EAF PROCESS OPTIMIZATION BASED ON CONTINUOUS ANALYSIS OF OFF-GASES AND REAL-TIME CONTROL OF CHEMICAL PACKAGE PARAMETERS: THE CASE OF TAMSA[1]

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ABSTRACT

Techint Goodfellow Technologies (formerly Stantec) implemented their Goodfellow EFSOP™ system at Tubos de Acero de Mexico, SA (TAMSA) in late 2002. The technology was used to optimize the use of chemical energy within the electric arc furnace (EAF). The project was a success providing TAMSA a 4.4% reduction in conversion costs (oxygen, methane, electricity and carbon) and a reduction of 1 minute in power-on-time. Subsequently, in late 2003, Techint installed and commissioned their KT-Chemical package at TAMSA. The Goodfellow EFSOP™ system was again used to optimize chemical energy usage within the EAF. The Goodfellow Expert Furnace System Optimization Process (Goodfellow EFSOP™) is a proprietary process that uses continuous off-gas analysis, along with process monitoring to optimize the use of chemical energy within the electric arc furnace (EAF). Optimization is achieved by adjustments to the electric furnace process (carbon charge practice, injected carbon, methane and oxygen), according to analysis of off-gas measurements. Further benefits are provided through dynamic control of oxygen and methane in response to real-time off-gas composition. This paper details the application of the Goodfellow EFSOP™ optimization process to the KT chemical package at TAMSA and concludes with a summary of the achievements provided by the merging of these two technologies. Ultimately, a reduction in, electrical energy (12.3%) and methane consumption (33%) were achieved at TAMSA. Economically, these savings outweigh the increase in total carbon usage (11%) and oxygen consumption (14.6%) and have provided an overall 2% reduction in power-on-time (1 minute), considering an increase in tapping weight by 11% (from 142 to 158) tons liquid steel to . Iron oxidation has also been reduced, as indicated by slag chemistry, from over 40% initially to 32% at present. Electrode consumption has been reduced by 9%.

Key-words: EAF process optimization, off-gas analysis, furnace optimization, Goodfellow EFSOP™

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INTRODUCTION

The Goodfellow Expert Furnace System Optimization Process (Goodfellow EFSOP™) is a proprietary process capable of electric arc furnace (EAF) process optimization based on continuous analysis of furnace off-gas. Techint Goodfellow Technologies (formally Stantec) was retained by Tubos de Acero de Mexico S.A. de C.V. (TAMSA) to install the Goodfellow EFSOP™ system and to use their expertise to improve the efficiency of TAMSA's EAF steel-making practice in Veracruz, Mexico.

Installation and commissioning of the Goodfellow EFSOP™ system at TAMSA was completed in December 2002. At that time, TAMSA was using only conventional burners and a single manipulated door lance within their EAF. Initial optimization of TAMSA's practice has been reported elsewhere.[1, 2] Modifications included changes to the carbon, oxygen and methane practices, fume system operation and the implementation of closed loop control for oxygen and methane in response to off-gas composition.

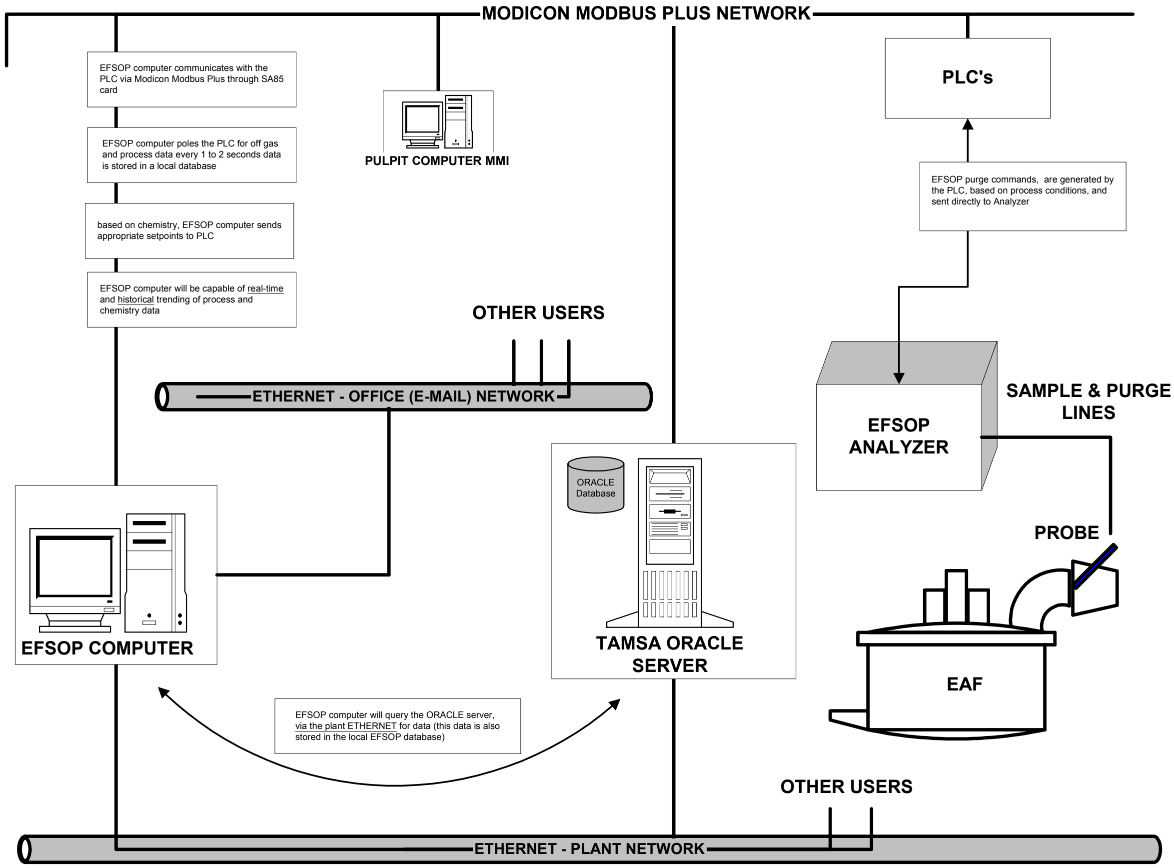
In December 2003, Techint Goodfellow Technologies (formally Stantec) was again retained by TAMSA to provide their expertise in furnace optimization for the commissioning of their newly installed KT chemical package; provided by Techint Technologies. The package included fixed wall oxygen and carbon injectors. TAMSA retained conventional burners, fitted with Techint designed nozzle tips, so as to provide additional post-combustion capabilities.

The project at TAMSA provided the opportunity for the Goodfellow EFSOP™ team to work directly with Techint in the commissioning and implementation of the KT chemical package at TAMSA. The positive synergy, between the two technologies, has resulted in the purchase of the Goodfellow EFSOP™ business unit by Techint Technologies Inc, Milan, Italy, from Stantec. The new business unit is called Techint Goodfellow Technologies Inc. and operates out of Mississauga, Canada.

GOODFELLOW EFSOP^{TM} SYSTEM

The Goodfellow EFSOP^{TM} System uses state-of-the-art off-gas analysis, combined with process data acquisition, model based analysis and real-time control to optimize chemical energy usage within the EAF. In general, optimization objectives include: reducing conversion energy costs (energy and material); increasing productivity; increasing yield; and improve safety by minimizing the risk of explosion within the EAF.

The components of the Goodfellow EFSOP^{TM} System are shown in Figure 1. The key features include the Goodfellow EFSOP^{TM} patented water-cooled sample probe, the Goodfellow EFSOP^{TM} gas analysis system and the Goodfellow EFSOP^{TM} Supervisory Control and Data Acquisition (SCADA) system.



EFSOP computer communicates with the PLC via Modicon Modbus Plus through SA85 card

EFSOP computer poles the PLC for off gas and process data every 1 to 2 seconds data is stored in a local database

based on chemistry, EFSOP computer sends appropriate setpoints to PLC

EFSOP computer will be capable of real-time and historical trending of process and chemistry data

EFSOP purge commands, are generated by the PLC, based on process conditions, and sent directly to Analyzer

EFSOP computer will query the ORACLE server, via the plant ETHERNET for data (this data is also stored in the local EFSOP database)

Figure 1. Schematic of the Goodfellow EFSOP™ System at TAMSA

The off-gas analysis system measures oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO) and hydrogen (H_2). The sample is extracted continuously through a patented water-cooled sample probe. Off-gas composition and process operational variables are used to define the furnace operation and then to optimize the chemical energy usage within the EAF.

In general, optimization is achieved by controlling the evolution and combustion of chemical energy within the EAF. his is possible by balancing the use of chemical energy within the EAF through adjustments to oxygen, methane and carbon practices. Additional details of the Goodfellow EFSOP™ System can be found in previous technical papers.(1-7)

KT INJECTION SYSTEM

The patented KT oxygen lances and KT carbon Injectors are the most effective multi-point lances for EAF applications. Over 250 lances have been successfully installed and continue to operate in more than 20 countries world-wide. KT oxygen lances are installed in the slag line above the steel bath, working as a burner during the melting of the scrap and as a supersonic oxygen injector during refining. They are able to provide oxygen at a velocity of 2.5 Mach and maintain a compact stream up to 2 meters from the nozzle tip.
The KT carbon injectors are also installed in the slag line and fixed in protective boxes in the upper shell. Carbon is injected directly into the slag layer; reducing refractory wear, improving

the formation of foamy slag and enhancing arc energy transfer. Effective carbon lancing also lowers the FeO content of the slag and thereby improves yield.

At TAMSA three oxygen injectors and three carbon injectors have been installed. In order to supplement the advanced decarburization abilities of the KT injectors, TAMSA has elected to retain their conventional burners for post-combustion. The burner tips have been replaced with Techint designed burner nozzles. In addition, TAMSA has retained their door lance for clearing scrap from the door area before sampling.

ANALYSIS AND MODELLING

The KT injector system was installed and a generic operational program was implemented. The Goodfellow EFSOP™ system was then used to fine-tune the program based on observed off-gas chemistry. Once sufficient data had been collected, the furnace practice was modeled using Techint Goodfellow's proprietary DECSIM electric EAF simulator.

The simulator takes as its inputs methane and oxygen rates, carbon injection rates, the amount and timing of charged carbon, fifth hole additions (including lime, HBI, DRI, etc.) and scrap mix. The simulator is tuned by adjustment of modeling parameters so that predicted off-gas chemistry matches the chemistry measured by the Goodfellow EFSOP™ system.

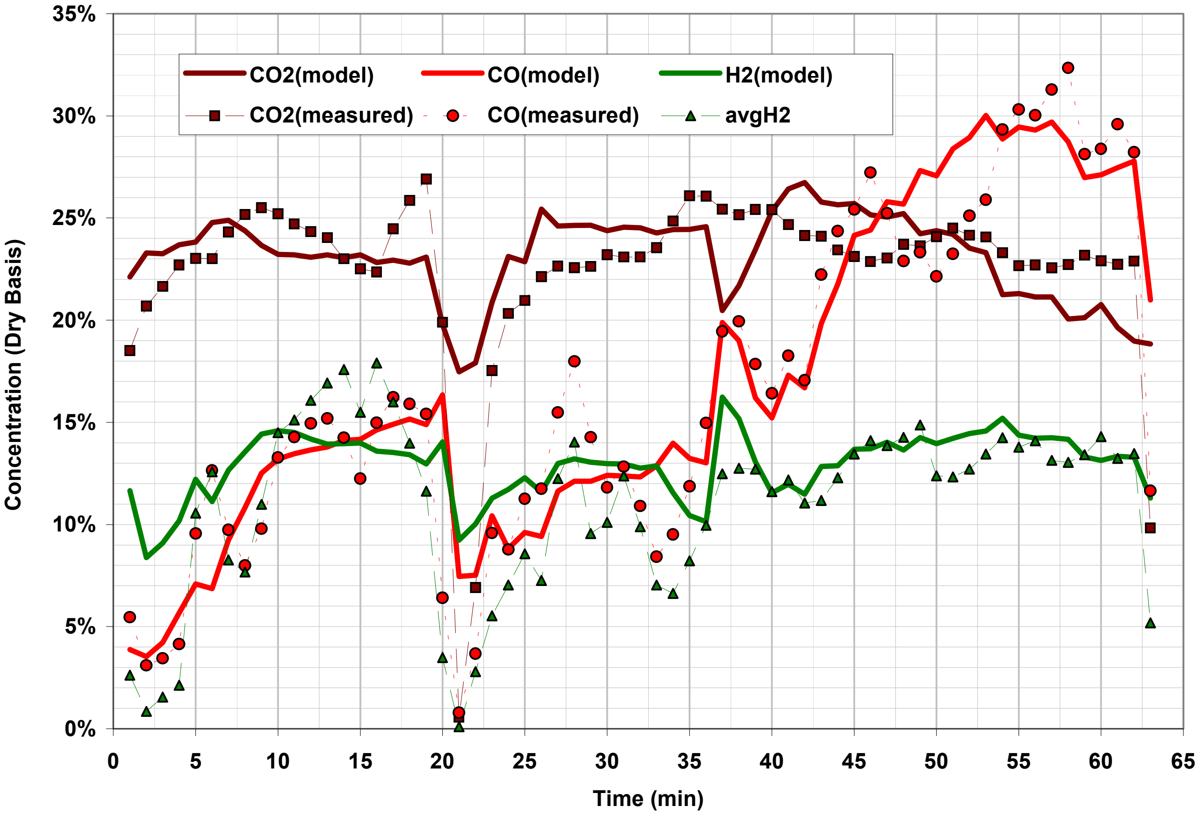


Figure 2. A comparison of predicted off-gas composition and measured composition

Figure 2 is an example heat before optimization. The figure is a plot of measured off-gas composition (CO_2, CO, H_2) and the corresponding predicted values.

The comparison indicates that adequate agreement exists between the measured and predicted values. Oxygen (O_2) is not shown because oxygen concentrations for this particular example were essentially zero throughout the heat.

In addition to off-gas chemistry, it is important that the simulation model be able to predict the evolution of carbon and the extent of air in-leakage into the furnace. Air in-leakage into the furnace is estimated from the nitrogen in the off-gas.

Nitrogen is not measured directly but is taken as the difference from 100% of the sum of the measured gases. The extent of carbon evolution is simply the sum of the measured carbon dioxide (CO_2) and carbon monoxide (CO). The figure shows adequate agreement between the values determined by the EFSOP™ measurement and those predicted by the simulator.

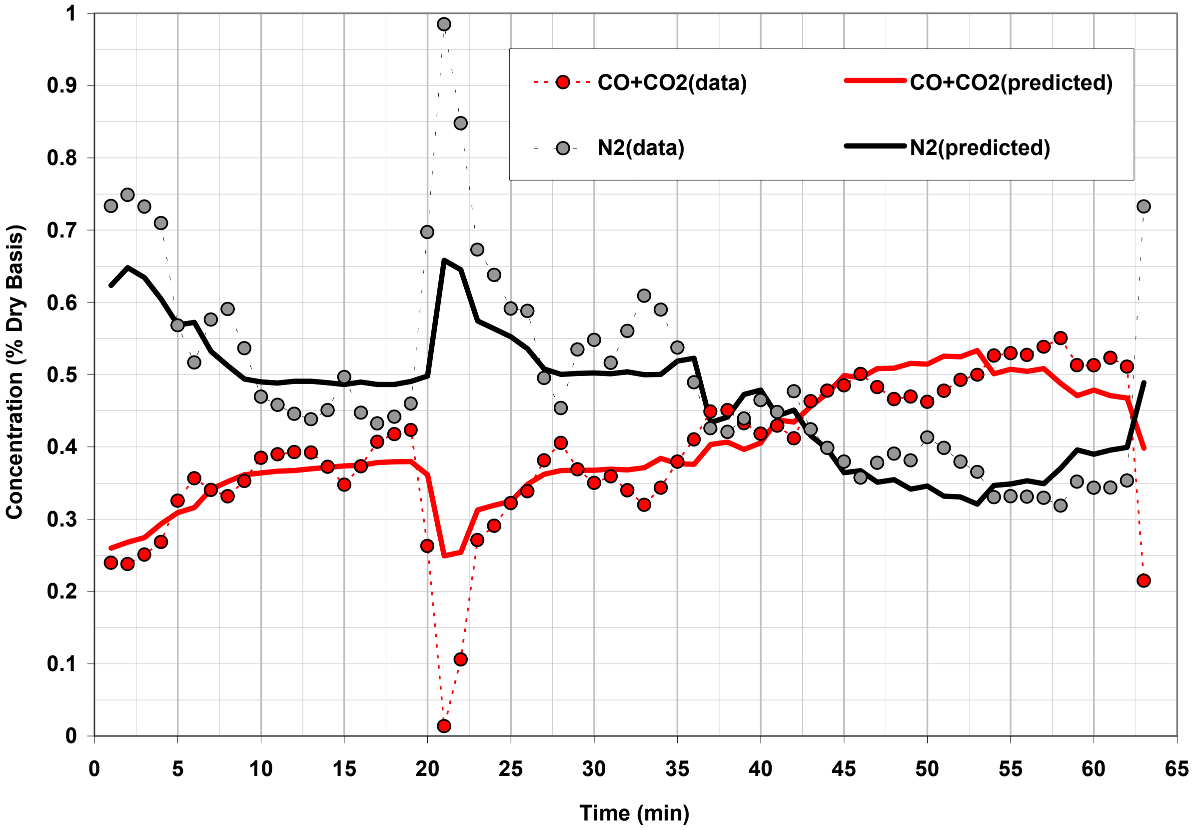


Figure 3. A comparison of predicted carbon evolution and air-inleakage with values determined from the measured Goodfellow EFSOP™ off-gas concentrations.

One important result provided by the DECSIM analysis is an estimate of the off-gas energy losses. That is, energy that is lost from the process with the off-gas leaving the furnace. For the particular example above, the off-gas energy profile is shown in Figure 4.

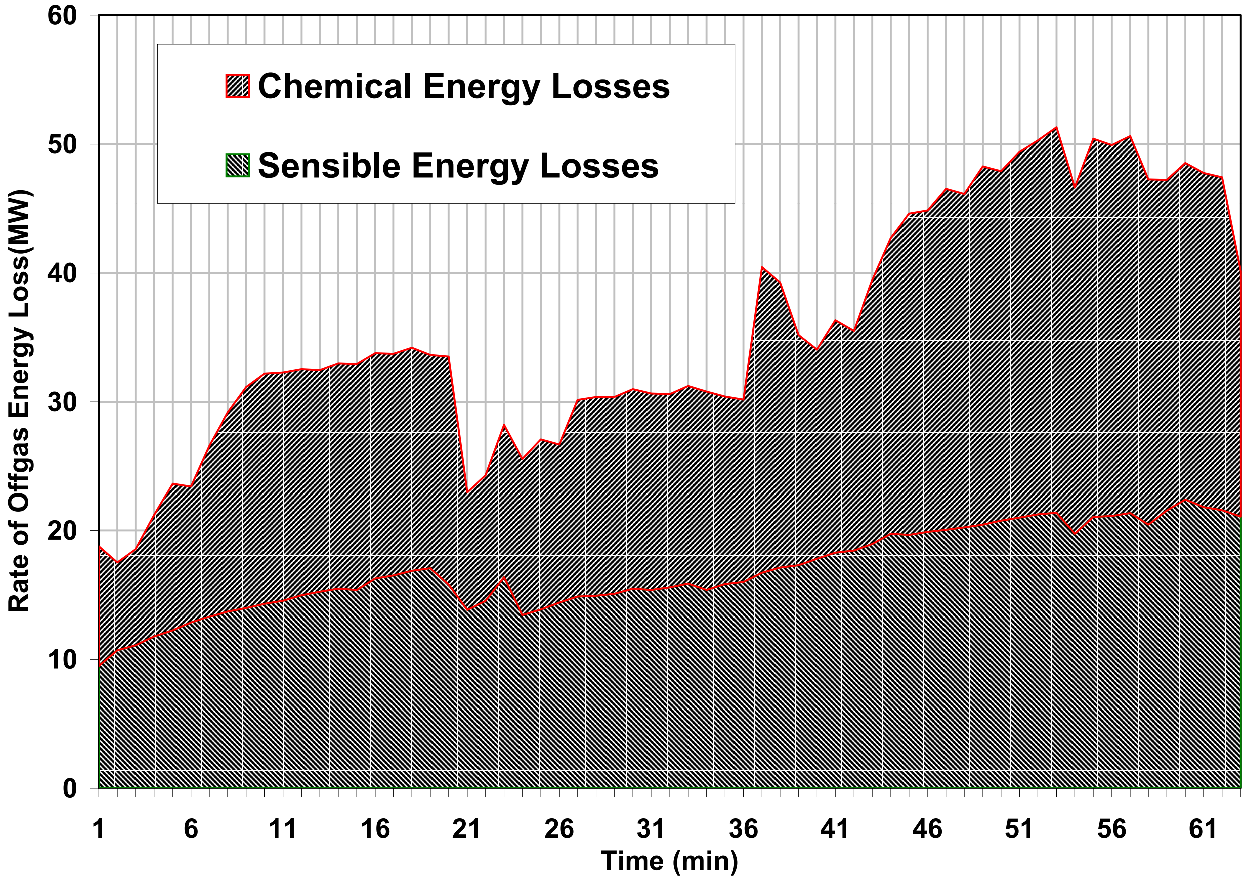


Figure 4. An example of Off-gas Energy Losses for a heat before optimization.

The figure is a profile of the energy lost from the furnace through the off-gas. There are two components: 1) the sensible energy losses and 2) the chemical energy losses. The sensible heat lost to the off-gas is a function of the gas temperature and the heat capacity of the components of the off-gas.

Chemical energy losses are calculated as the potential energy that would have been recovered had the components of the off-gas been combusted to completion within the furnace. This typically does happen downstream of the combustion gap and so the sum of chemical and sensible energy give an estimate of the heat load to the primary fume system. For this particular example, the heat load to the fume system peaked at about 50 MW during the second charge. Furthermore, as this chemical heat is combusted after the gases leave the furnace, it represents a degree of inefficiency in the operating practice; as the energy is not used within the furnace to heat and melt steel.

The figure illustrates the high level of energy loss to the fume system, both in the form of heat and in the form of chemical potential energy. The goal of the EFSOP™ optimization process is to minimize waste energy loss by balancing the evolution of carbon with oxygen and methane usage so as to minimize waste energy to the fume system.

FURNACE OPTIMIZATION

The Goodfellow™ EFSOP system uses real-time off-gas measurements to optimize chemical energy usage within the EAF and to dynamically control oxygen and methane usage through burners and oxygen injectors.
The measured furnace off-gas chemistry and operating data, along with the DECSIM analysis provides valuable information regarding the pre-optimized operation of the furnace.

The simulator, once properly tuned, may be used to explore various optimization scenarios and to make informed decisions regarding adjustments to charged carbon, lance oxygen and lance carbon.

Furthermore, as the chemical analysis is real-time, it provides input to control algorithms for optimizing post-combustion in the free-board of the furnace.

The goals for the optimization project at TAMSA were to use off-gas chemistry measurements, along with process parameters to:

1) To develop a program for KT and burner control and for charged carbon usage. The program defines the intensity and timing of the KT injector flows (oxygen, methane and carbon) during melting and refining.
2) Implement closed loop control for controlling optimum oxygen and methane usage in response to real-time off-gas chemistry.

The first component is an off-line procedure whereby off-gas chemistry, along with process data is used to make adjustments to the way chemical energy, in general, is used within the furnace.
This may include adjustments to the charged carbon practice as well as the scrap mix and refining timing and intensity (lance carbon and oxygen program).
The DECSIM analysis forms a basis for the development and execution of on-site trials whereby optimization recommendations are implemented and evaluated.

The second component is implementation of closed-loop control for optimum post-combustion within the furnace free-board.
Closed-loop control allows the EFSOP™ system to adjust oxygen and methane usage in response to real-time off-gas composition. This is important as it allows EFSOP™ to respond favorably to unpredictable events that inevitably occur during melting and refining (e.g. flashing of hydrocarbons, carbon boils, scrap cave in, etc.).

At TAMSA, closed loop control was implemented on the four conventional burner trains and controlled both oxygen and methane.
Oxygen and methane are modulated between pre-determined maximum and minimum values in response to off-gas measurements. The goal is to achieve the most efficient level of post-combustion within the furnace freeboard. Similarity, closed-loop control has been implemented to control the shroud oxygen and methane on the KT oxygen injectors.

RESULTS AND CONCLUSIONS

Initially, the KT chemical package was installed at TAMSA (Dec. 2003) with a “generic” program defining the operation of the KT oxygen and carbon injectors over the course of the heat. The Goodfellow EFSOP™ system was then used to adjust the timing and intensity of methane, oxygen and carbon usage over the course of the heat. In addition, closed-loop control was implemented to control the shrouding oxygen and methane for the KT oxygen injectors and for the oxygen and methane flows of the Techint modified burners. Oxygen and methane set-points are controlled by the Goodfellow EFSOP™ system in response to real-time off-gas composition.

Analysis of the pre-optimized operation of the KT chemical package at TAMSA revealed that the “standard” program as implemented was resulting in a highly reducing off-gas environment over the course of the heat. Furthermore, high levels of FeO (>40%) had been observed in the slag. This indicated that either excessive amounts of carbon and methane were being used early in the heat and/or that carbon was being forced out of the furnace too quickly. Indications were that the furnace was being over-lanced and that insufficient post-combustion was being achieved. Over the course of a series of trials, adjustments were made to increase the level of post-combustion and reduce the intensity of oxygen lancing.

The combined benefits of the Goodfellow EFSOP™ system, along with the KT chemical package have been compared (see table I) to the original base-line established before the installation of the EFSOP™ system TAMSA. The base-line values are the average of TAMSA’s reported values for three months prior to the installation of the EFSOP™ system. The second column is the 12-month average beginning immediately after the installation of the KT chemical package and starting January 2004. Over the course of the year, numerous trials have been conducted resulting in modifications and improvements that continue to provide benefit to TAMSA.

Ultimately a reduction in; electrical energy (12.3%) and methane consumption (33%) have been achieved as evidenced by the average of the last two months of operation. Economically, these savings outweigh the increases to oxygen (14.6%) and carbon (11%) and have provided an overall 2% reduction in power-on-time from 62.5 minutes to 61.5 minutes, considering an increase of tapping weight from 142 to 158 tons of liquid steel (11.2% increase). Iron oxidation has also been reduced as indicated by slag FeO measurements; from over 40% initially to about 32% at present. Electrode consumption has been reduced by 9%.

Table 1. Optimization Results for EFSOP & KT Chemical Package

	Baseline before EFSOP	KT&EFSOP (Jan.-Dec. 2004)	KT&EFSOP (Nov.- Dec. 2004)	% Reduction
Electrical (kWh/tls)	444.2	406	389.6	12.3%
Power-on-time (min)	62.5	61.0	61.3	2%
Methane (Nm^3/tls)	13.0	8.2	8.7	33%
Total Carbon - injected, charged (kg/tls)	9.2	13.6	10.3	-11%
Oxygen (Nm^3/tls)	33.5	38.7	38.4	-14.6%
Heat Size (tons liquid steel)	142	146	158	11.2%

Scrap mix, in part, affects the rate, timing and quantity of carbon evolution in the electric arc furnace. Market conditions for scrap and product grade require that TAMSA continuously adjust the amount of alternative iron (pig iron, HBI, DRI) usage within their practice. To address this, alternate versions of the standard operating practice have been developed depending on the levels of alternative iron used during the heat. TAMSA is able to select different control programs, each customized for different scrap mixes.

Using the Goodfellow EFSOP™ system, TAMSA has been able to achieve operating savings regardless of the scrap mix or the amount of alternative iron (pig iron, HBI, DRI) used. Closed-loop control ensures efficient chemical energy combustion regardless of scrap mix as it is able to respond, in real-time, to unpredictable events (flashing of hydrocarbons, carbon boils, scrap cave in, etc.) that determine the way chemical energy evolves over the course of the heat.

The adaptability of Goodfellow EFSOP™ system has been demonstrated at TAMSA. Initially, installed to optimize and control the furnace with only conventional burners and a manipulated oxygen lance, the system was expanded to include KT oxygen injectors. The ability to measure and control chemical energy usage within the EAF with EFSOP™, has resulted in a better process understanding, continuing economic benefits and significantly more value to TAMSA.

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