Using SmartFurnace and ZoloScan laser off-gas information to optimize DRI melting at Nucor Hickman

2015

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Keywords: Electric Arc Furnace, DRI, Off Gas, Optimization.

INTRODUCTION

The ZoloSCAN TDLAS Off-Gas Analyzer system provides a reliable and fast real time measurement of the content of CO%, CO2%, H2O% and Temperature in the Off Gas. The information is then sent to the SmartFurnace Off-Gas Control module where it is used for closed loop control to optimize the fuels usage in the EAF.

The usage of DRI in Electric Arc Furnaces has recently become more frequent. The DRI quality changes, especially in the form of carbon content, even in a same batch of a DRI supplier. It is a real challenge to dynamically determinate the amount of carbon in the DRI during the Heat. Using the CO and CO2 measurements form the ZoloSCAN system, the SmartFurnace Off-Gas Control Module reduces the effects of these variations in the DRI carbon content, allowing for a more efficient Chemical Energy usage in the EAF.

The new control has been successfully implemented at Nucor Steel Arkansas (NSA). NSA has two DC Electric Arc Furnaces (EAF) using a DRI percentage in the scrap mix from 12% up to 40%. Both EAF operate with The SmartFurnace System.

The SmartFurnace System was installed on EAF #1 in 2013 and it includes the power input set-points, oxygen, natural gas, carbon flow set-points, and control of four supersonic burners with carbon injectors. It also includes automatic control of the DRI feed rate and timing of the DRI feed. In 2015 the ZoloSCAN TDLAS Off Gas Analyzer was installed on EAF #1 to improve the EAF efficiency in the use of chemical energy through the SmartFurnace System. Also algorithms have been developed to identify an abnormal water vapor concentration in the EAF.

DISCUSSION

SmartFurnace System Description

The SmartFurnace System is an integrated system which is designed to control all the furnace consumables as well as the electric power input. The system is divided in four main modules: the SmartArc (Electrical Power Input Control), the Chemical Energy Control Module, the DRI Control Module and the Off Gas Control Module. The main idea behind the SmartFurnace control system is that each sub-system or module must be optimizing the operation of the equipment it controls independently from the settings of other control modules. For example, if a power input profile is designed to produce a faster heat, the Chemical Energy Control Module will change the operation of

the burners in order to arrive with the correct carbon at the end of the heat. The DRI Control Module will modify the DRI flow rates in order to finish feeding the DRI on time. The Off Gas Control Module will analyze the information provided by the ZoloSCAN TDLAS Off Gas Analyzer, compensate the Chemical Energy Control to have a higher efficiency and alarm for any abnormal water situation. This system is designed to optimize each part of the process with minimal changes required when developing new practices. It also compensates for variations in the process.

SmartARC
The central concept behind the power profile is to provide the capability to start with a very simple program and then add more flexibility and functionality as needed. Several features in the system allow it to modify its operation in order to cope with process variations. The new stability meter provided a great advantage to help identify the heat stages and slag conditions during the heat. The SmartArc system takes full advantage of this measurement. Some of the most important features are described next.

Chemical Energy Control Module
The Chemical Energy Control Module is designed to provide a robust control system capable of handling different furnace conditions, scrap mixes, practice changes, etc. The main difference from a conventional burner program (based only on energy steps) is that the control module has several sub-modules with specific functions to determine the different requirements for process optimization. The system simultaneously predicts temperature of the steel and the carbon content based on consumables information. In turn, it controls the carbon content and slag foaming in order to achieve optimal results.

DRI Control Module
The DRI Control Module design has two main goals for the automatic DRI feed control: Optimize the time to start the DRI and control the steel temperature to avoid accumulation of un-melted DRI in the furnace. The DRI control module automatically starts the DRI feed based on energy consumption and arc stability. This feature improved the DC furnace bottom temperatures.

The DRI control module has several automatic functions which are considered during process variations. The module takes into consideration the chemical energy input and the energy losses due to delays. It also has the capability to use the details of the DRI quality to compensate automatically for variations within a certain range if data isn't available. The system incorporates the use of arc stability for the detection of the heat stages and plays a significant role in the DRI rate selection during the heat.

Off Gas Control Module
The Off Gas Control Module design has two main goals: Optimize the chemical energy into the EAF and detect abnormal water vapor events inside the EAF. The Off Gas Control Module estimate with algorithms the percentage of CO generated by all sources of Carbon into the EAF for example DRI, Carbon Injectors and close the loop control with the real value provide by the Zolo TDLAS Off Gas Analyzer. The Off Gas Module will increase or decrease the Carbon Injection and Oxygen to reduce the emissions of CO and increment the percentage of CO2 produced during the combustion of Carbon and Oxygen into the EAF optimizing the chemical inputs in the EAF.

The Off Gas Control Module estimates with algorithms the levels of water vapor during all stages of the heat. The Off Gas Control Module compares the estimated water vapor with the real time water vapor sent by the Zolo TDLAS Off Gas Analyzer and determine if there is an abnormal quantity of water vapor inside the EAF. The next Figure represents all control modules available in the SmartFurnace:

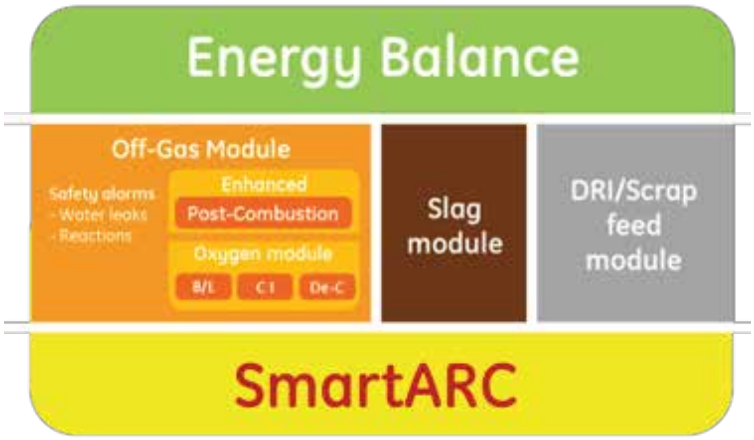

Figure 1. SmartFurnace Control Modules

Zolo TDLAS Off Gas Analyzer Description

ZoloSCAN is unique as a Tunable Diode Laser Absorption Spectroscopy (TDLAS) technology due to its proprietary multiplexing technology. Multiplexing enables many lasers to be combined onto one single light beam (or light path). The single multiplexed light path is pitched across the combustion space via a SensAlign Head. A second SensAlign Head is used as a catch head to receive the light and send it back to the control rack for de-multiplexing and signal processing1.

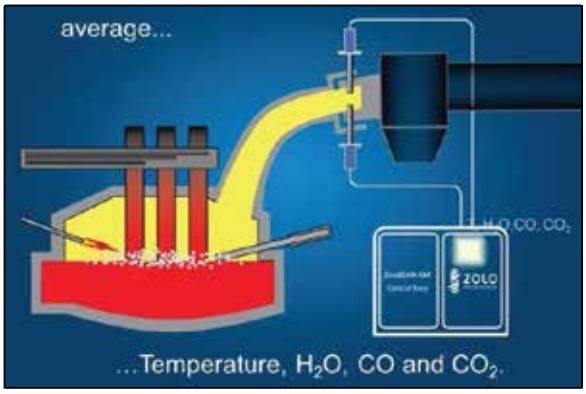

Figure 2. ZoloSCAN TDLAS Off Gas Analyzer System Overview

The Zolo TDLAS Off Gas Analyzer provides real-time, in-situ, simultaneous measurement of temperature, CO, CO2 and H2O at an agreed location near the 4thhole gap. The ZoloSCAN-EAFsystem is the only real-time combustion sensor that can obtain key combustion constituent measurements in the ultra-harsh environment of the EAF duct in less than 2 seconds.

Implementation of the SmartFurnace and ZoloSCAN TDLAS Off Gas Analyzer at Nucor Hickman Furnace Description

The EAF has a 26 ft diameter and 150 tap ton capacity while maintaining a 75 ton hot heel. The capacity of the transformer is 81.496 MVA. The EAFs are limited to a potential of 950 V and a current of 140 KA. Each furnace is equipped with a top feed system with a capacity of 300 Ton/hr, which is used for DRI, carbon, lime and dolomitic lime. The furnace is equipped with 4 PTI burners with a maximum flow capacity of 2000 scfm of oxygen and 300 scfm for natural gas; Figure 3 shows the position of the burners and the roof feeding2.

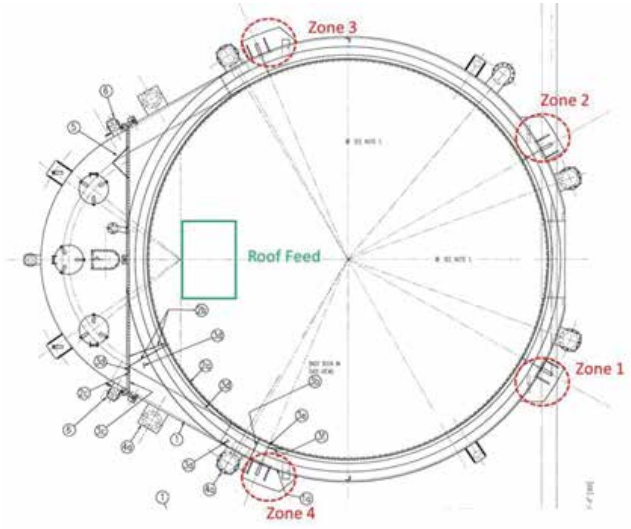

Figure 3. EAF layout diagram

When the composition or metallization of the DRI changes, or the quantity of DRI used on a particular heat, the contribution of Carbon into the bath may change considerable and is very dependent of the DRI rate used and the heat stage. These variations of DRI will directly change the emissions of CO during the process.

The Off Gas Module control take the Information from the Zolo Off Gas Analyser and validate all input variables such as operational limits, quality of the signal and process the variables in order to have a robust control.

The next figure show and extract of the Off Gas Control Module logic inside the SmartFurnace, where other sub-modules perform the data reading validation and process all the signals in the Off Gas Control Module.

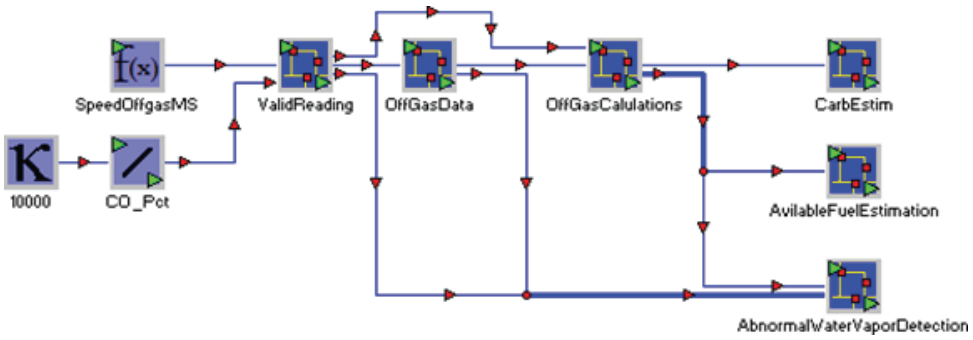

Figure 4. Off Gas Control Module

During the process is a challenge to estimate what will be the amount of CO emissions ejected by the Steel Process and determine an acceptable range considering the needs and natural behaviour of the process. The Off Gas Control Module estimates the COCO2Ratio=(CO2Pct/(COPct+Co2Pct))*100 in the gas emission as a function of the DRI Rate Flow and other variables like the percentage of the total Heat weight in the furnace, Carbon Injection Flow, Natural Gas and Oxygen Flows, Energy Consumption and Temperature of the Off Gas.

Using the estimated COCO2Ratio, the Off Gas Control Module will take action optimizing the Chemical Energy usage in coordination with the other Control Modules of the SmartFurnace to guarantee the best performance in the EAF. The next figure shows different composites using the COCO2Ratio to close the loop control with the real time signal from the Off Gas Analyzer.

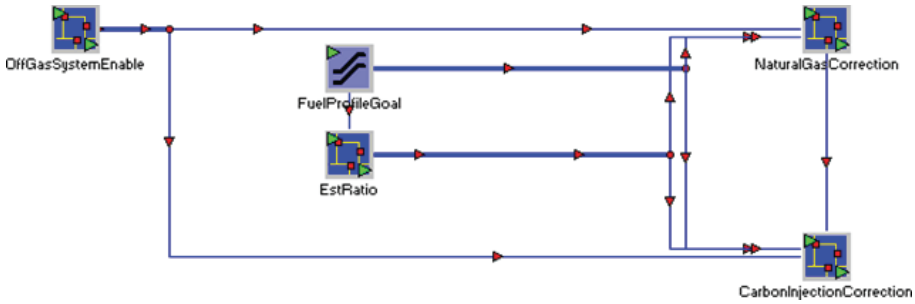

Figure 5. Off Gas Control Module, Natural Gas and Carbon Injection Correction.

The Off Gas Control Module individually modify each Carbon Injector to ensure the best efficiency, the next figure concerns the operation on the Carbon Injector in burner #4 and shows the Estimated COCO2 Ratio (EstCOCO2Ratio), the COCO2Ratio, The Total DRI Flow, Carbon Reference Off Gas Corrected (B4CCarbRefOff).

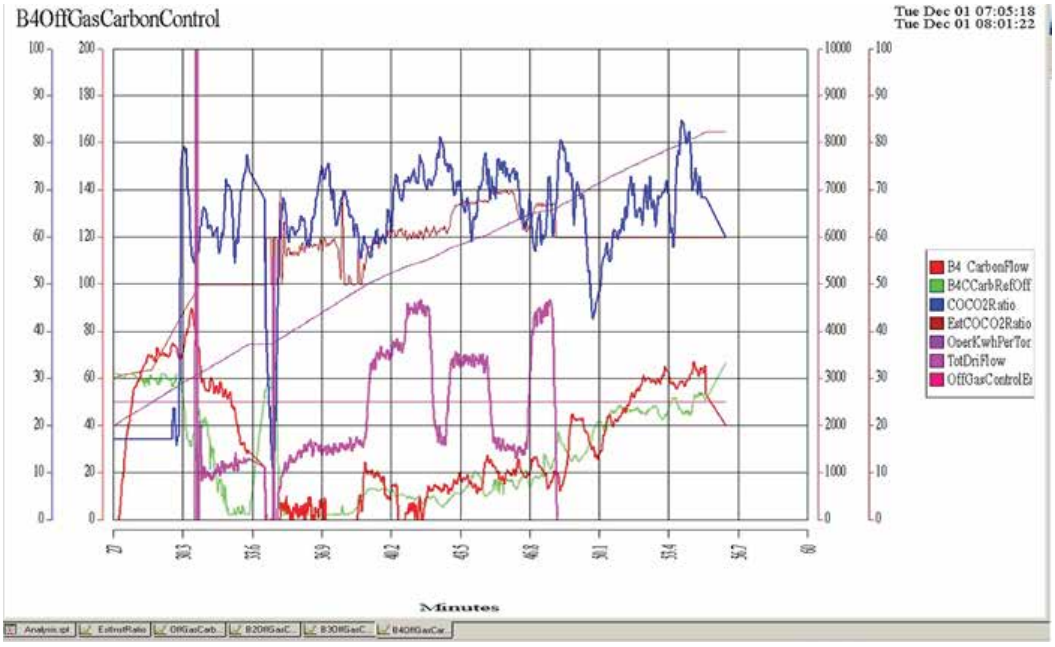

Figure 6. Off Gas Control Module controlling the COCO2 Ratio

Figure 6 shows a clear example to observe the response of the CO to CO2 Ratio from the Off-Gas probe when the DRI flow set- point is changing.

The system compensations correct up to a certain point for variations in DRI quality. The main variation in DRI quality is the carbon content, and when less Carbon is present in the DRI there is also less CO emissions. The system compensates for these variations based of the Off Gas probe feedback.

Detection of abnormal water vapor

The Off Gas Control Module detects an abnormal quantity of water vapor inside the EAF in the different stages of the Heat. The Off Gas Control Module estimate the actual amount of water vapor inside the furnace using mainly the H2O% measured by the Off Gas Analyzer near to the 4thhole gap and the off gas flow measured by a Promecon meter several meters away the Off Gas analyzer and compensated by the temperature of the duct.

Using the H2O% and the Off Gas Flow, the Off Gas Control Module calculates the amount of mass water vapor produced by the EAF in each stage of the Heat. The Off Gas Control Module estimates the amount of water vapor and then compares the estimated value with the calculated value from the Off Gas Analyzer and the Promecon meter to detect an abnormal quantity of water vapor.

The number of variables used to estimate the water vapor inside the EAF is quite large. The Off Gas Control estimates the water vapor in function of Total Natural Gas Flow, Total Electrode Spray Water, Electrode Position, Off Gas Temperature, Air Intake, Furnace Pressure and others.

The next figure shows the real water vapor calculated and estimated during a heat where no abnormal situations where reported.

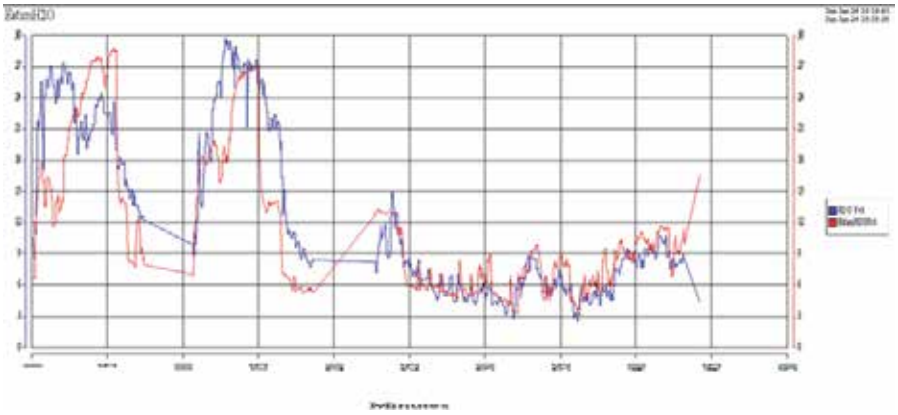

Figure 7. Estimated and Real Water Vapor by Off Gas Control Module

We observe on Figure 7 and accurate estimation of the Water Vapor (EstimH2OPct) and the calculated values from the Off Gas Analyzer and Promecon. The next figure shows the same variables than figure 7 but with an abnormal water vapor event.

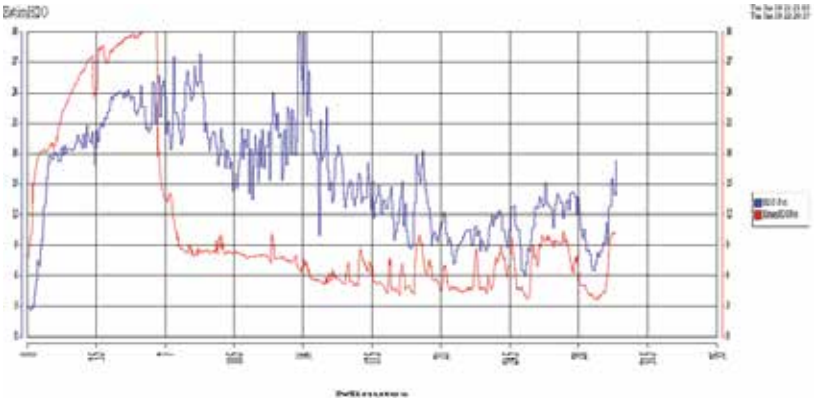

Figure 8. Estimated and Real Water Vapor with an abnormal water vapor detection.

We observe on Figure 8 a mayor difference between the real amount of water vapor going outside the EAF and the estimated value. During this heat an important water leak from one furnace panel was detected. The abnormal situation was only observe on this heat the previous and after heat all parameters were normal.

The Off Gas Control module integrates the excess of water vapor between the real and estimated signal and after a threshold it will alarm the Furnace Operator about an abnormal water vapor event inside the EAF.

RESULTS

The system adapts to different environments caused by the different DRI usages. In order to better analyze the results, the evaluation was carried out over two groups of heats with different charged DRI percentage. The Heats have been split by high DRI and low DRI percentage charged.

DRI Charged 16% (20-30 Tons), Total of Heats 129. Off Gas Control Enable 85 Heats.	
	Percentage of Savings
KWH/Ton	-1,43%
Power On Time	1,62%
O2PerTon (scf/Ton)	-6,70%
Gas Per Ton (scf/ton)	-6,88%
CarbInjPerTon (lb/ton)	-5,10%

DRI Charged 40% (60-80 Tons), Total of Heats 208. Off Gas Control Enable 109 Heats.	
	Percentage of Savings
KWH/Ton	-3,10%
Power On Time	-2,08%
O2PerTon (scf/Ton)	-5,39%
Gas Per Ton (scf/ton)	-7,59%
CarbInjPerTon (lb/ton)	-7,21%

CONCLUSIONS

Furnaces represent the largest cost and energy usage in steel mills. Maintaining efficiency and adapting to different circumstances is something needed in order to attain sustainable results. The Off Gas control Module has proved remarkable benefits optimizing the EAF using the ZoloSCAN TDLAS Off Gas Analyzer coupled to the SmartARC.

The capability to adapt to all changes caused by DRI usage has been enhanced making the process more safety with cleaner emission and more efficient.

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