TENOVA'S NEXTGEN® SYSTEM BRINGS DEMONSTRATED PAYBACK FOR EAF/BOF STEELMAKING OPERATIONS*

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Abstract

Tenova's NextGen® is the first proven hybrid extractive/laser system for continuous and full spectrum analysis (CO, CO_2, 2, H_2, H_2O vapor, N_2) to be offered for improved process control of the BOF and EAF steel making process. Complete off-gas analysis is achievable using a single analyzer and compact sampling station located in vicinity to sampling points. To add, Tenova's proprietary systems for flow and temperature measurement provide an important insight into the furnace/fume system operation. This paper will describe proven results from NextGen® installations within the EAF environment. The overall benefits of the system have demonstrated significant payback in terms of increased yield and productivity, real-time dynamic control of chemical energy and fume system suction and real-time water leak detection for greater plant safety.

Keywords: NextGen; Yield; Productivity; Process Control.

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1 INTRODUCTION

Carbon plays an important role in all modern steelmaking processes imparting excellent mechanical properties to the final steel product. It also acts as the primary reducing agent in both integrated and non-integrated steelmaking, reacting with various oxides and gaseous oxygen to provide a main source of energy. This article describes how Tenova's off-gas solutions can be implemented to dynamically control and optimize an EAF process, and be an effective tool for end-point prediction of Carbon [C], Temperature [T] and Phosphorus [P] levels on a BOF operation.

2 DEVELOPMENT

2.1 NEXTGEN® Off-gas Analysis Technology

With over 95 installations world-wide, Tenova's EFSOP® technology has been proven as the leading system for off-gas analysis in both EAF and BOF steelmaking. In addition to its excellent reliability and low maintenance record, the next generation of EFSOP®, known as NEXTGEN® provides customers with much more than off-gas analysis hardware. It is the only technology proven to reliably analyze for existing process off-gas directly at the furnace exit for use in process optimization and dynamic closed loop control, providing proven savings as signed off by steel plant managers.

The NEXTGEN® system is a breakthrough hybrid extractive/laser technology that combines exceptional start-to-end heat reliability of extractive technology by using a high volume pump and filters to continuously extract and clean the gas prior to analysis, together with the multipoint response and calibration advantages of laser technology. Tenova's NEXTGEN® System provides a full spectrum (CO, CO_2, O_2, H_2, H_2O vapor) off-gas analysis for maximum process control functionality with less hardware and lower installation & maintenance costs.

Reliability – Positive extraction using a high volume pump remains the very best way to ensure high system reliability and to avoid lost analytical signals. Tenova's NEXTGEN® system uses off-gas extraction via a patented probe that contains a redesigned primary filter that eliminates water vapor condensation.

Compact – The sampling station is mounted directly on the shop floor without the need for an environmentally protective room and is connected to the probe with a short heated line. Each station contains a high volume pump, secondary filters and proprietary laser & analytical cells and station is connected to the central multipoint optical analyzer by fiber and coax cables.

Fast Analytical Response & Uninterrupted Laser Signals – The compactness & close proximity of the sampling station to the redesigned probe together with active high volume suction dramatically shorten the system's analytical response delay. The NEXTGEN® analytical response time from probe tip to analysis is ~8 seconds or less which is between 4 to 5 times shorter than the typical response time of traditional extractive methods.

Full Spectrum/Multipoint Analysis – A sampling station is connected to the central multipoint optical analyzer located in the control room. This unit contains the physical lasers and sends light of the correct wavelength to the analytical cells in each sampling station. The signals from the analytical cells are continuously analyzed to provide full-spectrum off-gas chemistry.

Operator Safety Improvement – The NEXTGEN® system offers significantly improved operator safety since the sampling stations are mounted directly on the shop floor under the canopy hood with no off-gas physically at the central analyzer. This removes all concerns stemming from a possible CO leak in a confined space.

Future Expandability – The NEXTGEN® system full spectrum analysis combined with the OVM & OTM off-gas sensors and SCADA PLC link will enable expansion of the system capabilities in the future to include Tenova's iEAF® / iBOF® software which closes a mass & energy balance in real-time for:

EAF: dynamic optimized control of both the chemical energy & electrical energy

BOF: prediction of the End-Point [C] [T] [P]

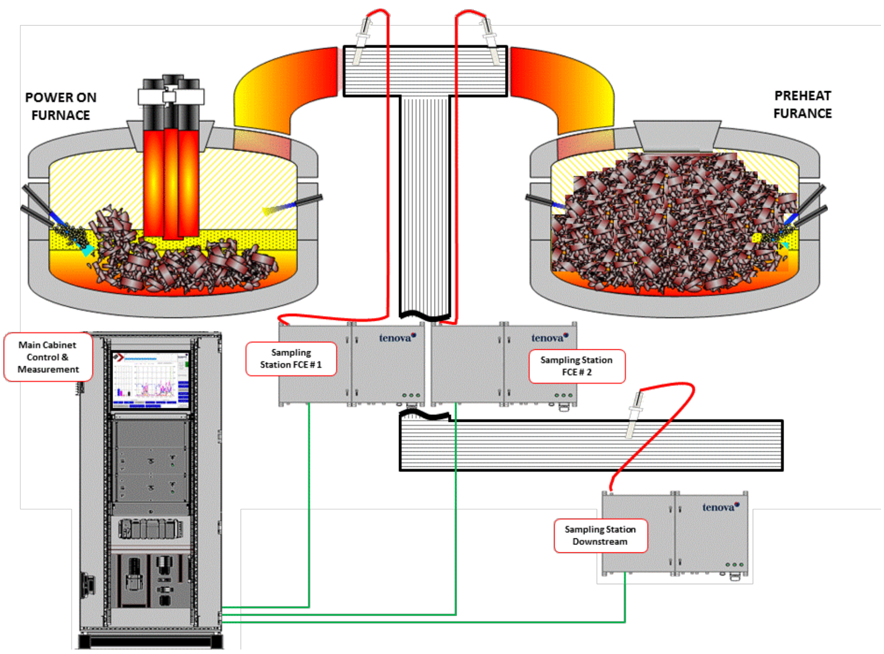

Figure 1. Complete NEXTGEN® System configuration in s twin shell EAF configuration

Hardware

The main components of the NEXTGEN® system are detailed below;

Patented Water Cooled Probe & Heated Element – Mounted through an access port in the water-cooled duct, the patented probe is unique in the industry due to its rugged design to survive the harsh environments and the intense conditions at the combustion gap. The probe has a proven track record with over 95 installations worldwide in a variety of high combustion furnace operations.

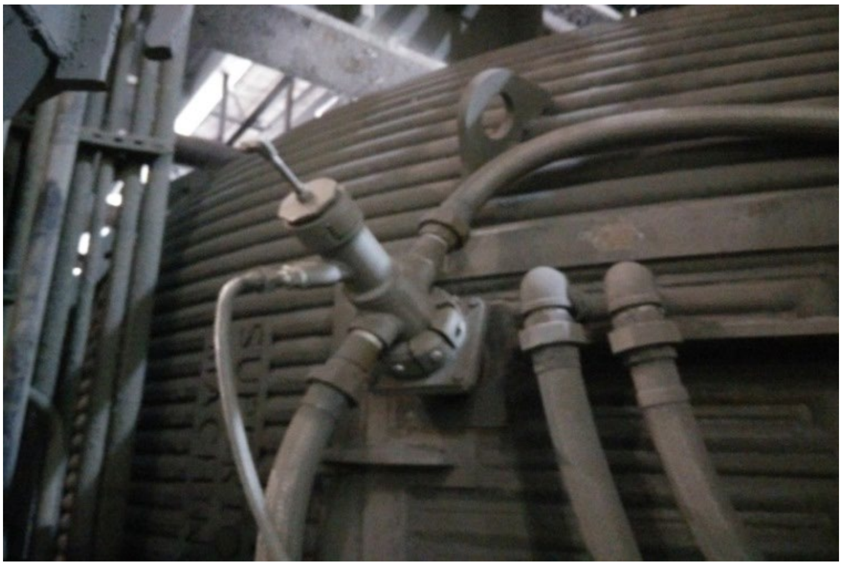

Figure 1. Probe Installation in a water-cooled panel

Heated Line(s) - The off-gas sample is drawn from the probe to the rapid response sampling station through a short protected heated sample line using a high volume pump. The temperature of the heated lines is automatically controlled above the gas dew point to eliminate the possibility of water vapor condensation prior to analysis.

Figure 2: Heated Line on a Down-stream location

Sampling Stations – The sampling station is designed to ensure continuous off-gas analysis during power-on and pre-heating periods. The sampling station is located directly on the shop floor and does not require any controlled environment room. The connections to the unit include nitrogen for purging, heated sample lines, power and fiber/coax/Ethernet to the central multipoint optical analyzer.

Figure 4. Sampling Station

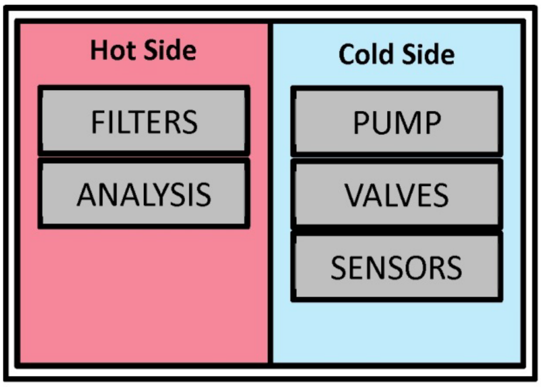

Figure 5. Main Sampling Station Components

Central Multipoint Optical Analyzer – The multipoint optical analyzer includes a PLC for controlling each of the sampling stations via Ethernet. The unit is compact, modular and can be tailor designed with multiple lasers, based on the off-gas analysis requirements. Typically this central unit is located at the control pulpit. The analyzer's laser system is self-calibrating and does not require a manual calibration check or the use of specialized calibration gases. The unit is interfaced with the PLC Level 1 to synchronize each sampling station's operation with the furnace operation cycle.

Figure 6. Analyzer Cabinet

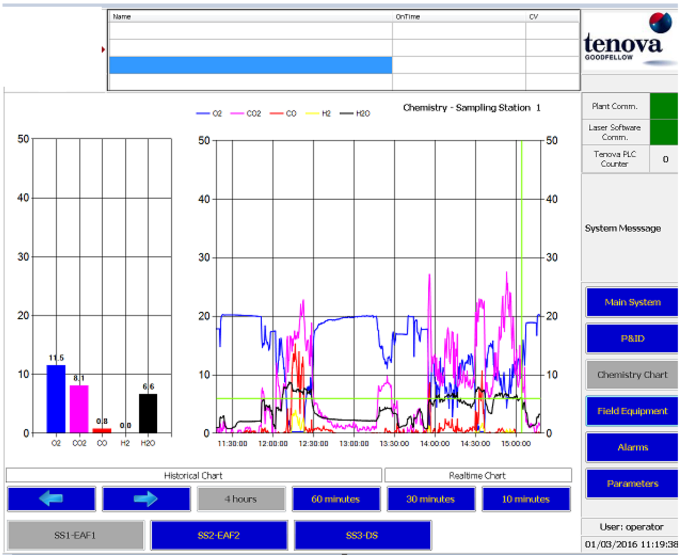

Figure 7. Central Analyzer HMI Screenshot

Optical Velocity Measurement (OVM): The OVM developed is used for continuous measurement of gas velocities in dust-bearing high temperature gases. The OVM sensor is being used to monitor off-gas velocity and to calculate the mass flow rate of the off-gas through different stages of the furnace operation. It is a passive non-contact sensor with no consumable parts and requires minimal maintenance. Figure 8 and 9 show the general schematic of the system and the installation of the OVM.

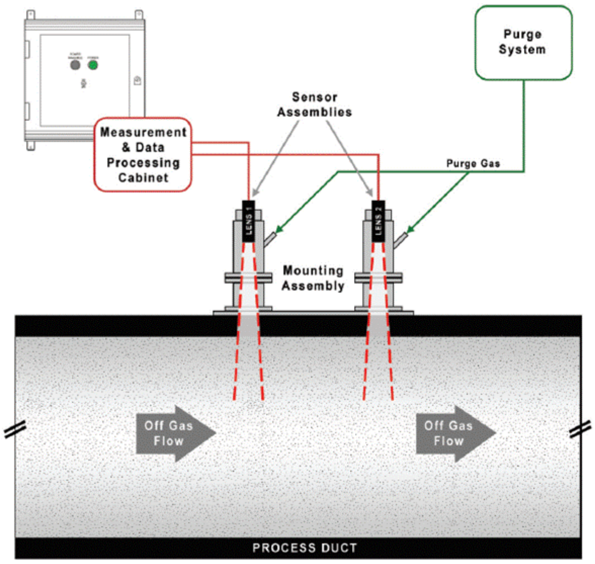

Figure 8. Off-gas Velocity Measurement

Figure 9. Installation of OVM

Optical Temperature Measurement (OTM): The OTM is a passive sensor without consumable parts and requires minimal maintenance. It continuously measures the temperature of gases at temperatures between 600°C to 3,000°C with a 1° C resolution. Because the OTM uses a ratio method for measuring off-gas temperature, the precision of the readings are largely unaffected by dust accumulation on the unit's lens. The temperature measurement is being used for end point prediction of the BOF and optimization of EAF plus water detection application.

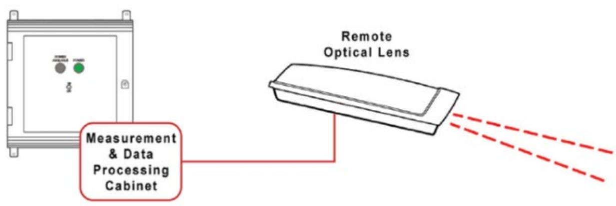

Figure 10. Off-gas Temperature Measurement

Figure 11. Installation of OTM

2.2 Tenova's EAF Technology Solution

Modern EAF practice relies on an ever increasing use of chemical energy (C, Fuels & O_2) to maximize productivity and reduce energy costs. However, poor control of the combustion process will lead to dramatically reduced efficiency and significantly increased direct process GHG emissions.

Tenova's iEAF® is an innovative technology that links proven and reliable NEXTGEN® off-gas analysis technology with a series of advanced primary and secondary sensors and process models to dynamically control and optimize the "entire" EAF process in a closed loop fashion. Unlike traditional EAF control technology which paces the furnace process largely on the basis of a specific kWh electrical energy counter, iEAF® technology uses the real-time mass & energy balance to dynamically control EAF operation based on “NET ENERGY”

NET ENERGY = Electrical + Chemical – Losses

NET ENERGY is a true measure of the real-time combined electrical and chemical energy utilization efficiency for the EAF process; determination of NET ENERGY allows the EAF to be paced on the basis of **“**MELTING %” which represents a measure of the relative proportion of molten slag/steel and solid scrap in the EAF at any point in the process. Where iEAF® technology has been applied, results to date confirm that MELTING% control and specific NET ENERGY are the best methods to pace the EAF process, enabling precise determination of the onset of a flat bath condition and accurately predicts end-point carbon and temperature.

Tenova’s iEAF® technology provides a complete mass & energy balance in real-time which contributes to the operator’s experience, a true understanding of chemical and electrical energy efficiency from start to end of every heat. As such, changes in real-time burner, oxidation and electrical energy efficiencies are properly accounted for by the iEAF® technology and furnace pacing, control and efficiency is much more predictable and can be optimized for improved energy and productivity savings; this solution is applicable for EAF that operates with a mix of scrap, HM and/or DRI.

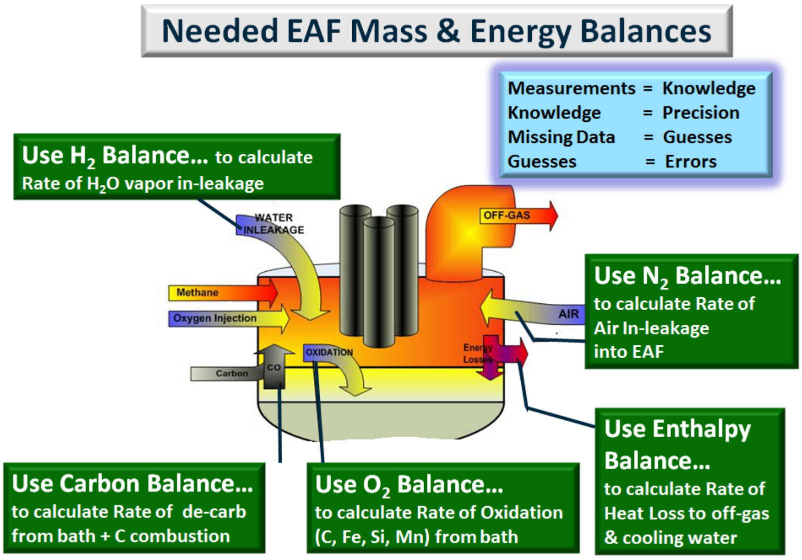

Figure 12. EAF Mass & Energy Balance

2.3 iEAF® Performance

Tenova currently has 7 iEAF® systems installed or underway worldwide. Based on plant experience to date, iEAF® technology has proven to be a valuable operating and control tool successfully extending direct dynamic control functions for burners, lances, injectors and draft based on off-gas chemistry into functional real-time dynamic control of all electrical and chemical energy inputs adjusted in real-time for process energy losses. Results to date indicate iEAF® technology will save an additional 10-12 kWh of energy per tls over and above NEXTGEN® alone.

ITEM	7 Most Recent Installations (NA & EU)	
	AVERAGE UNIT BENEFITS	AVERAGE % BENEFITS
Electricity	- 12.3 kWh per net ton	- 3.2 %
Natural Gas	- 27.6 scf per net ton	- 8.0 %
Total Carbon	- 10.0 lb per net ton	- 10.2 %
Oxygen	- 50.5 Scf per net ton	- 4.1 %
Productivity	+ 3.8 Net tons per hour	+ 3.9 %

Figure 13. Latest Results for an iEAF® implementation

2.4 Tenova's BOF Technology Solutions

A typical integrated steel plant operating without surplus off-gas energy recovery will emit approximately 1,844 kg CO_2/tls from both direct and indirect sources. Tenova's iBOF® technology is an innovative, modular solution that can be tailored to meet the specific needs of each individual BOF shop. It integrates off-gas analysis technology with additional sensors and process models into a modular solution designed to provide;

- **End-Point Phosphorus, Carbon & Temperature control** without expensive sub-lance technology;
- **Early Warning Slop Detection system** for slop avoidance without significantly lower productivity;
- **Optimized Post Combustion** for increased scrap melting; and/or,
- **Automatic Tapping control** for improved safety and reduced slag carryover.

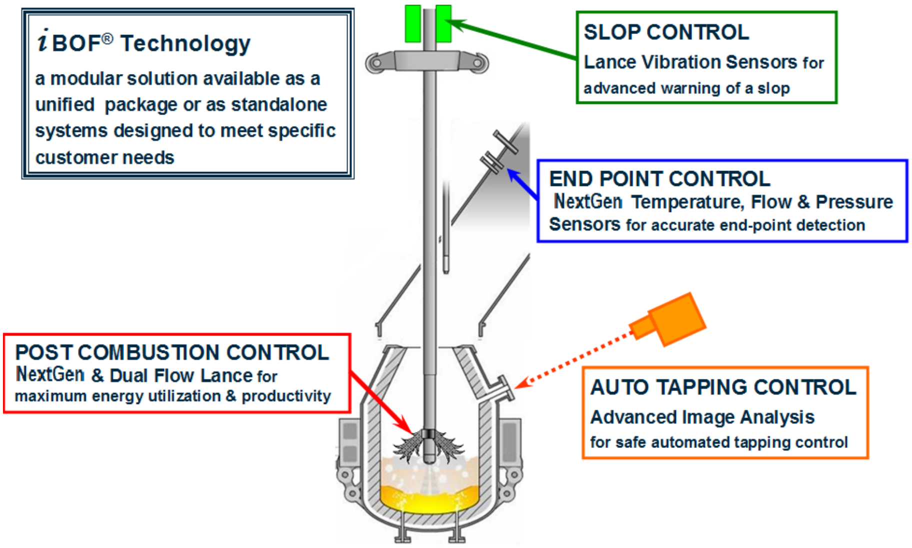

Figure 14: Tenova's iBOF® Solution

NEXTGEN® [P], [C] & temperature end-point for enhanced [P] control
This solution significantly improves carbon and temperature end-point control thereby lowering conversion costs (reduced O_2, refractory, consumables & tap alloys), increasing productivity (fewer re-blows & delays) and % yield (lower FeO).

Final [P] levels are established right at the end of the blow, thus avoiding both “under-blowing” and “over-blowing” situations critical for effective [P] control. Failing to turn down at the correct [C] and [T] is a critical mistake and can negate the benefits of a good [P] control slag practice. Turning down “too early” is particularly critical when HM [P] levels are increased. An early end to the blow can result in re-blows not only for [C] and temperature but also for [P].

To better understand the impact of turn down practice on [P] control at various HM [P] levels, Tenova Goodfellow developed a comprehensive in-blow and end-of-blow BOF process control model. To enable the model to be fully predictive under varying process conditions and avoid the problems normally encountered with statistical based models, the iBOF® process model is based on thermodynamic and kinetic fundamentals employing a real-time heat and mass balance for the BOF operation. As such, the iBOF® process model can be used not only for real-time BOF end point detection and control but also to simulate and investigate the effects of HM and BOF practice changes.

Figures 15 (a) and 15 (b) compare model predictions (solid lines) with actual in-blow and end-of-blow [C] & [P] analysis from a 200 MT top blown BOF converter (data points) for both normal and elevated HM [P] levels. Figure 15 (a) shows the endpoint window to hit < 0.015% [P] at turn down is quite wide when utilizing a normal North American HM [P] level of 0.04%. Under such circumstances, re-blows for [P] are very rare.

However as shown in Figure 15 (b), the endpoint window to hit < 0.015% [P] narrows considerably when the HM [P] is increased to 0.1%. Additional increases in HM [P] levels will tighten the turn down window even further. Under such elevated [P] conditions, without an effective endpoint control model, turning down too early becomes increasingly problematic. As shown in Figure 5 earlier, “over-blowing” is also problematic since it results in [P] reversion back to the metal thereby once again negating the benefits of a good slag practice.

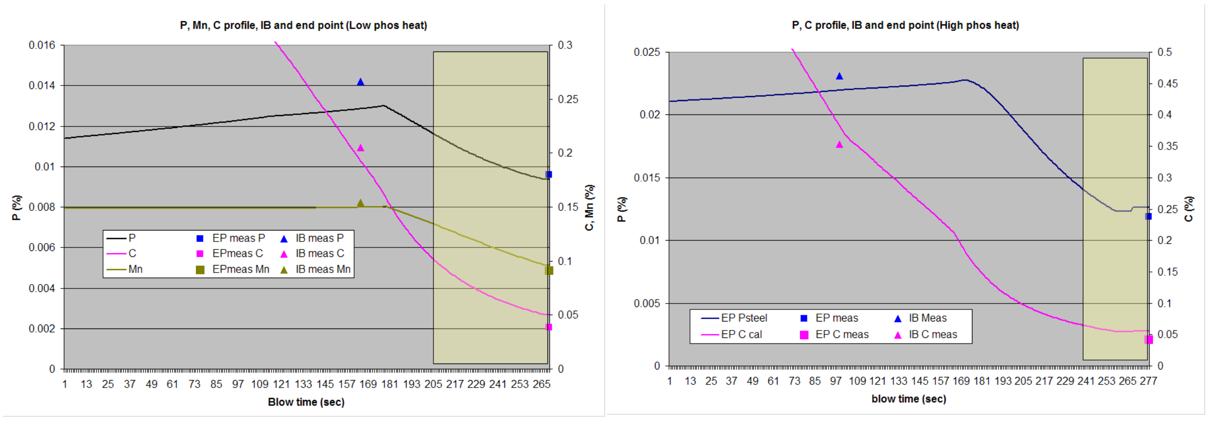

Figure 15. The iBOF® Model.
Left: (a) predictions compared to in-blow and post-blow melt samples for normal
Right: (b) elevated HM [P] levels.

Figures 16 (a) and 16 (b) below shows the iBOF® end-point model predictions for slag chemistry and the effect on metal chemistry of over-blowing a heat when using a low [P] HM. The model confirms the expected result, extending the blow dramatically reduces yield through rapidly increasing FeO which in turn results in [P] reversion.

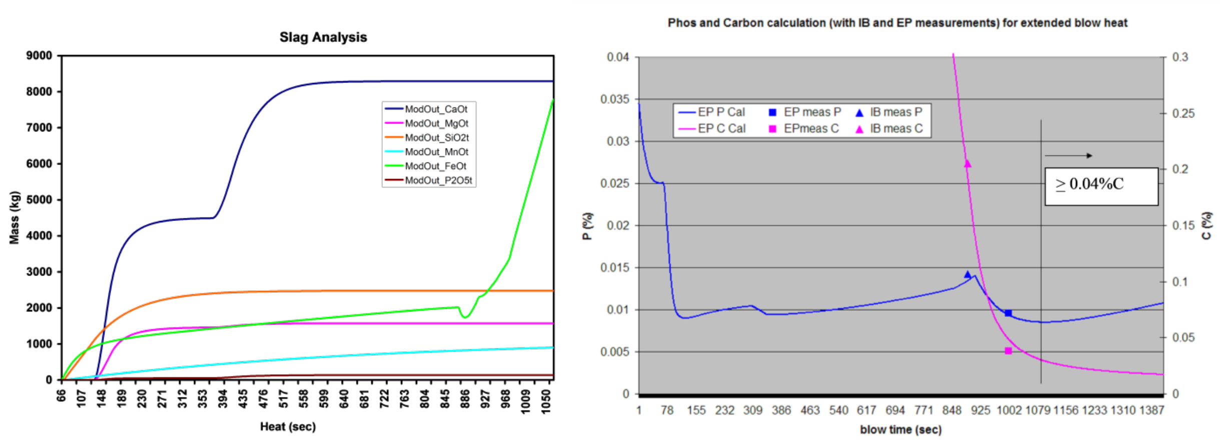

Figure 16. The iBOF® Model.
Left: (a) predictions compared to in-blow and post-blow melt samples for normal
Right: (b) elevated HM [P] levels.

iBOF® provides proven effective end-point control to avoid both early and late turn downs which is increasingly critical for effective [P] control when using high [P] HM. Optimized slag chemistry control together with effective end-point control is the cornerstone of a good [P] control strategy. Maintaining a slag rich in dissolved CaO with a V-Ratio of about 3 and MgO additions curtailed to levels no higher than required to minimize refractory wear will enhance the PR. Real-time slop detection and mitigation technology become more critical as slag volumes increase when utilizing HM with increasingly elevated [P] levels.

3 CONCLUSION

The off-gas technology provides a level of dynamic EAF control through a combination of direct dynamic control functions (burners, lances, injectors & furnace draft) and indirect control benefits which provide ongoing value from improved refractory, electrode & delta life; shorter power-on-times; reduced electricity, injected/charged carbon, fuel & O_2 consumption; higher % yield, & productivity. The iEAF® technology has been confirmed as providing an advanced level of EAF control and savings. iEAF® technology provides a complete EAF mass & energy balance in real-time giving operators a true understanding of chemical and electrical energy efficiency from start to end of every heat. As such, changes in real-time burner profiles, electrical energy efficiency, slag optimizer solution, endpoint for [C] & [T] are properly accounted for by iEAF® technology allowing furnace pacing, control and process efficiency.

BOF steelmakers are increasingly turning to higher [P] containing iron ores requiring plant operators to function at higher than traditional [P] levels. While specialized practices have been developed for high [P] HM, they add complexity, decrease productivity & yield and increase operating cost. Tenova's iBOF® technology is ideal for achieving enhanced [P] control, the end-point control, providing effective real-time [P], [C] & T end-point control to avoid both under and over blowing issues that affect turndown [P].

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