A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 53 2008 Issue 2

M. POZZI*, J. MAIOLO*, V. SCIPOLO*, D. MASOERO**, N. VENERI***

OPERATING RESULTS OF GOODFELLOW EFSOP® AT RIVA, VERONA, ITALY

REZULTATY PRACY GOODFELLOW EFSOP® W ZAKŁADZIE RIVA, WERONA, WŁOCHY

Tenova, formerly Techint Technologies, is a leading world-wide supplier of advanced technologies, products and services for the metal and mining industries. Tenova Goodfellow Inc. (TGI), formerly Techint Goodfellow Technologies Inc., has developed the Goodfellow Expert Furnace System Optimization Process (EFSOP®), which uses continuous extraction and analysis of EAF off-gases to dynamically optimize the chemical energy usage within the furnace. The benefits of the Goodfellow EFSOP® system are increased process knowledge, lower conversion costs, and increased productivity.

In November 2005, Tenova installed and commissioned two state-of-the-art Goodfellow EFSOP® systems for RIVA ACCIAIO S.p.A. for their Verona meltshop. This dual system installation represented the first Goodfellow EFSOP® installation in the Italian market.

These new systems were installed on each of the two 80 ton Tenova EAFs at RIVA, Verona plant and incorporated continuous off-gas based closed-loop process control. Process analysis of the furnace operation commenced immediately after installation and commissioning of the EFSOP® system. Ultimately process optimization included changes to the carbon/oxygen and methane practice, fume system adjustments, electrical practice adjustments and closed-loop control of oxygen, methane and injected carbon.

This paper outlines the path to EAF optimization and the benefits achieved at RIVA, Verona by using the Goodfellow EFSOP® system.

Keywords: EFSOP® Off-gas analysis, Combustion optimization, Electric arc furnace, Dynamic control

Tenova, dawniej Technit Technologies, jest wiodącym światowym dostawcą wysoko rozwiniętych technologii, produktów i usług dla przemysłu metalowego i górniczego. W Tenova Goodfellow Inc. (TGI), przedtem Techint Goodfellow Technologies Inc. rozwinięto ekspertowy system optymalizacji procesu piecowego EFSOP®, w którym wykorzystywana jest ciągła analiza gazów wylotowych z pieca łukowego do dynamicznej optymalizacji energii użytej w procesie. Zaletami systemu Goodfellow EFSOP ® jest rosnąca wiedza o procesie, niższe koszty przystosowania systemu oraz zwiększona wydajność.

W listopadzie 2005, Tenova zainstalowała i nadzorowała dwa aktualnie rozwijane systemy EFSOP® w stalowni RIVA ACCIAIO S.p.A. w Weronie. Jest to pierwsze wdrożenie na rynku włoskim. Systemy te zostały zainstalowane na dwóch 80 Mg piecach łukowych w zakładzie RIVA w Weronie i sterują procesem w obwodzie zamkniętym w oparciu o gazy wylotowe. Analiza procesu rozpoczęła się natychmiast po instalacji i nadzorze systemu. Ostatecznie optymalizacja procesu zawiera zmiany do stosownej praktyki wdmuchiwania węgla, tlenu i metanu, regulację systemu odciągowego dla gazów, elektrycznego oraz sterowanie w obwodzie zamkniętym tlenem, metanem i wdmuchiwaniem węgla .

W artykule przedstawiono zarys optymalizacji pieca łukowego i korzyści osiągnięte w przedsiębiorstwie RIVA, wynikające z zastosowania systemu Goodfellow EFSOP®.

1. Introduction

The Riva Group consists of several companies operating in the iron and steel production industry and related activities. It is the outright industry leader in its sector in Italy, the 3rd in Europe, and 10th in the world. This position was attained over half a century, as the result of an expansion policy which included the acquisition, restructuring and revitalization of several companies.

Today the group owns 38 production and processing plants, 20 of which are located in Italy where most (63%) of the steel is manufactured and 70% of the turnover is achieved. It commands a considerable international presence, with works in Germany, France, Belgium, Spain,

---

* TENOVA GOODFELLOW INC.
** TENOVA SPA
*** RIVA ACCIAIO SPA

Greece, Tunisia and Canada. The Group's factories cover all the stages of steel process, starting from raw steel production (both integrated-cycle and electric furnace) through to hot and cold rolling, and up to the manufacture of coated products and special finishing.

The overall crude steel production of the Group was 18,2 million tons in 2006. Steel production and processing are integrated with other diversified and synergistic activities, such as: scrap recovery; refractory material production and rolling cylinder manufacturing.

Riva Galtarossa, the production site in Verona, operates two Tagliaferri AC electric arc furnaces of 76 metric tonne tap weight. Each furnace operates with a 43 MVA transformer and is equipped with three water-cooled coherent burner/lances, one EBT burner and three carbon and lime injectors. The downstream equipment consists of one Tagliaferri ladle furnace and two 6-strand (140 mm × 140 mm) billet casters. In the spirit of continuous improvement, Riva Galtarossa invested in the EFSOP® system to lower production costs and increase productivity. 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® System Overview

Tenova Goodfellow Inc., ("TGI") has developed a proprietary Expert Furnace System Optimization Process trademarked EFSOP®. The EFSOP Holistic Optimization™ System is proprietary hardware and software technology that continuously samples furnace off-gas and uses this off-gas analysis along with real-time operating data from select process points to provide dynamic process control and optimization. With 39 steel plant systems either operating or being installed worldwide, and more than 300,000 heats analyzed to date, the EFSOP® Holistic Optimization™ System has quickly become the steel industry's accepted standard for off-gas based real-time process control and optimization.

The EFSOP Holistic Optimization™ System has a proven track record of generating significant savings thereby providing an exceptionally fast payback period. EFSOP® provides a truly holistic systematic approach to off-gas based process optimization by integrating off-gas analysis together with real-time operating data from select process points. Tenova Goodfellow's holistic approach enables EFSOP® users to generate significant savings from increased productivity and yield, reduced electrical and chemical energy consumption plus from reduced consumables.

The holistic approach followed to reach the performance presented in this paper is shown in Fig. 1: the optimization is based on an improved bucket preparation procedure which considers the steel quality constraints; slag optimization by means of a dynamic control of carbon and lime injectors; dynamic closed loop control of the oxygen lance and burners; electrical pattern and setting adjustments and the fume system control.

All of these factors have an impact on the steelmaking process and on the optimization strategy. The process must be optimized as a whole where the benefit of any strategy is balanced against costs incurred.

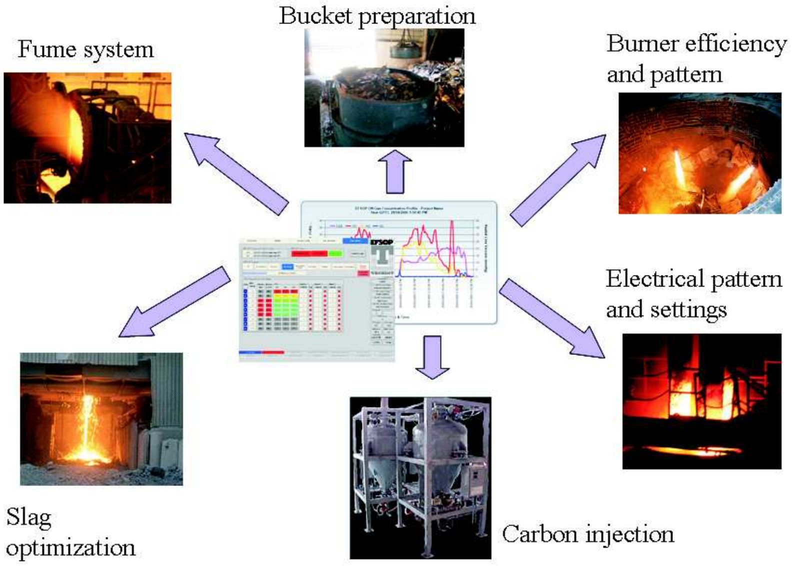

Fig. 1. EFSOP Holistic Optimization™ System approach at Riva Verona

3. Installation

Initial installation and commissioning of the two EFSOP® systems for each of the two RIVA furnaces was completed in November 2006. After initial commissioning, and at the start of the testing and optimization phase, it was necessary to extend the capabilities of the EFSOP® system in order to harmonize the presence of the EFSOP® system in the rich automation network of the plant.

The EFSOP® system is networked thru Ethernet connection with the PLCs of the plant and with the level 2 supervisory PC. It gathers all the information relevant to the process and provides dynamic working points to the burners, oxygen lances, and carbon and lime injectors. It also displays fundamental parameters in order to guide the tuning and operation of the fume system.

Closed-loop control of the burners and injectors was implemented in January 2006, by which time all the functionalities of the system, off gas analysis, control code, redundancy of the PCs 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. Being directly connected with the level 2 system, EFSOP® receives all the information regarding the steel grade in production during the heat and it can automatically load the best burner pattern to optimize the melting of the scrap and to reach the end quality requirements. The level 2 system also loads the correspondent electrical pattern, tuned to match the behaviour of the burner and lances. As EFSOP® dynamically controls the injection ports, different electrical patterns have been developed in order to always match chemical and electrical timing.

The EFSOP® system directly controls the 3 coherent jet fixed wall injectors, the sump burner and the three carbon and lime injectors. It also exchanges operating data (two chemical energy delivery systems, carbon and lime injectors and fume system) 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 900 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.

Since installation, the system has proved to be impressively reliable. The probes of both furnaces have worked without fail for more than two years through over twenty thousand heats. The heated line, mechanical, electrical and analyzer have demonstrated the same level of performance. The control code and HMI redundancy functions have ensured continuous operation.

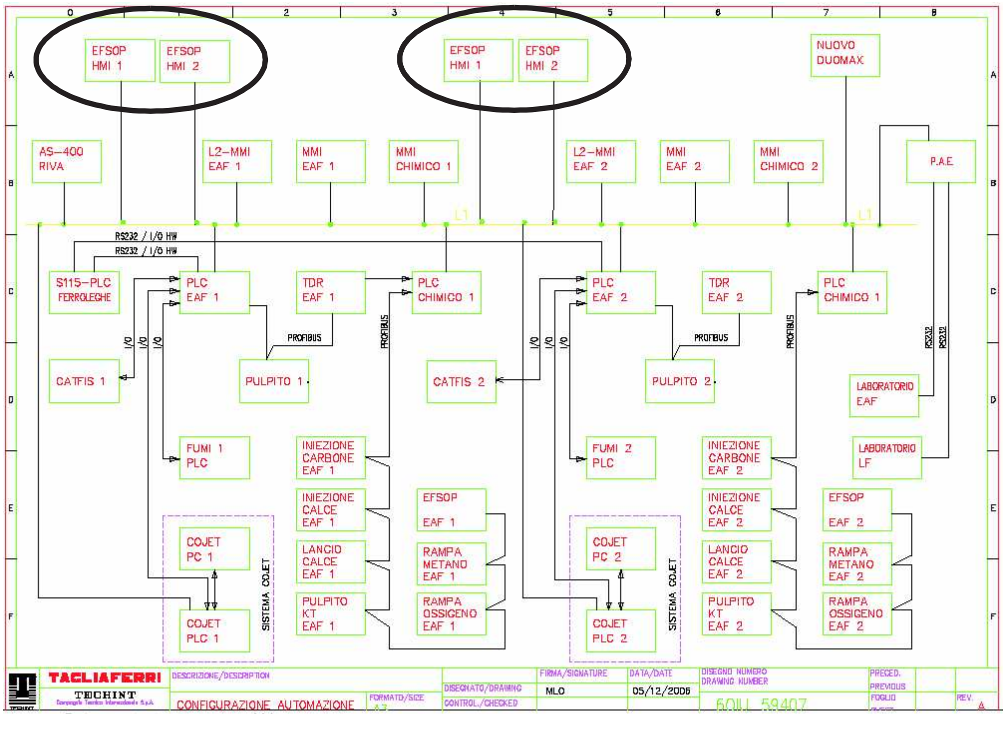

Fig. 2. Integration of EFSOP® in the existing Tenova's automation system in Riva Verona

4. Optimization Stages

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, carbon material layering for the bucket preparation, charged and injected carbon efficiency, oxidation and decarburization of the bath and also stirring and stratification of the liquid steel.

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. It also provides flexibility of operation for the utilization of different chemical and electrical programs ensuring optimum usage of the consumables, increasing productivity and decreasing carbon emissions.

4.1. Fume system draft

The off-gas analysis made it possible to verify the operation of the fume system. Generally, the fume system should be tuned to maximize EAF productivity while working within constraints to prevent bag-house problems.

Upon installation of the EFSOP® system, it was noted that RIVA was operating with an excessively oxidizing furnace due to the high rate of suction on their EAF's. The operation of the furnaces was modelled using TGI's proprietary EAF simulator, DECSIM. The simulator was tuned so that the predicted off-gas concentration profile adequately matched the off-gas composition provided during a typical heat as measured by the EFSOP® system.

The model provided an estimate of the off-gas energy losses as shown in Fig. 3. The charts are representative of the rate of energy lost from the furnace through the off-gas. Energy lost via the off-gas is comprised of two components; namely, sensible energy and chemical energy. 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 energy that would have been recovered in the furnace had the combustible components of the off-gas been combusted to completion within the furnace freeboard and the energy transferred to the steel. The pre-optimized operation is shown in figure 4 and indicates that hardly any chemical energy was found to be leaving the EAF over the course of the heat. Excessive in-leakage air was entering the furnace, providing natural post combustion, but also a high cooling effect due to the nitrogen ballast contained in the air.

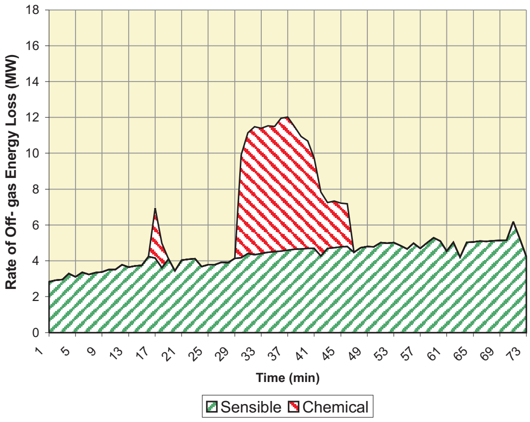

Fig. 3. Chemical and sensible off gases energy loss with standard plant practice

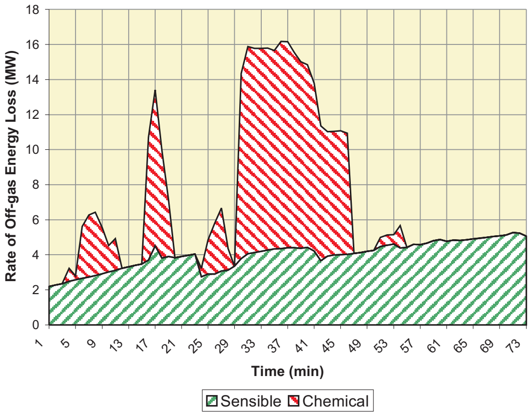

Fig. 4. Simulated ch. and sens. off gases energy loss with reduced false air practice

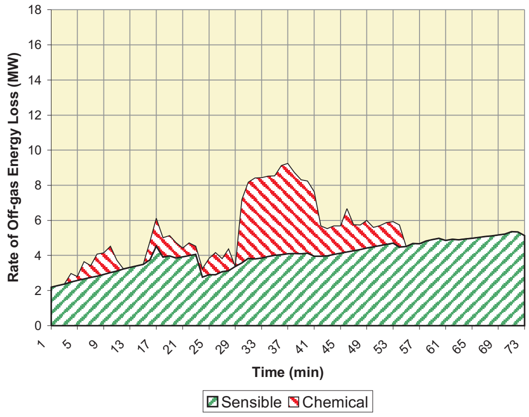

Fig. 5. Simulated ch. and sens. off gases energy loss after optimization

Figure 4 shows the same operation with a reduced level of in-leakage air entering the furnace. As indicated the sensible energy losses leaving the EAF are significantly reduced.

Closed-loop control of the oxygen would ensure efficient combustion of chemical energy within the furnace freeboard; resulting in a more efficient operation as showed in the Fig. 5 after the optimization.

The reduction of the draft on the primary fume system, by balancing the suction between primary and secondary circuits, decreased the entrance of in-leakage air into the furnace and resulted in a more efficient, slightly reducing (instead of oxidizing), freeboard environment. The EFSOP® system and subsequent analysis by TGI's process engineers alerted to address issues with the mechanical operation and functionality of the fume system. The repairs made brought immediate benefits in terms consumptions reduction

4.2. Closed loop control

Tuning of the fume system resulted in a desirable, slightly reducing furnace freeboard environment. It was then possible to optimize the existing plant standard practice to match the average chemical condition of the furnace; determined by observation and analysis of hundreds of heats. Over this practice, was developed and implemented a customized closed loop control practice for the dynamic control of oxygen and methane. 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.

4.3. 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 speed up the melting phase and to reduce even more the power on time. The electrical program was defined in terms of kWh/t steps and kWh/ton limits for charging and refining. 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.

4.4. Bucket layering

The off gas analysis, together with trials in the field provided a guideline for the correct preparation of the bucket in terms of the layering of the carbon materials. A new operative practice was developed to define the optimum location of pig iron and carbon in the bucket accordingly to observations in the off gas analysis. Analysis of the off-gas profile made it possible to determine the most efficient size of charge carbon according to the profile observed during melting and decarburization. The modification suggested by TGI process engineers and implemented by the plant reduced drastically the consumption of carbon and increased further the efficiency of the melting process.

5. Results

The basic strategy employed by Tenova Goodfellow is to make small process adjustments in the correct direction. As such, benefits are noted to have increased over the course of the optimization period. At the beginning of the optimisation period, TGI concentrated its efforts towards tuning the system to the complexity and completeness of the automation system at Riva, Verona. The same period was also critical for the plant because of unfortunate problems at the casting machine and rolling mills and the resulting long periods of furnace down-time.

The path to optimization is shown in Figs. 6, 7, and 8 below. The figures show the time trend of the reference variables for the calculation of the performance. The graphs contain two vertical bars to delimitate the periods: antecedent to the installation; during installation, commissioning and tuning, and optimization. A comparison of the performance during the optimization period with the previous months performance shows increasing benefits in terms of increased productivity.

The increased productivity is due to a reduction in power-on-time that today is at the historical minimum for RIVA, Verona. The trends for consumables follow the same pattern with an initial increase due to trials for tuning the EFSOP® system and due to modifications to the electrical practice, injector system modifications and fume system tuning. The reduction of the consumables starts to be effective from March 2006 and has improved in the subsequent months.

Figure 6 shows the historical trend for the consumables: electrical consumption, methane and oxygen. The trend is in % of difference with respect to the baseline values. As already introduced above it is possible to notice the period of high consumption just at the beginning of the performance period where a lot of changes to the major parameters for the melting process occur. After the tuning of the system and after the needed period for the operators to adapt to the new practice, the performance has been completely and constantly achieved.

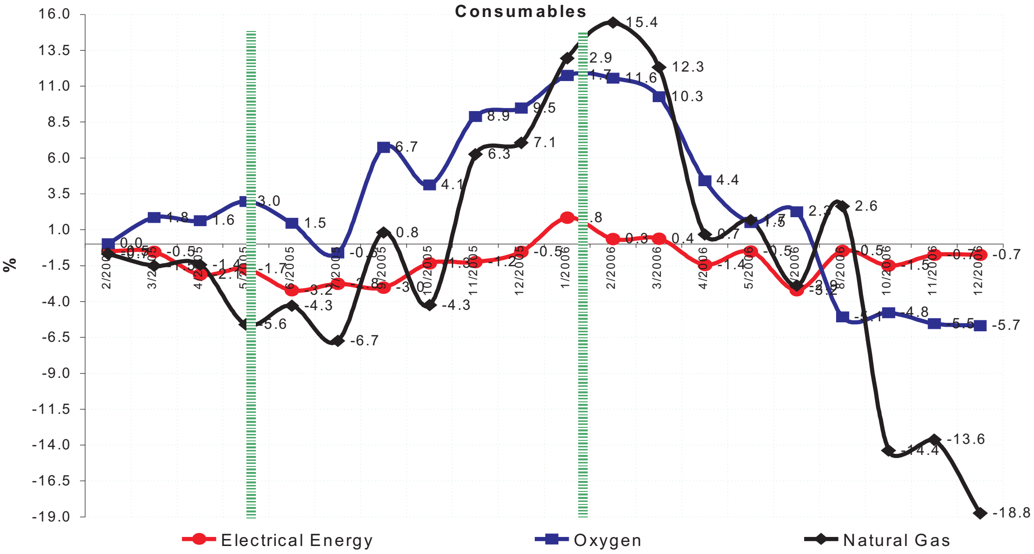

Fig. 6. Consumables trend for the performance parameters

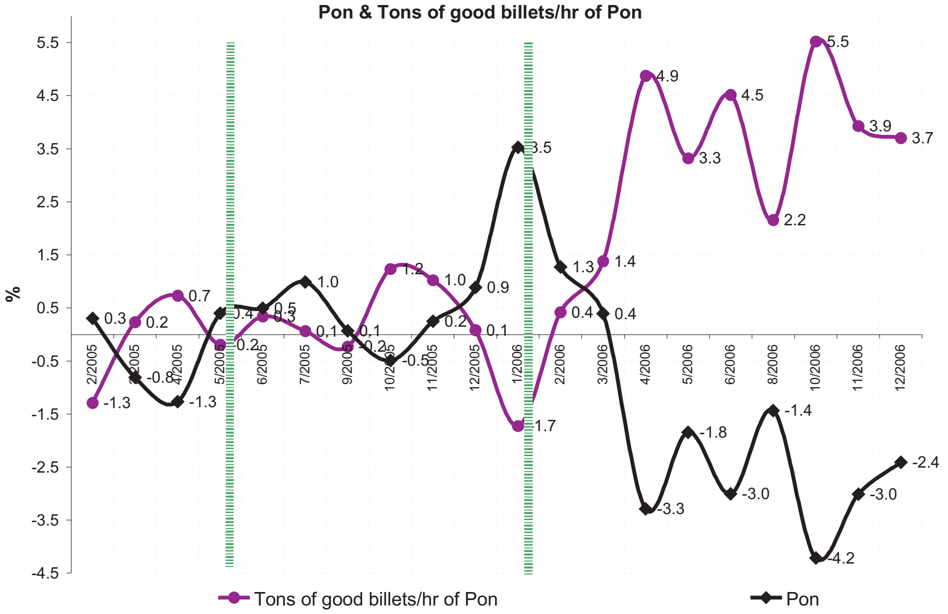

Fig. 7. Power on time and productivity trend

Figure 7 shows the behaviour of the power on time and the productivity. During the installation period (the central part of the graph, between the two vertical lines) the values of power on time and productivity oscillate around the baseline value. After the tuning period, during the second part of the optimization phase the power on time and the productivity reached the best level of the past years.

Figure 8 shows the % variation and trends for carbon injected and carbon charge. It also displays the consistent and important reduction of CO_2 emissions due to the decrease in the total carbon usage. Not only charged carbon but also injected carbon was reduced due to a more constant and controlled oxygen injection and a more efficient charged carbon practice during the heat.

The decrease of total emissions through the furnace is another very important parameter to take into consideration in the near future, especially for the European steel market, due to the increase of the cost of the CO_2 tonne emissions.

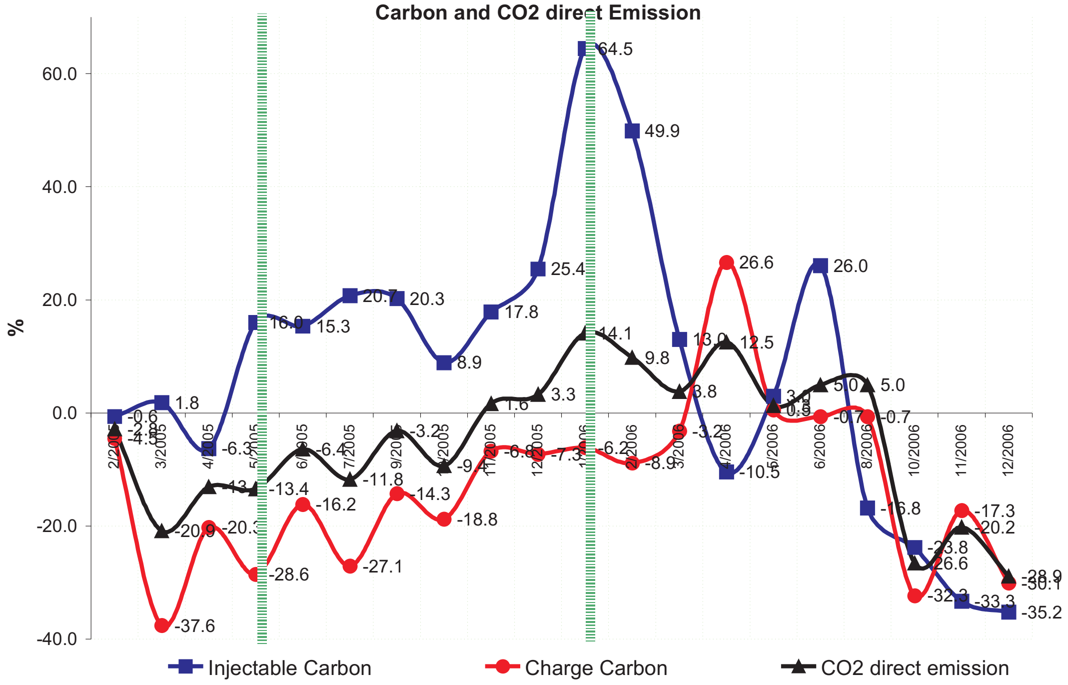

Fig. 8. Injected and charged carbon decrease. CO_2 emission trend

Parameters	% variation with Tenova Goodfellow EFSOP® system
Natural Gas	-15.24
Oxygen	-5.2
Electrical energy	-1.0
Charge carbon	-26.32
Injectable carbon	-30.24
Electrode	equal
CO_2 direct emission	-24.9
Metallic yield	equal
Power on (Pon)	-3.35
Tons of good billets/h	3.32
Tons of good billets/h of Pon	4.47
Ton of good billets considered	216,206
Number of heats considered	2,914

Fig. 9. % variation for the performance parameters obtained by the EFSOP® system

As mentioned in the previous section, many process adjustments were suggested and implemented to achieve the performance objectives at RIVA. An initial trial, in June 2006, during which the rpm of the fume system fans was reduced, demonstrated the potential for process improvements that could be achieved by mechanical and automation adjustments to the fume system.

During the two-week summer shut-down period in August 2006, plant personnel implemented measures to improve the reliability of the carbon injection system and for carbon charging in the bucket to better control the automatic charge of the coal and its quantity. A reduction in carbon usage, after the modifications, was noted immediately.

The last modification to the dampers of the fume system during the months of September and October, 2006, provided the opportunity for the EFSOP® system to work at its best for the dynamic control of methane and oxygen. The end result was that the environment of the EAF was optimally controlled with the consumables reaching the minimum historical levels.

The performance values obtained are presented in Fig. 9 and are calculated over a period of three months including October, November and December 2006.

They are presented as % variation with respect to the baseline values calculated for the first six months of 2005, prior the installation of the EFSOP® system.

6. Conclusions

The optimization of the EAF operation in Riva Acciaio Galtarossa, was the result of a complex and holistic effort that took into account all aspects of the EAF operation. The EFSOP® Technology provided valuable information needed in order to improve the already optimized plant practices. Gross adjustments were made that shifted the practice to a point where EFSOP® could effectively provide fine-tuning of the operation through closed loop control. The harmony reached at the automation level was challenging, for many reasons, but in the end proved to be one of the keys to success.

The holistic approach followed to reach the performance and once again, the flexibility and comprehensiveness of the EFSOP® technology has been demonstrated. At RIVA, EFSOP® has provided valuable and reliable information for the general optimization of the melting process, not substituting the functionality of the other furnace systems, but increasing them.

Received: 3 April 2008.

Acknowledgements

The authors would like to thank the director of Riva Galtarossa plant Ing. Marzoli, for his support during the installation and optimization phases; the melt shop manager Mr. Bertelli for the prompt response to TGI requests and suggestions; and the plant maintenance team for their professionalism in assisting with the installation and the regular maintenance of the Goodfellow EFSOP® system.

REFERENCES

[1] H.D. Goodfellow, M. Pozzi, J.M. Maiolo, Dynamic process control and optimization for EAF steelmakers, Metallurgical Plant and Technology International, November 2006.

[2] M.I. Khan, H.D. Goodfellow, J.A. Maiolo, O.I. Negru, Optimization of EAF Practices Based On Real-Time Off-Gas Chemistry Analysis Using Goodfellow EFSOP®, SOHN International Symposium, San Diego, CA, August 27-31, 2006.

[3] H.D. Goodfellow, M. Pozzi, J.A. Maiolo, Holistic Approach to Process Optimization for EAF Steelmakers, AISTech 2006, Cleveland, OH, May 1-4, 2006.

[4] M. Pozzi, J.A. Maiolo, F. Memoli, EAF process optimisation with Techint Technologies, Steel Times International, April 2005.