Further advances in EAF efficiency with Pyrejet burner injection

American Combustion, a division of Air Liquide, has developed PyreJet – a proprietary multi-functional burner/injection system for the Electric Arc Furnace. With many patented design features, the system has shown considerable advantages in more than 17 installations with different operating conditions.

By* V Shifrin, A Popenov, L Coudurier, & M Devaux

Progress in the use of oxygen to aid combustion and decarburising in Electric Arc Furnace (EAF) operation has been an important factor in the growing popularity of the EAF in steel production. With the EAF share of the world total steel production predicted to rise from 33% in 1999 to an estimated 42-45% in 2010 (IISI), further gains in efficiency may well accelerate this rising consumption of oxygen.

Oxygen is now used for four key tasks in EAFs: through a lance for decarburisation; via injectors for post-combustion; via burners for scrap melting; and by injection to improve slag foaming through the generation of CO bubbles.

Employing a multi-functional, wall-mounted tool to perform all four of these tasks ensures a better furnace practice which can be used to reduce heat loss and help reduce steel melt nitrogen content and thus improve steel quality. Additionally, with injectors mounted in several different locations, decarburisation can be speeded and the homogeneity of temperature and chemistry in the steel bath improved.

The Air Liquide *ALARC-JET* has been successfully developed to inject oxygen at supersonic speeds to provide a highly impinging jet into the liquid bath at up to 1.8 metres. (See *Steel Times International* Jul 2001 p20). This can be adapted to a wide range of EAF conditions to provide the optimum configuration for any particular furnace, and especially for shaft furnaces or for an EBT balcony.

Multi-stream supersonic jet

Developed by American Combustion – now a division of Air Liquide – the *PyreJet* has taken supersonic oxygen jet design a stage further. This new proprietary multi-functional, multi-nozzle burner/injector system delivers efficient oxy-fuel combustion under EAF operating conditions. It enhances supersonic oxygen injection and carbon fines injection while providing useful post-combustion of carbon monoxide, slag foaming and melt refining.

Comparative trial installations show promising results in:

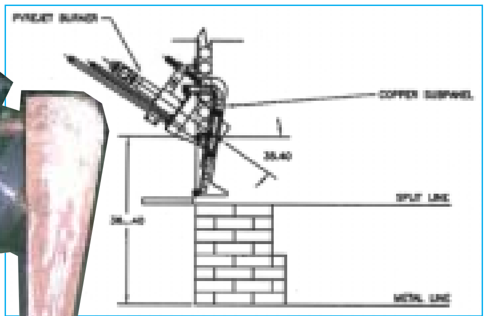
- Reductions in electrical power consumption;
- Reduction in power-on-time;
- Increase in active power input;
- Increased oxygen efficiency;
- Reduction in injection carbon;
- Reduction in refractory wear.

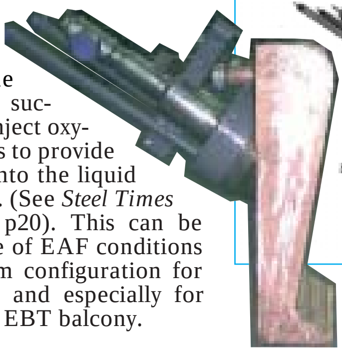
System description

The PyreJet burner/injector uses a water-cooled combustion chamber for the active staged mixing and burning of natural gas streams. The oxygen stream is discharged through a Laval nozzle at a supersonic velocity in excess of 2.0Mach. This enables the PyreJet to inject a tightly focused oxygen jet, which is capable of maintaining a supersonic velocity as far away as 1.8 m from the burner discharge nozzle.

Design & development

The PyreJet burner system is installed in several locations in the EAF to assist scrap melting and melt refining. Amongst other features, the installation includes two types of oxy-fuel burners – PyrOx(1) and PyreJet(1) – which are similarly designed and have the capability to melt and cut the scrap.





2a *A typical PyreJet installation*
2b *Photo of the PyreJet assembly*

The PyreJet burner employs water-cooled copper burner tiles on the furnace wall surrounding the burner, and a deep combustion chamber to control flame formation and flame shape, and to protect the gas and oxygen discharge holes from plugging with splashed slag and steel.

The PyreJet burner combustor is also equipped with a replaceable carbon injection pipe located near the burner centreline. This allows carbon to be entrained and driven into the slag by a highly inspirating supersonic oxygen stream at 2.1 Mach nozzle exit velocity (**Fig 1**).

It is preferable that the PyreJet burners be installed in water-cooled copper panels which can be seen in **Fig 1**. A typical PyreJet burner installation is shown in **Fig 2a**, with a photograph **Fig 2b** of the assembly.

1 *Pyrejet burner nozzle viewed from within furnace showing carbon pipe outlet and burner set in water-cooled copper wall tiles*

Operating theory

During supersonic lancing, a major portion of oxygen reaching the melt surface is consumed by the oxidation of carbon and iron, and by dissolution into the melt.

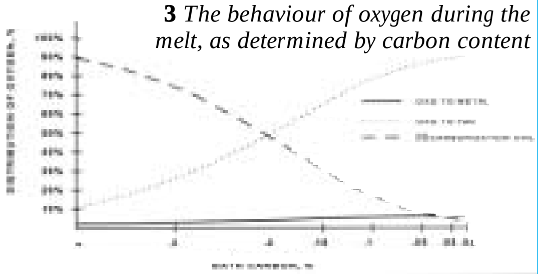
The carbon content of the melt and the melt temperature greatly influence the thermodynamic equilibrium, the distribution of oxygen participating in oxidation of melt iron, carbon and other alloying elements and the completion of the carbon oxidation. Due to competition for oxygen, only a small portion of CO can be oxidised to CO_2 at the melt surface. At the beginning of the refining period, when the melt carbon content is relatively high, nearly 90% of conveyed oxygen is consumed by decarburisation.

During the final stage of refining oxidation of iron becomes predominant. If extremely low tap carbon (0.02-0.03%) are required, as much as 90% of the oxygen will produce FeO (**Fig 3**).

At the end of the steel making cycle, if the intensive oxidation of iron were not counterbalanced by an adequate foamy slag practice, a significant yield loss and refractory erosion would take place due to the high FeO content and the high temperature of the slag.

The removal of carbon from the melt is accomplished in two stages. During the first exothermic stage, a film of iron oxide is formed whenever gaseous oxygen contacts both the melt surface and the droplets of iron contained in the slag in the lancing zone. The film of iron oxide formed in the

3 *The behaviour of oxygen during the melt, as determined by carbon content*



*The authors are with Air Liquide, Air Liquide, Metals Marketing Group, 57, avenue Carnot, BP 313, 94503 Champigny-sur-Marne cedex, France Tel +33 1 4983 5228 Fax +33 1 4983 5217 e-mail michel.devaux@airliquide.com

	Shell #4 WC Lance/ Burners	Shell #3 PyreJet
Power-on-time (mins)	48.5	44.2
Power Input (MW)	84.0	88.4
NatGas Consp (Nm^3/t)	4.0	6.0
Oxygen Consp (Nm^3/t)	30	28
Injection Carbon, (kg/t)	12	8

Table 1 *PyreJet performance at SDI (April-May 2000) (metric tonnes)*

lancing zone is later partially reduced during the second stage by the carbon dissolved in the melt. The second reaction is endothermic. At a lower melt temperature (below 1566°C) this reaction is controlled by the diffusion rate of the carbon through the melt.

Based on these two stages, the following practical rules are established for operation of the PyreJet:

- To avoid local slag over-oxidation, oxygen lancing is accompanied by simultaneous carbon co-injection, especially if the final melt carbon content is below 0.1%.
- Aggressive oxygen lancing begins when both stages of carbon removal are kinetically feasible to prevent slag over-oxidation.

Oxygen utilisation and the consistency of foamy slag practice can both be improved by the use of multiple points of oxygen/ carbon co-injection in the EAF. Multi-point co-injection also provides for better nitrogen control, lower refractory erosion and improves metallic yield.

Operating conditions & versatility

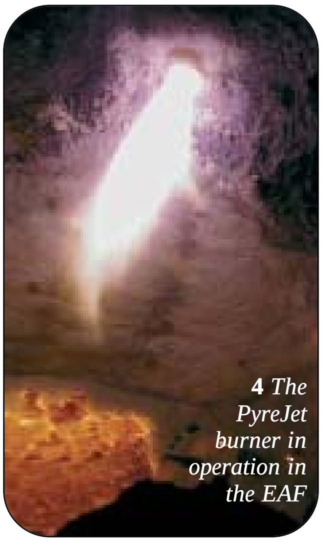
Recognising that EAFs have different operating conditions, the PyreJet system has been designed to optimise EAF performance by multi-point injection of auxiliary heat, oxygen and carbon fines and post combustion. System optimisation during the burner system design phase, installation and commissioning includes the following:

– Selection of appropriate number of burners and their positions;
– Estimated firing schedule;
– Oxygen lancing schedule;
– Layout of carbon fines injection points;
– Carbon injection schedule.

Heating & cutting through scrap

Fig 4 shows a PyreJet in operation in an EAF. The PyreJet system control program is fully automated to ensure the consistency of EAF operation. At the beginning of each charge, the PyreJet burners operate as regular oxy-fuel burners heating the scrap located in the cold spots and partially melting it. Then the fuel/oxygen flows are reduced and the oxygen flow is increased to initiate soft lancing in order to cut scrap in the more remote areas and get access to the melt.

It is very critical that the burner reliably and consistently cleans the scrap from the adjacent area so that supersonic lancing is possible without any danger of rebound from the remaining scrap. The self-protecting design of the burners allows for a reliable, low maintenance operation.



***4** The PyreJet burner in operation in the EAF*

Supersonic oxygen & carbon injection

When a passage to the bath is clear, the supersonic oxygen flow is increased to achieve 2.1 Mach exit velocity. A long, contained, supersonic oxygen jet then impacts the melt and raises the temperature due to the exothermic oxidising reaction and the bath agitation and homogenisation. Carbon injection by the PyreJet burners begins to deoxidise the slag and to maintain a thick foamy slag layer.

The amount of oxygen and carbon introduced by the PyreJet burners is calculated on the basis of the scrap mix and the desired melt carbon content. Carbon injection may be initiated simultaneously with oxygen lancing to balance the slag temperature and chemistry in the jet impact area, enhancing foamy slag formation. If the scrap mix contains a substantial amount of excess carbon, the carbon fines injection can be delayed to allow the oxygen jet to perform an initial rapid reduction of the melt carbon.

	BEFORE	AFTER
Power on Time (mins)	67	57
Electrical Consp (kWh/t)	530	440
Nat Gas Consp Nm^3/t	0	8.0
Oxygen Consp Nm^3/t	10	24
Furnace Brick Life, heats	400	1000
Gunning Mat Consp (kg/t)	3.2	1.8

Table 2 PyreJet operating results at KES (metric tonnes)

The homogeneous and efficient foamy slag layer created by the PyreJet allows the active power input to be increased, especially during the refining period. With a flat bath, the voltage in the EAF can be increased without the negative effects of arc radiation on the water cooled panels. Increases in voltage of up to 10% are possible, if the transformer capacity permits.

Foamy slag

The generation of a thick layer of foamy slag not only improves electrical efficiency and metallic yield but also protects the refractory from erosion. The thick slag layer helps to capture some of the oxygen that rebounds from the metal interface as well as droplets of metal that are inevitably generated during lancing. The endothermic reaction between injected carbon and slag oxides lowers the temperature and so slows chemical attack of the furnace lining by the slag before the slag basicity increases as a result of the dissolution of lime.

The carbon/oxygen co-injection continues until the required chemistry of the melt is achieved. A final melt carbon content as low as 0.02% can be accomplished by using PyreJet technology.

Operating results

Steel Dynamics, Inc

Steel Dynamics, Inc (SDI), Butler, USA is a flat rolled product producer that operates two 150 tonne AC twin shell EAFs equipped with 120MVA transformers. The product mix necessitates tap carbon as low as 0.025%. The scrap charge consists of busheling (15-20%), bundles (15-25%), shredded (10-15%), pig iron (15-25%), with smaller amounts of P&S, #1HM, and other 'high residual' scrap. The first PyreJet system was installed in April 2000 with the second in September 2000. Each system consists of three PyreJets of 2000 Nm^3/hr (1200 scfm) oxygen capacity. **Table 1** represents comparison of Shells #3 (PyreJet) and #4 (Burners & WC lance) for the first two months after the PyreJet was installed in shell #3.

SDI also uses hot metal produced by the on-site Iron Dynamics plant. Typically, they substitute the second charge with 55 tonnes of hot metal. The hot metal supply is not very consistent; therefore, it is not possible to make a proper statistical representation of the results over a period of time. However, by SDI's estimate, production of hot metal heats in the PyreJet shell showed a 1.5 minutes power-on-time advantage and 10kWh/t electrical savings. A much less violent bath behaviour was also noted.

Kentucky Electric Steel (KES)

KES has two 50 ton AC EAFs equipped with 25MVA transformers. The PyreJet systems were installed in November of 1998. Each furnace has two PyreJet burners and one PyrOx burner. The tap carbon varies from 0.05 to 0.50%. It is worth mentioning that the logistics of the shop dictate strict control of power demand. Installation of the PyreJet system has cut power demand for the EAFs by 20%. The main operating data before and after the PyreJet was installation are summarised in **Table 2**.

North Star Steel Texas

North Star Steel Texas (NSST) operates a 110 tonne AC EAF equipped with 65MVA transformer. The plant is primarily producing wire. For auxiliary equipment EAF has a water cooled door lance, three sidewall and one EBT burner from American Combustion. In an effort to increase production after conversion of the shop from two EAFs to one, NSST installed one PyreJet in place of one of the conventional burners in December 2000. Installation of the second PyreJet unit is currently pending.

	BEFORE	AFTER
Power-on-time (mins)	64.8	62.5
Electrical Consp, kWh/t	415	400

Table 3 *Addition of one PyreJet at NSST (metric tonnes)*

The operating comparison before and after installation is presented in **Table 3**.

These case studies show that Air Liquide's PyreJet technology has been successfully implemented on a number of AC and DC EAFs. The results indicate improvements in the following areas:

– 10-90kWh/tonne electrical savings
– Up to 10 minutes decrease in power on-time
– Up to 5% increase in active power input
– Increased oxygen efficiency
– Up to 50% savings in injection carbon

A large number of new PyreJet installations are currently under way in North America, South America and Asia. ■

(1)US Patent Nos 4,622,007; 5,599,375; 5,788,921; 5,858,302