

One bucket charging Fastarc™ in Jacksonville

D. Patrizio, M. Orsini

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 (≈ 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:

Electric arc furnace, melt shop, thermal efficiency, Fast Arc, single bucket

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.

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.

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.



FIG. 1 Jacksonville electric arc furnace.

Forno elettrico ad arco di Jacksonville.

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

TAB. 1
Main
geometrical
data.
Principali dati
geometrici.

Electrical 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 cir-

Damiano Patrizio
Senior Engineer, Process Technology - Danieli Centro Met - Italy

Massimo Orsini
Engineering, Process Technology - Danieli Centro Met - Italy

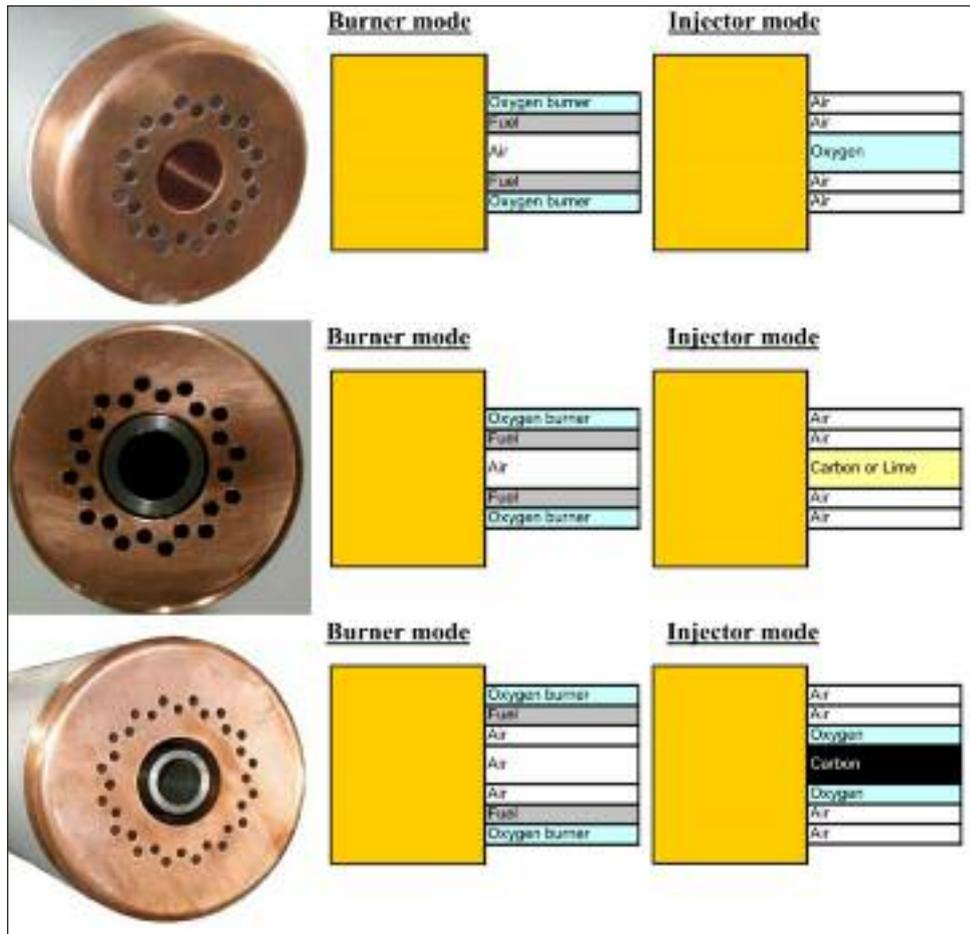


FIG. 2
Nozzle and operative modes for Oxygenjet (top), Carbonjet/Limejet (center) and Hijet (bottom).

Ugelli e modi operativi per: lancia ossigeno (in alto), lancia carbone (in centro) ed hijet (sotto).



FIG. 3
Bulged panels.
Cassoni in rame.

cuit 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.

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.

FastArc™ 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.

Figure 2 shows the installed injectors.

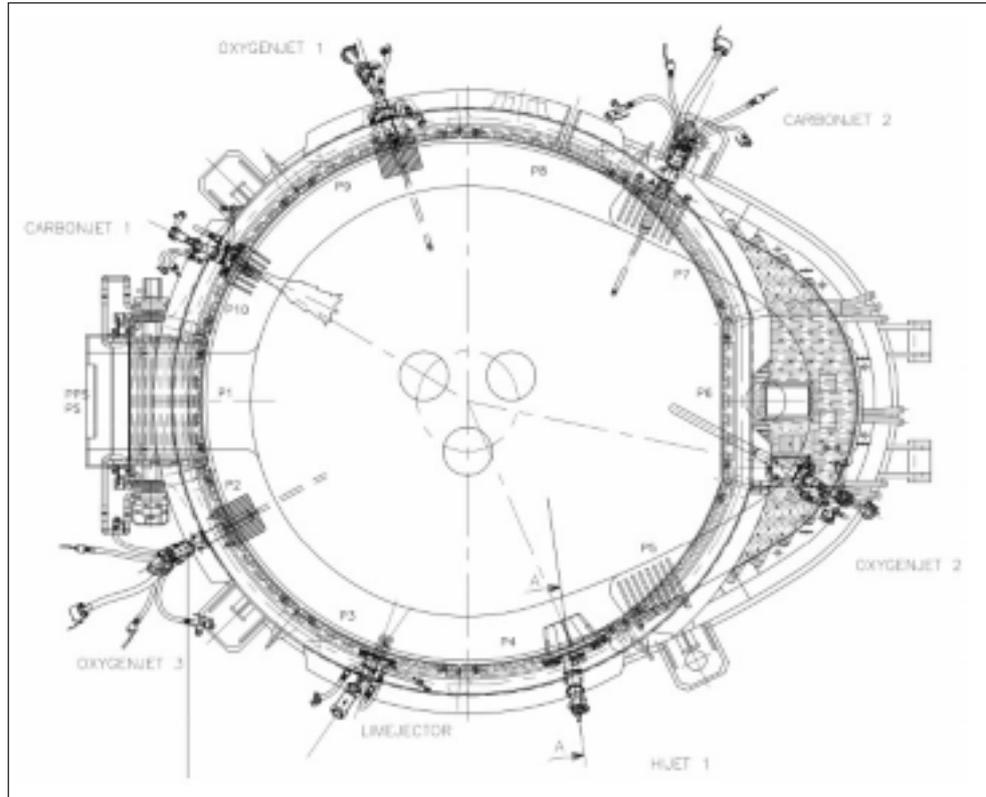
In case of Lime and Carbonjets a pilot flame is maintained during the injection period in order to protect the material flow and supply oxygen for post-combustion by setting oxygen to natural gas ratio greater than stoichiometric.

Oxygenjets 1 and 3 and the Hijet are installed in copper bulged

FIG. 4

Modules' Layout.

Disposizione dei moduli all'interno dell'EAF.



TAB. 2

Modules' features.

Caratteristiche dei moduli.

Module	Oxygen flowrate [Nm ³ /h]	Material flowrate [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

panels (Figure 3) which allow getting modules close to the bath by protecting them from scrap collapse and ensuring easier bath penetration of oxygen. Figure 4 shows the layout of the modules in the EAF.

Carbon and Limejets are distributed around all the surface of the bath to produce a homogeneous foaming slag layer above the steel level. Oxygenjets also are uniformly distributed in order to insure homogeneous oxygen supply and bath decarburisation. The flowrates and the power at which the modules are used are reported in Tabella 2.

PROCESS DESCRIPTION

Charging Material

The main products of the Jacksonville plant are billets for rebar

FIG. 5

Examples of scrap charged in Jacksonville EAF: shredded (on left) and cast iron (on right).

Esempi di rottame caricato nel forno di Jacksonville: shredded (a sinistra) e cast iron (a destra).



Rebar Heats	Wire Heats
Mix HM1 & 2	P & S
Shredded	Shredded
Turning + Skulls	Busheling
Cast Iron	Pig Iron

TAB. 3 Charge mix.

Composizione della carica.

and wire rod. The charge mix for the two cases is reported in Table 3. Figure 5 shows examples of scrap charged in the EAF. The scrap density is 750 - 850 kg/m³ 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.

Melting Procedure

Figure 6 shows the detailed melting profile used in Jacksonville EAF.

OPERATIONAL RESULTS

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.

The overall results are reported in Table 4.

The plant has actually a bottle neck at the existing caster and large EAF Tap to Tap time, the consequence is a long waiting due to caster's low speed. 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, around 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 elimina-

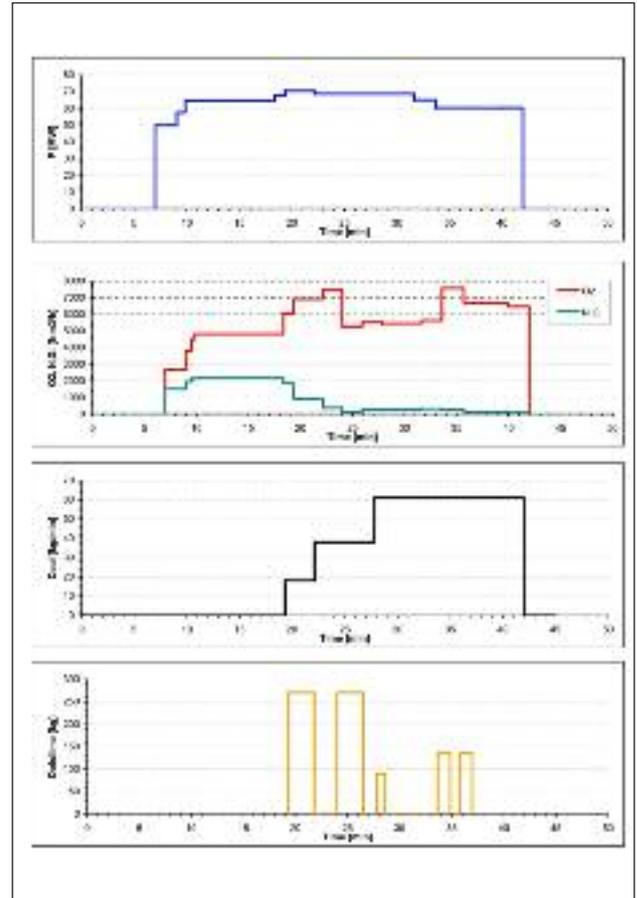


FIG. 6 Detailed melting profile.

Profili di fusione.

	Overall		Best		Data at 1630 °C (calculated from overall results)	
PROCESS TIMES						
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
TAPPING CONDITIONS						
Carbon Content	0.17	%	0.15	%	0.15	%
Temperature	1705	°C	1703	°C	1630	°C
ARRIVAL AT CASTER						
Temperature	1630	°C	1627	°C		°C
Temperature Fall	75	°C	76	°C		°C
CONSUMPTIONS						
Electric Energy	405	kWh/t	390	kWh/t	373	kWh/t
Oxygen	37	Nm ³ /t	36	Nm ³ /t	33	Nm ³ /t
Natural Gas	5.5	Nm ³ /t	5.5	Nm ³ /t	5.4	Nm ³ /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

TAB. 4 Achieved results (based on liquid steel weight).

Risultati ottenuti (rapportati alla massa di acciaio liquido).

ted 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 Nm³/tls.

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. Figure 7 shows the dependence of temperature on time and energy consumption.

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. 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:

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

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 flowrates.

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 Tabella 5.

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 8 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. 4.1) 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.

The basicity indexes are the following:

$$\begin{aligned} \text{IB}_2 &= \text{CaO}/\text{SiO}_2 = 1.7 \\ \text{IB}_3 &= \text{CaO}/[\text{SiO}_2 + \text{Al}_2\text{O}_3] = 1.2 \end{aligned}$$

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

TAB. 5
Average slag composition.
Composizione media della scoria.

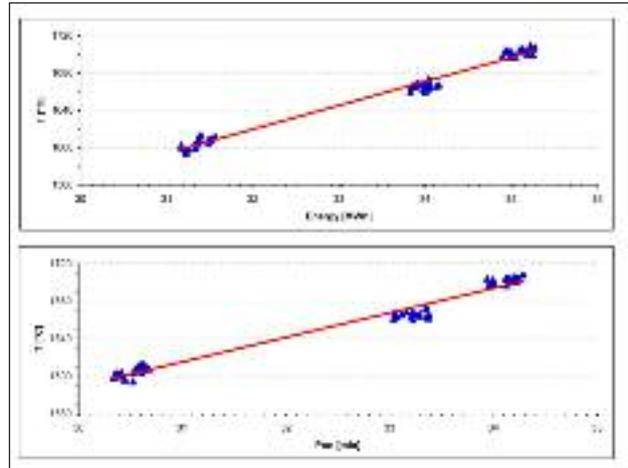


FIG. 7 **Temperature rise as function of energy consumption and time.**

Incrementi di temperatura in funzione del consumo di energia e del tempo.

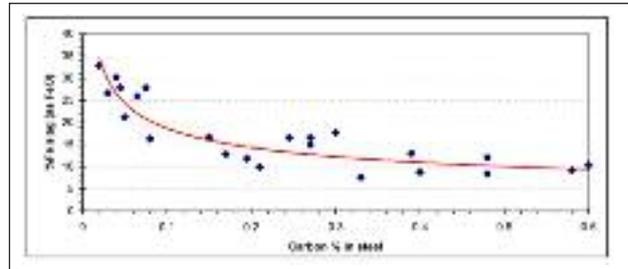


FIG. 8 **%Fe lost in slag (as FeO) in function of carbon content in steel.**

Percentuale di Fe in scoria (come FeO) in funzione del contenuto di carbonio nell'acciaio.

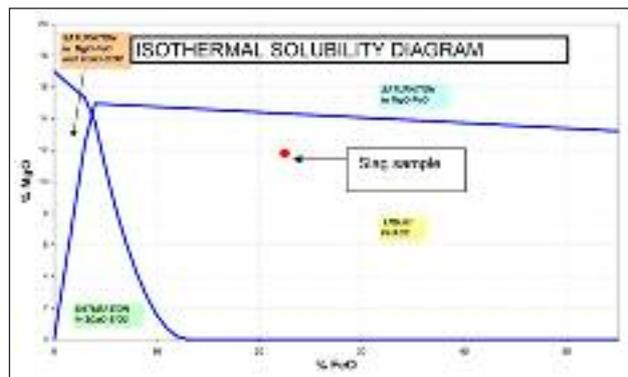


FIG. 9 **Isothermal solubility diagram.**

Diagramma di solubilità isoterma.

Slag's viscosity is likely not to be very high because of high fluxing agents' content (SiO₂, Al₂O₃, [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%, see Figure 9).

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.

Fumes

Fumes analysis has shown very interesting results too foremost regarding the post-combustion ratio. Figure 10 shows where outgoing fumes are sampled to be analyzed.

It's really worth watching the variation of CO and CO₂ percentage during the process. Figure 11 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 CO₂ 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.

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 O₂ to N.G. ratio greater than stoichiometric. The used excess flowrate is around 700 - 750 Nm³/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 CO₂ 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 CO₂ production and releasing energy.

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 12, the sum of the energy inputs and of the energy outputs is reported.

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 Nm³/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-com-



FIG. 10 *Fumes sampling probe location.*

Posizionamento del campionatore della composizione dei fumi.

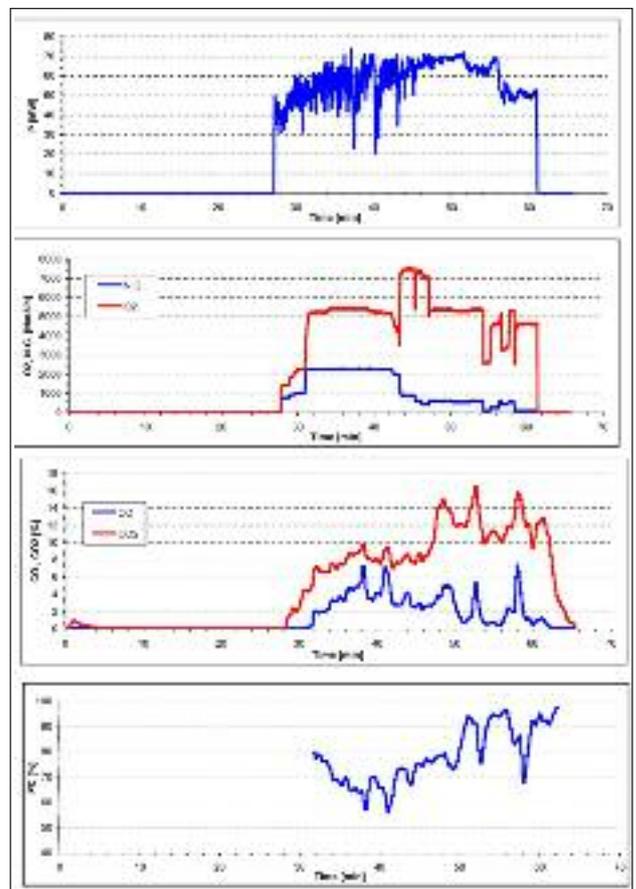


FIG. 11 *Fume analysis results.*

Andamento dell'efficienza di post-combustione in funzione del tempo.

bustion 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,

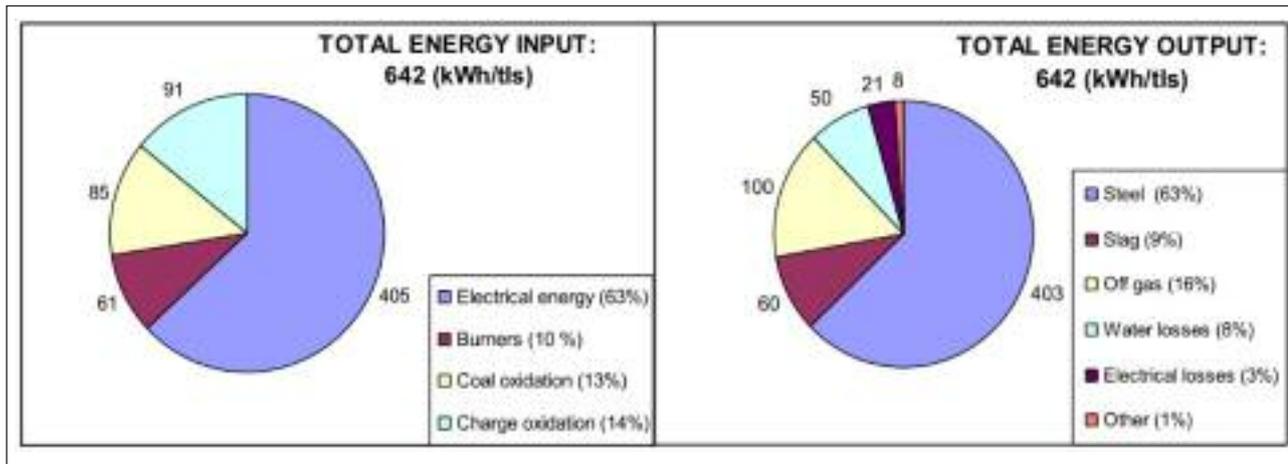


FIG. 12 Energy balance.
Bilancio energetico.

- 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 13,
- 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, CO₂, H₂O, O₂. No measure of temperature or flow-rate was taken in correspondence of the sampling probe location. Anyhow the percentage of CO and CO₂ 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 Nm³/tls, 8.2 Nm³/tls of oxygen are engaged in the combustion of CO inside the furnace.

More specifically this means that 1 Nm³/tls derives from the excess of oxygen during the burner phase, while the remaining 7.2 Nm³/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/Nm³, 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.

FUTURE DEVELOPMENTS

Some developments are foreseen for the furnace in the near future. First of all a second Limejet will be installed taking the place of Carbonjet 2 in order to perform all slagbuilders addi-



FIG. 13 Trends of outlet temperature and inlet temperature in Jacksonville EAF during the heat.

Andamenti delle temperature di ingresso e di uscita dei pannelli dell'acqua di raffreddamento dell'EAF di Jacksonville per un'intera colata.

tion 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.4.2 (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).

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

TAB. 6 Expected future improvements.

Miglioramenti futuri previsti.

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.

Abstract

Processo Monocesta Fastarc™ a Jacksonville

Parole chiave: forno elettrico, acciaieria, efficienza termica, Fast Arc, singola cesta

Il presente lavoro descrive le caratteristiche principali del sistema AC Fastarc™ del forno elettrico Danieli installato nell'impianto Gerdau Ameristeel a Jacksonville (Florida - U.S.A.).

Il nuovo forno UHP Fastarc™ ne rappresenta lo stato dell'arte della tecnologia EAF. Esso ha una capacità stimata di 95 sht (≈ 86 t) ed è in grado di fondere una singola cesta con il 100% di rottame.

Grazie all'utilizzo esteso di energia chimica per mezzo del sistema di iniezione DANARC, e al dimensionamento ottimizzato del trasformatore (90 + 12% MVA), il forno ha raggiunto alte velocità di fusione della carica con scenari di risparmio energetico molto promettenti. L'EAF ha già raggiunto tempi di power on dell'ordine di 35 minuti con produttività massima di 115 t/h. Questo risultato è stato raggiunto grazie all'efficiente utilizzo dell'iniezione di ossigeno, carbone e calce, il quale ha permesso di garantire una buona schiumazione della scoria durante tutto il processo. L'analisi dei fumi ha rivelato un alto grado di post-combustione in forno, confermando un miglioramento anche sotto questo aspetto. Sono state dimostrate condizioni di omogeneità termica del bagno grazie a riduzioni della caduta di temperatura tra uscita dell'EAF e arrivo in colata continua (l'acciaieria non dispone di LF).

Il seguente lavoro presenta risultati molto interessanti dal punto di vista dei consumi e dell'efficienza termica, tenendo conto dell'analisi dei dati raccolti negli ultimi mesi di esercizio, del nuovo design concept e delle parti meccaniche ed elettriche installate.