SMS SIEMAG BOF PROCESS MODEL: STABLE AND OPTIMIZED PERFORMANCE UNDER SUBOPTIMAL CONDITIONS [1]

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Abstract

Automation in the steel industry has played a crucial role in enhancing safety and productivity as well as in facilitating the steelmaking operation. For proper functioning of the Level 2 model, the variation in the input conditions should be minimal. But this is actually very difficult to achieve as most of the steel plants have very high fluctuations in their input conditions, such as hot metal weight and chemistry, scrap type and chemistry, flux and coolant chemistry. These conditions may vary on a heat to heat basis and in some steel plants some of the important parameters are not known. This paper studies the effect of the input conditions on the end-of-blow result, for example errors in hot metal weight and carbon analysis. Trials were performed in steel plants to see the actual conditions and the model was tuned to negate the errors as far as possible. Emphasis was made on a correction calculation based on an in-blow measurement and the detection of the end of blow via waste gas analysis to achieve the carbon and temperature aim.

Key words: Basic oxygen furnace; Process model; Dynamical decarburization; Automation; Duplex process.

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1 TYPICAL PROCESS ROUTE

A typical process route of a Basic Oxygen Furnace (BOF) steel plant is shown in Figure 1.

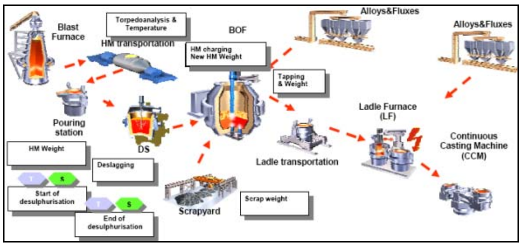

Figure 1: Typical process route of a BOF steel plant.

2 BOF PROCESS MODEL

Process models for the BOF processes are utilized in a large number of BOF steel plants around the world. In the last few years it has become obvious that only with the help of metallurgical mathematical models can a complex process like BOF be run in an optimum manner in respect of charging materials and the available equipment. Several steel plants have developed models for their own process, tailored to their equipment and their special environment. Experience shows that the transfer of such models to a different steel plant with different technological conditions does not fulfil the expected goals. Considering this experience, SMS Siemag AG has developed a model with structure and properties that allow transferability to other plants and installations.

The BOF model with all possible functionalities has been designed to provide a fully computer-controlled blowing process. The operators are informed about all current activities in an easy and convenient manner. The implementation of such a model definitely improves the performance of production. The basis of the control procedure is the calculation of charged materials, determination of the oxygen quantity that has to be blown and optimum choice of blowing pattern.

Automatic process control by the BOF model ensures the exact adjustment of the following process parameters:

- steel temperature
- amount of steel
- carbon content
- phosphorus content
- final analysis after tapping
- FeO content in slag

The model predicts and detects the critical point and end point of the process by using the information available from process measurements such as laboratory and waste gas analysis. It estimates charge materials like hot metal, scrap and slag-forming agents as well as process gases such as oxygen, nitrogen or argon. The prediction calculation is performed for different technological steps before, during and after the oxygen blowing. The mathematical core of the BOF model is the solution of mass, oxygen and energy balances based on the main reactions ongoing in the converter, compare Figure 2.

$$
\begin{aligned}
\{O_2\} &= 2[O] \\
[C]+[O] &= \{CO\} \\
[Mn]+[O] &= [MnO] \\
[Fe]+[O] &= [FeO] \\
[Si]+2[O] &= [SiO_2]
\end{aligned}
$$

$$
[FeO]+[C] = [Fe]+\{CO\} \qquad K_c(T) = \frac{a_{Fe}\,p_{co}}{a_{FeO}\,a_c}
$$

$$
5[FeO]+2[P] = 5[Fe]+[P_2O_5] \qquad K_p(T) = \frac{a_{Fe}^{5}\,a_{P_2O_5}}{a_{FeO}^{5}\,a_p^{2}}
$$

Figure 2: Basic reactions considered in the mass, oxygen and energy balances.

The mathematical model takes into account the following characteristics:

- Dividing of the decarburization treatment into two different periods separated by the critical point of the process (main and dynamic decarburization) under consideration of the premature oxidation of Si and Al, compare Figure 3
- Process continuity concerning decarburization speed at the critical point, compare Figure 4
- Oxygen balance, compare Figure 5
- Energy balance.

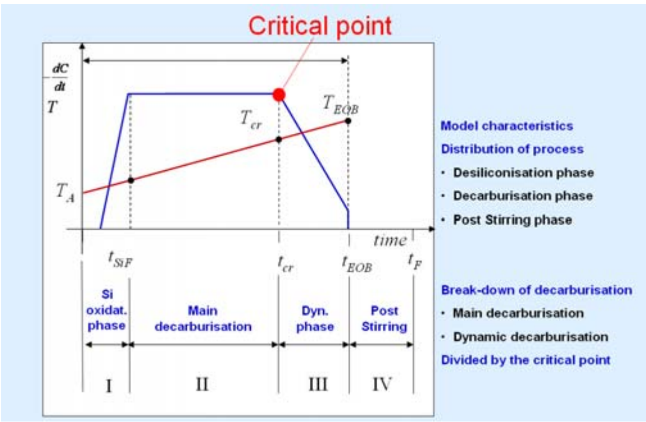

Figure 3: Process phases of the BOF process.

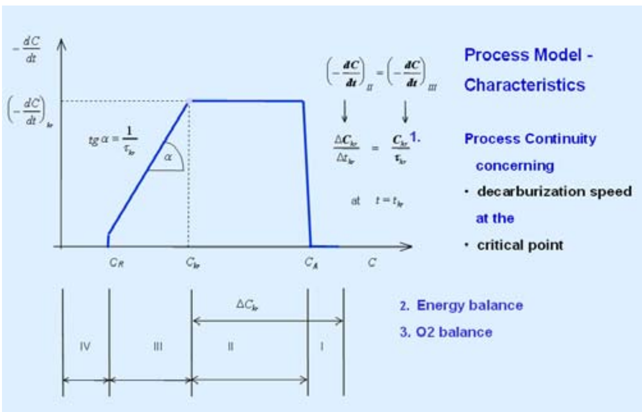

Figure 4: Decarburization kinetics of the BOF process.

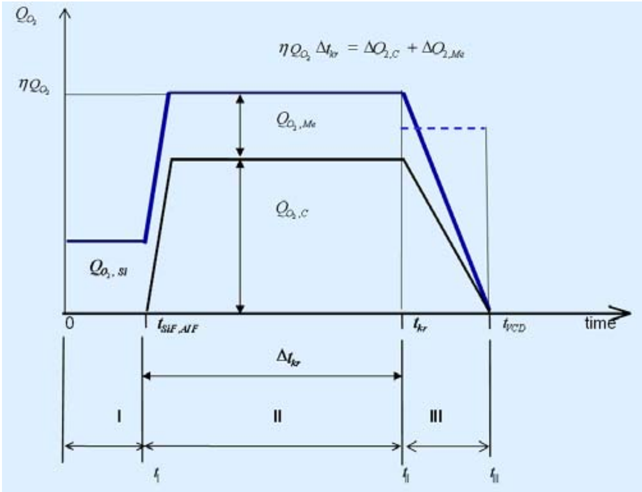

Figure 5: O_2 balance of the BOF process.

The figure below gives a general overview of all main functions and features of the model.

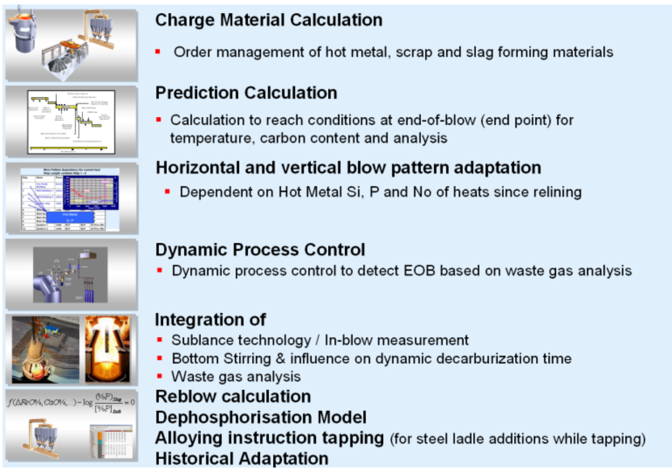

Figure 6: Main BOF model functions and features.

One of the principal features of the process calculation is the process prediction. It includes an overview of charged materials, process gases and technological actions that have to be performed in the treatment.

It concerns:

- Weight of hot metal
- Weight of scrap
- Composition of scrap ordered according to the customer-specific scrap menus
- Weight of the iron ore and/or sponge iron (DRI)
- Weight of additional heating materials (C, FeSi)
- Amount of lime, dolomite or other agents added during blowing
- Basicity of the final slag
- Required gases (oxygen, argon, nitrogen)

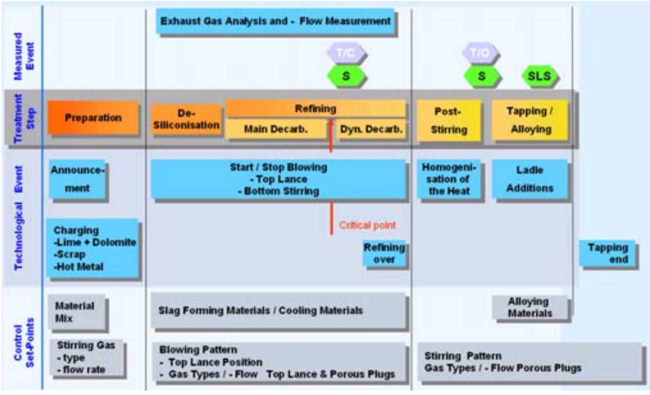

Figure 7: General BOF process overview.

Legend for measured actions:
S – steel analysis
SLS – slag analysis
T/C – temperature and Carbon measurement
T/O – temperature and Oxygen measurement

Requirements regarding input data, practice data and the supplied setpoints are shown in Figure 8.

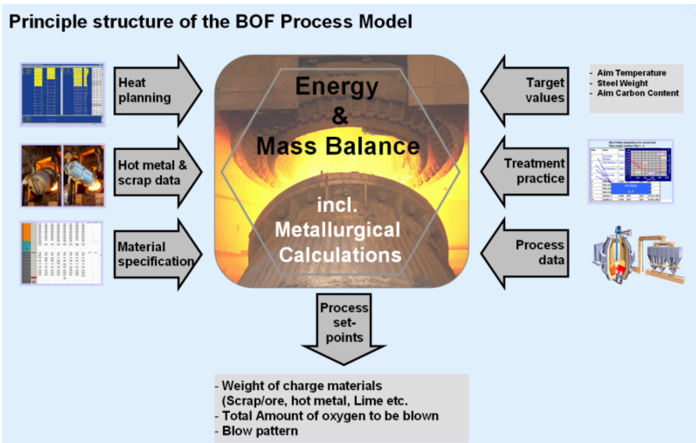

Figure 8: BOF model overview. Input data and calculated setpoints.

3 BOF PROCESS CONTROL CONDITIONS

The accuracy of the BOF process model is high, depending on the variation of input conditions. The table below shows most of the requirements.

Figure 9: BOF process control requirements.

Deviations of model results are directly dependent on the input data. These conditions may vary from heat to heat. In practice, full compliance with the requirements for BOF process control is always limited.

4 THEORETICAL DEVIATIONS

If information concerning the hot metal and scrap is known, then the estimated error in the process prediction is calculable.
Table 1 shows the most interesting relationships between the important process parameters.

Table 1: Theoretical deviation at end-of-blow (EOB)

Error	HM/Scrap [%]	ΔT EoB, Cel°	ΔC EoB, %
Good	+/- 1	+/- 25	+0.014/ -0.012
Medium	+/- 3	+/- 44	+0.022/ -0.015
Very bad	+/- 5	+/- 68	+0.035/ -0.017

The complex error calculated for the temperature and carbon is based on the following components:

- Measuring accuracy of hot metal temperature
- Measuring accuracy of hot metal analysis
  (approx. +/- 0.1%, which is a typical laboratory error for carbon at 4%)
- Accuracy of scrap weighing (e.g. weighing error and/or scrap losses during charging)
- Accuracy of hot metal weighing (hot metal ladle is not completely discharged)

The absolutely required and expected *good* input conditions are dependent on a properly operated weighing system by crane with a weighing accuracy below 0.5%. If weighing is not performed after desulphurization treatment, an error of 3% in the hot metal weight is possible: This error relates to metal losses during the de-slagging procedure. The error condition *very bad* (which is an outlier) describes charging of scrap with losses due to the oversize of scrap pieces or inaccurate charging into the vessel.
Due to the inaccuracy of the starting conditions, the real carbon and temperature in the bath might differ from the estimated values. To reach the required target window of temperature and carbon at the end of the process, an in-blow measurement has to be carried out. The purpose of this is the correction of the blown oxygen amount and coolants or heaters for the further process period, as shown in Figure 10. The ideal moment for the in-blow measurement is the end of the main blow phase.

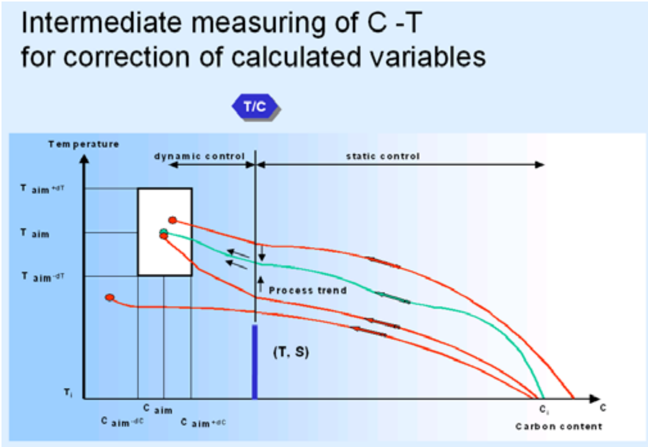

Figure 10: Effect of variation in input data.

To improve the hit rate of carbon at EOB the final blowing switch-off occurs via waste gas control, see Figure 11.

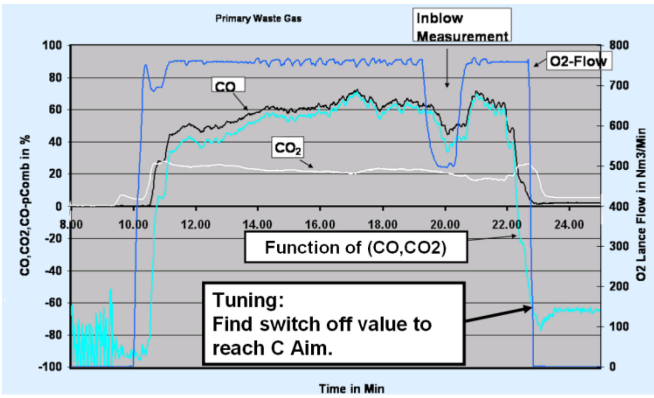

Figure 11: Detection of end-of-blow via waste gas measurement.

The last BOF campaign controlled by the model shows the following hit rates:

Table 2: Hit rate including error propagation

Hit rate	BOF 1	BOF 2	BOF 3
C	97.88	98.85	98.1
T	85.71	86.51	93.5
C&T	83.90	85.51	91.7
Reblow	2.78	1.60	1.87

These results are achieved under suboptimal conditions due to the following:

- Strong variation of Si in hot metal in the range 0.3-1.8%
- Hot metal weighing accuracy at 3% for BOF 1&2 and 1% for BOF 3
- Scrap weighing accuracy at 1%
- High Fe oxide in scrap
- Irregular bottom stirring due to excessive operation caused by high Fe oxide in scrap
- Low flux quality and wrong operation of dolomite

In the case described above, the model was tuned according to the following targets:

- C EOB was/should be less than the target C EOB

- T EOB was/should be above the target T EOB to avoid oxygen reblow

This can be seen in Figure 12 below, where the difference C EOB – C target is mainly negative and the difference T EOB - T target mainly positive.

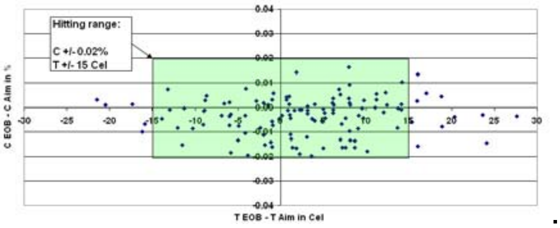

Figure 12: Distribution of deviation to C target & T target

5 AUTOMATIC HORIZONTAL AND VERTICAL BLOW-PATTERN ADAPTATION

Additionally to the material and oxygen calculation in the BOF model, an automatic horizontal and vertical blow-pattern adaptation has been developed and implemented in the model. In accordance with the input data (hot metal analysis, target phosphorus and final carbon, heats since relining), the oxygen lance height (distance from the steel bath) is adjusted automatically during the blow. The duration of blowing steps is dependent on the melt chemistry. The horizontal and vertical blow-pattern adaptation also improves the efficiency of the dephosphorization (P≈0.005%). (International patent application WO2010/0785111 by SMS Siemag AG)

6 BOF MODEL: NEW OPTIONAL FEATURES DEVELOPED FOR USE DURING FUTURE PROJECTS

6.1 BOF Duplex Process

High phosphorus content in hot metal and high dephosphorization requirements make it necessary to split the process into two handling steps.

1. Desiliconization and dephosphorization.
2. Standard BOF process

Either the heat after the first step is de-slagged and the process continues in the same vessel or the heat is tapped after the first step and charged into a second BOF in order to continue with the standard BOF treatment.

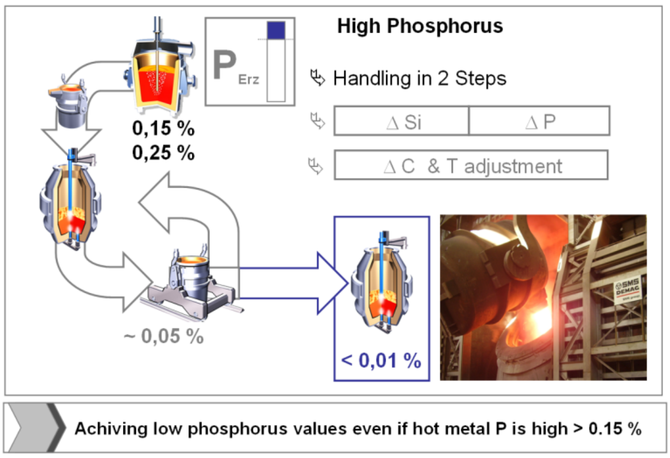

Figure 13: BOF- Duplex Process – Dephosphorization.

6.2 Use of High Amounts of Ore and Dri within the BOF Process for Customers With Low Scrap Availability:

If no or only low amounts of scrap are to be used during the BOF process, the ore is calculated as a coolant by the model.
If this amount is high (around 10 % of the added hot metal weight) the distribution of the ore addition during the heat must be controlled via a proper ore addition strategy. This strategy has been implemented on the basis of practical experience.
Note: Ore additions in the vessel are an additional oxygen source and have a strong cooling effect on the process due to the reduction of iron oxide by carbon. Therefore, the use of high amounts of ore must be considered when designing the capacity of the entire gas cleaning and recovery system.
The coolant effect of one ton of ore is approximately the same as the coolant effect of three tons of scrap. The coolant effect of DRI is only a little higher then the coolant effect of scrap. Hence the total DRI amounts in cases where low scrap is used are much higher than in cases where ore replaces scrap.
In general, if DRI is to be used as coolant, the same roles are valid. If the required DRI amount is becoming too high, a part of it must be charged via the scrap chute.

6.3 Enhancement of Tapping Addition Calculation

The consideration of the reaction kinetics due to thermodynamic non-equilibrium and the interaction of metallic components and slag reactions is used to calculate the material additions with the aim of achieving the start analysis for next treatment aggregate upon its arrival. This function has been tested offline on process data from ArcelorMittal Poland S.A. Oddział Kraków, the former Sendzimir Steelworks Cracow.

	Previous approach	New approach
Tapping addition calculation	Element efficiencies (Parameter)	Kinetics
	Estimation	De-oxidation Calculation Al / Si / C

Defined start analysis for next treatment aggregate

Figure 14: Kinetic model for steel and slag analysis progress after tapping.

6.4 EOB Temperature Control Via Waste Gas Data

Based on waste gas data, a function for determining the current steel temperature close to EOB was implemented. This function will be tested during some of our coming commissioning operations.

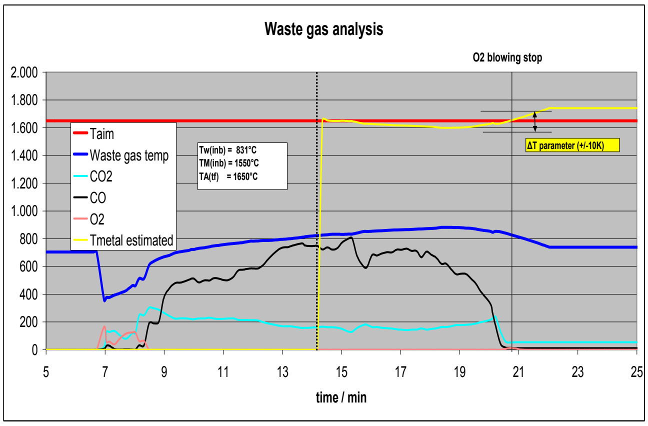

Figure 15: EOB Temperature control via waste gas data (T, CO,CO_2,…).

6.5 SMS Siemag Process Model for other Refining Processes

Similar to the BOF model, all other SMS refining process models start with a desiliconization phase. The special feature of all models is the process prediction based on the calculation of the critical carbon when the kinetics of the decarburization change from the constant (main decarburization) to the exponential (dynamic decarburization) type.

The different processes have different main decarburization speeds and different time constants during the dynamic decarburization phase. Typically, after the required carbon target at end-of-blow is achieved, reduction of the slag is performed to regain the decisive metal oxide as effectively as possible.

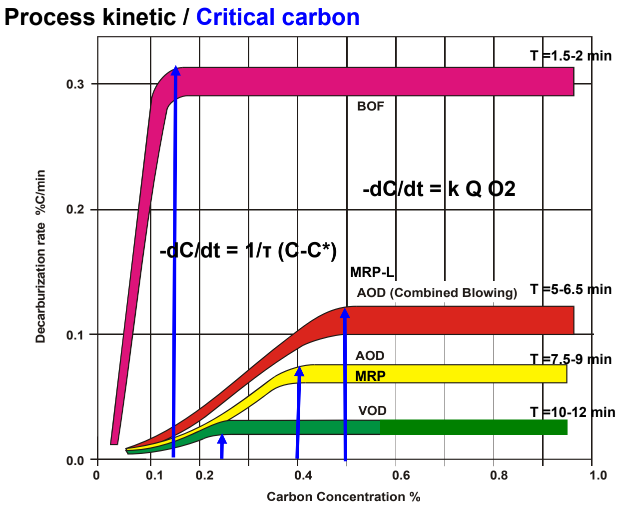

Figure 16: Comparison of reaction time constants of different decarburization processes.

The following refining models are available:

- Argon Oxygen Decarburisation process model for
  - Stainless steel production using (O_2, Ar, N_2 and CO_2)
  - FeMn reduction using (O_2, Ar, N_2 and CO_2)
  - FeCr reduction using (O_2, Ar, N_2 and CO_2)
  - FeNi reduction using (O_2, Ar, N_2 and CO_2)
- Metal Refining Process
- Vacuum Oxygen Decarburisation
- Combined AOD/VOD for stainless steel production and for FeMnLC production.