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A FASTER, MORE EFFICIENT EAF

SZYBSZY I BARDZIEJ WYDAJNY PIEC ŁUKOWY

When the market is in an expansion phase, the necessity to increase the production is a must involving an expansion of the production facilities. The revamping of an existing plant set several constrains, mainly due to the ladle size, therefore the reduction of the tap to tap is the only solution: a faster furnace.

When the market is stable or in recession, it is necessary to reduce the transformation costs through the efficiency of the whole process and of the production facilities, mainly the one of the melting furnace.

The present paper has the aim to catalogue the main items affecting the "faster" and the "efficient" adjectives and to illustrate the last technological developments, such as the UHCP (Ultra High Chemical Power) furnace, that Concast has implemented allowing a further step ahead.

Some outstanding UHCP will be analysed.

Keywords: EAF benchmark, O_2 and C injection, process control tools, UHCP EAF, high productivity EAF, Heat Transfer Efficiency

Koniunktura rynku powoduje wzrost produkcji, a to wiąże się z rozwojem oraz unowocześnianiem urządzeń do produkcji. Modernizacja istniejących hut stwarza różne ograniczenia, głównie spowodowane wielkością kadzi, dlatego istnieje tylko jeden sposób aby zmniejszyć czas trwania wytopu: szybsze piece. W sytuacji, gdy rynek jest stabilny lub w warunkach recesji, konieczne jest zmniejszenie kosztów produkcji poprzez podwyższenie sprawności całego procesu lub poszczególnych etapów, a zwłaszcza etapu topnienia wsadu. Głównym celem tego prezentowanego artykułu było skatalogowanie ważnych czynników wpływających na "szybkość" oraz "sprawność" oraz zaprezentowanie najnowszych osiągnięć technologicznych, takich jak piec UHCP (Ultra High Chemical Power), który Concast stworzył w oparciu o najnowsze rozwiązania. Pewne najważniejsze cechy UHCP zostaną przeanalizowane.

1. Introduction

The speed and the efficiency are two characteristics of a system that sometimes can not be present at the same time. When the melting efficiency function foresees a maximum, the theoretical optimum working point could be just that one but, if the speed factor, i.e. tap to tap time, is a must, it is important is to find a correlation between all the factors and the system answer to the variation of of such parameters to understand the system behaviour.

Several authors has proposed models, more or less complex, trying to link the typical production factors, such as the gas, oxygen, carbon etc, to find out the electric energy consumption and the power on, considering implicitly the heat transfer efficiency (HTE) of the system independently of the technology utilised to melt the steel [1].

We would like to catalogue the main items affecting the "faster" and the "efficient" adjectives and to illustrate the last technological developments that Concast has implemented allowing a further small step ahead.

Remark: All the consumption figures are in metric units and refer to good billet.

The electric arc furnace (EAF) has completed, by now, one hundred years, therefore the technology is mature. Its evolution has been quite strong decreasing, for example, the tap to tap time, which can be considered

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one of the most important indicators, by 5 times in some decades!

Several attempts have been done in order to propose different concepts of the furnace but without remarkable success. The present state of the art of the EAF is still based on the classical formulation, enough close to the original idea, obviously technologically improved to make the EAF faster and more efficient.

The investments in new equipment are based or on the maximum possible productivity increase or in the attempt to increase the melting efficiency reducing the transformation costs.

When the market is in expansion, it is frequent that a net increase of the production volume has the priority over the fine tuning of the technological process parameters.

The process technology optimisation is the activity which generally predominates during a period of a market contraction or when, for some reasons, the production volumes cannot be simply increased.

Selection of a proper investing strategy is similar to planning of a trip by car when it is necessary to decide what is more important: to get to the final destination as fast as possible (but possibly as safe as possible ...), minimizing travelling time, or to optimise fuel consumption what obviously increases travelling time?

2. Faster

Faster: a furnace characterized by short, or very short, cycle times can be installed in an existing plant or in a new one.

If installed in a new plant, all the layout and the facilities should be designed to match the short cycle time but the same can not be said for the existing plants.

Such projects, usually, have a lot of constraints, from the electric power available up to the auxiliary systems such as raw material handling, oxygen production plant and furnace off-gas circuit.

Nevertheless, in the optic of an increase of the production, the main project limitation is always related to the actual tapping weight with which all available production facilities are matched: foundations, buildings, cranes, ladles, CCM turret etc. Increase of the tapping capacity is theoretically possible only within a limited range: if a significant increase of the tapping weight is required, it is better to think about building of a new plant.

Considering all constraints, it can be concluded, in the simplest way, the productivity increase is achievable through a decrease of the furnace production cycle time.

Particularly, in case of low and medium size furnaces, high productivity can be achieved with tap-to-tap times shorter than 40 minutes [2].

Further productivity boost to a level of 40 heats/day or more, requiring operation with tap-to-tap times of less than 36 minutes, involves remarkable implications on the facilities upstream and downstream the furnace, on the plant layout and on the material flow as well as on the process scheduling and logistics.

First of all, the production time scheduling must be examined in details. The scrap yard must be able to feed the EAF on time and with charge prepared in accordance with proper recipes.

Downstream the EAF, the most critical position is the ladle refining station (LRS). If the EAF tap-to-tap time approaches values of less than 36 minutes, available time for secondary steel refining may be insufficient and the traditional layout solution to have in line the EAF and the LRS, is not more sustainable.

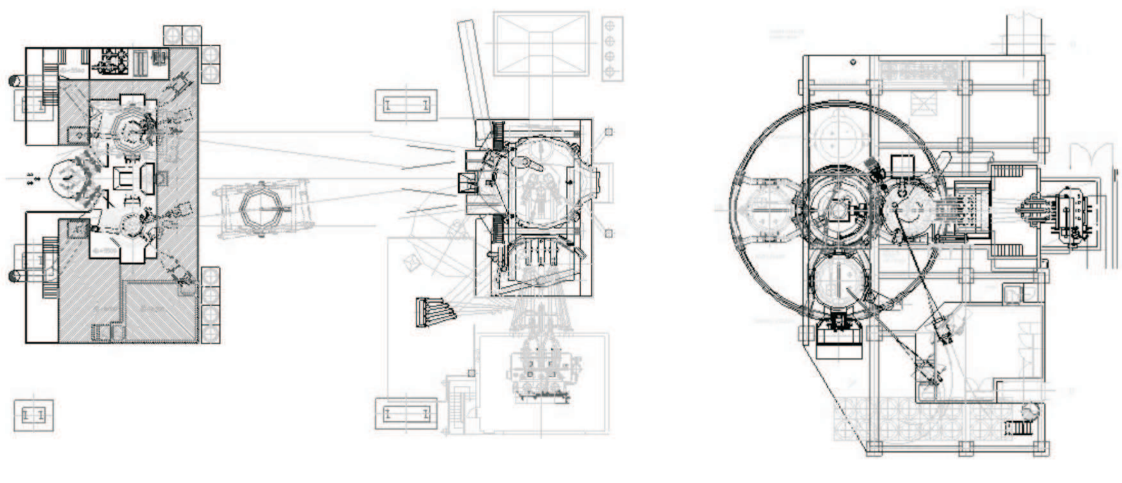


Fig. 1. Layout With Twin LRS and ladle carousel cars

The figure 1 shows two different approaches to solve the LRS bottle neck.

The left picture shows a LRS utilising two ladle positions and one set of on swingable electrode arms.

The arms can be moved from one ladle position to the other one in a very short time. This allows for certain overlapping of LRS cycles up to possibility of having two ladles being handled at the same time.

On the right picture it is shown a carousel, able to manage up to three ladles, realized with three independent ladle cars moving on a circular track. Using the clock convention, at 9 hours, there is the pick/place position, at 12 hours a stand by position, at 3 hours the heating position and finally at 6 hours the auxiliary trimming and rinsing position.

The ladle cars are engaged and moved on the track by a hydraulic motor positioned in the centre of the carousel.

The decrease of the tap-to-tap time can be obtained optimising both power-on and power-off times of the furnace cycle.

The power-on time is influenced mainly by:

- Raw material charge structure and its behaviour during melting.
- Available transformer power.
- Chemical energy tools power and efficiency
- Electrode regulation efficiency.
- Melting profile design and execution.
- Required refining/superheating time.

With the exception on the available transformer and injectors power, any other item is related in direct or indirect way to the melting efficiency , generally speaking the HTE.

The power-off time is mainly governed by:

- Bucket charging time.
- Speed of the furnace movements.
- Sampling practice.
- Tapping time.
- Duration of turnaround operations.
- Adopted refractory maintenance philosophy.

The items referring to the power off are less homogeneous compared to the ones of the power on since, sometimes, are related to the operator skill, to the furnace management strategies or to the speed of the machine movements.

Since furnaces need to be operated faster and faster, the importance of concentrating efforts on the power-off time reduction is clearly seen.

For standard furnaces operated with tap-to-tap time of 60 minutes, typical power-off times are in range of 12 – 15 minutes, including the operative maintenance, i.e. 20% – 25% of the total cycle time. The same power-off times included within a tap-to-tap cycle of 36 minutes corresponds to 33% – 42% of the total cycle time! It is then absolutely necessary to reduce power-off times to about 7-8 minutes to fulfil the condition that the power-off time is at the level of 20% of the total cycle time.

Some strategies to reduce the power-off time (excluding the increase of the furnace movement speeds that can not be increased beyond some safety limits) the following solutions may be considered:

- Single bucket charging practice.
- Tapping time reduction (tap hole diameter increase).
- Tapping with power-on (at least 1/3 of the total tapping time).
- Automated sill cleaning.
- Automated electrode jointing on the furnace.
- Efficient slag foaming and minimised refractory wear so eliminating or reducing the gunning practices for the refractory repairing.

3. Efficient

Over the last few years, Concast developed the UHCP (Ultra High Chemical Power) EAF [3] concept based on two points: the intensive/efficient use of chemical energy and electric power greater than 1 MVA/t (close to 1 MW/t).

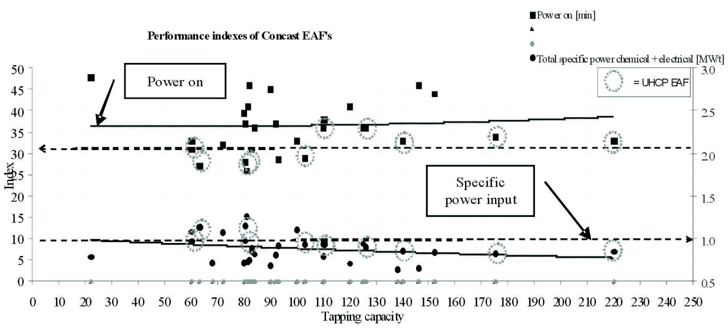


Fig. 2. UHCP furnaces compared with other furnaces

The following figure 2, compares the UHCP EAFs (marked with a green circle) with other Concast furnaces commissioned in the last decade.

The upper part of the diagram indicates the power-on time (left Y-axis) while the lower part, the specific total power input considering the electrical + the chemical power (right Y-axis).

One of the main reasons for the use of such intensive power is the continuous demand for decreasing the power-on time.

The main benchmark considered is the UHCP_index, i.e. the chemical power input (burners + oxidations) vs. the total power input.

With the UHCP EAF, the chemical power input, compared to the electric power input, is very high. In an UHCP EAF the total burner power is close to 40% of the electric power input.

This solution has been applied from small to large-sized furnaces, leading to outstanding performance results.

Two of these top-scoring reference furnaces, used as didactic examples of high productivity installations, are presented in this paper.

Concast has concentrated on a few of the above points, taking them into account in the design of the UHCP EAF, in order to achieve a reliable and repeatable design leading to the top-scoring solutions.

Concerning the power-on time, the efforts concentrated on are:

- Intensive and efficient use of chemical energy.
- Application of intensive electric power input close to, or even exceeding, 1 MW/t.

This is the main reason why Concast is fully involved in the development of techniques and equipment able to withstand a high power input density.

For example, the Concast injection technology is based on very powerful injectors characterized by a burner power up to 8 MW and an oxygen injection up to 3.500 Nm^3/h.

The main reason why the injectors power has to be pushed so high is because the reduction of the power on follows an exponential law. To halve the power on the power input must increase of three times: in order to keep the specific oxygen use constant, the power of the injectors has to follow a similar exponential law.

Without high power injectors, it is not possible to keep the oxygen consumption on such a fast EAF on the same consumption level as that of a slower EAF; furthermore a larger power per injector avoids the multiplication of the injection units simplifying the complexity of the on-board piping and of the upper and lower shells.

Until several years ago, the limitation of 3 MW for one injector was considered the limit, over which there would have been risks for power management, low oxygen efficiency and maintenance problems of the shell and roof panels.

With the UHCP EAF, the chemical power input compared to the electric power input is very high. Figure 3 below compares the UHCP EAFs with other Concast furnaces. In an UHCP EAF, the total burner power is close to 40% of the electric power input.

The level to which the chemical energy can be pushed can be studied from two different points of view: one thermodynamic and the other economic but do not bring to the same conclusions.

The first approach considers the efficiency of the energy utilization but also its grade of usability (the exergy method). It is clear to the common sense that we should have to consider the well-to-liquid-steel yield in all the situations where the electric energy is produced by fossil fuels (excluding therefore the nuclear and the renewable energy).

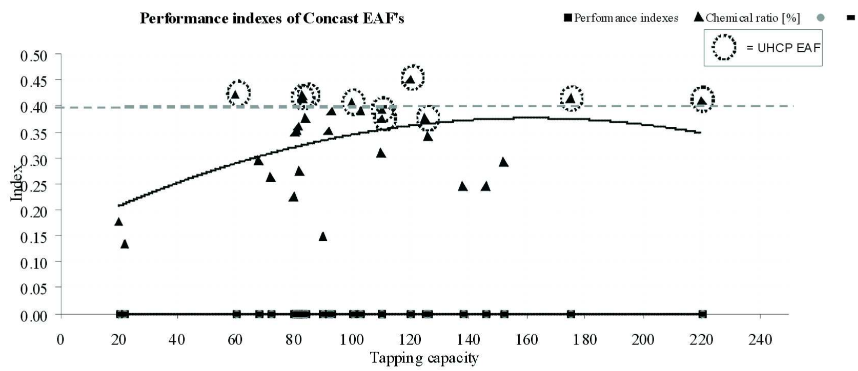


Fig. 3. UHCP Index, Burner Power vs. Electric Power Input

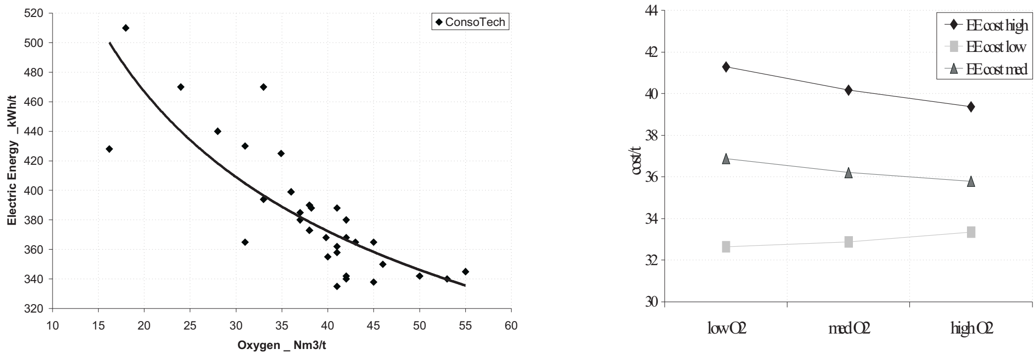


Fig. 4. Electric energy vs. oxygen consumption and influence on melting costs

The heat transfer efficiency (HTE) is a time dependent variable, therefore strictly related to the melting phase. Without entering into equations, the HTE is higher as higher is the availability of the exchange surface (scrap surface) and there is sufficient residence time for the hot gases. In flat bath operation the HTE decreases dramatically. We know it also from the story of the glorious Martin furnace… Obviously the hot gases must have a high temperature in order to guarantee the necessary power but unfortunately the flame temperature achievable with gases is not so "high" and, in case of short melting time, the necessary power to melt the steel can be reached only with really extensive flow-rate.

Some interesting studies are now in progress, allowing a step ahead in this direction, based on a different melting process idea.

Coming back to the EAF, the level of chemical power input is a compromise between the direct transformation cost and the productivity.

As said in the previous example of the car, if we are in hurry it is better to push on the accelerator (caution!), if not, it is better to think about the economy of the trip.

The optimization of the melting costs is heavily dependent not only on the thermal efficiency of the furnace itself but also on the market price of the energy vectors, namely electricity, carbon, gas and oxygen.

Therefore the same furnace, in two different countries, can have different working points.

According to a lot of well-known parameters, it is possible to assume that an extra cubic meter of oxygen is able to participate in the melting process with energy ranging from 3 to 5 kWh/t and its influence on the reduction of the power-on is a bit less than proportional.

In the next figure 4, on the left-hand side, some Concast furnaces working with different oxygen consumptions are correlated. It is clear that, even with different furnace sizes, the assumption of oxygen contribution in the order of four kWh/t is realistic.

On the right-hand side of the figure, there is an estimation of the same furnace working in three different countries characterized by three different energy vector costs (the numerical value is just for reference only).

Where electric energy cost is high, it is important to use the oxygen technology systems as much as possible (the slope of the curve is high) whilst where the electric energy cost is "cheaper" than the fossil fuel, there is not much interest in pushing oxygen technology except in the case of needing to increase productivity.

4. The fastest: Nucor Steel – Texas

For Concast it is an honour to have in their reference list the EAF installed at Nucor Steel - Jewett Texas [4].

This furnace, thanks to the outstanding work of the Nucor team, has become a milestone, an absolute benchmark in steelmaking furnaces for productivity results.

Today, after the installation of the IV generation ConsoTech injection system, the plant is able to have an annual output of 1,100,000 t and operates with an average tap-to-tap time in the range of 30-32 minutes. The best results achieved so far was a tap-to-tap time of 28 minutes which allows the production of 50 heats per day!

At the moment the Nucor EAF production cycle is shorter than the best results obtained from one oxygen converter. One can imagine how "stressed" are the production facilities downstream the EAF. A real "Formula 1" operating team (with Ferrari class equipment) is needed!

The main feature of this furnace is a single bucket charging practice that allows a power-off time of 7 minutes.

The volume of the Nucor scrap bucket (140 m^3) is adequate for a single-batch charge, even when the scrap density is in the lower range of 0.65 t/m^3. With a typical scrap density of 0.73 t/m^3 , the available bucket volume is 90% utilized. The average furnace charging time is limited to 50 – 70 seconds per heat, including the electrode movements, roof opening and closing.

Each injector can work as a standard oxy-fuel burner (5 MW), post-combustion injector (1000 Nm^3/h) and supersonic lance (2500 Nm^3/h).

In total, four injectors have been installed in special patented wall-mounted water-cooled boxes (BRT).

This BRT solution has been designed in order to fulfil three main objectives:

- Installation of injectors in very low position with respect to the level of the metal bath (near to steel concept)
- Maintenance-free mechanical solution (BRT patent)
- Maximum possible reduction of refractory wear beneath the injectors.

The wall-mounted ConsoTech copper boxes are coupled with carbon injectors which are operated at a rate of up to 80 kg/min.

The position and angle of inclination of each injector also had to be carefully selected to obtain uniform slag foaming and full coverage of the liquid bath area.

In order to enhance the post-combustion reaction within the furnace volume, the injection of carbon starts as soon as the burner operation is completed. Early foamy slag formation greatly improves stability of the arc and the energy yield.

The patented BRT box, where the injector is inserted, is based on a completely different mechanical concept.

It is no longer made on a cast-based structure but on independent water-cooled copper bars, CNC made, forming a case of the required dimensions.

This system has been proven to work "near to steel", totally avoiding the problems of cracks, water leakage and early consumption of the traditional cast copper boxes.

Fig. 5. BRT box and carbon injector installed on the EAF shell

After one year from installation, the above- mentioned objectives have been successfully achieved. Particularly impressive is the reduction in the refractory consumption underneath the injectors and in the roof delta centre piece.

The average daily performance resulting from the Nucor-Jewett furnace is shown below.

TABLE 1

Electric energy consumption vs. oxygen consumption (metric unit, t of good billet

Feature		Performance	
Tapping capacity	82 t	Power-on time	24 min
Shell diameter	6700 mm	Power-off time	8 min
Shell volume	140 m^3	Tap-to-tap time	32 min
Height of WC panels	3100 mm	Heats per day	45
Hot heel weight	25-35 t	Productivity	150 t/h
Transformer	110 MVA	Energy	380 kWh/t at 1640°C
Reactor	On-line 2.5 Ω/phase	Natural gas	4.8 Nm^3/t
Injectors	4	Oxygen	30 Nm^3/t
Burner mode	5 MW	C__fine	14 kg/t
Lance mode	2500 Nm^3/h	Electrode	1.5 kg/t

5. The Benchmark: Icdas #1 – Turkey

For Concast, the furnace supplied to Icdas Biga steel plant in Turkey [5], located on the Marmara sea, was the first UHCP EAF but also quickly become a milestone in the UHCP furnace design concept.

The close cooperation with the exceptionally-skilled and determined Icdas team was essential to get a top scoring EAF.

The sheer size of the "Biga#1 EAF", 175 t tapping capacity, the power input necessary to achieve its high levels of performance (168 MVA transformer power, 21,000 Nm^3/h O_2 and 39 MW CH_4 power) and the full integration of the off-gas system with a scrap pre-heater, have required innovative solutions in design, construction and operation of the furnace.

A summary of the Icdas yearly average EAF performance, measured on good billets, shows:

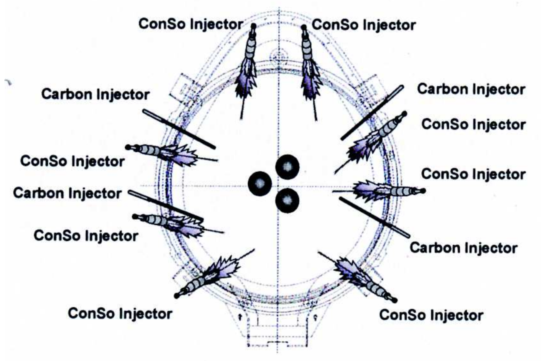
TABLE 2

Summary of the Icdas Biga #1 furnace

Productivity	230 t/h
Tap-to-tap	47 min
Electric energy consumption	290 kWh/t with hot scrap
Electric energy consumption	325 kWh/t with cold scrap
Total oxygen consumption	47 Nm^3/t
Total natural gas consumption	6 Nm^3/t
Electrode consumption	0.9 kg/t

performing a yearly production of 1,650,000 t with one EAF only!

After three years of success and really outstanding performance, the Icdas group decided to build a parallel



Capacity:	220 t
Shell diameter :	8.7 m
Charging volume:	280 m^3
Transformer:	230 MVA @1600 V
Reactor:	1 Ω/ph
Injectors:	8x8 MW
	8x3500 Nm^3/h
C injectors:	4x80 kg/min
UHCP:	0.41 MW/MW
Electric density:	3.1 MW/m^2
Radiation index:	280 kWV/cm^2
Injection density :	127 $Nm^3/h/t$

Fig. 6. BRT box and carbon injector installed on the EAF shell

meltshop and to sign a contract with Concast for a new furnace, based on a 220 t of tapping capacity, designed to reach a total yearly production of approx. 2,300,000 t/y [6]. It will be commissioned in summer 2008.

The distribution of the injectors in the shell is based on eight injectors with two of them installed in the EBT area.

Even if in the sketch, it seems that the injectors are too close, in reality, with a circumference of 27 m we have an injector (of 8 MW) every 3 m. This means an injection power density of approx. 2 MW/m of shell circumference!

Each injector is installed in a very low position according to the "near to steel" concept.

Due to the requirement to maintain the power-on time at less than 32 minutes, the average electric active power input will be in the region of 145 MW.

It can be obtained using a suitable transformer with an incredibly high apparent power of 230 MVA and secondary voltage ranging from 1600 V to 800 V.

A reactor with 1 Ohm/phase reactance, equipped with an on-load tap changer is considered to be very helpful to guarantee smooth and stable arcing conditions within a complete working range.

Since the primary currents will be close to 3200 A, a solution with two parallel circuit breakers will be necessary.

At this point the issue of tolerable arc lengths and maximum-permitted Radiation Index needs to be revised introducing equivalent expressions including further variables such as the electric energy input, the arc coverage index related to the foaming slag management and the specific oxygen injection density.

Using the solid UHCP EAF operational experience gained so far and adopting extrapolation methods, it is possible to forecast the performance data of this "giant" size EAF on values very close to the Icdas Biga #1 EAF.

6. Conclusions

Experience gained with the execution of the latest UHCP EAF projects have proved that it is possible to design furnaces capable of having a thermal efficiency higher than before and a cycle time in the order of 30 minutes.

The main technical points discussed can be resumed as follows: a higher capacity to withstand increased electric power input; an injection system that can be installed "near to steel" without negative reliability results and an EAF geometry that favours a better thermal balance of the furnace.

Furthermore, this design can be realised without undue risk, thanks to the fact that all previous technological limitations, such as the intensive utilization of oxygen technology or the application of electric power input greater than 1 MW/t, have been successfully resolved as can be seen in the Nucor Texas and in the Icdas furnaces.

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