IMPLEMENTATION OF PYREJET^{TM} TECHNOLOGY IN ELECTRIC ARC FURNACES AT SIDERURGICA BARRA MANSA

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Synopsis: Siderurgica Barra Mansa (SBM) is a Brazilian long product steel producer located in the state of Rio de Janeiro. The melt shop operates two 50 tonne EAFs and one billet continuous caster. A drastic reduction in electrical consumption was required due to severe energy crises that occurred in Brazil in 2001.

SBM made a tremendous effort to reduce electrical consumption to under 400 kWh/t in the beginning of 2001. In August 2001 SBM implemented PYREJET^{TM} technology from Air Liquide on both furnaces in an attempt to further reduce conversion cost and to increase productivity. Within one month after the implementation the following results were achieved:

- Electrical consumption of 330-340 kWh/t
- 20% reduction in electrode consumption
- 12% reduction in power on time
- Over 1% increase in metallic yield
- Over 30% decrease in refractory consumption

PYREJET^{TM} is multi-function injector located on the sidewall of the EAF for completely automated injection of fuel, oxygen and carbon for the EAF process. This technology was pioneered by ACI in 1994-1995. Currently almost 20 EAFs worldwide are equipped with PYREJET^{TM} systems.

1 INTRODUCTION

Siderurgica Barra Mansa (SBM) operates two 50 tonne EAFs to make long products. Furnace #1 is an EBT equipped with a lance manipulator that can inject oxygen through each of two consumable lance pipes at a rate of 1600 Nm^3/h. A third lance pipe in the manipulator injects carbon for producing foamy slag. Furnace #2 has an older shell possessing the traditionally designed taphole spout. Prior to August 2001, decarburization was carried out using manual lance pipes inserted into the slag door to inject oxygen into the bath. Carbon was also injected into Furnace #2 using a manual lance pipe inserted into the slag door. SBM did not use any burners on either of Furnace #1 or Furnace #2 prior to August 2001.

At the beginning of the year 2001 the average electrical consumption of the two furnaces was 475 kWh/tonne and oxygen consumption was typically about 37 Nm^3/tonne. A typical scrap charge included 30 % pig iron. The power-on-time and tap-to-tap time values were approximately 50 minutes and 65 minutes respectively, for a standard heat.

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In Brazil, a drought resulted in a severe energy crisis. The power shortages put pressure on steelmakers to reduce their power consumption. This fact, along with the desire to increase the productivity of the furnaces at SBM, prompted them to invest in the ACI PyreJet system on both furnaces.

Prior to the installation of the PyreJet systems at SBM, significant efforts were made towards reducing the electrical energy required to make steel. Figure 1 shows that significant reduction of electrical energy was achieved on both furnaces prior to August when the PyreJet systems were installed on both furnaces. In June 2001, further power curtailments forced SBM to operate only one furnace at a time.

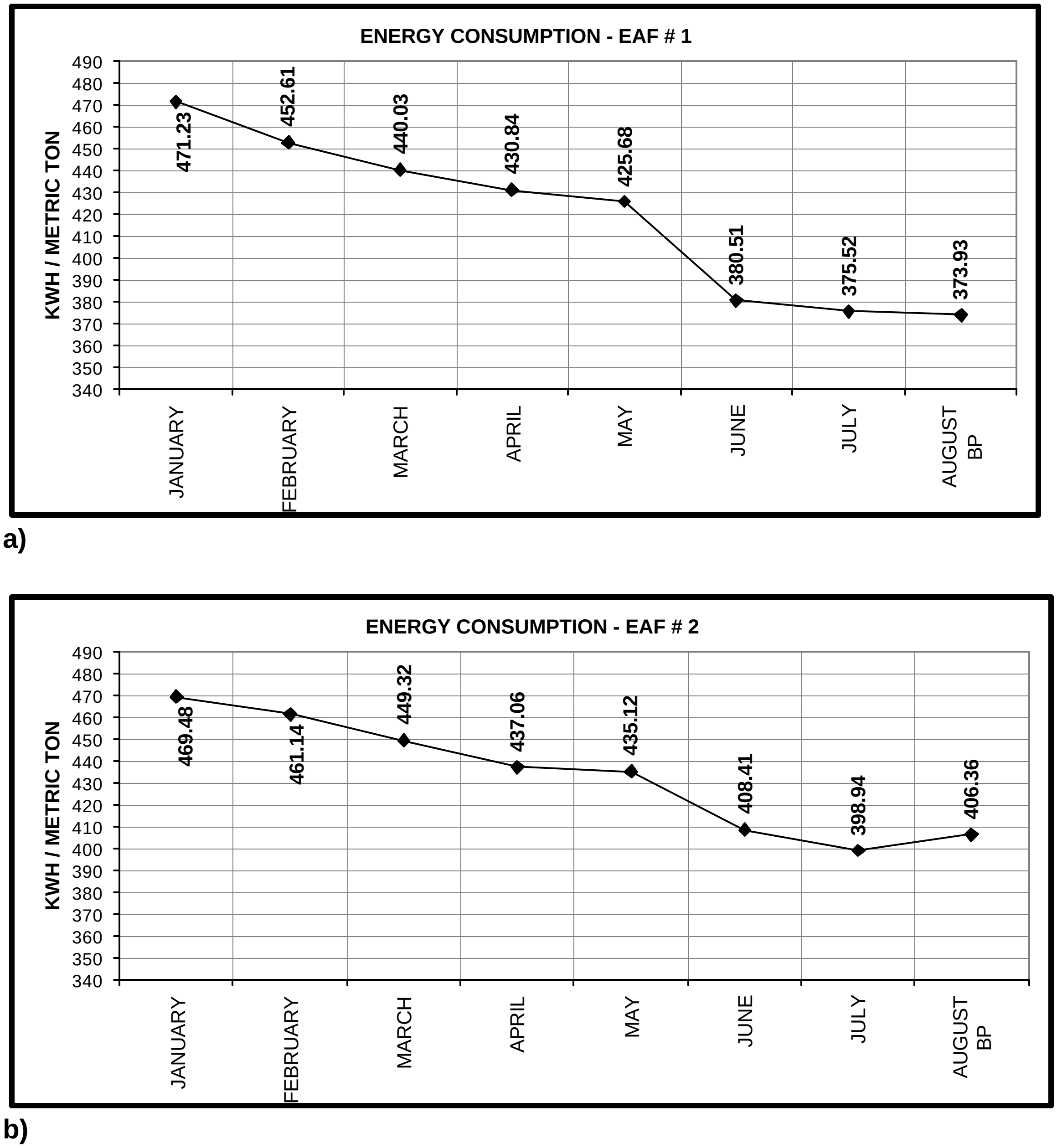


Figure 1. Electrical Energy Consumption of both Furnaces Prior to PyreJet Installation.

The reduction in electrical energy between January 2001 and June 2001 was achieved by increasing the oxygen intensity of both furnaces and improvements to the electrode regulation system. When SBM went a single furnace operation in June 2001, it became possible to significantly increase the oxygen intensity and therefore, the proportion of chemical energy of the operating furnace. As a result, electrical energy consumption reduced from 426 kWh/tonne to 380 kWh/tonne on Furnace #1 and from 435 kWh/tonne to 405 kWh/tonne on Furnace #2.

Three PyreJet burners were installed on Furnace #1 while Furnace #2 was equipped with two PyreJets and one Pyrox burner. SBM's expectations from the two PyreJet systems were an overall power consumption decrease of 50 kWh/tonne based on a typical energy consumption of 475 kWh/tonne from both furnaces at the beginning of the year 2001. However, since significant progress was made in reducing the electrical energy consumption of both furnaces prior to the installation of the PyreJet systems, it was realized that an additional reduction in electrical energy consumption of 50 kWh/tonne with PyreJets would be very difficult to achieve. Therefore, the energy saving expectations of the PyreJet systems were relaxed to between 20 and 25 kWh/tonne

2 ACI PYREJET SYSTEM

The new PyreJet systems (US Patent Nos. 4,622,007; 5,599,375; 5,788,921; 5,858,302) combine the following operating capabilities:

- Efficient oxy/fuel combustion for EAF operating conditions
- Enhanced supersonic oxygen injection
- Carbon fines injection
- Useful post-combustion of CO

The PyreJet burner/injector utilizes a deep water-cooled combustion chamber for the active staged mixing and burning of natural gas streams positioned between central and outer streams of oxygen. The central oxygen stream is discharged through a Laval nozzle with supersonic velocity in excess of 2.0 Mach. This enables the PyreJet to inject a flame enhanced, tightly focused oxygen jet. The oxygen jet is capable of maintaining a supersonic velocity as far as 6 feet away from the burner-discharging nozzle. This feature of the PyreJet burner provides the opportunity to introduce additional chemical energy to the EAF cold spots, which are very difficult to reach with other devices (water-cooled lances, consumable pipes) during the early stages of scrap melting and refining. The PyreJet burner evolved from the Pyrox burner that was developed by ACI as a very efficient oxy-fuel burner for the EAF. Figure **2** shows a picture of the PyreJet.

Figure 2. PyreJet Assembly

The inner part of the PyreJet containing supersonic nozzle is affixed to the combustor and can be quickly and easily disconnected and removed from the combustor. This allows for burners to be changed with minimum interruption of operation. Natural gas and peripheral oxygen are introduced as a plurality of streams surrounding a primary oxygen jet stream directed along the central axis of the combustion chamber.

The PyreJet Burner combustor is also equipped with a replaceable carbon injection pipe located near the burner centerline. This allows carbon to be entrained and driven into the slag by the peripheral flame and supersonic oxygen stream at 2.1 Mach exit velocity.

It is highly recommended to control both supersonic and peripheral oxygen separately even though a combined control is possible in principle. During the high fire mode, for proper flame shape and chemistry, it's important to have equal distribution of oxygen between the center and periphery streams. Later, when supersonic oxygen lancing is required, the oxygen distribution between the center and periphery changes considerably. The precise control of oxygen distribution is only possible when both flows are controlled individually. It is preferable that both Pyrox and PyreJet burners be installed in water-cooled copper panels.

In the beginning of each charge the Pyrox and PyreJet burners operate as regular oxy-fuel burners heating the scrap located in the cold spots. After the scrap is preheated and partially melted in, the fuel and oxygen flows are reduced and the central oxygen flow is increased to initiate soft lancing in order to cut scrap in the more remote areas and get access to the melt. At this point it is important to begin penetrating the melt in order to begin making the slag. The early formation of a slag will stabilize the arc earlier and improve the efficiency of electrical energy transfer to the steel. In addition, it is very critical that the burner reliably and consistently cleans the adjacent area of scrap so that supersonic lancing can begin early without any danger of flame and oxygen rebound from the remaining scrap. The self-protecting design of the burners allows for a reliable, low maintenance operation in the event that some rebound of the flame occurs.

When a passage to the bath is clear the Pyrox burners initiate holding fire while PyreJet burners begin to inject carbon for slag foaming and oxygen for melt refining. The central supersonic flow is increased to achieve 2.0-2.1 Mach exit velocity while a shrouding flame is maintained by the reduced flows of fuel and peripheral oxygen to protect the integrity of the supersonic steam of oxygen. A long, contained supersonic oxygen jet then impacts the melt to begin the refining process. In the impact area the melt temperature is raised from the exothermic oxidizing reaction and by the bath agitation and homogenization. Carbon injection by the PyreJet burners begins to deoxidize the slag and to maintain a thick foamy slag layer. The amount of oxygen and carbon introduced by the PyreJet burners are established based on scrap mix and aimed melt carbon. Carbon injection may be initiated simultaneously with oxygen lancing to balance the slag temperature and chemistry in the jet impact area, enhancing foamy slag formation. If the scrap mix contains a substantial amount of excess carbon, the carbon fines injection can be delayed to allow the oxygen jet to perform an initial rapid reduction of the melt carbon.

A thick layer of foamy slag generated by the use of PyreJet burners not only improves electrical efficiency and metallic yield but protects refractory from erosion. The thick slag layer helps to capture some amount of oxygen that rebounds from the metal interface as well as droplets of metal that are inevitably generated during lancing. The endothermic reaction of injected carbon with slag oxides reduces the temperature and slows the chemical attack of the refractories by the slag by reducing the amount of corrosive FeO in the slag.

The carbon/oxygen co-injection continues until the required chemistry of the melt is achieved. The final melt carbon content as low as 0.03% can be accomplished by using PyreJet technology. The PyreJet system control program is fully automated to ensure the consistency of the EAF operation.

3 IMPLEMENTATION OF PYREJET SYSTEMS

The general arrangement of the PyreJet system on SBM EAF #1 is shown in Figure 3.

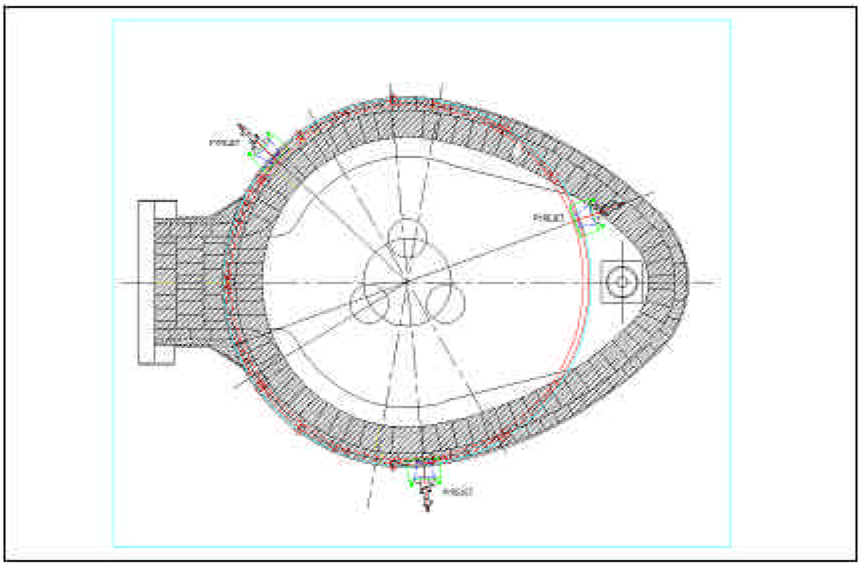


Figure 3 : PyreJet locations on EAF #1

Every electric arc furnace operation is defined by the raw materials available to a given plant site as well as the type of product being produced. As a result, each furnace provides unique challenges that must be overcome in order to gain the maximum achievable benefits of the PyreJet system. The furnaces at SBM provided their own challenges that had to be overcome to provide maximum benefits to the operation. These challenges and their solutions are provided below.

3.1 Start-up Challenges.

As described above, SBM had made significant progress in reducing electrical energy consumption from 475 kWh/tonne to 380 kWh/tonne prior to installing the PyreJet systems. Since approximately 30 percent of SBM's scrap charge is pig iron, which contains approximately 4.5 percent carbon, the charge contains plenty of carbon to be oxidized from the melt to produce chemical energy. However, despite this extra energy from the oxidation of a high carbon charge, there are other aspects of melting pig iron that makes operating an EAF difficult:

- Pig iron has a tendency to form large clumps in the furnace. These clumps are difficult to melt and can cause violent boiling when suddenly dissolved.
- During their single furnace operation, SBM blows oxygen into the furnace using two lance-pipes that each deliver 1600 Nm^3/h of oxygen to the furnace. The pipes are inserted into the slag door and deliver oxygen to the charge continuously during the entire heat. This aggressive use of oxygen provides energy in the form of post-combustion while the charge is solid and it permits early formation of the slag and decarburization of the bath after each charge is melted down.
- The large energy input to the furnace (from the lance pipes) is difficult to duplicate with the PyreJets because early in the heat, there is cold scrap in front of the

burners, which will deflect oxygen back at the walls of the furnace. This can cause damage to the furnace walls and brick. Therefore, aggressive introduction of oxygen to the furnace using PyreJets is delayed (compared to the operation with consumable pipe) until the scrap is melted down.

3.2 Start-up Solutions and Results.

The challenges listed above were overcome using the techniques described below:

3.2.1 Pig Iron

To effectively deal with the high proportion of pig iron in the charge using the PyreJet burners, it was important to get oxygen to the bath as quickly as possible. This required utilizing the full power (4.0 MW) of the PyreJet burner during the first 4 to 5 minutes of each charge to melt a path to the liquid pool in the bottom of the furnace. This serves two purposes: 1) remove scrap from in front of the burners so that no oxygen can rebound back to the furnace walls and 2) quickly provide a route for delivering oxygen to the liquid steel. After 3 to 4 minutes of using the burner at 4 MW, the oxygen flow through the supersonic nozzle was increased to deliver oxygen to the bath, to cut any remaining scrap and to provide mixing and decarburization.

3.2.2 Chemical Energy Input

SBM's use of two consumable lance pipes is effective for delivering chemical energy to the heat. To successfully be able to duplicate and improve on their performance with the lance pipe, it was necessary to deliver as much heat to the furnace using the PyreJet burners as is achieved with the 2 slag door lance pipes. Therefore, it was required that 4.0 MW of PyreJet power be used during the first 4 to 5 minutes to melt a path to the liquid pool of steel so that large volumes of oxygen could be introduced. Prior to the installation of the PyreJet burners, the slag door lance pipes could deliver 3200 Nm^3/h (2029 scfm) to the furnace. After 4 to 5 minutes at 4 MW power, the natural gas flow was reduced and oxygen to gas ratio was increased to cut scrap and provide oxygen to the bath. At that time, it was possible to introduce large volumes of oxygen (3100 Nm^3/h on #2 Furnace and 4500 Nm^3/h on #1 Furnace at 13 bar O_2 pressure) to duplicate the chemical energy input generated by the two consumable slag door pipes.

This strategy was successful as it enabled the operation to reduce its electrical power consumption by more than 20 kWh/tonne on #1 Furnace and by 35 kWh/tonne on # 2 Furnace using only PyreJet burners to deliver the oxygen. The consumable lance pipes were never used for decarburization and were only used occasionally to cut scrap at the slag door. Power-on-time was reduced by 4 minutes on #1 Furnace and 6 minutes on #2 Furnace. Data suggests that significant increases in yield also resulted from using the PyreJet burners with no slag door lances. Figure 4 illustrates how electrical energy consumption improved during the 10 days after start-up.

4 OPERATING RESULTS SINCE START-UP (August to November 2001)

Since the installation and start-up of the PyreJet systems at SBM, further refinements to the steelmaking practice there has taken place resulting in further improvements in EAF operation from that observed at the end of the start-up. These results are described below.

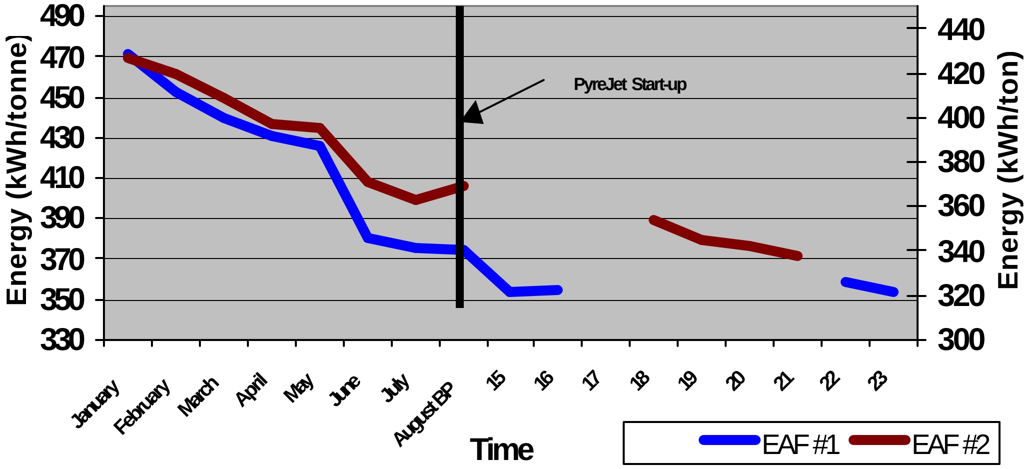


Figure 4. Evolution of Electrical Energy Consumption after PyreJet Start-up at SBM Brazil

4.1 Electrical Energy Consumption

As mentioned above, the energy crisis in Brazil has continued to prevent SBM from operating two EAFs simultaneously. As a result, SBM has made efforts to bring the productivity of Furnace #1 as high as possible to replace some of the production that was previously possible with two furnaces. Since August 2001, the majority of the steel made at SBM was produced in Furnace #1, which is the more modern and efficient of the two furnaces.

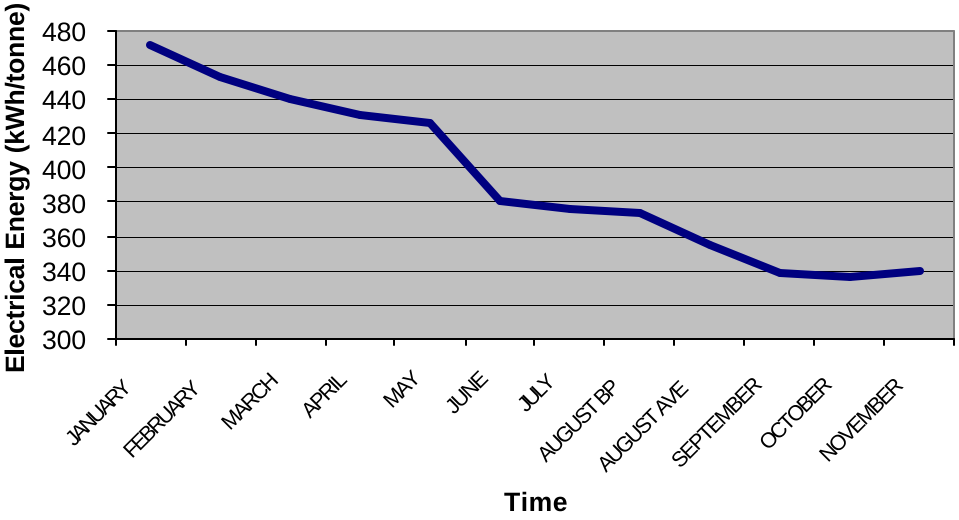


Figure 5. Evolution of Electrical Energy Consumption of Furnace #1 at SBM in 2001.

Figure 5 shows the evolution of electrical energy consumption at SBM's Furnace #1. The PyreJet systems were designed to completely replace the consumable lance and manipulator at the SBM furnaces. During the start-up and qualifying of the PyreJet systems in August 2001, the PyreJets completely replaced the consumable lance to perform all the required steel decarburization. Melt carbon concentrations below 0.04% were easily achieved.

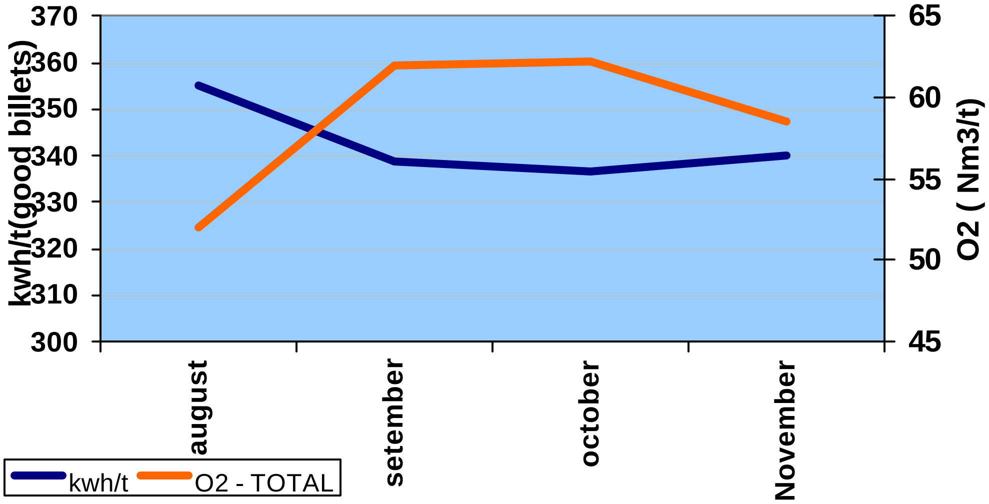


Figure 6. Relationship between Oxygen use and Electrical Energy Consumption (August 2001 – November 2001)

After August 2001, the electrical energy consumption continued to decline by increasing the oxygen intensity of the operation. Figure 6 demonstrates how electrical energy consumption could be replaced by chemical energy. Oxygen is converted into chemical energy as it refines the steel. As can be seen that in Figure 6 further improvements in electrical energy consumption were observed when the PyreJet system was supplemented by using a small amount of oxygen delivered by consumable lance pipe early in the heat to assist scrap melting. Typically, and additional 10 – 15 kWh/tonne of electrical savings could be realized when approximately 10 Nm^3/tonne of oxygen was delivered through consumable lance pipes. Since August, SBM has averaged less than 340 kWh/tonne using this technique. The extra chemical energy resulted in a reduction of power-on-time of approximately 6 minutes (from 50 minutes to 44 minutes).

4.2 Metallic Yield

One main method of determining whether or not an EAF is using an appropriate amount of oxygen is by tracking the metallic yield of the operation. Between January 2001 and July 2001, the average yield of steelmaking at SBM was 89.6 %. Between August 14, 2001 and August 31, 2001, the yield averaged 90.3%. Yield continued to stay approximately one percent higher than before PyreJet installation between September and November 2001. The metallic yield averaged 90.3% for the month of November.

The observed increase in metallic yield after start-up of the PyreJet probably results for two reasons:

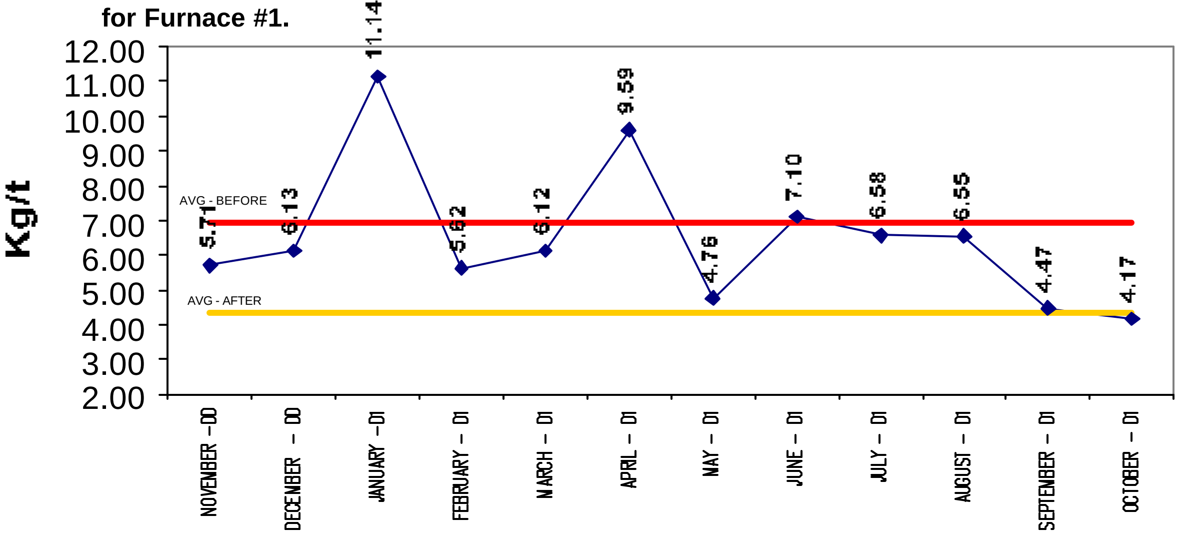
1. Oxygen used for decarburization is distributed around the circumference of the furnace. Therefore, it is less likely that particular regions of the furnace will be over-oxidized as is often the case when using a door lance. When using a traditional door lance, the region in front of the slag door tends to get over-oxidized because of concentration gradients throughout the melt necessitate that the carbon concentration be lower around the slag door than in the back of the furnace. This is necessary to achieve the desired overall tap carbon concentration. However, because carbon concentration is lower at the door than the back of the furnace, there will be more FeO in the slag in that region and this slag is likely to escape through the slag door.
2. The slag door remains closed for a much greater proportion of the heat when using the PyreJet system. This helps to keep the oxidized slag from escaping the furnace. Therefore, carbon injected uniformly around the circumference of the furnace using the PyreJet system can reduce the FeO in the slag before the slag can escape through the slag door. As a result, less iron units escape the furnace before tapping.

4.3 Refractory Consumption

Figure 7 illustrates the reduction in refractory consumption that was observed after the PyreJet system was installed on Furnace #1. During the nine months prior to the PyreJet installation, refractory consumption averaged 6.93 kg/tonne. During the two months after PyreJet installation, refractory consumption dropped to 4.32 kg/tonne.

This dramatic decrease in refractory consumption is related to the increase in yield described in section 4.2 above. FeO produced by the injection of oxygen into the furnace is very corrosive to refractories. The PyreJet system produces less FeO because decarburization is distributed more uniformly around the furnace. Carbon is injected through each PyreJet allowing a significant reduction in slag FeO. The resulting effect is lower refractory consumption.

Figure 7 : Refractory Consumption between November 2000 and November 2001 for Furnace #1.



4.4 Electrode Consumption

Figure 8 compares the electrode consumption prior to and after installation of the PyreJet systems at SBM. Prior to installation of PyreJet systems at SBM, electrode consumption averaged 2.32 kg/tonne. By November 2001, electrode consumption had decreased 18 percent to 1.9 kg/tonne.

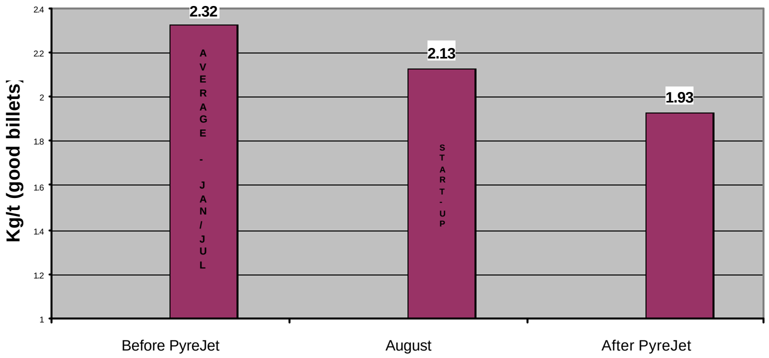


Figure 8 Comparison between Electrode Consumption at SBM Before and After PyreJet Installation.

The observed reduction in electrode consumption can be explained by considering the condition of the slag. Electrode consumption is lower in steelmaking operations where a good foamy slag practice is in place. It is important to maintain a good foamy slag in every region of the furnace to protect the electrodes from oxidation. EAF operations using conventional lances to inject oxygen and carbon through the slag door tend to make a good foamy slag only in the region surrounding the slag door. Slag quality in the back of the furnace tends to be lower because that area does not have access to carbon and oxygen injection.

While operating the EAF with PyreJet system, oxygen injection is distributed around the circumference of the furnace. Since oxygen injection into the melt is required in order to create a slag (through the oxidation of Si, Mn, Al, etc.), the PyreJet system produces a high quality slag in most areas in the furnace. This, coupled with an efficient foamy slag carbon injection system, produces a foamy slag in both the back and front of the furnace and protects the electrodes from excessive oxidation.

5 CONCLUSIONS

The PyreJet systems at SBM have dramatically improved the operation and productivity of the electric arc furnaces at that steel plant. Table 1 highlights the EAF operation improvements that occurred after SBM installed the PyreJet systems.

Parameter	**Before PyreJet**	**After PyreJet**
Electrical Energy (kWh/tonne)	**380**	**340**
Power-On-Time (min)	**50.0**	**44.0**
Metallic Yield (%)	**88.7**	**90.0**

Refractory Consumption (kg/tonne)	**6.93**	**4.32**
Electrode Consumption (kg/tonne)	**2.32**	**1.90**
Oxygen Consumption (Nm^{3}tonne)	**46**	**59**

Table 1. Operating Parameters at SBM Before and After PyreJet Installation.

The resulting improvements have allowed SBM to reduce electrical consumption, improve productivity on a single furnace operation. Lower refractory and electrode consumption resulting from PyreJet installation has also contributed significantly to improving costs of SBM's steelmaking operation.