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Blast-furnace coke: A coal-blending model

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SYNOPSIS

The relationships between coal properties, the strength of coke, and the performance of a blast furnace were investigated by means of correlation studies, and a linear programming model was developed for the prediction of a coal blend based on these relationships. The unique feature of this approach is that it utilizes a knowledge of the minimum blast-furnace coke requirements, rather than the maximum attainable coke quality. The model predicts the least expensive coal blend that would still comply with the minimum coke-quality requirements of a blast furnace. The study also confirms the existence of a relationship between the rank and caking parameters of coal, and the hot strength of coke. The effect of coke-oven operating parameters on coke quality is also discussed.

SAMEVATTING

Die onderlinge verwantskap tussen steenkooleienskappe, die sterkte van kooks en hoogoondgedrag is met behulp van korrelasie-studies ondersoek, en 'n liniêre programmeringsmodel wat hierdie onderlinge verwantskappe ten grondslag het, is ontwikkel ten einde 'n optimum steenkoolmengsel te voorspel waaruit metallurgiese kooks wat geskik is vir optimale hoogoondbedryf vervaardig kan word. Hierdie enigsins unieke benadering is daarin geleë dat die minimum kookseienskappe wat deur die hoogoond benodig word, eerder as die maksimum bereikbare kooksgehalte, as vertrekpunt geneem word. Die model word gevolglik gebruik om die mees koste effektiewe steenkoolmengsel te voorspel sodat kooks gelewer word wat die hoogoond in staat stel om steeds vloeiyster optimaal te produseer. Die studie toon verder dat daar 'n verwantskap tussen steenkoolrang en bindingseienskappe van steenkool, en die warmsterkte van kooks bestaan. Laastens word die invloed van kooksoond-bedryfsparameters op die gehalte van kooks kortliks bespreek.

Introduction

The economy of blast-furnace operations is closely linked to the cost of the coke that is used as fuel and reducing agent since the cost of the coke constitutes a significant fraction of the operating costs of a modern blast furnace. There is consequently much incentive from an economic point of view for optimizing the properties of coke, quite apart from the obvious technological advantages that would ensue from such optimization. However, the exact way in which coke properties have to be optimized, and the criteria used to define the quality of blast-furnace coke, have been the subject of much controversy in the past. One school of thought places great emphasis on the value of the 'cold strength' of coke[1], whereas another school favours 'hot strength' as a more significant parameter[2]. Unfortunately, cold strength and hot strength are not clearly defined entities, and the methods used for quantifying these parameters by experimental measurement vary from one to another.

One group of workers argues that, while the reactivity of coke is used as a measure of hot strength, the reactivities of different cokes tend to be equalized at high temperature owing to recirculation of the alkalis, thus rendering hot strength an insensitive parameter. Consequently, so it is argued, cold strength, which is essentially the physical strength determined at room temperature, remains the best basis for predicting the performance of coke in a blast furnace. Cold strength of coke is determined in large measure by the rank and caking properties of the coal from which it is produced. Consequently, cold strength and coal properties have to be defined in a more quantitative manner before a study can be made of the relationships between the various parameters influencing the cold strength of coke. A parameter that is often used[2,3] to define the cold strength of coke is the DI^{150}_{15} value, which is explained in Addendum 1. Coal properties, on the other hand, can be evaluated in terms of coal rank parameters, such as the reflectivity of reactives (RoR), and caking parameters, such as fluidity (Addendum 2). The influence of rank and caking properties on the cold strength of coke can be obtained, and such relationships, following Miura[4], are shown schematically in Fig. 1.

Arguments advanced in favour of the use of hot strength as a parameter to predict coke performance rely

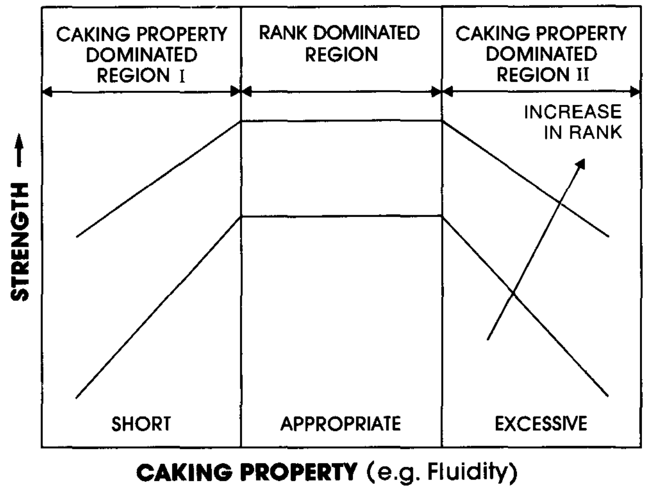

Fig. 1—A schematic illustration of the dependence of coke strength on the coal rank and caking properties of coal[4]

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heavily on the knowledge that coke behaves quite differently at elevated temperatures from its performance at room temperature. Furthermore, coke is subjected to thermal stresses in the blast furnace, to mechanical breakdown as a result of the downward movement of the burden, and to chemical degradation. Because of the requirement that coke must remain intact under these circumstances, the hot strength cannot be uniquely defined by a single experimentally determined parameter. Consequently, the carbon dioxide-reactivity index and the strength after reaction with carbon dioxide are used together in an attempt to fully define the hot strength. The indices most often used as a measure of the hot strength of coke are the NSC-CSR (coke strength after reaction) and the NSC-CRI (coke reactivity index)[5], which are determined by means of a static test. Iscor recently developed a dynamic test in which coke reacts with carbon dioxide at the same time as the tumbling action. This test is designed to simulate more accurately the behaviour of coke under the actual operating conditions of a blast furnace. The two indices obtained in this dynamic test are the CO_2-RI (coke reactivity index) and the SARI-10 index, which is a measure of the extent of chemical degradation. These hot-strength indices are explained more fully in Addendum 1. Because the newly developed Iscor test is being used for the evaluation of coke properties at the Vanderbijlpark works of Iscor Ltd, where the present investigation was conducted, the CO_2-RI and SARI-10 indices were used as measures of the hot strength of coke in this study.

Cognizance should be taken of the fact that numerous other tests have been developed, and indeed are used by various ironmakers, to characterize the properties of coke. However, an analysis of the applicability and importance of each of these tests falls beyond the scope of the present discussion. Suffice it to state that the existence of such a multitude of tests is not surprising in view of the very complex structure of coke and the numerous coal properties that may determine the final character of the coke. It is also important to note that the extent to which experimental techniques can be employed successfully to characterize the properties of coke may well vary from one blast-furnace operation to another, and indeed most often do.

The following method is often used to optimize coke properties. Either hot strength or cold strength is selected, usually by means of correlation studies, as the most significant parameter determining the performance of the coke in the blast furnace. The next step is to seek an optimum value for this parameter. Once such a coke property has been defined, an attempt is made to produce coke of at least this quality or better by selecting various coals, each with different, but specified, coal properties, and blending them in a pre-defined manner before the blend is charged into the coke oven. This method, used by many investigators in the past, can be illustrated by the approach taken by Valia in a recent study[6].

Valia selected the CSR as the most significant coke property determining the behaviour of coke in a blast furnace since CSR has been correlated with many blast-furnace process parameters on a large number of blast furnaces[2,5,7]. A value of 57,5 was determined as the optimum value for this hot-strength parameter. Valia then proceeded to identify those coal properties which control the CSR value of the coke. By means of a step-wise multiple regression analysis, he identified the plastic range[6] and the catalytic index[6] of coals as the coal properties that most significantly influenced the CSR value of the coke produced from such a coal or coal blends. The CSR was then related mathematically to the two independent coal variables, plastic range and catalytic index. Consequently, coals can be blended in such a way as to yield a specified plastic range as measured by a Gieseler plastometer, and a specified catalytic index as determined by carbon dioxide gasification. A coal blend used as feedstock for a coke oven and consisting of coals with these pre-selected and optimized properties will then produce coke of the required CSR.

Other investigators have also attempted to predict selected coke properties from the composition of a coal blend. Munnix[8], Nishioka *et al.*[9], Suginoba *et al.*[10], and Steyn and Smith[11], for example, all concentrated on predicting cold strength, while Hara *et al.*[5], Burger[12], and Pieters[13] developed models for predicting the hot strength of coke. These models are used to predict the value of a pre-selected *coke quality* parameter from a knowledge of certain coal properties. The previously determined *coke rate/coke quality* relationship is then used to predict the coke rate in the blast furnace. The disadvantage of this approach is that various coal blends could yield the pre-selected coke property, but such a blend may not necessarily represent the least expensive blend.

A more effective approach is to predict the performance of coke in the blast furnace directly from a knowledge of the relevant coal properties without having to rely on the optimization of selected coke characteristics as an intermediate step in the model. Such a model should preferably include both the hot- and the cold-strength requirements of coke, and it should also incorporate a relationship between the coal parameters and the cost of the coal. The advantage of such an approach is that coal selection can then be optimized both from a quality and an economic point of view.

In pursuit of this goal, the approach taken in the present study was as follows. The relationships between the coke rate and the hot strength, as well as the cold strength, of the coke used in a blast furnace were determined, and the optimum values of these parameters, which yielded an acceptable coke rate, were fixed. Then, the properties of a coal blend that can attain these optimum coke properties were established. In this way, the coke rate in the blast furnace could be minimized by using the best possible blend of locally available coals during the production of coke.

Experimental Procedure

A comprehensive statistical analysis was conducted on data accumulated at blast furnace D and the coke ovens of the Vanderbijlpark Works of Iscor Ltd. This investigation spanned a period of almost eighteen months and singular, as well as multiple, linear regression techniques were used to correlate coal and coke properties. In the study of the relationships between the coke quality (hot and cold strength) and the coke rate of the blast furnace, polynomial curve-fitting techniques were used in the analysis of plant data.

The procedure was briefly as follows.

(1) Relationships were determined statistically between coal and coke properties.
(2) A model was derived and used to predict the required coke quality from coal blends of locally available coals.
(3) The relationships between coke quality and coke rate (kilograms of coke per tonne of hot metal produced) were determined, again by statistical analysis of plant data.
(4) Finally, a coal-blending model was developed in which those properties of coal required to produce optimum coke quality were used directly to predict the minimum coke rate in a blast furnace.

The cold strength of the coke was determined experimentally by use of the DI_{15}^{150} index as a measure of cold strength. The hot strength of the coke was also determined experimentally and is represented by the strength after reaction in terms of the SARI-10 index, and the reactivity of the coke in terms of the CO_2-RI index.

The relevant properties of coal, or coal parameters as they are often referred to, used in the correlation studies in an attempt to ascertain which coal properties determine the hot and cold strengths of coke are listed in Fig. 2.

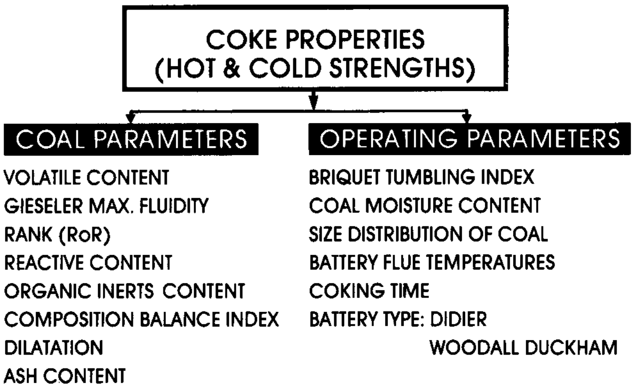

Fig. 2—The coal and operating parameters studied

During the course of the investigation, an attempt was made to establish which coke-oven *operating* parameters, apart from coal properties, have a determining influence on the eventual quality of the coke. Some of these parameters have a significant influence on the quality of coke, and these are also listed in Fig. 2. However, because this part of the investigation does not relate directly to the development of a coal-blending model but is nevertheless of overriding importance in any attempt to optimize coke production, the results and conclusions of this separate investigation are briefly outlined in Addendum 3. These parameters are not taken into account in the following discussion.

Results and Discussion

Relationships between Coal Parameters and Coke Quality

The relationship between the cold strength as measured by the DI_{30}^{150} index, which is similar to the DI_{15}^{150} index (Addendum 1), and the volatile content of the coal is shown in Fig. 3. The correlation coefficient is 0,74. Because plant data, and not carefully monitored experimental measurements, were used in the correlation studies, and also because a large number of variables influence the coke quality, a correlation coefficient of 0,74 is regarded as significant. These findings confirm the well-established relationship between the rank of coking coal and the quality of the coke produced from it. The mere fact that this relationship was obtained in the study indicated that useful relationships could be derived from the available data. Although a multitude of relationships was established (Fig. 2), only those which are significant enough to be used in a predictive model will be discussed.

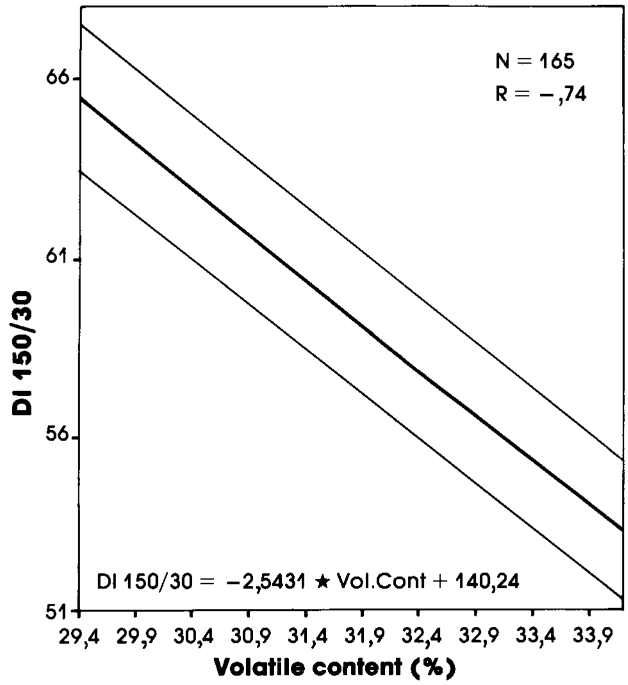

Fig. 3—The effect of the volatile content (indication of rank) of coal on the cold strength of coke

The importance of both rank and caking parameters of coal in determining the *cold* strength of coke has already been referred to, and the relationships established by Miura[4] were shown schematically in Fig. 1. It is evident from this diagram that, in the *region dominated by caking property* (region 1), an increase in fluidity (caking property) will result in an increase in the cold strength of the coke. However, should the fluidity be increased any further into the *rank-dominated region*, no corresponding increase in strength will result, and a further increase of fluidity into the *region dominated by caking property* (region 2) will even result in a decrease in the cold strength. What is equally important is that a decrease in strength can be effected by a decrease in the rank of the coal, at least in the rank-dominated region, even when the fluidity is increased significantly. Miyazu *et al.*[14] found that an increase in fluidity up to a value of approximately 80 ddpm (dial divisions per minute) results in an increase in the cold strength of coke, but fluidity values above this inflection point do not yield a corresponding increase in cold strength.

A relationship similar to that found by Miyazu *et al.*[14] was established in the present investigation and is shown in Fig. 4. It follows from this diagram that the transition from fluidity control to coal-rank control occurs at a fluidity value between 80 and 100 ddpm for the coals that were evaluated. The practical significance of this observation is that, once the fluidity of a coal blend reaches this value, a further increase in the cold strength of the coke can be obtained only by increasing the rank.

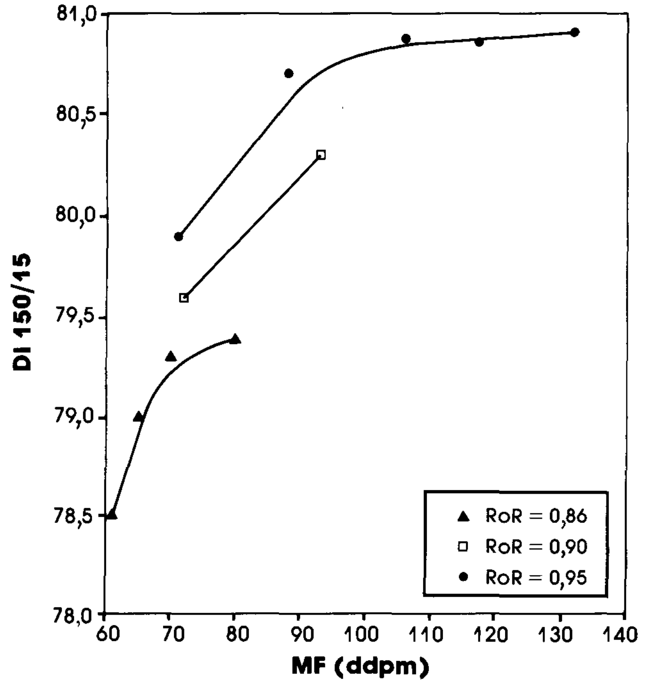

Fig. 4—The influence of maximum fluidity (MF) and coal rank on the cold strength of coke

The effect of Gieseler maximum fluidity on the hot strength of local coals was also investigated, and almost similar results were obtained. These results are shown in Fig. 5, and it is evident that transitions in the hot-strength parameters, SARI–10 and CO_2–RI, also occur at fluidities of approximately 100 ddpm.

The relationship between cold strength (DI^{150}_{15}) on the one hand and reactives and inerts on the other are shown in Fig. 6. It is clear that the cold strength of coke reaches an optimum value at a reactives content of some 81 per cent and an organic-inerts content of approximately 12,5 per cent. The same optimum values were found for the DI^{150}_{30} index.

Prediction of the Hot and Cold Strength of Coke

The correlation studies on the plant data and the experimentally determined indices of coke quality were obtained, as previously indicated, by linear regression techniques to give relationships between certain coal properties and the cold-strength parameter, DI^{150}_{15}, as well as the hot-strength parameters, SARI–10 and CO_2–RI.

The following relationships were found:

$$\left.\begin{aligned} DI^{150}_{15} &= -(0{,}297 \times (\text{volatile content, \%})) \\ &\quad + (0{,}238 \times (\ln \text{maximum fluid, ddpm})) + 88{,}40 \ \ldots\ldots\ldots\ldots \\ \text{SARI–10} &= (0{,}326 \times (\text{inert content, \%})) + 86{,}17 \ \ldots\ldots\ldots\ldots \\ CO_2\text{–RI} &= -27{,}696 \times (\text{RoR}) + 49{,}81. \ \ldots\ldots \end{aligned}\right\} (1)$$

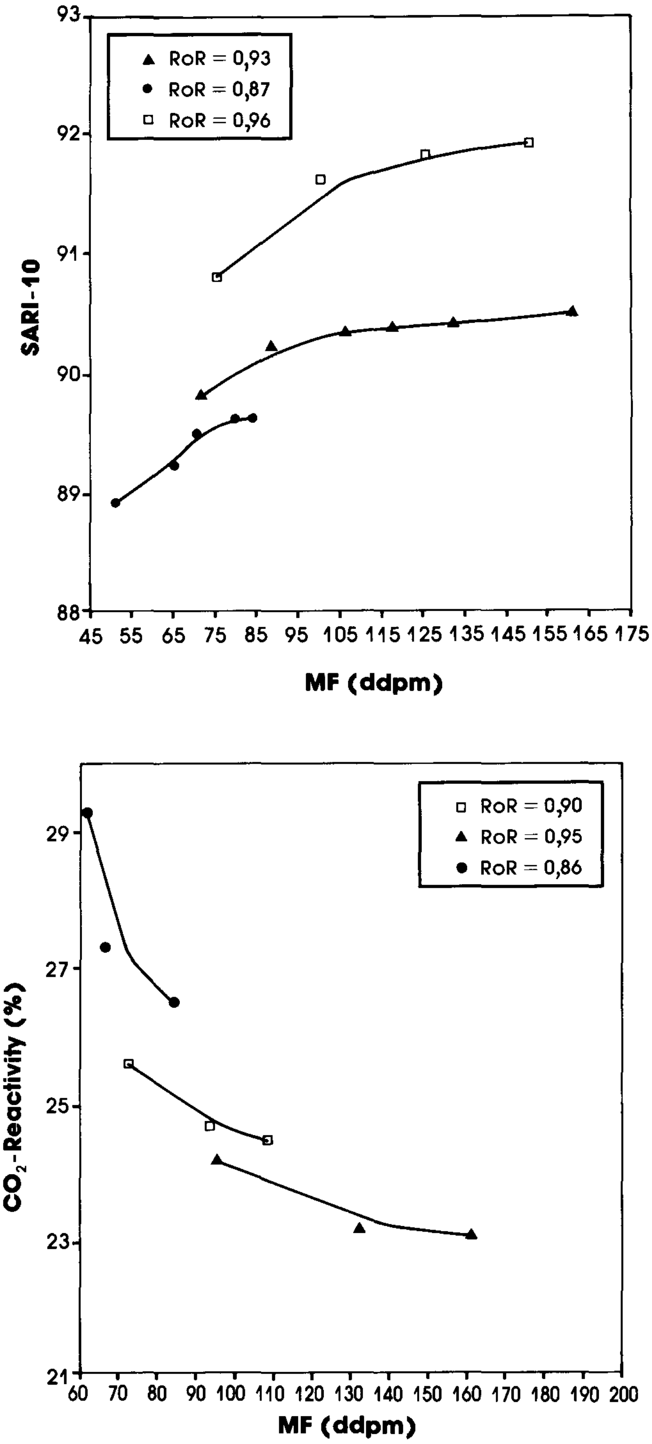

Fig. 5—The effect of maximum fluidity (MF) and coal rank on the hot strength of coke

It should be emphasized again that these relationships differ from those given in Addendum 3 and should not be compared with those because the data in Addendum 3 include the effects of some *operating* parameters that were not incorporated in the coal-blending model under discussion.

Once these relationships, equations (1), had been established, it was possible from a knowledge of the following coal properties, to predict the strength of coke produced from a given coal blend:

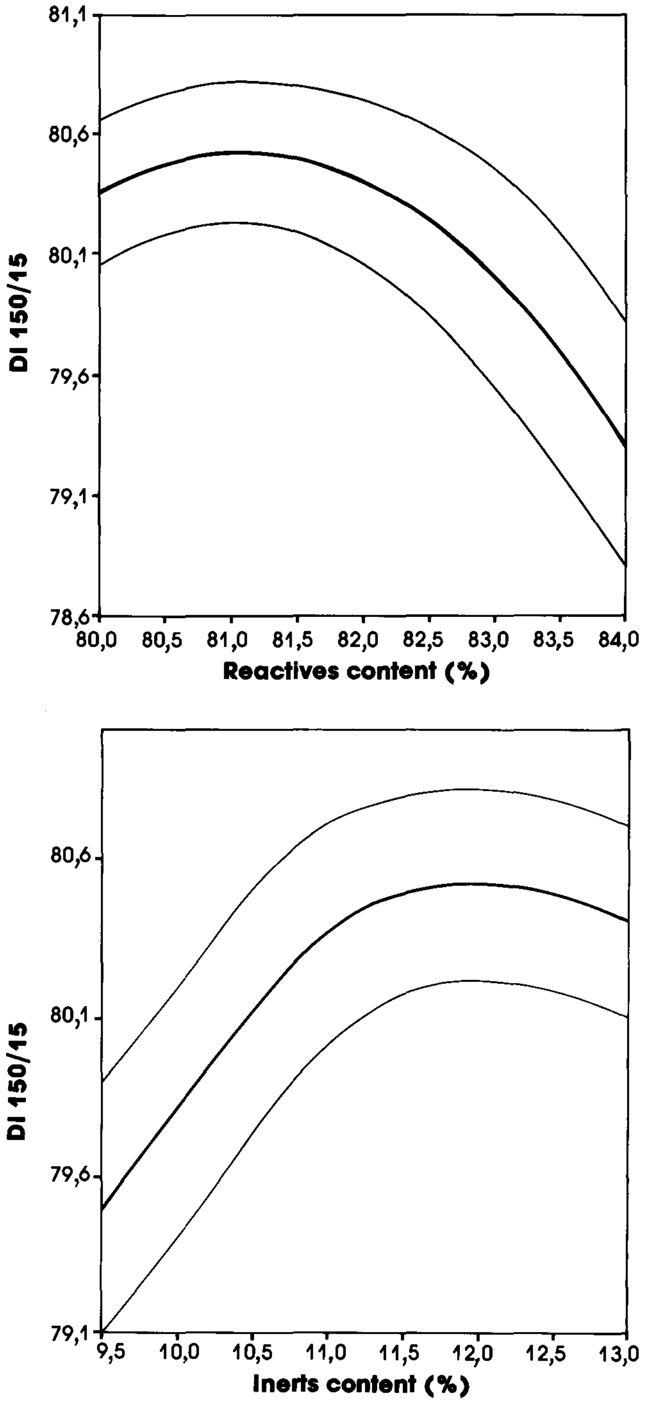

Fig. 6—The effect of reactives and inerts on the cold strength of coke

Volatile content RoR	Rank parameters
Fluidity Inert content	Caking parameters

Relationship between Coke Quality and Blast-furnace Performance

In this instance, the coke rate was chosen as an indicator of blast-furnace performance, and relationships were established between the coke rate and the cold strength, as well as the hot strength, of the coke used in the furnace. These relationships were obtained by polynomial curve-fitting techniques from 100 data sets collected from Blast Furnace D at the Vanderbijlpark Works of Iscor Ltd.

The relationship between the cold strength as given by the DI_{15}^{150} index and the coke rate of Blast Furnace D is shown in Fig. 7, while the relationships between the hot-strength indices and the coke rate are given in Figs. 8 and 9.

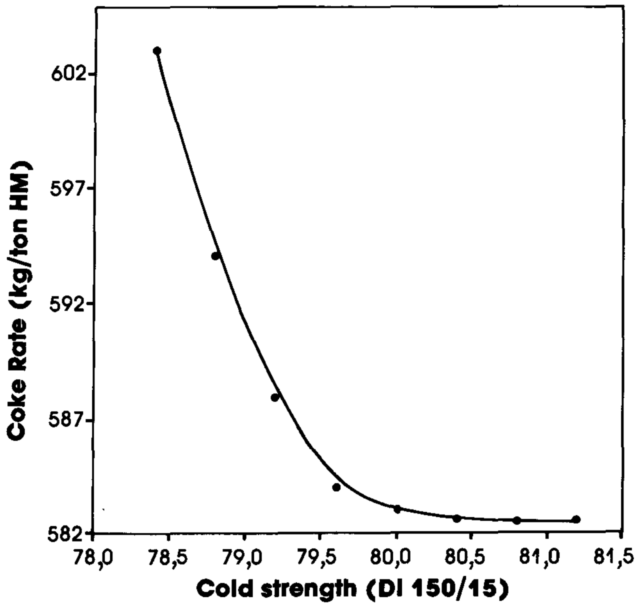

Fig. 7—The influence of the cold strength of coke on the coke rate in a blast furnace

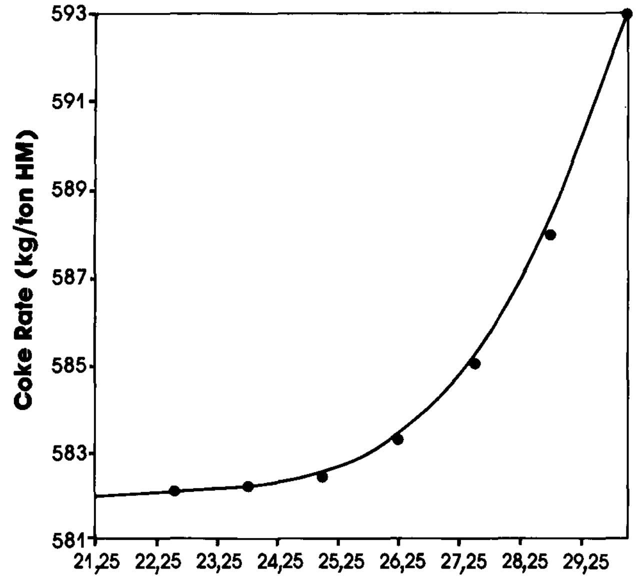

Fig. 8.—The influence of the carbon dioxide reactivity of coke on the coke rate in a blast furnace

It is evident from Fig. 7 that the coke rate is decreased markedly by an increase in the cold strength of the coke up to a DI_{15}^{150} value of approximately 80. A more careful analysis of the results reveals that the turning point occurred at a DI_{15}^{150} value of 79,8, and it follows that an

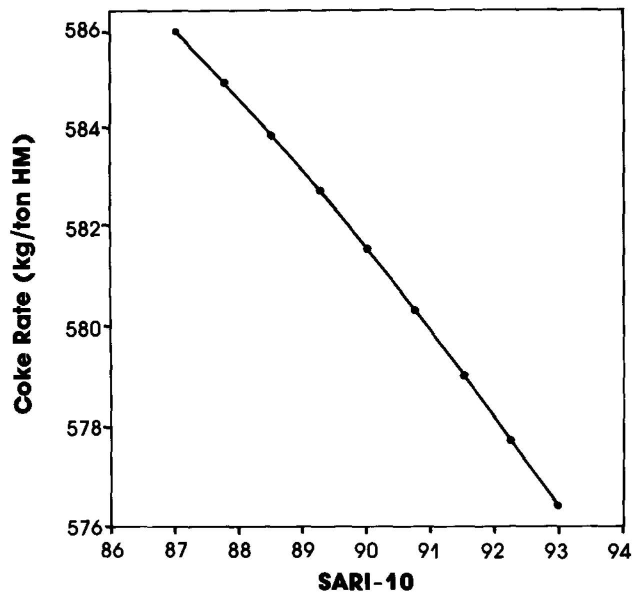

Fig. 9—The influence of SARI-10 on the coke rate in a blast furnace

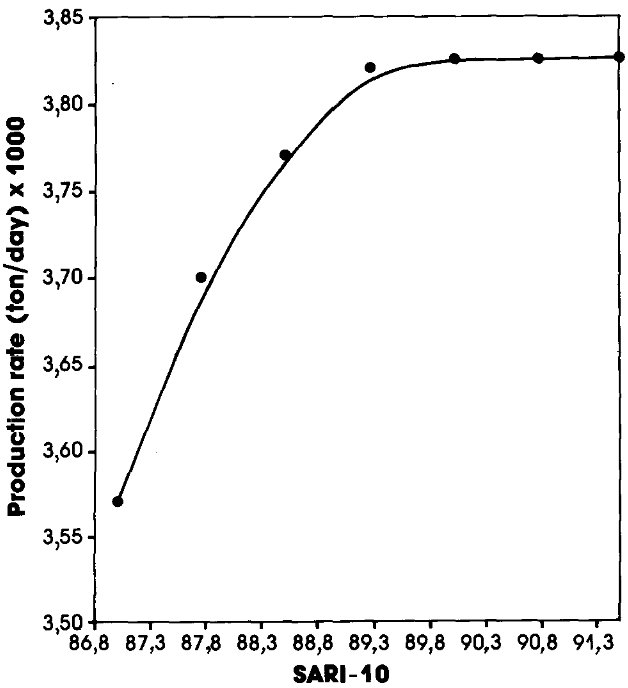

Fig. 10—The influence of SARI-10 on the production rate of a blast furnace

increase in cold strength above that value is of no avail as far as a decrease in coke rate is concerned. Coals should consequently be blended in such a way that a DI_{15}^{150} value approaching 79,8 is obtained. Similarly, a threshold CO_2–RI value of 25,5 was found in the relationship between the CO_2–RI and the coke rate. This relationship is shown in Fig. 8. The aim should evidently be to blend coals in such a way that a CO_2–RI index of 25,5 is approached. Concerning the hot strength (SARI–10), it is evident from Fig. 9 that there is a linear relationship between the coke rate of Blast Furnace D and the SARI–10 hot-strength index.

The existence of threshold values for the strength of coke is of the utmost importance, and the implications in terms of a coal-blending model are far-reaching. Consequently, the validity of the conclusion that such threshold values exist was investigated further by correlating the production rate of the same furnace with the relevant coke-strength indices. Not only was the existence of threshold values for the DI_{15}^{150} and CO_2–RI indices confirmed, but a threshold value of 88,6 for the SARI–10 index was also found, as clearly shown in Fig. 10. On the basis of these findings, it is now possible to predict the minimum coke-quality requirements in order to ensure stable performance of the Vanderbijlpark D Furnace. These requirements can be formulated as follows:

$$\left.\begin{array}{ll} DI_{15}^{150} & \geq 79{,}8 \ldots\ldots\ldots\ldots \\ \text{SARI–10} & \geq 88{,}6 \text{ and as high as possible} \ldots\ldots \\ CO_2\text{–RI} & \leq 25{,}5 \ldots\ldots\ldots\ldots \end{array}\right\} \quad (2)$$

These conclusions are important and deserve some comment. Fig. 8 shows that the coke rate is strongly dependent on the hot strength of the coke used in a furnace, providing conclusive evidence that the hot strength of coke as determined by means of a dynamic test is an important design parameter in coke production, at least for Blast Furnace D at the Vanderbijlpark works of Iscor. Furthermore, it is evident that threshold values exist for the coke properties under discussion. These threshold values should be borne in mind in the make-up of a coal blend since the selection of different coals in the blend will clearly be influenced by the extent to which coke properties can be optimized, thereby determining the basic cost of the blend.

A Coal-blend Prediction Model

The unique feature of the present approach in establishing a coal-blending prediction model is that it utilizes a knowledge of the minimum requirements for blast-furnace coke, rather than the maximum attainable coke quality.

In order to further relate blast-furnace performance to coal properties, rather than to coke quality, the relationships derived from the correlation studies and shown as equations (1) were used as a starting point in the formulation of a linear programming model.

This set of three equations contains three important coke-quality parameters, which are regarded as *constants* in the formulation of the model:

index DI_{15}^{150},	a measure of the cold strength
index SARI–10,	a measure of the strength after reaction
index CO_2–RI,	a measure of the reactivity of coke.

Four coal-quality parameters, the *variables*, are included in the same set of equations:

two rank parameters:	volatile content and RoR
two caking parameters:	maximum fluidity and inert content.

In order to solve this system of three equations and four variables, boundary conditions need to be set. This was achieved by the use of relevant information obtained from the correlation studies. The threshold values on the relationships between *coke quality* and *coke rate* were used to define the values of the constants:

from Fig. 7: $DI_{15}^{150} \geq 79{,}8$
from Fig. 8: CO_2–RI $\leq 25{,}5$
from Fig. 10: SARI–10 $\geq 88{,}6$.

It is evident from Fig. 4 that the cold strength of coke is increased by an increase in the fluidity of the coal used to produce the coke, but only up to a value of 100 ddpm. This value for the fluidity was consequently substituted in the set of equations (1), leaving only three variables to be solved in three equations. The solution to these equations yields the following minimum quality requirements for the coal used to manufacture metallurgical coke:

Volatile content	$\leq$ 32,6%
RoR	$\geq$ 0,88
Organic-inerts content	$\geq$ 7,5%
Fluidity	= 100 ddpm (assumption made from Fig. 4).

These requirements, which were obtained independently of the individual coal species in the blend, can now be used as the constraints, while the quantity of each coal species in the blend can be utilized as the variables in the linear-programming model. In the present study, the coal blends comprised five different coal species, their relevant characteristics being given in Table I.

TABLE I
PROPERTIES OF COALS USED IN THE LINEAR PROGRAMMING MODEL

Coal species	Volatile content % (db)	RoR	Organic-inerts content* %	Maximum fluidity ddpm
Coal 1	37,3	9,67	4,1	9
Coal 2	34,0	0,88	18,1	44
Coal 3	23,7	1,22	20,4	3307
Coal 4	30,0	1,00	16,6	4052
Coal 5	21,5	1,32	25,9	2041
Constraint RHS	$\leqslant$32,6	$\geqslant$0,88	$\geqslant$7,5	$\geqslant$100

* Mineral matter is included and was calculated by means of Parr's equation: $MM = [1{,}05 \times (\% \text{ ash}) + 0{,}55 \times (\% \text{ sulphur})]/2$

The maximum fluidity constraint has already been accounted for in the determination of the minimum DI_{15}^{150} value. In Fig. 5 it was shown that optimum cold strength is achieved at an organic-inerts content of approximately 12,5 per cent. The restriction on organic-inerts content can therefore be changed from an inequality ($\geq$ 7,5 per cent organic inerts) to an equality (= 12,5).

The three *constraint equations* can subsequently be formulated from Table I and are as follows:

Volatile content: $(\text{Coal}\,1 \times 37{,}3) + (\text{Coal}\,2 \times 34{,}0) + (\text{Coal}\,3 \times 23{,}7) + (\text{Coal} \times 30{,}0) + (\text{Coal}\,5 \times 21{,}5) \leq 32{,}6$

RoR: $(\text{Coal}\,1 \times 0{,}67) + (\text{Coal}\,2 \times 0{,}88) + (\text{Coal}\,3 \times 1{,}22) + (\text{Coal}\,4 \times 1{,}00) + (\text{Coal}\,5 \times 1{,}32) \geq 0{,}88$

Organic inerts: $(\text{Coal}\,1 \times 4{,}1) + (\text{Coal}\,2 \times 18{,}1) + (\text{Coal}\,3 \times 20{,}4) + (\text{Coal}\,4 \times 16{,}6) + (\text{Coal}\,5 \times 25{,}9) = 12{,}5$.

In these equations, Coal X (X = 1 to 5) represents the fraction of that specific coal species in the blend.

It is also necessary to set the further constraint that none of the variables (coal species) should be smaller than zero so as to ensure that the model yields meaningful results.

In the construction of the *objective function*, the costs of the different coal species are assigned to respective coefficients of the variables and can be formulated as follows:

Minimize $Z = (\text{Coal}\,1 \times A) + (\text{Coal}\,2 \times B) + (\text{Coal}\,3 \times C) + (\text{Coal}\,4 \times D) + (\text{Coal}\,5 \times E)$,

where A, B, ... E represent the cost of the coals used in the blend. The least expensive blend that would still yield coke of sufficient quality will consequently be predicted by the cost-minimization linear programming model.

It should be emphasized that any of the coefficients in the constraint equations or objective function could be manipulated depending on the cost of the coal or compositional changes in the blend. When real costs are substituted in the objective function, the cost of a predicted optimum blend can be compared with a typical day-to-day blend. In such an exercise, the predicted blend was found to be 18 per cent less expensive than the blend normally used.

Obviously, aspects such as the sulphur content of the coal, its ash content and availability, long-term contracts with suppliers, and transport costs would have to be incorporated in a comprehensive model. Even operating conditions are omitted from the simplified model outlined above. However, these could, and should, be built into a more comprehensive model by their incorporation in the restrictions. A simplified version of the coal-blending prediction model was deliberately used in this instance to illustrate and to emphasize the fundamental principles involved in the formulation of the model. Consequently, the real value of the model is that it clearly demonstrates a meaningful approach to the development of coal-blending models. The most economical coal blend based on coal properties that still complies with minimum blast-furnace coke quality (hot *and* cold strength) is predicted. It must be emphasized that the specific equations derived in this study and used in the model are valid only for Vanderbijlpark coke ovens with their unique coal blends, specific production schedules, types of batteries, etc., and not necessarily for other operations. However, the fundamental principles of the model remain valid.

Conclusions

(1) The hot and cold strengths of metallurgical coke are determined by the caking properties and the rank of the coals used to produce the coke.
(2) Blast-furnace performance as measured by coke rate is greatly dependent on the hot strength of the coke.
(3) The minimum coke-quality requirements for stable operation of the D Furnace at the Vanderbijlpark works of Iscor Ltd have been established.
(4) A coal-blending prediction model was formulated by establishing the minimum blast-furnace coke-quality requirements, rather than the maximum attainable

coke quality, and the model was applied to optimize a chosen coal blend from an economic point of view.

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Addendum 1: Hot and Cold Strength of Coke

Cold Strength

In determining the cold strength of coke as represented by the DI_{15}^{150} and DI_{30}^{150} indices, 10 kg of plus 50 mm coke is tumbled in a cylindrical drum (1,5 m by 1,5 m) fitted with six lifters. After 150 revolutions at a speed of 15 r/min, the coke is removed and screened on a 15 mm sieve. The percentage by mass of coke remaining on the sieve is expressed as the DI_{15}^{150} strength index. The same procedure is followed using a 30 mm sieve in the determination of the DI_{30}^{150} index.

Hot Strength

During the hot-strength test, the coke reacts with carbon dioxide gas according to the Boudouard reaction:

$$C_{coke} + CO_2 = 2CO.$$

The mass of the coke sample decreases continuously during the test. A very reactive coke (high rate of Boudouard reaction) would consequently lose more mass than an inert coke.

(1) *NSC method.* The indices used by NSC to represent the hot strength of coke are CSR (coke strength after reaction) and CRI (coke reactivity index). Firstly, 200 g of coke between 19 and 21 mm in size is reacted with carbon dioxide (5 l/min) for 120 minutes at 1100°C. After the reaction, the coke is cooled to room temperature in a nitrogen atmosphere and the mass is determined. The CRI index is represented by

$$\text{CRI} = [(200 - \text{mass after reaction})/200] \times 100.$$

After the mass of the coke has been determined, it is tumbled in an I-type tumbler for 30 minutes at 20 r/min. The coke is subsequently screened on a 10 mm sieve and the CSR index is determined as follows:

$$\text{CSR} = [(\text{mass of } +10\text{ mm coke remaining on sieve})/(\text{mass after reaction})] \times 100.$$

(2) *Iscor dynamic method (MLD).* The MLD dynamic test (MLD = modified Linder drum) developed at Iscor to determine the hot strength of coke differs from the NSC test in that the latter is a static test. In the MLD method, the carbon dioxide reaction occurs in a rotating drum, as opposed to the static reaction vessel in the NSC test. The MLD method is also performed at a temperature of 1100°C, but a 1500 g sample between 30 and 25 mm in particle size is used. The drum rotates at a speed of 3 r/min for 120 minutes while the carbon dioxide is supplied constantly at a rate of 37 l/min. The CO_2 reactivity index is expressed as follows:

$$CO_2\text{-RI} = [(1500 - \text{mass after reaction})/(1500)] \times 1000,$$

and the strength-after-reaction index by

$$\text{SARI-10} = [(\text{oversize fraction remaining on 10 mm sieve})/(\text{mass after reaction})] \times 100.$$

Addendum 2: Description of Some Coal Parameters

(1) *RoR* represents the rank of coal in terms of the mean maximum reflectivity of all the reactive species present in the coal[1].

(2) *Fluidity* is a parameter that indicates the ability of coal to liquidize upon being heated through its plastic range. It is measured in dial divisions per minute (ddpm), a high ddpm value indicating a high fluidity.

(3) *Organic inerts* group together the carbonaceous fractions in coal that do not soften upon heating. Ash fractions (inorganic inerts) are therefore excluded.

(4) *Reactives* are those carbonaceous fractions that usually soften upon heating, and under pressure (coke oven) tend to flow around the inerts and bind them together.

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Addendum 3: The Influence of Coke-oven Operating Conditions on Coke Quality

Although operating conditions were not included in the hot- and cold-strength prediction equations used in the development of the coal-blending model, they do have a pronounced influence on the final coke quality. Their effects on coke quality are therefore briefly outlined below.

The effect of operating conditions on coke quality was studied during periods when the composition of the coal blend was kept constant. However, the ability to synchronize the operating parameters with the coke produced presented a problem, as illustrated by the following examples.

(1) Sampling and testing of the moisture content of coal is usually done approximately one day before the specific coal blend is charged into the coke ovens.
(2) Size grading is done almost two days before the coal is charged into the battery, creating even a greater degree of uncertainty as to which coke is produced from a particular blend.

It was found that the moisture content of coal is the most significant operating parameter affecting coke quality (cold and hot strength). Moisture content was chosen as an operating parameter because it is determined by factors such as rain and time spent in the stockyard, and is therefore virtually independent of the coal itself, although certain coals tend to contain more moisture than others. In seven consecutive periods during which the coal blend was kept constant, the hot- and cold-strength indices of the coke decreased with an increase in moisture content of the coal. This observation emphasizes the value and importance of a coal-drying facility.

Because the moisture content of coal has such a pronounced influence on coke quality, it is recommended that coke-quality prediction models, especially models used routinely at coke ovens, should include moisture content as a variable.

Correlation studies similar to those outlined earlier but taking coke-oven operating parameters into account yielded the following predictive relationships between coke-quality parameters, coal characteristics, and coke-oven operating conditions:

DI_{15}^{150} = −(0,308 × volatile content, %) + (0,018 × temperature, °C) − 0,473 × moisture content, %) + 69,68

DI_{30}^{150} = −(1,562 × volatile content, %) + (0,026 × maximum fluidity, ddpm) − (1,642 × moisture content, %) + 118,48

CO_2–RI = 165,335 − (22,550 × RoR) − 0,0913 × temperature °C)

SARI–10 = 90,529 + (0,302 × organic inerts, %) − (0,576 × moisture content, %).

The use of these relationships can be of great assistance to coke-over operators in predicting expected coke quality.

The following conclusions can be drawn.

(1) The moisture content of coal is the most important operating parameter affecting coke quality. An increase in moisture content results in a decrease in coke quality.
(2) Four simple equations that relate coke properties to coal and to furnace operating parameters can be used to predict expected coke-quality indices on a daily basis.

Institute of Materials*

Dr W.L. Mercer, President of The Institute of Metals, speaking at the Institute's Council Dinner on 29th November, 1990, welcomed the fact that the Institute's members, at the Extraordinary General Meeting held on 23rd October, 1990, had voted overwhelmingly in favour of the formation of an Institute of Materials.

Although the Institute of Ceramics and the Plastics and Rubber Institute, with whom The Institute of Metals had been discussing a merger for the past two-and-a-half years, had so far failed to achieve the required 75 per cent vote of approval from their members, The Institute of Metals very much hoped that they would still be able to join, on the terms already agreed, whenever they were able to achieve the required majority.

Dr Mercer confirmed that The Institute of Metals Resolutions had now been passed to the Privy Council for its consideration and approval. This would provide the legal framework for an Institute of Materials, the target date for the inauguration being 1st January, 1992.

The President pointed out that the boundaries between materials of all kinds were becoming more and more blurred, and the new Institute of Materials would have a vital role to play in the new era of advanced-materials technology through the provision of a strong professional base and effective career education and training.

The UK, the President went on, was facing a serious disadvantage with commercial applications, such as an uncooled ceramic-and-metal-composite diesel engine emerging from Japan, and a major new multi-million dollar R&D programme likely to be undertaken in the USA. This would cover items ranging from ceramic and metal-matrix composites to advanced polymers, diamond thin films, and bio-materials.

In view of the dominant role predicted for advanced engineering materials early in the 21st century, Dr Mercer concluded that the Institute had a duty, not only to its members, but to the community as a whole, to maintain the momentum already built-up towards an Institute of Materials.

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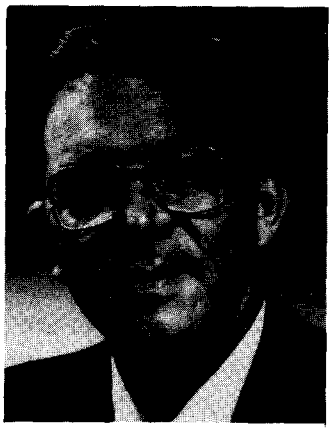
* Released by The Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB, England.

New AS&TS President



Professor A.N. Brown has been inaugurated as President of the Associated Scientific and Technical Societies. He is the Head of the Department of Mining Engineering at the University of Pretoria, and has held that appointment for the past ten years. He is also a Council Member and Past President of The South African Institute of Mining and Metallurgy, which is a founder society of AS&TS.

The inauguration took place at the first Annual General Meeting to be held since AS&TS changed its headquarters. For some 55 years its home was Kelvin House, Hollard Street, in the CBD. However, the facilities became progressively inadequate to accommodate the needs of its many members, and earlier this year the historical site of the former Union Observatory was purchased from the CSIR and became the new home of AS&TS.

Modifications to existing buildings and structures have made it possible to accommodate most of the member societies. Plans have been drawn up for further development of the site, which is very beautiful and has great potential. The plans include living accommodation, symposium rooms, and other social facilities.

A great deal of money will be required for the desired development, but the present economic climate in the country is not very favourable for the raising of such funds. The programme has therefore been planned to be implemented in stages as funds become available. After the disruption caused by the relocation of the societies, it is necessary for the societies to close ranks and give AS&TS unstinting support if it is to succeed in serving its member societies effectively in the years that lie ahead.

Alluvial mining

An international conference on alluvial mining will be held in London (England) from 11th to 13th November, 1991.

Alluvial mining is one of the most diverse sectors of the minerals industry. Methods range from simple pick-and-shovel mining to treat several cubic metres per day, through to very large dredgers with capacities of millions of cubic metres per year. Alluvial mining is carried out both onshore and offshore, and in environments ranging from polar to humid, tropical to desert. This Conference, organized by The Institution of Mining and Metallurgy, will reflect that diversity.

Technical and operational aspects of the following broad topics will be discussed.

Exploration

Strategy, remote sensing, reconnaissance geology and sampling, target definition, drilling, bulk sampling, deposit delineation.

Reserve definition and mine planning

Sampling strategies, geostatistics, block definition, mineral valuation, reserve inventory, pilot mining.

Geotechnical topics

Investigation of ground conditions, excavatability, stability, ground treatment, hydrology, dewatering and drainage, geotechnical risk assessment.

Wet and dry mining systems

Dredgers, gravel pumps, draglines, hydraulic excavators, hand mining.

Equipment design and supply

Conditions, regulations, transport limitations and lack of services, particularly in remote locations.

Mineral processing

Trommels, screens, jigs, spiral separators, sluices, heavy-medium separators, cyclones, magnetic separators, tailings treatment and disposal.

Finance and investment

Risk assessment, exploration finance, feasibility studies, mine finance criteria, government investment policies, multinational agency policies, project insurance.

Environmental impact

Environmental law, baseline studies, environmental assessment, management monitoring, waste disposal and pollution control, restoration, rehabilitation, past mining land use.

Enquiries should be directed to

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