HIGH-TECH DANIELI FASTARC™ EAF[1]

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Abstract
Danieli advanced technology in steelmaking is a result of years of experience supported by persistent R&D activity and collaboration with clients. The result of this activity is the New High-Tech Danieli FastArc™ EAF. The new electric arc furnace will be equipped with roof and wall Energy Saving Long Life panel, high specific power (till 1.4 MVA/$t_{liq.}$), complete and powerful chemical-energy package consisting of side-wall oxygen, gas and carbon injection systems, together with lime injection, high automation and process control level as well as an efficient dedusting and environmental system. Danieli FastArc™ with above mentioned equipment and single bucket scrap charging practice is capable to obtain a Tap to Tap time of about 30 min. and electrical consumption less than 350 kWh for ton of liquid steel. Respective design, figures and technologies applied are the topic of this article.
Key words: Electric arc furnace; FastArc; Productivity; Meltshop

FASTARC™ – FEA DANIELI DE ALTA TECNOLOGIA

Resumo
A avançada tecnologia Danieli em produção de aço é resultado de anos de experiência suportado pela atividade continua do departamento de Pesquisa & Desenvolvimento Danieli em colaboração com os seus clientes. O resultado desta atividade é o Novo FEA Danieli de Alta Tecnologia - FastArc™ . O novo forno elétrico a arco é equipado com abóbada e painéis refrigerados - Energy Saving Long Life (Longa Vida & Economizadores de Energia), alta potência específica (até 1,4 MVA/$t_{liq.}$), pacote de energia-química potente e completo, compreendendo sistemas de injetores de parede para oxigênio, gás e carbono, além de injeção de cal, alto nível de automação e controle de processo, bem como um sistema de despoeiramento e ambiental eficiente. O forno FastArc™ Danieli com os equipamentos acima mencionados e prática de carregamento de apenas 1 cesto de sucata é capaz de obter um tempo de "Tap to Tap" de aproximadamente 30 min. e consumo de energia menor do que 350 kWh por tonelada de aço líquido. O projeto, dados e tecnologia aplicada são tópicos deste trabalho.
Palavras-chave: Forno elétrico a arco; FastArc; Produtividade; Aciaria

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Introduction

Danieli & C. plans ambitious tasks for its electric arc furnaces:

- To increase the best state of the art productivity figures by 25-30%;
- To reduce the electric energy consumption down to 350 kWh/t (based on scrap charge);
- To improve consistency and reproducibility (> 93% plant utilisation);
- To improve the environmental impact

Fig. 1 – Reliable Danieli EAF Danarc→ technology has evolved in the new generation of FastArc^{TM} melting furnaces.

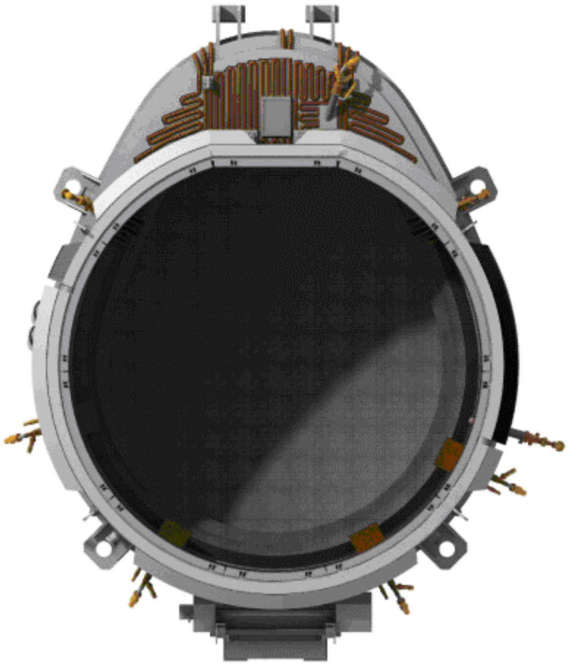


Fig. 2 - DANIELI FastArc^{TM} shell design.

Intensive activities oriented to the realisation of such ambitious target are in progress under the registered trademark of FastArc^{TM}. The project is based on years of consolidated experience enhanced by research support, full-scale experiments and close collaboration with clients.

Some peculiarities of the FastArc^{TM} are the following:

- medium size AC furnace with capacity up to 120 t and planned years by production of 1.4 Mt_{liq} ;
- single bucket charging practice;
- high specific power supply (till 1.4 $MVA/t_{liq.}$);
- the furnace roof and walls are equipped with Energy Saving panels;
- an increase of chemical energy with more sophisticated control;
- high automation and reliable process regulation.

In this paper mechanical design, technical solutions and process parameters will be briefly outlined.

Mechanical design
In order to fulfil two most important technological features of FastArc^{TM} process - single bucket charging and high specific energy input ($\leq$1.4 MVA/$t_{liq.}$) with high ratio of chemical energy, a series of improvements in mechanical design of the EAF Danarc^{TM} have been introduced.
Moreover, a number of new innovative technical solutions provide the automatic fulfilment of the required process' actions, nowadays mainly dealt manually consuming time and men labour:

- Remote tapping and tap hole refilling from the control room with the aid of slag detection;
- Robotic sill level cleaning during power on time;
- Power-on steel sampling, continuous temperature and carbon tracking.

In the following, design characteristics of relevant mechanical components will be shortly presented.

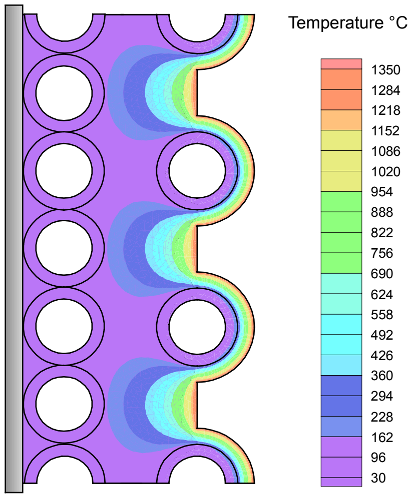
Shell design
The furnace shape and the melting vessel design have been completely revised (**Erro! A origem da referência não foi encontrada.**) in order to maximise the energy transfer from the arc to the scrap, avoiding cave-ins and dynamically selecting the appropriate voltage and current per electrode.
The furnace movements have been accelerated to contract the turnaround, but smoothed to prevent dynamic ageing. Fast furnace back tilting (more than 5°/s) in combination with infrared steel visualisation assists the operator to avoid the EAF slag to drop into the ladle.

The shell is modular, facilitating assembling and refractory maintenance above all (see **Erro! A origem da referência não foi encontrada.**). Quick vessel exchange permits to reduce the production shut-down to 4 hours only, promoting the whole steel plant utilisation factor.
The corresponding lower part is specially designed for eccentric bottom tapping with a smooth transition to the EBT section.
Optimised ratio between bath height and diameter (H/D), enables better stirring and more intensive metallurgical reaction.

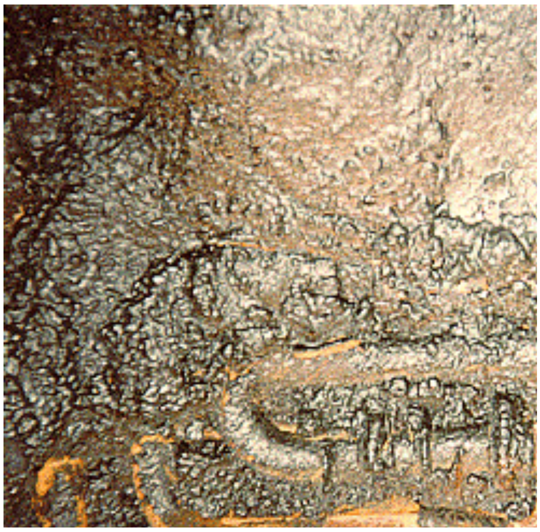
Extensive research & development of optimum bath design led to state the ideal furnace shaping for each project

Long Life Energy Saving Panel
Danieli & C. patented energy saving panels are adopted at the walls and the roof to increase the furnace reliability. Their ability to maintain a stable self-regenerating, insulating slag layer over water cooled pipework reduces the energy losses as well as the damage probability.
Energy saving panels consist of two layers of water-cooled tubes. The one directly exposed to the arc radiation has a larger pitch between the tubes to entrap the process slag acting as a heat mirror and as a thermal and electrical insulator.
Slag coating partially melts during the peak heat flux phases, lowering the thermal stress on the steel pipes. During slag foaming a thick layer of renewed slag is sticking again on the panel in an endless process.

The dual layer design permits also to avoid large safety problems and downtime when a break or water leakage appears. In few minutes the broken layer (usually the inner) can be excluded from the water circuit, emptied and sacrificed without any production interruption. The outer layer will provide the required protection to the wall. The panel can be easily repaired at the vessel exchange by adding a new layer.



design phase



in operation

Fig. 3 - DANIELI Long Life Energy Saving panels.

Average and maximal values of heat flux and panel slag surface temperature (see Fig.3) for standard and energy saving panels are given in Table 1.

Table 1 - Average and maximal values of heat flux and temperature for standard and energy saving panels.

Heat Flux	ENERGY SAVING	STANDARD
Average [kW/m^2]	310	335
Maximal [kW/m^2]	452	563

Panel Slag Surface Temperature	ENERGY SAVING	STANDARD
Average [°C]	822	234
Maximal [°C]	1111	640

It can be appreciated that in the case of energy saving panels, the max heat flux (452 kW/m^2) is about 20% lower than in the case of standard panels. At the same time, the difference between the corresponding average values is about 10%.
Therefore, the energy saving panels permit to reduce peak of heat flux with a large benefit on the panel lifetime.

The main advantages of DANIELI Long Life Energy Saving panels are:

- Increase of arc power,
- reduction in energy losses,
- increase in productivity,
- increase in panels' lifetime,

- reduced operational down-time in case of failure,
- higher operational reliability,

Roof design.
The roof of the DANIELI FastArc^{TM} EAF is Long Life Energy Saving type, with single point lifting system guaranteeing the following performances (see Fig. 4):

- smaller weight with respect to the conventional roof;
- minimisation of energy losses;
- higher operational reliability;
- shorter time of roof delta replacement;
- reduction of fumes velocity and fines' draught.

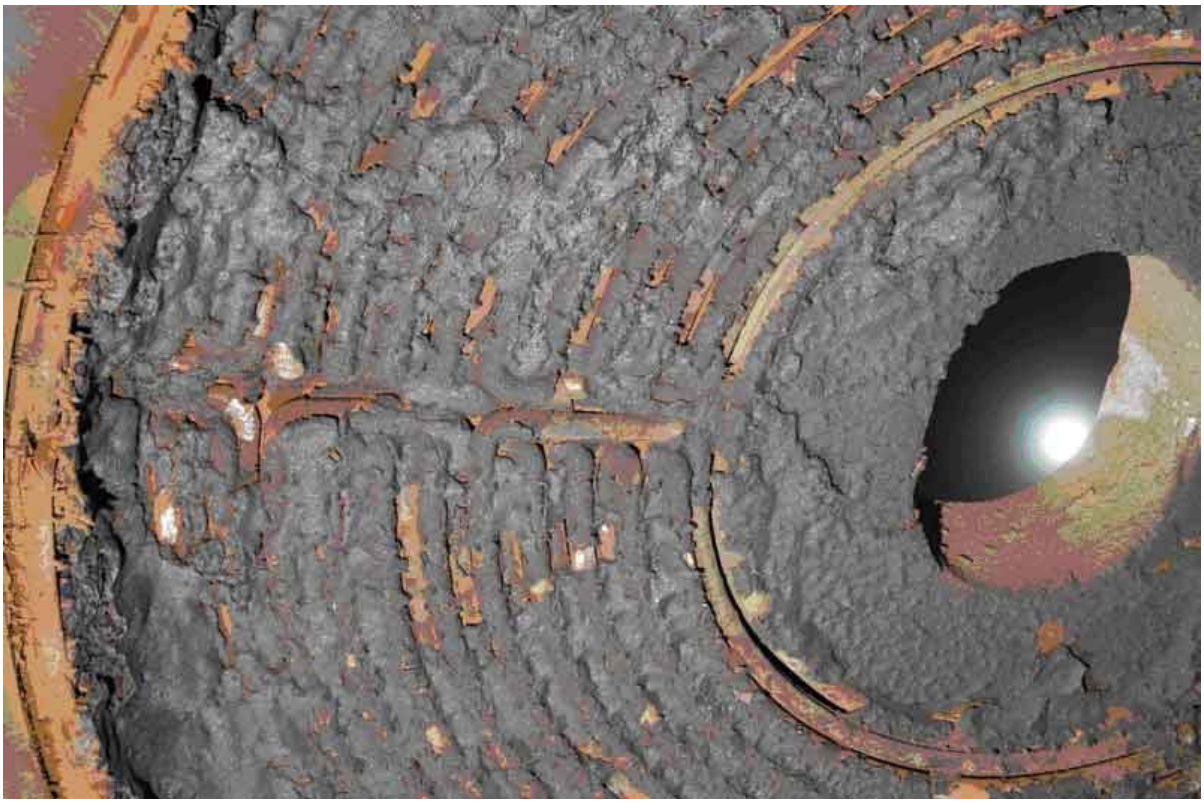


Fig. 4 - New Energy Saving Long Life roof.

Single bucket charging practice
The distinguish characteristics of the DANIELI FastArc^{TM} EAF is single bucket charging. The DANIELI & C. is the first world-wide company that designed, tested and in 1997 good results were obtained by applying preheated single bucket on industrial scale.
The motivation to persist on single bucket charging is validated by the diagram on Fig. 5 showing relative difference between main process parameters for 1 and 2 bucket charging practice.

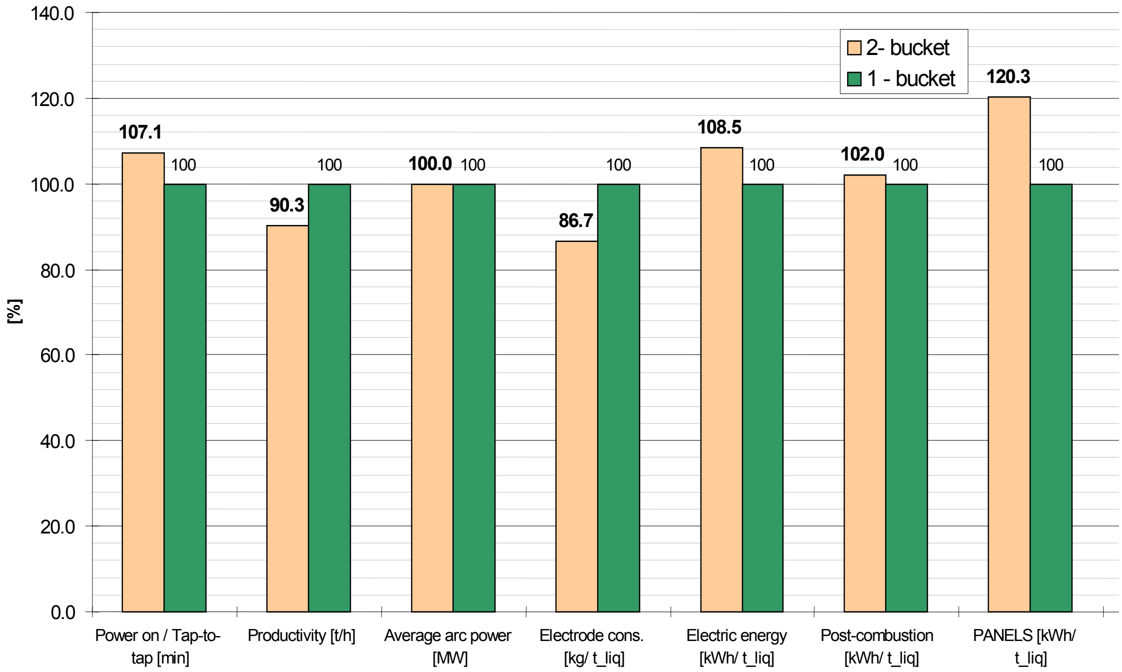


Fig. 5 - The variation of relevant process parameters in [%] for 2 and 1 bucket EAF charging.

The above quantified together with additional benefits of one bucket charging practice can be summarised as follows:

- Decreasing power off time ;
- Reducing radiation losses of bath during scrap charging;
- Higher post combustion degree and heat transfer efficiency due to prolonged permanence of fumes in the furnace;
- More efficient scrap preheating in the furnace due to higher energy recovery from fumes;
- Higher arc efficiency during long arc operation due to extended scrap shielding towards the EAF wall panels.
- Improved environmental impact due to less roof openings, CO emissions from EAF and less dust emissions in fume duct due to scrap filtration ability.
- Higher productivity and lower production costs.

Equipment for innovative process management

In order to reach the declared performance, the DANIELI FastArc™ EAF will be equipped with a number of devices providing efficient chemical energy management. All the equipment unit has been studied with extensive support of computotional fluid dynamics (CFD), full-scale experimentation and prototyping with the concrete aim of combining efficiency and reliability.

DanHELIX® burners

The DanHELIX® burner is a specially sized swirled flat flame oxygen - fuel burner. The flame slope is generated by four individual flames sources, two directed to the burner axis and two inclined far from. Therefore the flame is spreading on a wide flat area of scrap in front of the burner itself and a higher power per unit can be applied as compared to a conventional burner.

The peculiar design of the burner copper tip has been developed by extensive and deep CFD analysis (see Fig. 6).

It is featuring the following peculiarities:

- Nominal burner power is 6.5 MW per unit;
- Optimal mixing degree between oxygen and fuel next to the burner tip obtaining a combustion efficiency higher than 97%;
- Low direct iron oxidising potential with stoichiometric feeding thanks to the absence of free oxygen in the flame;
- High heat transfer capability for increased flame radiosity;
- Larger flame impingement volume due to the special tip design (the flame cone is spreading approximately on a 35° cone angle);
- Even distribution of the thermal heat flux over a wider area of scrap;
- High flame stability ranging from 10% to 150% of the nominal power and from 0.5 to 2 times the stoichiometric ratio.

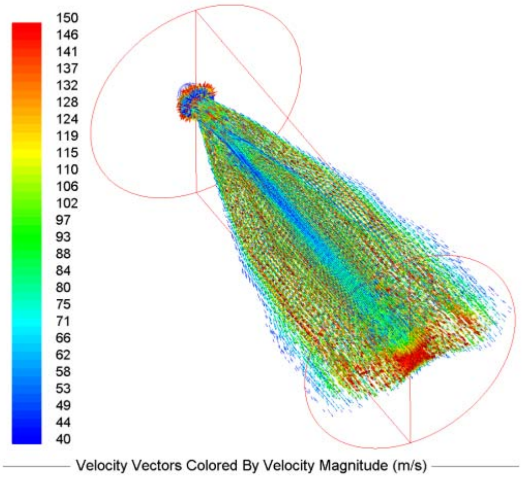


Fig. 6 - CFD flame flow visualization (*left*) and DanHELIX® burner in operation (*right*).

DanHELIX® burners are ideal for the application on:

- Cold spots in rapid melting furnaces (it is possible to increase the local specific power per unit);
- Furnaces suffering from heavy charge oxidation (among all the ones for stainless steelmaking or high-alloyed products);
- On the cold spots of large capacity furnaces to guarantee wall cleaning;
- On weakly powered furnaces charging heavy or pressed scrap and bundles.

The process benefits are:

- Increase in the melting rate and furnace productivity;
- Decrease in the electric arc energy specific consumption;
- Decrease in the coal consumption;
- Decrease in the lime and refractory consumption.

DanHELIOS® modules

Oxygen supply will be provided by DanHELIOS® (Danieli patent). This is a multifunctional device working in the first phase of process like the flat flame burner with a power of 6.5 MW, and in the second phase like an efficient oxygen-jet. During the first phase, the dual stage burner permits to automatically and continuously

modulate the burner from a large and flat flame (see Fig. 7) to a longer and more concentrated one.
Operating as a large flame burner it heats up rapidly the metallic charge and produces a cave-in it partially filled by liquid steel;
Turning smoothly the flame from large to a concentrated one enables a rapid melt down of the solids or unmolten residuals fallen in the liquid pool.

Fig. 7- DanHELIOS® flame characteristics - turning from large to concentrated flame.

During the second phase used as oxygen-jet, a specially designed supersonic nozzle of aerodynamic shape delivers the oxygen at high speed to the liquid metal by a well-focussed and stiff free-jet eventually guided by a shrouding flame.

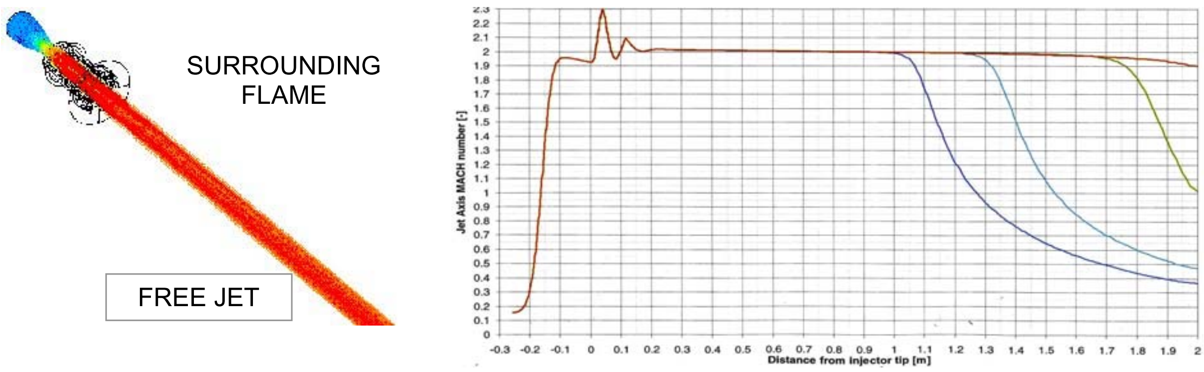


Fig. 8 - Supersonic oxygen jet obtained from DanHELIOS module

EBT Jet®

EBTJet is multifunctional devices working as a burner (during the melting phase), and like an oxygen jet during the refining phase of the process to help the bath decarburisation. It is specially designed to avoid any possibly of scrap clogging or EBT channel blinding during tapping.

DeepJet® carbon injector (see Fig. 9).
Carbon is injected into the furnace by means of the DeepJet®(Danieli patent). It is a self cleaning carbon injector specially designed to promote slag foaming, injecting coal powders into the slag, with “close to zero” losses into the FTP.
A jet surrounding flame, properly shaped, is enhancing the powder efficiency by shielding the coal jet from the furnace environment and accelerating the small particles by its expansion effect.
The installation places for the DeepJet® are appropriately chosen to promote CO post-combustion, too.

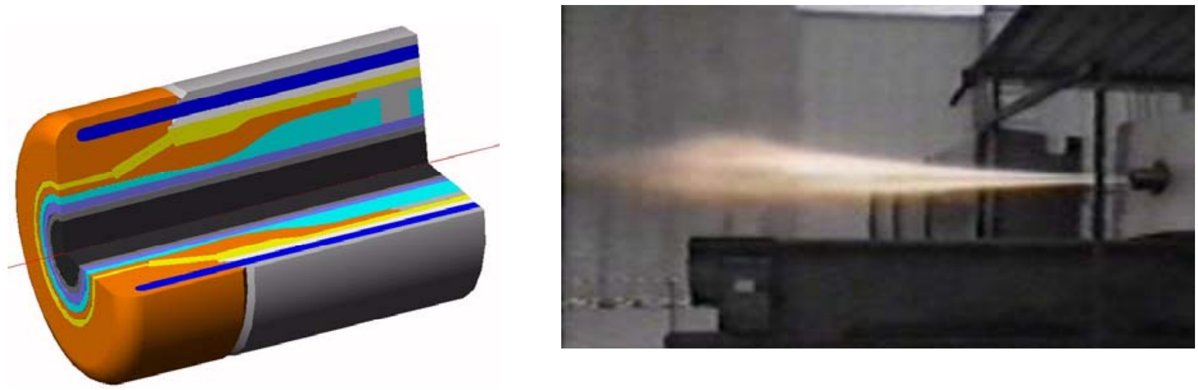


Fig. 9 - DeepJet® carbon injector – head design and efficiency testing.

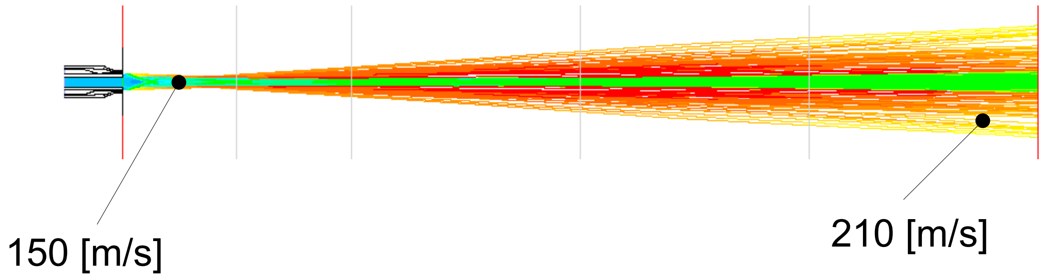


Fig. 10 – Velocity field of carbon particles surrounded by flame generated by DeepJet®.

DANIELI LimeJet.
New high efficiency LimeJet is conceived to deliver lime or other similar slag formers next to the bath at high flow rates up to 400 kg/min.
It is a wall mounted injector integrating burning functions with an axial pneumatic injector for coarse grain lime or dolomite addition. The injector is realised with a suitably designed water-cooled copper tip providing a powerful burner (6.5 MW) for heating and melting the scrap in front of the unit.
Fast scrap caving ensures the possibility to inject slag-forming materials from the beginning of the heat while a close-to-bath unit mounting guarantees high material yield as well as quick response. Moreover, thanks to its compact design it easily fits on a sealed water-cooled steel tile box and can be especially directed on the furnace hot spots to protect the refractory and rapidly foam the slag.

DANIELI Cooled Box and Cooling Block
A special attention is paid to the installation issues of the above described devices.
These units have to be placed in the proper location around the furnace shell to distribute evenly the chemical energy, the oxygen and the carbon in the cold spots to

balance the furnace, according to the main process requirements, depending from the charge material, transformer rating and furnace size.
The special design and mechanical construction enables easy assembling and replacement of the injectors without need for short-term maintenance.

The units will be installed in water-cooled copper box mounted fit on walls in the proximity of bath level without any risk of break-out (Fig. 11), providing a precise injector orientation and allowing for a little adjustment in case of need.
The main process benefits of the copper box are:

- higher oxygen and coal efficiency;
- better furnace energy balance;
- greater productivity;
- less maintenance

Moreover, by the installation of refractory-copper cooling blocks, the refractory lifetime in the slag zone in remarkably enhanced.

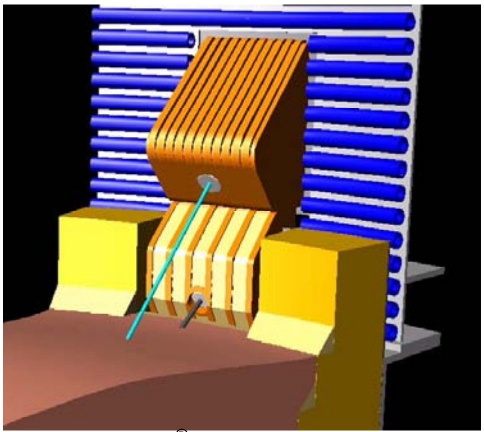


Fig. 11 - DanHelios® integrated burner supersonic oxygen injector is fit in a COPPER CAST BOX and located over a COAL INJECTOR INTEGRATED COOLING BLOCK.

Fig. 12 - Sill level cleaning robot

Main automation issues

Within the renewal project, a great attention has been paid to the process control system, aiming at obtaining the best efficiency, top performances, the highest safety and full control of environmental emissions. These objective are obtained by:

- Hi-Reg Plus electrode regulation system, developed to maximise the active power transfer to charge and characterised by fast response position control of the electrodes, optimising the electric energy supply and reducing electrode consumption.
- The new level two, integrated with innovative functionality which makes the automation system a reliable tool for EAF process control;
- High regulation speeds of electrodes mast movements;
- High speed tilting movements with slag and tapping control automatic systems;
- Foaming slag height, controlling adequate coal and lime injection;
- Continuous temperature measurement during refining phase;
- Continuous off-gas analysis with feedback regulation on oxygen injectors;
- Robotic slag door cleaning system (Fig. 12).

In particular, the integrated Level 2 provides:

1. Continuous display of process status: melt & slag weight, temperature, composition;
2. Automatic equipment and process check to detect the ready to tap status;
3. Feed back to check outcome of executed action ;
4. Direct on line evaluation of thermal efficiency;
5. Data logging allowing optimisation of model parameters;
6. Improved monitoring of every single process phase.

Performance figures

The guaranteed performances of the new furnace are summarised in Table 2.

Power Supply	AC
Size	120 t_{spill}
Specific Power	1.2-1.4 (MVA/t_{spill})
Power On	≤28 (min.)
Tap to Tap	35 (min.)
Tapping Temperature	1630 (°C)
Charge	Single Bucket
Scrap Density	0.7-0.8 (t/m^3)
Panels ad Roof	Energy Saving Long Life
Electric Energy Consumption	340-355 (kWh/t)
Electrode Consumption	1.2 (kg/$t_{spill.}$)
Oxygen consumption	35-40 (Nm^3/$t_{spill.}$)
Gas consumption	6 (Nm^3/$t_{spill.}$)
Charge carbon	<12 (kg/$t_{spill.}$)
Injected carbon	<10 (kg/$t_{spill.}$)
Lime	40 (kg/$t_{spill.}$)
Yield	90% (93%)

Table 2 - DANIELI FastArcTM EAF performance figure.

Conclusions

The attainment of these outstanding performances is in progress by continuous innovations of devices and process performances based on intensive research and fruitful collaboration with customer. Naturally, the selection of appropriate scrap and charge type are necessary to obtain such high performances.

It is possible to install the great part of improvements and devices on EAF already in plant operation in order to increases the production performances.

The complete success of the project is achieved in the steel plant. Hence, specific courses addressed to the customer technical staff will be held by Danieli specialised team in order to provide fully understanding of process and the corresponding equipment.