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DYNAMIC CONTROL AND OPTIMIZATION OF EAF CHEMICAL ENERGY USING TENOVA'S EFSOP® TECHNOLOGY[1]

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Abstract

In February 2010, Tenova Goodfellow Inc. installed its proprietary EFSOP® (Expert Furnace System Optimization Process) system on a 140 ton electric arc furnace (EAF), with the objective of improving performance and operating costs through the reduction of electricity, oxygen, methane, injected and charge carbon use. Goodfellow EFSOP® uses real-time analysis of EAF off-gases to optimize and control dynamically the chemical energy usage within the electric arc furnace (EAF). The primary benefits offered by Tenova's EFSOP® System are lower conversion costs, increased productivity, increased process knowledge and safety. The improved process control afforded by the EFSOP® system makes it possible to take a holistic approach to furnace optimization that can be tailored to reaching the operational objectives of each melt shop. This paper will outline the main components and features of the EFSOP® technology implemented and will discuss the successful outcome of the project including EAF optimization strategy, benefits and savings in relation to this project.

Key words: Off-gas analysis; Optimization; Chemical energy; EAF steelmaking; EFSOP.

CONTROLE DINÂMICO E OTIMIZAÇÃO DA ENERGIA QUÍMICA DO FEA UTILIZANDO A TECNOLOGIA EFSOP® DA TENOVA

Resumo

Em fevereiro de 2010, a Tenova Goodfellow Inc. instalou o seu sistema EFSOP® (*Expert Furnace System Optimization Process* – Processo Especializado de Otimização do Sistema do Forno) em um forno elétrico a arco (FEA) de 140 toneladas, com o objetivo de melhorar o desempenho e os custos operacionais através da redução na utilização de eletricidade, oxigênio, metano e carbono injetado e carregado. O EFSOP® da Goodfellow utiliza a análise em tempo real dos gases de exaustão do FEA para otimizar e controlar dinamicamente o uso da energia química no forno elétrico a arco (FEA). Os benefícios primários oferecidos pelo Sistema EFSOP® da Tenova são custos de conversão menores, aumento da produtividade, aumento do conhecimento do processo e da segurança. O melhor controle do processo propiciado pelo sistema EFSOP® permite obter uma aproximação holística à otimização do forno que pode ser particularizada para se atingirem os objetivos operacionais de cada aciaria. Este trabalho apresenta os principais componentes e características da tecnologia EFSOP® implantados, e discute o sucesso obtido no projeto incluindo a estratégia de otimização do FEA, além dos benefícios e economias resultantes.

Palavras-chave: Análise de gases de exaustão; Otimização; Energia química; Aciaria elétrica; EFSOP.

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1 INTRODUCTION

The EFSOP® system is a reliable off-gas analysis system capable of withstanding the harsh environment of the EAF with minimal maintenance, while accurately measuring the O_2, CO, CO_2 and H_2 concentration(s) of furnace off-gas directly upstream of the fourth hole.
Originally developed in the 1990's as a robust off-gas analysis system used to evaluate the heat load on the EAF primary fume system, today's EFSOP® is a tool used for the Holistic optimization of the EAF process. The off-gas analysis provides process engineers a window into the operation of their furnace. Based on this information optimization objectives can be achieved by adjustments to the various aspects of the EAF process: including fume system control to maximize combustion and minimize energy losses to false air entering the EAF freeboard; adjustment to the charged carbon practice to minimize the heat load to the primary fume system; scrap distribution in the charge buckets to mitigate inconsistencies in operation due to scrap diversity; burner intensity and timing to optimize energy evolution in the freeboard; refining practice through the intensity and timing of injected carbon and lanced oxygen; and overall furnace pacing to ensure consistency of operation.
This paper discusses the application of the EFSOP® system on a 140 ton electric arc furnace equipped with a chemical package; which includes three coherent lance/burners, three carbon injection ports, and door burner for slag door cleaning. Off-gas analysis was used to dynamically control burner oxygen and gas injection, and as an offline tool for diagnosing bath mixing and oxidation issues.

2 MATERIALS AND METHODS

The EFSOP® system measures the O_2, CO, CO_2 and H_2 concentration(s) of furnace off-gas directly upstream of the fourth hole. The patented EFSOP® probe and customized filtration system which ensures accurate off-gas analysis and high instrument reliability (with an average uptime of 95%) with minimal maintenance.


Figure 1. EFSOP® patented probe in fume system.

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To ensure a reliable and continuous sample during power-on-time, the system comes equipped with purging functionality whereby the probe is automatically purged during power-off periods. When sampling, gases are extracted continuously and in real-time from the process and conveyed to the off-gas analyzer; via a dedicated sampling and conditioning system. The slight delay in sampling and analysis is negligible with respect to the time constant of the EAF process.

Data from the off-gas analyzer is sent, via the plant's PLC network, to the EFSOP® PC-based SCADA system. The analysis is then used to gauge the extent of combustion within the furnace and determine the optimum control set-points for oxygen and methane. In addition, the SCADA system features an automated email function whereby daily process information is sent to TGI for monitoring and analysis.

Previous applications of the EFSOP® technology for EAF optimization have been presented and published elsewhere.(1-4)

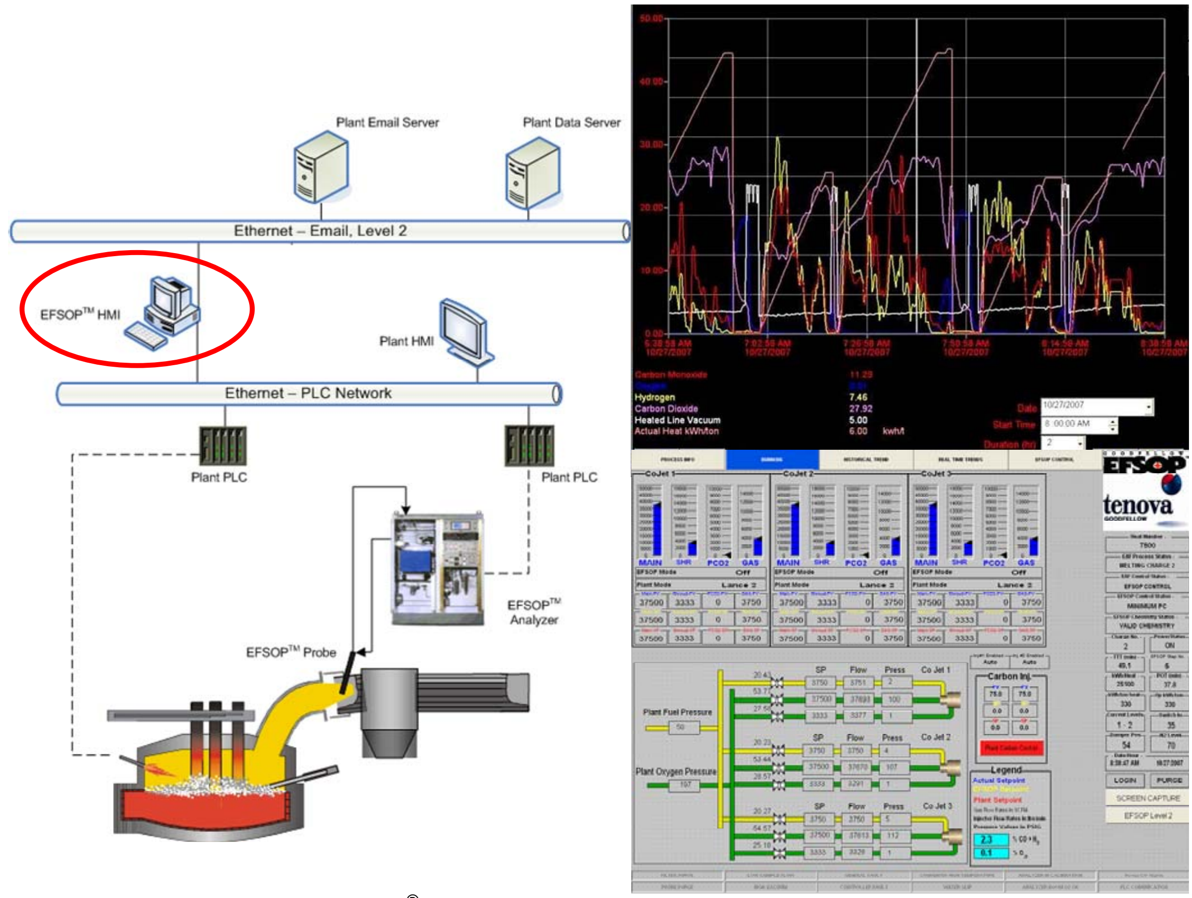

Figure 2. Schematic of EFSOP® System in plant Level 1 and Level 2 Ethernet network and screenshots of typical HMI.

3 RESULTS AND DISCUSSION

3.1 Post Combustion Optimization

Initial observation of furnace off-gas profiles indicated that this plant's off-gas contained high concentrations of combustible gases (H_2 and CO) throughout the melting phase. Figure 3 is a representative heat and shows high concentration (greater than 10%) of H_2 and CO during the first 10 minutes of both charges. This off-gas composition represents a loss of chemical energy to the fume system which

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could be instead developed inside the furnace by increasing excess oxygen injection when H_2 and CO are present in the off-gas.

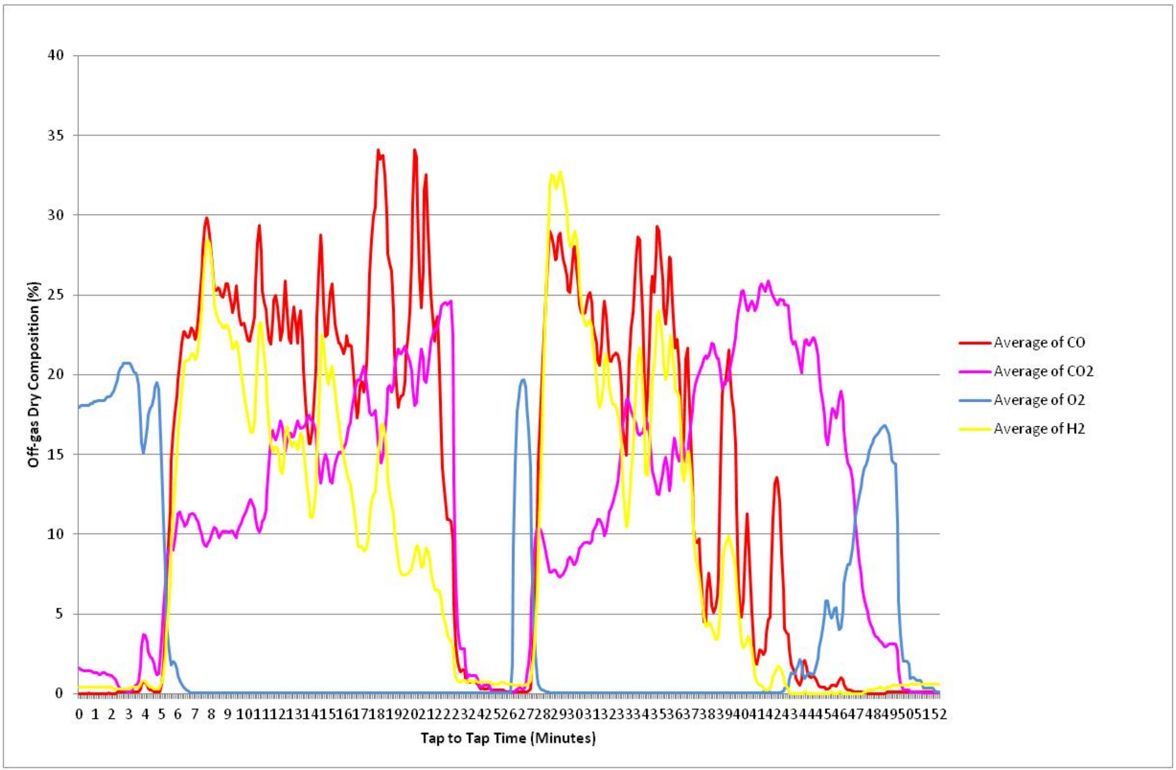

Figure 3. Typical off-gas chemistry of a two charge heat showing high concentration of CO and H_2 in melt phase.

Closed Loop Control (CLC) of the burners was installed to dynamically modify the chemical profiles according to the off-gas composition; increasing post combustion oxygen when combustible gasses were present, and limiting excess oxygen when they were not. The benefit of closed loop control of oxygen and gas is the flexibility it allows for accommodating varying scrap chemical energy. Reducing methane when there is a high concentration of combustible gasses in the off-gas has the benefit of reducing furnace costs and overall carbon emissions, whereas reducing excess oxygen in an oxidizing furnace has the benefit of avoiding oxygen wastage, and reducing electrode side wall oxidation.

Dynamic control of burners and lance optimization, discussed in the next section, resulted in a savings of 0.63 Euro/tgb. The breakdown in savings is shown in Table 1.

Table 1. EAF consumption cost savings

EAF Consumption Parameters	Savings (€/tgb)
Electrical	0.10
Oxygen	0.27
Natural Gas	0.12
Injected Carbon	-0.03
Charged Carbon	0.17
TOTAL	0.63

3.2 Lance Optimization

The second phase of optimization concentrated on identifying source of high oxidation of the liquid bath, high FeO in the slag, and high electrode consumption rate through lancing analysis. Patterns in the off-gas profiles during lancing and refining were studied to determine a link to lancing efficiency.
In the EAF, when oxygen is blown directly into the molten steel bath, decarburization occurs and there is an increase in both CO levels and in the ratio of $CO:H_2$ due to the liberated carbon evolved from the bath. Bath decarburization was visible in the off-gas chemistry in greater concentrations during the first charge lancing phase, than during the refining phase, in fact, an oxidizing environment was often seen during the last stages of refining; suggesting that carbon supplied to the furnace is depleted early in the process.

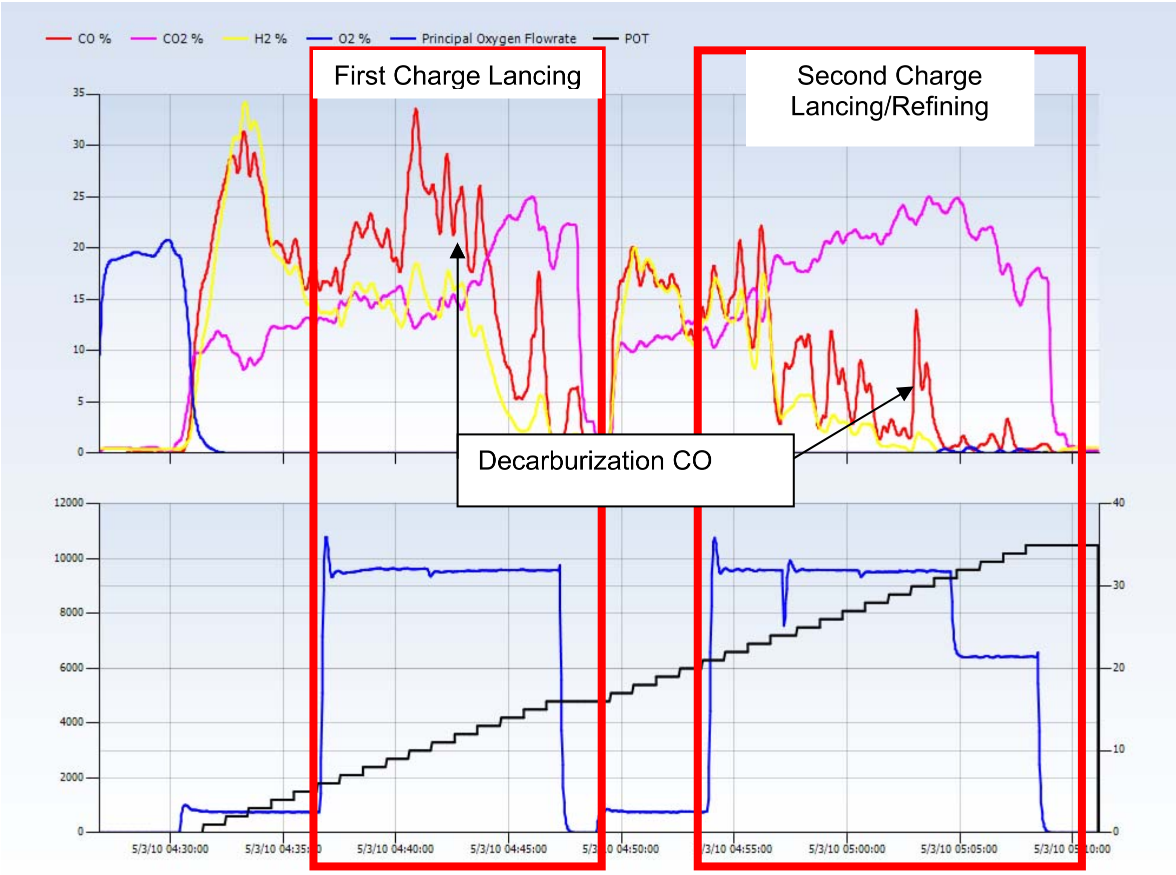

Figure 4. Off-gas and lancing timing showing significantly more evolution of carbon from the bath during first charge than during refining.

Patterns depicting solid scrap lancing were also observed in the off-gas profile during onset of lancing phase and are another source of high FeO. Alternatively to lancing into a liquid bath, when oxygen is blown directly onto solid scrap an increase in $CO:H_2$ ratio is not observed because oxygen is reacting with solid hydrocarbons in the scrap and both H_2 and CO are formed. It is therefore possible to gauge the effectiveness and efficiency of “scrap cutting” and make adjustments to optimize its use. Figure 4 presents an example of a heat where there is a longer period of scrap lancing before onset of liquid phase as visible in the delay in separation between CO and H_2.

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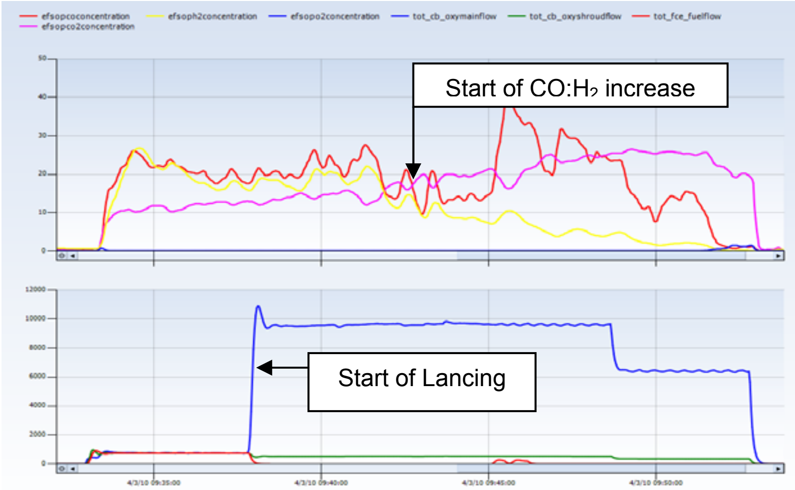

Figure 5. Solid scrap lancing at start of refining phase extends for 4 minutes.

Oxygen lancing onto solid scrap is beneficial in that there is generation of heat from the direct oxidation of iron and the increase in surface area in the case of high-density scrap. The drawback to this practice is that the high levels of FeO during melt-in cause an earlier than desired release of dissolved carbon. Ultimately, this practice requires greater charge carbon be used so as to ensure sufficient carbon remains in the furnace during refining. If carbon is depleted too early, the ability to maintain a foamy slag and yield suffer. Additionally, over-oxidation of the steel bath may result requiring an increased use of de-oxidants to kill the steel at the ladle.

For this particular process the following optimization steps were taken on the lancing operation:

- lancing was delayed in order to match better with the onset of the liquid bath which reduced the ppmO2 in the bath at the end of the heat;
- lancing in the first charge was stepped down at the end of the charge to preserve carbon in the bath for the refining phase;
- different profiles were established for charges with a high percentage of dense scrap that required early lancing for significant scrap cutting purposes;
- soft lance flow rate were used in “scrap cutting” phases in order to reduce overall oxidation.

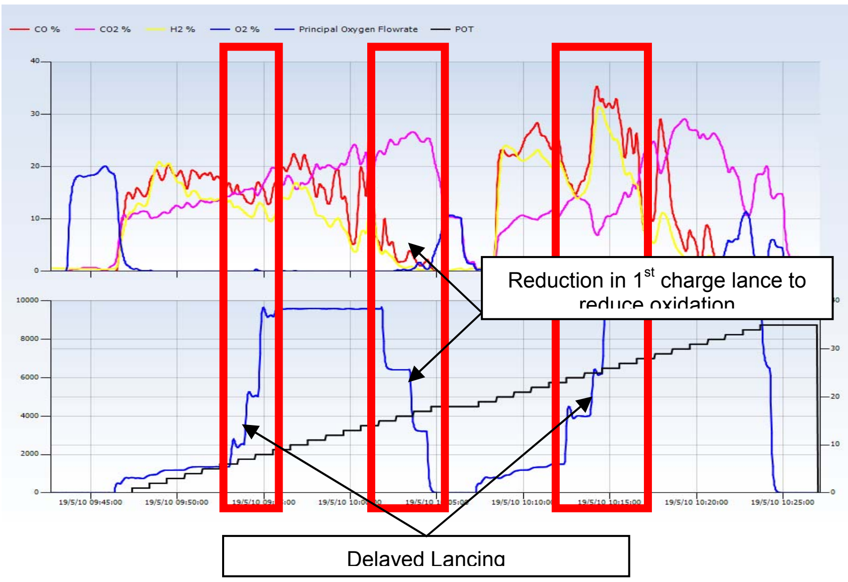

Figure 6. Modified lancing practice after off-gas analysis for ppmO2 reduction.

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The use of the off-gas analysis profiles to identify the issue of bath oxidation and ineffective lancing and the subsequent modifications to the oxygen lance practice resulted in reductions in charged carbon, oxygen injection, slag FeO, secondary metallurgy ladle additions (Table 2) and ladle refractory wear.

Table 2. Ladle Furnace consumption savings due to EAF oxidation management

	FeSi	C	SiMn	CaF
High Carbon Grade	18% ↓	34% ↓	3% ↓	56% ↓
Low Carbon Grade	19% ↓	1% ↓	5% ↓	28% ↓

3.3 Bath Mixing

During optimization of this particular furnace, a phenomenon of regularly occurring CO spikes was observed in the off-gas analysis. CO spikes occur when there is a rapid evolution of CO gas from the furnace. The most common reasons that this occurs are cave-ins and carbon boils. This phenomenon was of interest as it coincided with greater than typical inconsistent measurement of bath carbon and temperature near the end of refining making it difficult to effectively determine end-of-heat.

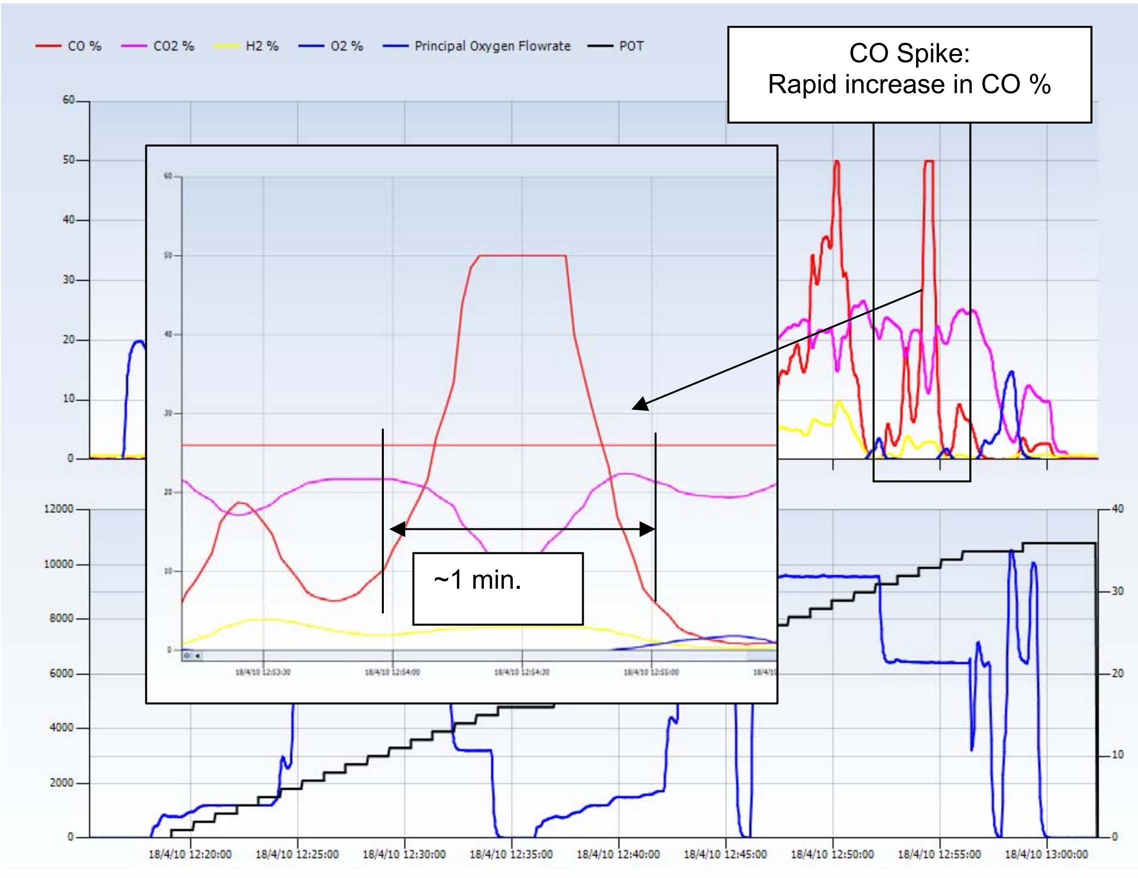

Figure 7. Close-up of CO spike showing long duration of CO generation indicating carbon boil.

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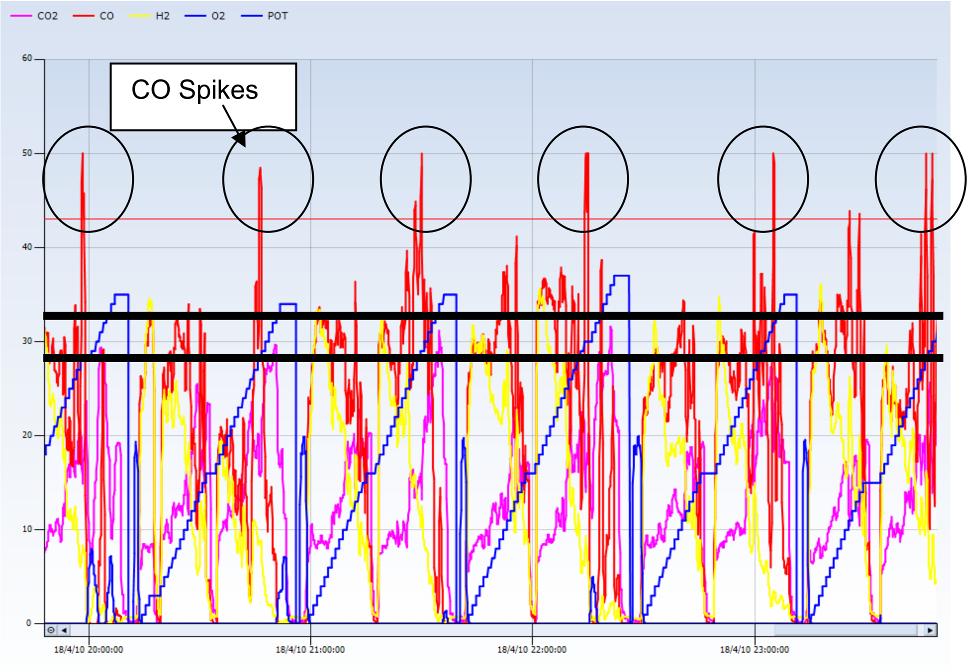

Figure 8. Series of heats with CO spike occurring within 28 min to 33 min power-on-time, indicative of practice-related rather than random event.

The analysis of this phenomenon came up with the following observations:

- the extended period of time (> 30 seconds) of each CO spike suggests a runaway reaction and not a sudden event; therefore it is more likely a carbon boil than a cave in (Figure 7);
- CO spikes occurred with great regularity making the evolution of CO as a matter of practice and not of chance (Figure 8);
- this phenomenon was seen only late in the refractory life;
- often an oxidizing environment (little CO being evolved) was observed in the period immediately preceding the CO spike.

Based on the above observations this phenomenon was theorized as carbon boils caused by the delayed onset of bath mixing due to a decrease in lance efficiency at lower bath heights. The plant’s practice of charging carbon on the bottom of the first bucket led to a high carbon concentration in the furnace heel. Without efficient bath mixing a layered affect resulted where there existed, in the lower part of the bath, a layer of liquid iron with low temperature and high carbon concentration covered by an upper layer having a higher-temperature and being highly oxidized. The eventual mixing of these two layers, caused by the high temperature differential later in the refining phase, results in the rapid evolution of CO as FeO reacts with dissolved carbon. Lances were operating in such a way that changes in distance between lance and bath made a significant effect on the ability to mix the bath late in the furnace campaign when refractory consumption resulted in lower bath height.
Several trials were conducted to resolve the issue not only of violent carbon boil events and end heat measurements but to understand the best practices to improve overall bath mixing in late shell furnaces. The trials are summarized in Table 3.

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Table 3. Bath mixing trials

	Description	Off-gas result	Furnace Result
1	Increase Lance Flow rate for better bath penetration. 1st Charge Carbon: 100% of original total carbon	CO spikes still occurring	Improvement in refining efficiency but bath mixing issue persists.
2	1st Charge Carbon: 0kg Conveyed Carbon: 75% of original total carbon. Trial 1 Lance Flow rate.	CO spikes disappeared.	End points are more consistent. Suspicious of refractory wear from over oxidized first charge bath.
3	1st Charge Carbon: 50% of original total carbon. Conveyed Carbon: 25% of original total carbon. Trial 1 Lance Flow rate.	CO spikes still occurring	Improvement in refining efficiency but bath mixing issue persists.
4	Superheating 1st Charge. 1st Charge Carbon: 50% of original total carbon. Conveyed Carbon: 25% of original total carbon. Trial 1 Lance Flow rate.	CO spikes still occurring but to a lesser degree and earlier in refining.	Improvement in refining efficiency, bath mixing issue resolves spontaneously at an earlier time in the heat. End points are more consistent.

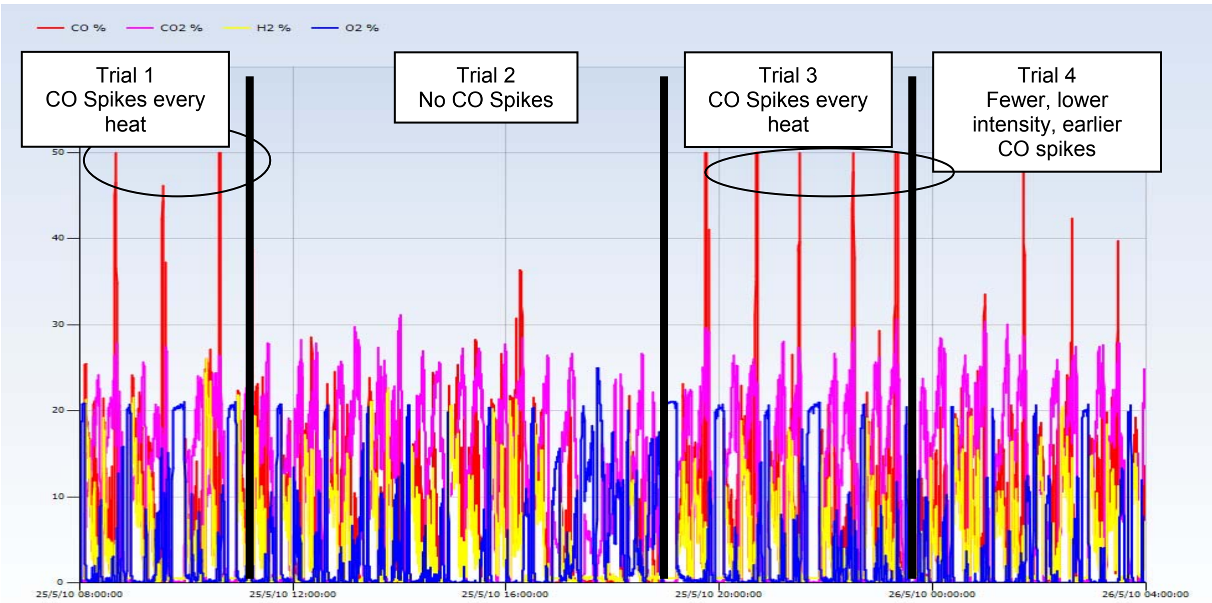

Figure 9. Series of heats during trials to improve bath mixing showing a cessation of CO spikes in trial 2 (removal of 1st charge carbon) and reduced CO spikes in trial 4 (1st charge super heat).

Though removal of first charge carbon had the best effect on violent carbon boils, the refractory wear during the first charge and the expense of the conveyed roof practice prevented permanent implementation of this plan. Trial 4 had the overall best results with more manageable carbon boils, an overall improvement in lance efficiency based on CO generation in the off-gas and more consistent tap conditions. Based on these trials a separate burner profile for late campaign heats was established where a higher lance flow rate is used during refining, and the length of the first charge melt practice is extended to provide superheating to the carbon concentrated first charge bath. These changes resulted in a reduction of CO spikes during refining and greater control and reliability in endpoint timing.

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4 CONCLUSIONS

Real time and dynamic furnace off-gas analysis does not only provide an indication of the extent of combustion in the freeboard but equally importantly provides information that allows process engineers to quantify and understand a variety of different process phenomenon occurring in the EAF. At this plant, the data helped operators to better understand complications they were having with regards to high bath oxidation and periodic inconsistent endpoints, and provided evidence of changes in lancing and bath mixing efficiencies at different stages of the refractory life. The plant received both immediate financial benefit of a reduced cost practice with dynamic control to adjust to changing scrap conditions, as well as longer term savings in furnace and ladle refractory wear, and secondary metallurgy.

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