OPTIMATIONS MODELS OF COKING COALS BLENDS

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"E N S I D E S A"

1. INTRODUCCION

With the introduction in 1976 of the Coals Park of "Aboño" it was necessary for Ensidesa to use a coal mixing optimization model in order to make coke. In fact, the storing installations, grinding, dosification and mixing of the Coal Park of Aboño allow us to work simultaneously with a great number of coals in the coal blend. Such a number is normally geater than 18 coals, and in many cases it reached the number of 22. In addition, the need to use up to a maximum national coals (at present it reaches 25 % in the blend) it demands that widely separated coals in the range scale be used and consequently, with very different properties. So in the coking coal blend of Ensidesa we can find a semianthraciteus infusible coal, 11 % volatile materials and 2.0 % statistical reflectance, as well as 35 % volatile matters coal, 0.7 or 0.8 % reflectance and a maximum Gieseler fluidity greater than 60.000 within these two types of coals, which in one way may be considered extremes, there is a wide variety with intermediate properties, being either national, Polish, Australian or North American, high, medium or low in volatiles or even inert additives, such as petroleum coke. Given the complexity of the raw material used, it is indispensable to use an optimization model, as otherwise the rigurous resolution of the problem would be practically impossible, especially if we bear in mind that, when calculating the mixture of each month, we must take into account the situation that will arise several months later, since the model not only provides the composition of the coal paste which will be consumed in the actual month, but it must be useful to plan the buying of the necessary coals in the near future, naturally, respecting the stocks there will be in the ports, the supply and the long-term contracts which we may have.

Besides, the optimization model of coking coal blends is not - only useful to establish the most economical mixture among all, that fulfill definitive quality specifications, but that in - addition, may be used for solving a great number of problems, - in which the relationship of quantity to be consumed, quality - and price of one or several coals intervenes. Thats to say, - such questions which involve the preference in the buying of - raw materials, penalization of a coal when it does not fulfill specifications, partial or total substitution of a coal in the mixture certain conditions being fulfilled, and more which will be laid out later.

2. OPTIMATION MODELS OF COKING COALS BLENDS

Ensidesa has solved the optimization problems of coal coking - blends using different models which differed one from the other fundamentally in the objective function, which depends on the - different manufacturing processes which it contemplates. On the other hand they all have in common the function of giving as a solution a coal coking blend which:

a) Is the most favourable from an economical point of view, - although in this case the concept "most favourable from an - economical point of view" is relative and depends on the - Objetive function which is used.

b) The paste and coke fulfill minimum quality especifications - previously established. Once such especifications have been reached they must have a certain degree of freedom, whereas on the contrary we could not speak of optimization and the - benefits achieved, on the whole, they will be greater is the degree of freedom in which the model moves.

c) The quality of paste be adequate too, to the manufacturing conditions which exist in the process (dangerous pushes in batteries, plasticity, reflectance in terms of the function and working rate of the batteries, etc.)

Figure 1 shows schematically the simplest model of - - optimization of mixtures. The main restrictions imposed on - the paste and on the coke can be seen, as well as the funda-- mental relationships which exist between the individual coals and the coke. It must be pointed out that in this first model, the objective function is the price of mixture, not taking - into account at all the quality of that coke in the blast - furnace process.

In the scheme of figure 1 the statistical equations of the - type

$$\sigma_{AB}^2 = \sum_i Xi^2 \cdot \sigma_{Ai}^2$$

have been omitted, whereas σAB^2 and σAi^2 represent, respectively, the variance for the blend and for coal i of a certain property or analysis and Xi the proportion of coal i in the blend, - which allow:

1) To calculate with posterior the typical estimation error - in the forecast of this specified property (for example, - ashes of the coal blend), once the model has found the - optimum solution and the variants are known for a property in the component coals.

2) Bearing them in mind in the optimization calculations, - lining approximately the equation

$$\sigma_{AB} = \sqrt{\Sigma Xi^2 \cdot \sigma_{Ai}^2}$$

with which predicted equations and limitation of that - - property will remain in the form of

$$AB = \sum_{i=1}^{i=n} (Xi\ Ai - Z\beta\ Xi) \lesseqgtr M_A$$

Symbolizing the lineal function which substitutes the quadratic, varying Z (taken from the normal distribution curve) according to the typical error which is considered and M_A, being the - - established maximum/minimum values.

The use of an objetive function which only takes into account a partial aspect of the process may lead to obtain solutions - - which, although being mathematically exact, are not economically valid. For example, in this case the optimization will give us a solution, within all the blends which fulfill the equations - of an established condition, the one having the minimum price. This mixture, on the other hand, does not have to be the one - that provides the greatest economics when it is included in the analysis of the most advanced process of the blast furnace. In general, it will be possible to find another mixture that even having a price of mixture a little more expensive than the - - optimization, produces a better quality coke, such that saves - amply in the blast furnace (in coke consumption) the excess in price which has been paid for the mixture. The same can be - said if the estimation of the subproducts is considerate or not. A model which not only takes into account the prices, but also the prices and performance of the materials in the global - - process must be used in both cases, above all if the same are - related to the quality of the different coals used.

According to the latter, the greater is the optimization model

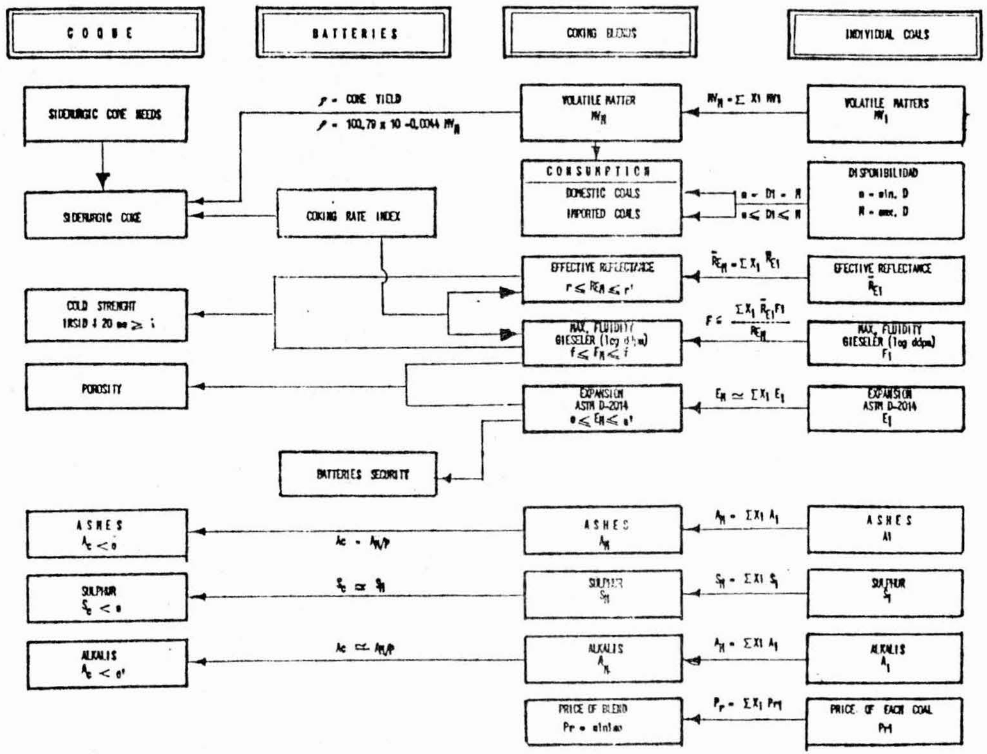

Figure 1 - SIMPLE OPTIMIZATION MODEL OF BATTERY BLENDS. THE ELECTED OBJECTIVE FUNCTION IS THE PRICE OF COKE.

used, the greater will be the obtained savings. In figure 2 - the General Model of optimization of raw materials used by Ensi desa has been represented, with which the coals of the battery blends, the mineral fines to be sinterized, lump ores, pellets and fluxes are optimized economically. Now then in those cases in which we only pretend to optimize coals and not iron minerals and bearing in mind that the nature of the minerals does not - exhert excessive influence over the nature of the coke the - - intermediate model in figure 3 may be used, in which some - - constant conditions have been supposed for the iron minerals - and, therefore, they do not have any influence in the optimization.

3. THE EFFECTIVE CARBON OF COKE

It is obvius, the necessity which exists in connect the - - formation phase in the coal blend with the production process - of pig iron in the blast furnace, since the latter is not - - independent of the former, if it is desired that the optimization achieve real savings. As we have already mentioned previously, it is no use obtaining by optimization a very cheap mixture, if the coke resulting from it is such bad quality that it provokes in the blast furnace an additional rise of the specific - - consumption of coke in the blast furnace, such that on the whole less economy is obtained than if a somewhat more expensive - - mixture had been chosen, but in such a way that it yielded a - better quality coke, which could compensate by means of saving in consumption of coke in the blast furnace, the excess price - paid for the mixture therefore, it is not enough to optimize - the price of mixture, but that a model of equations of bond - must be used between the mixture of batteries and the blast - furnace process, especially as far as the relations of the - -

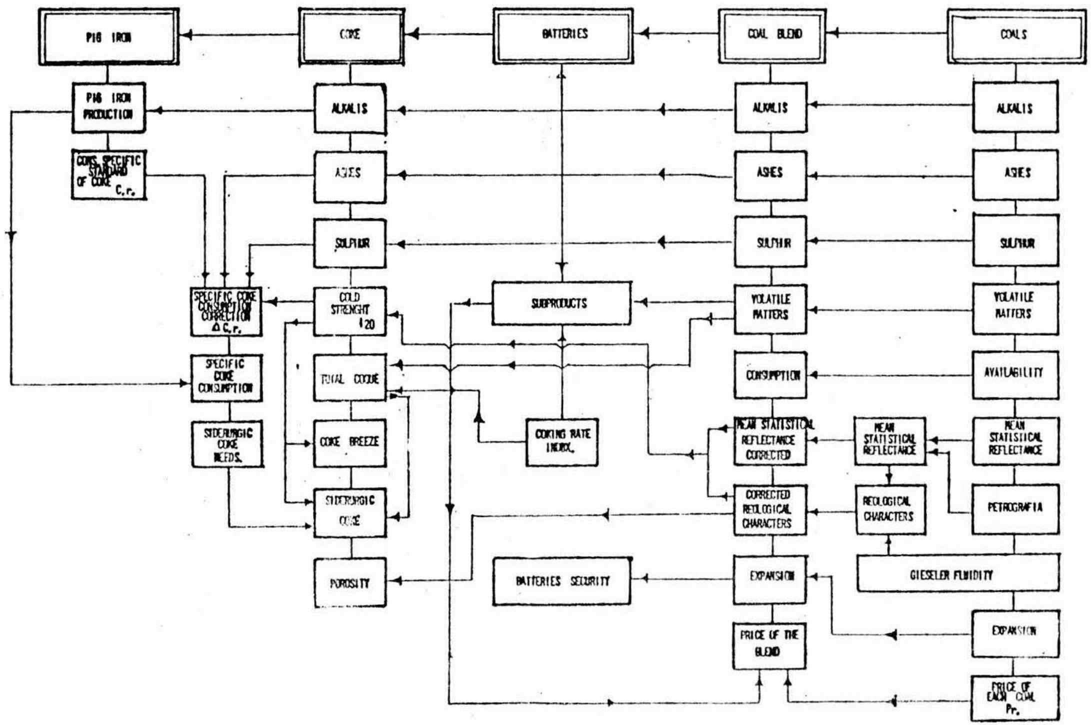

Figure 2 - Battery blend optimization model. The objective function is the price of real ton.

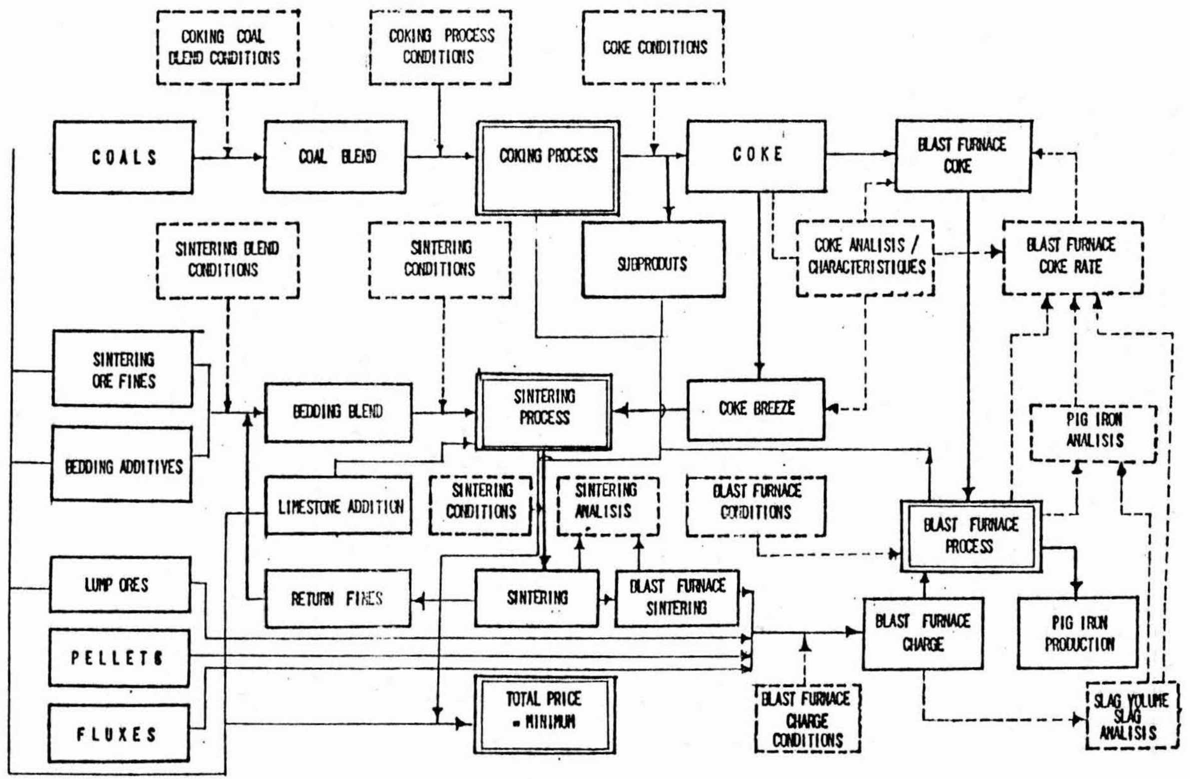

Figure 3 - OPTIMIZATION GENERAL MODEL.

quality of coke with the increment of specific consumption of coque is concerned. At this point the "efective carbon" - - concept appears, developed by V. Flint as the carbon which - remains really free to fulfill the reduction functions in the blast furnace, once the consumed carbon has been discounted in the slagging of its own ashes and sulphur. Such a concept is translated, in general terms, in knowing the influence which - exherts the quality of the coke in the specific coke consumption, the rest of the factors of the blast furnace load remaining - constant.

The application of the increment of the specific consumption - of coke in the blast furnace given by Flint to the furnaces of Ensidesa has not been very satisfactory, giving errors of - - 35 Kg/T in the forecast of the blast furnace coke rate - - (average monthly).

Other authors formulas have been tried, such as Von Bogdandy - or that of JISI, with better results than Flint, but the best exactitude was obtained when a formula was established - -- adjusting by means of refressions the owns process results. In figure 4 we may observe in graphical form the goodness of the adjustment of the specific monthly average consumptions - - forecasted to the real, using the Von Bogdandy formulas, JISI - and Ensidesa. In the case of the Ensidesa formula, typical - errors were obtained between 10 and 12'5 Kg/T p.i. being in - those terms related to the following coal and coke:

$$CE = CE_o + 8.0 * (Cz - Czo) + 50.0 * (S - S_o) + 3,5 *$$
$$* (A - Ao) - 4,4 * (I - Io)$$

where Czo; So; Ao and Io are respectively the contents in ashes,

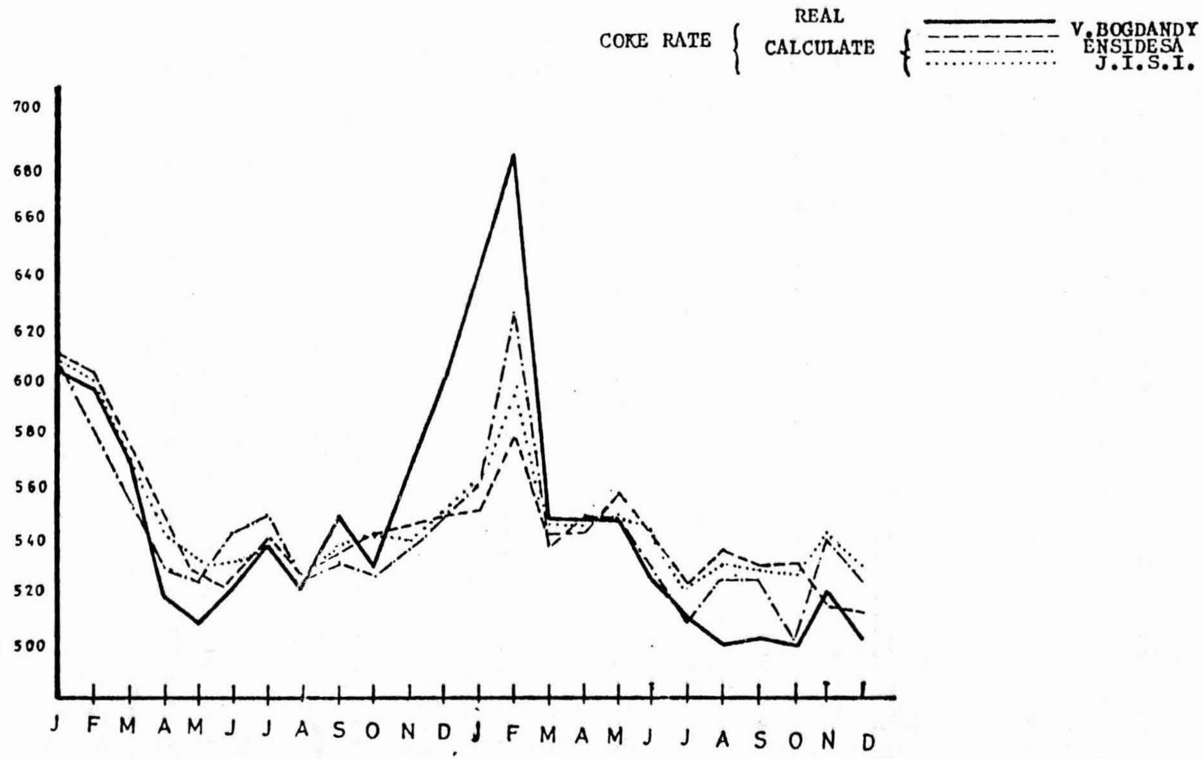

Figure 4 - Blast Furnace coke rate Kg/t.p.i.

sulphurs and alcaline oxides of standard coke and Io its cold strenght (IRSID + 20 mm) and Cz, S, A and I are the - - corresponding coke values manufactured by the model. $C.E_o$ is a blast furnace coke rate constant in standard conditions.

4. OUTLAY OF THE CURVES IN "S"

Cj be the individual coal which we wish to study, and be Mj and mj; respectively, the maximum and minimum quantities which are possible to be engaged.

On applying the adequate Optimization Model, in which the coal Cj, which we wish to study intervenes, an optimized solution is obtained where Cj will take part in a q_o quantity.

A diagram has been represented in figure 5 where the figures - of the material quantities appear in order Cj which would - - apply in the abscissa solution the prices which such raw - - materials may have.

The tracing of the curve q1, q2..., qn ; q'_1, q'_2... q'_n, of figure 5 is done in the following way.

First of all the restrictions mj and Mj, of the optimization - model are eliminated, which in other words means, on a new - optimization being done, the coal Cj, does not have to fulfill the equation:

$$mj \leqslant qj \leqslant Mj$$

anymore but that any quantity q1, will be obtained, which will only coincide with qo in the case that the first optimization qo be between mj and Mj.

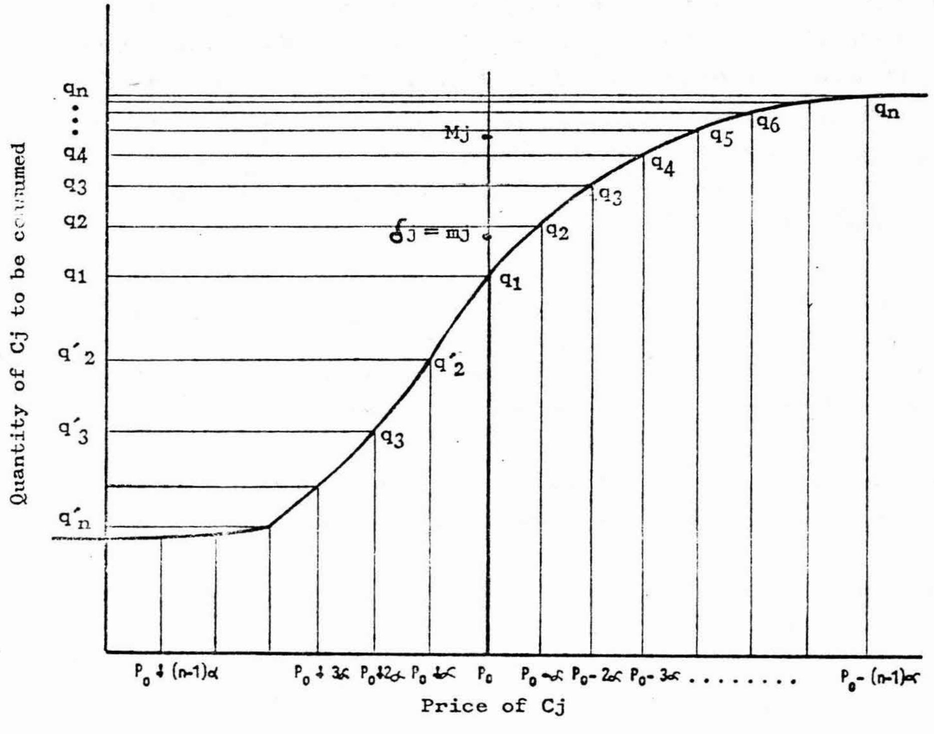

Figure 5 - Tracing of the curve quality - quantity - price for a material that enters an optimized mixture. In this - case $\delta j = mj$.

In the rest of the cases q_1 will be different, being in general:

$$q_1 > M_j \quad \text{if} \quad q_o = M_j$$
$$q_1 < m_j \quad \text{if} \quad q_o = m_j$$

If next we decrease the original price of coal Po, by a fraction of the same α , 2α ,.. $(n - 1)\alpha$, and we carry out succesive optimizations with these prices, keeping the rest of the start - conditions ~~constant~~ we will obtain a series of points q2, q3,... qn, which represent the new quantities of the coal Cj which - - will optimize the mixture in these conditions. It must be - - pointed out that:

$$q_1 \leqslant q_2 \leqslant \cdots \leqslant q_n$$

since the price of coal Cj is being lowered, the quantity in - which it enters the mixture must not be diminished.

In general, the quantity will tend to stabilize itself starting from a certain value q, by technical limitations of the mixture or of operation which will not be able to overflow although its price may be null.

In the same manner, on applying the original price of the - - material to be studied, increments α , 2α ,... $(n - 1)\alpha$ a - subcession of points is obtained q'2, q'3,... which represent - the new quantities of coal Cj which will optimize the mixture - in these conditions. The succesion of points represented by q' is monotonous decreasing, and in general will be stabilized by a determined value q'k which may or may not be different from - zero, due to techical conditions. In the case that the - - stabilization is produced with $q'k > o$. The coal Cj must come -

into the solution with a minimum quantity although its price - may be very high since its presence is necessary to reach the demanded characteristics.

5. APPLICATION OF THE CURVES IN "S" FOR THE VALUING OF COAL

The curve previously traced divides the coal compsumption and plan in two regions. The upper region represents a zone in - which the price of coal Cj is excessive in relation to the - quantity consumed. This zone is represented by the point $Q'1$ in figure 6.

In order for the inclusion Cj to be favorable in the mixture - it must, either reduce the consumption up to the quantity of - q_1 or obtain a decrease of its price up to $P'1$.

The zone of the lower region represents in case of - - - infrautilization of Cj which is represented in figure 6 by the point $Q''1$. In this case it only makes sense to increase the - quantity to be consumed from $q''1$ to q_1 if it is possible.

In case of a revision in prices, if the coal Cj is situated in point $Q''1$ of the lower zone the buyer may admit an increment of price from P''_1, as long as the tonage $q''1$ is not modified since the substitution of C_j, for other coal of the already included in the optimizations will be more unfavourable economically - speaking.

According to the former, an availability of coal being given, the most favourable relation amongst the quality to be consumed and the price to be paid for Cj, is obtained when corresponding

../..

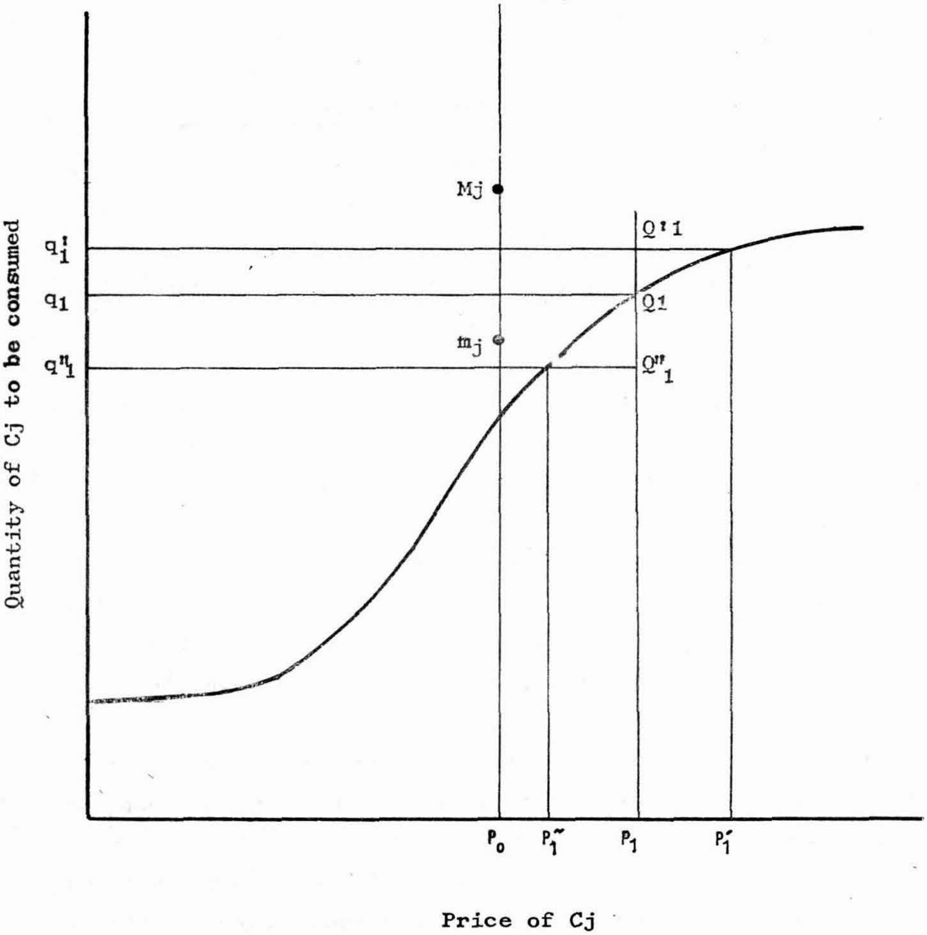

Figure 6 - Use of the "curves in S" for the acquisition of raw materials. The materials situated in the field above the curve are expensive. The price must be lowered or its consumption restrained.

The materials situated in the lower part of the curve are cheap. Its consumption must be raised up to the level marked by the curve.

Q to that material is situated on the curve on "S".

Really the curves on "S" do not present the continnous aspect which figures 5 and 6 have but staircased, as the one which - may be seen in figure 7. In this figure, the horizontal traces represent mixtures with the same composition, for this reason - the lowering of price of raw materials in these traces is due, solely, to the diminishing price of Cj. When the optimized - solution changes its base the quantity of Cj rises, the lowerig in price which is obtained already has two components: one duo to the decreasement in price of Cj, and the other produced by a new regrouping of raw materials, with which the total reduction in price is, in this case, proportionally superior to the one - obtained in the horizontal traces.

The practical application of the curves in "S" may be carried - out on any of the models of optimation of coals which is - - available, although it is preferible to carry out the study -- over the most evolved model, that is, the one which takes more into account the quality of the products obtained over latter - processes.

6. PRACTICAL APPLICATION OF CURVES IN "S" TO THE VALUING OF COALS

The tracing of curves in "S" previously exposed is really the - most simplest and elementary case. The study of the price - - consumption relationship, may be complemented simultaneously - with other questions related with the coal studied as well as - other parameters relative to the mixture, individual coals, -- coke etc.

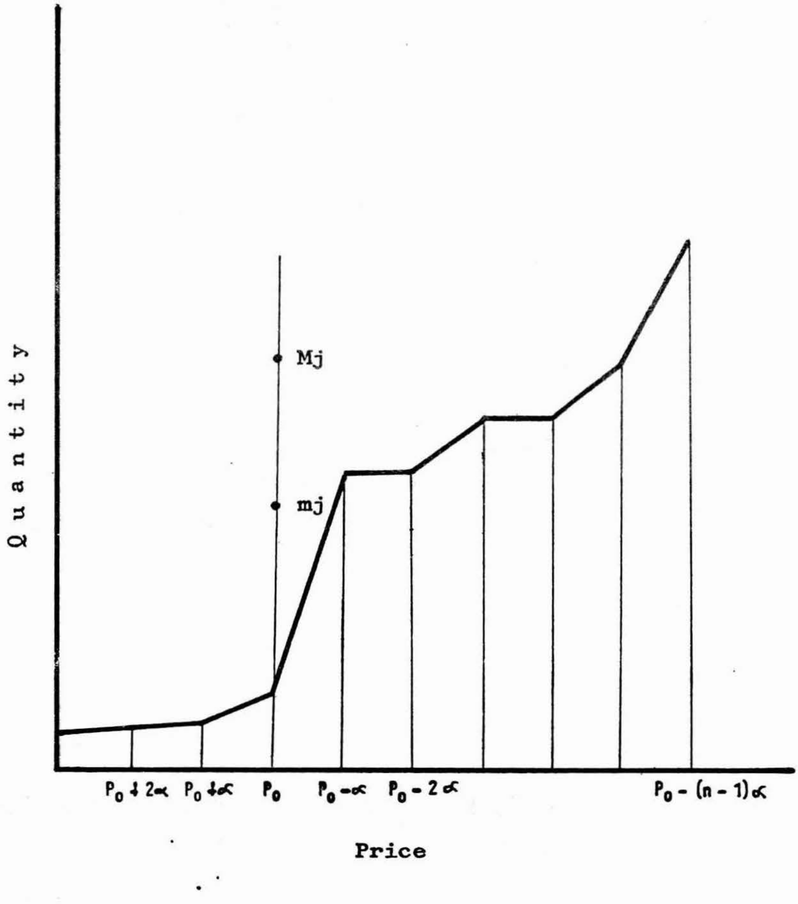

Figure 7 - Real aspect of an optimization curve "quantity - quality - price".

As examples of application of the curves in "S" may be - - indicated, without exahusting the subject, are the following:

a) Curves in "S" of a coal, modifying the availability limits of other coals.

b) Curves in "S" of a coal, modifying the price of other coals.

c) Curves in "S" of a coal valuing the modification of some of their characteristics for example, ashes and sulphur.

In figure 8 a real example of the evaluation of the - - price-consumption relationship for a coal is represented, - using as an objective function the minimum price of the - - mixture which fulfills determined characteristics to give out a desirable quality coke.

The fine trace line which cuts the curve in "S" (thick trace) represents the total price of the mixture, in millions of - dollars.

The real point of work (T) is found above the curve "S" for - which reason the consumption of this coal in the misture - should be drastically lowered, or rather lower in the order of 2 dollars its price, maintaining its consumption practically - constant.

In figure 8b the curve in "S" is represented by the same coal, applying, in this case, a mathematical model which includes - the valuing of the influence of the quality of coke in the - Blast Furnace (Model 3 of Ensidesa). Due to the fact that - such a coal is extraordinarely high in ashes and sulphur, - while the position of the working point was near the curve in

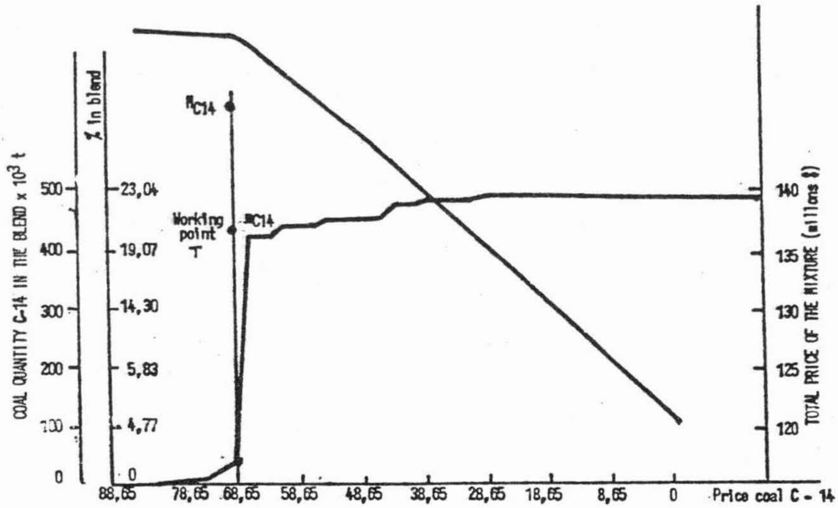

Figure 8a

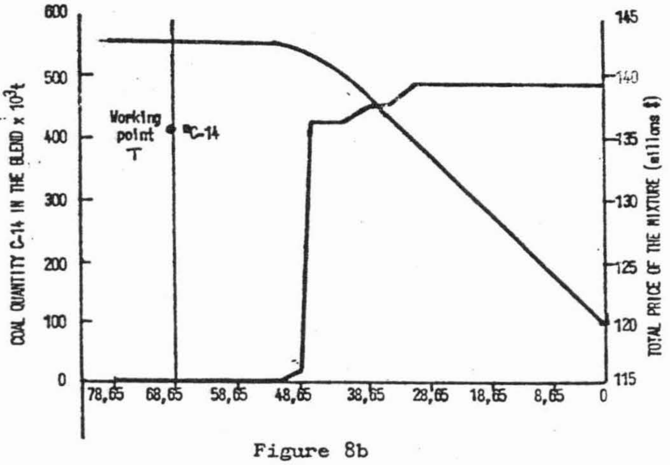

Figure 8b

"S" when it was optimized strictly to the price of the mixture (Model 1), when the influence of coke is valued in the Blas - Furnace, the position of the working point is very far from - the curve in "S", understanding that the use of this coal is - uneconomical.

The comparison between figures 8a and 8b is an example of the importance which the application of one or the other model may have when valuing a definite coal.

In figure 9 different curves in "S" are studied of the coal - from the previous example, keeping within the variacion field to a samall environment of the real price, with different - - availabilities of an average coal, which intervenes with it in the mixture.

In figure 10_a the evolution of coal consumption is represented (A-13, U.S.A. low in volatiles) in terms of the price of coal - situated in the "Aboño" Coals Park. In figure 10_b the - - parallel evolution of 5 coals is represented when price of - coal varies.

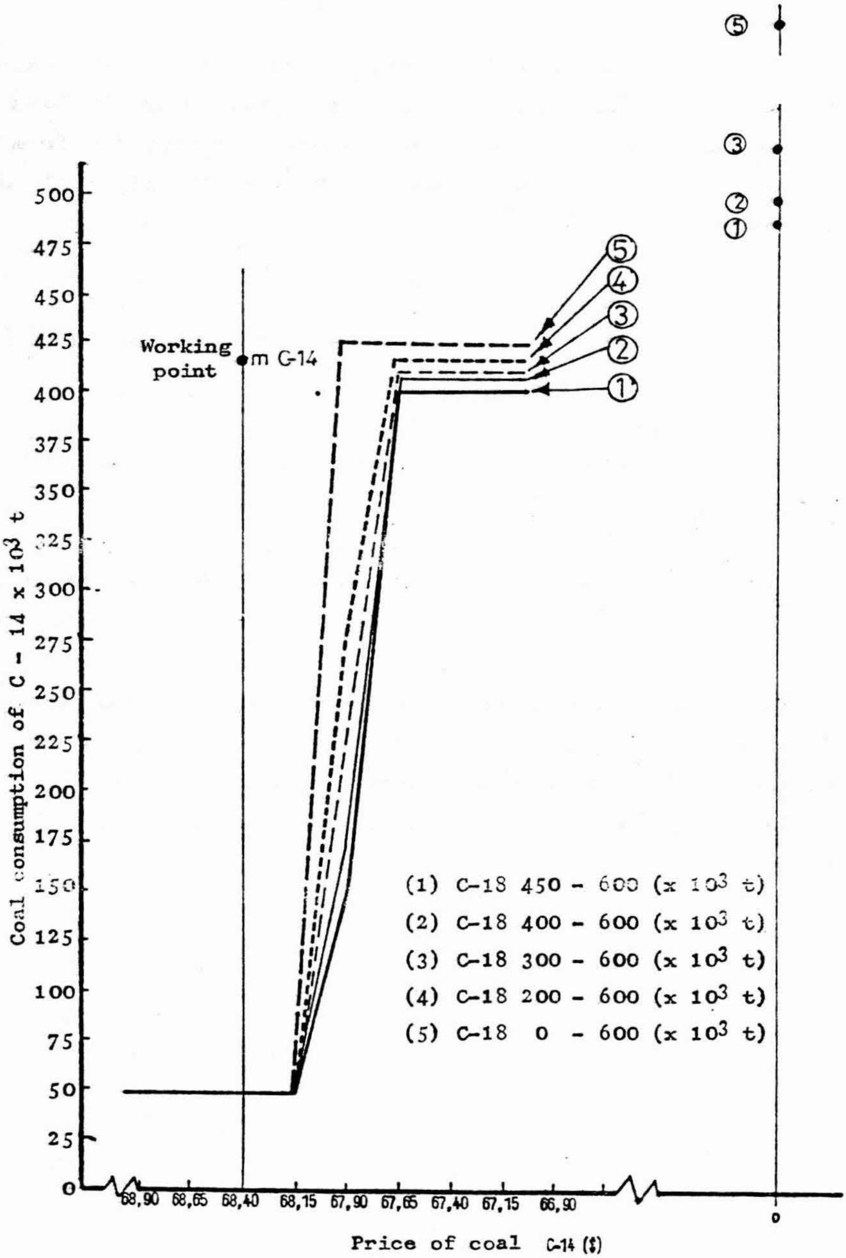

Figure 9 - Evaluation of the consumption of coal according to its price for availability of coal C-18.

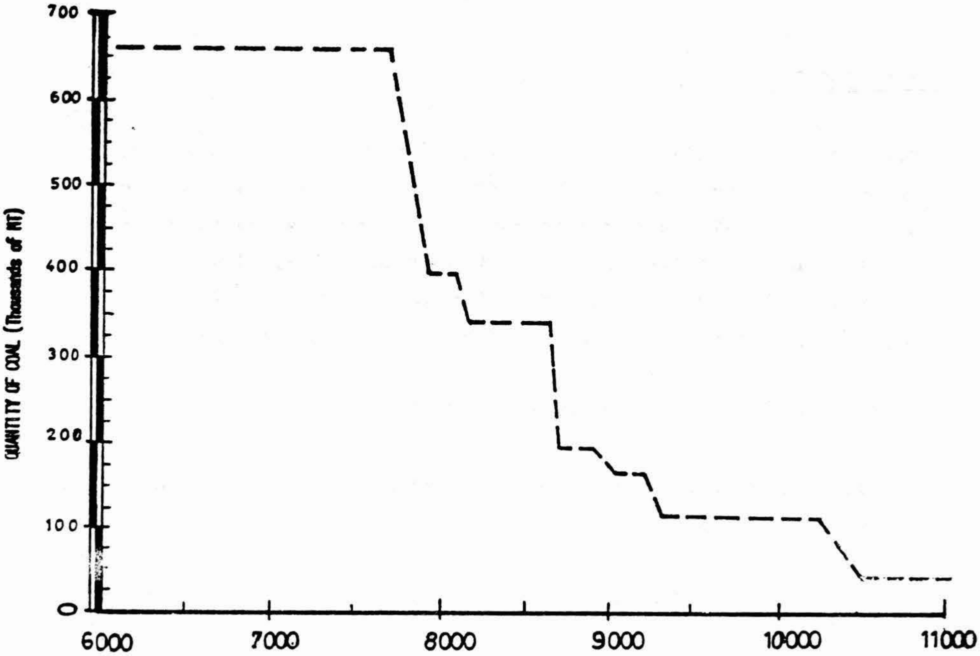

FIGURE 10a - Price of Coal Ptas./MT

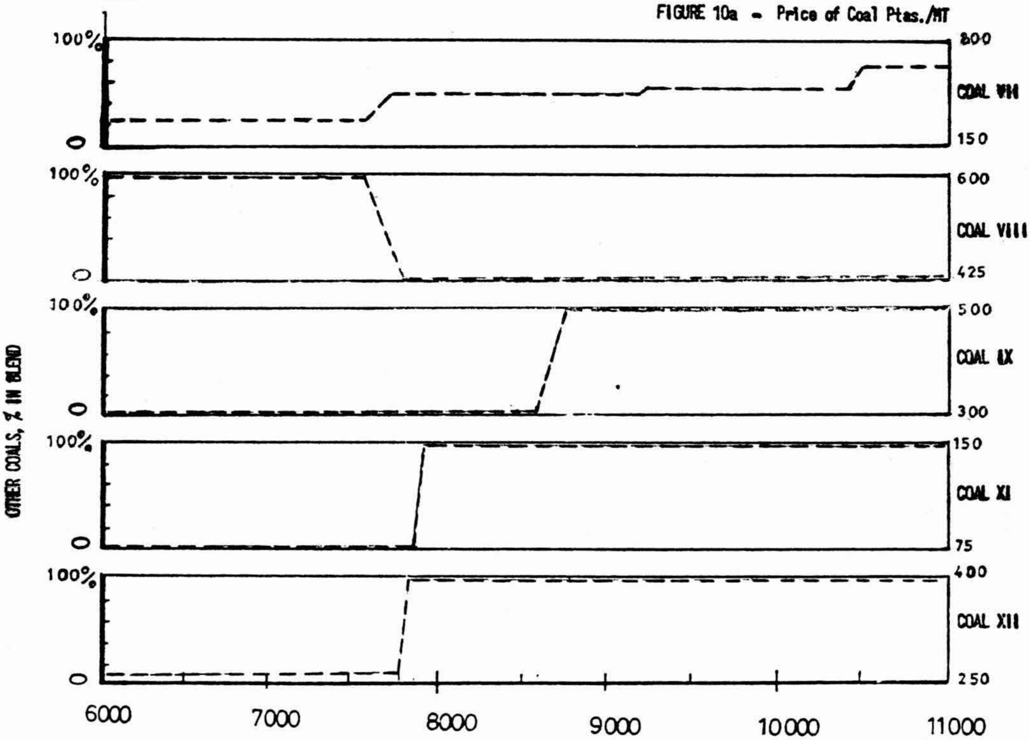

FIGURE 10b - Price of Coal Ptas./MT

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