

Off-Gas Technology for EAF Operations

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ABSTRACT

Since the introduction of the Off-Gas analysis instrumentation for the Electric Arc Furnace (EAF), different applications have been developed to improve process efficiency and safety. AMI Automation has integrated Off-Gas parameters such as CO, CO₂ and H₂O composition, temperature, and flowrate into the SmartFurnace™ modules to improve their monitoring and optimization capacities.

The Chemical Energy module estimates the best operating conditions in the EAF, based on real time data, with the goal of increasing process efficiency and reduce variability. The set points for burners, lances, injectors, and continuous feeders are calculated by dynamic algorithms and process models. The database is enhanced with the addition of the Off-Gas parameters, improving the accuracy of the end-point prediction tools.

The Abnormal Water Vapor Detection module identifies unexpected sources of water in the Off-Gas that could pose a potential safety hazard. For this purpose, the Off-Gas information, along with the SmartFurnace™ catalog, are used to train a machine learning algorithm able to predict the H₂O extracted from the EAF.

A carbon emissions monitoring tool has been introduced to attend the latest efforts to reduce emissions in the steel industry. Its main goal is to provide an accurate and reliable CO₂ emissions measurement to understand the influence of different conditions such as raw materials, melting profiles and chemical practices, and thus, select the strategies to reduce the operation's environmental impact.

A description of these technologies and the latest updates in Off-Gas measurement installations is described in this paper.

INTRODUCTION

Developments in chemical energy optimization have been continuously improving the steelmaking process in EAFs around the world. The SmartFurnace™ optimization system introduces a Chemical Energy Module; a dynamic algorithm able to select the optimal setpoints for oxygen, natural gas, carbon, and fluxes in the EAF.

The Chemical Energy Module interacts with the DigitARCTM PX3 electrode regulator and an electrical supervisory control application (SmartArc) to provide an integral optimization of the process. These programs are connected to the PLCs through the process network using proprietary drivers, and to the electrode, burners, and fluxes actuators. These interactions are described in Figure 1.

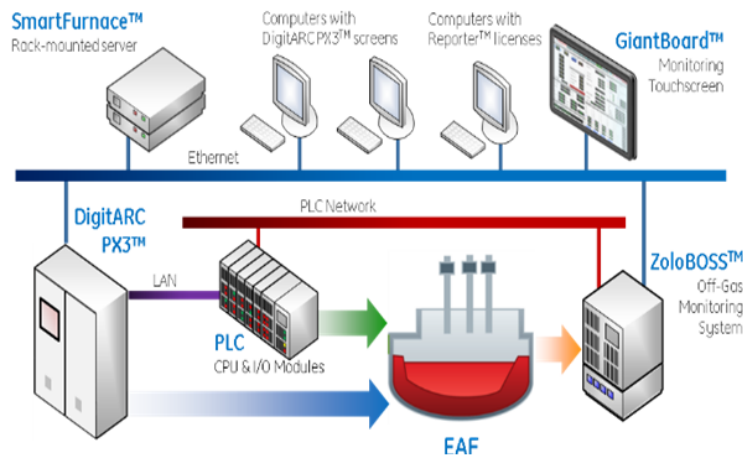


Fig. 1 – SmartFurnace System Architecture

One major milestone has been the introduction of an Off-Gas Analyzer: a device capable of resisting the harsh conditions of the furnace while measuring the CO, CO₂, and H₂O composition and Temperature of the Off-Gas. These values are used by the SmartFurnace™ modules to improve the accuracy of the optimization modules and to approach other topics previously inaccessible due to the lack of information.

Among the existing applications, those related to safety are of special interest to the industry. A prompt detection of abnormal water levels in the Off-Gas can reduce the risk of explosions and prevent safety hazards.

Another use of the Off-gas analysis is the monitoring of carbon emissions. An effort to reduce emissions is taking place in the steel industry. In order to meet sustainability targets, every process requires to keep track of their carbon contributions. The CO and CO₂ real-time measurement supplies additional info to the carbon material balance in the EAF.

OFF-GAS MONITORING SYSTEMS

A few technologies have been developed to analyze the Off-Gas composition and its temperature. Combined with the SmartFurnace™, the Tunable Diode Laser Absorption Spectroscopy (TDLAS) technology of the ZoloSCAN monitoring system has been installed in multiple facilities. It has proved to accurately provide real-time monitoring of CO, CO₂ and H₂O concentration, as well as the temperature of the Off-Gas [1]. Laser transmitter and receiver heads with automatic alignment are installed on the duct, sending a single laser ray through optic fiber up to the duct gap, and returning to the control cabinet again by optic fiber. The usual setup of the ZoloSCAN probe is shown on Figure 2.

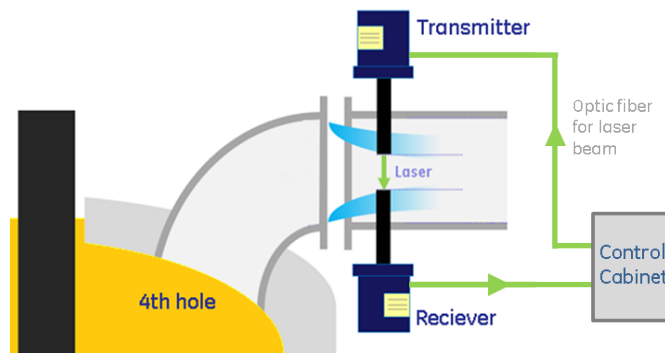


Fig. 2 – Usual setup of the ZoloSCAN Off Gas monitoring probe.

Due to the characteristics of the gas extraction, a camera array could also be added to the system setup to monitor the gas output through the roof.

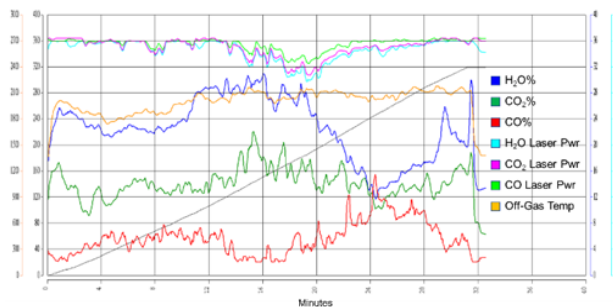


Fig. 3 – Example of the Off-gas analysis at the EAF measured by ZoloSCAN throughout a heat.

Another technology has been implemented recently with promising results. A high sensitivity IR sensor can perform the Off-Gas analysis as well as a measurement of its velocity. The system is not intrusive; works with a simple integration to the duct wall (as shown in Figure 4), requires very low maintenance and is calibration free.

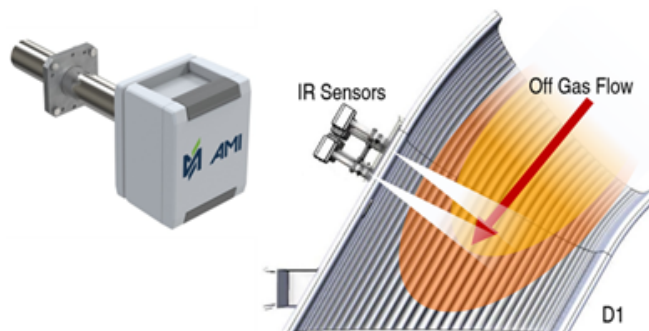


Fig. 4 – IR Off Gas sensor

The mass flow can be estimated from the Off-Gas velocity. The IR sensors measure the time of flight of distinctive signal patterns created by solid particles pulled in the Off-Gas. The gas velocity is then calculated with a correlation function.

DATA PROCESSING TOOLS - SMARTKNB

Visual KB is a graphic programming interface making possible to develop solutions merging data acquisition, complex process logic and machine learning models, all in the same environment.

To match the new technologies developed for data acquisition and monitoring, a dedicated software recently developed by AMI has been released; the SmartKnB platform. SmartKnB offers the same opportunities than Visual KB, plus other interesting features in an updated user-friendly environment (Figure 5).

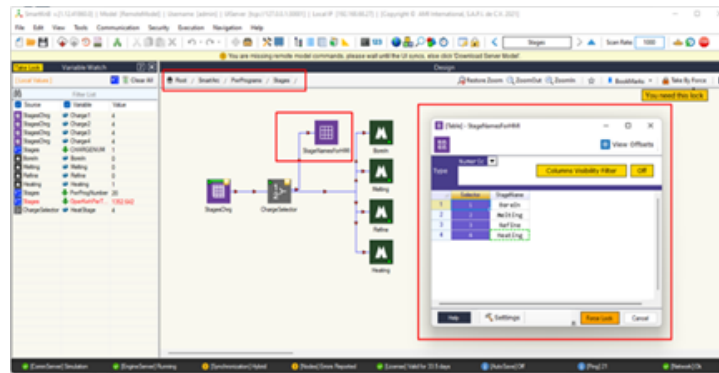


Fig. 5 – SmartKnB Interface. Real time data (left) and Design panel (right).

The new platform has the possibility of processing images. Installing advanced cameras, capable of withstanding the harsh environment of a steel plant, can provide immediate feedback of the surroundings. Besides opening a wide range of possibilities to explore vision applications, other useful features are included on the software update. See figure 6.



Fig. 6 – SmartKnB new features.

AMI OPTIMIZATION APPLICATIONS

The Chemical Energy Module controls the rates of Gas, Oxygen and Carbon, as well as the weight and timing of the different fluxes (Carbon, Dololime and Lime) through continuous monitoring of the actual heat conditions. Parameters recollected from previous heats allows it to automatically adapt the profiles to the current furnace operation. Its main goal is to reduce conversion costs while meeting the tapping conditions and keeping the good shape of the furnace.

The oxygen PPM (O₂ PPM) estimation is the core element of the Chemical Energy Module's dynamic closed loop control. Based on a complex material balance, it predicts the carbon/oxygen content of the bath in real time. Knowing the conditions of the bath allows us to meet the heat targets more quickly, reducing waste and delays.

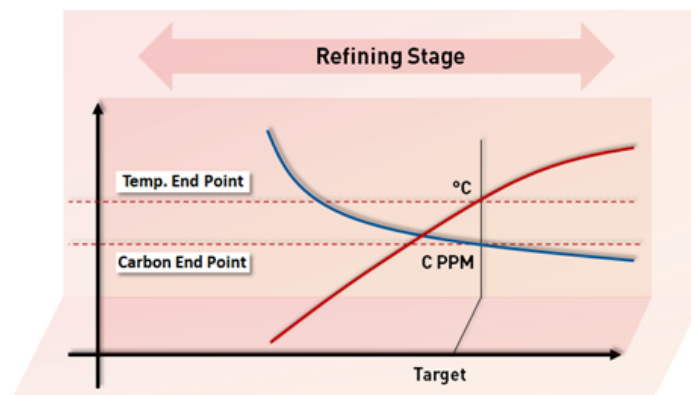


Fig. 7 – End point conditions at the EAF

The O₂ PPM estimation is used to control the oxygen/carbon ratio to be used on the different stages of the heat, translated on Burners, Lances and Carbon Injectors set points. The reactions anticipated on the material balance are also considered on an energy balance, where the chemical energy is quantified to improve the estimation of the steel bath temperature. The optimal slag conditions are also impacted by the O₂ PPM estimation, since the FeO generated is proportional to the oxygen dissolved in the bath.

The Chemical Energy Module's capabilities can be enhanced with the Off-Gas monitoring when available. The Off-Gas analysis adds extra data to the material balance, improving its accuracy. A straightforward way to use this information is to estimate the carbon content in the scrap mix. Based on operations with different scrap blends, a correlation can be observed between CO% levels and the average free carbon content in the scrap mix. The oxygen and carbon profile will be affected by the amount of carbon available, giving us the possibility to use more chemical energy when carbon is available and to be careful with the oxidation of the bath when conditions require it. Figure 8 shows the variation in CO% levels for different scrap blends used at the same EAF.

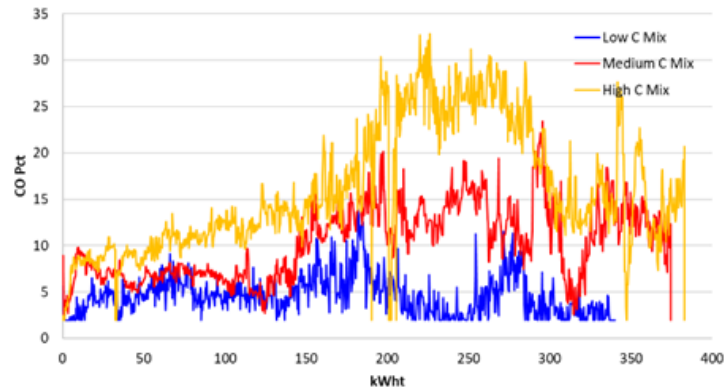
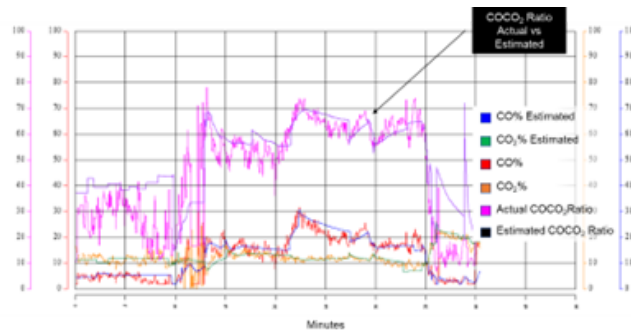
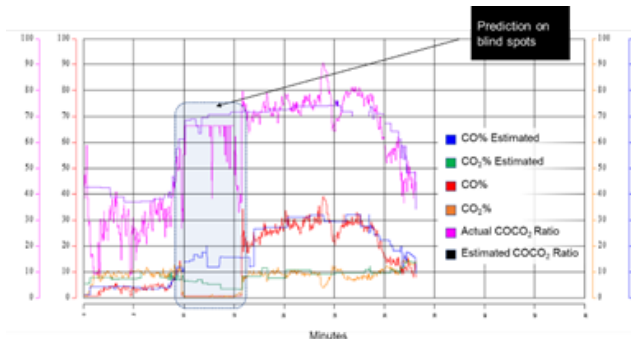


Fig. 8 – CO% profile for different Scrap Blends

Since the scrap mix shows a specific pattern of emissions with the same chemical profile (O₂, NG, Carbon), deviations from this pattern can be identified to adjust the setpoints. Carbon emissions can be estimated from a machine learning model that considers different operating variables and results in the expected CO% and CO₂% levels during the heat (Figure 9). The estimators can be trained to detect different scenarios and be helpful to predict Off-Gas analysis when the quality of the laser signal is low (Figure 10).


 Fig. 9 – CO, CO₂ estimations vs Off-Gas analysis

 Fig. 10 – CO, CO₂ predictions on blind spots

Continuous DRI feeding is a clear example of how to use the Off-Gas estimators. When the composition or metallization of the DRI changes on a particular heat, the contribution of carbon into the bath may change considerably depending on the DRI rate used and the heat stage. These variations of DRI impact the emissions of CO during the process [2]. Historical data from the Off-Gas is used to train a $COCO2Ratio = (CO2\% / (CO\% + CO2\%))$ estimator; a function of the DRI rate flow and other variables like the percentage of the total heat weight, carbon injection flow, natural gas and oxygen flows, energy consumption and temperature of the Off-Gas.

Taking the COCO2Ratio estimation as a reference of the DRI quality, the Off-Gas compensation modifies the DRI feed rate to ensure the best efficiency and avoid banking or reaction issues. Figure 11 shows an example of how the DRI feed rate affects the Off-gas emissions.

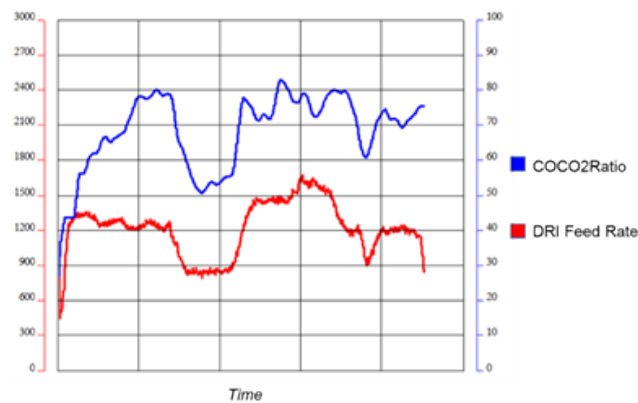


Fig. 11 – COCO2 Ratio vs DRI Feed Rate

The chemical energy from the combustion of different carbon sources can be monitored with the COCO2 ratio. The presence of high CO levels indicates excessive use of injected coal and high energy losses in the extraction system. In terms of safety, CO peaks must be controlled to avoid explosions due to the accumulation of chemical potential energy in the duct. The chemical module can automatically adjust the oxygen and carbon setpoints to control high CO levels. The energy losses due to carbon incomplete combustion are calculated as follows:

$$\Delta Q_{xi} = x_i m \int_{T_1}^{T_2} C_p(T) \cdot dT + x_i m \Delta H_{Rx}$$

Where x_i is the fraction of CO in the Offgas, rh is the mass flow of the Off-gas, C_p is the specific heat capacity of CO as a function of the temperature and ΔH_{Rx} is the oxidation energy of CO to form CO₂.

Another way in which Off-Gas information is useful is to optimize the use of injection carbon. In many cases this input is used too early in the melting process, causing complications such as cross-arcs, disconnections, and poor carbon efficiency due to the amount of material escaping through the extraction system. By monitoring some auxiliary parameters of the Off-Gas, such as the power of the laser signals, it is possible to identify when the material is being fed efficiently and thus select the best time to start the carbon injection (Figure 12).

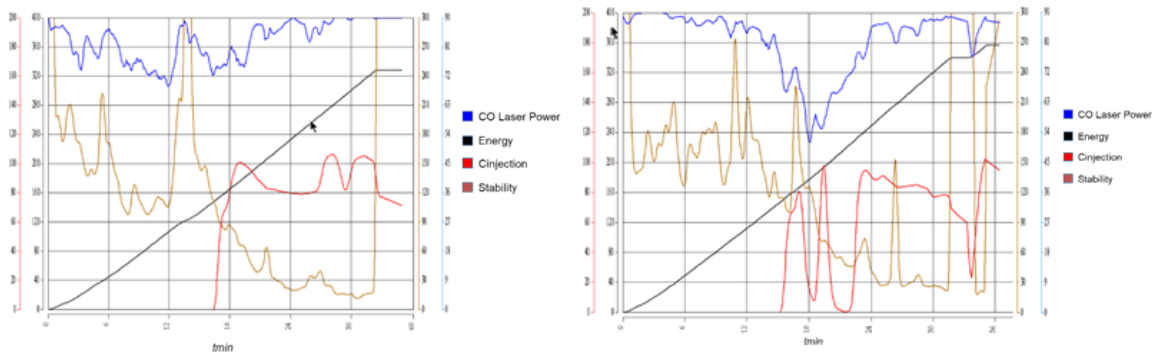


Fig. 12 – CO Laser Power vs a) Early carbon injection and b) Optimal carbon injection

AMI SAFETY APPLICATIONS

On the safety side, the goal of the Abnormal Water Vapor (AWV) Module is to warn the operators whenever excess water is detected, especially to avoid explosions or risky situations. Due to potential high safety risks, this system needs to be reliable, sensitive, and fast.

By using a complex algorithm that considers the H₂O concentration of the off gas, its temperature, the gas flow through the flow meter, and the intensity signals from a camera array, the water vapor mass is calculated. Other variables such as preheating time, damper position, natural gas consumption, duct temperature, pressure and moisture of the air, must be considered in order to have an accurate estimation of the H₂O vapor in the furnace. This information is used to create a profile of the typical water vapor found under normal circumstances.

The sensitivity of the measured H₂O% has been demonstrated by the difference in water vapor corresponding to electrode water spray adjustments [3]. Figure 14 shows the AWV model estimated water vapor percentage and the ZoloSCAN measured H₂O% on a typical heat with normal water vapor throughout the heat. The measured H₂O% and the estimated H₂O% follow each other closely.

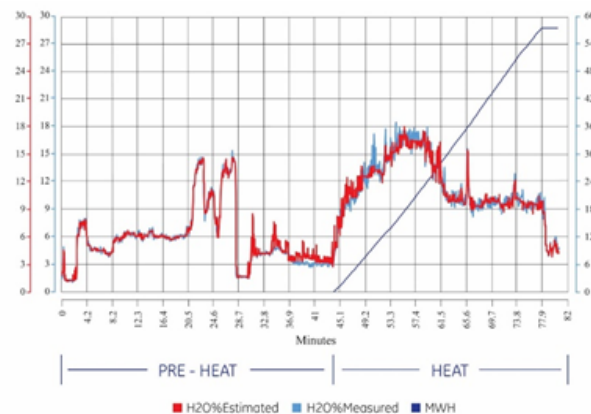


Fig. 14 – : Estimated H₂O and Measured H₂O in the Off Gas

Figure 15 shows an example of a real water leak detected by the AWV Module. After 20 minutes into the heat, the measured H₂O% is much greater than the estimated H₂O%. A positive difference between the two accumulates in an alarm integration value (AWV Accum), which will result in an alarm being sent if the integration value exceeds a defined threshold. On this heat the alarm was activated, and the operators reported a medium roof panel leak, which was repaired after tapping.



Fig. 15 – Detection of a Water Leak

AMI ENVIRONMENTAL APPLICATIONS

The Fume extraction system forms part of the overall material and energy balance of the EAF. Direct emissions from the furnace in the form of CO₂ can be easily monitored with the use of the Off-Gas composition and velocity. A large part of the emissions monitoring and control tasks are completed by quantifying the mass and energy losses in the Off-Gas, used in the estimation of O₂ PPM and temperature, centerpieces of the chemical module.

It is also necessary to differentiate the carbon sources within the operation to identify areas of opportunity and avoid excessive CO₂ generation. For this purpose, the O₂ PPM estimation, the estimated slag composition, and the Off-Gas mass rate are combined with the mass balance to close the carbon control loop. A mass balance as shown in Figure 15 is used to perform the general calculations. Factors particular to each furnace are considered to refine the calculations, such as furnace wear and life, electrode consumption and dynamic raw material compositions. Real-time emissions estimation for a DRI/scrap heat are shown in Figure 16.

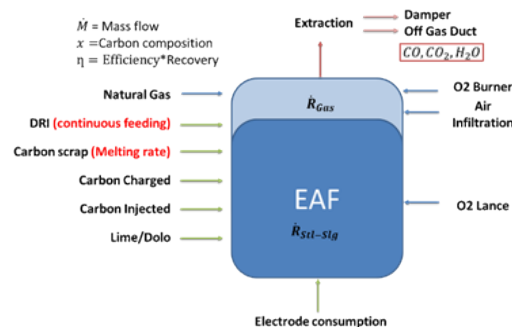


Fig. 16 – Carbon mass balance at the EAF

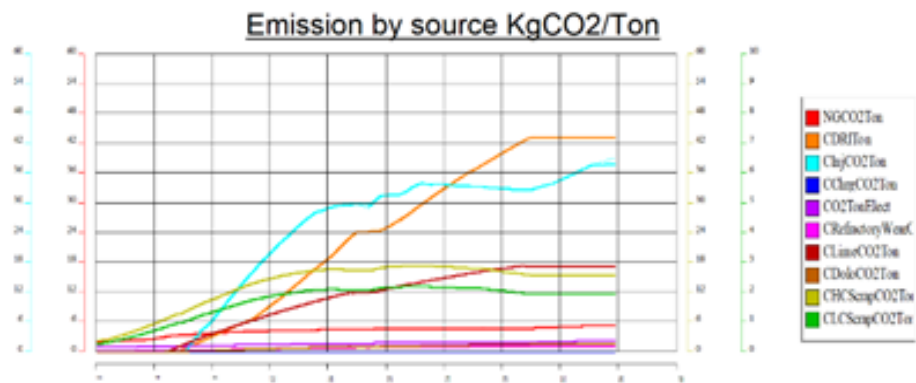


Fig. 17 – Carbon emissions per source on a continuous DRI feeding heat

CONCLUSION

A new transformation of the steel industry is underway. Materials and equipment capable of withstanding the aggressive conditions of the melting process are available for the development of new applications. What was once a simple model based on rules of thumb is now strengthened by reliable and accurate measurements. Vision equipment, continuous temperature gauges, and Off-Gas monitoring equipment are just a few examples.

AMI Automation is at the forefront of developing applications addressing the present and future needs of the industry. More precise control of end-point conditions, early detection of water in the furnace and timely monitoring of carbon emissions are among the list of developments made in recent years. The use of learning algorithms and the wide availability of data make these applications a valuable resource for the operation.

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