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SUCCESSFUL START-UP AND BENCHMARK OPERATING RESULTS OF 100-T FASTARC® EAF AT KOSCO, KOREA[1]

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Abstract
A new 100-t, full-platform, split-shell AC EAF is operating at the Kosco meltshop in Busan, South Korea. Start-up of the plant was successfully completed in May 2009. Excellent performances in terms of productivity and consumptions were steadily reached after just 80 heats. The outstanding results (131 t/h productivity with 354 kWh/tls, 29 Nm^3/tls oxygen) have been obtained through optimal choice of oxygen and carbon injection systems (Fastarc® technology) and high efficiency of electric energy supply, both supported by a reliable automation system for process control.
Key words: EAF; injection technology; emissions

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1 INTRODUCTION

Evolution of electric steelmaking is directed towards higher productivity and improvement of energy savings. The capability to handle high power input in an EAF throughout the process depends on efficiency and reliability of injection technology. A proper utilization of chemical energy improves arc efficiency and results in a decrease of electrical consumption due to high thermal yield of oxidation reactions.
The choice of the best energy input balance depends on factors such as the price of the different energy sources and local regulations concerning emissions into atmosphere. Injection package should therefore be designed in order to allow for enough flexibility of utilization. In this paper, the operation of 100 ton EAF operating at Kosco – South Korea is described, focusing on the relevant results obtained in terms of energy consumptions. In particular, the effect of two different energy input mixes is examined, focusing both on process efficiency and environmental impact in terms of CO_2 emissions.

2 EAF MAIN FEATURES

The main geometrical data of the furnace are reported in Table 1.

Table 1 – Main EAF geometrical data

Lower shell diameter	6.5 m
Total volume	128 m^3
Height of panels	3 m
Pitch circle diameter	1250 mm
Electrodes diameter	610 mm

Figure 1 - Kosco 100-t Fastarc AC electric arc furnace and ladle ready to be transferred to the steel refining station.

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The EAF is based on an eccentric bottom tapping (EBT), split-shell, full platform design. It works keeping a hot heel of 15 t, with a tapped weight of 100 t. Power is supplied through conductive arms by a 100 +10% MVA transformer; the melting program is based on a two-buckets practice. The following charge mix has been used during start-up:

Table 2 – Charge mix during start-up

Cast iron (motors)	5 %
Turnings	10 %
Busheling	15 %
Return scrap	20 %
Light scrap	50 %

The EAF is equipped with innovative, energy saving panels, specially designed to decrease heat losses to cooling water (Fig. 2), and at the same time to last longer (up to 20,000 heats) because of reduced thermal stress. The water-cooled panels are made up of a coiled tube arranged on two surfaces, whose design makes it possible to entrap slag, which acts as a heat insulator. This solution also makes it possible to reduce the cooled surface exposed to radiant heat by 50%. Seamless pipes are used to avoid breakage points and water leakages, and to increase panel life and operational safety.

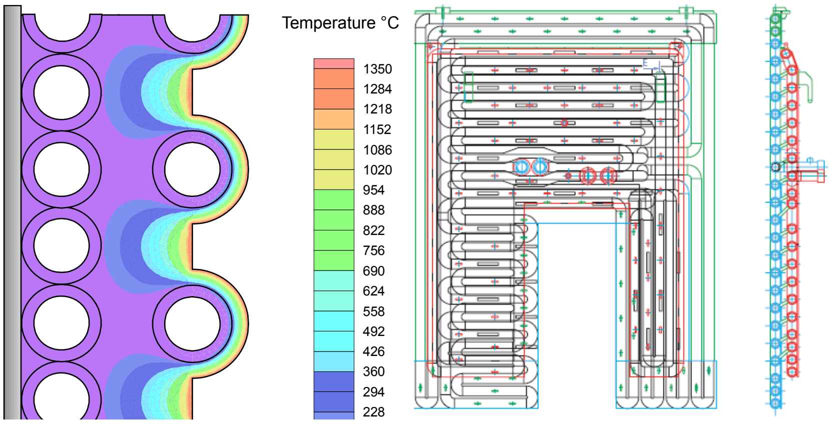

Figure 2 – Energy saving panels: design and temperature gradients.

3 ELECTRICAL PART

The AC EAF is supplied by a MV line characterized by a frequency of 60 Hz and a rated voltage of 22 kV. The EAF transformer has a rated apparent power of 100 + 10% MVA and allows the operator to select up to 19 tap positions, based on the best combination of arc tension, arc current and power factor during the various process stages. A series reactor is installed in order to increase the circuit reactance (rated inductance 1.25 mH, rated reactance 0.47 Ω, 6 tap positions). The maximum power achieved is 80 MW. The electrode control package HiReg®Plus guarantees power delivery in stable and reliable conditions. In particular, the ability to evaluate arc stability and slag coverage by realtime harmonic monitoring provides effective supervision of preset operating points and makes it possible to check for optimal slag foaming.

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4 FASTARC® INJECTION TECHNOLOGY

The furnace is designed with the FastArc® injection system, which allows metallurgical reactions to be carried out efficiently and homogeneously. In addition, optimal modules layout and injection profiles result in adequate slag foaming from the very earlier stages of the process, with an increase in heat transfer from the arc to the melt, and protection of refractories and panels from thermal stress. The modules layout is reported in Figure 3. Both oxygenjets and carbonjets act as burners in the first stage of each bucket melting, in order to clean areas in front of injectors from scrap and allow oxygen and coal injection in the following phases. The injectors are designed to obtain high efficiency during all stages of the process.

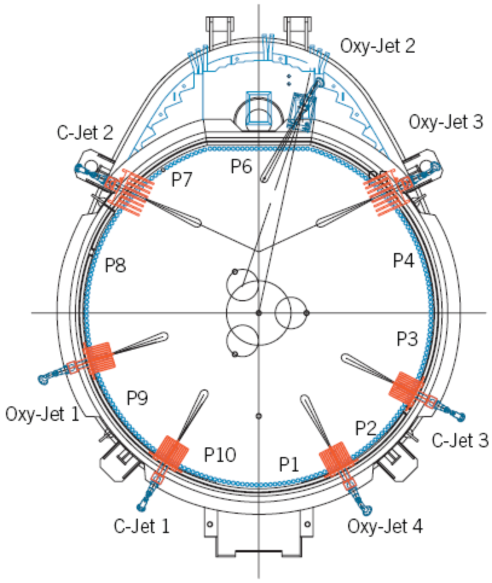

Figure 3 - Injection modules layout.

As shown in Figure 5, during burner phase oxygen and fuel are fed through the external nozzles, while central nozzles are used during lance phase. Nominal capacity of injectors is reported in Table 3. Injectors are installed on copper, water cooled bulged panels (Figure 4), which make it possible to place the modules closer to the bath, ensuring easier penetration into the melt and at the same time protecting against scrap collapse. The ROBOX consumable lances manipulator is used to inject oxygen and carbon from the slag door. The package allows forward and backward movements, as well as variation of the angular position. The CATFIS package is used for automatic temperature and steel sampling.

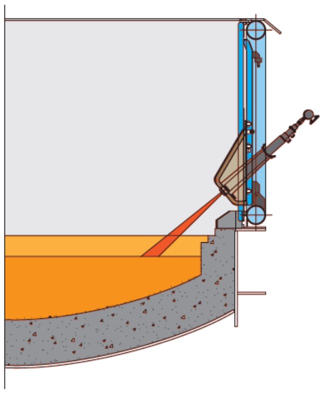

Figure 4 - Oxygenjet installed on a water-cooled, copper bulged panel.

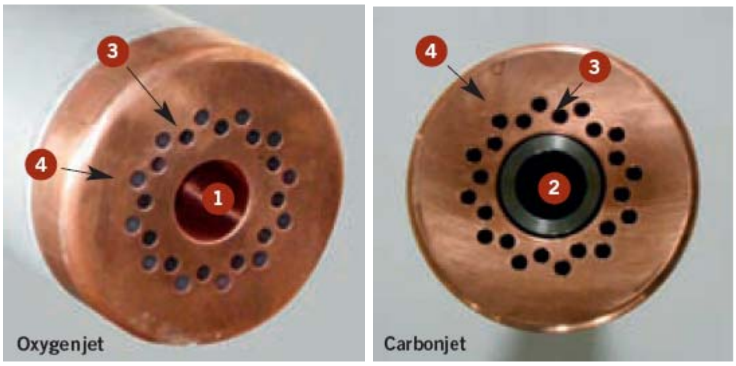

Figure 5 - Oxygenjet and Carbonjet tip design: 1-oxygen, lance phase, 2-carbon, 3-fuel, 4-oxygen, burner phase.

Table 3 – Injectors capacity

Module	fuel	Oxygen, lance	Oxygen, burner	Carbon	Power, burner phase
Oxygenjet	4 x 350 Nm^3/h	4 x 1800 Nm^3/h	4 x 800 Nm^3/h	-	4 x 3,5 MW
Carbonjet	3 x 350 Nm^3/h	-	3 x 800 Nm^3/h	3 x 30 kg/min	3 x 3,5 MW
Oxygen lance	-	2 x 1000 Nm^3/h	-	-	-
Carbon lance	-	-	-	1 x 30 kg/min	-

5 MELTING PROFILE

All injectors are used as burners during the first phases of buckets melting. At the beginning, oxygen to gas ratio is kept lower than stoichiometric (O_2: 480 Nm^3/h, gas: 250 Nm^3/h) in order to obtain a hot flame that preheats the scrap, with reduced power to avoid risk of backflame. The preheating allows increasing power and oxygen to gas ratio (O_2: 800 Nm^3/h, gas: 350 Nm^3/h) in the last burner phase. In the final stage of buckets melting Oxyjets 1-3 are used in lance mode (feeding through central nozzle) at 1000 to 1500 Nm^3/h, together with coal injected by the three carbonjets (15 to 25 kg/min). During refining, all oxygenjets work at their nominal flowrate (1800 Nm^3/h) and even the two door lances are employed (1000 Nm^3/h each). In this phase, optimal slag foaming is reached by means of efficient coal injection from carbonjets 2-3 and door lance (30 kg/min each).

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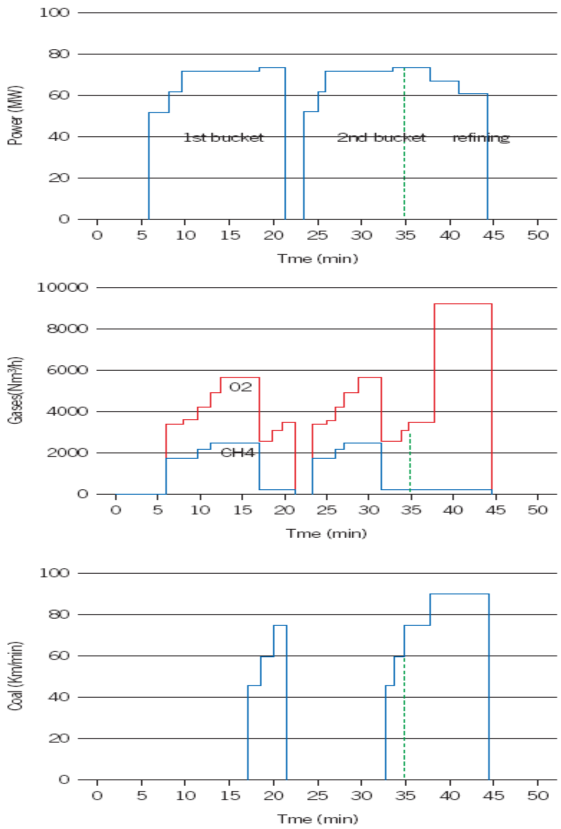

Figure 6 - Melting profile showing active power input and alternative energy input.

A pilot flame (O_2: 160 Nm^3/h, gas: 70 Nm^3/h) is maintained for all carbonjets in order to keep clean the area in front of modules. Regarding the slagbuilders, 1,5 t of lime and 700 kg of dololime are charged during the 1st bucket melting whereas 1,5 t of lime is charged during 2nd bucket melting. Both additives are charged through the 5th hole.

6 EXCELLENCE OF OPERATIVE RESULTS

Thanks to excellent work of the modules equipment and an outstanding mechanical stability of the whole machine, contractual parameters have been performed in a very short time during the start-up (Figure 8).
High production rates were achieved immediately giving to the furnace a good thermal steadiness and allowing the fine tuning of the system, so that contractual requirements were reached and even improved in less than one month after the hot tests.
In particular, the reliability of Hireg®Plus for automatic control of electrode position has been effective from the early heats in allowing stable power supply, and therefore reduced power-on. In Figure 9 a typical trend of active power during the melt is reported. The achieved maximum power varies from 75 to 80 MW, whereas the average power is 67 – 68 MW during the melting phase and 62 – 63 MW during the refining phase. The relevant results obtained in terms of productivity and specific consumptions are summarized in Table 4.

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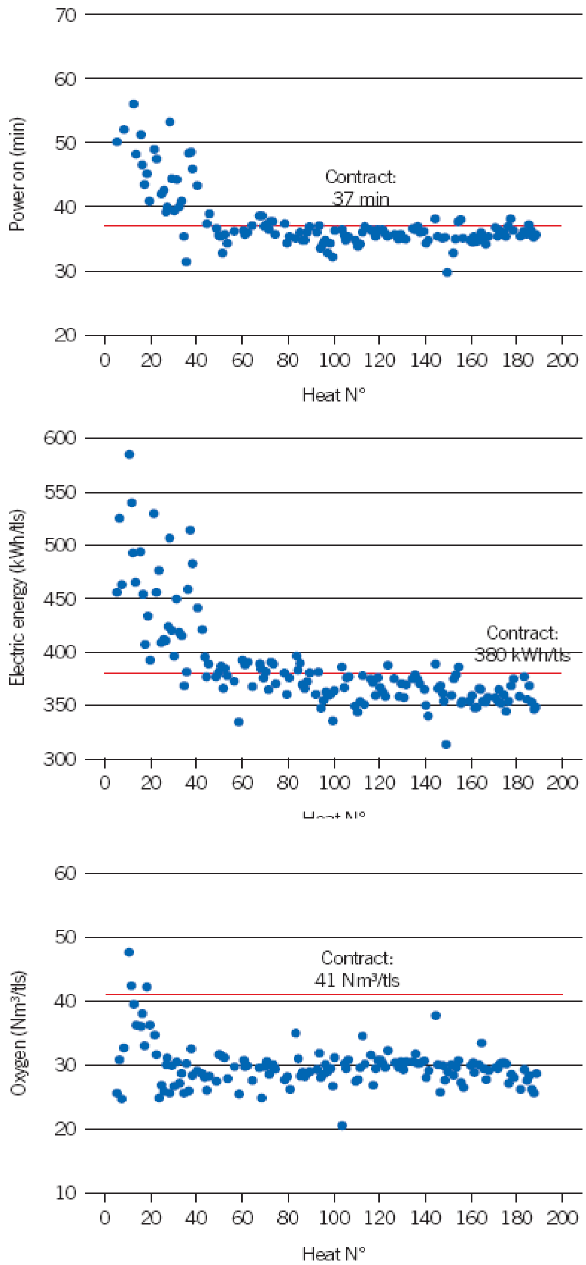

Figure 7 - Successful start up in less than 100 heats (20 days).

Table 4 – Comparison between contractual values and operative results

	Contract	**Best results** (based on daily average)
Tap to tap (min)	48	45,4
Power on (min)	37	34,7
Productivity (t/h)	125	131
Electric energy consumption (kWh/tls)	380	354
Oxygen consumption (Nm^3/tls)	41	29,4
Elecrodes consumption (kg/tls)	1,45	1,37

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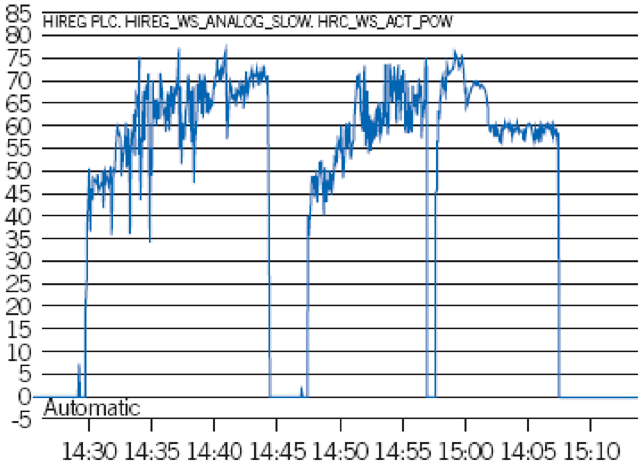

Figure 8 - Active power trend.

7 FLEXIBILITY IN CHEMICAL ENERGY UTILIZATION

Performances show that the best efficiency of energy input has been achieved. In particular, the thermal yield of injected oxygen is very high. According to results of process simulation, the heat released by exothermic reactions during O_2 lancing phase is 5 kWh/Nm^3. This is due to optimized configuration of modules and melting profile, which makes it possible to achieve the maximum efficiency in every stage of the process; and to the particular charge mix with appreciable quantities of elements to be oxidized (due for instance to cast iron). In Figure 10, the several chemical energy inputs are compared, based on mass and energy balances for heats 160-190 (average specific consumptions are reported in Table 5). The evaluation has been done considering for carbon and fuel the theoretical energy input resulting from complete combustion to CO_2.

Table 5 - Average specific consumptions (heats 100-190, after start-up)

		average
Electric energy consumption	kWh/tls	363
Fuel	Nm^3/tls	6,7
Oxygen consumption	Nm^3/tls	28,6
Coal (charged)	Kg/tls	9,8
Coal (injected)	Kg/tls	9,6

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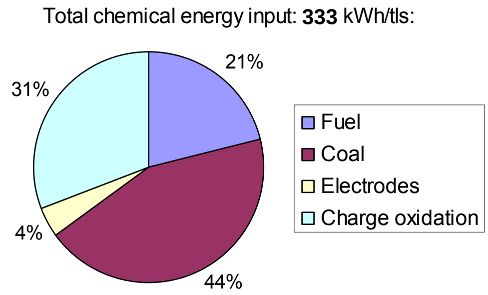

Figure 9 - Chemical energy sources (heats 100-190, after start-up).

The most recent data collected show that a different chemical energy mix is now adopted: one year after start-up, energy inputs and specific consumptions are reported in Figure 11 and Table 6.

Table 6 - Average specific consumptions (one year after start-up)

		average
Electric energy consumption	kWh/tls	378
Fuel	Nm^3/tls	1,9
Oxygen consumption	Nm^3/tls	27,3
Coal (charged)	Kg/tls	0
Coal (injected)	Kg/tls	14,5

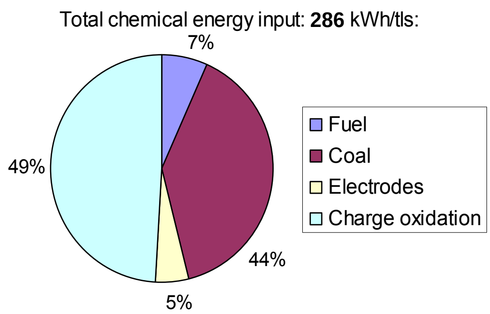

Figure 10- Chemical energy sources (one year after start-up).

Decreasing chemical energy input from 333 kWh/tls to 286 kWh/tls, electric energy consumption has only slightly increased (+15 kWh/tls). This means that energy efficiency, expressed as a ratio between liquid steel enthalpy and total energy inputs (chemical and electric) has been raised up from 55.1 to 57.7%. This result is related to the increase of energy input from oxidation of metallic elements of the charge (+38 kWh/tls) which compensates for the lower theorical input from fuel and coal (-85 kWh/tls), even if this alone cannot explain the only limited increase in electric consumption. In fact, a drawback of high utilization of energy from elements oxidation is improper composition of slag and therefore risk of poor foaming. In Figure 12, slag properties are reported on the solubility diagram.

Table 7 - Slag properties (2010)

compound	Composition (%)
CaO	28,3
MgO	6,9
SiO_2	17,2
Al_2O_3	8,6
FeO	27,9
MnO	9,7

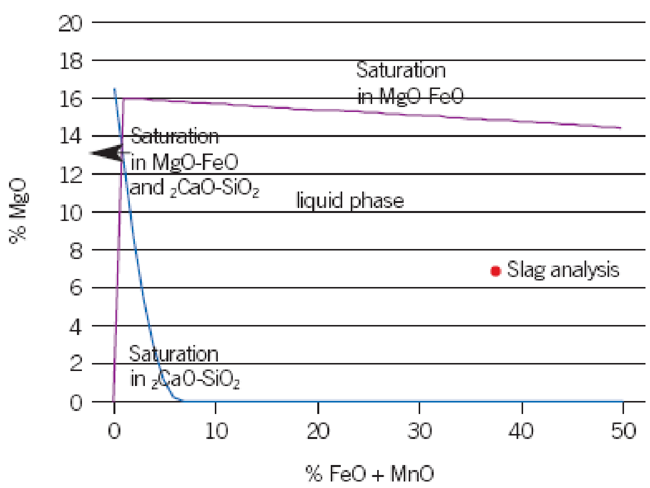

Figure 11 – Slag properties (2010)

In theory, slag composition that results from the new practice is excessively fluid, so that it should be difficult to make it foam. Basicity indexes are rather low:

Table 8 – Basicity indexes

IB2	CaO/SiO_2	1,6
IB3	$CaO/(SiO_2+Al_2O_3)$	1,1

Nevertheless, this does not decrease heat transfer efficiency from the arc to the bath. Most probably, this is a consequence of a proper utilization of oxygen and carbon injection, due to optimal design and layout of injectors that leads to adequate foaming in different process conditions, and therefore allows flexibility in terms of the energy mix that can be employed.

8 FASTARC® INJECTION TECHNOLOGY AND MINIMIZATION OF CO_2 EMISSIONS

The recent performance results of the Kosco EAF show that Fastarc® injection technology can be successfully employed to reduce global CO_2 emissions, related to both electrical and chemical energy employed. This consideration results from the comparison of consumptions during start-up and one year later, related to the two different energy input practices allowed by the flexibility of modules utilization. In the following table the CO_2 generation associated with the several energy sources is reported, for both practices adopted. The significant decrease of fuel and coal consumptions has lead to lower CO_2 production. This is made possible because of

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the limited increase of electric energy due to high rangeability and efficiency of injection technology that has allowed an optimal utilization of energy from elements oxidation. In the evaluation, a value of 0.52 kg CO_2/kWh of electric energy has been considered, which is valid for South Korea. As a consequence, the decrease in annual CO_2 global emissions, based on 0,8 Mt/y productivity, is 11,800 t/y (19,200 t/y considering only the meltshop). This is a significant result, considering the relevance of issues related to environmental impact of fossil fuels utilization.

Table 9 - Global CO_2 emissions related to different energy inputs

	Start-up		One year after start-up	
	Energy input (kWh/tls)	CO_2 (kg/tls)	Energy input (kWh/tls)	CO_2 (kg/tls)
Electric energy	363	189	378	197
Fuel	70	13	19	4
Coal	146	60	113	45
Charge oxidation	103	16	141	16
electrodes	14	5	13	5
Total	696	283	664	267

9 CONCLUSIONS

The start-up of the 100 t, AC EAF at Kosco's new meltshop represents a great success for Danieli, since not only a very short time has been needed to achieve steady furnace performances, but also specific consumptions that have been reached are significantly lower than expected. Within 20 days (100 heats) the process has been optimized thanks to the reliability of all the mechanical equipment and of the automation system. In particular, from the early heats the Hireg®Plus control package has allowed a stable power supply, with power-on time 2 minutes lower than the contracted value. The efforts made in the design stage to obtain high efficiency of energy utilization (proper sizing and arrangement of injection system - Fastarc® technology – and installation of energy saving water cooled panels) has resulted in very low electric energy consumptions (354 kWh/tls), still obtained with 29 Nm^3/tls of oxygen (12 Nm^3/tls less than foreseen). One year after start-up, excellent operative performances are still being constantly obtained. Efficiency and rangeability of Fastarc® injection technology, as well as higher energy input from charged elements oxidation, has led to further reduction of fuel, oxygen and carbon consumptions (-4 Nm^3/tls, -2 Nm^3/tls, - 5 kg/tls respectively), with limited increase of electric energy demand (+15 kWh/tls). This result has been reached despite the presence of a slag that, in principle, should not be adequate for foaming because of consistent amounts of fluxing oxidized compounds, but that actually foams efficiently thanks to homogeneous generation of fine bubbles inside the bath due to optimal injection fluodynamics. With this practice, further reduction of Kosco EAF emissions has been achieved (19,200 t/y of CO_2 less than one year before). The positive impact on the environment concerns not only the meltshop, but is valid on a global scale since electric consumption has not significantly increased. As a matter of fact, considering the average efficiency of power stations in South Korea, release of CO_2 into the atmosphere has been decreased by 12,800 t/y.