



# ONE BUCKET CHARGING FAST ARC™ IN JACKSONVILLE<sup>1</sup>

Damiano Patrizio <sup>2</sup>  
Gianluca Cappellari <sup>3</sup>

## Abstract

This paper describes the main features of the AC Fastarc™ EAF supplied by Danieli to the Gerdau Ameristeel plant in Jacksonville (Florida - U.S.A.). The new state-of-the-art UHP Fastarc™ EAF has a rated capacity of 95 sht ( $\approx 86$  t) and is capable to handle a single bucket practice, with 100% scrap charging practice. Thanks to the extended utilization of chemical energy, by means of DANARC™ injection system with Modules technology, and proper sizing of EAF transformer (90 + 12% MVA) the furnace has achieved very fast scrap melting, with promising consumptions figures. The EAF has already achieved Pon time in the range of 35 min, with maximum productivity up to 115 t/h: this results has been achieved thanks to proper oxygen carbon and lime injection, which has allowed to keep good foaming slag condition during all process and lead to fast scarp melting and liquid steel heating up. Moreover the promising performance has been confirmed by the fumes analysis, which has demonstrated the high post-combustion degree inside the EAF. The homogeneous thermal condition of the liquid bath has been clearly proven by limited steel temperature drops between EAF and caster arrival, in spite of process line without ladle furnace upstream the caster. This paper shows the very interesting results in terms of thermal efficiency and consumptions, based on the data collected in the last months of EAF operation, and the innovative design applied in process, mechanical and electrical parts of the EAF.

**Keywords:** Fastarc™; Single bucket; DANARC.

## Resumo

Este artigo descreve as principais características do Fastarc AC™ EAF fornecido pela Danieli para a fábrica da Gerdau Ameristeel em Jacksonville (Flórida - E.U.A.). O novo estado-da-arte UHP Fastarc™ EAF possui uma capacidade nominal de 95 sht ( $\approx 86$  t) é possível um único carregamento, com 100% de carregamento de sucata. Graças a grande utilização de energia química, por meio do DANARC™ sistema de injeção com tecnologia de módulos, e dimensionamento adequado do transformador do FEA (90 + 12 % MVA), o forno tem alcançado o derretimento de sucata muito rápido, com promissores valores de consumos. O FEA já conseguiu tempo no intervalo de 35 min, com o máximo de produtividade de até 115 t / h: este resultado foi alcançado graças à adequada injeção de oxigênio, carbono e cal, o que permitiu manter uma boa condição de escória espumante durante todo o processo e levar ao derretimento rápido da escória e aquecimento do aço líquido.. Além disso, o desempenho promissor foi confirmado pela análise de gases, o que demonstra o alto grau da pós combustão no interior do FEA. A homogênea distribuição térmica do banho líquido foi claramente comprovada pela limitada queda da temperatura do aço entre o FEA e Lingotamento. Este trabalho mostra os resultados muito interessantes em termos de eficiência térmica e consumo, com base nos dados recolhidos nos últimos meses de operação do FEA, e o design inovador aplicados no processo, as partes mecânica e elétrica do FEA.

**Palavras-chave:** Fastarc™; Carregamento único; DANARC.

<sup>1</sup> Technical contribution to the 41<sup>th</sup> Steelmaking Seminar – International, May, 23<sup>rd</sup>-26<sup>th</sup> 2010, Resende, RJ, Brazil.

<sup>2</sup> Senior Engineer, Process Technology - Danieli Centro Met - Italy

<sup>3</sup> Senior Engineering, Proposal Steelmaking - Danieli Centro Met - Italy

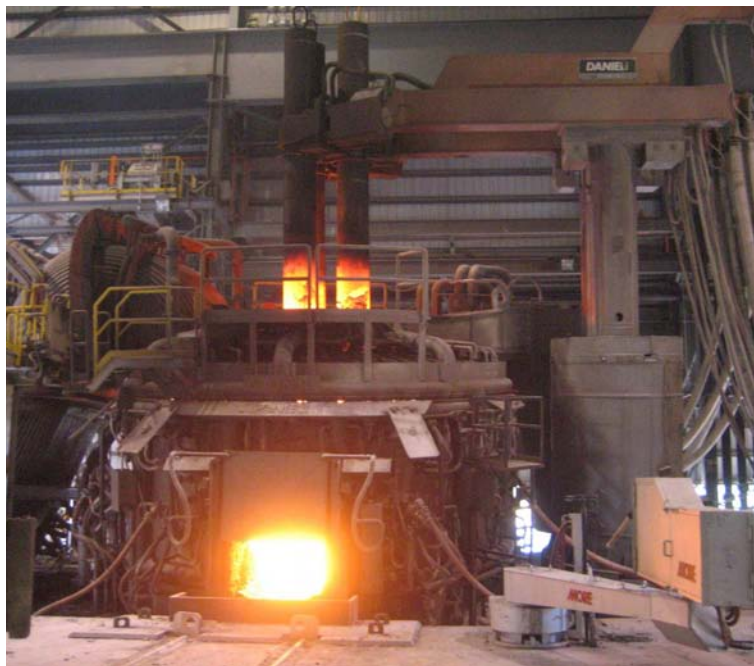


## 1 INTRODUCTION

In the beginning of electric arc furnace utilization the melting of scrap was performed by using only arc radiation as energy source. In the last decades instead, the importance of chemical energy has been becoming very high and now its correct utilization is a fundamental aspect in order to produce steel fast and with low costs. In matter of this, the plant of Jacksonville can be considered a representative example thanks to the excellent results achieved in terms of process time, electrical consumption and thermal efficiency of chemical energy. The correct utilization of oxygen, coal and lime injection has allowed increasing oxygen efficiency and exploiting post-combustion reaction of CO in the fumes as much as possible.

## 2 EAF FEATURES

The EAF works by keeping a hot heel of 20 t and is designed for a rated tapped size of 95 sht (86 t). The one bucket charging practice has been chosen in order to minimize the power off time. In order to achieve a productivity of about 116 t/h, the expected Tap to Tap time is 44.5 min. Jacksonville's EAF is shown in Figure 1, whereas the main geometrical data of the furnace are reported in Table 1.



**Figure 1** – Jacksonville electric arc furnace.

**Table 1** – Main geometrical data

Lower Shell Diameter [m]	6.5
Total Volume [m <sup>3</sup> ]	130
Pitch Circle [mm]	1250
Electrodes Diameter [mm]	610

The furnace feeds directly the continuous caster and all ferroalloys additions are made during the tapping phase. The steel is tapped at higher temperature (1700 °C) than usual, in order to guarantee the correct superheat value at caster arrival, without



the refining stage in the ladle furnace. Moreover the carbon content at tapping is higher than 0.15 %, which allows limiting the tapping additions thus reducing the relative costs.

## 2.1 Eletrical Part

The AC EAF is supplied by a HV line characterized by a frequency of 60 Hz and a rated voltage of 230 kV which is turned into 34.5 kV (MV line voltage) by the step down transformer. In the MV line an off-load series reactor is installed in order to increase the circuit reactance. The EAF transformer has a rated apparent power of 90 + 12% MVA and allows selecting 15 different tap positions to choose the best combination of arc tension, arc current and power factor during the various process stages. The furnace's secondary circuit is designed for a maximum current of 65 kA.

## 2.2 Specific Power

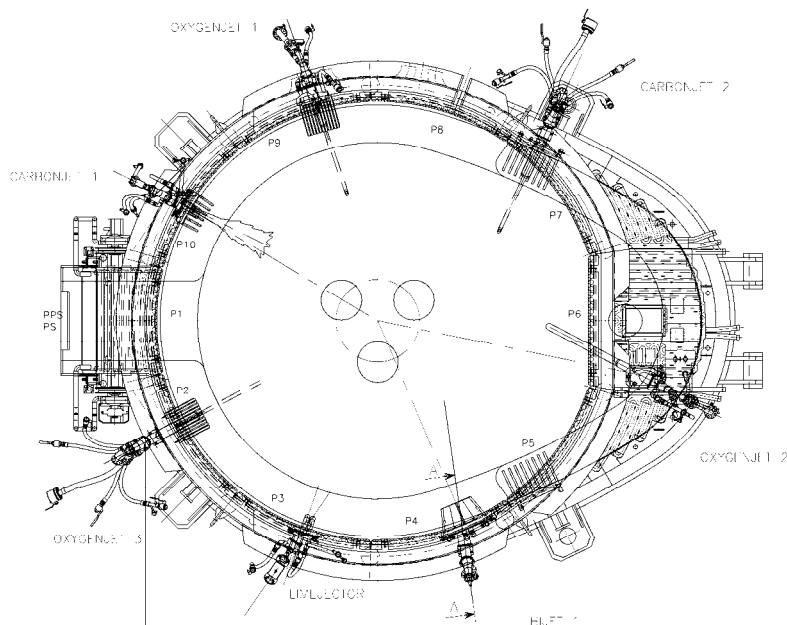
For Jacksonville's EAF, a very high specific power has been chosen: 77-78 MW as maximum power. Being the average tapped weight equal to 87.3 t, the obtained specific power is around 0.9 MW/t which is a very high value in comparison to other existing EAFs. Current's values next to the maximum limit of 65 kA are handled without risks for the electrical plant; moreover the good foaming slag layer allows transferring this energy to the bath and protects wall and roof panels.

## 2.3 Fast Arc™ Injection Technology

On Jacksonville's EAF, the "Modules System" has been conceived with four types of injectors, each one with its own specific function, in order to achieve the best possible performance.

In case of Lime and Carbonjets a pilot flame is maintained during the injection period in order to protect the material flow and supply oxygen for post-combustion by setting oxygen to natural gas ratio greater than stoichiometric.

Oxygenjets 1 and 3 and the Hijet are installed in copper bulged panels, which allow getting modules close to the bath by protecting them from scrap collapse and ensuring easier bath penetration of oxygen. Figure 2 shows the layout of the modules in the EAF.



**Figure 2 – Injectors layout.**

Carbon and Limejets are distributed around all the surface of the bath to produce a homogeneous foaming slag layer above the steel level, injecting respectively coal and lime.

Oxygenjets also are uniformly distributed in order to insure homogeneous oxygen supply and bath decarburisation.

The flow rates and the power at which the injectors are used are reported in Table 2.

**Table 2 – injectors characteristics**

Module	Oxygen flow rate [Nm <sup>3</sup> /h]	Material flow rate [kg/min]	Max Burner Power [MW]
Oxygenjet 1	2250	-	3.5
Oxygenjet 2-3	1930	-	3.5
Hijet	1930	15 – 30	3.5
Carbonjet 1-2	-	15 – 30	3.5
Limejet	-	110	3.5

### 3 CHARGING MATERIAL

The main products of the Jacksonville plant are billets for rebar and wire rod. The charge mix for the two cases is reported in *Table 3.*

**Table 3 – charge composition**

<b>Rebar Heats</b>
Mix HM1 & 2
Shredded
Turning + Skulls
Cast Iron

<b>Wire Heats</b>
P & S
Shredded
Busheling
Pig Iron

The scrap density is 750 – 850 kg/m<sup>3</sup> due to the large use of shredded (produced inside the plant itself), cast iron and pig iron. This dense scrap allows charging all





material with only one bucket reducing power off time and improving consumption and process conditions.

## 4 OPERATIONAL RESULTS

### 4.1 Consumptions

The consumptions' evaluation takes into account 200 consecutive heats. Among these, 7 sequences of at least 17 consecutive heats (the total number is 156) have been selected and their average production, process times and consumptions were calculated.

The average charged scrap weight is 94 t, whereas the tapped steel is equal to 87.3 t. The achieved yield is 93 % thanks to good scrap quality and foremost right process control, which allows reducing iron losses in the slag in terms of both iron oxide and embedded metal iron, reported in slag analysis.

**Table 4 – Achieved results (related to tons of liquid steel)**

	<b>Overall</b>		<b>Best</b>		<b>Data at 1630 °C</b> <small>(calculated from overall results)</small>	
<b>Process Times</b>						
Tap to Tap	56	min	54	min	52.5	min
Power on	35	min	34.5	min	31.5	min
Net Tap to Tap	45-46	min	43-44	min	42-43	min
Average Power	61	MW	61	MW	61	MW
<b>Tapping Conditions</b>						
Carbon Content	0.17	%	0.15	%	0.15	%
Temperature	1705	°C	1703	°C	1630	°C
<b>Arrival at Caster</b>						
Temperature	1630	°C	1627	°C		°C
Temperature Fall	75	°C	76	°C		°C
<b>Consumptions</b>						
Electric Energy	405	kWh/t	390	kWh/t	373	kWh/t
Oxygen	37	Nm <sup>3</sup> /t	36	Nm <sup>3</sup> /t	33	Nm <sup>3</sup> /t
Natural Gas	5.5	Nm <sup>3</sup> /t	5.5	Nm <sup>3</sup> /t	5.4	Nm <sup>3</sup> /t
Injected Coal	14	kg/t	13	kg/t	12	kg/t
Charged Lime	28.5	kg/t	25	kg/t	28.5	kg/t
Injected Dolomite	12	kg/t	13	kg/t	12	kg/t

#### 4.1.1 The overall results are reported in Table 4

The plant has actually a bottle neck at the existing caster with a long waiting due to caster's low speed. The consequence is an extension of the EAF Tap to Tap time. A net Tap to Tap time has been calculated which takes in consideration only the part due to EAF needs by neglecting the delay due to the caster which can be assessed to be around 10 – 11 min. In this way the net furnace productivity becomes 114 – 116 t/h which completely matches the requirements.

The achieved electric energy consumption is quite low, foremost by taking in consideration the tapping temperature of 1705 °C, a round 80 °C greater than usual values of 1620 – 1630 °C (no LF available), and the caster's delays. Any doubt regarding the reliability of the recorded tapping temperature can be eliminated by analyzing the temperature fall at caster arrival. This value (75 °C) is certainly realistic and by taking in consideration that all ferroalloys are charged during tapping, it's



possible to state that it's very low too. This result therefore confirms that the bath is uniformly heated up during the refining stage and that the measured temperature is representative for the whole tapped steel.

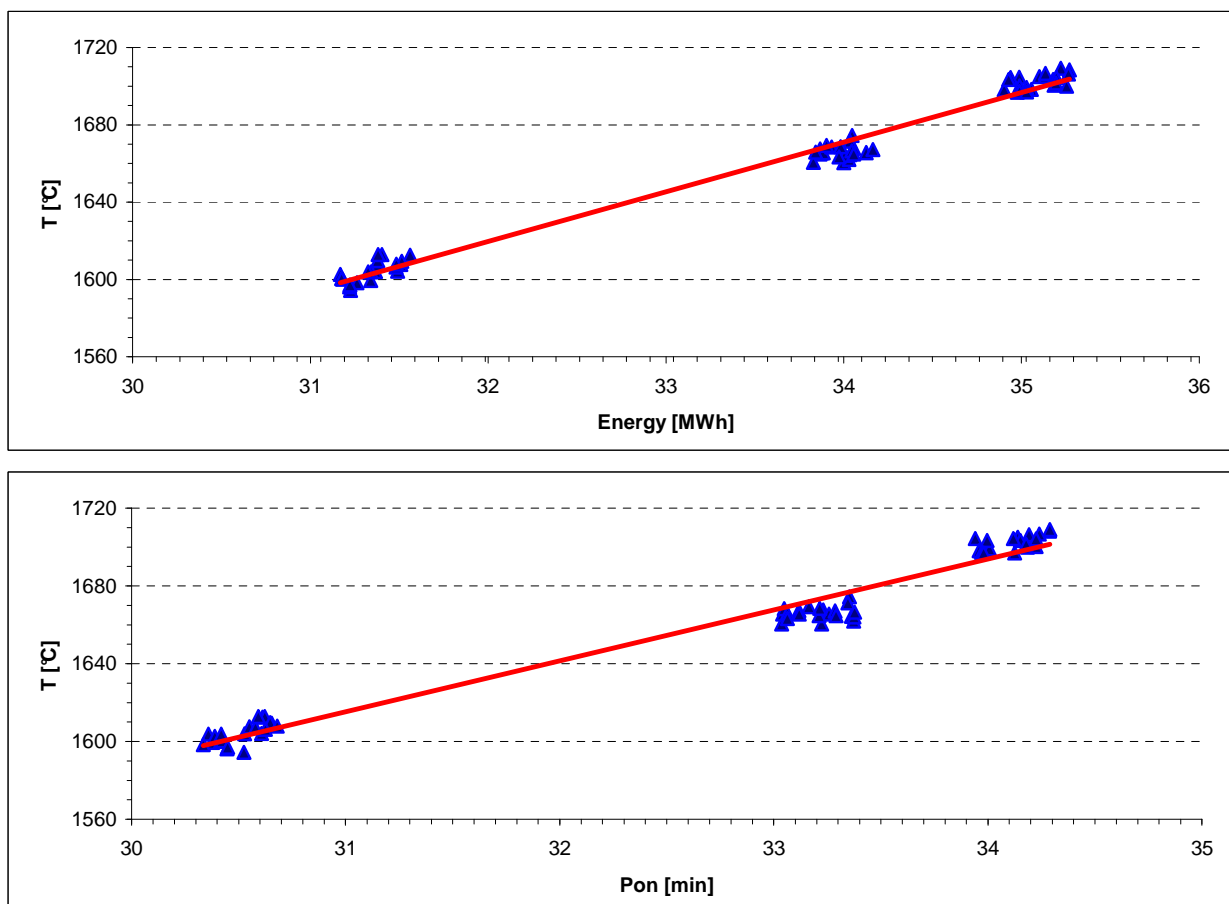
Table 4 shows also the best results achieved referred to a sequence of 10 consecutive heats. It's worth pointing out that the achieved energy consumption is really excellent and could be considered a benchmark level for standard EAFs which tap steel at lower temperatures.

In the last column of the potential results if the process would have been stopped at the temperature of 1630 °C are reported.

A decrease of 2.9 minutes in power on time is achieved considering a superheating speed of 26 °C/MWh (see following paragraph), consequently electrical energy is reduced to 373 kWh/tls and the oxygen consumption lowers to 33 Nm<sup>3</sup>/tls.

## 4.2 Heating Rate

Measures of temperature rise during the refining stage have been collected in order to estimate the efficiency of the energy transfer from the arc to the steel in flat bath conditions which is strictly related to the foaming slag efficiency. The Figure shows the dependence of temperature on time and energy consumption.



**Figure 4** – Temperature increase in function of energy consumption and time.

The slope of the two curves is respectively 26 °C/MWh and 26 °C/min. The value which is usually considered as specific heat of the steel during refining is 0.55 kWh/t °C. Starting from this value it is possible to estimate which should be the



heating rate with the assumed arc thermal efficiency. By knowing that the average tapped steel weight is 87 t and considering a hot heel of 20 tons, the result is:

$$\left(0.55 \frac{kWh}{t \cdot ^\circ C} \cdot 107t\right)^{-1} \cdot 1000 \frac{kWh}{MWh} = 17 \frac{^\circ C}{MWh}$$

The ratio between the value obtained from the measures and this one is 1.53 (= 26 / 17), which means that the arc thermal yield in Jacksonville EAF is 53% greater than the usually supposed value. This result can be explained with excellent arc coverage due to a slag which foams easily and allows heat transfer from the arc to the bath thanks to the correct choice of oxygen, coal and lime flow rates.

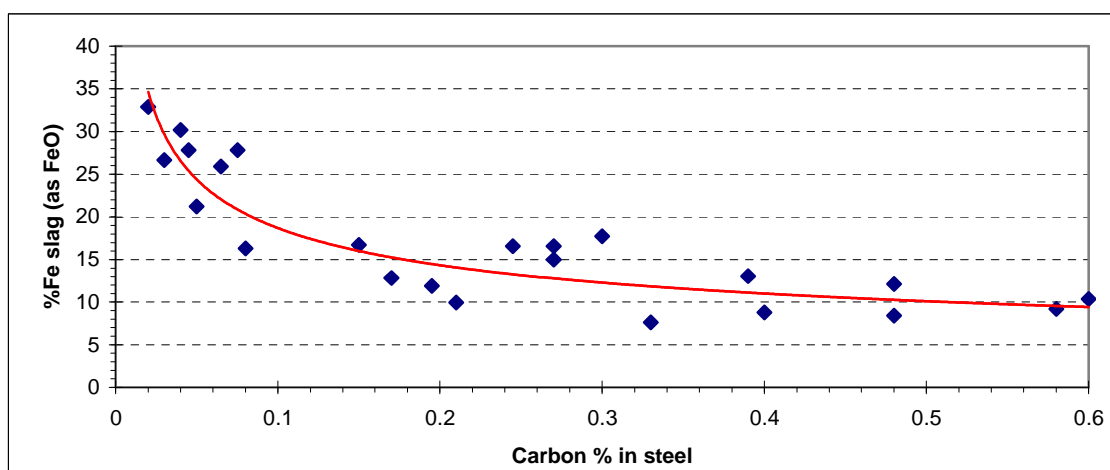
### 4.3 Slag Samples

Slag samples were taken at the end of the heat and therefore the measured composition is related to the slag which was in the furnace just before tapping. The average slag composition is reported in the following Table 5.

**Table 5 – Average slag composition**

CaO	MgO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	MnO	Fe <sub>2</sub> O <sub>3</sub>	Others
30.0 %	11.8 %	17.8 %	7.7 %	6.4 %	22.5 %	3.8 %

The slag oxidation degree results very low because of a carbon content in the steel equal to 0.15% and the iron losses in the slag are limited to 15.8 % (*Figure 5* shows the variation of these value in dependence of steel carbon content based on empirical measures in various plants). This value certainly allows reaching high yields (93 % as reported in Par. 0) but at the same time proves the goodness of achieved electric consumption. In fact if it were possible to oxidize more iron increasing its percentage in the slag up to 22-23 %, the yield would slightly fall (92 %) whereas around 10 kWh/t of electric energy would be saved.



**Figure 5 – Percentage of Fe in slag (as FeO) in function of carbon content in the steel.**

The basicity indexes are the following:

$$IB_2 = CaO/SiO_2 = 1.7$$

$$IB_3 = CaO/[SiO_2+Al_2O_3] = 1.2$$



Slag's viscosity is likely not to be very high because of high fluxing agents' content ( $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $[\text{FeO}]_n$ ) and high tapping temperature. MgO, whose percentage is quite large, acts surely as viscofying agent even if greater contents would be needed in order to reach the proper viscosity value (at these conditions the saturation percentage of MgO is around 14-15%, Figure 6).

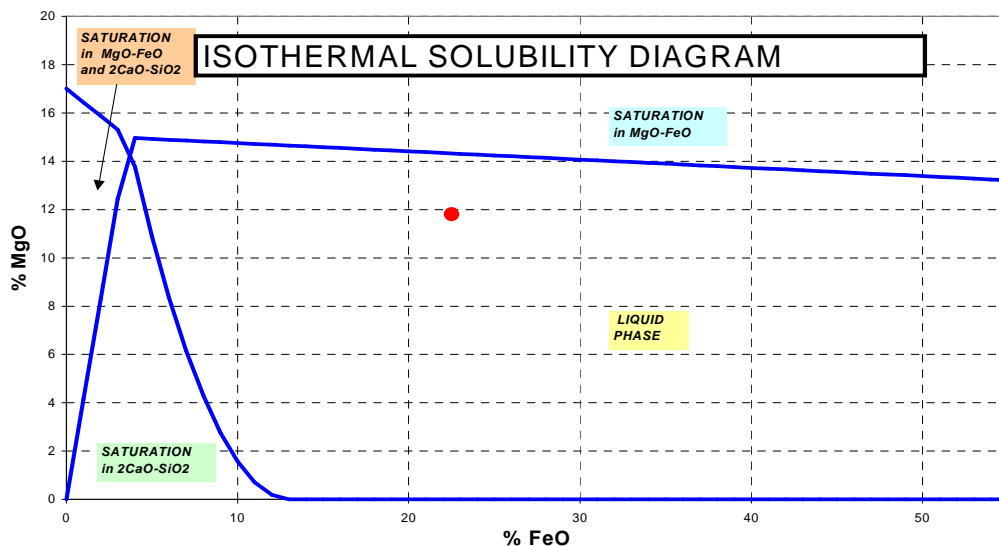


Figure 6 – Isothermal solubility diagram.

The slag's great efficiency in energy transfer from the arc to the bath must be a consequence of the proper regulation of carbon, oxygen and lime injection. A possible explanation is that the homogeneous injectors' distribution around the bath leads to uniform formation of CO bubbles which perform a good foaming of the whole slag layer. Moreover Hijet allows greater coal's penetration into the slag layer leading to CO bubbles generation in depth in the slag: these ones together with bubbles derived from bath decarburisation spend more time inside the slag and therefore the foaming effect is likely to be more efficient.

#### 4.4 Fumes

Fumes analysis has shown very interesting results too foremost regarding the post-combustion ratio. *Figure 7* shows where outgoing fumes are sampled to be analyzed.



Figure 7 – location of the off gas probe.





Figure 8 shows the data of a representative heat. The 0 value of the time scale refers to the start of measure and it's not related to the process time. Electric energy, oxygen and gas profiles are reported as reference for fumes' composition. The CO<sub>2</sub> is constantly greater than CO content during all process with post-combustion ratio values of 60 – 70 % during burner phase and 80 – 90% during lance phase. This result means that high degrees of post-combustion are achieved inside the furnace, much greater than expected ones.

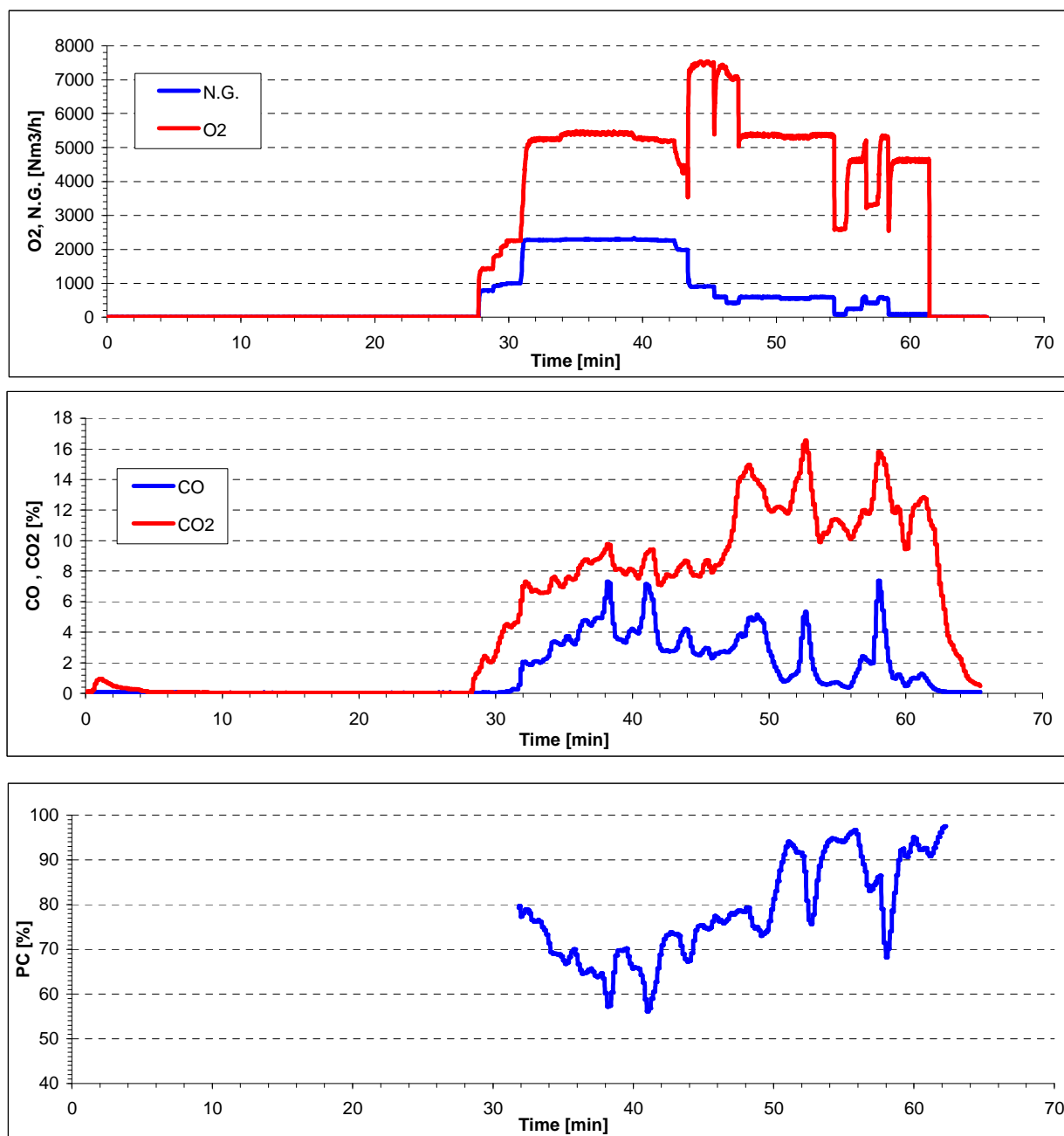


Figure 8 – Trend of post combustion ratio in function of time.

This very good result is likely due to two main reasons:

- because of single bucket utilization, the scrap level in the first half of the heat is very high and even if post-combustion reaction happens near the EAF top, the released energy can be exchanged with the scrap.



- during the second half of the heat, the good foaming slag layer which is in contact with the steel increases the residence time of CO bubbles allowing the post-combustion reaction to happen inside the slag. In this way the released energy is transferred to the bath.

The oxygen which is necessary for post-combustion derives from:

- excess oxygen during burner phase thanks to O<sub>2</sub> to N.G. ratio greater than stoichiometric. The used excess flow rate is around 700 – 750 Nm<sup>3</sup>/h;
- shrouding utilization for Carbon and Limejets and foremost from oxygen injected from Hijet annular nozzle during lance phase.

A further confirmation of the high amount of CO<sub>2</sub> in the fumes is the temperature measured after the settling chamber. In this point the expected value is around 800 °C whereas the measured one is close to 450 °C. The difference is likely due to the lack of CO in the fumes which would react with oxygen, which comes in with air entering from the gap between EAF elbow and FTP primary duct, giving CO<sub>2</sub> production and releasing energy.

## 5 PROCESS SIMULATION

Based on the collected data concerning: consumption, slag analysis, off gas analysis and thermal losses in the water-cooled panels of the EAF, the energy balance of the process was analyzed.

In Figure 9, the sum of the energy inputs and of the energy outputs is reported.

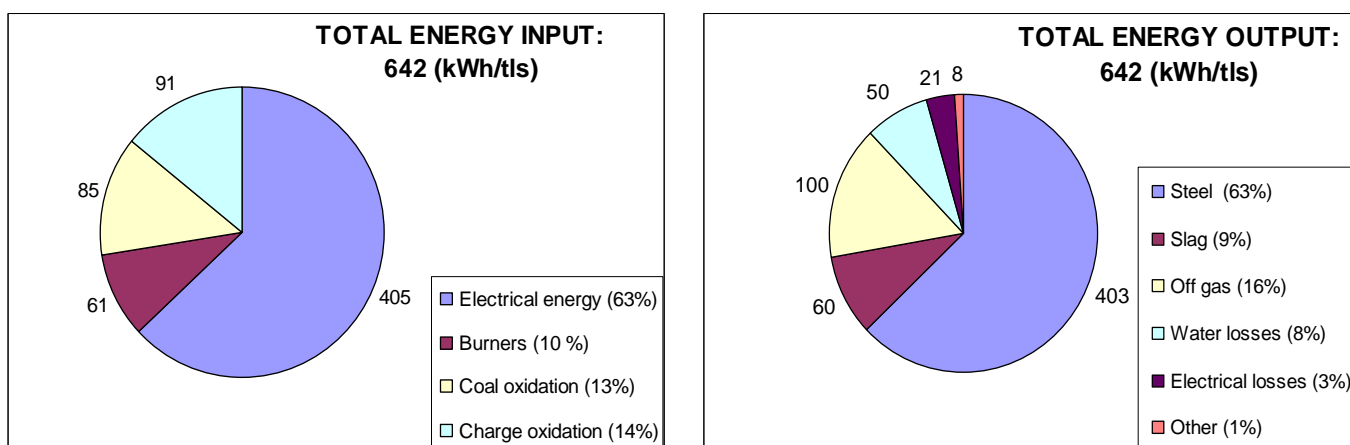


Figure 9 – Energy balance.

The total **energy input** is given by:

- electrical energy, 405 kWh/tls,
- burner energy, 61 kWh/tls according to a natural gas consumption of 5.5 Nm<sup>3</sup>/tls,
- charge oxidation, 91 kWh/tls due to the oxidation of the elements present in the charge: C, Si, Mn and Fe in the amount allowed from the slag analysis,
- coal oxidation, 85 kWh/tls: in this term we considered the combustion of coal injected to CO, plus the partial post-combustion of CO, taking into consideration an average PCR inside the EAF equal to 72%.

The total **energy output** is given by:

- steel enthalpy, calculated according to the average tap temperature of 1705°C,
- slag enthalpy, calculated according to the slag amount considered in the process, 103 kg/tls. This figure is confirmed from the slag builders addition, 40.5 kg/tls, and the slag composition, above reported,



- water losses were calculated from the average delta T measurements in the water-cooled panels of the roof and of the shell. The difference of temperature (output –input) from the start to the end of the process is varying from 1.5 to 7.2 °C, that in terms of thermal losses corresponds to 2 MW at the beginning of the process and 12 MW at the end of the process, see Figure 10.



**Figure 10** – trends of outlet and inlet temperatures in water cooled panels in the Jacksonville EAF.

- electrical losses: these are the losses due to Joule effect with an average secondary current of 55 kA,
- dispersion from refractory, hot heel and remaining slag,
- off-gas losses. These losses are intended as sensible heat in the off gas. The data measured from the EAF off-gas is only the analysis, more specifically CO, CO<sub>2</sub>, H<sub>2</sub>O, O<sub>2</sub>. No measure of temperature or flow-rate was taken in correspondence of the sampling probe location. Anyhow the percentage of CO and CO<sub>2</sub> measured allowed determining the degree of post-combustion occurred inside the EAF, and consequently the overall energy developed from the carbon combustion.

From this analysis we can state that the global energy yield, expressed as the ratio between the liquid steel enthalpy and the sum of the energy inputs of the process is equal to 63%.

This value is higher than what experienced in other processes, that usually have the same overall consumption, but tapping at lower temperatures (1630 °C), and with tap carbon of approx. 0.06-0.08 %.

From the thermal and mass balance it results that among the overall oxygen consumption, 37 Nm<sup>3</sup>/tls, 8.2 Nm<sup>3</sup>/tls of oxygen are engaged in the combustion of CO inside the furnace.

More specifically this means that 1 Nm<sup>3</sup>/tls derives from the excess of oxygen during the burner phase, while the remaining 7.2 Nm<sup>3</sup>/tls of oxygen are supplied during the lance phase.

In other words 35 % of the oxygen supplied during the lance phase is engaged in post-combustion of CO.

The energetic benefit of this post-combustion oxygen is calculated to be 4.7 kWh/Nm<sup>3</sup>, which corresponds to a net input of 38.5 kWh/tls.



These results were achieved without having any detrimental effect on the process yield, which is maintained at high levels, 93 %. From the slag analysis and the slag amount we can consider that the iron lost in the slag is limited to 16 kg/tls.

## 6 FUTURE DEVELOPMENTS

Some developments are foreseen for the furnace in the near future. First of all a second Limejet is going to be installed taking the place of Carbonjet 2 in order to perform all slagbuilders addition by injection limiting powder release and improving slag control.

Afterwards the installation of a LF and the caster revamping are likely to be done in the following years and consequently tapping temperature will be able to be decreased up to 1620 – 1630 °C improving EAF times (eliminating delays) and reducing consumption. By assuming the heating rate values reported in Par.0 (26 °C/min) the time saving is around 3 min whereas by using the same power during refining (60 MW) energy saving is around 30 kWh/t which means 375 kWh/t as overall consumption. The delays' elimination would lead to a further reduction of energy consumption of around 17 – 19 kWh/t, being possible to assess that the furnace loses 1.73 kWh/t per minute of delay. Table 6 shows the expected improvements due to the future developments (productivity is calculated by assuming 10 min as average power off time and 87 t as tapped size).

**Table 6 – Future improvements**

Power on	min	32
Productivity	t/h	125
Electric Energy	kWh/t	355

## 7 CONCLUSIONS

Jacksonville's EAF process has demonstrated good thermal efficiency. This has been achieved exploiting the excellent quality of the material charged, its high degree of metallization, and the one bucket process.

These two preconditions allowed to combine in the best way the speed of the process, given by the electrical power applied, with the efficiency of the alternative energy applied that allowed to exploit in good extent the CO post-combustion. This result was obtained in the full respect of the tapping conditions requested by the absence of a ladle furnace, and without having detrimental effects on the process yield.

As described in the future improvements as soon as a ladle furnace is installed and the logistic delays are eliminated, a further increase in the EAF performance is expected.