presently operates four technical scale slot-type coke ovens, the only ones in Canada for assessing coking coal quality. They are almost exclusively relied upon by Canadian mining companies, commercial coke makers and governments for evaluating coking coals.

CANMET's 18-inch test oven was recently modified. Since no accurate predictive methods exist to calculate the influence of the oven changes on coke quality an experimental program was necessary. Coke quality is a function of interacting variables—oven charge properties and preparation, and coke oven physical characteristics and operation, schematically seen in Figure 1. It was decided to use a typical industrial coking blend to fix the oven charge properties and then to study the influence of charge preparation and oven operation on each other and on coke quality. The test blend was supplied by a member company of the Canadian Carbonization Research Association* who co-sponsored the program with CANMET, and consisted of three coals identified as A, B and C whose chemical and rheological properties are summarized in Table 1. This blend is typical of those used by Canadian coke makers.

The test program results were used to select a set of standard test oven operating conditions felt to simulate industrial practice.

Once these conditions were chosen, several industrial coking blends were carbonized in the oven. The resulting coke properties were compared to those produced industrially.

OVEN OPERATION

The largest CANMET test oven is a movable-wall oven with an 18-inch wide coking chamber similar to commercial ovens and 700-lb capacity. A schematic is shown in Figure 2. During rebuilding, the most significant design modification was replacement of the silicon carbide bricks of the heating wall with commercial silica bricks used in industrial ovens, to try to duplicate more reliably

*An association of Canadian coal associated industries, dedicated to cokemaking R & D. CANMET acts as secretariat for the Association.

the heat transfer conditions found in industrial coke oven batteries. The oven is heated electrically by Globar elements located in heating chambers on either side of the oven charge. The heating chambers are similar in purpose to the gas heating flues of industrial coke ovens and by this analogy are referred to as flues. Operationally the major change made was to keep the flue temperature constant rather than following the programmed increase used previously. The constant temperature mode was subsequently adopted for this oven as standard practice because of ease of control.

Coke is made as follows. The coal or coal blend is first crushed to a predetermined size, adjusted to a predetermined moisture level and fed from a hopper into the oven, through a charge hole in the top. The charged coal or blend is then levelled by raking out any excess coal through a small levelling door located at the top of the main oven door. The charge oven bulk density is calculated from knowledge of the amount charged and oven volume. The charge is carbonized until one-half hour after the charge centre temperature has reached a specified temperature. This takes about 16-20 hours. The two oven end doors are then removed and the coke is pushed out. The coke is immediately cooled with water in a "quench" box and dropped 10 ft to a concrete floor to simulate coke handling at the commercial coke oven. Test oven operation is similar to industrial practice. Since the heat transfer conditions and the other coking variables reflect industrial practice, it is felt that coke properties from such test ovens should be similar to those from industrial ovens.

INTERACTION OF COKING VARIABLES

Since the charge properties and oven physical characteristics were fixed, only charge preparation and oven operations were considered in studying interaction of variables. The two principal operating variables are bulk density of the charges and coking time, the time for the centre of the charge to reach a specified temperature. Figure 3 shows how these and other factors interact.

It is relatively easy to achieve a charge pulverization level similar to that used industrially. However, controlling bulk density is another matter. Charge mechanical conditioning such as drop height of the charge into the oven differs greatly between test ovens and industrial ovens. Also, charge oiling, a common industrial practice to increase bulk density, is not used at CANMET. Therefore, moisture and pulverization levels are the methods used for controlling charge bulk density in routine CANMET oven test work. The effects of changing moisture and pulverization levels on charge oven bulk density appear in Figure 4. Target blend moisture levels were 3, 5 and 7 per cent. Sieve analysis of two oven charges that are typical of the two target blend pulverization levels of 75 and 90 per cent passing 1/8-in. sieve, appear in Table 2. In Figure 4 it can be seen that charge moisture content and not pulverization level is the principal variable affecting oven bulk density. Since the pulverization levels used in this

study cover a wider range than generally used industrially, yet had little influence on charge bulk density, it can be considered that resulting CANMET oven bulk density is only dependent upon charge moisture content and appears to increase linearly with decreased moisture content. As the influence of charge moisture on the bulk density can vary from oven to oven, charge oven bulk density is the preferred term for discussion.

The influence of charge oven bulk density and test oven flue temperature on coking rate is seen in Figure 5. The resulting coking time to a centre temperature of 900°C appears to be directly proportional to bulk density. As would be expected, a decrease in the flue temperature increases coking time. Since charge oven bulk density is usually standardized, coking time is a function of flue temperature in most test work.

INFLUENCE OF COKING VARIABLES ON COKE QUALITY

The most important coke quality parameters related to blast furnace performance and productivity are strength indexes. In North America the most commonly used index is the ASTM stability factor. This is the percentage of coke remaining above a 1-in. screen after 22 lb of 2-in. by 3-in. coke has been tumbled for 1400 revolutions at 24 ± 1 rpm in a 3-ft diam. by 1.5-ft long cylindrical drum equipped with two equispaced 2-in. lifters set at 90 degrees to the drum wall.

Figure 6 shows the influence of charge oven bulk density, coal pulverization level and oven flue temperature on the ASTM stability factor of coke produced from a commercial coking blend in the rebuilt oven. Coke stability increases dramatically with charge oven bulk density for all coking rates and pulverization levels, from a barely acceptable value for blast furnace coke of about 50 to very high values approaching 60. At any given bulk density, the finer grind produces coke with higher stability factors.

The data have been replotted in Figure 7 to show more clearly the influence of flue temperature on the coke stability. For the fine pulverized blend, flue temperature had little influence on coke quality. For the coarser grind, more typical of industrial practice, decreases in coke quality were observed with increasing flue temperature for the 3 and 5 per cent moisture charges, which correspond to oven bulk densities of approximately 51 and 48 lb/cu ft respectively, but had little effect on the 7 per cent moisture, or 45 lb/cu ft, charge. It can be seen from Figures 6 and 7, that for the variable levels studied charge oven bulk density appears to play the predominant role in influencing ASTM coke stability.

Coke size is also important to the iron maker. Proper sizing, preferably to a fairly narrow size distribution, reduces the resistance of the blast furnace burden to the passage of gas so that high productivity can be achieved by blowing the maximum amount of air through the furnace. Figure 8 shows the influence of coke oven flue temperature on the size distribution of the resulting coke. It was found, although not noted in Figure 8, that oven

bulk density had only a minor influence on coke size in this study. Oven flue temperature appeared to be the principal variable influencing coke size. Figure 8 shows that the coke size fractions change with increasing coking time. Higher flue temperatures tend to narrow the size range of the coke, yet can be seen in Figures 6 and 7 to decrease stability factors.

The CANMET test ovens have different constructions and are operated using different coking conditions selected with the objective of producing coke of a similar ASTM stability factor. The stability factor of coke produced from either the rebuilt 18- or 12-inch CANMET test ovens for a given coal or blend appear to be equivalent, as seen in Figure 9. These ovens are operated at similar charge pulverization levels, but at different charge bulk density and flue temperature conditions. For example, 18- and 12-inch ovens are operated at a dry charge oven bulk density of about 46.5 and 51 lb/cu ft respectively. Although the stability factors of cokes produced from these ovens are similar, other coke quality parameters vary.

In consultation with industrial representatives at the Technical Committee of the Canadian Carbonization Research Association, standard operating conditions reflecting industrial practice were selected for the rebricked 18-inch technical scale coke oven. These were a charge pulverization level of 80 ± 5 per cent below 1/8 inch, charge oven bulk density of 46.5 lb/cu ft and coking time of 18 hours to charge centre temperature of 1000°C. Using these criteria and the results of the 18-inch oven study, a set of standard conditions were selected for the oven. They are: oven charge pulverization level of 80 per cent passing 1/8 inch sieve, charge moisture content of 6 per cent and flue temperature of approximately 1125°C.

The results in Figure 5 can be used to derive empirical equations to relate coke stability values to changes in oven operating conditions. This was done with multiple linear regression analysis using the standard operating conditions as a basis of comparison. The relationship for the coal blend tested in the rebuilt 18-inch oven is as follows:

Predicted Stability = 52.7 (predicted stability at standard conditions)

-1.40 (Actual charge per cent moisture - 6%)

+0.087 (Actual % charge passing 1/8-in. sieve - 80%)

-0.010 (Actual oven flue temp., °C - 1125°C)

(Correlation coefficient = 0.90; standard error = 1.33).

INDUSTRIAL VERSUS CANMET COKE QUALITY

Several Canadian steel companies supplied samples of industrial coking blends to CANMET to assess how the quality of industrial coke compared with coke produced from the re-built 18-inch test oven run at the standardized coking conditions outlined above. Exact correspondence of coke properties was not expected since industrial coke samples are normally taken shortly before entering the blast furnace (skip coke) rather than at the coke oven. Skip rather than oven coke properties relate better to blast furnace performance. Industrial oven coke undergoes considerable mechanical agitation before arriving at the blast furnace, causing degradation of weaker coke pieces and relief of internal stress along coke fissures. The result is a "stabilized" coke that has a higher stability factor and smaller mean size than oven coke.

Each battery sampled their coal blend going into the oven battery over a period from 1 day to 1 week. The samples were blended and moisture adjusted before charging to the CANMET oven, but the pulverization level was not changed. Stabilities of industrial skip coke and CANMET oven coke are seen in Table 3. As expected the test oven and industrial results differed. Industrial skip coke had higher stabilities and smaller mean size. Further studies to quantify the differences between test and industrial oven coke are underway.

CONCLUSIONS

The conclusions drawn from this study relate only to the coal blend, range of variable levels and oven used.

Coke-making operating variables have been shown to have a significant influence on each other and on coke quality. Increasing oven bulk density and the charge pulverization level increased the coke strength. Increasing flue temperature decreased the mean coke size, but had little influence on coke strength.

To try to simulate industrial practice, the following oven operating conditions for the rebuilt 18-inch oven have been chosen; oven flue temperature about 1125°C, charge moisture 6 per cent, degree of charge pulverization 80 per cent passing 1/8 inch sieve. These conditions result in a dry charge oven bulk density of about 46.5 lb/cu ft with a coking time of 18 hours to a charge centre temperature of 1000°C.

Coke produced in the rebuilt oven operated at the standardized conditions differed somewhat from the quality of industrial skip coke produced from the same coal blends. Further investigations to quantify this difference are currently under way.

ACKNOWLEDGEMENTS

The authors would like to thank the Canadian Carbonization Research Association for their guidance and encouragement in conducting this work and the unnamed member of C.C.R.A. for supplying the coals used. They gratefully acknowledge the contributions of Mr. T.A. Lloyd whose section prepared the coal, Mr. W. Gardiner whose section ran the coking tests, and Mr. K. Hampel for preparation of the tables and figures.