CALCULATIONS ABOUT COMPLEX COKING COAL BLENDS

Por:

Manuel Sirgado Echeverría

Doctor Minning Engineer

EMPRESA NACIONAL SIDERURGICA, S.A.
"E N S I D E S A"

1. INTRODUCTION

The average maximum reflectivity (or statistical average) of - vitrinites is of paramount importance as a criteria at the -- time of preparing coking mixtures, it being of good cold - - mechanical strenght.

However, when the coal blends are very complex and contain - - coal extremes, as much in the maximum as is the minimum range of the scale, the average maximum reflectivity (or statistical average) can lose meaning and become defective, for which in our opinion, it would be necessary to generalize the reflectivity concept, using as a criteria the actual reflectivity (and not the statistical average).

In addition, with the utilization in the battery mixtures of - inert coal additives, such as petroleum coke, it was necessary to go a step further in this generalization of the reflectance criteria, arriving at what we call the corrected effective -- reflecance.

The concepts of mean effective reflectance and corrected mean effective reflectance will be discussed throughout the extent of this report.

The addition of oils and other substances can alter the - - plasticity of the blend, making it possible to use the concept of actual plasticity in the same way as the concept of - - reflectance.

2. CHARACTERISTICS OF DOMESTIC COALS

Simply speaking, the domestic (Spanish) coals used in the - - coking process can be classified into one of the following -

groups: (Fig. 1).

a) High volatile coals with little plasticity

These are coals of low range, containing volatiles (d.a.f.) in the order of 41 %, with an mean statistical reflectance understood to be between 0.6 and 0.9, an FSI understood to be between 2 and 4, and a Miximum Gieseler Fluidity of 5 to 100 ddpm.

b) High volatile coals with little plasticity

These are coals with reflectances understood to be between 0.8 and 1.1 %, volatile matters (d.a.f.) understood to be between 33 and 39 %; with an FSI superior to 7.0 and a -- Maximum Gieseler Fluidity superior to 3,500 ddpm, although the normal is that they are above 60,000 ddpm.

c) Medium to low volatile coals

These have a reflectivity range understood to be between - 1.2 and 1.6 %. The percentage of their volatile matters - (d.a.f.) is between 22 and 30 % and an FSI superior to 7.5.

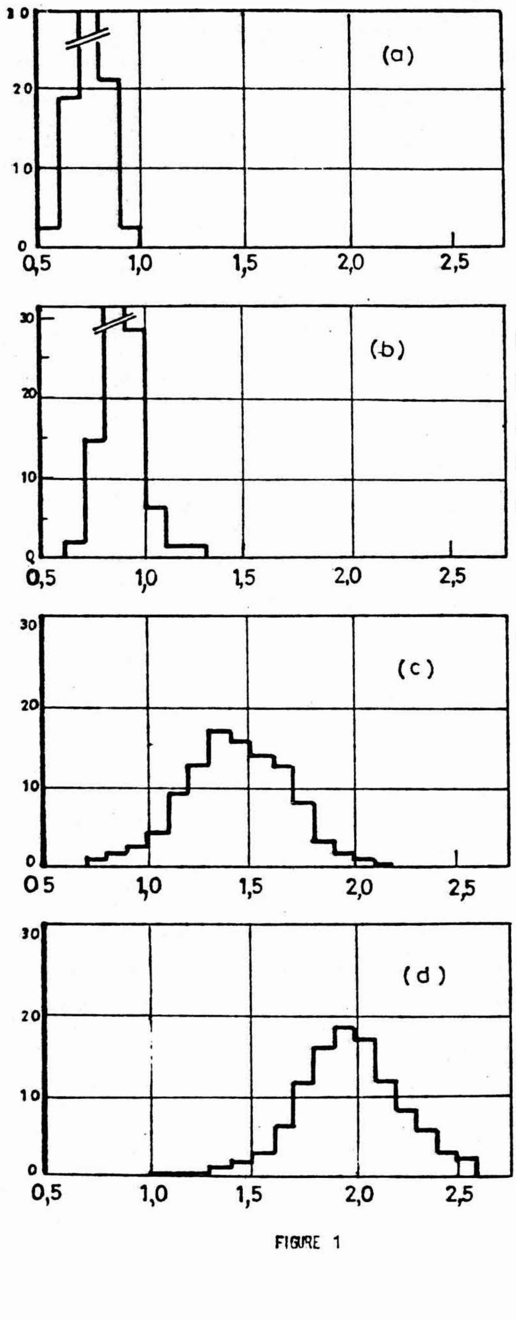
d) Semianthracite coals

They have reflectivities superior to 2.0; they are - - practically infusible, FSI = 1.0. In the Gieseler plasticity test they do not soften, and their percentage of volatile - materials (d.a.f.) is around 13 %.

In order to complement these domestic coals, which are consumed at a rate of approximately 25 %, it is necessary to import - other kinds (high, medium, low and inert additives) from - - different countries such as Poland, the United States, Germany, Australia, etc.

Due to this, the histograms of reflectivity of the battery - blends of ENSIDESA are very wide, the range of vitrinites - -

DOMESTIC COKING COALS CHARACTERISTIQUES



(a)
Volatile Matter (daf) = 40 %
Max. Fluidity (lg ddpm) = 0,70
Mean Reflectance % = 0,76
F.S.I. = 2
ASTM D-2014 (1 %) = -15,0 %

(b)
Volatile Matter (daf) = 36 %
Max. Fluidity (lg ddpm) = 4,37
Mean Reflectance % = 0,87
F.S.I. = 8
ASTM D-2014 (1 %) = -12,0 %

(c)
Volatile Matter (daf) = 23 %
Max. Fluidity (lg ddpm) = 2,7
Mean Reflectance % = 1,43
F.S.I. = 8
ASTM D-2014 (1 %) = + 1,6 %

(d)
Volatile Matter = 13,0
Max. Fluidity (lg ddpm) = 0
F.S.I. = 1,0
ASTM D-2014 (1 %) = -16,2 %

FIGURE 1

generally being between level V6 and level V25. Given that, - and according to the level of reflectivity, the different - - vitrinites within the histogram each have determined functions in the blend, which must be perfectly calculated and balanced.

3. THE INFLUENCE OF THE COAL RANGE ON THE FISURATION OF THE COKE

The tensions which appear in the interior of the solid mass - during the formation of the semicoke and of the coke influence decisively the magnitude and the distances of the fissures - formed upon which depends the ability of the coke to resist - deterioration by fisuration. The tensions do not depend on - the absolute valor of the contraction, but rather on the - - differences of contractions produced in points very near the - solid mass.

It is very illustrative the theory developed by CERCHAR, (1), according to which, the differing tensions which are produced during the stage of the formation of the semicoke - between - the point of resolidification and 550 degrees Centigrade - are so great, the lower the temperatures of resolidification of - the coal or blend, that is to say, we refer to the fusible - coals, the less is its range. Above 550 degrees Centigrade - the behavior of all the coals with respect to the contraction of the semicoke is practically the same and, therefore, - - independent of range. When to a low range fusible coal is - added higer proportions of a fusible coal or a high range, a - series of blends is obtained which has intermediate properties with respecto to fisuration, but which rapidly approximates - the coals of the high range.

The inert additives (semicokes, cokes, semianthracites and - anthracites) have a velocity curve of different contractions - as compared to the fusible coals, their form depending - - fundamentaly on distinct factors, such as the scale of ranges of the inert coals (Fig. 2) or the criteria of the process of artificial inerts (2).

The series produced from blends with different proportions of fusible coals has different properties than when one of the - coal is infusible. In the first case, the high range coal - acts on the first range of the velocity curve of contraction of the low range coal, softening it while in the second case, the action of the inert additive can act upon both ranges - simultaneously (3), (4).

4. THE ACTUAL REFLECTIVITY AS A CRITERIA OF RANGE

The Parque de Carbones de Aboño (a blending coal park) allows ENSIDESA to prepare battery blends of more than twenty - - different kinds of coals in piles of 30,000 to 40,000 tons. - It is clear that the enormous size that these piles have - - would make any necessary rectification troublesome to say the least if, once the battery blend is formed, the quality was - found not to be as programmed. The problem has a different - dimension than when the battery blend is dosified continuously from chutes which permit the correction of any error or - - mistake in the dosification instantaneously. The formation - of battery blends in piles of 40,000 tons makes necessary a - pre-estimation of the mechanical strenght of the coke in - - terms of very accurate measurement, because if the criteria - of the range estimation, "the maximum reflectance (or - - statistical) mean", was sufficient to pre-estimate when the - blend only contained fusible coals, in those cases in which - sizable proportions of coals with vitrinites outside the - levels of V7 to V18 were added, said criteria was defective in many occasions, thus making necessary a more generalize - - concept, proposing as a replacement the average actual - - - reflectivity concept.

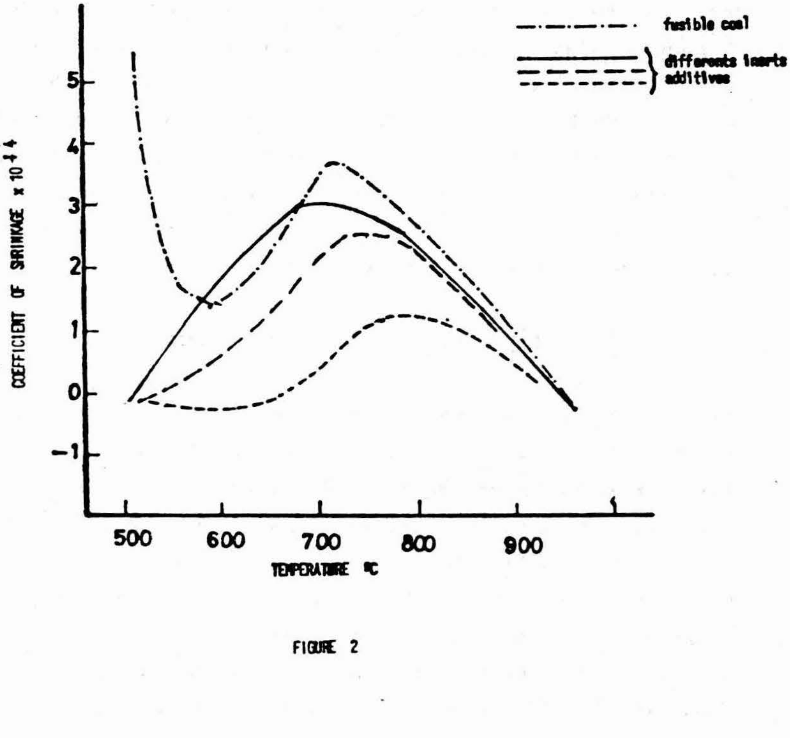

fusible coal
differents inerts
additives
COEFFICIENT OF SHRINKAGE x 10-4
5
4
3
2
1
0
−1
500
600
700
800
900
TEMPERATURE °C

FIGURE 2

The mean effective reflectance (maximum or statistical) of a - coal or blend is defined as the value of the mean reflectance (maximum or statistical) of the fusible vitrinites of said - coal or blend. We consider fusible vitrinites of a coal - those which are between the levels V7 and V18.

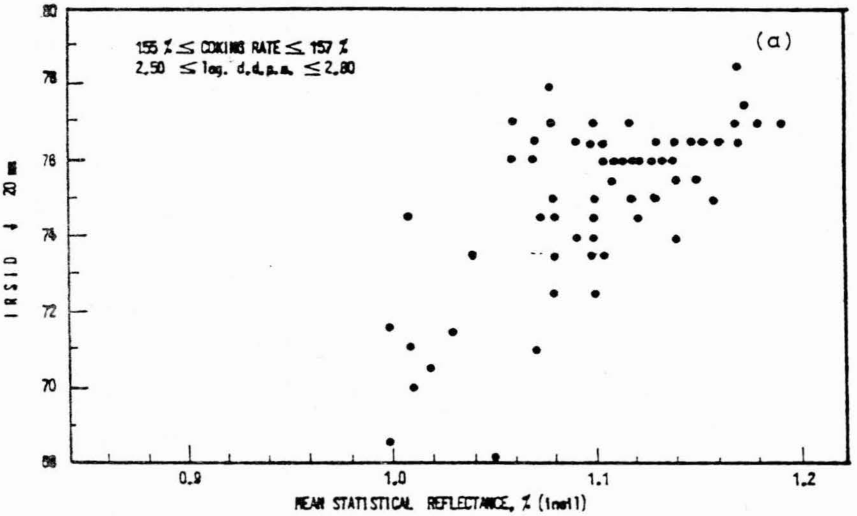
A simple example will show the necessity of developing the - aforementioned concept:

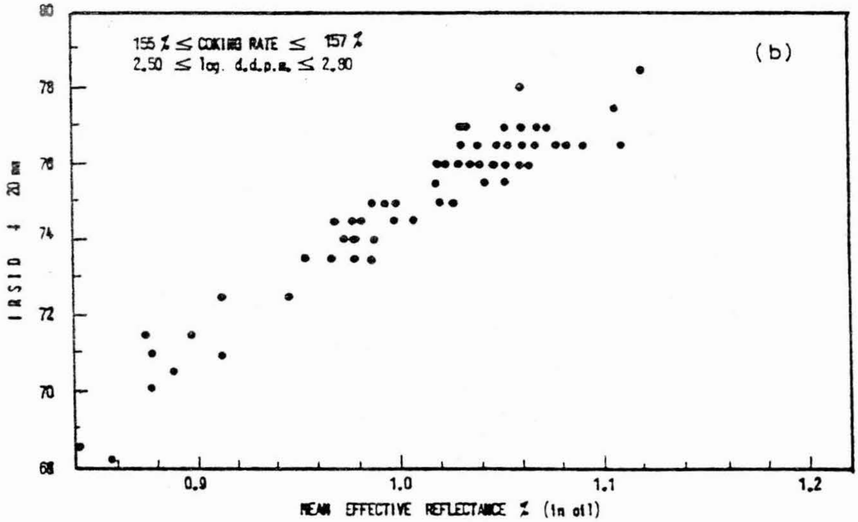
Assuming that we have two coal blends, one of them formed by - 9 parts of fusible coal of 1 % reflectance and one part inert coal (anthracite) of 2.5 % reflectivity: and the other blend - formed with the same 9 parts fusible coal and one part of an - anthracite with a range superior to the first one, for example, 5 % reflectivity; and supposing that all the coals have the - same percentage of vitrinites the average reflectivity - for the two blends would be respectively:

$$\overline{RM}_1 = 1.15\ \% \quad \text{and} \quad \overline{RM}_2 = 1.40\ \%$$

Although the antifusurant behavior of the two anthracites is - not the same, still it is sufficient enough to suppose so in a first trial or approximation. Thus, we find ourselves here - with two blends having mean reflectances very different - - although the qualities of their coke are very similar. The - use of the mean reflectivity as a criteria of range in order - to pre-estimate qualities of coke is not valid in this case. - This problem is even more complicated when taking into account that 1.15 % and 1.40 % reflectivity can be obtained in very - different ways: adding to the blends only fusible coals, or - as well adding fusible and infusible coals.

Figure 3 compares the difference of exactitude obtained when -


(a)
155 % ≤ COKING RATE ≤ 157 %
2.50 ≤ log. d.d.p.m. ≤ 2.80
80
78
76
74
72
70
68
IRSID + 20 mm
0.9
1.0
1.1
1.2
MEAN STATISTICAL REFLECTANCE, % (in oil)


(b)
155 % ≤ COKING RATE ≤ 157 %
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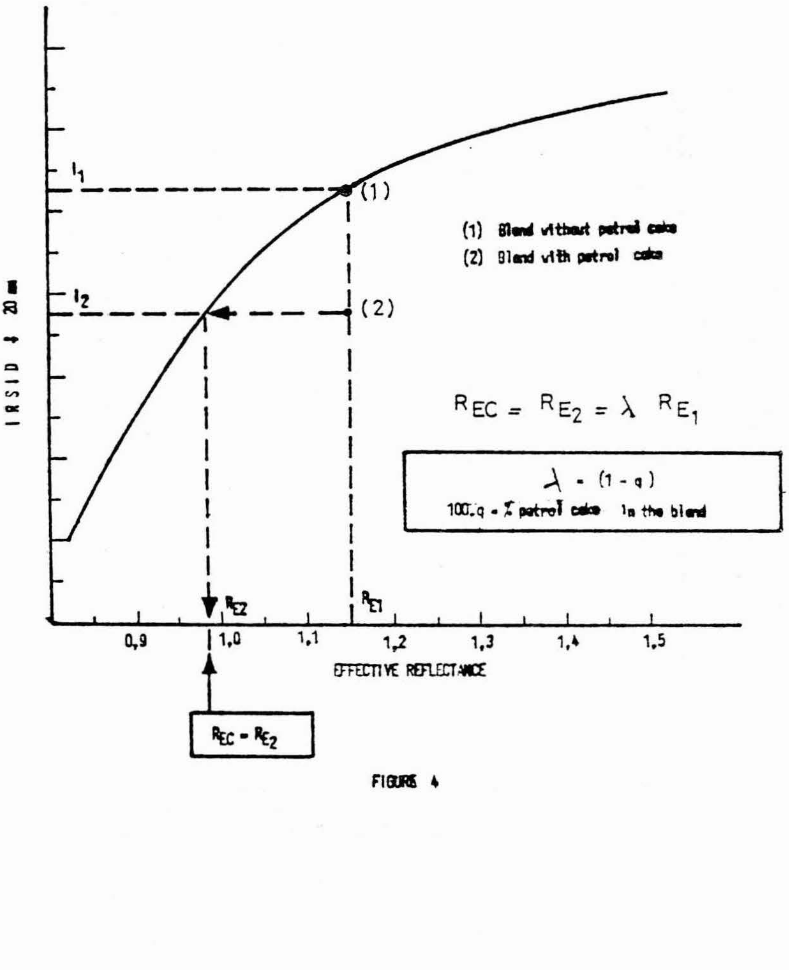
78
76
74
72
70
68
IRSID + 20 mm
0.9
1.0
1.1
1.2
MEAN EFFECTIVE REFLECTANCE % (in oil)

FIGURA 3



I₁
I₂
(1)
(2)
(1) Blend without petrol coke
(2) Blend with petrol coke
IRSID + 20 mm
REC = RE2 = λ RE1
λ = (1 - q)
100.q = % petrol coke in the blend
RE2
RE1
0,9
1,0
1,1
1,2
1,3
1,4
1,5
EFFECTIVE REFLECTANCE
REC = RE2

FIGURE 4

one pre-estimates the quality of the coke with the mean - statistical reflectance and with the mean effective - - reflectance (statistical) for blends to which one has - - added variable quantities (between 0 and 13 %) - - - semianthracite coal, but not petroleum coke. The - - mechanical strenght of the coke was measured at the exit - of the sieves. The width of the batteries was only 350 mm, and thus the cold mechanical strenght of the coke was very sensible to the changes of the range criteria and the - - conditions of the process. This explains also the high - working rate in which it functioned. The plasticity of - the blends was limite to levels of between 2.5 and 2.80, - in order to avoid other influences outside the norm of - this example.

5. GENERALIZATIONS ABOUT REFLECTIVITY FOR ANTIFISURANT BLENDS WITHOUT VITRINITES. CORRECTED EFFECTIVE REFLECTIVITY

The mean statistical reflectances (or average maximum) of a blend, with or without the addition of a percentage of - 100q of petroleum coke, are the same in both cases. This - is so because, given the fact that the reflector power is measured by vitrinites and the petroleum coke does not -- have it, the result therefore in both cases is the same. - However, whether or not a blend has a quantity of petroleum coke in its composition does affect the pre-estimation of the mechanical strenght of the coke produced. Indeed, in Fig. 4 is shown a curve of pre-estimation of the IRSID + 20 mm, in function of the effective reflectance, very similar to what was shown in Fig. 3b.

In that figure, a coking blend was individualized that - contained no petroleum coke, and that had an mean effective reflectance equal to R_{E1}, giving a quality of coke equal to - I_1, situated on the curve of pre-estimation. Upon adding to - this same blend a quantity q (so much for one in weight) of - petroleum coke, a result of I_2 was obtained, inferior to the - first, but the new blend nevertheless having the same average actual reflectance, due to the fact that the petroleum coke - has no vitrinites and therefore in the histogram of reflectance, it is not present.

The result of IRSID - 20 mm, I_2, obtained corresponded to a - normal blend that would have a reflectance of R_{E_2}. In order - to avoid the inconvinience of modifying the value of the - - reflectance because of the presence of this type of inert but at the same time allowing the inerts to modify the quality of the coke obtained (or desired), the concept of mean effective reflectance had to be modified for these types of blends, the new concept being the CORRECTED MEAN EFFECTIVE REFLECTANCE R_{E_C}, which is equivalent to (in the case of Fig. 4):

$$R_{E_C} = R_{E_2} = R_{E_1} \cdot \lambda$$

λ being a parameter that must be determined statistically, which in the petroleum coke used in the Batteries of ENSIDESA has - been found to be:

$$\lambda = (1 - q), \text{valid for } q \leqslant 0.15$$

q being so much for one in weight of petroleum coke in the - blend, referring to the total blend.

In accordance with the aforementioned, given a blend that - - contains antifisurantes, what is referred to as the corrected mean effective reflectance is the effective reflectance that a blend would have without these additives and that would give - tha same quality of coke. This same concept is applicable when inert oxided coals are added to a blend. In this case, the vitrinites must be eliminated in the histogram of reflectance and corrected by using the corrected mean effective - - reflectance, λ.

In accordance with the aforementioned, the corrected mean - effective reflectance, different from the other types of - reflectance that we have studied, is not a criteria that can be determined experimentally in a laboratory, but one that must be obtained through a metallurgical study of industrial data.

6. ADDITIVITY OF THE DIFFERENT TYPES OF REFLECTIVITY (5)

Given that the n coal which form a blend do not have the same percentage of vitrinites, the formula of the average maximum (or statistical) reflectivity is not lineal.

In Table I are represented the reflectivity histograms of the n coals that are used in a blend. In this table, E^j is the - mean value of reflectance on the j level of reflectance; α_i^j is the so much for one of vitrinite that coal i has on he -- level j; Vi and VFi are the so much for one of vitrinite total and fusible vitrinite, respectively, of coal i. The - percentage of coal in the blend is 100·X i.

With this term, the mean maximum (or statistical) reflectance of blend RB is expressed as the following formula:

$$\bar{R}_B = \frac{\sum_{i=1}^{i=n} x_i V_i A_i}{\sum_{i=1}^{i=n} x_i V_i}$$

taking into account that

$$A^{J}_{B} = \frac{\sum_{i=1}^{i=n} x\, iViAi}{\sum_{i=1}^{i=n} x\, iVi}$$

If we suppose that the fusible intervals of crystalization is understood between V8 and V18 (Table I) and if we define Bi - by the expression:

$$Bi = Vi - VFi$$

the value of the mean effective reflectance (maximum or - - statistical) is determined by:

$$\overline{RE}_B = \frac{\sum_{i=1}^{i=n} x\, iBi\overline{RE}i}{\sum_{i=1}^{i=n} x\, iBi}$$

where $\overline{RE}_i$, the effective reflectance of coal i is given by - the expression

$$REi = \sum_{j=8}^{j=18} \frac{A^j_i\, E^j}{VF_i}$$

For the corrected effective reflectance, the additive formula is the following:

$$\overline{REC} = \frac{\sum_{i=1}^{i=n} x\, iBi\overline{RE}i}{\sum_{i=1}^{i=n} x\, iBi} (1 - q)$$

In Table II, a practical example is shown of the calculations for the MEAN EFFECTIVE REFLECTANCE and the CORRECTED MEAN - EFFECTIVE REFLECTANCE of the same blend to which was added - 7 % of petroleum coke (coal blend), which was converted to - 6.54 referring to the total blend.

TABLE I - MEAN EFFECTIVE REFLECTANCE WITHOUT INERT ADDITIVES

COAL	%	V	V_F	B	E^4	E^5	E^6	E^7	E^8	...	E^J	- -	E^{16}	E^{17}	E^{18}	E^{19}	E^{20}	...	$E^{\blacksquare}$
C_1	$100.x_1$	V_1	V_{F1}	$B1 = V_1 . V_{F1}$	α_1^4	α_1^5	α_1^6	α_1^7	α_1^8	...	α_1^j		α_1^{16}	α_1^{17}	α_1^{18}	α_1^{19}	α_1^{20}	...	$\alpha_1^{\blacksquare}$
C_2	$100.x_2$	V_2	V_{F2}	$B2 = V_2 . V_{F2}$	α_2^4	α_2^5	α_2^6	α_2^7	α_2^8	...	α_2^j		α_2^{16}	α_2^{17}	α_2^{18}	α_2^{19}	α_2^{20}	...	$\alpha_2^{\blacksquare}$
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	...	⋮	...	⋮	⋮	⋮	⋮	⋮	...	⋮
C_i	$100.x_i$	V_i	V_{Fi}	$Bi = V_i . V_{Fi}$	α_i^4	α_i^5	α_i^6	α_i^7	α_i^8	...	α_i^j	...	α_i^{16}	α_i^{17}	α_i^{18}	α_i^{19}	α_i^{20}	...	$\alpha_i^{\blacksquare}$
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	...	⋮	...	⋮	⋮	⋮	⋮	⋮	...	⋮
C_n	$100.x_n$	V_n	V_{Fn}	$B_n = V_n . V_{Fn}$	α_n^4	α_n^5	α_n^6	α_n^7	α_n^8	...	α_n^j	...	α_n^{16}	α_n^{17}	α_n^{18}	α_n^{19}	α_n^{20}	...	$\alpha_n^{\blacksquare}$

TABLE II - DIFFERENT KINDS OF REFLECTANCE ON COAL BLENDS (WITH AND WITHOUT INERT ADDITIVES)

	X'_1	X_1	V_1	V_{F1}	B_1	$\bar{R}_1$	$\bar{R}_E$			E^4	E^5	E^6	E^7	E^8	E^9	E^{10}	E^{11}	E^{12}	E^{13}	E^{14}	E^{15}	E^{16}	E^{17}	E^{18}	E^{19}	E^{20}	E^{21}	E^{22}	E^{23}	V_1R_1	B_xR_E
C_1	34	31,79	70	82	57,4	0,997	1,078			3 -	4 -	5 -	6 -	10 12,2	15 18,3	25 30,5	15 18,3	10 12,2	5 6,1	2 2,4										0,698	0,619
C_2	27	25,23	62	97	60,1	1,225	1,240						3 -	4 4,1	5 5,1	6 6,2	25 25,6	25 25,8	15 15,5	10 10,3	5 5,1	2 2,1								0,700	0,746
C_3	14	13,08	80	32	25,6	0,740	0,931			7 -	11 -	25 -	25 -	15 46,9	10 31,3	5 15,6	2 6,2													0,592	0,238
C_4	12	11,21	81	18	14,6	2,078	1,728														3 16,7	4 22,2	5 27,8	6 33,3	10 -	15 -	25 -	25 -	7 -	1,683	0,252
C_5	13	12,15	67	83	55,6	1,607	1,635										3 3,6	4 4,8	5 6,0	6 7,2	10 12	15 18,1	25 30,2	15 18,1	10 -	5 -	2 -			1,137	0,900
Σ	100																														
q	-	6,54																													
Σ	-	100																													

- WITHOUT PETROL COKE BLEND

$$\left(R_M = \frac{\sum_{1=1}^{1=n} X'_1 V_1 \bar{R}_1}{\sum_{1=1}^{n} X'_1 V_1} = \frac{0{,}875}{0{,}702} = \underline{1{,}247}\right) \qquad \left(R_{EM} \frac{\sum_{1=8}^{1=18} X'_1 B_1 R_{E1}}{\sum_{1=8} X'_1 B_1} = \frac{0{,}594}{0{,}483} = \underline{1{,}230}\right)$$

- 6,5 % PETROL-COKE BLEND

$$\left(R_M = \frac{\sum_{1=1}^{1=n} X_1 V_1 \bar{R}_1}{\sum_{1=1}^{1=n} X_1 V_1} = \frac{0{,}818}{0{,}656} = \underline{1{,}247}\right) \qquad \left(R_{EMC} \frac{\sum^{1=18} X_1 B_1 \bar{R}_{E1}}{\sum_{1=8} X_1 B_1} (1-q) = \frac{0{,}5548}{0{,}4540} \times 0{,}9346 = \underline{1{,}1398}\right)$$

7. REOLOGICAL CHARACTERISTICS

As is well known, the resistance to breakdown by abrasion of coke is determined by the grade of aglomeration obtained by - the different grains therein. The more perfect the assimilation of the grains in the mass, the better will be the overall cohesion of the masa and therefore the better will be the - resistance of the coke grains to degradation when passed - through the sieves. While it is true that the coking of only one coal or of a blend which contains fusible coals in a - - range very near to plasticity is not excesively important - because the grains melt almost simultaneously and this - - contributes greatly to the aglomeration, in general, the more complex the batteries of blends, the more seperated, with - respect to range, will be the coals or greater will be the - percentage of inerts, and of more importance will have the - process of obtaining sufficient plasticity during the period of softening of the battery blend.

It is also known that, once a minimum plasticity is obtained, there exists a optimal interval that should not be extended, to do so thereby producing characteristics which would - - seriously affect negatively the quality of the coke. This - optimal interval of plasticity depends upon the coorking rate, the average of the blends, and the quality of the coke that - is desired to be obtained. In ENSIDESA, the fluidity of the blend is not a calculated independently of the rest of the - factors of the blend, but is related to the mean range of the same by way of the REOLOGICAL CHARACTERISTIC ϕ_M of the - - battery blend.

The reological characteristic of a coal or blend is defined - as the product of the loraritm of the Maximum Gieseler Fluidity by the mean reflectance of that coal

$$\phi = \bar{R}_E * \lg F = \bar{R}_E * P$$

The reological characteristic has the property of being lineally additive, that is to say:

$$\phi_B = \sum_{i\,n\,1}^{i=n} Xi\phi i$$

being n the number of coals in the blend and 100 *,Xi and Øi, respectively, the percentage of the coal i in the blend and its reaological characteristic.

The aforementioned formula continues to be valid in the case of blend which contain additives (inerts) of the type of petroleum coke if the reological characteristic is generalized. For this, it is sufficient to make the value zero of the reological characteristic of the petroleum coke. (6)

The reological characteristic, apart from its use as a criteria for the pre-estimation of cold strenght index has allowed the solution of some problems supposing the validity of the law of lineal additivity of the logarithm of the Gieseler Plasticity were insoluable. Such is the case, of determining by calculation the Gieseler Fluidity of the Brazilian coal from Santa Catarina, because experimentally it is not possible being above the maximum level of commercial plastometers (60,000 ddpm). When different blend of this coal and a less fusible coal are made, in a way that they can be determined experimentally, and the law of lineal additivity of the logarithm of the maximum fluidity is applied to the results, solutions were obtained that fell within the range of the commercial plastometers which was in contradiction of the experiments. The problem had a logical solution when calculated with the reological characteristic.

8. PRE-ESTIMATION OF THE

Having obtained the index of the process of the batteries and the cold coke stre ght as a minimum, the mean effective - - reflectance and the reological characteristic can be determined necessary to obtain the pre-estimation.

On figures 5 and 6, there is an abacus of pre-estimation curves of IRSID + 20 mm in function of the actual reflectance and - the correction according to the value of the reological - - characteristic for coking rates superior to 140 %.

The coking rates can be superior to 140 % by treating the - batteries with only 350 mm of width, the reason for which are obtained mechanical strenght relatively low, upon establishing large thermical gradiants in the coke. However, these - - batteries have been chosen because there are wide variations in their preestimation curves and therefore are very - - - illustrative as examples.

9. OTHER CRITERIA TAKEN INTO ACCOUNT IN THE CALCULATION OF THE - BATTERY BLEND

In addition ot the normal criteria, such as ashes, volatile matter, sulphur, alkalis and phosphor, and those of pre-estimation of the mechanical strenght of the coke that we have seen: effctive reflectance and reological characteristic, in practice there are also other limitations imposed on the production of battery blend, some referring to the quality of coke desired, and - others related to the security of the batterie or to the yield of the coke and its by products.

The most important limitations related to the cold strenght - of coke are:

- Continuity of the reflectance histogram, especially between the levels 1.1 and 1.3 %. Being important that in these - reflectance there should exist a quantity of vitrinites.

- Reactive/Inerts relation, that for the battery blend are - situated between two limits maximum and minimum. The value obtained in our blends was around 3.5 with a maximum of 3.8 and a minimum or 2.9.

- 100 % of the semifusinite is considered inert.

- Dangerous presions against the walls. It is necessary to - limit the wall pressure in the battery blends.

- Equations which combine the range with the yield of the -- coke and its by-products.

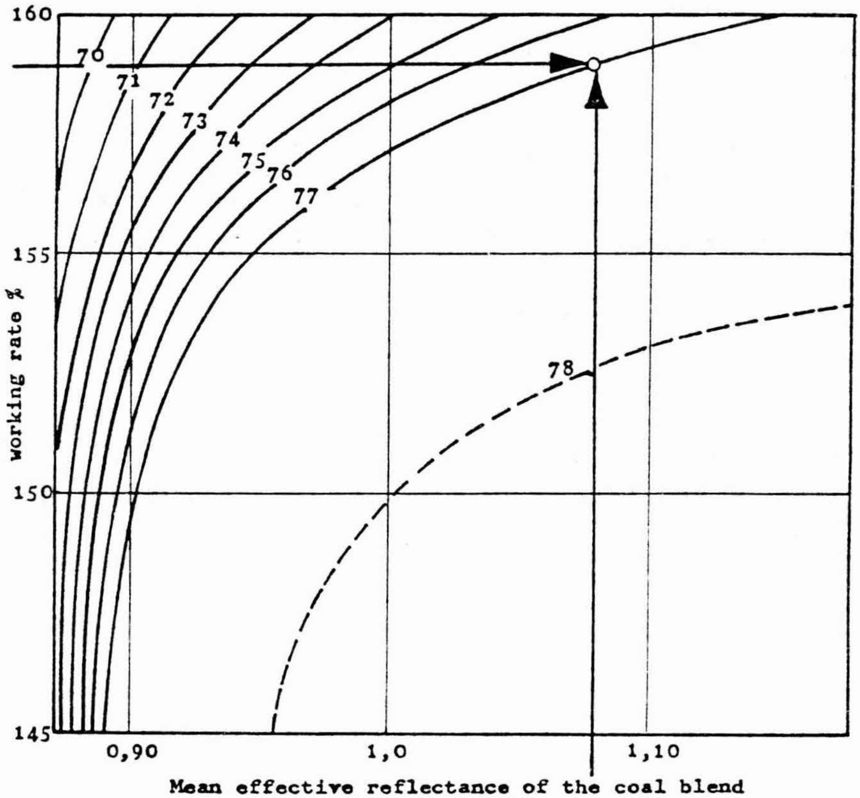


Figure 5 - Pre-estimation of the IRSID + 20 mm for the batteries of Avilés, in function of the mean effective - - reflectance of the blends, and the coking rate. The - value obtained for the IRSID + 20 mm must be corrected later for plasticity. See figure 6.

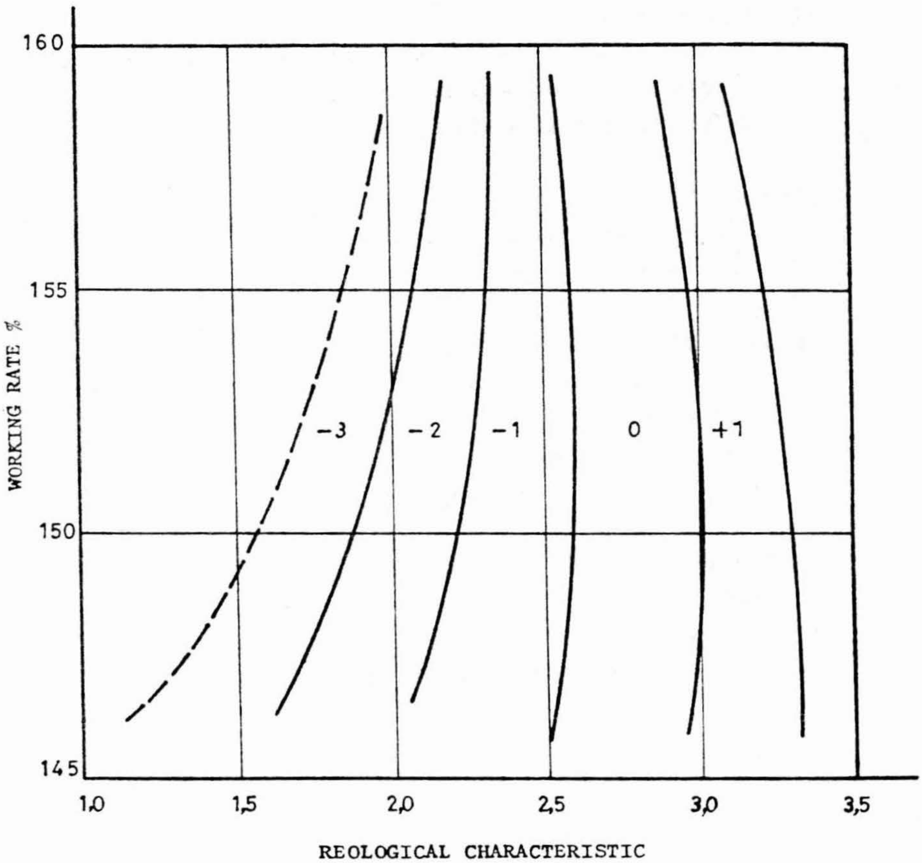


Figure 6 - IRSID + 20 mm correction

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