ELECTRIC ARC FURNACE SIDE-WALL FIX INJECTORS[1]
DEVELOPMENTS AND OPERATIONAL RESULTS

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Abstract

The Electric Arc Furnace continues to evolve into a highly efficient melting unit, using less electric energy and more carbonaceous fuel generated energy. In recent years, steel-makers have looked for chemical energy injection systems to reduce the energy cost, to promote more stable and predictable chemical reactions into the melting process so as to achieve better recovery rates and improve conversion costs as a final result. The improved practice includes: • Side-wall injection of carbon, oxygen and lime through multiple fixed lances that allow a closed furnace operation. •Calibrated additions of carbon, oxygen and lime to optimize FeO content in the slag, improve foamy slag characteristics and lower residual tramp gasses into tapped steel. •Precise control of oxygen injection to satisfy chemical energy exothermic reactions. The evolving technology deploys furnace side-wall fixed units that can act as high-fire burners and multi-stream supersonic jets of oxygen and powdered solids. Although several manufacturers supply systems that provide injection of oxygen for successful decarburisation and for oxidation reactions, the efficient injection of solids, such as fuel carbon and foaming carbon, or lime and dolomite for slag conditioning, has always represented a challenge. MORE has recently developed new coaxial injection systems, based on BOC Gases original patented technologies, that shroud and enhance solids propulsion with supersonic oxygen and/or flame. A reduced number of injectors, that require low capital investment and minimal maintenance costs, ensure now a much better recovery rate of all injected solid particles. The application of the new injection technologies, and related operational results achieved in several EAF with different charge mixes, are herein described.

Key words: Chemical energy; Foaming slag; Supersonic oxygen injection; Sonic carbon injection; Lime injection.

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CHEMICAL ENERGY TECHNOLOGY CONCEPT

Early advances were made in the use of oxygen in the EAF by substituting retractable door or side wall lances with fixed injectors placed at strategic positions in the furnace side walls and recently onto EBT sump panels. Many devices, that combine burner mode and oxygen injection have improved overall energy balance, foamed slag conditioning and metallic yield. While most of the available systems on the market provide effective oxygen injection for decarburisation and oxidation reactions, the efficient injection of solids, such as fuel carbon and foaming carbon, or lime and dolomite for slag conditioning, has been a challenge.
MORE, in the last years, has considered oxygen injection efficiency improvement in the EAF melting process intimately associated to solids injection (carbon and fluxes) as the corner stone for additional improvements related to conversion cost and metallurgy.
MORE chemical energy technology includes a variety of fixed injectors, and related control devices, i.e.: valves stands, carbon/lime dispensers, automation system, that deliver an advanced burner flame then supersonic oxygen, carbon fines for two applications ("deep" into the steel and "soft" into the slag) and fluxes (lime or dololime into the slag).

The equipment on board of the EAF shell is made-up of four different tools, each developed to satisfy a very specific requirement of the melting process:

1. HI_JET : for the injection of the carbon fines at high speed (provides the same benefits of a submerged carbon/oxygen tuyere with the advantage that it is installed into a water cooled panel and not into the refractory lining). This equipment injects the carbon fines shrouded in an annular supersonic stream of oxygen. As a result the highly coherent, high speed (> 400 m/sec) injection of the carbon fines penetrate into the steel bath. High energy recovery is obtained associated with the ability to precisely control steel final C.
2. OXYGENJET : for supersonic oxygen injection. This injector delivers a highly coherent supersonic stream of oxygen that penetrates into the steel bath for C oxidation and other oxidizing reactions in the steel/slag interface.
3. CARBONJET: for low speed carbon injection. The carbon injection into the slag promotes FeO and MnO reduction with consequent early slag foaming metallic yield better control.
4. LIMEJET: for the injection of the fluxes into the slag. Typical injected solids are lime and/or dololime used to control slag chemistry and foaming of it (V-ratios).

All the above mentioned tools work as high efficiency oxy-fuel burners (up to 4 MW) for heating and assisted melting of scrap after each scrap bucket charge. The burner mode is of primary importance in the EAF melting process; it must transfer heat efficiency to the scrap pile that supports subsequent scrap melting. Each burner flame prepares the area in front of the injector by creating a cavity where oxygen and "deep" carbon will be injected into the liquid pool and "soft" carbon and fluxes will be injected into the slag.

From the melting process point of view, the use of two separate carbon injection tools (Hi_Jet and CARBONJET) with flow-rate precise control and dedicated dispensers, simultaneously create a great amount of exothermic chemical energy by the combustion of C to CO in the liquid bath and retain it in the slag/steel interface by the early and excellent foamed slag generation. Moreover, the foamed slag becomes the vehicle that transfers and distributes the chemical energy generated over the entire liquid steel surface.

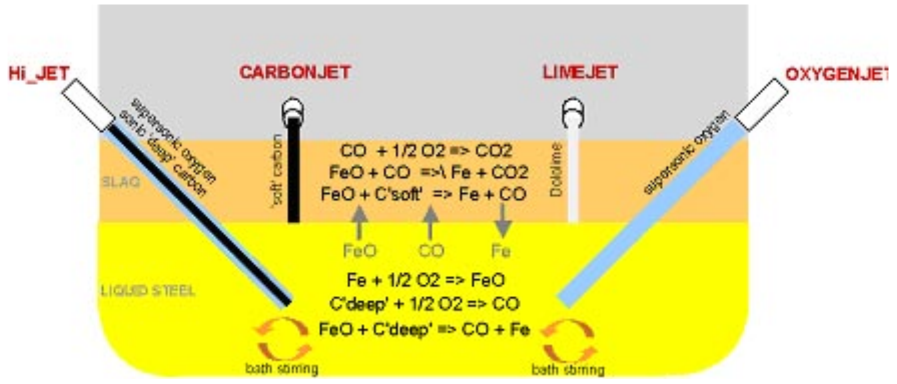
The following main exothermic reactions are created in the liquid steel by ‘deep’ carbon injection:

$C + ½ O_2 = CO$
$FeO + C = CO + Fe$

In the slag interface, the injection of ‘soft’ carbon creates the following main reactions that condition slag foaming, reduce the FeO and also deliver energy:

$FeO + C = CO + Fe$
$C + CO_2 = 2CO$

The adoption of HI_JET units, with carbon recovery of about 95%, has eliminated or considerably reduced the need for carbon in the bucket. With “deep” carbon injection it is now possible to have a better control of the oxygen activity (O_2 ppm) in the steel (with consequent alloys savings) and recarburisation is also feasible.



Picture-1

HI_JET “deep” carbon injection is also associated to DRI/HBI charges to compensate for low carbon content in the charged material. This tool eliminates the practice of charge carbon via the roof or into the scrap bucket.

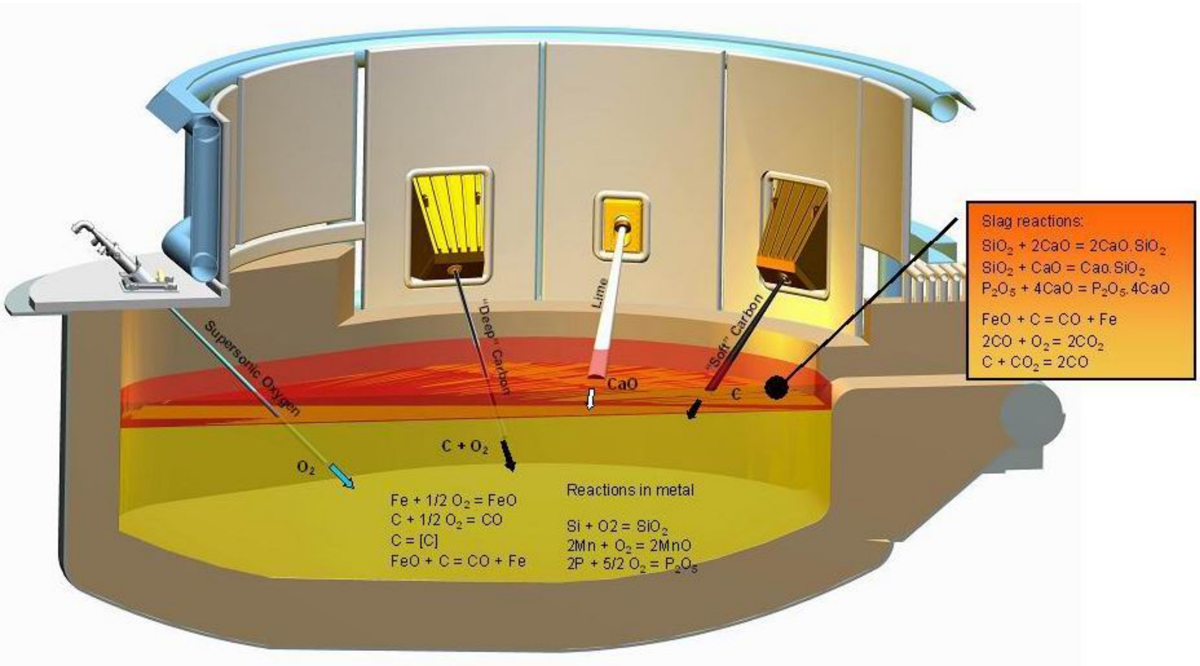
The installation of OXYGENJET injectors allows the oxidizing exothermic reaction into the steel bath, into the slag layer and the post-combust CO as shown in pictures 1 and 2 to be generated.

Due to the high kinetic gas and solid fines streams that penetrate into the liquid steel, HI_JET and OXYGENJET injectors promote bath stirring that eliminates temperature and chemistry stratification.
Picture 1 (above) summarizes the main reactions in the steel and slag associated to the use of Hi_JET, CARBONJET and OXYGENJET injectors.

It is now possible to achieve optimum control and conditioning of foamed slag chemistry with the injection of lime/dololime fluxing materials into the slag by way of the LIMEJET injector and its associated dispenser.

This injector allows maximum flexibility to satisfy materials quantity over injection time available. The possibility to inject fluxes efficiently also during the superheating phase is critical to manage slag basicity (content of CaO, MgO). Fluxes injection at that time is also the key to retain foamed slag, with process overall associated benefits, because it neutralizes the temperature and FeO high levels that are reached shortly before tapping.

Picture 2 below shows a typical installation of injectors in an EAF EBT shell; it also summarizes the main reactions that take place in the steel and slag by use of Hi_JET, CARBONJET, OXYGENJET and LIMEJET injectors.



Picture-2

MORE INJECTION SYSTEMS OPERATIONAL RESULTS

MORE's long term experience together with the new injection tools described above are at work in several EAFs with different shell design, mix charge and tapped steel characteristics. Several examples of recent applications of the MORE Injection Technology are outlined below (all specific indexes refer to tapped weight).

North Star Bluescope Steel (Delta, OH, USA) - Ton means Metric Ton

EAF type	AC twin shell twin shaft arc furnace
Heat size (tapping)	170 ton
Nominal shell diameter	7300 mm
Transformer rating	140 MVA
Productivity	2.2 Mton/year of hot rolled band
INJECTION TOOLS	2 Hi_JET 1 OXYGENJET 1 CARBONJET 6 BURNERS
Power On [min]	38
Electrical Energy [kWh/Ton]	319
Electrode [Kg/Ton]	1,1
Total Oxygen [Nm^3/Ton]	44,4
Total Natural gas [Nm^3/Ton]	11
Roof charge carbon [Kg/Ton]	2,9
Injected Carbon [Kg/Ton]	11,8
Total carbon [Kg/Ton]	14,7

Average data as of October 2005

Duferco La Louviere (Belgium) - Ton means Metric Ton

EAF type	DC, EBT, 4 billet anodes
Heat size (tapping)	90 ton
Nominal shell diameter	6590 mm
Transformer rating	99 MVA
Charge	100% Scrap – 2 Buckets charge
Productivity	1 Mton/year of wire rod and coils
INJECTION TOOLS	4 Hi_JET 1CARBONJET 1 LIMEJET 2 BURNERS
Power on time [min]	31
Electrical Energy [kWh/Ton]	354
Electrode [Kg/Ton]	1,1
Total oxygen [Nm^3/Ton]	43,0
Total natural gas [Nm^3/Ton]	5,5
Bucket charge carbon [Kg/Ton]	8,9
Injected carbon [Kg/Ton]	16,5
Total carbon [Kg/Ton]	25,4

Average data as of September 2005

Gerdau Ameristeel Knoxville (TN, USA) - Ton means Metric Ton

EAF type	AC, EBT, CONSTEEL®
Heat size	55 t
Nominal shell diameter	5100 mm
Transformer	45 MVA
Charge	100% Scrap – Continuous feed
Productivity	600.000 ton/year of rebars
INJECTION TOOLS	1 Hi_JET 1 OXYGENJET 1CARBONJET
Power on time [min]	43
Electrical Energy [kWh/mt]	358
Electrodes [Kg/mt]	1.90
Total oxygen [Nm^3/mt]	36.5
Natural gas [Nm^3/mt]	2.6
Injected tot. Carbon [Kg/mt]	30

Average data as of December 2005

Charter Steel (Saukville, USA) - Ton means Metric Ton

EAF type	DC, EBT, Pins bottom anode
Heat size	91 t
Nominal shell diameter	5000 mm
Transformer	2 x 42 MVA
Charge	100% Scrap – 2 Buckets charge
Product	600.000 ton/year of SBQ steel grades
INJECTION TOOLS	1 Hi_JET 2 OXYGENJET 2 CARBONJET 1 LIMEJET
Power on time [min]	45
Electric Energy [kWh/mt]	418
Electrode [Kg/mt]	2.1
Oxygen [Nm^3/mt]	32.7
Natural gas [Nm^3/mt]	2.6
Bucket charge carbon [Kg/mt]	19.9
Injected carbon [Kg/mt]	15.1
Total carbon [Kg/mt]	35

Average data as of October 2005

INJECTORS TECHNICAL AND SCIENTIFIC ASPECTS

During the last three years, MORE R&D specialists have been focused to review the performances of each injection tool. As a result, a new generation of extremely efficient injectors that can satisfy the challenge of advanced fixed wall injection requirements, has been developed, tested and put into industrial service.

Within the EAF melting process MORE identified four different operating requirements that were in need of fine-tuning and optimization in order to maximize injectors' individual performances:

1. Burner mode – satisfied by all injectors.
2. Supersonic-coherent oxygen injection – satisfied by OXYGENJET injector.
3. Carbon fines ‘soft’ Injection (slag level) – satisfied by CARBONJET injector.
4. Supersonic oxygen associated with deep carbon injection (liquid steel level) – satisfied by HI_JET injector.

1. BURNER MODE.

Each injector can generate a flame of oxygen - natural gas of up to 4MW capacity. A specific research project has been performed to improve combustion and heat transfer efficiency to the scrap surface. The result is a PSF (Premixed Swirled Flame) optimized for each type of injector. The peculiar burner tip design dramatically improves the mixing of reactants and avoids the generation of a cold flame. Figure-1 shows the temperature field of a premixed swirled oxy-natural gas flame.

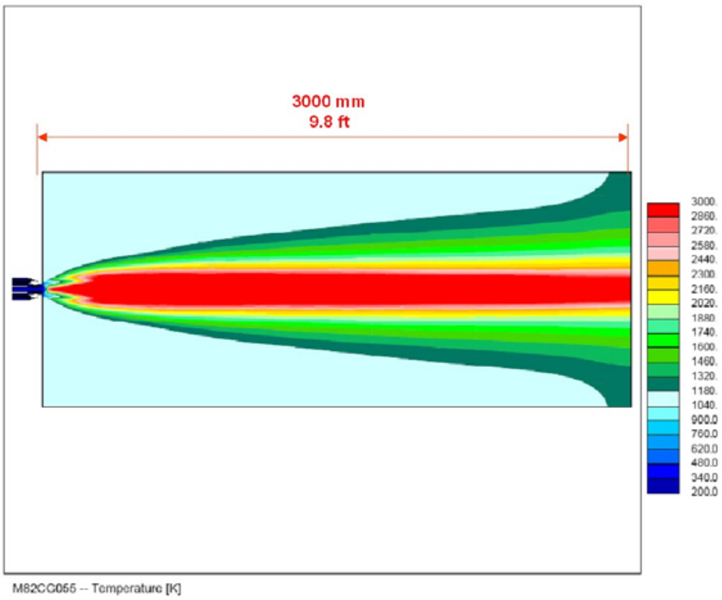


Figure-1

When cold scrap lays in front of the injector, non mixed oxygen can flashback and damage the injector and/or adjacent furnace wc panels. To avoid this side effect the reactants need to be ignited as close as possible to the injector tip. The PSF configuration develops a very hot flame close to the injector, improves flame stability and its heat transfer ability, especially to the scrap located in the injector area.

The PSF significantly helps to minimize the risk that unburned natural gas flows through the scrap pile producing endothermic reactions by cracking.

The new burner concept and design provides nozzle self cleaning capability. “On site” comparison with a standard diffusion flame burner, the new tip design has shown a huge advantage in terms of nozzle cleanliness after a significant number of heats (>600).

2. SUPERSONIC-COHERENT OXYGEN INJECTION - OXYGENJET.

This injector is capable of generating a highly coherent supersonic stream of oxygen that remains such up to the steel bath. MORE has developed a "Method of Characteristics with Boundary Layer Correction Code" to design the Asymmetric Supersonic Nozzle.

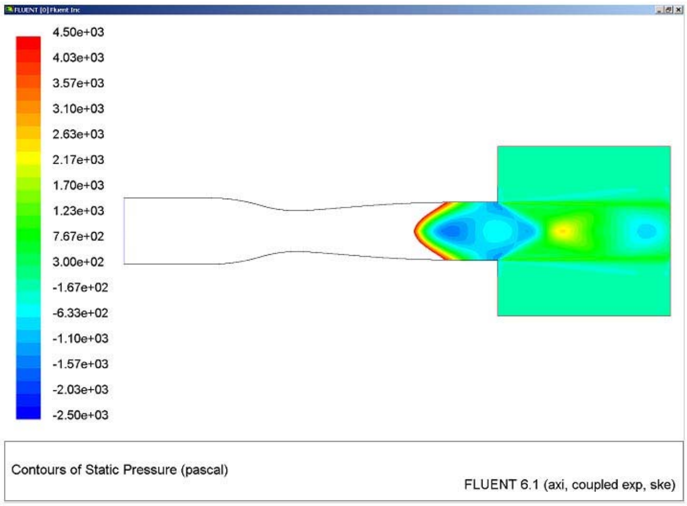
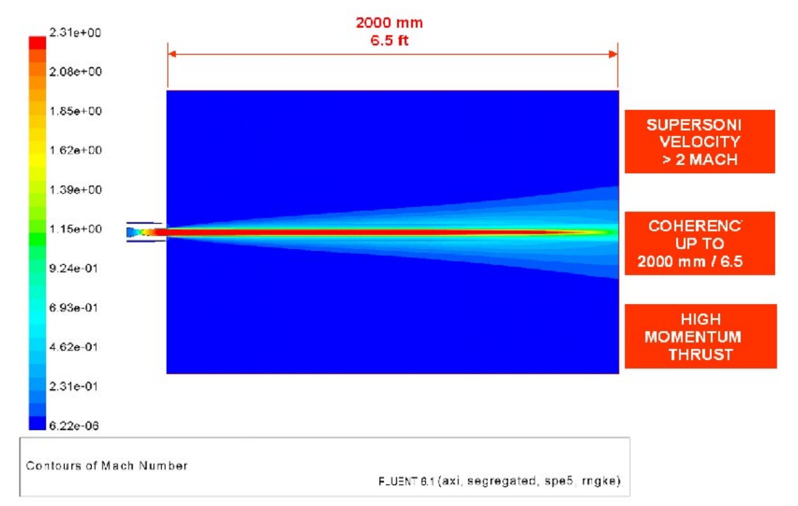


Figure 2

Nozzles designed with this code are practically shock-free, with static pressure at the exit section that perfectly matches the ambient pressure and the streamlines parallel to the injector axis. Figure 2 shows oxygen stream static pressure at the nozzle exit, the maximum pressure difference between the supersonic stream of oxygen and the ambient is only 0.04 bar (4000 Pa).

All these properties associated with the shrouding generated by CO post combustion within the EAF shell (carbon monoxide ranges between 20% to 40% during the injection of carbon and oxygen) allows to retain oxygen supersonic velocity up to a distance of roughly 2 meters. Figure-3 shows the oxygen stream characteristics.



The OXYGENJET injector, with low turbulence low energy loss nozzle, is usually positioned at a distance between 1.4÷1.6 meters from the steel bath (taken along the stream direction). The OXYGENJET injector does not need to use a natural gas flame to shroud the supersonic stream thus resulting in substantial savings of natural gas when compared to other oxygen injectors available on the market.

3. 'SOFT' CARBON INJECTION (SLAG LEVEL) - CARBONJET.

This injector is able to perform carbon fines injection in order to provide slag FeO reduction and subsequent CO gas generation for slag foaming.
The tool injects the carbon fines at low velocity in order to deposit the particles just inside the slag layer. Figure 4 shows carbon particles velocity and 3D spreading up to 3 meters.

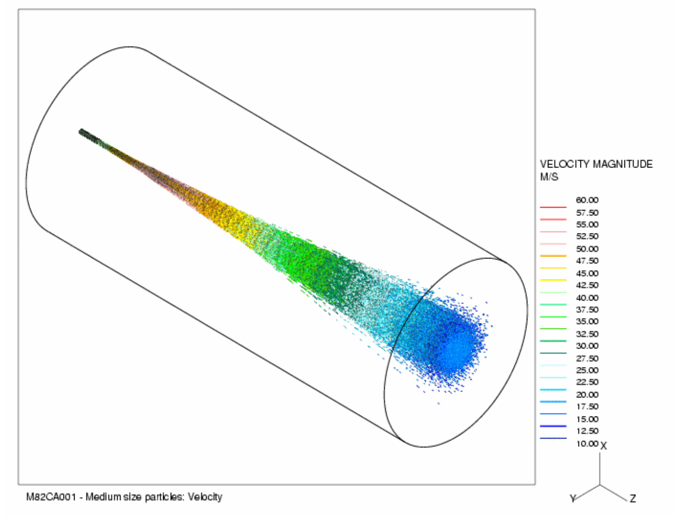


Figure-4

The injector has a wear-resistant pipe that withstands carbon particles abrasion effect. The carbon pipe tip, which is exposed to the thermal load of the furnace, is replaceable and made of wear and high temperature resistant material. It can be easily changed once it is damaged or worn out by the carbon. In the unlikely event of a "cold balloon" formation in front of the injector, the CARBONJET allows the injection of some oxygen to clean this area and to avoiding its clogging.

4. SUPERSONIC OXYGEN COMBINED WITH "DEEP" CARBON INJECTION – Hi_JET.

This unique injector, the concept of which is taken from an original BOC Gases patent, incorporates the latest developments of fixed injection. The peculiarity of this tool is the injection of the carbon fines embedded in an annular supersonic oxygen stream. Due to the high velocity oxygen stream, the carbon particles exchange momentum with the oxygen and increase their speed up to 400 m/s; figure-5 shows HI_JET carbon particles velocity up to a distance of 2 meters.

The carbon high velocity (about ten times that of soft injection) pierces through the slag layer and delivers the carbon particles directly into the molten steel without direct interaction with the slag. Figure-6 shows carbon particles stream shrouded by supersonic oxygen in the EAF. As a consequence all carbon particles react with the supersonic injected oxygen and bath dissolved oxygen. This method allows great control of the oxygen diluted into the steel, obtained by changing the injected carbon / oxygen ratios; similarly recarburisation is possible. Due to particles high velocity and momentum, the loss of carbon through the off gas duct becomes negligible, even if the injector is positioned directly under the off gas roof opening.

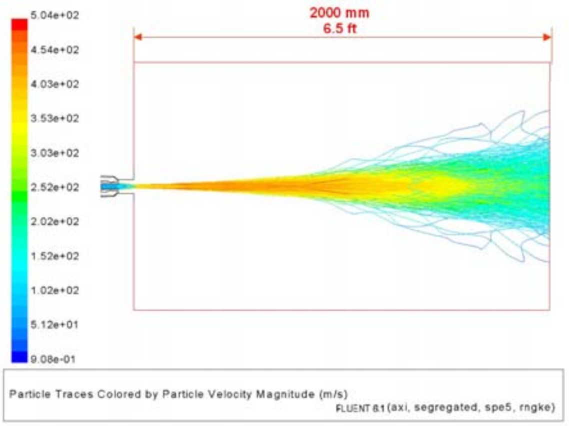


Figure-5


Figure-6

To inject oxygen and carbon in a coaxial mode, MORE has developed a “Method of Characteristics with a Boundary Layer Correction Code” for an Asymmetric Annular Supersonic Nozzle. The code, that differs from the OXYGENJET injector nozzle, also takes into consideration the effects of the coaxial carbon injection and produces a shock-free and nearly adapted supersonic oxygen stream.

All these properties, associated with the shrouding generated by CO post combustion within the EAF shell (carbon monoxide ranges between 20% to 40% during the injection of carbon and oxygen) allows to retain oxygen supersonic velocity up to a distance of roughly 1.6 meters. The HI_JET injector, with low turbulence low energy loss nozzles, is usually positioned at a distance between 1.4÷1.6 meters from the steel bath (taken along the stream direction). It does not need to use natural gas flame to shroud the supersonic stream; as a result substantial savings of natural gas are achieved.