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STEEL EXPERT TAKES COMMAND – OPTIMIZED PERFORMANCE ON BOF CONVERTER[1]

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Abstract

The Steel Expert process model package for BOF converter comprises dynamic process guidance, a prediction model for simulation of the complete BOF production process and a number of setpoint models for the different production steps. This paper compares the achieved results from installations where the BOF melt shop is equipped either with a sublance, or an off-gas analyzing system, or both measurement systems. We will discuss the reproducible hitting ratios for temperature and carbon at end of blowing achieved for low carbon steel grades using sublance measurement and off-gas analysis for carbon prediction.The model performance in a steel plant using hot metal with high silicon content as input will be presented where a double slag practice with intermediate deslagging is applied. In another BOF shop we could demonstrate a considerable cost reduction of charge materials (e.g. scrap, fluxes, alloys) using all of the Steel Expert optimization features. Furthermore we will share additional benefits using the Steel Expert such as reduction of reblows for temperature and/or carbon, reduction of over blown heats and realization of a standardized and reproducible production practice.

Key words: Basic oxygen furnace; Process optimization; Process models.

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1 INTRODUCTION

Siemens VAI Level 2 process-optimization systems for BOF converters assist the steelmaker in achieving standardized and reproducible production of consistently high-quality steel. The Steel Expert BOF process model package comprises dynamic process guidance through a cyclic online model, a prediction model for simulation of the complete BOF production process and a number of setpoint models for the different production steps. The Dynacon end point prediction model based on continuous offgas measurement is an integral part of the Steel Expert Supervision online model. Since the first start-up of the redesigned Steel Expert process model packages in 2006 37 BOF converters have been equipped with the Siemens VAI process model solution.
This paper compares the achieved results from installations where the BOF melt shop is equipped either with a sublance, or an offgas analyzing system, or a combination of both measurement systems. We will discuss the reproducible hitting ratios for temperature and carbon at end of blowing achieved for low carbon steel grades based on various installations on BOF converters of different sizes.

2 STEEL EXPERT PROCESS MODELS

Siemens VAI´s comprehensive group of the so-called Steel Expert process models optimizes and controls the steelmaking process during the entire treatment at the BOF converter. The objective of the model package with respect to quality is to improve the hitting rate for carbon and temperature at end of blow and to ensure a stable and uniform production. After tapping the heat will be released exactly in accordance with the defined temperature and chemical composition as required by the production plan and the steel grade.
For this purpose metallurgical models for BOF converter process have been developed by Siemens VAI, which are based on physic-chemical and thermodynamic relations. Siemens VAI started with the first process models for converter metallurgy in the 1980's.
In 2005 Siemens VAI redesigned the complete process model set1. Empirical and statistical portions have been minimized as far as possible and approach the extent that is unavoidable. All model calculations use a common metallurgical calculation base (common parameter). This ensures a wide range of applications and steel plant practices and enables an easy adaptation of the models to different operating conditions. The new process models are no longer based only on the equilibrium calculation at blowing end, but rather on a dynamic calculation throughout the complete LD (BOF) process. In doing so, the effect of different blowing, stirring or material addition patterns on the course of the process can be considered within the model and "intermediate" results (e.g. in case of deslagging for low temperature dephosphorization) can be obtained.
The models can be used in the BOF process with varying scrap to hot metal relation, for operation with and without bottom stirring, for hot metal with high and low silicon

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and/or phosphorous content and for combined blowing (e.g. DeV and DeC process). The operator is guided and instructed through the different steps of production to ensure a consistent and reproducible production. He is assisted by a convenient user interface to start and supervise the production of a heat. The Level 2 process computer proposes the required actions of the operator according to model calculations based on the stored production schemes per steel grade (blowing schemes, bottom stirring schemes, additions etc.). Steel Expert continuously informs operating personnel about the overall state of the heat (i.e. weight, temperature and analysis) during treatment.

2.1 Steel Expert Supervision

The introduction of a cyclic online process model has been an important innovation which improved the hitting ratio of temperature and target chemical analysis. During the blowing process the model calculates cyclically the ongoing reactions in the steel bath and in the slag including the dissolution of charged materials. Furthermore oxidation and reduction reactions, pickup of oxygen, nitrogen and hydrogen, sulfur and phosphorus distribution between steel and slag, the post combustion from CO2 and H2 and the vaporization of the elements and oxides from steel and slag are considered by the advanced process model.
In Figure 1 a graphical display of the most important chemical elements of the steel bath (C, Si, Mn, P, and S) and the steel bath temperature is presented. On the left hand side the actual values of the last calculation cycle are displayed.

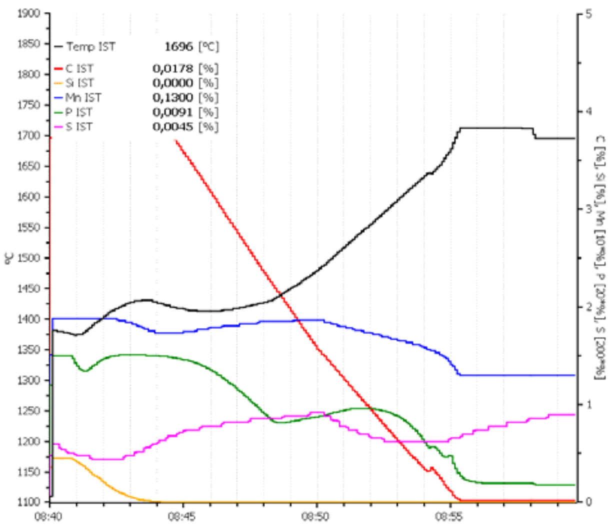

Figure 1. Calculated steel bath analysis and temperature during the blowing process

2.2 Dynacon Model

The Dynacon model – as a part of the Steel Expert Supervision – is the dynamic blow end prediction for carbon based on actual offgas data. From the actual offgas data – offgas flow, offgas analysis (CO, CO2, O2, N2) – as well as from actual process data Dynacon predicts the carbon content at the end of the blowing process from the

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typical shape of the offgas data close to blowing end (in Figure 2 basically after 21:18).

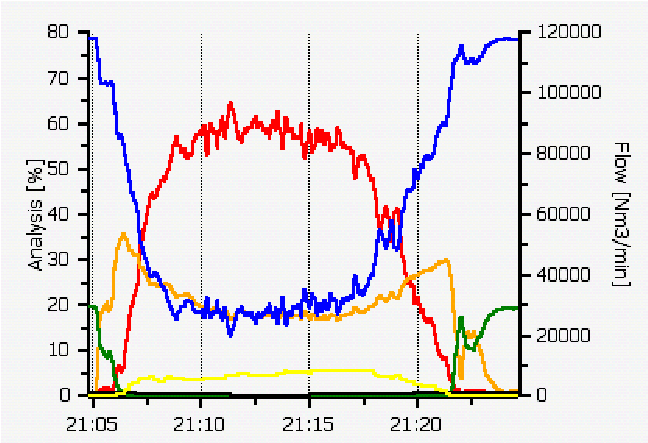

Figure 2. Typical offgas analysis for one heat

The result is a predicted carbon content at the end of the blowing process (typically for carbon contents below 0.3%) and a blowing end request to reach the target carbon content at blowing end. In combination with the dynamic online model (Steel Expert Supervision) a complete prediction of steel and slag (temperature, analysis and weight) can be made where the carbon content is taken from Dynacon and all other data are calculated by Steel Expert Supervision.
An example of the results is shown in Figure 1, where Dynacon started the prediction at approximately 0.35% carbon (this can be seen by the small bend in the red colored carbon curve). Before that the carbon content was purely calculated by Steel Expert Supervision without using any information from the offgas. All other data (T, Si, Mn…) are calculation results from Steel Expert Supervision. In addition to the carbon content Dynacon also cyclically predicts a remaining oxygen volume to be blown until the target carbon content at blowing end is reached.

2.3 Steel Expert Prediction

The unique Siemens VAI precalculation model simulates the whole BOF process before/after scrap and hot metal are charged into the converter. The Steel Expert Prediction determines the optimum blowing and stirring strategy, as well as the exact time and portioning of vessel additions. It consists of five different parts:

- Calculation of hot metal and scrap input.
- Calculation and distribution of heating agents, cooling agents, alloys, scraps and fluxes in order to reach the target weight, analysis and basicity.
- Calculation of blowing setpoints in order to reach the target carbon content and temperature.
- Calculation of ongoing reactions to predict the weight and analysis of steel, slag and offgas as well as the offgas temperature after each process step.
- Information and warnings for the operator if target values for a process phase not reached.

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For a precalculation of the setpoints (oxygen volume, slag former, heating and cooling agent additions, etc.) prior to and during the heat and to optimize the blowing, stirring and material additions patterns for the blowing phase, the same dynamic process models as for the Steel Expert Supervision cyclic online model are used. This procedure ensures identical behavior of the precalculation and the online process model.
The Precalculation Model is based on a predefined list of process steps (e.g. charging, main blowing, stirring, tapping) and target values from the Standard Melting Practice (SMP). If necessary, additional process steps (e.g. a Reblow step after main blowing end) can be inserted manually by the operator. The rules for blowing, stirring and material addition times are based on a standard melting practice as defined by the process engineer.
Figure 3 shows the typical HMI screen for the Steel Expert Prediction. The different sections of the screen display the target and input data, model results, calculated analyses for steel and slag and specific consumptions.

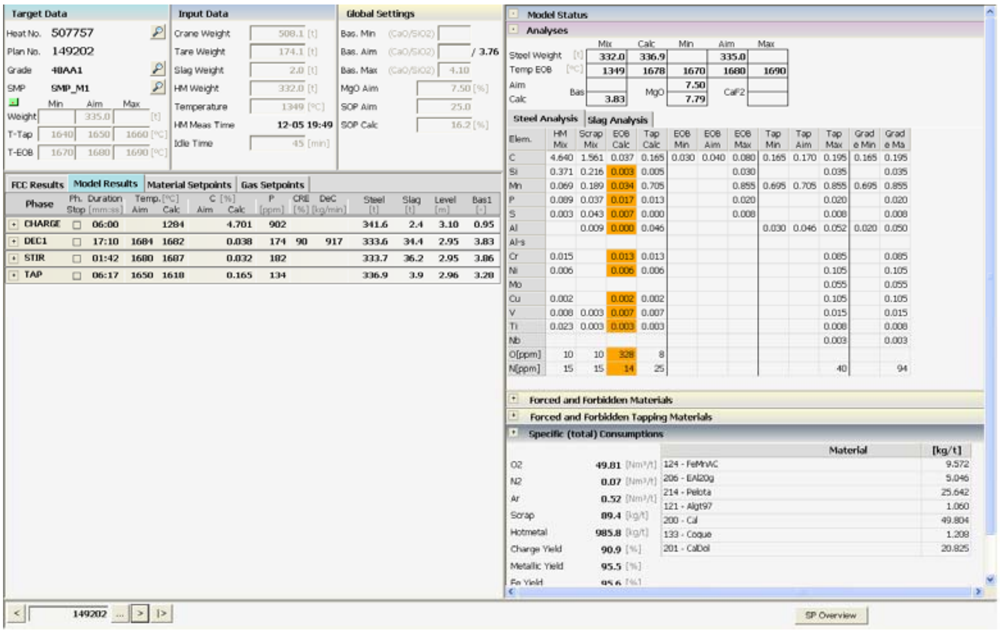

Figure 3. Main screen of the Steel Expert Prediction

2.4 Steel Expert Setpoint Models

The Steel Expert Setpoint models cover the whole production process starting from the ordering of scrap until alloying during tapping. All metallurgical reactions between steel and slag according to the additions are considered in order to reach the target analysis at the correct point in time.
The Siemens VAI Steel Expert model package comprises the following modules:
- Steel Expert First Charge Calculation (FCC):
Basis for the calculation are the target steel analysis, the target steel weight and target steel temperature, the actual hot metal analysis and hot metal temperature (from

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different sources) and the available scrap types on the scrap yard. If necessary, scrap cost optimization can be used. The Steel Expert FCC can be applied for different scenarios of variable input data (scrap: variable – hot metal: variable; scrap: variable – hot metal: fixed; scrap: fixed – hot metal: variable). The Steel Expert FCC calculates the optimum charge mix to reach the targets following the planned steel grade from the production schedule.

- Steel Expert Second Charge Calculation (SCC): Immediately after the actual data of charged hot metal and scrap, including the partial weights of the different scrap types, have been received, the Steel Expert SCC model calculates the necessary vessel additions and oxygen volume to achieve the target analysis and the target temperature of the steel at the end of blowing.
- Steel Expert Bath Level Calculation: The position of the blowing lance relative to the steel bath and its time variation during the blowing process determines certain metallurgical reactions, e.g. slag development, decarburization rate. Therefore the absolute position of the bath level should be known very accurately. One part of the bath level calculation determines the actual surface height of the steel bath based on the converter geometry. The second part of the calculation incorporates a feedback calculation of the converter lining status whenever an actual bath level measurement is available.
- Steel Expert Inblow Correction Calculation: The inblow correction calculation is started after a successful sublance measurement. Depending on the availability of the data (T, C) the cyclic online model takes over the measured values and applies some corrective measures due to the fact that the sublance measurement is done close to the hot spot. In general the temperature in the hot spot area is higher and the carbon content lower than the actual bulk values. Both effects are considered. The remaining required oxygen amount, heating or cooling agents and additional slag formers are calculated.
- Steel Expert Reblow Correction Calculation: The reblow correction calculation can be started if certain steel bath properties (e.g. temperature, C content or P content) are not within the specified target limits at end of blowing. The actual steel bath analysis and temperature are taken from a temperature measurement or from a steel sample after the main blowing phase. Prior to the start of the correction model the cyclic online model is synchronized with the measurement results. The required oxygen amount, heating or cooling agents and additional slag formers for reblow are calculated.
- Steel Expert Alloying: The alloying model calculates cost optimized the necessary alloying and deoxidation materials to be added into the tapping ladle. The model starts with the actual analysis from the laboratory or the last calculated result of the cyclic process model (Steel Expert Supervision) of the steel bath prior to tapping and calculates the required additions to reach the target steel analysis. The analysis of the alloying agents and their specific losses are taken into account.

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3 OPERATIONAL RESULTS

The achieved results from Steel Expert installations are shown in this section where the single BOF melt shops are equipped either with a sublance system, or an offgas analyzing system, or both measurement devices. Since the first start-up of the redesigned Steel Expert process model packages in 2006 37 BOF converters have been equipped with the Siemens VAI process model solution, 7 BOF converter projects are currently under execution. In Figure 4 the number of installations for the completed projects, the projects currently in execution and the sum of all references are plotted. "BOF" is the sum of all projects, "BOF (Sublance)" indicates the plants equipped with a sublance system, "BOF (Dynacon)" indicates the plants equipped with an offgas measurement system and "BOF (SL + Dyn)" stands for the combination of both measurement devices.

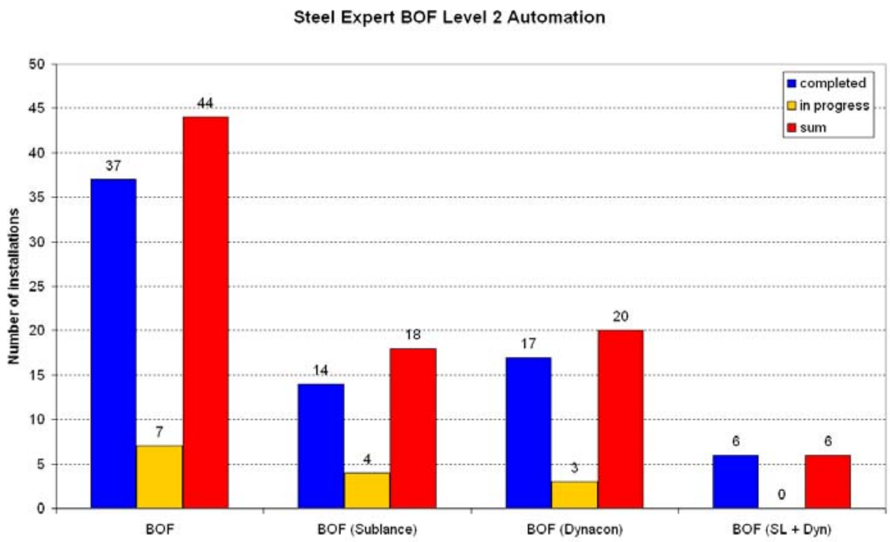

Figure 4. Number of Steel Expert installations since 2006

4.1 BOF Converter Equipped with Sublance

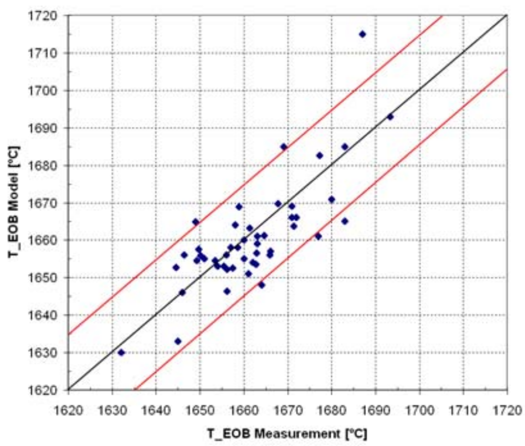

Figure 5. Measured temperature versus calculated temperature at end of blow

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After about 80 – 85% of the total blowing oxygen volume has been blown the sublance measurement is started. The oxygen flow rate is decreased to approximately 50% during the measurement cycle. Immediately when the measurement results are transmitted to the Level 2 system the Steel Expert Inblow correction calculation is started. Depending on the availability of the data (T, C) the Steel Expert Supervision cyclic online model takes over the measured values applying some corrective measures due to the fact that the sublance measurement is performed close to the hot spot. Based on the actual state of the heat – taken from the cyclic online model – the correction model calculates the required heating/cooling agents, fluxes and remaining oxygen volume to more precisely reach the carbon and temperature targets as well as the targeted basicity.
The model performance for low carbon heats on a 160 t BOF converter is shown in Figure 5 where the actual measured temperature at end of blow (EOB) is plotted against the calculated temperature of the Steel Expert Supervision at EOB. The hitting rate for the temperature at EOB (T target window: ± 15 K) is 90 % for all analyzed test heats. The average error (T_Measurement – T_Model) is 1.1 K and the standard deviation of the temperature error is 8.8 K in this BOF shop.
A carbon hitting rate at EOB (C target window: ± 0.010 %) of 88.9 % could be achieved. This BOF plant is aiming for carbon content at end of blow between 0.03% and 0.06% Carbon. A statistical analysis shows an average error (C_Sample – C_Model) of -0.0029% C with a standard deviation of the carbon error of 0.0085% C for all heats in the test period.

4.2 BOF Converter Equipped with Continuous Offgas Measurement

The Dynacon model is not only restricted to the Siemens VAI's LOMAS redundant gas sampling and analyzing system. A small number of projects have been successfully executed in the past using existing offgas analyzers from different vendors. Nevertheless most of the reference plants use the proven combination of the LOMAS analyzers and the Dynacon end point prediction model.
The redundant gas sampling and analyzing system LOMAS is specifically designed for very hot, corrosive and extremely dust loaden waste gas. Fully automatic and low maintenance operation includes automatic operating gas probe cleaning and filter regeneration. It measures via mass spectrometer up to 64 gas components, i.e. CO, CO2, H2, O2, N2 and Ar.
For successful model calculations special attention has to be paid to the accuracy of the input conditions. Detailed clarifications and some modifications in the plant logistics and equipment prior the start of the commissioning ended up in a faster start-up of the Steel Expert system. The most important areas to be considered are

- Weighing of all scrap chutes with sufficient accuracy
- Accuracy of the weighing equipment for empty and full ladles. The best experiences have been made using load cells on the charging crane.
- Automatic data transfer from hot metal ladle crane to the Level 2 system (avoiding of typing errors of the operators)
- Accuracy of the weighing equipment for charging materials (fluxes, heating

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agents, cooling agents)

- Hot metal samples from desulphurization station
- Standardized and reproducible temperature sampling in hot metal after desulphurization station

All of the recent 22 Dynacon installations have been commissioned on BOF converters with a moveable skirt enabling suppressed offgas combustion. Figure 6 shows the offgas analysis data and the skirt position (0%...open, 100%...closed) in black color (bold line). As indicated, the skirt remains open for the first 1-2 minutes, and then the skirt moves down towards the converter mouth. Close to the end of the main blowing phase the skirt is opened again which leads to a significant increase of false air during the last minutes of blowing period. The signal for opening of the skirt can be triggered by the Level 2 calculation based on defined percentage of the total blowing oxygen volume combined with the measured CO content in the offgas.

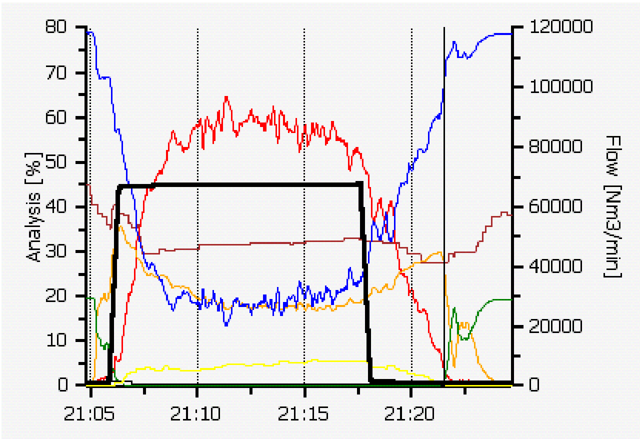

Figure 6. Offgas data, skirt position for a typical heat

On the left hand side of Figure 7 the actual measured carbon content of the steel bath at end of blow (EOB) is plotted against the calculated carbon of the Steel Expert Supervision at EOB using the Dynacon blow end prediction. The hitting rate for carbon at EOB (C target window: ± 0.015 %) is 87.9 %. In the right part of Figure 7 the actual measured temperature at end of blow (EOB) is plotted against the calculated temperature of the Steel Expert Supervision at EOB. The hitting rate for the temperature at EOB (T target window: ± 21 K) is 85 % for all considered test heats. The average error (T_Measurement – T_Model) has been statistically calculated as -2.1 K and the standard deviation of the temperature error is 14.8 K.

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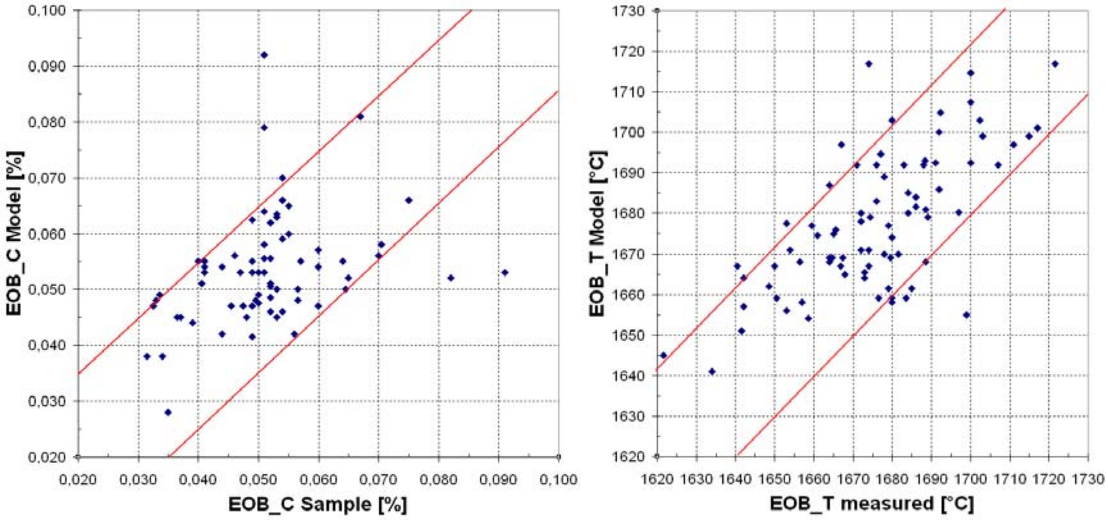

Figure 7. Measured versus calculated temperature/carbon at end of blow using offgas measurement

For another Steel Expert application with the Dynacon end point prediction the results are presented in Figure 8 with a hitting rate for carbon at EOB (C target window: + 0.01 / - 0.022 %) of 97.0 % for all analyzed test heats, an average error (C_Sample – C_Model) of 0.0024% carbon and a standard deviation of the carbon error of 0.0066%. The temperature hitting rate (T target window: ± 20 K) is 85 % with an average error (T_Measurement – T_Model) of +2.4 K and a standard deviation of the temperature error of 14.2 K.

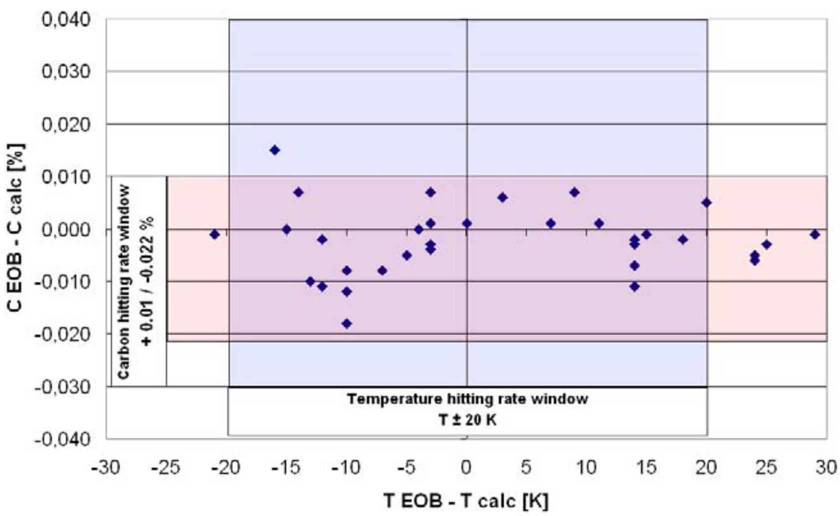

Figure 8. Hitting rate for Dynacon Blow End Prediction

4.3 BOF Converter Equipped with Offgas Measurement and Sublance

Dynamic control of the BOF blowing process is performed based on the combined information from the sublance system and the LOMAS continuous offgas measurement system. The main advantage compared to the usage of continuous offgas measurement only is the improved hitting rate for temperature due to the fact

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that there is actual process information during blowing available. Depending on the steel plant philosophy a temperature measurement only or a combined temperature and carbon measurement is performed. Based on the measured values the Steel Expert Inblow model calculates required heating/cooling agents, fluxes and remaining oxygen volume till the end of the main blowing phase. Near the end of the blowing process, the Dynacon model takes command based on the measured offgas data. Thus oxygen blowing is automatically stopped by the Level 2 system when the targeted carbon content and temperature of the steel bath are reached.

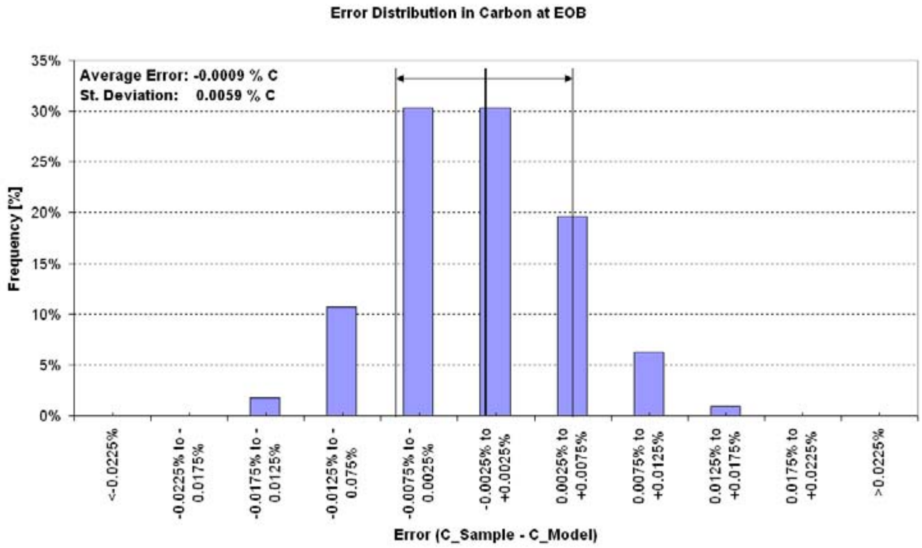

Figure 9. Error distribution on endpoint carbon using Dynacon endpoint prediction

The error distribution in measured carbon content at end of blow versus calculated carbon content by the process model is illustrated in Figure 9. The average error is -0.0009% carbon with a standard deviation of 0.0059%. The predicted carbon was in average a little bit lower than the measurement. The achieved hitting rate for a period with more than 100 test heats is 91.1% for a target window of ± 0.010 % of carbon. A statistical analysis of the error distribution in temperature at end of blow on another BOF installation is illustrated in Figure 10. The average error is +3.4 K with a standard deviation of 10.0 K. The predicted temperature was on average a little bit lower than the measurement. The achieved hitting rate for a period of more than 100 test heats is 85.6 % for a target window of ± 15 K.

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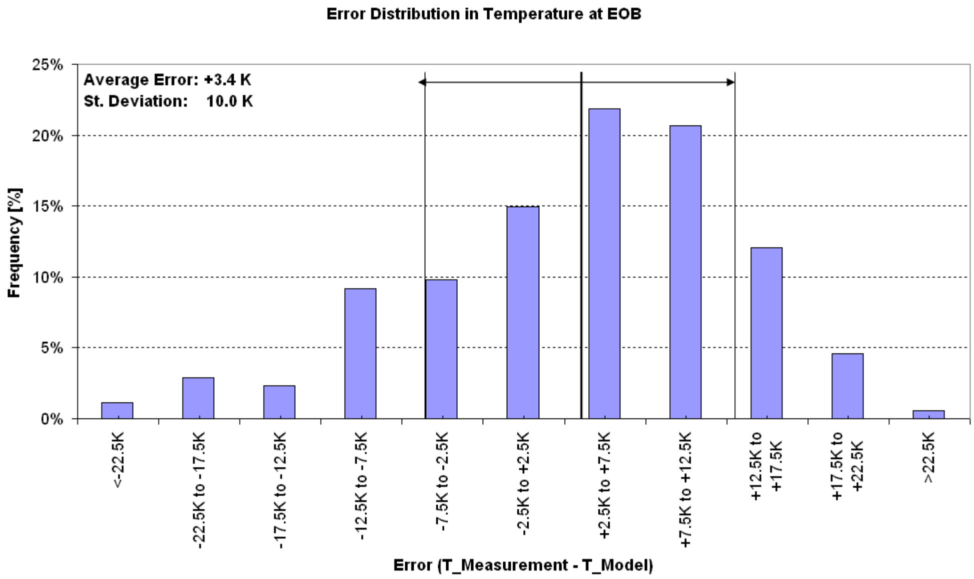

Figure 10. Error distribution on endpoint temperature using Steel Expert Supervision calculation

The actual measured temperature at end of blow (EOB) is plotted against the calculated temperature of the Steel Expert Supervision at EOB for the same BOF shop using sublance measurement and continuous offgas data in Figure 11.

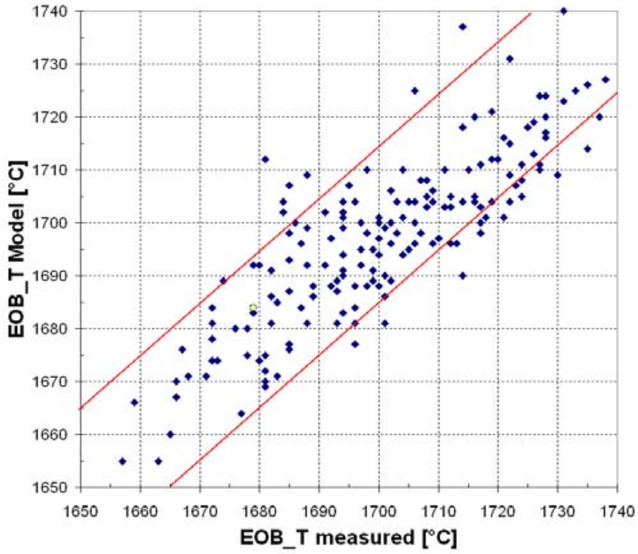

Figure 11. Measured steel bath temperature versus calculated temperature at end of blow

4 SUMMARY

Operational results from the recent 37 successfully commissioned Steel Expert BOF applications are demonstrating reproducible hitting ratios for temperature and carbon at end of blowing for BOF melt shops which are either equipped with a sublance, or an offgas analyzing system, or a combination of both measurement systems. The standardized and reproducible operation guided by the Steel Expert calculations leads to a significant reduction of lime consumption reaching a stable steel quality at end of

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BOF treatment. A cost optimized charge mix calculation assisted by the Steel Expert FCC calculation resulted in a considerable reduction of the scrap cost per heat.

BIBLIOGRAPHY

1 G. Flossmann, S. Dimitrov, "Innovative Solutions for Dynamic LD (BOF) Process Optimization," Iron & Steelmaking Conference, Linz, October 2006.