V. SCIPOLO*, M. KHAN*, S. PATIL*, G. HOLMES**

OPTIMIZATION OF THE EAF PROCESS AT CAPE GATE (PTY) LTD (DAVSTEEL DIVISION) USING GOODFELLOW EFSOP® TECHNOLOGY

OPTYMALIZACJA PROCESU W ELEKTRYCZNYM PIECU ŁUKOWYM W CAPE GATE (PTY) LTD (DAVSTEEL DIVISION) PRZY UŻYCIU TECHNOLOGII GOODFELLOW EFSOP®

Tenova Goodfellow Inc. has developed the Expert Furnace System Optimization Process (EFSOP®), which uses real-time analysis of EAF off-gases to dynamically optimize the chemical energy consumption within the electric arc furnace. In April 2006, Tenova Goodfellow installed and commissioned the EFSOP® Holistic Optimization™ system at Cape Gate (Pty) Ltd (Davsteel) in their 80 ton EAF at Vanderbijlpark, South Africa. Real-time data from the EFSOP® system was used to conduct a holistic optimization of the chemical and electrical energy distribution in the furnace. A dynamic closed-loop control of oxygen and methane was implemented in order to better utilize the sensible chemical energy available in the furnace. The charged and injected carbon practices were also modified according to the new furnace working parameters. A new, more effective, electrical program was also implemented following the optimized burner pattern and furnace conditions. As a result the Cape Gate meltshop has benefited significantly through improvements. The benefits have resulted in overall savings in excess of US $2.00/tls. This paper will provide background as to how the EFSOP®Holistic Optimization™ technology was applied to achieve these savings at Cape Gate (Pty) Ltd.

Keywords: EAF process optimization, off-gas analysis, furnace optimization, Goodfellow EFSOP®, post combustion

W firmie Tenova Goodfellow Inc. opracowano proces pod nazwą Expert Furnace System Optimization Process (EFSOP®), który wykorzystuje analizę gazów odlotowych z pieca łukowego w czasie rzeczywistym pozwalając na dynamiczną optymalizację zużycia chemicznej energii w piecu łukowym. W kwietniu 2006 r. Tenova Goodfellow wdrożyła system EFSOP® Holistic Optimization™ w Cape Gate (Pty) Ltd (Davsteel) w piecu łukowym o pojemności 80 ton w Vanderbijlpark, Południowa Afryka. Dane czasu rzeczywistego z EFSOP® zostały użyte do przeprowadzenia holistycznej optymalizacji rozkładu energii chemicznej i elektrycznej pieca. Dynamiczna kontrola tlenu i metanu za pomocą zamkniętej pętli została wprowadzona w celu lepszego wykorzystania chemicznej energii pieca. Zmodyfikowano również sposób ładowania i wdmuchiwania węgla zgodnie z parametrami roboczymi zmodernizowanego pieca. Wprowadzono również nowy wydajniejszy elektryczny program zgodny z optymalizowanym wzorcem palnika i warunkami panującymi w piecu. W wyniku tych prac stalownia Cape Gate osiągnęła dodatkowe korzyści rzędu powyżej $2.00/tonę. W niniejszej pracy przedstawiono zasady wprowadzenia technologii EFSOP®Holistic Optimization™, które pozwoliły na uzyskanie wymienionych oszczędności w zakładach Cape Gate (Pty) Ltd.

1. Introduction

Davsteel, the steel manufacturing division of the Cape Gate (Pty) Ltd group is situated in Vanderbijlpark with Marketing office located both in-house and in Johannesburg. Davsteel's main product range includes reinforcing bar in straight lengths as well as coils; light section profiles i.e. angles, flats and squares; and wire rod for the processing of wire and wire products. Sharon Wire and Oren Wire, both also divisions of Cape Gate (Pty) Ltd, utilize most of the wire rod production for a wide variety of wire and wire products including stay wire cable and scraper rope. The latter two products are manufactured by Cape Gate Marepha (Pty) Ltd., a black empowerment company.

Davsteel operates one Tagliaferri AC electric arc furnaces of 76 metric tonne tap weight equipped with a 65 MVA transformer and three water-cooled Techint KT burner/lances, one door burner and three Techint

* TENOVA GOODFELLOW INC., MISSISSAUGA, ON CANADA
** CAPE GATE (PTY) LTD (DAVSTEEL DIVISION

KT carbon injectors. The electrical digital regulation is Techint TDR-H.

Davsteel recently invested in the EFSOP® Holistic Optimization™ system to lower production costs, increase productivity and decrease the load to the fume system. The parameters used to determine the performance of the technology were: electrical, oxygen, methane, metallic yield, carbon consumption, and productivity (measured in terms of tonnes of liquid steel per hour of power on).

2. EFSOP® Holistic Optimization™ System Overview

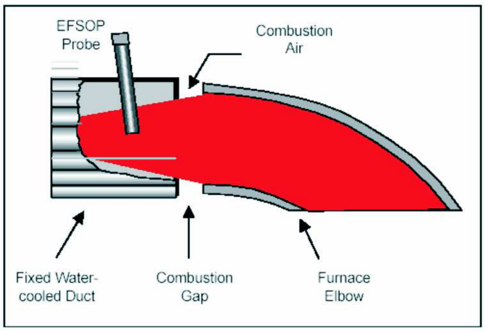
The Expert Furnace System Optimization Process (EFSOP®) is a dynamic control and optimization system for chemical energy usage in the electric arc steelmaking furnaces (EAF); based on real-time measurements of off-gas composition taken at the fourth hole of the furnace. The principle components of the EFSOP® system are the patented water-cooled sampling probe located upstream at the fourth hole and heated line, the off-gas analysis and purging system and the EFSOP® HMI.

The patented probe, custom designed for use in the harsh environment of the EAF is installed in the primary water-cooled duct of the EAF just downstream of the combustion gap. The location and positioning of the probe are such that the off-gas is sampled from within the combustion cone; before dilution with combustion air from the gap. The EFSOP® probe has proven to be highly reliable with maintenance requirements typically only about 15 minutes per week. Life expectancy for the probe is typically in excess of 1 year.

The extracted gases are transported, via a heated sample line, to the proprietary EFSOP® gas analysis & purging system. Initially the off-gases are filtered, dried and then analyzed in real-time for oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO) and hydrogen (H_2) composition. The analyzer is designed for rapid results in order to allow for real time measurements. The EFSOP® proprietary analyzer has proven to be highly reliable with the first commercial analyzer installed in 1998 still in service today. Total service time including calibration is typically less than 1 hour per week.

A secondary function of the EFSOP® analyzer is to periodically back-purge the sampling line and probe to remove accretions inside the barrel of the probe and dust build-up from the internal filter within the probe. The system is purged only during natural breaks (e.g. charging, tapping) in the EAF process so as to ensure reliable and continuous off-gas composition measurements during melting and refining. Off-gas composition measurements, as well as operational alarms and outputs from the analyzer are tied into the plants PLC via standard I/O. Both analog and digital outputs from the analyzer and digital inputs to the analyzer are hardwired to the plant's PLC network.

The EFSOP® SCADA system consists of a high-speed computer and GE,s iFix SCADA development package. Through connection to the plant's PLC network, the EFSOP® computer is able to log, not only off-gas composition measurements and analyzer alarms, but also many key operational furnace and melt-shop parameters. The SCADA system also performs necessary calculations and sends process set-points back to the PLCs for the dynamic control of the melting process. Data is archived on the EFSOP® HMI for further analysis and for real-time and historical trending. Operators and plant personnel have access to historical trends of data through customizable trending screens. Alarms from the analyzer are displayed as annunciators.



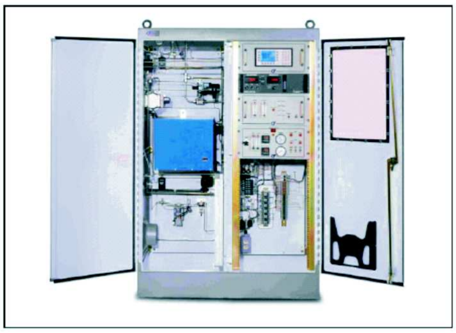


Fig. 1. Positioning of the patented EFSOP® probe in the duct and picture of the EFSOP® analyzer

he typical benefits of the EFSOP® system include improvement of the process efficiency and consistency, increased productivity, lower conversion costs, better control of process variables, improvement of process understanding, environmental benefits and enhanced safety through real-time water leak and combustible gas detection which reduces explosion risk. Additional information about the Goodfellow EFSOP® system can be found in previous technical papers [1−10].

3. Implementation of the EFSOP® Holistic Optimization™ System at Cape Gate

The project started with the kick-off meeting on site in November 2005 to review and discuss the installation requirements. The equipment was installed and commissioned in April 2006. Analysis of the operation with furnace off-gas measurement was performed in June 2006 and process optimization started towards the end of June 2006.

The EFSOP® system provides the opportunity for real-time holistic optimization of the furnace practice because it is networked through Ethernet connection with the PLCs of the plant. It gathers all the information relevant to the process and provides dynamic working points to the burners and oxygen lances. Closed-loop control of the burners and injectors was implemented in June 2006, by which time all the functionalities of the system, off gas analysis, control code and data acquisition had been successfully tested.

At the completion of the installation the EFSOP® system assumed a supervisory function in the architecture of the existing network. The EFSOP® system dynamically controls the three KT fixed wall oxygen and methane injectors and provides static set points for the three carbon injectors.

A different electrical pattern has been developed, since EFSOP® dynamically controls the injection ports, in order to match chemical and electrical timing. In addition the EFSOP® SCADA system exchanges operating data with the PLCs of the EAF. This comprehensive communication and data transfer and analysis allows for the holistic control and supervision of all the technologies responsible for the melting and refining process. More than 600 data points are transmitted and received per second. All of the acquired data is stored in a local historical database and made available for the benefit of the plant and Tenova Goodfellow's process engineers.

4. Optimization strategy

The functionalities of the EFSOP® system provide a holistic approach for the understanding and optimization of the melting and refining process. EFSOP® is not a simple gas analyzer for post combustion control. The system has in fact demonstrated its multiple capabilities and features. Through the off-gas analysis it provides important steel-making information that was previously unavailable such as lance and burner efficiency, chemical energy loss through the off-gases, charged and injected carbon efficiency, oxidation and decarburization of the bath. Post-combustion control, in response to off-gas analysis, works within the capabilities of the chemical energy delivery systems to control the chemical environment of the EAF and ensure the efficient utilization of methane, oxygen and carbon.

The overall composition of the off-gas in Davsteel showed since the beginning a highly "reducing" environment, due to high concentration of hydrogen (H_2) and carbon monoxide (CO), as shown in Figure 2. Therefore a high quantity of chemical energy was leaving the furnace decreasing the energy efficiency within the EAF and increasing the load to the fume system.

The optimization stages implemented in order to efficiently deliver the energy to the metallic charge included the optimization of burners and lances program, carbon injector flow and electrical pattern.

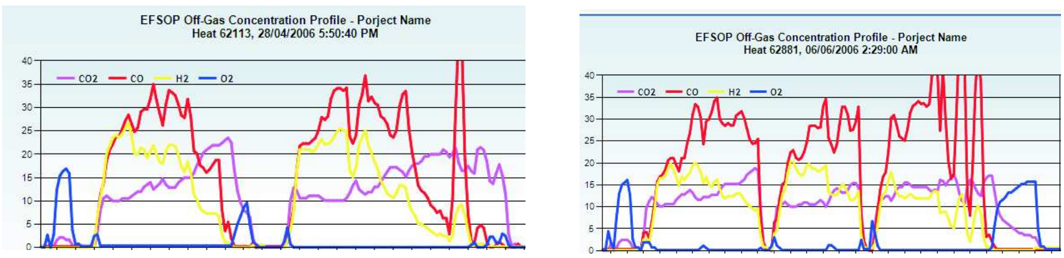


Fig. 2. Example of off-gas composition before optimization

5. Burner/Lance efficiency and Closed Loop Control

Through the off-gas analysis it was possible to determine the efficiency of the oxygen and methane injectors during the burner phase. The KT injectors in Davsteel consist of two oxygen ports, shroud and main and one methane port. The main oxygen and methane injection were modulated by proportional valves that allowed for a precise flow control. The shroud oxygen line was instead controlled by three on off valves that were singularly open and closed accordingly to the desired flow.

The off-gas analysis displayed an unusual composition during the beginning of the melting phase where high burner power was used (see Figure 3). High spikes of H_2 and CO were measured once the burners reached the working point. This was due to poor mixing of the oxygen and methane that lead to a partial combustion.

Figure 3 shows the EFSOP® analysis against oxygen and methane flows (Nm3/hr). During the burner phase, oxygen and methane at stoichiometric ratio, the chemistry shows a spike and high concentration of CO and H_2 that is the indication of a poor mixing of the fuel and oxidant.

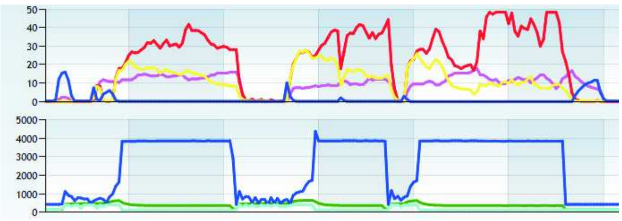


Fig. 3. Off-gas chemistry and O_2 and CH_4 flows

The shroud oxygen ON/OFF valves were manually adjusted in order to reach the most efficient combination of shroud oxygen to be used during the burner and lance phases. This first modification alone increased the efficiency of the methane injection during the melting period and improved the shroud effect during the lancing period. Benefits were registered in terms of a reduction of PON time and electrical consumption and increased productivity.

Once the shroud oxygen had been adjusted to maximize combustion efficiency an improved standard practice and Closed Loop Control were implemented. A new static practice was implemented with a longer more efficient burner period and with set points that match the average chemical condition of the furnace determined by observation and analysis of hundreds of heats. Over and above this practice, was developed and implemented a customized closed loop control practice for the dynamic control of oxygen and methane. The shroud oxygen of the KT lance was controlled in order to post-combust the high concentration of CO and H_2 present in the furnace and the methane flow was dynamically adjusted in order to reduce any waste of fuel and in order to maximize the free oxygen available for the post-combustion.

The dynamic control algorithm provides the adjustment of the set points around the improved standard practice adapting continuously to the variability of the chemical environment. Through this dynamic practice, the efficiency of combustion was highly enhanced. The new improved standard practice and the customized closed loop control maximized the chemical energy efficiency and consequently resulted in a reduction in power on time, consumables and a further increase of the productivity.

6. Electrical program

TGI's holistic approach to optimization of an electric furnace aims to achieve synchronization of the chemical and electrical energy delivery to the EAF. Consequently, the electrical pattern was modified in order to follow the longer burner phase and the shorter refining phase of the new standard practice and in order to speed up the melting phase reducing further the power on time.

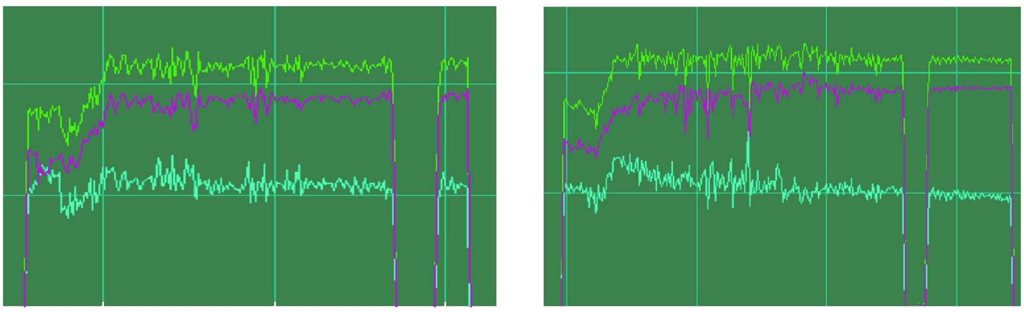


Fig. 4. Plant original and optimized electrical pattern: total power (green), active power (magenta) and reactive power (blue). The refining period has been stabilized

At each step a working point constituted by reactor tap and current set points have been modified to ensure that the chemical energy and electrical energy were properly synchronized. Moreover the parameters of the TDR-H electrical regulation have been refined achieving a more stabilized electrical pattern especially during the over heating period, shown in Figure 4.

7. Carbon Injection

Carbon injection was also optimized, in order to maximize FeO reduction. The fixed orifices of the injectors were adjusted decreasing the flow and increasing the particle penetration. The carbon injection was reduced in flow and increased in time obtaining a more consistent slag foaming and reducing the carbon dispersion in the fumes.

8. EFSOP® Results

The overall adjustments performed during the optimization period and dynamically implemented by the EFSOP® Holistic Optimization™ system increased the efficiency of the energy transfer to the scrap, increased the efficiency of combustion and decreased the chemical energy. The CO and H_2 present in the furnace were efficiently combusted by the shroud oxygen. More CO_2 and therefore more sensible energy were leaving the furnace and load to the fume system has been dramatically reduced as shown in Figure 5.

The path to optimization is shown in Figure 6 and Figure 7 below. The figures show the time trend of the reference variables for the calculation of performance. The graphs contain two vertical bars to differentiate the periods: before commissioning the EFSOP®, during

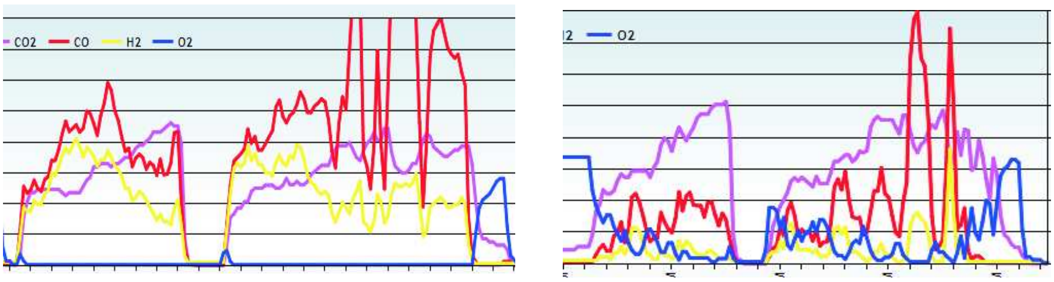


Fig. 5. Off-gas chemistry before and after optimization

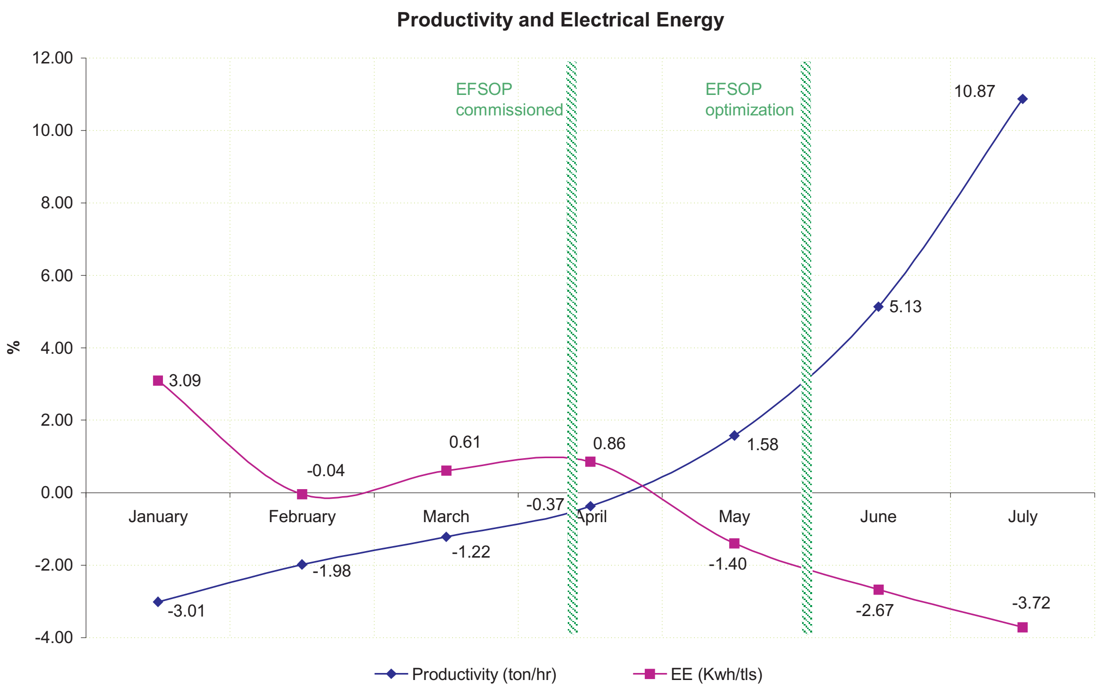


Fig. 6. Productivity and electrical consumption performance

EFSOP® process tuning and optimization and after the installation of EFSOP® dynamic closed loop control. A comparison of the performance during the optimization period with the non-EFSOP® months shows benefits in terms of increased productivity which is due to a reduction in power-on-time. The trends for consumable consumption also show a reduction.

Figure 6 shows the historical trend for electrical consumption and productivity. The trend is in % difference with respect to the baseline values. The electrical consumption has been highly decreased due to the increased utilization efficiency of chemical energy and the more stable electrical pattern. The productivity increased drastically due to the strong reduction of the PON time.

Figure 7 shows the behaviour of the oxygen and methane consumption. Despite the longer burner period the methane consumption decreases in comparison with the baseline period. EFSOP® dynamic closed loop control is proven to save methane anytime there is available chemical energy from CO and H_2 in the furnace. Oxygen consumption decreased due to the PON reduction and due to the higher efficiency of the lance. The optimized shroud allowed for a more coherent and stable supersonic jet and therefore a higher efficiency for the oxygen injection has been achieved.

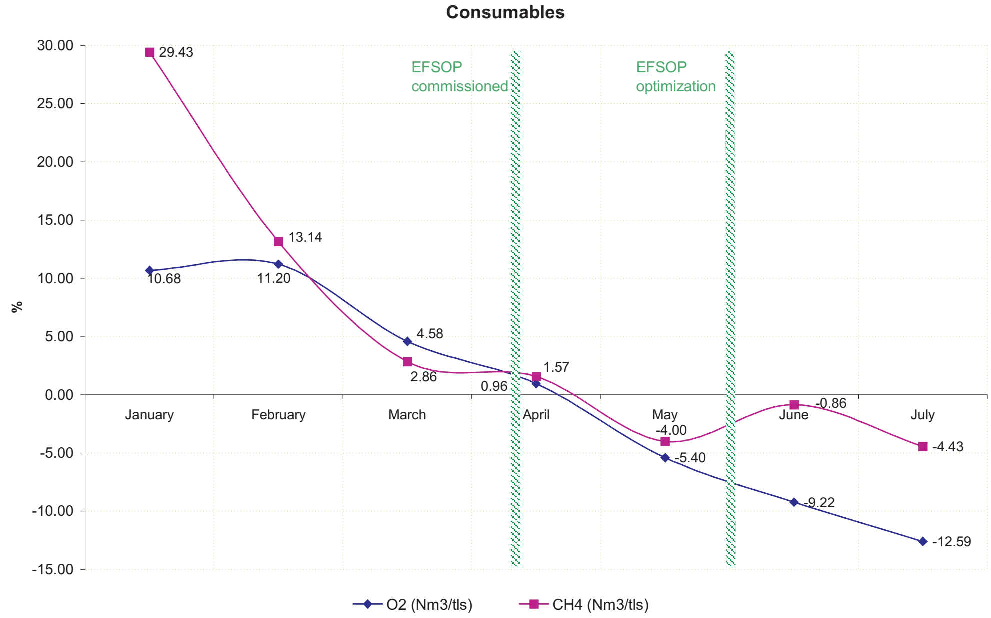


Fig. 7. O_2 and CH_4 performance

Table 1 shows the absolute performance against the baseline values for the month of July 06.

TABLE 1

July performance against baseline

Performance Parameter	Unit	Baseline Value: Avg of March Apr, May 06	Performance Value: July 06	Savings
Electrical Consumption	kWh/tls	490.3	471.6	−18.21
Oxygen Consumption	Nm^3/tls	49.9	43.5	−6.4
Fuel Consumption	Nm^3/tls	7.0	6.7	−0.31
Charge Carbon	kg/tls	1.1	1.0	−0.1
Power On Time	Min	42.3	38.3	−4.0
Productivity	T/hr	102.5	113.6	+11.1

9. Conclusion

The implementation of EFSOP® Holistic Optimization™ of the chemical and electrical energy utilization in the furnace at Cape Gate has demonstrated an improvement in the overall meltshop performance by reducing conversion costs by over US $2.00 per tls, increasing productivity by over 11% and significantly reducing raw materials consumption.

EFSOP® optimization of the EAF operation was the result of a complex and holistic effort that took into account all aspects of the EAF operation.

The standard practice was studied in order to reduce the load on the fume system and benefit from the increased efficiency of the injection system. The closed-loop control algorithm allowed for more complete, dynamic and efficient post combustion. The electrical parameters adjustment reduced even more the electrical consumption and the PON.

The holistic approach followed to reach the performance and once again, the flexibility and comprehensiveness of the EFSOP® technology has been demonstrated. At Cape Gate, EFSOP® Holistic Optimization™ has provided valuable and reliable information for optimization and improved understanding of cause and effects in the melting process.

With forty systems either installed or underway worldwide, the EFSOP® Holistic Optimization™ system has demonstrated proven reliability with low maintenance requirements plus an excellent payback from reduced conversion cost and increased productivity.

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