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A Dynamic Process-control System for Steel Converters

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Since 1978 MEFOS, The Foundation for Metallurgical Research, Luleå, Sweden, has been continuously developing and extending the MEFCON software package for different types of converter processes in the steelmaking, non-ferrous, and ferro-alloy industries.

The package is based mainly on what can be regarded as an online computation of heat and mass balances. To obtain appropriate accuracy in these balances, measurements of input and output quantities, or equivalents, as well as temperatures, are required.

The process-control software makes the current status of the metallurgical process highly visible to the operator at all times. For example, the metal analysis, temperatures, slag analysis, and quantity are calculated continuously based on measurements.

The use of the system greatly improves the supervision of all the plant variables such as material flowrates, decarburization rate, oxygen yield, and off-gas flowrate and analysis.

Introduction

Since 1978 MEFOS, The Foundation for Metallurgical Research, Luleå, Sweden, has been developing and extending a software package for different types of converter processes. The package has been named MEFCON. This is a computer process model that works in true real-time.

The process model uses measurable variables, such as gas flowrates, off-gas flowrate, and off-gas analysis, and calculates second-by-second heat and mass balances. In this way, non-measurable quantities, like carbon content, bath temperature, and oxygen build-up in a converter can be made visible to the converter operator at all times during the processing.

Originally, the MEFCON system was used mainly for steel in LD and OBM converters with all their prefixes, but lately the system has been modified to work both on stainless steel converting in AOD and CLU, and on oxygen converting of ferro-alloys.

Description of the System

Layout

The MEFCON system comprises about 16 main software modules, each of which has its own duties. For example, the module MFOBM 8 carries out all the calculations concerning gas supplies to the system. The raw measured variables are fed into the system, and the calculated variables are then fed into the next module. Metal and slag analyses and bath temperatures are the final output. The layout of the system is shown in Figure 1.

The modules are connected together in execution chains. Communication between the modules is via a real-time database and a shared memory segment. The real-time database is divided into analogue inputs, calculated values, digital inputs and outputs, and analogue outputs. Plant-dependent constants are erected into the database.

Function

The MEFCON system is based mainly on what could be regarded as the second-by-second computation of heat and mass balances. The inputs to these balances are either directly measured values or calculated, non-measurable values.

Figure 2 shows the principal measurement points needed for the MEFCON system. The main mass balances are for oxygen, carbon, other metal components, CaO, MgO, and other slag components. The most critical balance is the oxygen balance, since it greatly affects the compositions of both the metal and the slag, and also the temperature calculation.

The oxygen deposit in the converter is calculated as the difference between the ingoing O_2 in gases and materials, and the outgoing O_2 in CO, CO_2, and dust in the converter gas. The O_2 is then 'distributed' among the slag-forming elements in the metal according to semi-equilibrium conditions. From this, the metal and slag analyses are calculated.

The heat balance is used to calculate the temperature of the metal and the slag. It takes into consideration physical heat in the ingoing materials, reaction heats, and element solution heat. On the outgoing side are physical heat in the converter off-gas and furnace heat losses, consisting of radiation losses and losses through the lining. The heat remaining in the converter is physical heat in the metal and slag. This heat is distributed to the metal and

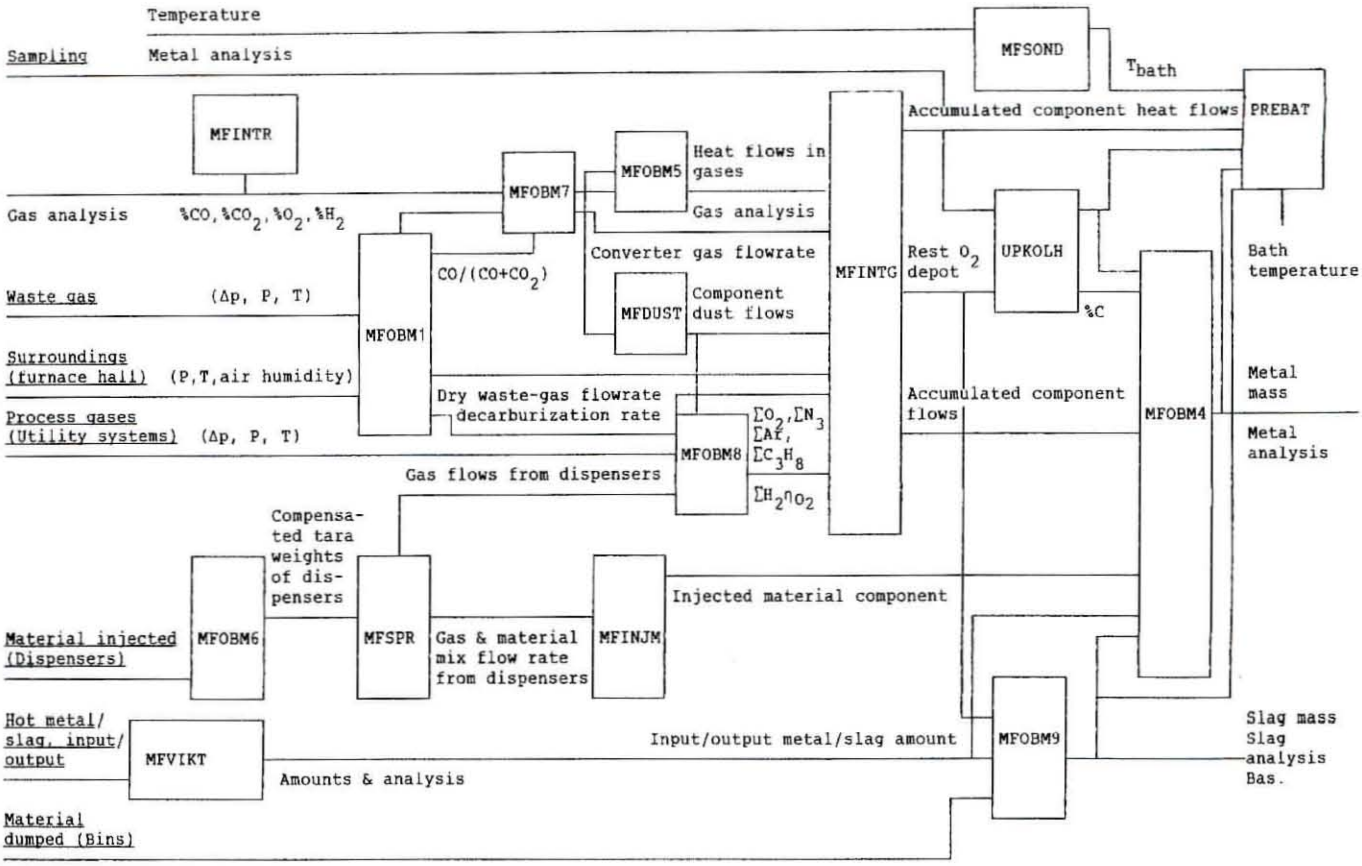

FIGURE 1. Simplified data flow diagram for MEFCON

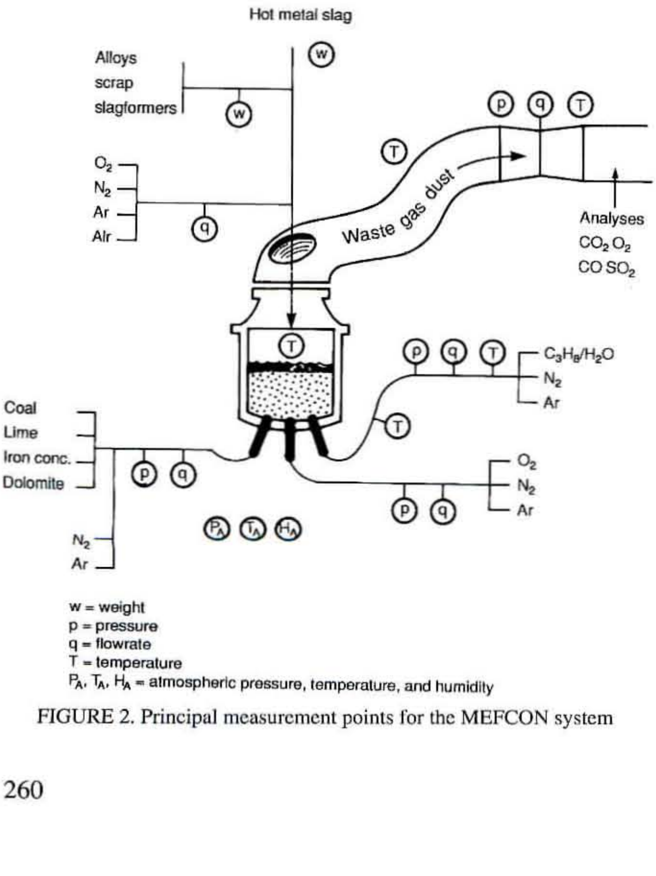

FIGURE 2. Principal measurement points for the MEFCON system

slag according to temperature-dependent enthalpy equations.

The calculated bath temperature is shown to the operator during the blow. Figure 3 illustrates the calculated bath temperature for two charges in a production-scale LD. The addition of sinter to the charge is indicated clearly by a temperature drop. The measured temperatures before and after argon bubbling are also shown.

The carbon content calculated from the mass balance is dependent on the given starting values, such as metal mass and analysis, and scrap mass and analysis. Accurate scrap analyses are particularly difficult to obtain. At the end of the blow, the starting values have a large effect on the relative accuracy of the calculated carbon content. So that a

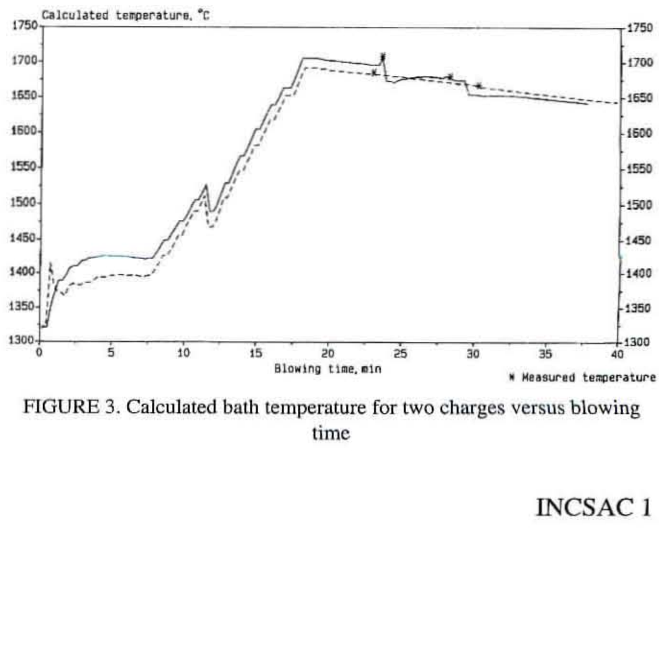

FIGURE 3. Calculated bath temperature for two charges versus blowing time

more accurate calculation of the carbon content at the end of the blow can be obtained, a model was developed for the determination of the carbon end-point, and the model was incorporated in the MEFCON.

The model states that

$$\%C = f\left(\frac{dq_{CO_2}}{dq_{O_2}} * \frac{dq_{CO}}{dq_{O_2}}\right) \qquad [1]$$

where q is the flow of CO and CO_2 in the off-gas and the O_2 flow. This function can be rewritten as follows:

% C = f (total ingoing O_2, dC/dt, % CO/(% CO + CO_2) in the converter gas). [2]

Since the values on the right-hand side of this expression are measured, or can be calculated from measured values, the carbon content can be calculated at the end of the blow with great accuracy.

Results

Oxygen Steelmaking

Since the MEFCON was first developed for oxygen steelmaking, most of the tests on the system have been conducted on these types of processes. Many tests have been carried out in the 6 t universal converter at MEFOS, and very good results have been obtained.

Of greater interest to the steel industry is that two tests have been carried out on a production-scale LBE converter. MEFCON was then installed in a mobile system that was linked up to the measurement points in a steel shop as needed.

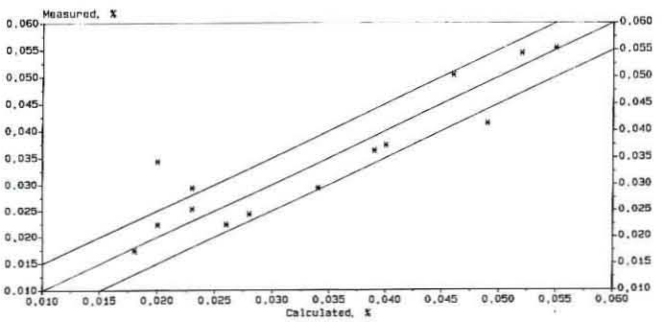

FIGURE 4. Carbon content after oxygen blowing

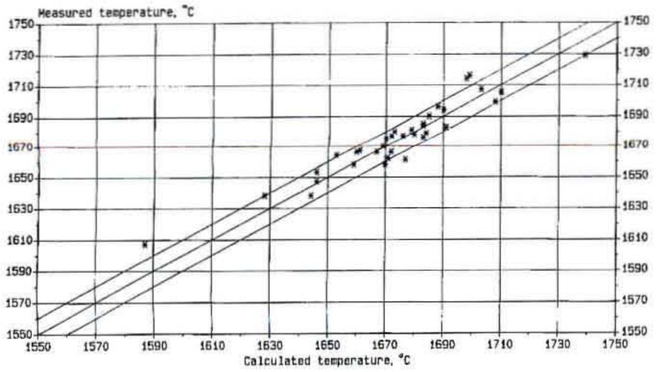

FIGURE 5. Calculated temperatures and measured temperatures at the end of the blow

A third test campaign, of 6 to 8 weeks' duration, was carried out at a steel shop during the third quarter of 1991.

The results of the plant trials show that the calculated values for end-point carbon content, end-point bath temperature, and total metal and slag analyses, were very accurate. Figure 4 compares the calculated carbon content at the end of the oxygen blow with the analysed carbon content at that time. Figure 5 shows all the measured temperatures for 24 charges versus the calculated temperatures.

The iron oxide content of the slag during the blow is of special interest to converter operators. With the MEFCON system, the operator can obtain an instant view of the iron oxide content of the slag and also the amount of iron oxide formed; in other words, the total oxygen content in the slag. Figure 6 shows the iron oxide content in the slag for two charges, one of which was overblown. This situation was detected by MEFCON. If the system had been operational, an alarm would have warned the operator, who would have responded accordingly.

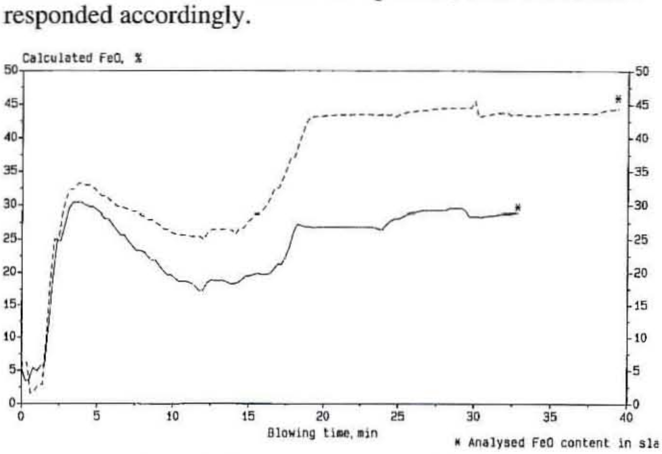

FIGURE 6. FeO content of slag versus blowing time

Stainless-steelmaking

In stainless-steel production there are other parameters that are of interest to the operator. Carbon content and temperature are, of course, important here, but the Cr_2O_3 content of the slag and the decarburization rate are also of great interest. The MEFCON system supplies the operator with this information on a continuous basis.

To date, the MEFCON version for use with an AOD converter has been tested in the 6 t converter at MEFOS. Figure 7 shows two intermediate values calculated by

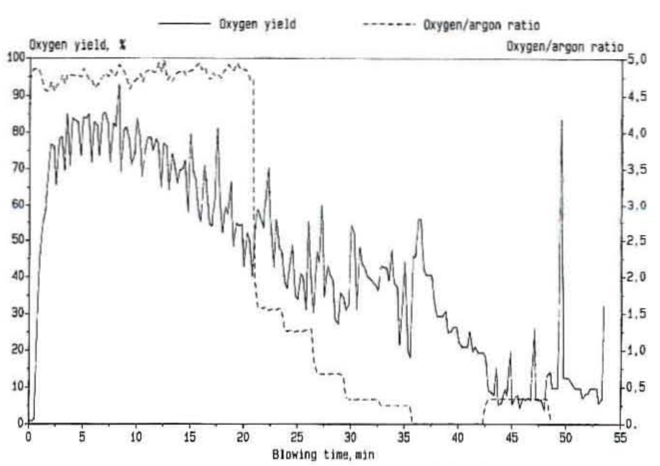

FIGURE 7. FeO content of slag versus blowing time

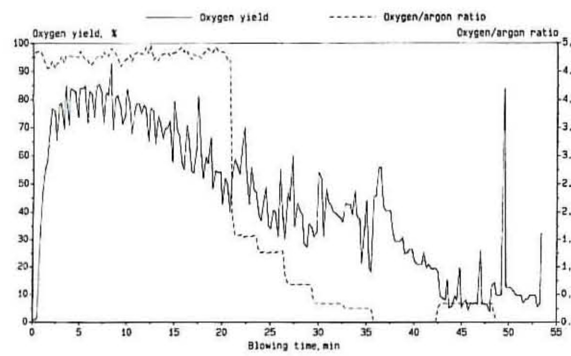

FIGURE 8. Oxygen build-up in slag and decarburization rate during AOD converting

MEFCON: the decarburization rate and the oxygen/argon ratio. These values can be presented to the operator, but they are also used in further calculations; for example, the oxygen in the converter available for the formation of slag (Figure 8).

At the end of decarburization, the calculated oxygen build-up in the converter showed the operator the amount of ferrosilicon needed for reduction. During the whole blow, the bath temperature was also visible to the operator, and excessive temperatures, and therefore excessive chromium losses, could be avoided.

It is planned to carry out plant trials with the MEFCON AOD version at a stainless-steel plant during the winter of 1991/1992.

Conversion of Ferroalloys

The MEFCON system has also been modified to calculate the status of metal and slag during the decarburization of various ferroalloys.

The conditions for slag formation in a ferro-alloy converter are different from those in a steel converter. This means that the distribution equations for the calculated oxygen free from slag formation are also different.

To date the system has been tested only in the 6 t converter at MEFOS. The results show that the process can be monitored very successfully and that critical parameters, such as oxygen yield and oxygen deposit available for slag formation, can be controlled (Figure 9).

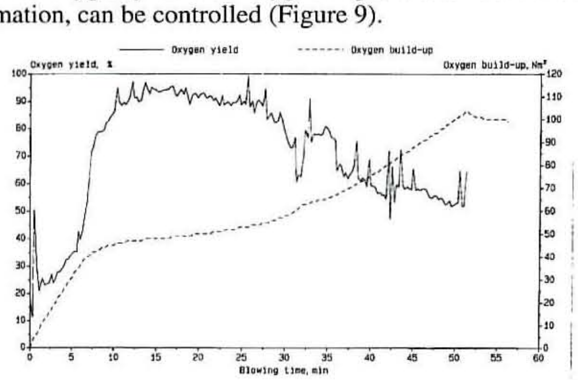

FIGURE 9. Oxygen yield and oxygen build-up in slag during ferroalloy converting

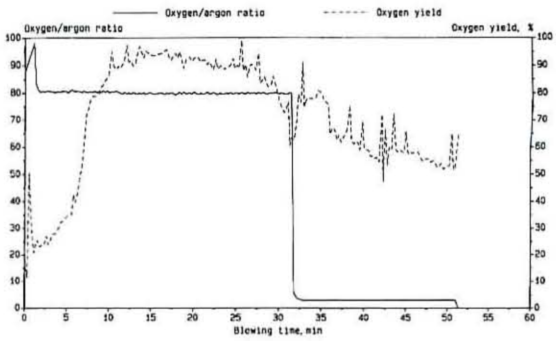

FIGURE 10. Oxygen/argon ratio and oxygen yield during ferroalloy converting

Figure 10 shows how the oxygen yield changes when the gas mixture (oxygen/argon ratio) occurs during a blow.

Figure 11 shows the calculated carbon and MnO in the slag during a conversion in the 6 t converter. The change in the MnO content when FeSi was added to the melt is noticeable.

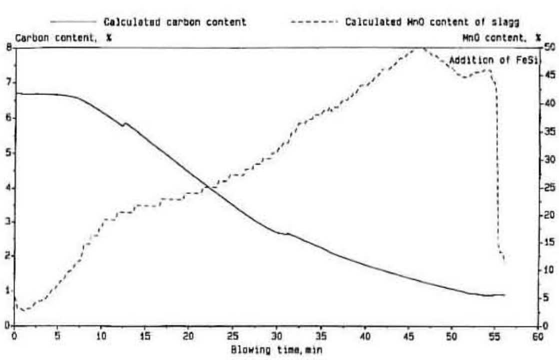

FIGURE 11. Calculated carbon and MnO content during ferroalloy converting

Conclusion

The MEFCON system is a very flexible tool for improving the supervision and control of converter processes. Since the system depends only on measured values and thermodynamic equations, no statistical data are needed for good performance. This means that the changes that occur during a blow are 'observed' by the system, and the operators are accordingly notified on a real-time basis.

The MEFCON system has so far been developed for three different converter processes: oxygen steelmaking in LD or OBM, stainless-steelmaking in AOD or CLU, and ferroalloy converting. The system has been proved on an industrial scale for oxygen steelmaking, and will soon be tested for stainless-steelmaking.