Computer Supported Calculation and Evaluation of the Correct Composition of BOF Converter Slag

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Abstract

The paper presents the software package ‘ ***COAT – Control Optimization & Analysis Tool*** ‘ for calculation of the correct adjustment of the slag formers in the BOF process. In addition the software allows for evaluation of the results from various operating BOF shops. The software is easy to handle.
The metallurgical fundamentals and some aspects of the underlying model of the software are presented. The benefits and the saving potential from use of this software are demonstrated.

1. Introduction

An optimal and constant production process in a BOF shop is only possible by controlling the metallurgical process within close limits. The complex relation between the addition of slag formers and the steel quality is governed by well–established metallurgical equations, necessitating usage of computers to achieve the optimal result in real–time. This optimization is especially important with regard to the constantly increasing demands on the final steel quality. Depending on the quality of the input materials and the lance blowing practice, this is very often a difficult task to achieve. Especially in cases when low phosphorous and low sulphur contents have to be finally achieved in steel, the importance of the correct slag composition often receives insufficient consideration. The slag composition is not only of importance for the metallurgical results, it has also a great influence on converter lining life, on the steel yield, and therefore on the total cost of the BOF steel production.

In this paper we first present the metallurgical background leading to the model serving as a basis for the easy to use software package COAT, which is introduced in Section 3. We then describe the two parts of COAT, in Section 4 we present the calculation of the optimal additions of slag formers. In Section 5 the evaluation tool of COAT is described. It allows for controlling the success and the fine tuning of the addition of the slag formers. We finally discuss some practical examples from various BOF steel plants as a comparison of good and bad working practice. We close the paper by a summary.

2. Metallurgical Background

The quality of the used lime and dolomite is of great importance for the optimization of the blowing process. The degree of burning, varying CaO- and MgO-contents, the SiO_2-content, the H_2O-content in delivery condition and right before charging into the converter as well as the fine particles heavily influence the stability and therefore the metallurgical result of the

BOF process. Especially the fines in lime and dolomite have a great influence. Corresponding investigations revealed that lime and dolomite particles of a size of
below 5 – 6 mm get lost for the BOF process because they are extracted by the off gas system before reaching the bath surface; quite often up to more than 30 % of the amounts of added lime and dolomite get lost because of a too high degree of fines. Unfortunately the lime and dolomite loss due to too high fine content is not consistent; otherwise it could be easily compensated by adding correspondingly higher amounts of lime and dolomite. A separation between fine and coarse particles already takes place when lime and dolomite is filled into the storage bunker by forming a dumping cone. Depending on the ratio of fine and coarse particles, extracted from the bunker and conveyed into the converter, varying metallurgical results will be experienced. In order to achieve a more stable process many steel plants screen, especially the lime, right before charging it into the storage bunker or prior to charging it into the converter.

3. Introduction of COAT : Control Optimization & Analysis Tool

The software package is a joint product of Saar–Metallwerke GmbH and ISCA Prof. Louis, both located in Saarbrücken, Germany. Saar–Metall, leading expert in the production of BOF lance tips as well as of all kinds of water cooled copper fittings for iron, steel and metal making, supplied the metallurgical knowledge fundamental for the software package.
ISCA Prof. Louis, a company specialized in mathematical modelling of technological processes and the development of the corresponding software contributed this know–how in the production of the software package.
The software is easy to handle, it runs on any PC under Windows XP. Other platforms and the integration in productions systems are possible.

4. The Optimization Tool of COAT

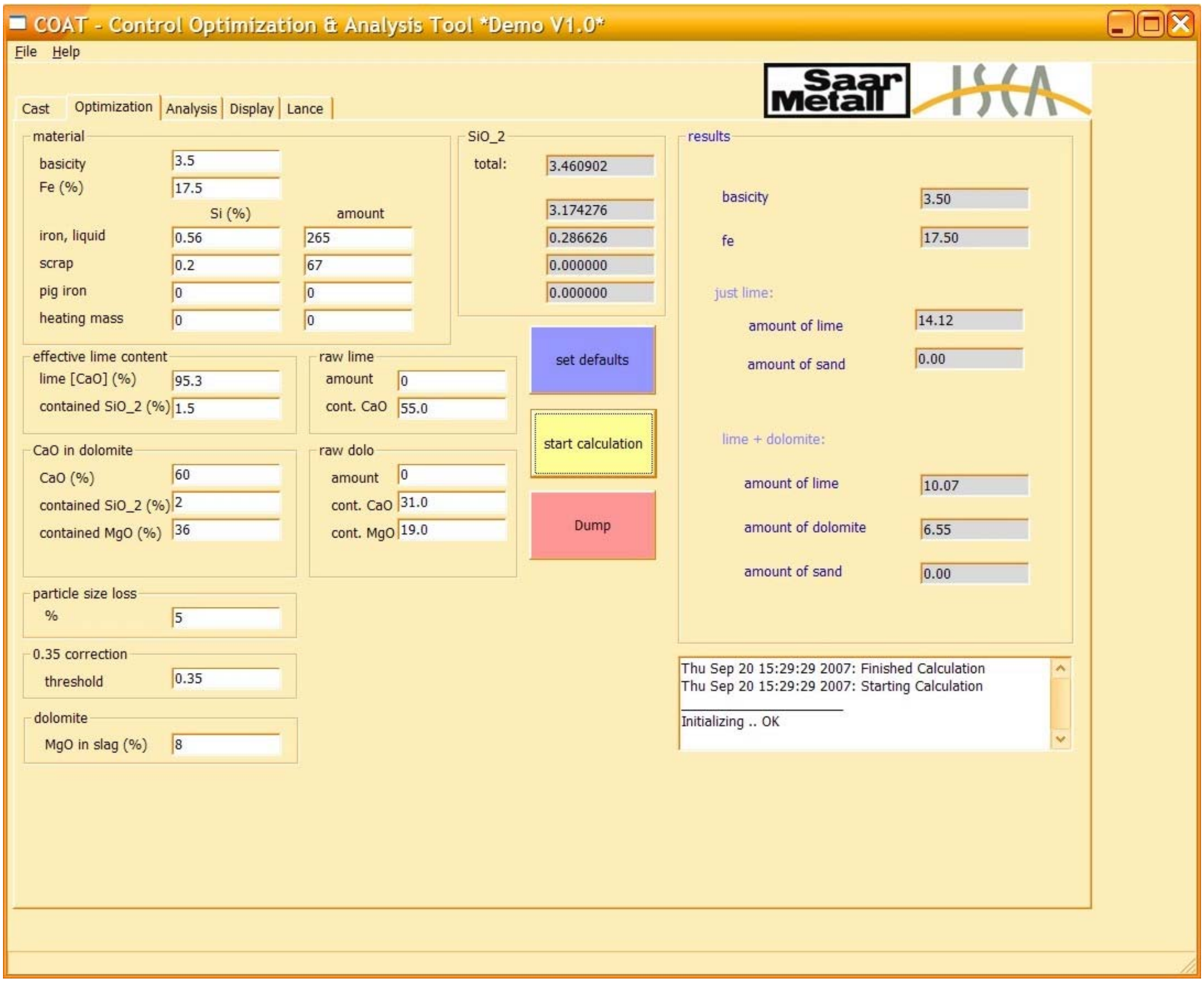
The computer model calculates the correct slag composition, and therefore the correct amounts of lime and dolomite to be added. The calculation model considers the chemical composition of the input materials, the saturation degrees of slags and desired metallurgical aim figures. The basis of the calculation is the slag basicity, the corresponding Fe-contents in slag in equilibrium condition and the aim phosphorous content in steel at blow end. Furthermore, on the basis of the slag analysis prior to tapping of the steel for each heat the lime loss is calculated. The figure for the lime loss can be used for the calculation of the following heat, so that a continuous adoption of the lime loss rate is ensured, providing better stability of the slag composition.

The COAT calculation model is not just a heat balance calculation, it is an optimization of the slag composition. Of course the result of this calculation can be easily adapted to an existing heat balance calculation software.

The correct calculation of the amounts of necessary slag formers to be added is a great help for the steel plant operator to minimize the consumption figures and therefore the cost of BOF steel making. Because of unawareness of the saturation contents, the BOF slag quite often is either below or above the saturation lines of technical BOF slags in the 3 phase diagram CaO-FeO-SiO_2, see [1,2]. The slags are therefore either super or under saturated. Under-saturated slag is especially detrimental for the converter lining in cases where the slag formers are also added too late during blowing, see [3,4]. Super saturated slag contains a more or less high undissolved share of the added slag formers, which protects the lining and usually even leads to converter build-ups. On the other hand super-saturated slag increases the slag viscosity, decreases the slag reactivity, providing no metallurgical advantages or, under curtain circumstances, even disadvantages. Even a saving of just 1 kg lime per ton of steel ensures a considerable saving potential per year, not only from less added lime, but also through lower iron losses due to lower slag volumes.

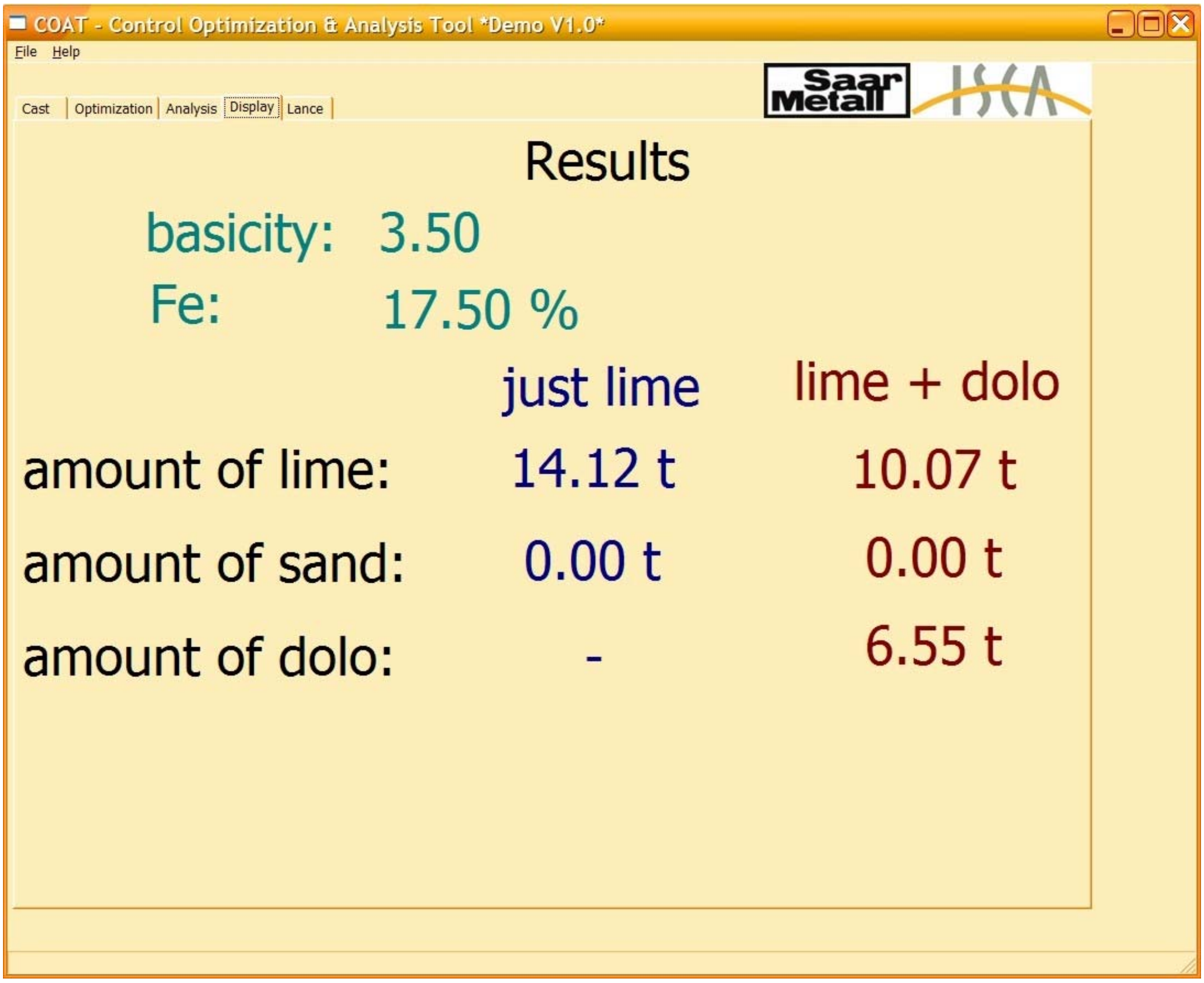
COAT also provides a proposal for a well adapted lance pattern. The lance distance to the steel bath surface is calculated in relation to the Si-content of the charged hot metal, i.e. on the existing amount of slag, the blowing hardness of the lance, resulting from the nozzle design of the lance tip or the oxygen exit velocity as well as the number of nozzles in the lance tip. It is clear that lance tips from different suppliers can have different designs for the same application, thus demanding a different lance pattern. The proposal of the software for the lance pattern is optimized for the Saar Metall lances, but can be adapted to the pattern for different lance suppliers, when their design is known.

The program starts with an introduction mask as shown in the following screenshot.



Screenshot 1: Input mask where basicity is defined as the ratio CaO/SiO_2

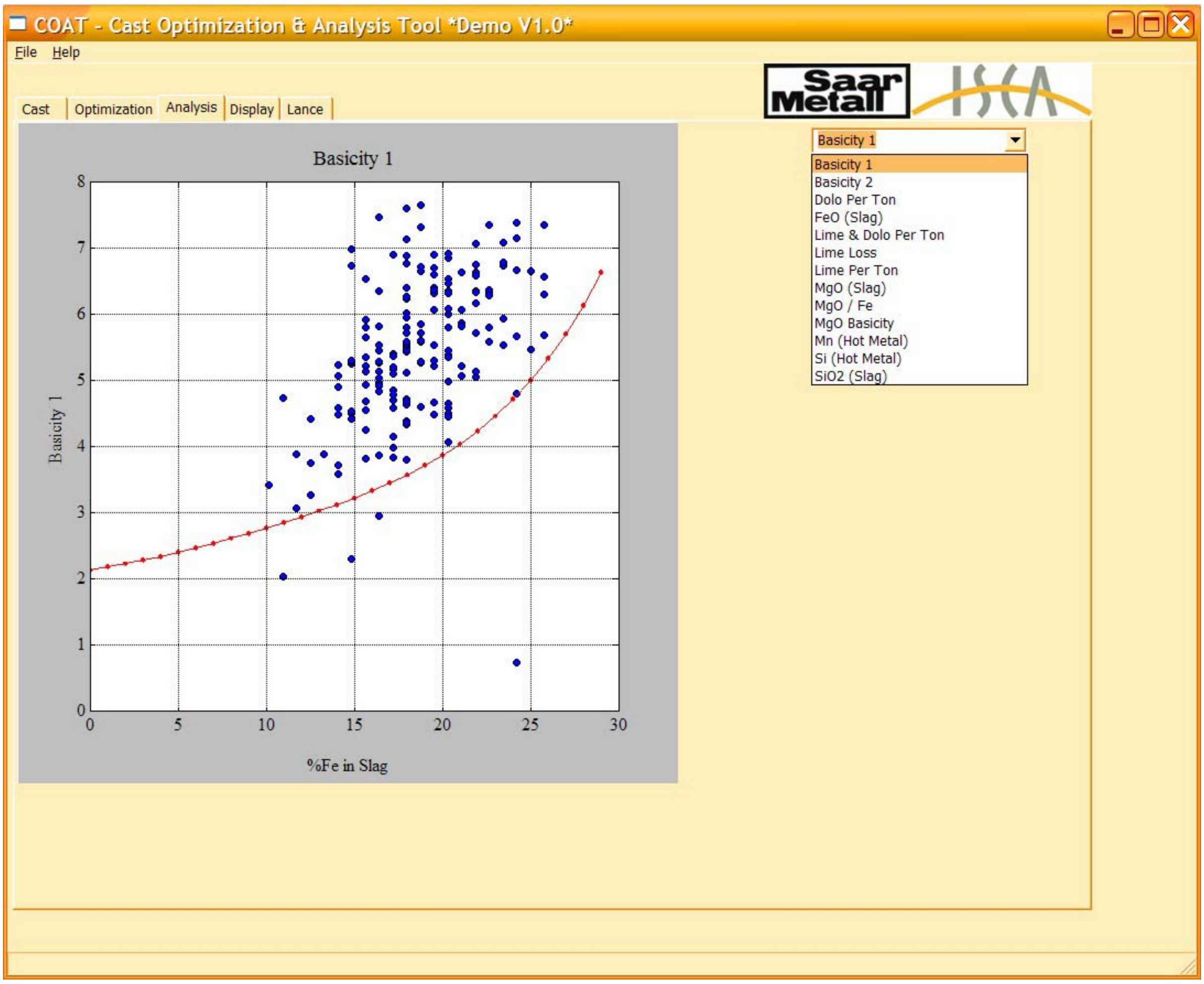
Here for example the Si content of the different slag formers are introduced. The final result of the optimization step is then given as shown in the next figure.



Screenshot 2: Easy to read results directly usable in the production

5. The Evaluation Tool of COAT

In order to optimise the slag composition in a BOF shop it is essential to continuously survey the slag composition. Precondition is of course, as it is very common in most of the BOF shops today, to take slag samples after each consecutive heat after blow end. A varying quality of the input materials can result in undesired changes in the process, and the metallurgical results. These figures are provided by an evaluation package of the COAT software. All relevant data of a heat are stored automatically in a data bank. This data bank is the basis of all calculation operations to be executed, which are necessary to run the result evaluation software. One possible outcome is shown in the next picture.



Screenshot 3: Example of the analysis tool, showing the relation between % Fe in slag and the basicity as the ratio CaO/SiO_2

The evaluation program can be started either to check individual heats or for a larger number of heats in certain time intervals. Furthermore heats from different shifts can be easily compared with each other. In case of trial series or test heats a fast and easy evaluation of the results is also possible. The results can be shown either as frequency distributions, including the corresponding average figures and deviations, or as specific relationships which are of special interest for the BOF steel maker. In the corresponding diagrams the equilibrium lines for technical slags are also found. These diagrams give immediate information of what has to be done in order to improve the results. Also slow progressing changes can be detected early, so that counter measures can be taken in time. Overall, the work of the BOF steel maker is very much facilitated by using the new software.

6. Discussion of various results achieved by the evaluation software

In the following a few examples are demonstrated. These examples come from various BOF shops, which are not identified here. For each evaluation step 2 diagrams are shown, i.e. one case with a bad result to be improved and in the second case which comes quite close to the ideal case, respectively to the set figures. Partly the differences are rather big.

In figures 1 and 2 are frequency distributions of the Si-content in hot metal to be processed by two BOF shops. Immediately recognisable is the shop where problems have to be expected during blowing, especially in the case that the lance pattern is not properly adapted to the differing Si-contents in hot metal.

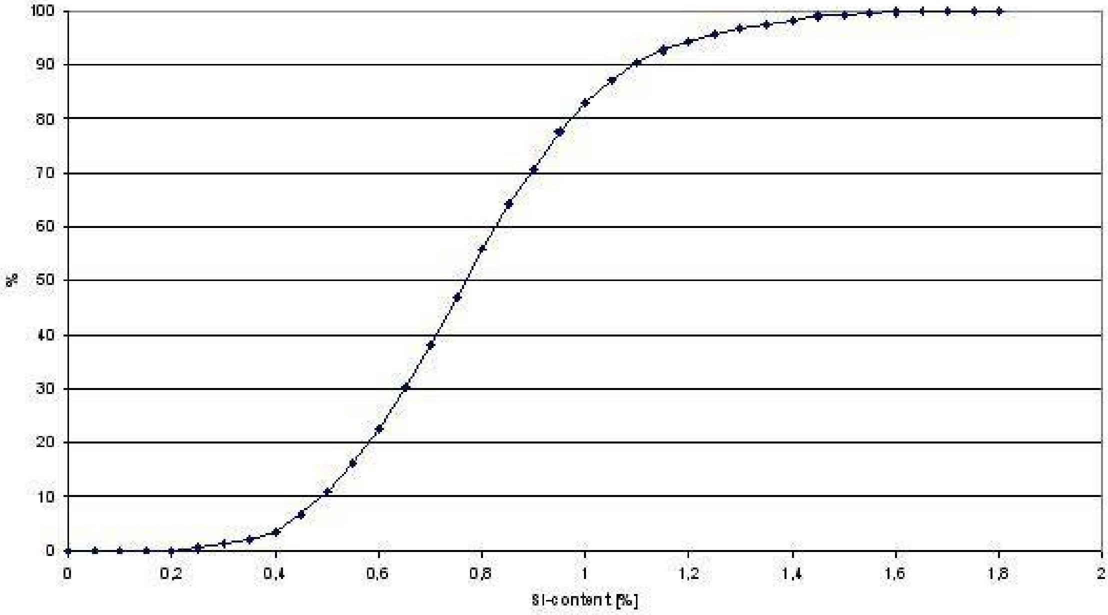


Fig 1: Si distribution in hot metal

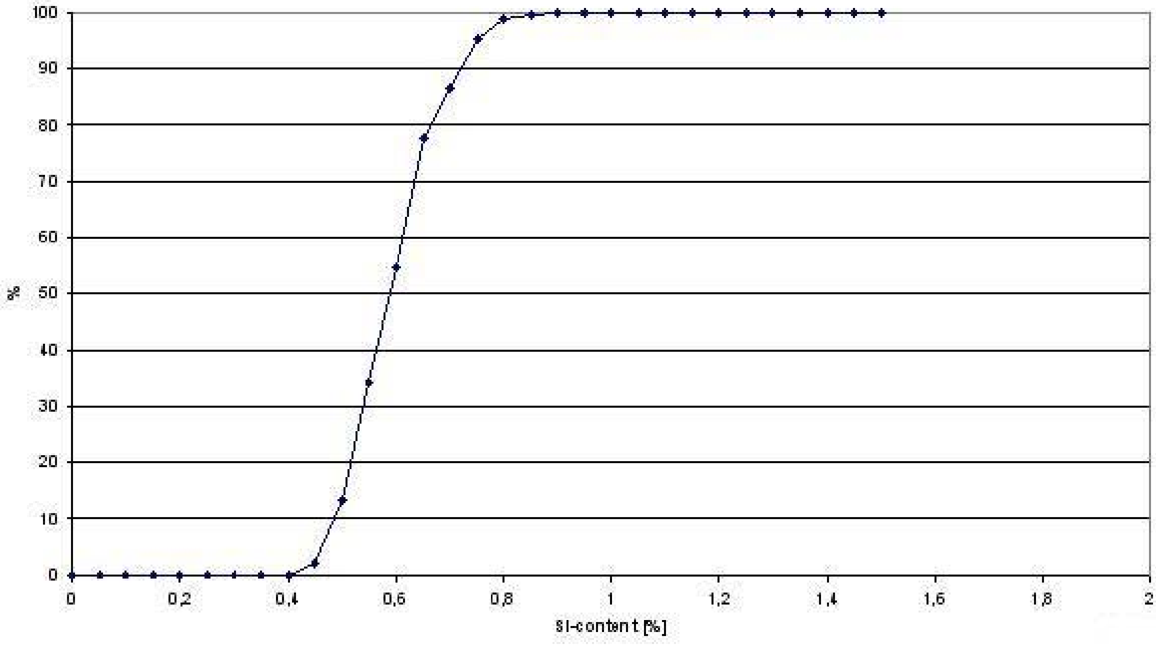


Fig 2: Si distribution in hot metal

Figures 3 and 4 show the frequency distribution of the Fe-content in slag. Figure 3 indicates a normal distribution, while figure 4 indicates not only a high average figure, but also a strong variation. The lance tip is not responsible for the bad result shown in figure 4, as is rather often assumed. The reason for the bad results is a lance pattern not properly adapted to the hot metal chemistry, or a wrong calculation of the addition of the necessary slag formers, including too high set figures for the basicity.

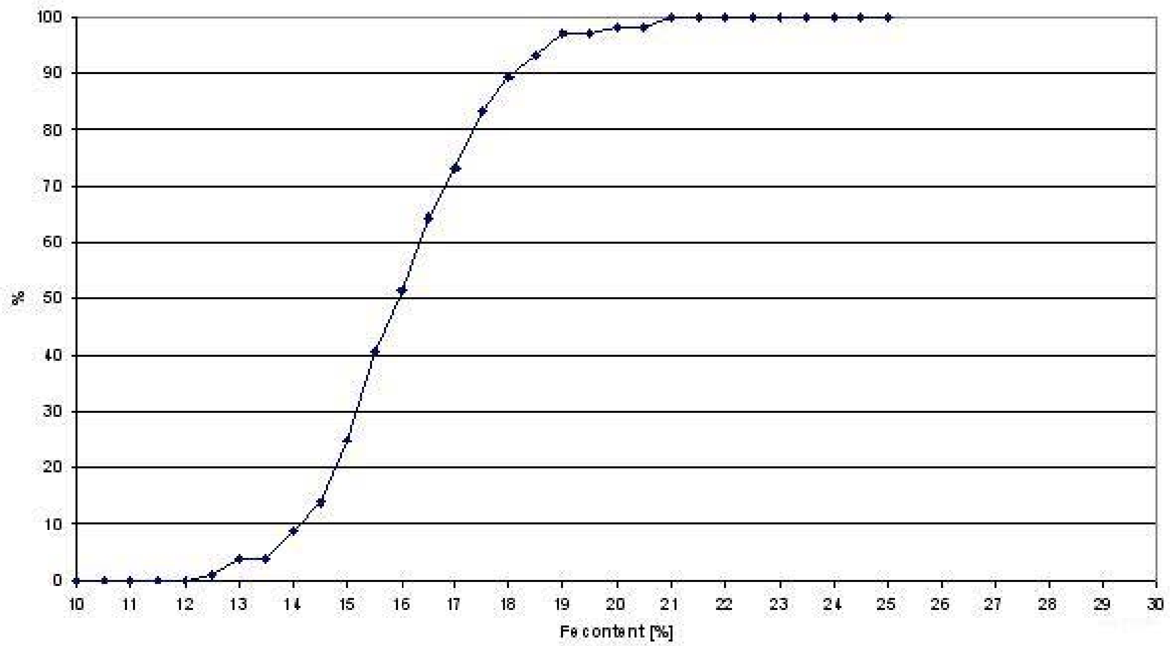


Fig 3: Fe distribution

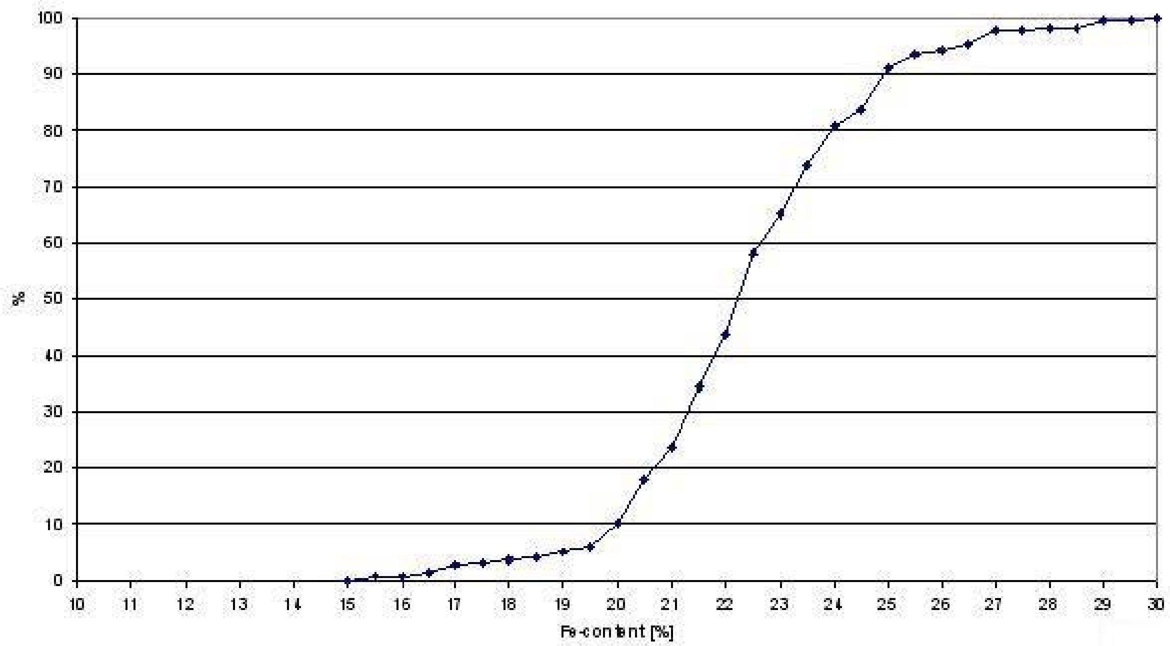


Fig 4: Fe distribution

Another reason is often the basicity figures, as clearly shown in figure 5a (heavily lime supersaturated slag) and figure 5b (lime undersaturated slag). In both figures the basicities (defined as relation CaO/SiO_2) are plotted against Fe –contents in slag. In figure 6 the results are positioned close to the saturation line which is shown in red. High basicities cause automatically higher Fe-contents in slag. In addition you see in this case which saving potential exists, not only refering to a too high lime addition rate, but also to too high iron losses from too high slag volumes (lower yield).

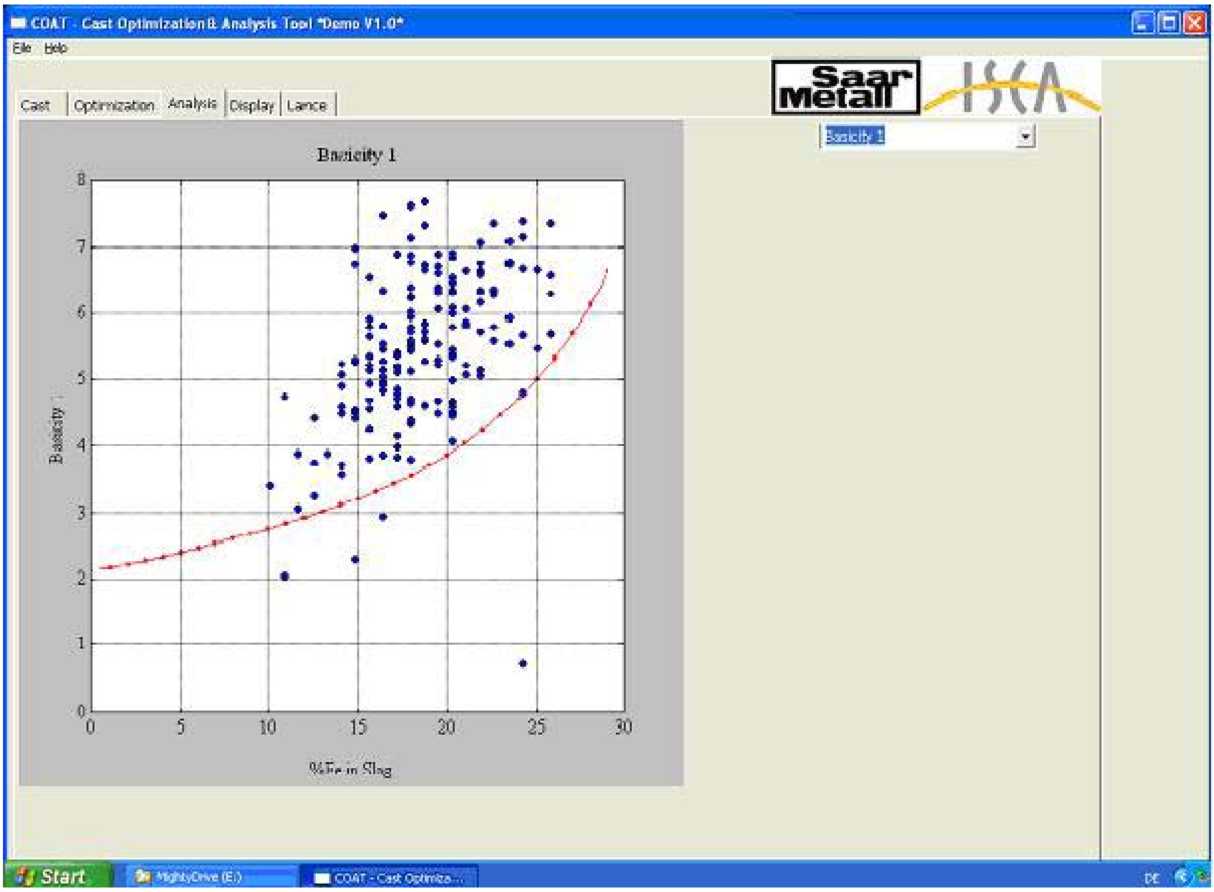


Fig 5a: Fe depending on basicity (CaO/SiO_2) (target line in red)

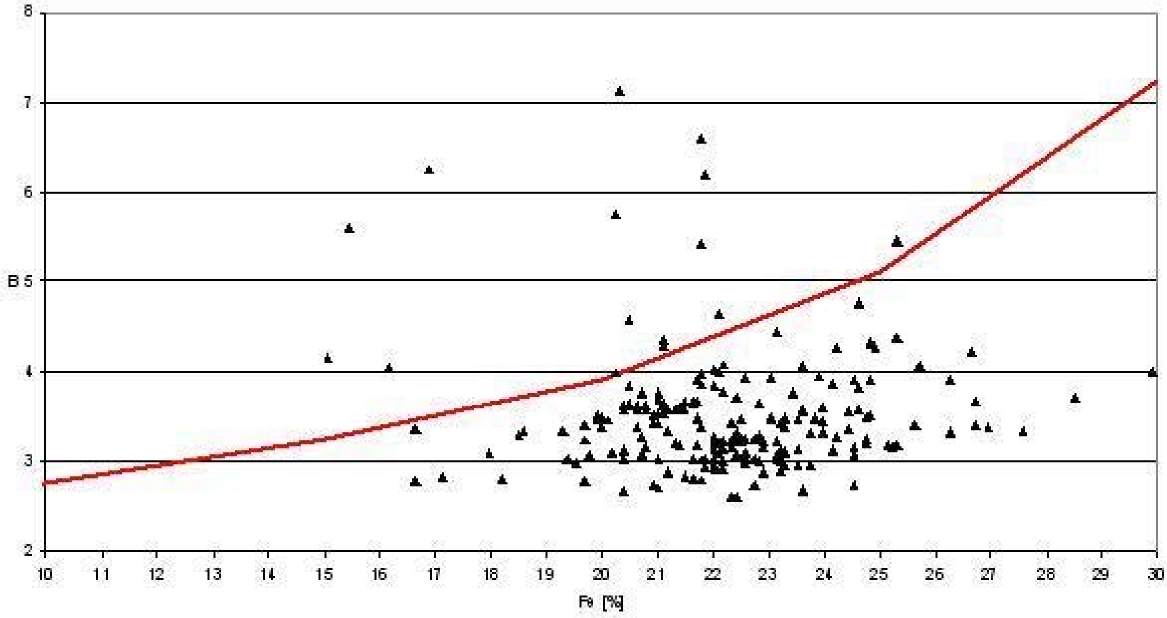


Fig 5b: Fe depending on basicity (CaO/SiO_2) (target line in red)

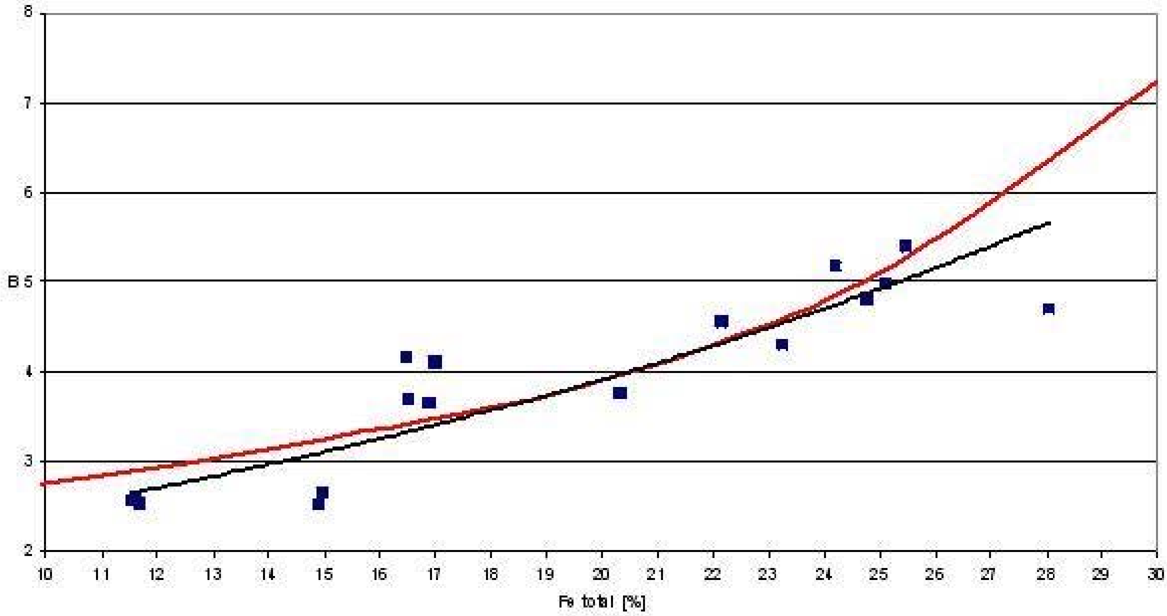


Fig 6: Fe depending on basicity (CaO/SiO_2) (target line in red)

It is sometimes found that the amounts of added lime and dolomite are calculated without regard to important input variables. Often a relationship on the Si-content in hot metal is not taken into account. In some cases work proceeds with constant or even decreasing lime/dolomite addition rates (Fig 7) for increasing Si contents in hot metal. Fig 8 indicates an example for the lime and dolomite addition rates per ton of hot metal independent of the Si content in hot metal. No clear line of relationship is discernible.

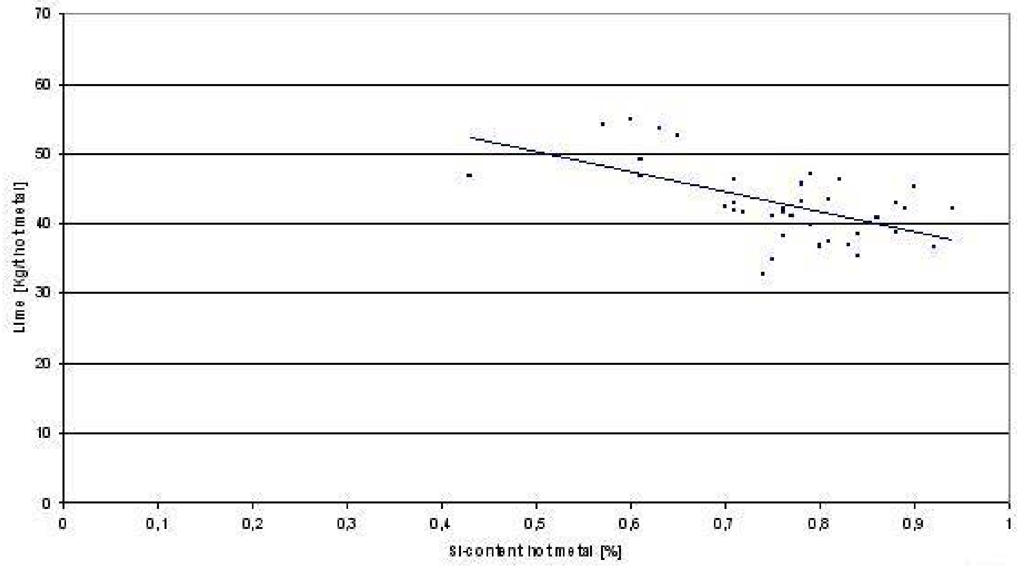


Fig 7: Lime addition depending on Si content in hot metal

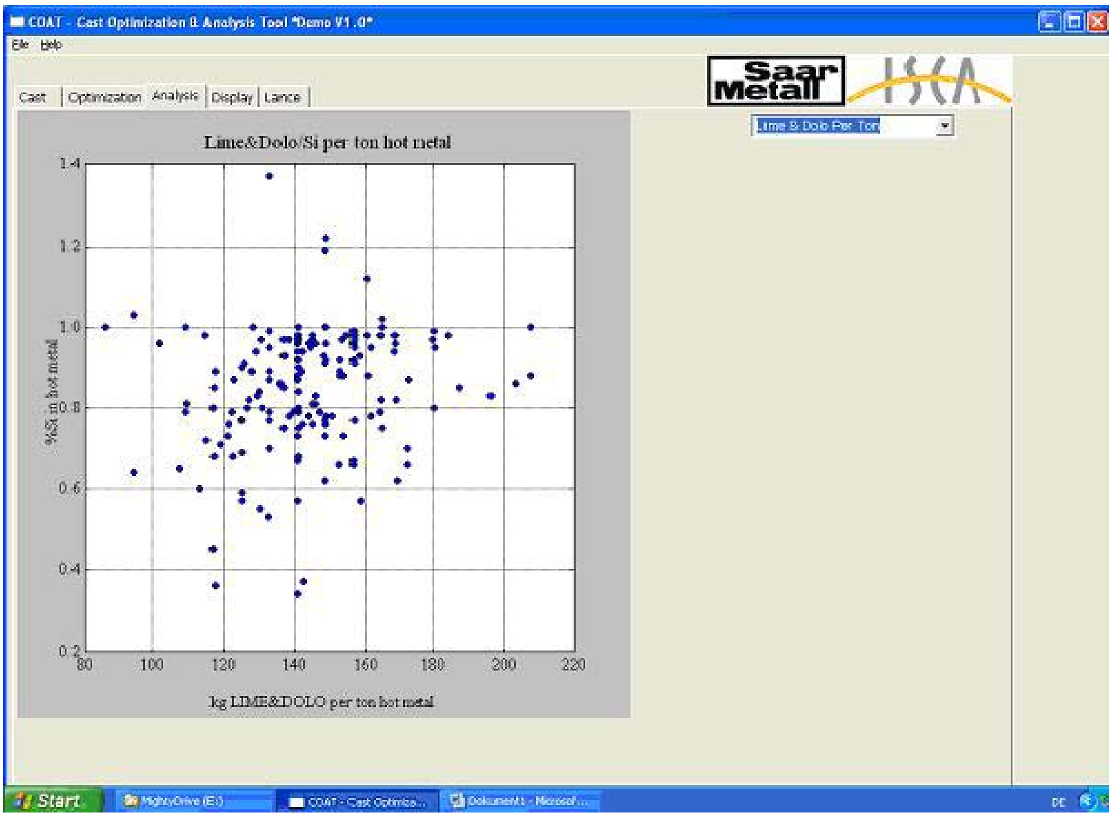


Fig 8: Lime and dolomite addition in dependence on the Si-content in hot metal

In opposition Figures 9 and 10 indicate a better working practice for the lime and dolomite addition rates. Despite small exceptions one recognizes a clear dependency of the addition rates on the Si–content in hot metal.

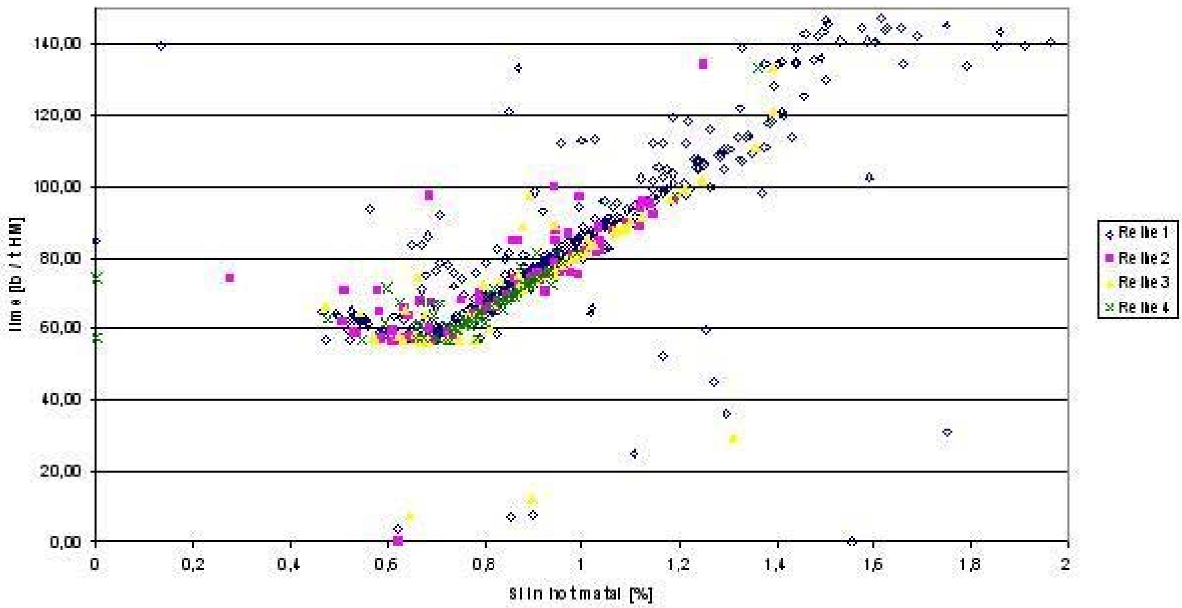


Fig 9: Lime rate in dependency on Si content

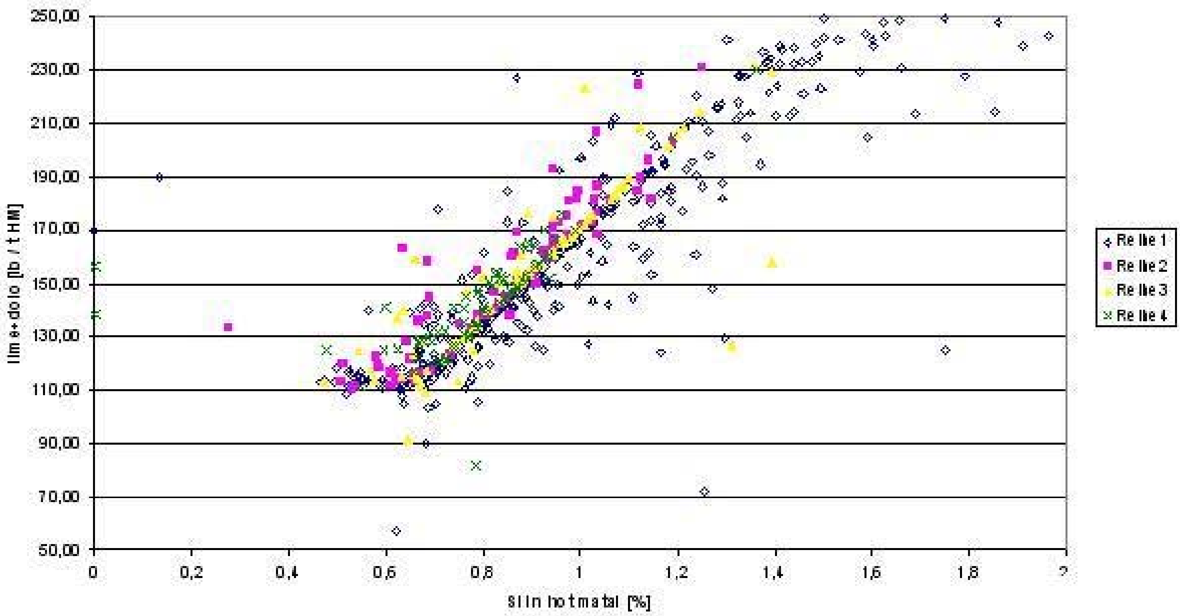


Fig 10: Burnt + dolo rate in dependency on Si content

In some BOF shops hot metal with high P-contents has to be processed. In order to avoid problems with dephosphorization and to maintain the turn down P-contents in steel in demand, an exact adjustment of the optimal slag composition is especially important. Figure 11 indicates which P_2O_5-contents in slag will provide which turn down P-contents in steel. In addition it indicates whether something has to be done with regard to the total slag quantity. Precondition is of course that the slag has a suitable composition for dephosphorization.

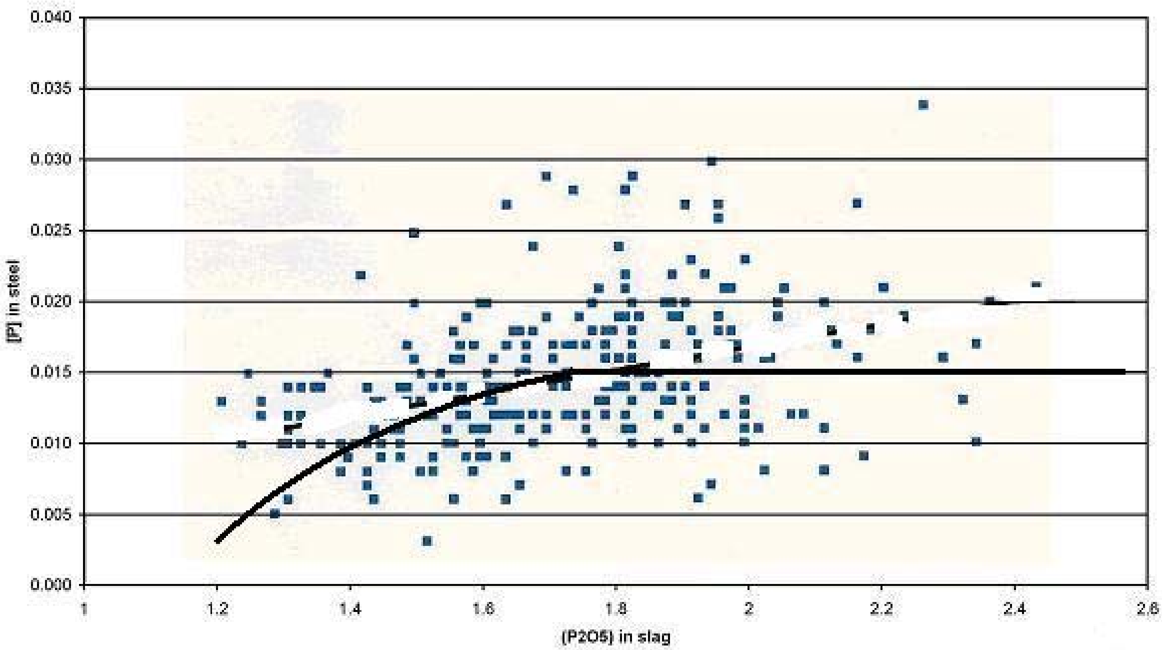


Fig 11: Dependency of P on P_2O_5

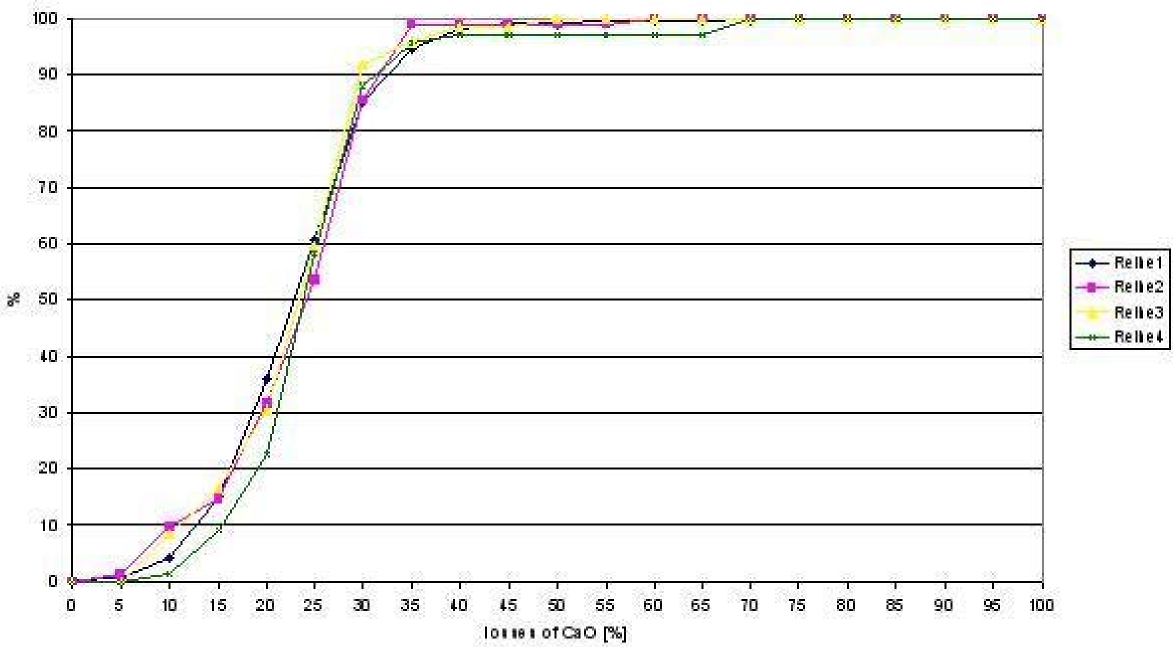


Fig 12: Losses of CaO from lime and dolo

Furthermore a statement about the lime losses can be made as shown in Figure 12. The given figures are calculated and a result of the theoretically achievable basicities, calculated on the basis of the additions, versus the achieved basicities, analyzed from the slag composition.

7. Summary

In summary, the whole software package for the adjustment of an optimal BOF slag composition by calculation the necessary amounts of slag formers to be added, is an ideal aide for the BOF steel plant operator. The provision of a qualified result evaluation program by “just pushing a button” allows for a continuous survey of the BOF process by the operators and the supervision personal.

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