Smart-Gas – A New Approach to Optimizing EAF Operations

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INTRODUCTION

In the high-tonnage, low-margin business of electric arc furnace (EAF) steelmaking, incremental improvements can contribute significantly to profits. Feedback of process information to the operator, metallurgists, and engineers is the key to continuous improvement of the operation. In many EAF operations, the only process feedback consists of electrical energy, oxygen and natural gas consumption along with indicators such as power-on time, tap-to-tap time, and yield. **A need exists for a simple tool that allows the EAF operator to obtain some immediate feedback on furnace performance**. In addition, such a tool must allow the operator to identify upset conditions and provide some insight as to the cause of these upset conditions. The net result of these requirements was the development of the Smart-Gas System.

Many EAF operations are trying to optimize practices. However, optimization cannot be achieved until EAFs are better controlled. The level of variation observed on even the best operations in the world indicates that operating consistency is a problem. Slag analysis is one of the few measurements that allow EAF operators to adjust parameters to improve EAF operations. Many important parameters are not measured in real time.

Almost all of the common measures of EAF operating efficiency are based on end-of-heat conditions. Some meltshops present this data to the operator immediately at the end of each heat, though it is common for the operator to get a weekly summary which allows evaluation of the previous week's heats. Immediate display of this data at the end of a heat allows the operator to determine how well the last heat was run but provides nothing to help the operator while a heat is being made. Although yield is an important indication of how effective the operation is, it is difficult to measure and can be quite variable on a heat-by-heat basis. The Smart-Gas System provides continuous real-time information on the efficiency of the furnace as well as an end-of-heat energy inventory.

In the past, steelmaking operations have not seen the need to monitor the performance of the off-gas system. Off-gas system operations were purely a means to an end, a function that was necessary in order to allow for EAF operation. However, from the point of view of the off-gas system designer, the EAF operation is of the utmost importance because the efficiency of energy transfer in the EAF directly affects the amount of energy in the off-gas, which in turn determines the sizing requirements of the system. The Smart-Gas System monitors the off-gas system to provide additional information to the operator to help make operating decisions.

Several papers have been presented previously which discuss EAF energy efficiency and the factors that can affect efficiency (1, 2, 3). In modern EAF operations, the typical amount of heat contained in the off-gas (both sensible and calorific heat) amounts to approximately 20 – 30 % of the total energy input to the EAF. In operations using a higher proportion of chemical energy input, energy losses to the off-gas can be higher at 30-50% of the total energy input. Energy losses to water-cooled EAF components can account for an average of 8 – 10 % of total energy inputs and in some cases can be as high as 20 %. **Monitoring of the off-gas system and water-cooled components using the Smart-Gas System allows EAF operators to identify periods of the operation where the energy transfer efficiency to the steel is low.** During these periods the energy input to the EAF is ineffective. In addition, high energy losses to the shell and off-gas system during these periods account for a significant portion of maintenance issues related to the furnace.

SMART-GAS SYSTEM DESCRIPTION AND CAPABILITIES

WorleyParsons GCT (GCT) and Nupro Corporation have developed Smart-Gas to be a simple tool for tracking off-gas system performance and providing real-time feedback to EAF steel-making operations. The concept behind the tool is a simple one: continuous off-gas flow rate and temperature measurement coupled to real time process data (via PLC connection) and a proprietary EAF model to allow the operator to identify and understand deviations in the operation of the EAF and the off-gas system. The Smart-Gas system is low maintenance and consists of relatively low-cost instrumentation.

The Smart-Gas System is specifically designed to monitor and assess the distribution of energy in the EAF and auxiliary systems in real-time. It can be used to reduce the energy losses through the furnace off-gas system and cooling water systems by identifying periods of poor energy utilization in the EAF operation and recommending corrective action. The Smart-Gas system alerts the operator when operation is outside of normal operating ranges. With this philosophy, control loops with short response times are not required to achieve a more stable operation of the EAF. The furnace operator is able to decide what actions, if any, to take when operation is outside of normal ranges. (i.e. open loop control). Closed loop control of burner natural gas, number of oxygen lances operating, and number of carbon injectors operating is also possible. The Smart-Gas system can also be used to monitor emissions and other environmental parameters in order to gain a better understanding of these parameters with respect to operating practices.

Smart-Gas uses a historical operations database to generate control curves for normal operation. These control curves allow the operator to identify periods when energy distribution deviates substantially from normal operation. This information, coupled with an end of heat energy inventory, provides a basis for continuous improvement of EAF operations. **The Smart-Gas System therefore allows the operator to make changes to the EAF operation immediately to improve energy efficiency in the EAF and minimize energy losses to the off-gas system and furnace roof and sidewalls.**

The potential uses of the Smart-Gas System are many and are dependent on the level of process data available within any given operation.

The objectives of the Smart-Gas System include:

- Real-time optimization of EAF operations
  - Improved energy efficiency and improved production costs
  - Provide optimum draft control for effective off-gas collection without over-drafting the furnace
  - Development of a more consistent operating practice
  - Minimization of off-gas energy losses
  - Minimization of energy losses to water-cooled EAF components
- Better understanding of the energy distribution during EAF operations
- Monitoring and minimization of emissions from EAF (if emissions monitors tied into system)

Some of the specific capabilities include:

- Energy Efficiency
  - Identify periods of low energy transfer efficiency (energy waste) in the EAF
  - Track efficiency of oxy-fuel burner operation to aid in adjustment of burner firing profiles
  - Track efficiency of oxygen injection operations to aid in adjustment of oxygen lancing profiles
  - Monitor carbon recovery to aid in adjustment of carbon injection profiles
- Monitor off-gas flow rate, temperature, and heat content at one or more locations in the off-gas system
- Recognize and track changes in feed scrap quality
- Slag
  - Monitor slag formation – to aid in adjustment of flux addition schedules and improve arc stability
  - Monitor effectiveness of slag foaming and efficiency of electrical energy transfer to the bath

In addition, the Smart-Gas System can be further customized by coupling it to other existing process sensors and process models to provide an even more comprehensive view of EAF process operations. The historical database generated by the Smart-Gas System can be used to analyze EAF performance and can be used to identify the need for beneficial changes in EAF operation aimed at improving energy efficiency. Some of the reporting tools that are available in Smart-Gas include Microsoft Access Heat Reports (Heat Energy Inventory, Shift/Daily/Weekly/Monthly/Yearly Heat Summaries, Furnace performance by crew) and Historical trends (Total furnace energy input, Off-gas energy losses, Power-on time, Tap-to-tap time, Total Energy Inputs (natural gas, oxygen, electrical).

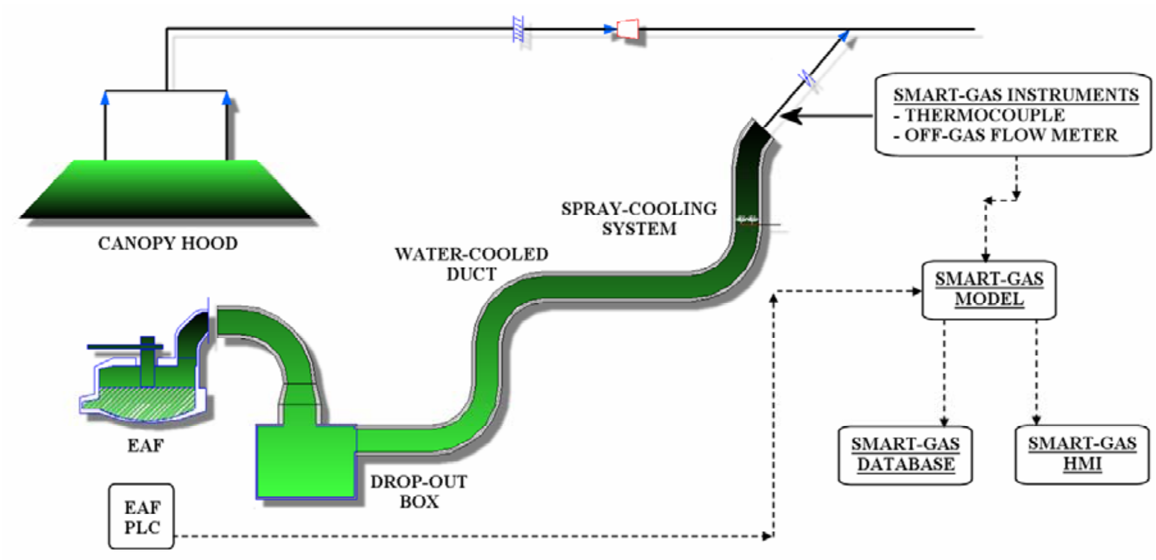

Figure 1 Typical Smart-Gas System Components

SMART-GAS SYSTEM RESULTS

The Smart-Gas System has been implemented on five electric arc furnaces worldwide. Each of these implementations has similar as well as unique features. This is due to the fact that the different priorities at each meltshop drive the specific implementation of Smart-Gas.

This paper will present three (3) different areas of the EAF operation where Smart-Gas can be used to optimize the operation:

- Quantification of energy losses and correlation of losses to specific operating practices using Smart-Gas
- Evaluation of operational changes using Smart-Gas
- Environmental monitoring and correlation of emissions with specific operations using Smart-Gas

Quantification of Energy Losses and Correlation of Losses To Specific Operating Practices

The Smart-Gas System sets itself apart in being able to present the instantaneous energy losses from the off-gas, furnace roof, and furnace sidewalls in real-time. The system provides overall energy loss trends for each of the above as well as trends for losses through individual water cooling circuits, if requested. At the end of the heat, the system also calculates the cumulative total energy losses for the off-gas, off-gas system, furnace roof, and furnace sidewalls.

In addition to trends and end of heat cumulative total losses, peaks of high energy loss can be correlated to specific operations in the furnace.

Overall off-gas energy losses

Figure 2 shows electrical energy input (solid line) and instantaneous off-gas energy losses (dotted line) versus operating time at one of the Smart-Gas installations. It can be seen that losses to the off-gas system increase towards the end of each meltdown period. This period also represents the time when oxygen and carbon injection are the greatest. This is not surprising as it becomes more difficult to effectively transfer energy to the steel bath as it becomes hotter.

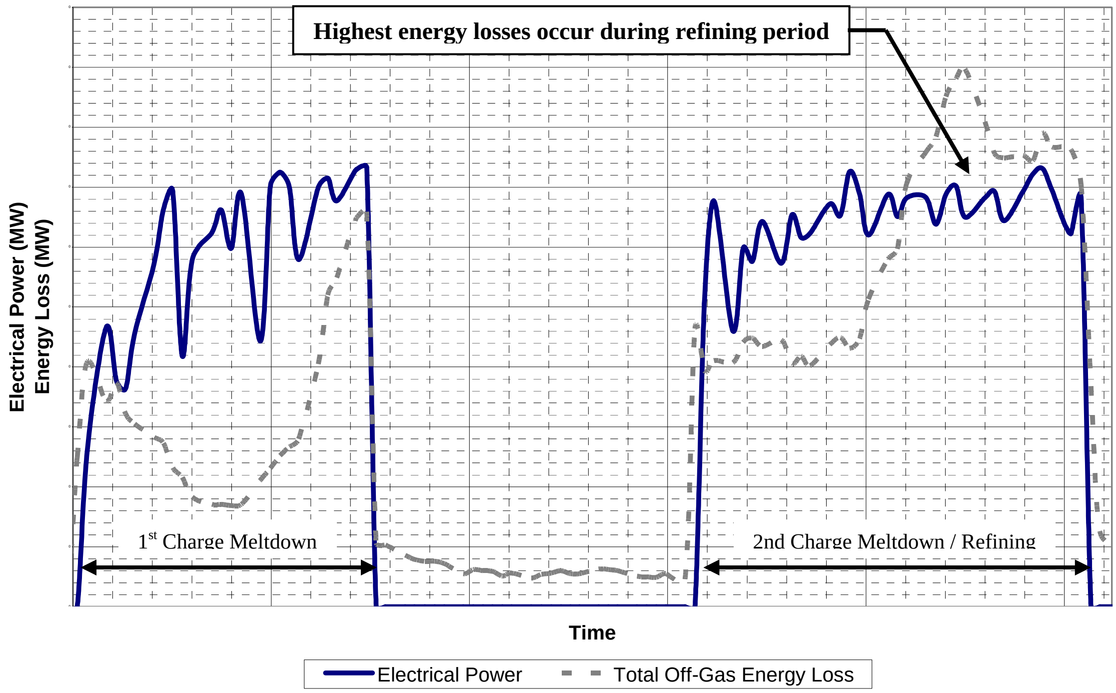

Figure 2 Smart-Gas System Electrical Power Input and Off-Gas Energy Loss Profile

Energy losses to furnace shell

As a means of benchmarking EAF operations, the heat total energy losses to the EAF roof and sidewalls can be compared for different Smart-Gas installations. A summary of the data is presented in Table I.

Table I Comparison of Smart-Gas Heat Total Roof and Sidewall Losses at Different Smart-Gas Installations

	Roof Losses (KWh/ton tapped)	**Sidewall Losses (KWh/ton tapped)**
Furnace A	16	33
Furnace B	13	40
Furnace C	20	24
Furnace D	21	24
Furnace E	15	16

Table I shows that the EAF roof and sidewall energy losses are quite different for the various furnaces. Some furnace operations focus on promoting slag build-up on the sidewall panels in order to reduce energy losses through the sidewalls. High sidewall losses can be due to little or no slag coating on the sidewalls and insufficient slag volume to cover the arc. These conditions lead to high radiative energy losses from the arc. As a result, energy losses to the water-cooled furnace components can be approximately 5-7 MWh per heat. Conservatively, sidewall losses in the range of 5-7 MWh could be reduced by 50 % with a change in slag practice. This reduction would result in savings of approximately $1.50 - $2.00 per ton.

Figure 3 shows the instantaneous energy loss rate through each of four sidewall water-cooling circuits at one of the Smart-Gas installations. The figure shows that, at times, sidewall circuit 1 experiences a much higher energy loss rate than the other three circuits. It was determined that the sidewall panels corresponding to this circuit are located near a carbon injector and the peaks in energy loss occur during the operation of the carbon injector. Based on these observations, recommendations have been made for reconfiguration of the carbon injectors to improve the carbon recovery.

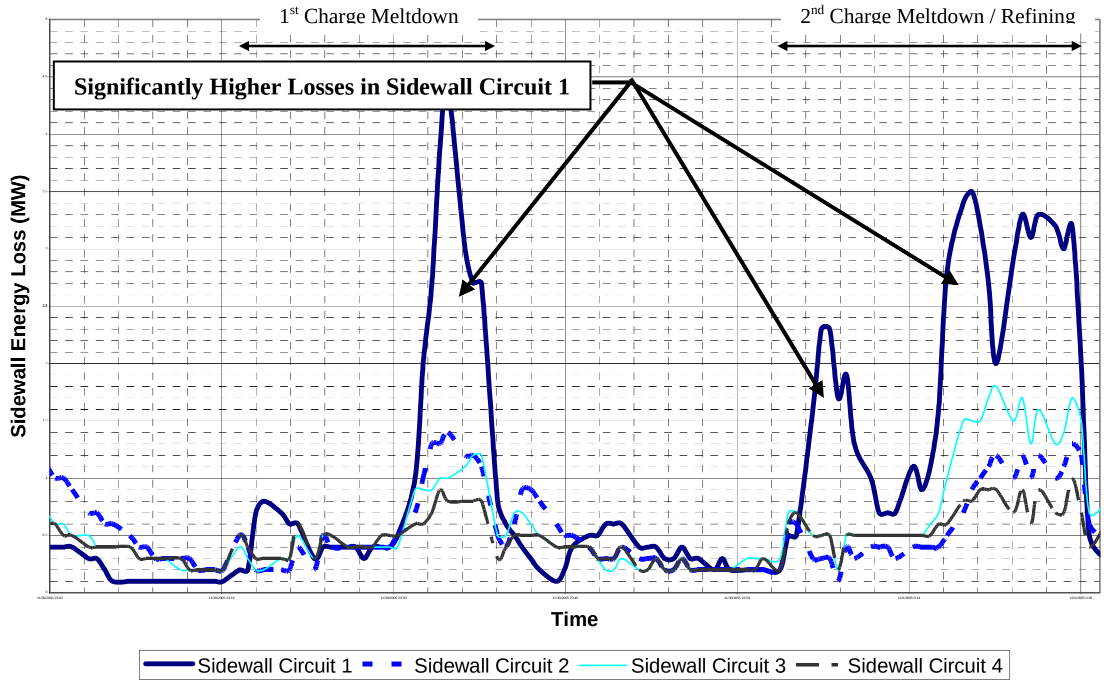

Figure 3 Smart-Gas System Sidewall Water-Cooling Circuit Energy Loss Profile

Evaluation of Operational Changes Using Smart-Gas

Modification of meltdown cycle

An important feature of the Smart-Gas System is its ability to provide real-time feedback to the furnace operator. A typical example of this benefit was demonstrated at one Smart-Gas installation. By observing energy losses to the off-gas system for various stages of the tap-to-tap cycle, it became apparent that high losses were occurring at the end of the meltdown of the first scrap charge (see Figure 3). Energy losses to the furnace sidewalls and roof also peaked during the same period. Based on this pattern which appeared to repeat on every heat, it was decided that it might be possible to drop the second charge sooner, thus reducing power-on time and at the same time improving energy efficiency.

It was also noted that even though 4 burner-injectors were available, the EAF operators continued to use the door lance to inject oxygen and carbon. In the longer term the door lance will be removed. However, at the present time, the door lance is needed because the burner-injectors are not located in optimal positions on the furnace shell. The burner-injector arrangement makes it difficult to melt out the area around the slag door without the door lance. The typical practice is to clear the slag door area about 5 minutes before the end of the first meltdown period. On some heats, pre-mature slag loss occurred once the slag door was cleared. A closer analysis of the operation also revealed that the carbon injection rate at the end of the first meltdown period far exceeded the amount of carbon required to match the oxygen injection rate.

An alternative practice has been recommended and trials are currently being conducted. The recommended practice is to drop the second charge earlier so that less energy is lost at the end of the first meltdown period. In addition it has been recommended that the slag door not be cleared until the second charge is melted. This will promote better slag retention in the furnace and will reduce air infiltration. Carbon injection will be reduced to match oxygen injection rates, resulting in reduced carbon consumption and less variation in slag FeO levels from heat to heat. Energy savings as well as productivity improvements are expected as a result of the recommended practice.

Formation of stable slag earlier

A review of energy distribution in the EAF at one Smart-Gas installation indicated high energy losses to the sidewall panels and the furnace roof. These losses increased as the scrap melted in. After extensive review, it was concluded that the slag depth was insufficient to bury the arc and as a result, radiative heat losses were higher than normal for this operation. A review of flux addition practices indicated that the flux additions were not being made until one-half to two-thirds of the way through meltdown. This was causing lower bank wear and resulted in a slag that was still being formed once the furnace hit flat bath. To exacerbate the problem further, the furnace bottom is very shallow and very little slag is carried over from heat to heat. As a result the arc was not being covered with a liquid slag and high energy losses were resulting.

The proposed solution to this problem was to add fluxes earlier in the cycle and to increase the amount of flux added. This meltshop adds fluxes through a roof feed system and under the recommended practice, flux additions were made onto the heel prior to charging the scrap. Additional flux was also added part way through meltdown. The effect of earlier slag formation was that the EAF operated at a much higher active power due to better arc stability. Active power was increased by 9% with the modified practice. For this specific operation, this increase in power availability has the potential to increase productivity by almost 9% and provide cost savings in excess of $7.00 per ton due to the higher active power.

In the future, this meltshop plans to test the effects of staging flux additions throughout the first and second meltdown periods. Even though increased productivity is not required right now, other benefits such as reduced equipment maintenance and the ability to make heats faster and more efficiently make these practice changes highly attractive. The meltshop will also evaluate the possibility of moving the feed location closer to the pitch circle so that the flux and roof carbon additions are made closer to the center of the furnace. This is expected to improve the recovery and utilization of these materials.

This example demonstrates the true flexibility of the Smart-Gas system as an operating tool. Simple analysis allows any user of Smart-Gas to monitor slag foaming effectiveness and make incremental changes in operating practices to lower operating costs and improve operating efficiency.

Improved carbon recovery

Carbon recovery is important for any EAF operation. The better the carbon recovery, the less carbon addition required to maintain the C/O/Fe balance and keep metallic yield at acceptable levels. The carry-over, or loss, of carbon from the furnace into the off-gas system results in extra heat load reporting to the gas handling system. At two Smart-Gas installations, charge carbon levels were adjusted to improve yield and to control slag foaming in the EAF. At one installation, yield was improved approximately 0.8 % with a small increase in charge carbon additions and modified practices aimed at better charge carbon recovery. In another instance, electrical energy and oxygen injection were decreased while carbon additions were increased to give an overall decrease in power-on and tap-to-tap time (reduction of approximately 3.3%).

At one installation, the Smart-Gas System showed peaks in energy losses to the sidewall adjacent to the roof feed port shortly after the carbon was added through the roof. In addition, energy losses to the off-gas also spiked at this time. This particular operation charges carbon through the roof about halfway through the first and second meltdown periods. The energy loss peaks during this period indicating that the carbon was reacting as soon as it was charged to the furnace and also indicating that very little of this carbon was being recovered to the bath. Thus the charge carbon was not fulfilling its intended purpose – to help control bath chemistry. Analysis of the energy losses through the water-cooled components in the off-gas system indicated that the charge carbon was likely breaking up and was burning in the off-gas as it was carried through the off-gas system. Other operations have also found that recovery of charge carbon is typically low unless carbon is added on the heel and the scrap then charged on top so that the carbon is pushed down into the bath.

To improve this situation, it was recommended to charge the carbon onto the heel prior to scrap charging. Charging the scrap on top of the carbon should push the carbon down into the bath and result in better recovery. The operation must take care to charge the scrap as soon as possible after the carbon has been charged as the carbon will otherwise burn up. Trials for this recommendation are in progress. Over the long term, it was recommended that the roof feed port be relocated so that the carbon would be dropped closer to the pitch circle where the slag would be fluid enough to allow for some penetration by the carbon.

The analysis of the energy loss to sidewall cooling circuits (Figure 3, above) and the energy loss to the off-gas system (Figure 4, below) were used to help determine that there was an excess of carbon being injected into the furnace. This is believed to be related to several issues including a shallow carbon injection angle, ineffective carbon penetration into the slag due to late slag formation and build-up of material on the carbon injection ports (injectors not optimally located in the furnace). These issues are being investigated and it is expected that total carbon injection quantity can be reduced by 10 – 25 % without adversely affecting EAF operations.

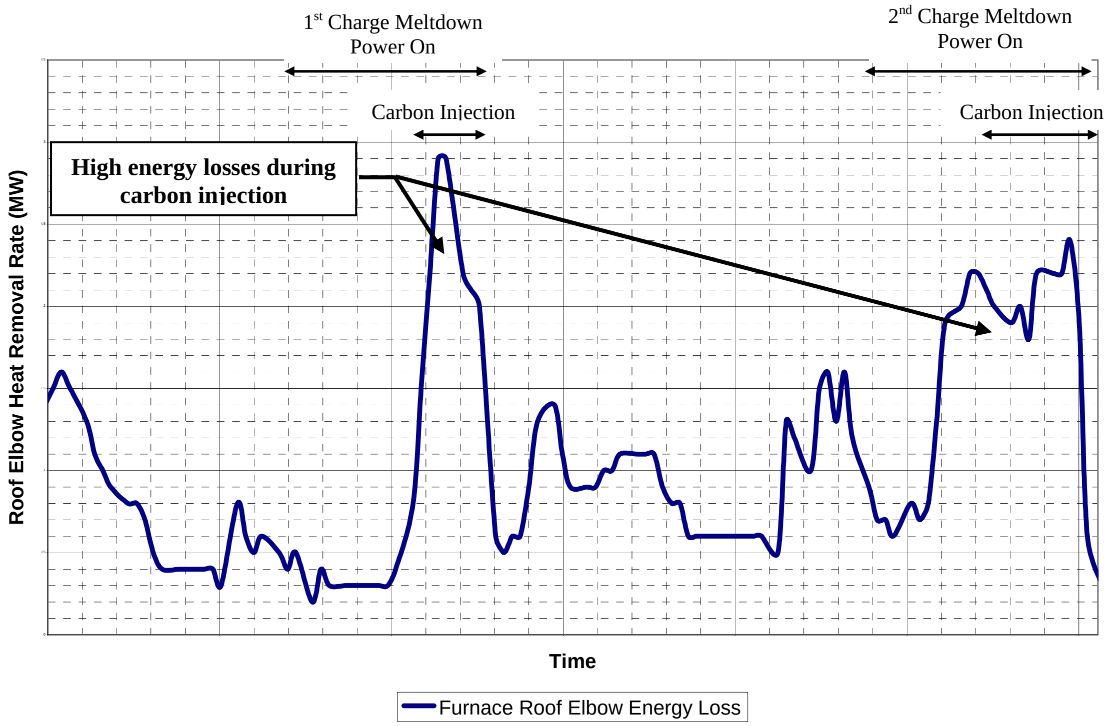

Figure 4 Smart-Gas System Roof Elbow Energy Loss Profile
Showing Correlation Between Carbon Injection and Peaks in Off-Gas Energy Loss

Energy losses due to excessive infiltration air

Over the years, many attempts have been made to quantify the effects of air infiltration to the EAF through the slag door. Of course the amount of air entering through the slag door will be dependent on the way the direct evacuation control (DEC) system is operated, DEC damper control logic, and the amount of suction applied to the EAF. At one Smart-Gas installation, the static pressure at the slag door was measured during various stages of the tap-to-tap cycle and the amount of infiltration air was calculated. Based on the off-gas temperature through the tap-to-tap cycle, the net effect on energy losses was calculated to be close to 8 MWh per heat. If even half of this air infiltration was eliminated it would result in savings of approximately $1.00 per ton.

Similar measurements were also carried out at a different Smart-Gas installation. Based on calculations conducted for this operation, savings of approximately $1.60 could be achieved by reducing air ingress through the slag door (based entirely on energy savings).

It is also important to note that other improvements would also result from reduction of air ingress including reduced electrode consumption, improved tap carbon control and increased metallic yield. Work is on-going to quantify the cost savings related to these additional savings.

Effect of scrap pre-heating

Observations of one Smart-Gas System indicated that large energy losses to the off-gas system occurred following charging and during the pre-heat phase as shown in Figure 5. It is likely that either the charge carbon is burning or perhaps a large amount of combustible material in the scrap is flashing off. Analysis at this meltshop indicated that both of these activities were contributing to high energy losses to the off-gas system during the period just following charging. As a result, the operation was modified so that the burner-injectors were set at low fire during the pre-heat stage. This operational change resulted in no change to electrical power consumption and yielded a reduction in oxygen and natural gas consumption. Based on several days of trials, no adverse effects were observed and long-term savings of $0.60 per ton are projected.

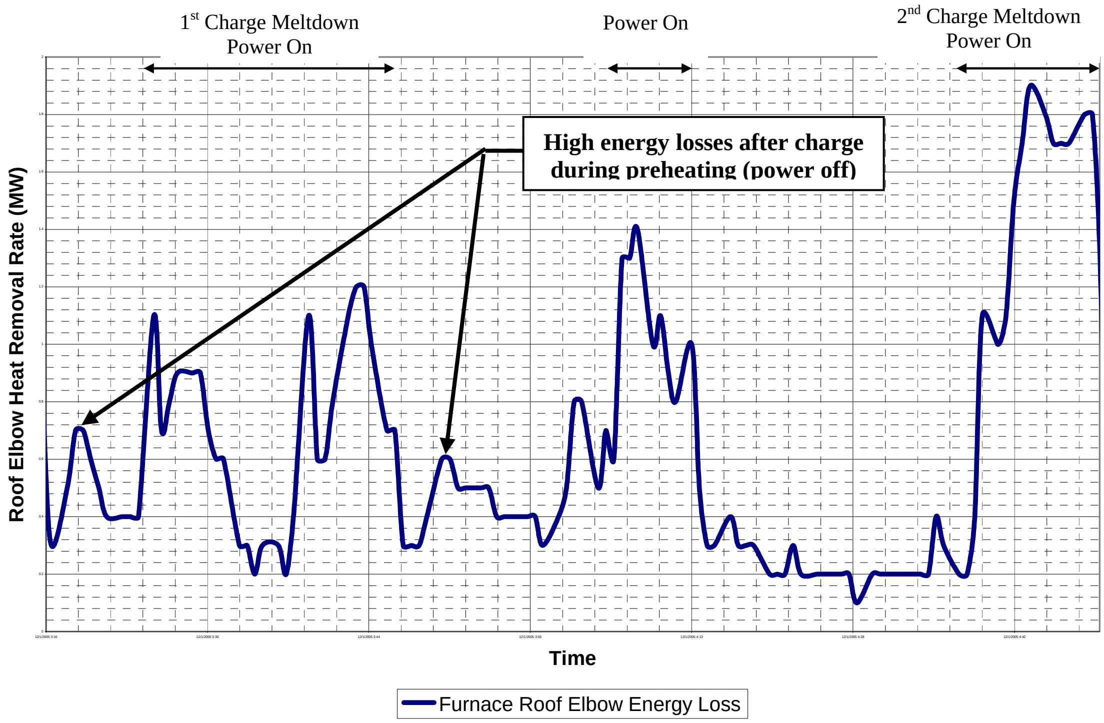

Figure 5 Smart-Gas System Roof Elbow Energy Loss Profile Showing Flash-Off

Evaluation of operations by crew and over Time

Smart-Gas is being used effectively to provide real-time feedback on EAF operations to the operators at several meltshops. The heat reporting tool is also in use at these facilities and has become a regular part of the meltshop operating report that summarizes the furnace energy consumption and energy efficiency. As all of these meltshops become more familiar with the reporting and process systems available within Smart-Gas, they are investigating further process changes to improve furnace efficiency and lower costs further. The Smart-Gas system is continuously being expanded and improved and is slowly becoming the fundamental tool upon which operations can rely to form the basis for a continuous improvement program.

Environmental Monitoring and Correlation of Emissions with Specific Operations using Smart-Gas

The motivation for using Smart-Gas at one of the installations was for environmental monitoring and it has been performing as originally specified. The system at this meltshop reads data from the continuous emissions monitoring system (CEMS) in addition to the furnace PLC. The system is then able to provide feedback to the operators regarding emissions based on historical data and the plant's environmental permit.

As the furnace operators at this installation have become more familiar with the system, they have begun to see that the system can be used as a tool to improve furnace operations as well. Significant improvements in EAF efficiency are anticipated and will be reported in a future paper.

Environmental considerations have become an area of increased concern for meltshops over the past 10 years. Through application of the Smart-Gas System, it is possible not only to quantify emissions, but also to relate these emissions to specific operating practices and changes to these practices. The Smart-Gas System represents the first tool that couples environmental and operating practices together in a meaningful way that lays the path for reductions in emissions in the future.

CONCLUSIONS

In order to evaluate the effect of process changes, it is imperative that process measurements be made to understand the overall behavior of the EAF and off-gas system. The Smart-Gas System is a process tool that can provide both real-time and historical process feedback for EAF operations. In the past, this has been a difficult task.

Through real-time analysis of the electrical and chemical energy distribution in the EAF, the Smart-Gas System promotes improved consistency and real-time optimization of EAF operations. With its unique feature of a built-in historical benchmarking as well as an energy and optional emission inventory at the end of each heat, the system can be used to realize energy savings and better operation under environmental constraints. The system also includes the option of linking to other models such as a C/O/Fe balance model or a slag optimization model to achieve additional operational improvements. The system draws on extensive EAF operating experience, simple low-maintenance instrumentation, combined with expert rules to improve EAF energy utilization.

For any EAF steelmaking operation interested in reducing production costs and improving energy efficiency, the Smart-Gas System is an ideal tool, specifically designed to monitor and assess the distribution of energy in the EAF and auxiliary systems. With these features, Smart-Gas system is an ideal tool to assist in achieving the continuous improvement goals of all EAF operations.

From the examples presented above, it can be seen that similar operating practices can result in greatly different behavior at any given EAF operation. This is because there are so many interactions between various operating parameters in the EAF. Thus it does not make sense to blindly apply a process change to a given EAF operation just because it provided a benefit at another operation where several other operating parameters might be quite different. Application of the Smart-Gas System can enable the furnace operator to make more informed decisions in the process of continuous improvement of the EAF operation.

Table II below presents some conservative estimates of the savings potential through implementation of a Smart-Gas System for an EAF facility. The projected savings in this table represent approximately 25 % of the actual savings that we have observed at the Smart-Gas installations so far.

Table II
Summary of Potential Smart-Gas Savings

Reduction of air ingress into EAF	$0.25 / ton
Reduction of electrode consumption due to reduced ingress air	$0.10 / ton
Reduction of natural gas consumption by turning off burners while least efficient	$0.25 / ton
Reduction of roof and sidewall losses	$0.20 / ton
Improved electrical efficiency with stable slag	$0.20 / ton
Total	**$1.00 / ton**

The types of savings generated by the Smart-Gas System will vary from one operation to another. We can however provide the following general guidelines. Based on the five installations to date, the typical payback for a Smart-Gas System is approximately 3 to 6 months. A typical project will last approximately 4 months when carried out within North America and approximately 6 months for overseas installations. For the installations currently in operation, the EAF operations have all shown improved operating consistency. Some portions of economic benefit of this improved consistency have been identified and described above but the total savings have yet to be fully quantified.

Future plans for improvement to the Smart-Gas System include integrating additional process models and to eventually provide guidance for every aspect of material additions to the EAF. As the understanding of interactions between process parameters grows through the application of Smart-Gas, EAF control and optimization will become a reality.

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