EAF process control

Goodfellow EFSOP™ is a proprietary system that uses continuous off-gas analysis and process monitoring to optimise the use of chemical energy within the EAF. Optimisation is achieved by adjustments to the carbon charge and injected carbon practice, together with dynamic control of oxygen and methane in response to real-time off-gas analysis. Use of the system at TAMSA, Mexico, have resulted in reductions in energy used, power-on time, iron oxidation and electrode consumption.

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The Goodfellow Expert Furnace System Optimisation Process (Goodfellow EFSOP™) is a proprietary process for EAF process optimisation based on continuous analysis of furnace off-gas. Techint Goodfellow 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 the EAF steel making practice in the Veracruz plant.

Installation and commissioning of the system was completed in December 2002. At that time, TAMSA was using only conventional burners and a single manipulated door lance. Initial optimisation of the steelmaking practice has been reported elsewhere **[1,2]** but 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 was retained to provide its expertise in furnace optimisation for the commissioning of its newly installed KT chemical package provided by Techint Technologies. The project provided the opportunity for the Goodfellow EFSOP team to work directly with Techint in the commissioning and implementation of the KT package and the positive synergy between the two technologies has resulted in the purchase of the Goodfellow EFSOP business unit by Techint Technologies from Stantec. The new business unit is called Techint Goodfellow Technologies Inc. and operates out of Mississauga, Canada.

GOODFELLOW EFSOP SYSTEM

The system uses off-gas analysis combined with process data acquisition, model based analysis and real-time control to optimise chemical energy usage within the EAF. In general, optimisation objectives include: reducing conversion energy costs (energy and materials); increasing productivity; increasing yield, and improved safety by minimising the risk of explosion within the EAF. The components of the system are shown in *Figure 1*. The key features include the patented water-cooled sample probe, the gas analysis system and the Supervisory Control and Data Acquisition (SCADA) system.

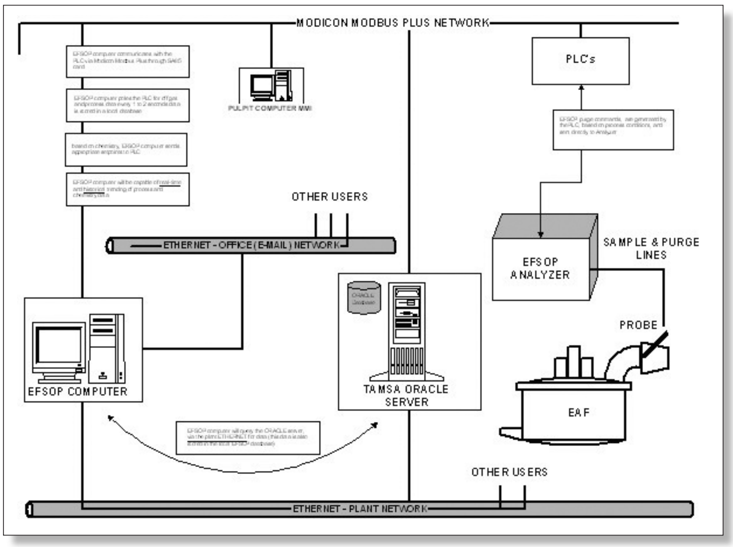

Fig.1 **Schematic of the Goodfellow EFSOP system at TAMSA**

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 the sample probe and off-gas composition and process operational variables are used to define the furnace operation and then to optimise the chemical energy usage within the EAF.

In general, optimisation is achieved by controlling the evolution and combustion of chemical energy within the EAF. This is possible by balancing the use of chemical energy through adjustments to oxygen, methane and carbon practices. Additional details of the system can be found in previous technical papers. **[1–7]**

KT INJECTION SYSTEM

The patented KT oxygen lances and KT carbon injectors

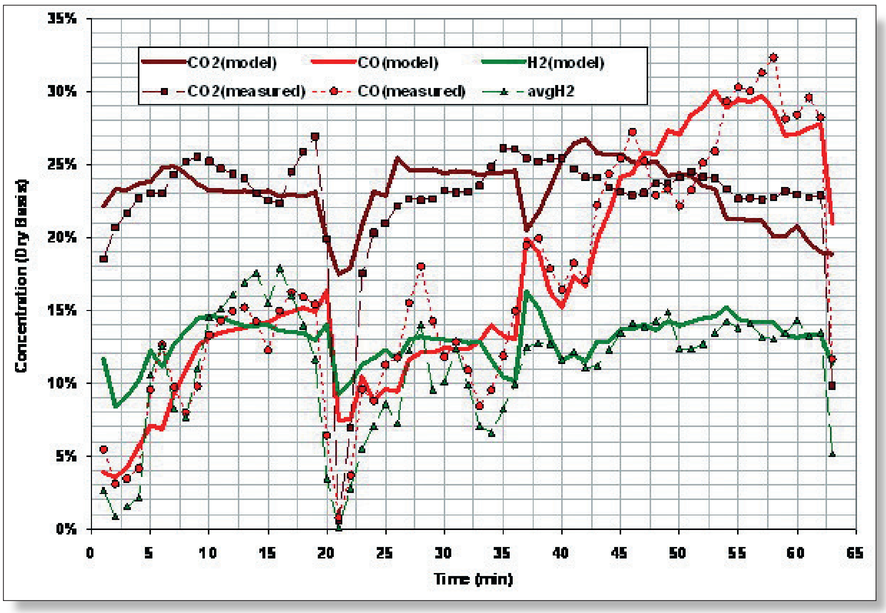

Fig.2 A comparison of predicted off-gas composition and measured composition

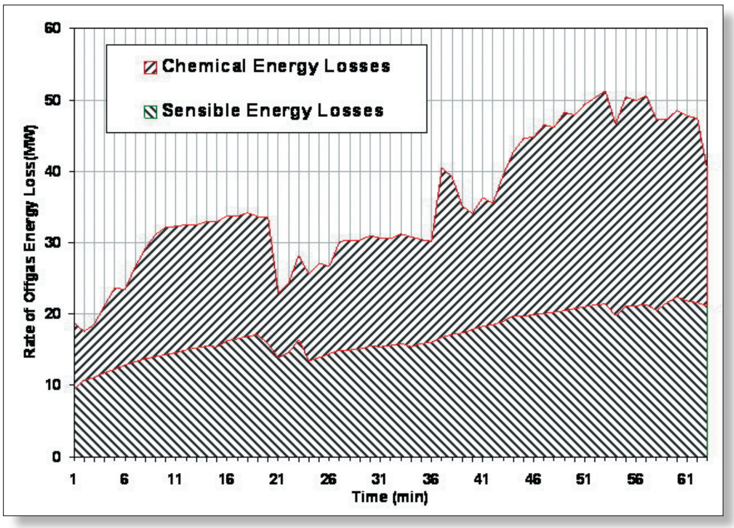

Fig.3 An example of off-gas energy losses for a heat before optimisation

are the most effective multi-point lances for EAF applications. Over 250 lances have been successfully installed in more than 20 countries. 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 Mach 2.5 and maintain a compact jet up to 2m 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.

Three oxygen injectors and three carbon injectors have been installed, but in order to supplement the advanced decarburisation 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 the door lance for clearing scrap from the door area before sampling was also retained.

ANALYSIS AND MODELLING

The KT injector system was installed and a generic operational program implemented. The 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 modelled using Techint Goodfellow's proprietary DECSIM EAF simulator. The simulator takes as its inputs methane and oxygen input rates, carbon injection rates, the amount and timing of charged carbon additions of lime, HBI, DRI, etc, and scrap mix. The simulator is tuned by adjustment of modelling parameters so that predicted off-gas chemistry matches the measured chemistry.

Figure 2 is an example heat before optimisation and 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 is not shown because 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. This 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 the sum of the measured carbon dioxide and carbon monoxide. The figure shows adequate agreement between the values determined by the EFSOP measurement and those predicted by the simulator.

One important result provided by the DECSIM analysis is an estimate of the off-gas energy losses. For the particular example above, the off-gas energy profile is shown in *Figure 3*. There are two components, the sensible energy losses and 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

	(1) Base line before EFSOP	(2) KT&EFSOP (Jan–Dec 2004)	(3) KT&EFSOP (Nov–Dec 2004)	% Change (column 1 to 3)
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 (tonnes liquid steel)	142	146	158	+11.2

Table 1 Optimisation Results for EFSOP & KT chemical package

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 gives 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 50MW 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 chemical potential energy. The goal of the optimisation process is to minimise waste energy loss by balancing the evolution of carbon with oxygen and methane usage.

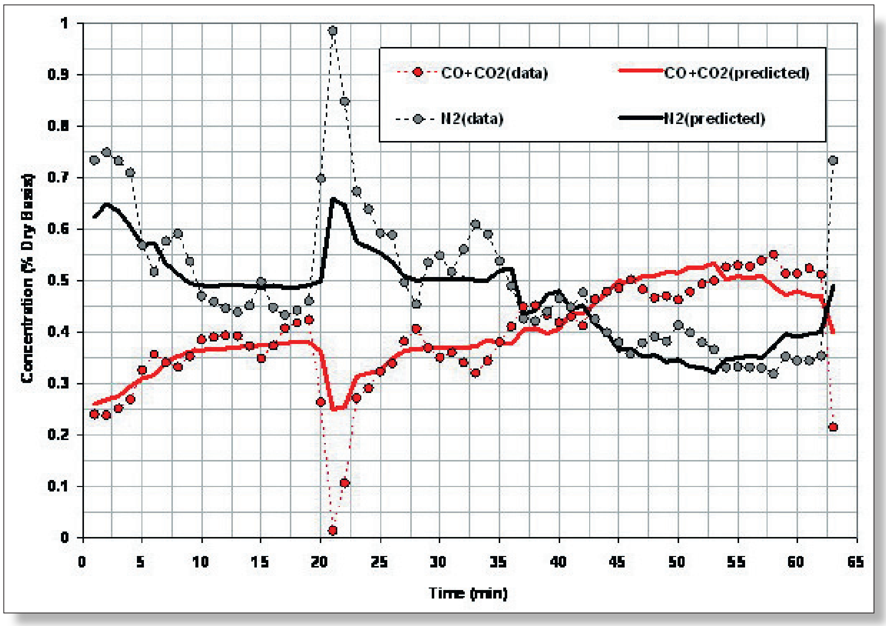

Fig.4 A comparison of predicted carbon evolution and air in-leakage

FURNACE OPTIMISATION

The measured furnace off-gas chemistry and operating data, along with the DECSIM analysis provides valuable information regarding the pre-optimised operation of the furnace. The simulator, once properly tuned, may be used to explore various optimisation scenarios and to make informed decisions regarding adjustments to charged carbon, lance oxygen and lance carbon.

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

- Develop a program for KT and burner control and for charged carbon usage.
- 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 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 optimisation recommendations are implemented and evaluated. The second component is implementation of closed-loop control for optimum post-combustion within the furnace freeboard.

Closed-loop control allows the system to adjust oxygen and methane usage in response to real-time off-gas composition. This is important as it allows EFSOP to respond favourably to unpredictable events that inevitably occur during melting and refining (eg, flashing of hydrocarbons, carbon boils and scrap cave in). Closed-loop control was implemented on the four conventional burner trains and controlled both oxygen and methane. between pre-determined maximum and minimum values. The goal is to achieve the most efficient level of post-combustion within the furnace freeboard. Similarly,

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closed-loop control has been implemented to control the shroud oxygen and methane on the KT oxygen injectors.

RESULTS

Initially, the KT chemical package was installed with a generic program defining the operation of the KT oxygen and carbon injectors over the course of the heat. The system was then used to adjust the timing and intensity of methane, oxygen and carbon usage. 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 system in response to real-time off-gas composition.

Analysis of the pre-optimised operation of the KT chemical package 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 which 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 overlanced 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 EFSOP and the KT chemical package have been compared to the original base-line data (see *Table 1*). The base-line values are the average of TAMSA's reported values for three months prior to the installation of the EFSOP system. Over the course of the year, numerous trials have been conducted resulting in modifications and improvements that continue to provide benefit to the plant.

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%.

Scrap mix, in part, affects the rate, timing and quantity of carbon evolution in the EAF. Market conditions for scrap and product grade require that TAMSA continuously adjusts the amount of alternative iron (pig iron, HBI, DRI) usage within its 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. Different control programs are selected for different scrap mixes and 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 (eg, flashing of hydrocarbons, carbon boils, scrap cave in) that determine the way chemical energy evolves over the course of the heat.

CONCLUSIONS

The adaptability of EFSOP has been demonstrated at TAMSA. Initially, installed to optimise 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 has resulted in a better process understanding, continuing economic benefits and significantly more value to TAMSA. MS

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