COMPOUNDING OF COAL BLENDS BASED ON A COKE STRENGTH PREDICTION MODEL

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1.   INTRODUCTION

A small plant producing foundry coke apart, all coke oven plants in Belgium are today owned by steel companies which produce coke for their own blast furnaces.

For many years, our coke was produced from domestic, high quality coking coals. Unfortunately, excessive production costs, due to unfavourable mining conditions (deep mines, thin seams and bad mining ratios, etc...) have, from the early sixties on, entailed the progressive closure of the majority of the Belgian coal pits.

Today, the greater part of our coking coals have to be imported from all over the world. Under these conditions, coking blends become much more complex as before and cost considerations as well as outside factors impose more frequent and more drastic changes in blend composition as before, when only domestic coals were used.

Simultaneously, the technological changes in iron- and in steelmaking require more than ever a consistant coke quality at a high level. In this respect, erratic changes in coke properties are even more harmfull for the blast furnace operation than the utilization of coke with a somewhat lower but constant quality.

The aim to produce a consistant high quality coke from blends of changing composition which contain on one side American and European coals and, on the other side, coals from Australia and Africa with higher inertinite contents, where we try to incorporate a maximum of cheaper weakly or non coking coals, can only be achieved with the help of an adequate model for the prediction of coke strength and for optimal blend composition. For the routine application in the daily coke oven practice, it is very useful to complete such a coke quality model in order to take account of limitations in supply, limits for the sulfur and alkali contents of the coke, etc...

Based on numerous tests carried out in a pilot coke oven, C.R.M. has developed a model allowing the correct evaluation of the suitability of coals for coke-making and the optimisation of coal blend composition, taking into account the various constraints imposed by the coke-maker.

2.   COKE STRENGTH PREDICTION MODEL

The problem to prepare coking coal blends from a variety of coals, with quite different properties, is not limited to our country but in fact in other parts of the world already this question arose at an earlier time. Thus, when we started our investigations, a series of coke quality prediction methods had already been published (1-12) and at the beginning, our intention was to select among the existing algorithms the most appropriate one for solving our own problems. For this purpose, we performed a great number of coking tests in our 300 kg pilot oven with numerous coals and coal blends for which the properties like the $\bar{R}$ max, the maximum Gieseler fluidity and the inert content varied within a wide range. All relevant coal properties were measured as well for the single coals as for the blends charged into the oven. The coking conditions however remained fixed for all the tests.

It should be noted that we did not test the method established by W. SIMONIS (4, 6) which gives excellent results for coals with a low content in inertinite but, according to the author, it cannot be extrapolated to the Gondwana type coals.

Unfortunately, it appeared that also none of the other existing prediction methods gave fully satisfactory results and this for the following reasons :

- Methods based exclusively on petrographic analyses do not take account of an eventual oxidation of the coals which impairs their coking properties.

- Methods based on the rank analysis and the maximum Gieseler fluidity like for example the N.K.K. procedure (7) where the mean maximum reflectance $(\overline{R}_{max})$ of the blend must be comprised between 1.2 and 1.3 % and the maximum Gieseler fluidity between 200 and 1000 d.d.p.m. are too restrictive. Blends corresponding to this range yield in fact coke of excellent quality ; however, many blends which do not comply with these criteria can also give a high coke quality (fig. 1).

Therefore, C.R.M. decided to develop a more general prediction method which should be valid for an as large as possible range of coals.

2.1. Principles of the C.R.M. prediction method

The prediction method developed by C.R.M. is only applicable to wet coals gravity charged and coked in classical slot ovens operating under normal conditions (13).

This method relates the coke strength indices to three important characteristics of the coal blend which are :

- the inert content,
- the caking ability of the reactive matters,
- the maximum Gieseler fluidity.

2.1.1. Inert content

The following components are considered as inerts :

- mineral matter (MM),
- fusinite (F),
- micrinite (M),
- sclerotinite (S),
- vitrinite, for which the maximum reflectance is equal or superior to 1.8 %
  (V_I). We thus have :

$$V_I = V_T \times \text{(proportion of vitrinite with a R max equal or superior to 1.8 \%)} \qquad (1)$$

- a first fraction of semi-fusinite (SF_{I1}) directly proportional to the fraction of inert vitrinite. The reflectance of the semi-fusinite is in fact always superior to that of the associated vitrinite but it varies in parallel to this latter. It therefore seems logical to admit that the proportion of inert semi-fusinite varies in the same way as the proportion of inert vitrinite. We thus obtain :

$$SF_{I1} = SF_T \times V_I/V_T \qquad (2)$$

- a second fraction of the semi-fusinite (SF_{I2}) equal to 2/3 of the remaining semi-fusinite. This takes account of the fact that the "non inert" semi-fusinite is not as reactive as the reactive vitrinite to which it is assimilated. Thus we have :

$$SF_{I2} = (SF_T - SF_{I1}) \times 2/3 \qquad (3)$$

The total inert content (TIC) expressed in volume percent, is the first characteristic index of the coal blend. It is defined by the following relation :

$$TIC = (MM) + (F) + (M) + (S) + (V_I) + (SF_{I1}) + (SF_{I2}) \qquad (4)$$

Accordingly the other constituents are considered as reactive.

They are :

- total exinite (E),
- vitrinite with a maxium reflectance below 1.8 % (V_R),
- semi-fusinite which is not considered as inert (SF_R).

The total reactive content of the blend (TRC) is given by :

$$TRC = (E) + (V_R) + (SF_R) = 100 - TIC \qquad (5)$$

2.1.2. Caking aptitude of the reactive matters

The caking aptitude of the reactive vitrinite is described by the vitrinite caking index VCI. This caking index has been calculated for each vitrinite class (steps of 0.05 % in reflectance) by means of an empirical relation, obtained by an elaborate statistical analysis of our coking test results. The highest caking index is obtained for vitrinites with a R_{max} of 1.625 % (class 1.60 - 1.65 %) which has been arbitrarily fixed at the value 1.

The VCI index for a certain vitrinite class is given by :

$$VCI = \frac{2.311 \times (1.8 - R_{max})^{0.3}}{\exp [1.8 \times (1.8 - R_{max})]} \qquad (6)$$

with $\qquad R_{max} < 1.8$ %

This relation is represented in fig. 2. The VCI caking index is similar to the strength index of SHAPIRO-GRAY (2) as appears when we adjust the ordinates of the two diagrams (fig. 3), except that the SHAPIRO-GRAY strength index also attributes caking properties to the vitrinite with a reflectance between 1.8 % and 2.2 %.

The caking aptitude of the other reactive matters, namely exinite and "non inert" semi-fusinite, are not well known. It is however reasonable to admit (like most of the other authors do) that it is similar to that of the reactive vitrinite present in the blend.

In consequence, the mean caking index of the total reactive matter is obtained by calculating the weighed mean of the caking indices of the different reactive vitrinite present in the blend. The reactives' caking index (RCI) is given by :

$$RCI = \frac{\sum_i f_i \times (VCI)_i}{\sum_i f_i} \qquad (7)$$

This mean caking index is always comprised between 0 and 1 ; it constitutes the second characteristic index of the coal blend.

2.1.3. Maximum Gieseler fluidity

The maximum fluidity of a coal blend is directly obtained by a Gieseler test performed according to the ASTM standard D 2639-74.

The decimal logarithm of this Gieseler fluidity (LGF) constitutes the third characteristic index of the coal blend.

2.2. Reference tests

The correlations established between, on one hand, the mechanical strength of the coke and, on the other hand, the principal characteristics of the coal blend, are based on a great number of pilot plant trials performed in our 300 kg movable-wall test oven.

Only the results from coking tests carried out under the following conditions have been considered :

- Coal grain size

Nominal grain size : 85 % inferior to 2 mm ; tolerated range : 80 - 90 % of grains inferior to 2 mm.

- Blend moisture content

  Nominal moisture content : 8 % ; tolerated range : 7.6 - 8.4 %.

- Charging density

  Mean value : 715 kg/m³ (dry basis) ; tolerated range : 660 - 770 kg/m³ (dry basis).

- Heating rate

  All the trials have been carried out in our electrically heated movable-wall Carbolite test oven lined with silicon-carbide bricks. The width of the oven was 457 mm. The heating programme was chosen in order to simulate as closely as possible the conditions prevailing in industrial units :

  - wall temperature at charging : 840°C,
  - wall temperature at pushing   : 1180°C,
  - heating rate of wall : 18°C/hour,
  - total coking time : 19 hours.

- Coke quenching

  The coke was dry-quenched in a water cooled gas-tight quenching car.

- Stabilization of coke

  Prior to the different tests for the evaluation of coke strength, the coke was stabilized by a drop of 5 meters on a steel plate.

2.3.   Relation between coke strength and the characteristic indices of the coal blend

A statistical analysis of the data from 180 coking tests performed under the conditions described here above has been achieved. We hereby obtained relations between the different coke strength indices applied in Europe (M 40, M 10, I 40, I 20 and I 10) on one hand, and the main characteristics of the coal blend (TIC, RCI and LGF) on the other hand.

For the mathematical adjustments, we have choosen an equation of the following type :

$$\text{Coke strength index} = \sum_{i = 1}^{20} k_i \times (TIC)^m \times (RCI)^n \times (LGF)^p \qquad (8)$$

with $\quad 0 \leqslant m + n + p \leqslant 3$

       The detailed equations obtained for the different strength indices are the following :

$$
\begin{aligned}
M\ 40 = &- 0.420 \times (TIC) + 265.7 \times (RCI) - 307.8 \times (RCI)^2 - 3.38 \times (LGF)^2 + 0.655 \\
&\times (TIC) \times (LGF) + 120.0 \times (RCI)^3 + 0.309 \times (LGF)^3 + 0.86 \times (RCI) \\
&\times (LGF)^2 - 0.1173 \times 10^{-1} \times (TIC)^2 \times (LGF) + 9.4 \qquad (9)
\end{aligned}
$$

$$
\begin{aligned}
M\ 10 = &- 88.4 \times (RCI) - 37.94 \times (LGF) + 35.0 \times (RCI)^2 + 8.16 \times (LGF)^2 + 47.03 \\
&\times (RCI) \times (LGF) + 0.7936 \times 10^{-4} \times (TIC)^3 - 0.550 \times (LGF)^3 - 11.30 \\
&\times (RCI)^2 \times (LGF) - 5.07 \times (RCI) \times (LGF)^2 + 0.245 \times 10^{-2} \times (TIC)^2 \times (LGF) \\
&- 0.223 \times (TIC) \times (RCI) \times (LGF) + 63.7 \qquad (10)
\end{aligned}
$$

$$
\begin{aligned}
I\ 40 = &\ 7.952 \times (TIC) + 117.2 \times (RCI) + 53.76 \times (LGF) - 0.2294 \times (TIC)^2 - 69.6 \\
&\times (RCI)^2 - 16.58 \times (LGF)^2 - 1.072 \times (TIC) \times (LGF) + 0.205 \times 10^{-2} \\
&\times (TIC)^3 + 1.374 \times (LGF)^3 + 0.2013 \times (TIC) \times (LGF)^2 + 0.303 \times (TIC) \\
&\times (RCI) \times (LGF) - 104.0 \qquad (11)
\end{aligned}
$$

$$
\begin{aligned}
I\ 20 = &- 1.640 \times (TIC) + 209.1 \times (RCI) + 58.96 \times (LGF) + 0.168 \times 10^{-1} \times (TIC)^2 \\
&- 110.8 \times (RCI)^2 - 13.16 \times (LGF)^2 - 108.66 \times (RCI) \times (LGF) + 0.818 \\
&\times (TIC) \times (LGF) + 1.015 \times (LGF)^3 + 43.34 \times (RCI)^2 \times (LGF) + 6.32 \times (RCI) \\
&\times (LGF)^2 - 0.2028 \times 10^{-1} \times (TIC)^2 \times (LGF) + 0.663 \times (TIC) \times (RCI) \\
&\times (LGF) - 6.1 \qquad (12)
\end{aligned}
$$

$$
\begin{aligned}
I\ 10 = &\ 1.625 \times (TIC) - 200.7 \times (RCI) - 61.90 \times (LGF) - 0.159 \times 10^{-1} \times (TIC)^2 \\
&+ 105.8 \times (RCI)^2 + 12.52 \times (LGF)^2 + 114.83 \times (RCI) \times (LGF) - 0.654 \\
&\times (TIC) \times (LGF) - 0.938 \times (LGF)^3 - 47.02 \times (RCI)^2 \times (LGF) - 6.03 \times (RCI) \\
&\times (LGF)^2 + 0.1761 \times 10^{-1} \times (TIC)^2 \times (LGF) - 0.734 \times (TIC) \times (RCI) \\
&\times (LGF) + 101.0 \qquad (13)
\end{aligned}
$$

Figures 4 - 8 show the iso-stability lines respectively for the M 40, M 10, I 40, I 20 and I 10 indices as a function of the total inert content (TIC) and the reactives' caking index (RCI) for blends with a maximum Gieseler fluidity of 500 d.d.p.m. Similar charts can be obtained for any other fluidity level.

Figures 9 - 13 show the relations between the predicted and the measured values for the different strength indices.

2.4. Accuracy of the C.R.M. prediction method

Table I summarizes the coefficient of determination (r^2) and the residual standard deviations (σ_R) for the different statistical adjustments.

It may be useful to make the following remarks :

a) The residual standard deviations indicated in table I do not directly reflect the accuracy of the prediction method but they also include the effects of all the fluctuations in the coal preparation and the coking tests as well as those of the measurements of the coke stability indices and of the coal properties.

b) A great part of the standard deviation has probably to be explained by the coke stability measurements. This appears clearly if we compare the standard deviation of tumbler test results measured on different samples of a same lot of coke (ISO standard 556-1980) with the residual standard deviations of the statictical adjustments of the C.R.M. prediction method (table II).

On the basis of these considerations, we may assert that the C.R.M. prediction method is quite accurate.

2.5. Applicability of the C.R.M. prediction method

We would like to stress the following points :

- The prediction method developed by C.R.M. is only valid for the classical coking process (wet coals charged by gravity into classical slot ovens operating under normal conditions).

- Rigorously, the adjustment equations are only valid for cokes produced in a pilot plant oven. As a matter of fact, the absolute values of the strength indices measured on the coke produced in our pilot oven differ from those obtained on coke manufactured from the same blend in an industrial plant applying similar coking conditions and water quenching. The abrasion indices in the pilot oven are worser mainly because the "door effect" and the relative importance of the coke cake surface are much greater in a pilot oven. The fissuration indices like M 40 and I 40, on the contrary, are more favourable at our pilot oven because we apply a slow dry-quenching method. The correction factors to be applied when transposing the pilot plant results to industrial ovens are given in table III. Such systematic differences however are of secondary importance because obviously the relative classification of different coal blends obtained by the C.R.M. model always makes it possible to make a choice which is equally valid for industrial ovens.

- The adjustments obtained only apply for the range of coals investigated in our trials, namely for coal blends with the following characteristics :

    - inert content between 15 and 45 %,
    - reactives' caking index between 0.35 and 0.95,
    - maximum Gieseler fluidity between 10 and 5000 d.d.p.m.

3. ADDITIVITY RULES APPLICABLE TO COAL BLENDS

Up to this point, we have discussed the prediction of coke quality for a given coal or blend for which the three relevant characteristics (inert content, caking index and maximum Gieseler fluidity) have been determined directly on the charge and are thus well known.

However, one has often the case where different types of coal are available but where the optimal blend composition has first to be determined. In this case, the coal characteristics used in the model are available for each individual constituent but not for the potential blends.

Nevertheless, the characteristic indices of any blend can be calculated from those of its different constituents by applying the formulae given hereafter.

3.1. Inert content

Knowing the inert content of each individual constituent, as well as the blend composition, the inert content of the blend can be rigorously calculated by :

$$(TIC)_b = \frac{\sum_j x_j \times (TIC)_j}{100} \tag{14}$$

3.2. Reactives' caking index

The knowledge of the inert content and the reactives' caking index for each of the blend constituents as well as the blend composition allows the exact computation of the caking behaviour of the total reactive matter present in the blend by means of the following formula :

$$(RCI)_b = \frac{\sum_j x_j \times [\, 100 - (TIC)_j \,] \times (RCI)_j}{\sum_j x_j \times [\, 100 - (TIC)_j \,]} \tag{15}$$

3.3. Maximum Gieseler fluidity

For the Gieseler fluidity, Japanese workers (9) have established a rule of additivity according to which :

$$Log_{10} (GF)_b = \frac{\sum_j x_j \times log_{10} (GF)_j}{100} \tag{16}$$

Obviously, this formula is not applicable when the fluidity of one of the blend constituents is equal to zero. For this reason, we have modified the relation (16) by adding 1 to each fluidity value thus obtaining the next formula :

$$Log_{10} [\, (GF)_b + 1 \,] = \frac{\sum_j x_j \times log_{10} [(GF)_j + 1]}{100} \tag{17}$$

Figure 14 shows the relation between the so calculated and the measured Gieseler fluidity for a variety of coking coal blends. We notice that the additivity rule is not perfectly observed, mainly for low fluidity blends. Fortunately, the relation is acceptable for blends with a fluidity above 100 d.d.p.m. So far all attempts to establish an improved formula for the evaluation of coal blend fluidities which also would take account of the compatibility of different types of coal have been unsuccessfull. Therefore, it is advisable to check the fluidity of the blend by a direct measurement in the case of low fluidity blends that are considered as suitable for coking. However blends with a Gieseler fluidity below 100 d.d.p.m. should be rejected because, as appears from fig. 15, for such blends the influence of fluidity on coke strength is very strong and even a slight oxidation of one ot its constituents would entail a strong loss in coke strength. In this range the achievement of a consistent coke quality is very difficult.

4.   OPTIMAL BLEND COMPOSITION

In order to respond to the wishes of its affiliated companies, C.R.M. has developed a computer model allowing optimal coal blend composition to be defined from the characteristics of available coals, whilst taking into account various constraints imposed on the coke-maker, e.g. limitations on certain types of supply, limitation on ash, sulphur and alkalis contents in the blend charged, limitation on coal blend costs, etc...

4.1.   Calculation data

The data necessary for the use of the model are as follows :

4.1.1.   Characteristics of each available coal

        - total inert content,
        - reactives' caking index,
        - maximum Gieseler fluidity,
        - volatile matter content (dry basis),
        - ash content (dry basis),
        - sulphur content,
        - alkali content,
        - price per tonne of dry coal.

4.1.2. Constraints on the contents of the different constituents in the blend

- minimum content of each constituent in the blend : where there is no specific constraint, the lower limit is set at zero, but may be other than zero for a coal of which consumption of a certain quantity is enforced ;

- maximum content of each constituent in the blend : where there is no specific constraint, the upper limit is set at 100 %, but can be held at a lower level for a coal which, for example, is only available in limited quantities or which generates excessive wall pressure.

4.1.3. Constraints on coal blend characteristics

- minimum and maximum values for Gieseler fluidity, in order to avoid "marginal" blends ;

- minimum volatile matter content in the blend, to avoid excessive wall forces ;

- maximum volatile matter content in the blend, to obtain a sufficiently high coke yield ;

- maximum ash level, as a function of blast furnace operation ;

- maximum sulphur content, to ensure high-quality iron ;

- maximum alkalis content, to avoid operational problems due to an excess of alkalis in the blast furnace ;

- maximum allowable cost, in order not to retain blends whose cost would be too high.

4.1.4. Increment of variation of coal blend composition

The user must set the increment by which the computer will systematically vary the content of each constituent in the blend, in the process of establishing the optimum composition.

It must be appreciated that too small an increment will lead to very extended computing times, when there are many constituents. On the other hand, if the increment is too large, a sufficiently-precise result will not be possible.

In practice, when there are many constituents, it is advisable to carry out an initial calculation, using an increment of 10 %, to define approximately, but very rapidly, a near-optimum composition, then to carry out a second calculation, using a lower increment, for example 2 %, restricting the composition range around that indicated in approximate fashion, by the initial calculation.

4.2.   Calculation method

In an initial calculation phase, the computer envisages all possible blend compositions, by systematically varying the content of each constituent, by constant increments or decrements (see 4.1.4.), but taking account directly of the constraints imposed by the coke-maker, with respect to the maximum and minimum levels of each constituent in the blend (see 4.1.2.).

In a second phase of the calculation, the computer checks that the characteristics of each blend so defined are in agreement with the various constraints set by the coke-maker (see 4.1.3.). Non-conforming blends are immediately rejected.

In a third stage, the computer calculates, for the blends retained, the three characteristics required for the prediction of coke strength. In order to do this, the computer uses as a basis the characteristics of the various coals (see 4.1.1.) and uses formulae developed in chapter 3.

In a fourth stage, the computer uses the formulae detailed in paragraph 2.3. to calculate the strength indices of the cokes which will normally be produced in a pilot oven from the various blends.

Finally, in a fifth stage, the computer classifies the various blends, in terms of decreasing coke quality, by considering successively the different coke strength indices generally measured in Western Europe (M 40, M 10, I 40, I 20 and I 10).

The results are presented in the form of five tables, one for each of the coke strength indices. Each table gives the composition and principal properties of the twelve blends giving the best cokes, as well as the various strength indices of these cokes.

When the coals available are of poor quality and the coke-maker imposes severe constraints, it is not always possible to define a satisfactory blend.

4.3.   Example of calculation

In order to illustrate the operating method of our model, we give below an example of calculation.

Table IV summarises the main characteristics of the different coals available.

The constraints with respect to the content of the various constituents of the blend are given in Table V. Coal B generates excessive wall pressure and is, therefore, voluntarilly limited to 30 %. By contrast, the content of coal C in the blend must be at least 20 %, since this coal is supplied under a regular contract. The other coals are not subject to any particular constraint.

Table VI summarises the requirements of the coke-maker with respect to the coal blend.

The increment chosen for varying the composition of the coal blend is 5 %.

Table VII summarises the composition and principal properties of 5 blends which, whilst satisfying the overall constraints, give the best I 20 indices. It ought not to be overlooked that the coke strength indices mentioned in this table are related to cokes produced in a pilot oven (see 2.5.).

5.   INDUSTRIAL APPLICATION

During the past few years, the majority of the Belgian coking plants have applied the C.R.M. model for selecting coals and for optimizing their coal blends. In several cases, the model was used for selecting cheaper but inferior coking coals to be introduced into a blend, however with the condition to maintain the coke strength at its previous high level.

In one specific case, the model showed that up to 40 % of the former blend could be replaced by a cheaper coal without deterioration of the coke quality. In view of the quality of the coal considered, these results seemed rather surprising and as a precaution we first confirmed them by some pilot plant tests. Subsequently, this coal was sucessfully used at the coke oven plant which produces 700.000 t of coke per year. The savings attained 1.5 US $/ton coke.

In a second similar case, an inferior coal could only be introduced into the blend by adding a second complementary coal which was also cheaper than the previously used coals. Here the total savings amounted to 2.5 US $ per ton of coal charged.

6.   CONCLUSION

On the basis of 180 carbonization tests carried out in a pilot oven, C.R.M. has developed an original method for the correct assessment of the coking properties of individual coals and coal blends.

This method makes it possible to predict the different coke strength indices generally applied in Western Europe (M 40, M 10, I 40, I 20 and I 10) from coal properties. Coal properties are described by three main characteristics, namely : the total inert content, the caking ability of the reactive matter and the decimal logarithm of the maximum Gieseler fluidity.

This method is currently applied by the major part of the Belgian coking plants for the optimization of their blend composition. It has allowed to achieve non negligible reductions in the cost of the coal fines without any detrimental effect on coke quality.

NOMENCLATURE

E	Exinite content, in volume percent (%).
F	Fusinite content, in volume percent (%).
f_i	Percentage of reactive vitrinite of class i (maximal reflectance by steps of 0.05 %) (%).
$(GF)_b$	Maximum Gieseler fluidity of the blend (d.d.p.m.)
$(GF)_j$	Maximum Gieseler fluidity of coal j (d.d.p.m.)
I 10	Coke strength index (ISO-Standard 556-1980).
I 20	Coke strength index (ISO-Standard 556-1980).
I 40	Coke strength index (ISO-Standard 556-1980).
LGF	Decimal logarithm of the maximal Gieseler fluidity expressed in d.d.p.m.
M	Micrinite content, in volume percent (%).
MM	Mineral matter content, in volume percent (%).
M 10	Coke strength index (ISO-Standard 556-1980).
M 40	Coke strength index (ISO-Standard 556-1980).
RCI	Reactives' caking index.
$(RCI)_b$	Reactives' caking index of the blend.
$(RCI)_j$	Reactives' caking index of coal j.
R max	Maximal vitrinite reflectance measured under oil at a wave length of 546 nm (%).
r_2	Coefficient of determination of a statistical adjustment.
S	Sclerotinite content, in volume percent (%).
SF_{I1}	First fraction of semi-fusinite considered as inert, expressed in volume percent (%)
SF_{I2}	Second fraction of semi-fusinite considered as inert, expressed in volume percent (%).
SF_R	Reactive semi-fusinite, expressed in volume percent (%).
SF_T	Total semi-fusinite, expressed in volume percent (%).
σ_R	Standard deviation of residuals of a statistical adjustment.

TIC   Total inert content, expressed in volume percent (%).

$(TIC)_b$ Total inert content of a blend, expressed in volume percent (%).

$(TIC)_j$ Total inert content of coal j, expressed in volume percent (%).

TRC   Total reactive content, expressed in volume percent (%).

VCI   Vitrinite caking index.

$(VCI)_i$ Caking index of reactive vitrinite of class i.

V_I Content in inert vitrinite, expressed in volume percent (%).

V_R Content in reactive vitrinite, expressed in volume percent (%).

V_T Total vitrinite content, expressed in volume percent (%).

x_j Percent of coal j in a blend (%).

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T A B L E   I

ACCURACY OF THE C.R.M. PREDICTION MODEL

Coke strength index	Coefficient of determination (r^2)	Standard deviation of residuals (σ_R)
M 40	0.91	1.43
M 10	0.92	0.72
I 40	0.89	2.75
I 20	0.88	1.64
I 10	0.88	1.58

T A B L E   I I

ACCURACY OF THE C.R.M. PREDICTION MODEL

Coke strength index	Standard deviation of tumbler test results (ISO Standard 556 - 1980)	Standard deviation of residuals (C.R.M. prediction method)
M 40	1.06	1.43
M 10	0.35	0.72
I 40	1.77	2.75
I 20	0.88	1.64
I 10	0.71	1.58

T A B L E   I I I

CORRESPONDENCE OF COKE STABILITY INDICES

Strength index	Pilot oven C.R.M.	4.2 m commercial oven
M 40	X_1	$X_1 - (4 \text{ to } 5)$
M 10	X_2	$X_2 - 1.5$
I 40	X_3	$X_3 - (7 \text{ to } 10)$
I 20	X_4	$X_4 + (3 \text{ to } 4)$
I 10	X_5	$X_5 - 4$

TABLE IV

COAL CHARACTERISTICS

COAL		A	B	C	D	E	F
Inert content, TIC,	(%)	26.7	16.3	25.4	45.2	23.7	37.0
Reactives' caking index, RCI,	(-)	0.82	0.92	0.59	0.77	0.55	0.35
Maximum Gieseler fluidity	(d.d.p.m.)	558	19	838	14	10,406	10
Volatile matter content, dry basis,	(%)	23.7	18.7	28.9	18.6	32.4	33.3
Ash content, dry basis,	(%)	7.0	4.8	5.6	9.9	5.3	7.1
Sulphur content, dry basis,	(%)	0.952	0.808	0.848	0.412	0.864	0.624
Alkali content, dry basis,	(%)	0.215	0.120	0.204	0.122	0.119	0.066
Cost	($/tonne of dry coal)	53.2	50.5	50.3	48.0	48.0	41.0

T A B L E   V

BLEND COMPOSITION CONSTRAINTS

Coal	Minimal amount in the blend (%)	Maximal amount in the blend (%)
A	0	100
B	0	30
C	20	100
D	0	100
E	0	100
F	0	100

T A B L E V I

BLEND CHARACTERISTICS CONSTRAINTS

Blend characteristics	Lower limit	Upper limit
Maximum Gieseler fluidity, (d.d.p.m.)	100	3000
Volatile matter content, dry basis, (%)	22	27
Ash content, dry basis, (%)	-	8
Sulphur content, dry basis, (%)	-	1
Alkali content, dry basis, (%)	-	0.2
Cost (\$/tonne of dry coal)	-	51.0

T A B L E   V I I

BLENDS GIVING THE BEST COKE STRENGTH (I 20 INDEX)

Blend number		1	2	3	4	5
Blend composition						
Coal A	(%)	40	30	30	30	30
Coal B	(%)	30	30	30	30	30
Coal C	(%)	20	30	25	20	25
Coal D	(%)	5	10	15	15	10
Coal E	(%)	0	0	0	5	5
Coal F	(%)	5	0	0	0	0
Blend characteristics						
Inert content,	(%)	24.8	25.1	26.1	26.0	25.0
Reactives' caking index,	(-)	0.79	0.78	0.79	0.79	0.78
Maximum Gieseler fluidity,	(d.d.p.m.)	152	161	131	149	183
Volatile matter content, dry basis,	(%)	23.5	23.3	22.7	22.9	23.4
Ash content, dry basis,	(%)	6.2	6.2	6.4	6.4	6.2
Sulphur content, dry basis,	(%)	0.845	0.824	0.802	0.803	0.824
Alkali content, dry basis,	(%)	0.17	0.17	0.17	0.17	0.17
Cost	($/tonne of dry coal)	50.9	51.0	50.9	50.8	50.9
Coke strength (pilot oven tests)						
M 40		86.0	85.9	85.5	85.6	86.0
M 10		7.6	7.6	7.6	7.6	7.6
I 40		63.9	63.7	63.1	63.2	63.8
I 20		77.0	77.0	76.9	76.9	76.9
I 10		21.9	22.0	22.0	22.0	22.1
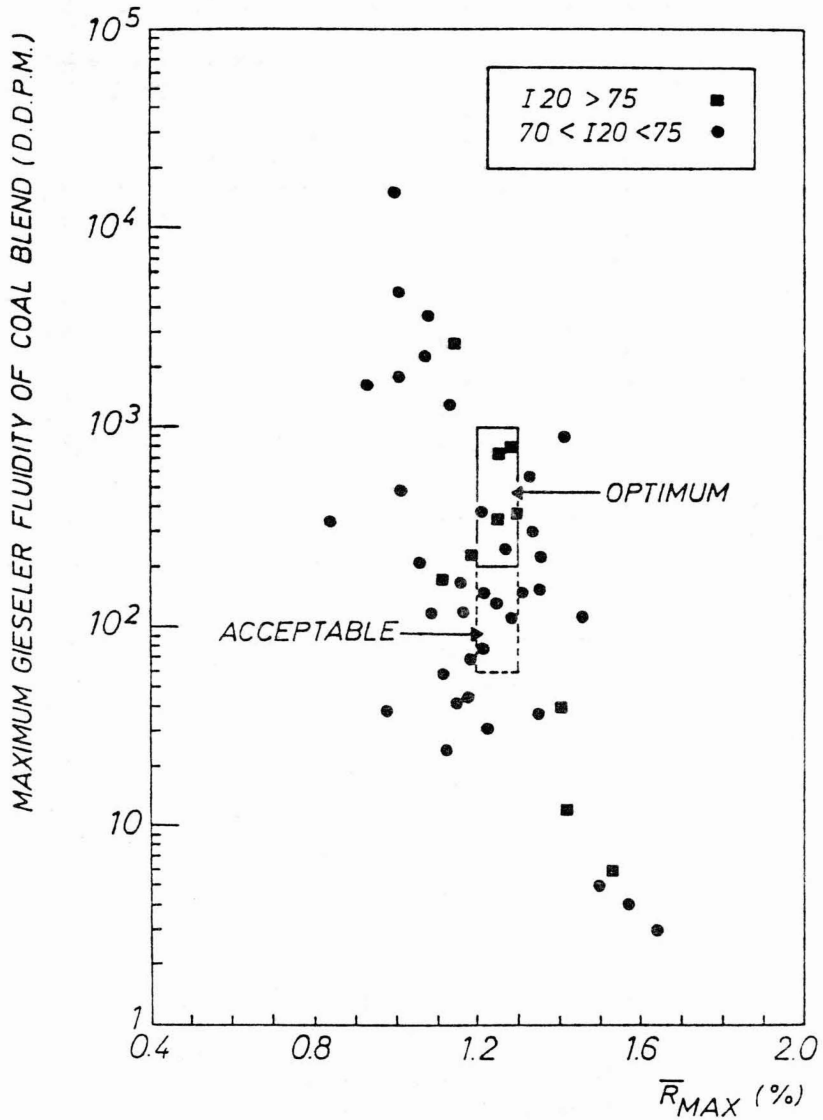
FIG.1 EVALUATION OF COKING APTITUDE OF COAL BLENDS FROM RANK ANALYSIS AND FLUIDITY MEASUREMENTS
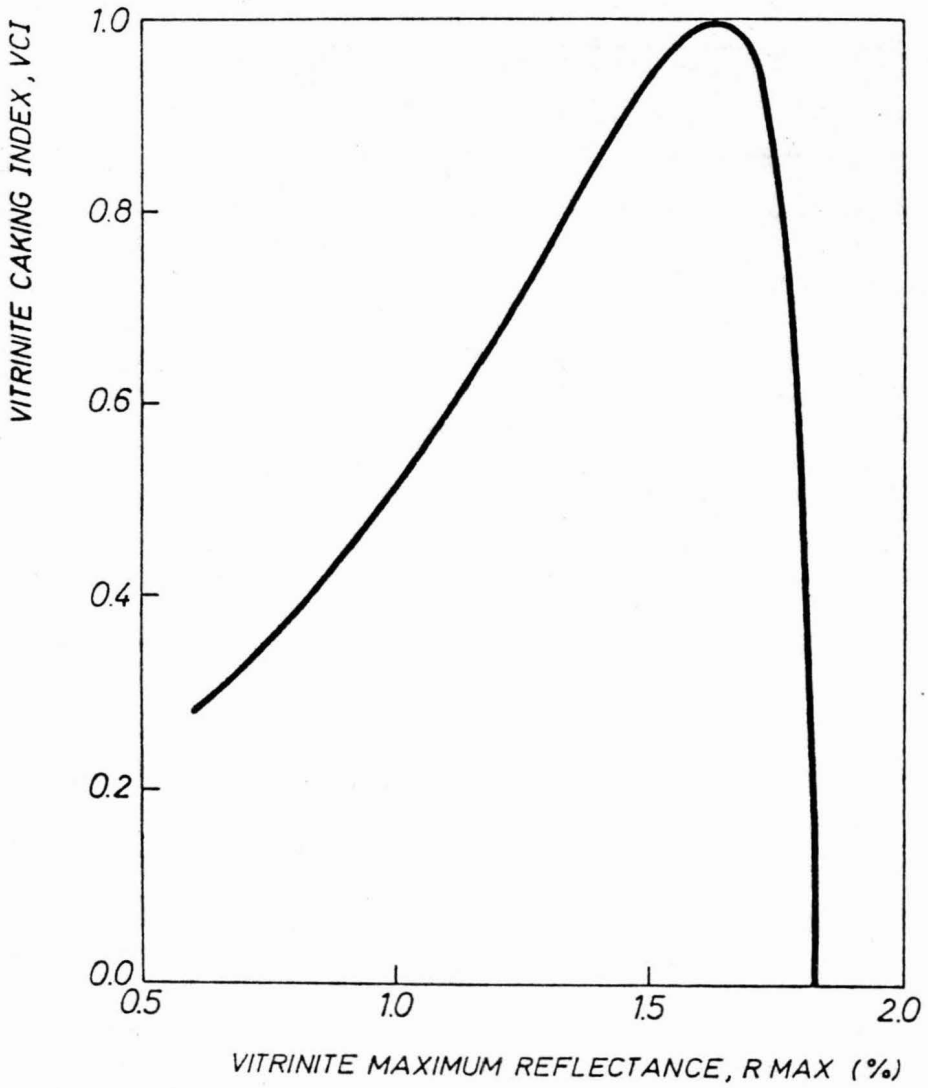
FIG. 2 VITRINITE CAKING INDEX VERSUS MAXIMUM REFLECTANCE
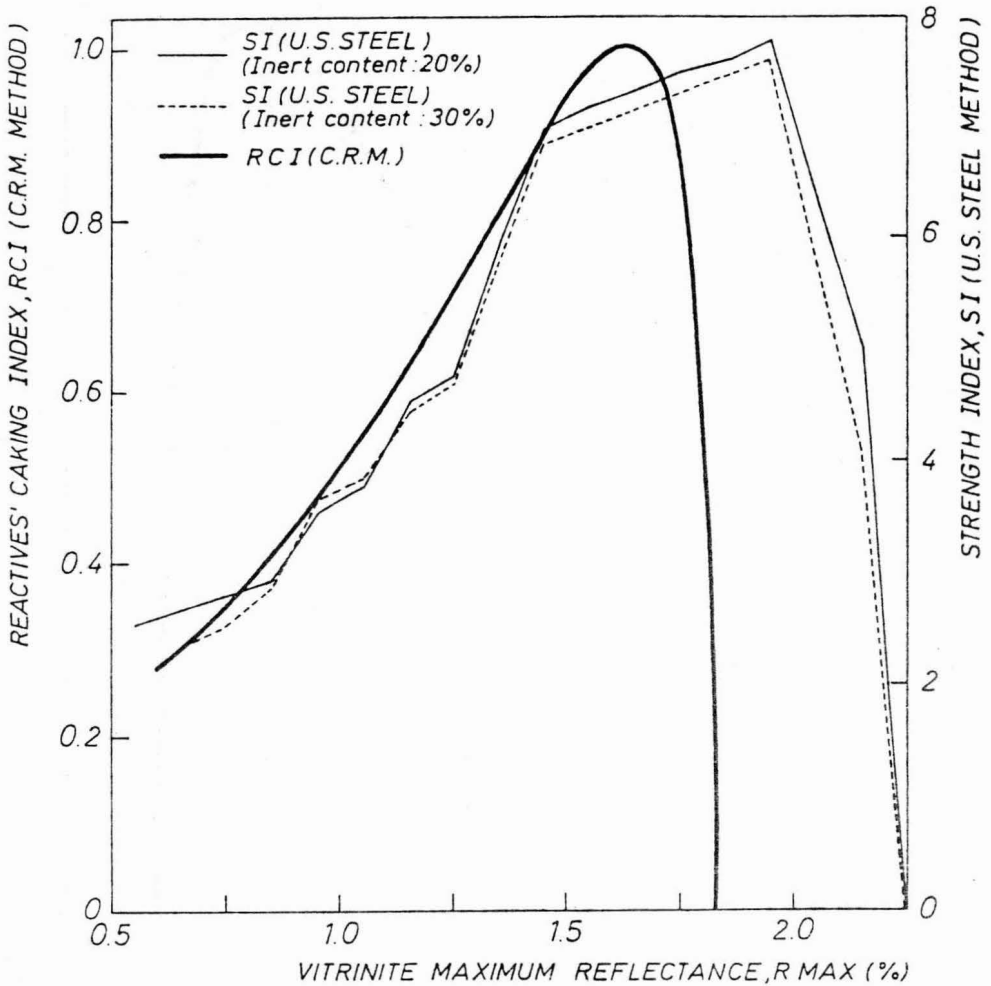
FIG. 3 COMPARISON BETWEEN REACTIVES' CAKING INDEX
(C.R.M. METHOD) AND STRENGTH INDEX (U.S. STEEL METHOD)
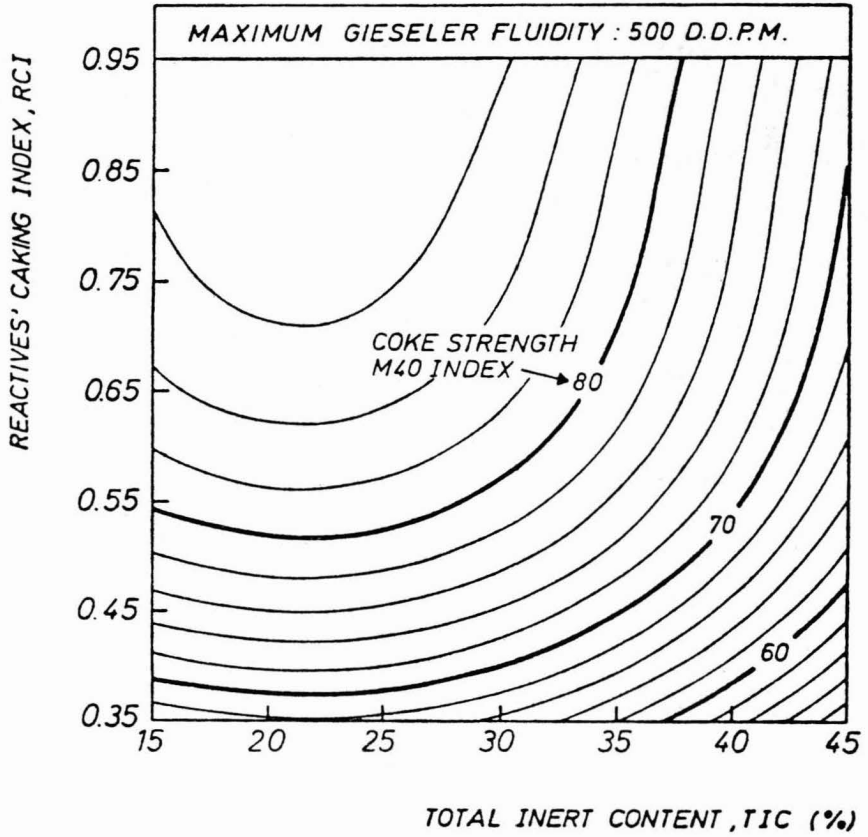
FIG.4 COKE STRENGTH INDEX M40 VERSUS COAL
CHARACTERISTICS FOR A GIVEN GIESELER FLUIDITY
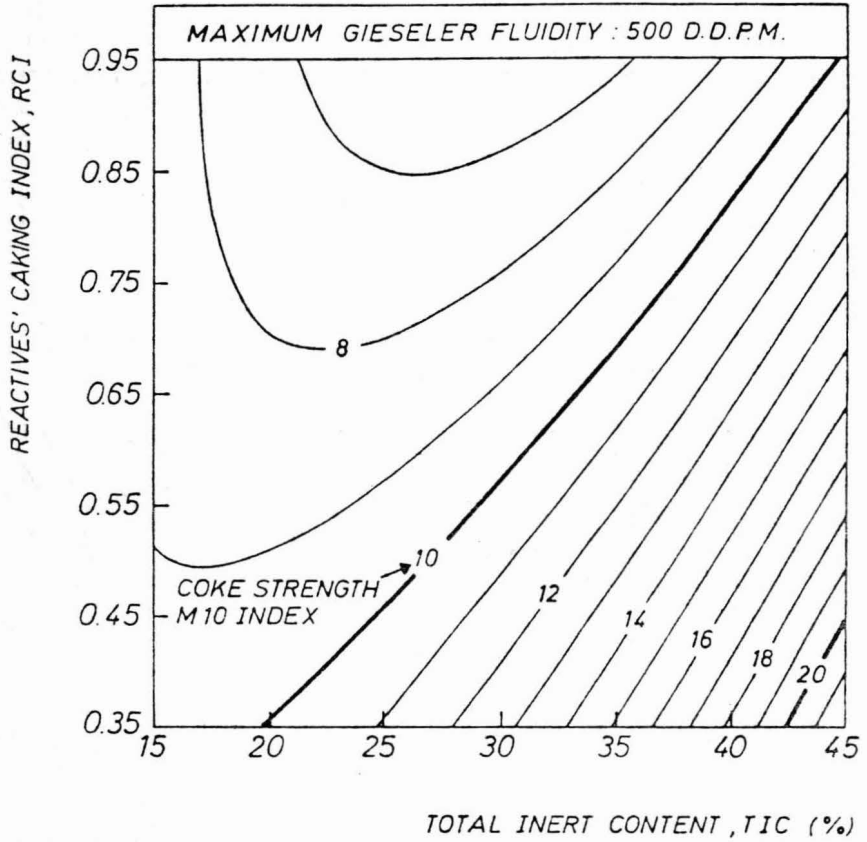
FIG. 5 COKE STRENGTH INDEX M10 VERSUS COAL
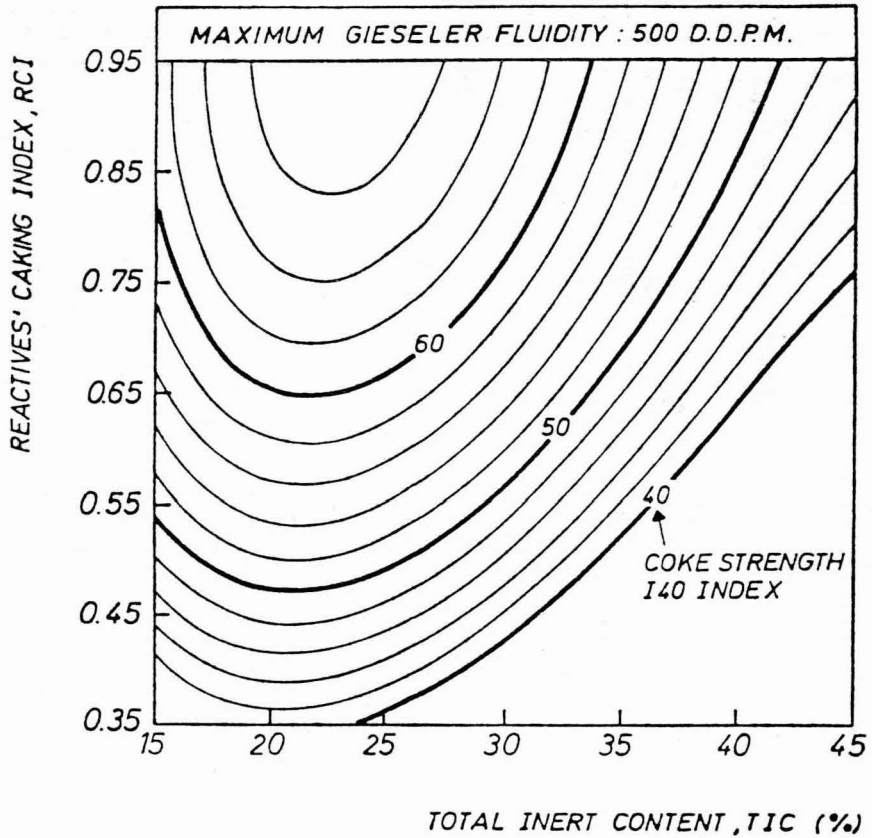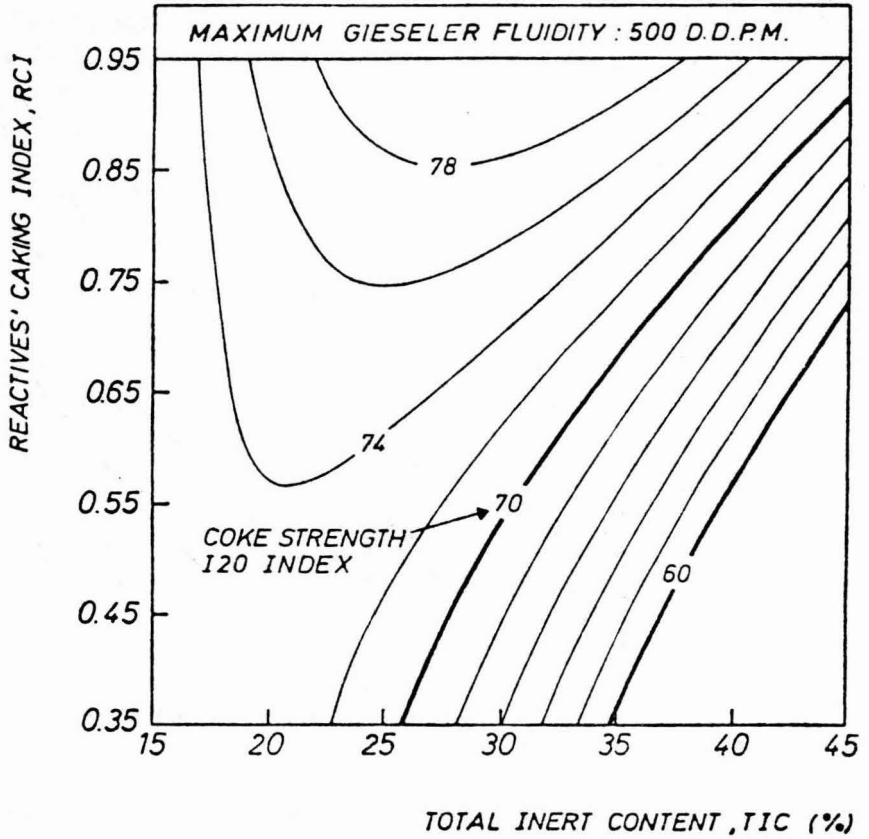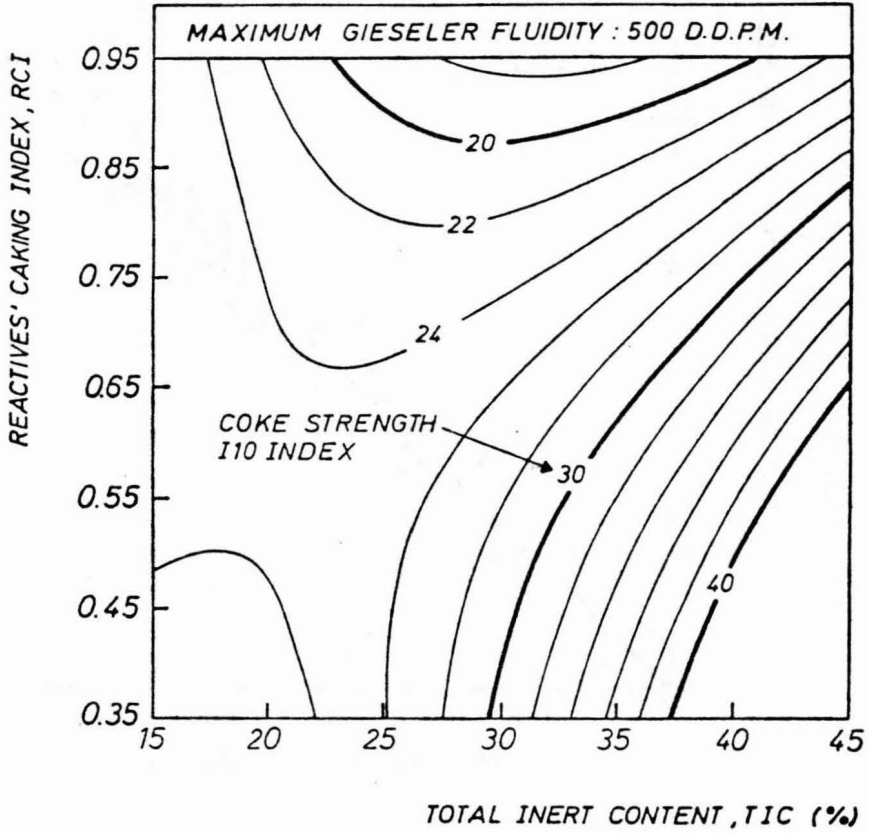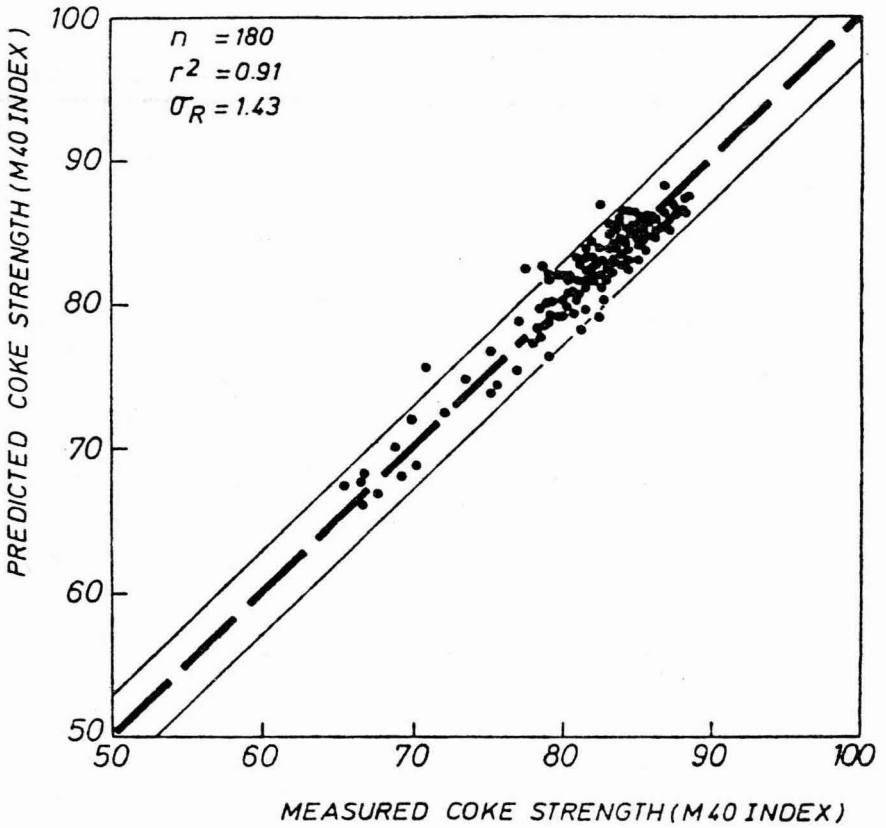CHARACTERISTICS FOR A GIVEN GIESELER FLUIDITY

FIG.6 COKE STRENGTH INDEX I40 VERSUS COAL
CHARACTERISTICS FOR A GIVEN GIESELER FLUIDITY

FIG.7 COKE STRENGTH INDEX I20 VERSUS COAL
CHARACTERISTICS FOR A GIVEN GIESELER FLUIDITY

FIG.8 COKE STRENGTH INDEX I10 VERSUS COAL
CHARACTERISTICS FOR A GIVEN GIESELER FLUIDITY

FIG.9 PREDICTED VERSUS MEASURED COKE STRENGTH
(M40 INDEX)
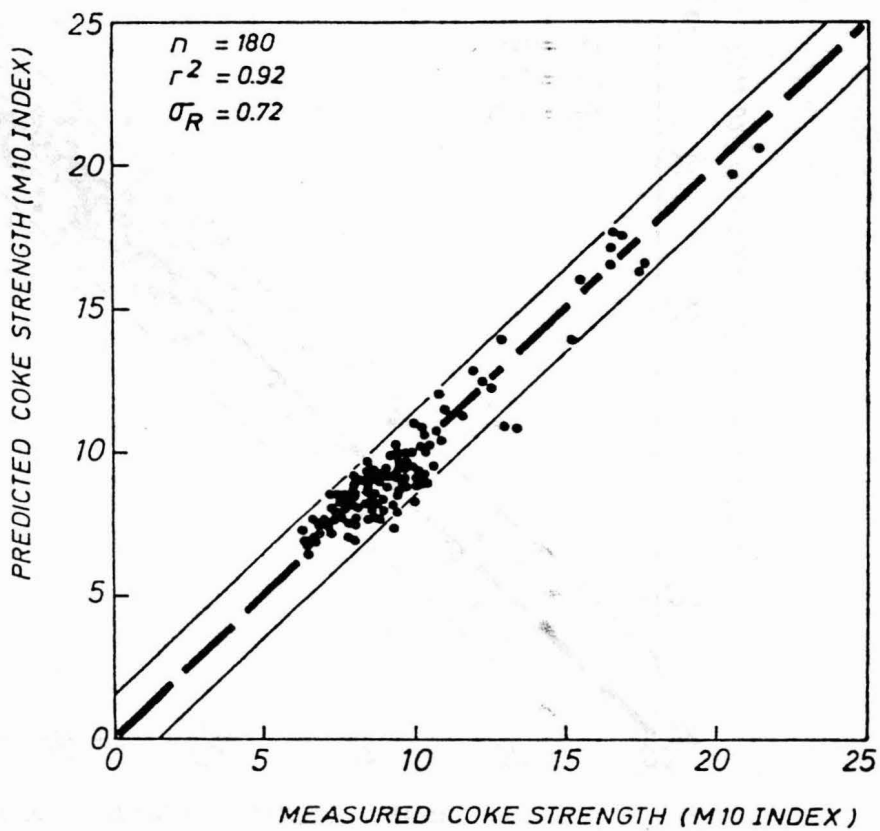
FIG.10 PREDICTED VERSUS MEASURED COKE STRENGTH
(M10 INDEX)
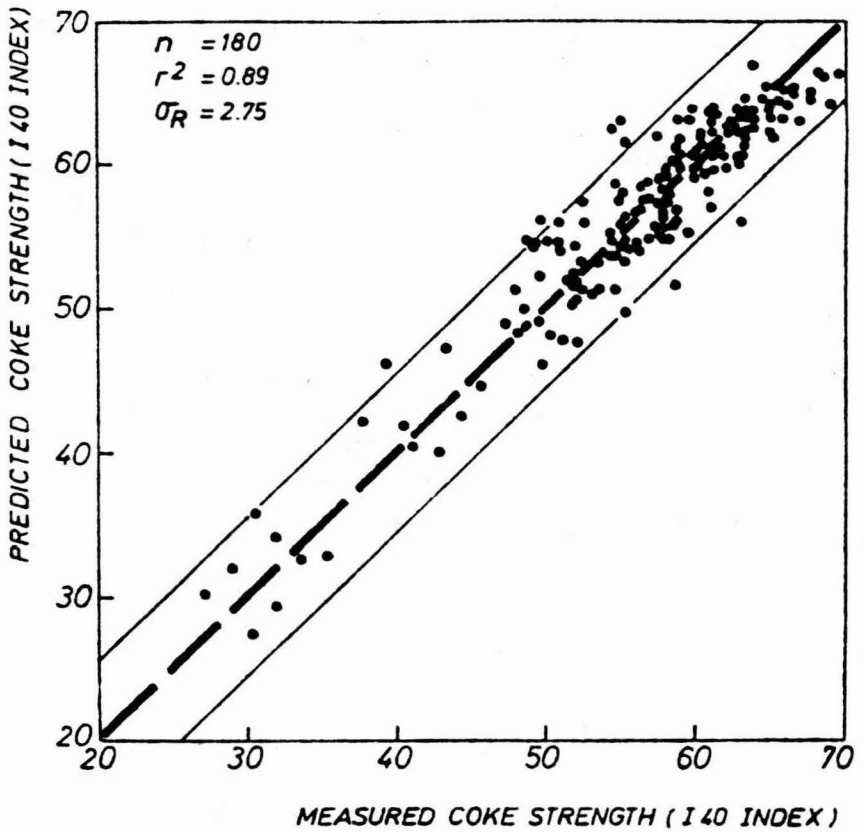
FIG.11 PREDICTED VERSUS MEASURED COKE STRENGTH
(I40 INDEX)
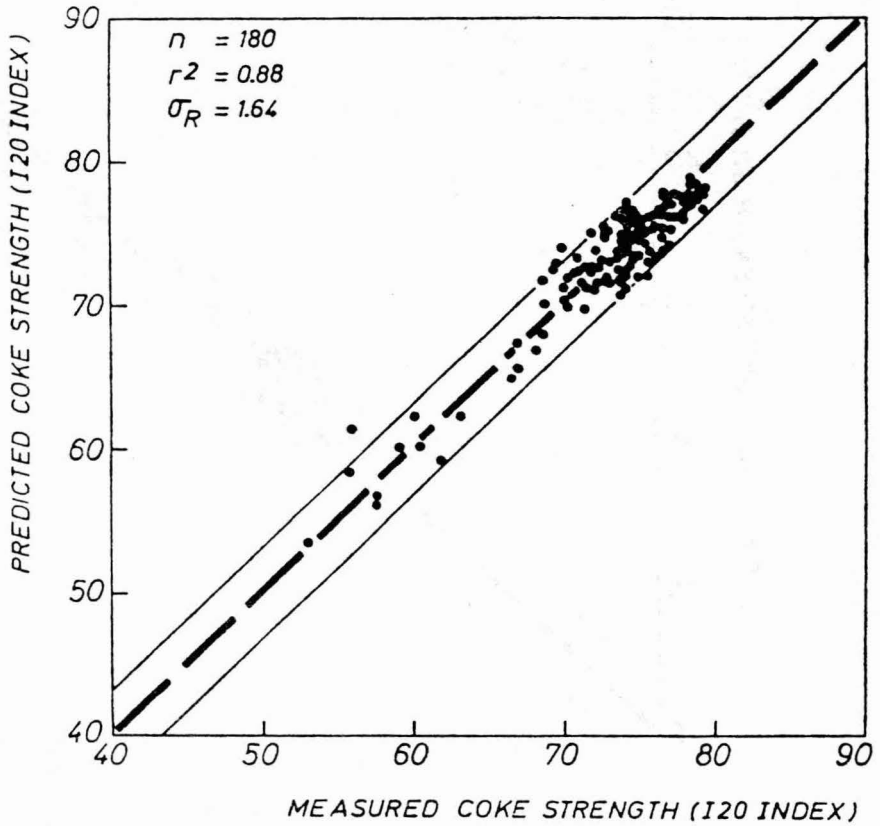
FIG.12 PREDICTED VERSUS MEASURED COKE STRENGTH
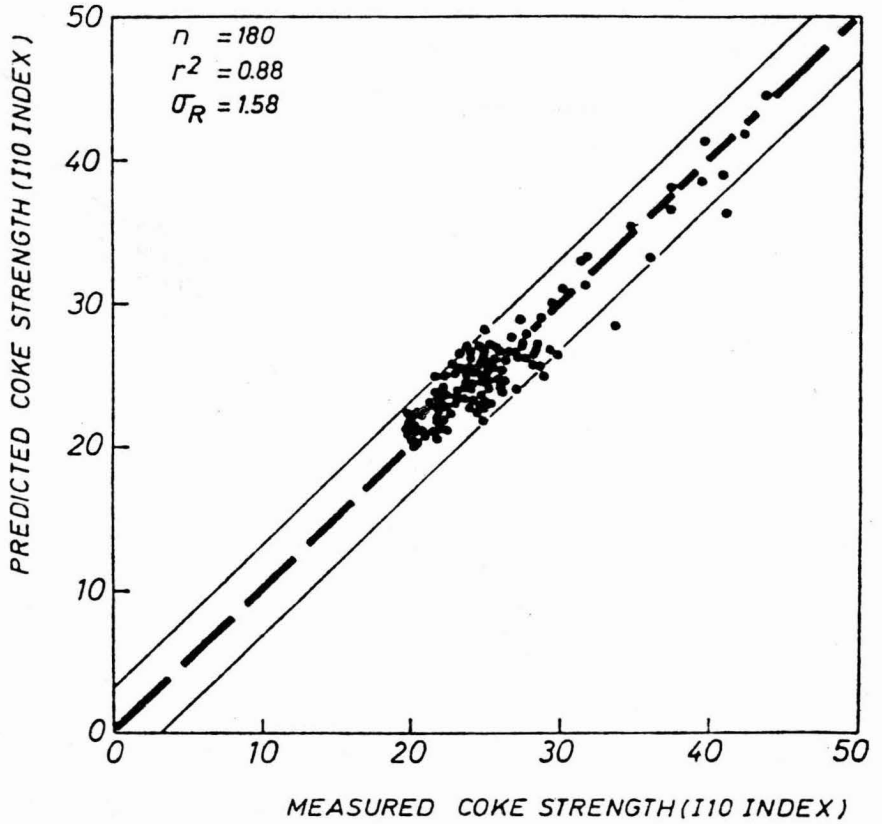(I20 INDEX)

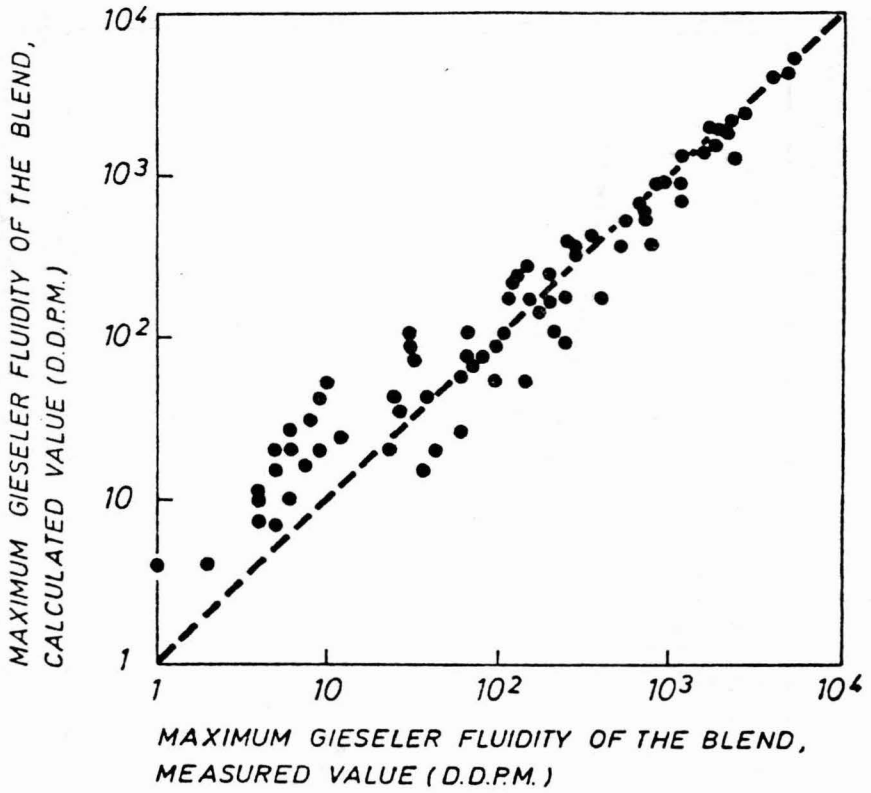FIG 13 PREDICTED VERSUS MEASURED COKE STRENGTH
(I10 INDEX)

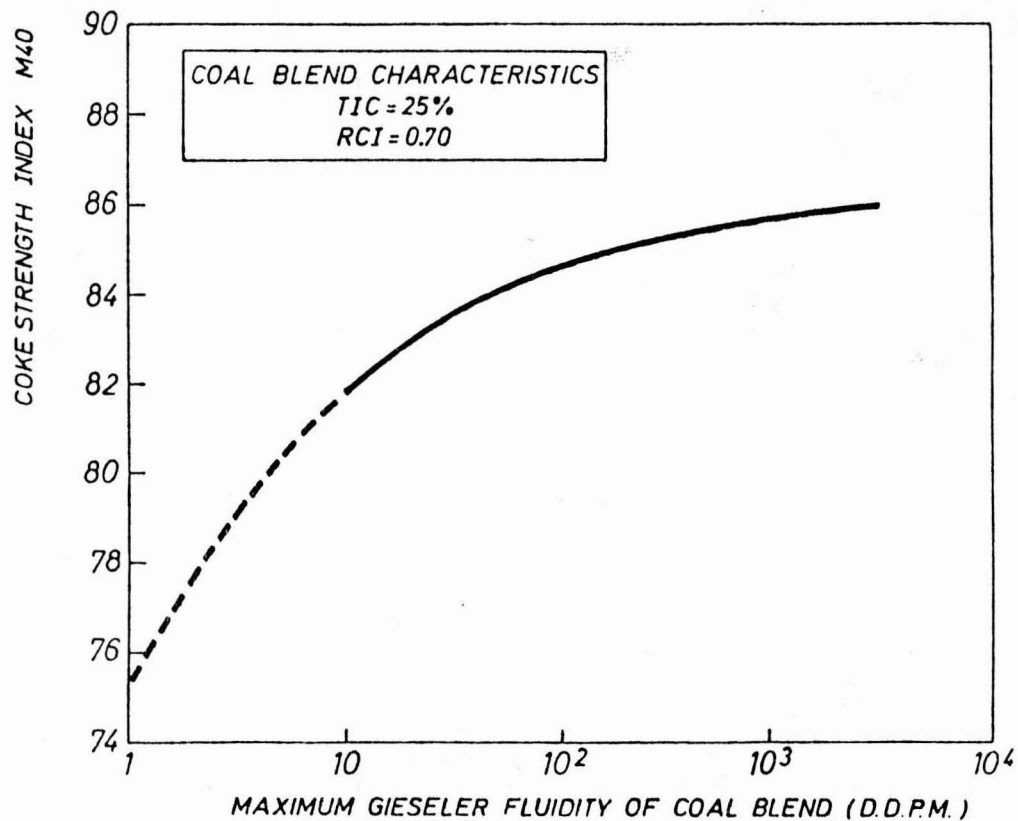FIG.14 RELATIONSHIP BETWEEN CALCULATED AND
MEASURED FLUIDITY FOR COAL BLENDS

FIG. 15 RELATIONSHIP BETWEEN COKE STRENGTH INDEX M40 AND COAL BLEND FLUIDITY