

# Latest experience with advanced chemical energy introduction to smaller size furnaces

Chemical energy plays an important role in EAF steelmaking. This paper looks at the application of chemical energy in smaller furnaces often used for producing special steel grades which creates different challenges to those in larger furnaces.

By J Brhel\*, V Shver\*, C Farmer\*, M Novák\*\*, R Heide\*\*, M Domovec\*\*\*, M Mastelák\*\*\*, J Kučera\*\*\* & P Tlamicha\*\*\*\*

THE chemical energy input to the EAF described in this paper is introduced via the PTI JetBOx™ system. The essential part of JetBOx technology is a water-cooled copper box which facilitates three functions: more rapid scrap melting by an oxy-fuel burner, supersonic oxygen injection for enhanced bath decarburisation, and carbon injection for promoting refining and the establishment of a foamy slag (Fig 1). The JetBOx provides increased efficiency in all areas of the introduction of chemical energy.

Research into burner technology has shown that the velocity of a supersonic gas stream will decrease rapidly due to turbulent mixing between the jet and the surrounding environment. Therefore, based on the theory of hydrodynamics, the PTI Jet burner uses a high temperature flame to shroud the supersonic oxygen jet which dramatically increases the jet length and efficiency. For oxygen injection, theoretical and empirical results show that, even with a shrouding flame, the supersonic jet will diverge somewhat at extended distances. Therefore, the key to promote oxygen efficiency is to make the stream enter the bath as early as possible, and at the shortest possible distance.

This is particularly important in smaller size EAF vessels with diameters less than 5m, as here there is generally a lower oxygen flow per injector (25 to 30Nm<sup>3</sup>/min compared to a typical 35 to 43Nm<sup>3</sup>/min common for larger furnaces). Apart from the shrouding flame and gas velocity the distance penetrated by the coherent jet is determined by the Laval nozzle critical diameter, which is smaller for a lower oxygen flow. Therefore the coherent distance for smaller injectors is generally shorter and to minimise the distance travelled by the oxygen to the bath is essential.

The copper box is designed for long life, with the ability to withstand the impact of falling scrap, while at the same time provide excellent cooling (Fig 2). It is located just above the last course of refractory brick with the front face aligned with the hot face of the refractory brick. This provides the following advantages:



JetBOx™ is mounted on the sidewall close to the metal loath



Fig 1 Principle of the JetBOx™ sidewall injection system

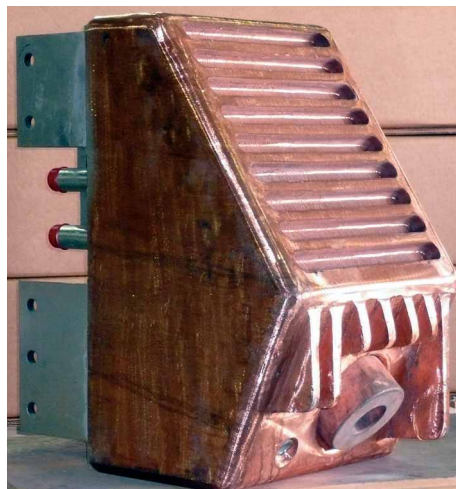


Fig 2 JetBOx™ unit stand alone and inside a hot furnace

- There is minimal chance of water-cooled panel failures due to aggressive burner programmes since the panels are located behind the copper box;
- Supersonic jet efficiency is maximised due to the relatively short length of the oxygen jet and the ability to use the optimal injection angle;
- Efficient oxygen use means less electrode oxidation;
- Refractory problems in the jet/bath area are minimised since the reaction zone is relatively far away from the brick face;
- The increased efficiency with supersonic oxygen also means less refractory wear at the roof delta;
- Injection carbon is applied close to the bath, parallel with the flame/jet, which promotes a better foamy slag and minimises carbon loss;
- The oxidation of iron to the slag is minimised due to the better bath stirring produced by the jets, and the ability to employ several reaction sites;
- Decarburisation can be accomplished with the door closed most of the time, which yields significant energy savings.

PTI has opted to inject carbon as close to the slag/metal interface as possible without redesign of the existing refractory configuration of the EAF. This is accomplished by the patented JetBOx design, which allows the carbon injection point to be only 50-75mm above the last course of refractory brick. Carbon is injected by means of a standard carbon steel pipe inserted through a water-cooled orifice. Typically the injection point in the PTI design is about 450-600mm above the hot metal level providing the following advantages:

- Carbon efficiency is excellent since the injection point is normally in the foamy slag;
- Carbon trajectory is parallel to the jet/flame and insures that carbon is carried deep into the slag/metal interface without disturbing the supersonic jet;
- The angle is such that splashes of slag or steel arising from the electrode arc or from charging scrap will not block the gas and oxygen orifices inside the combustion chamber (less plugging);

\*Process Technology International Inc (USA), \*\*Pilsen Steel sro (Czech Republic), \*\*\*Železiarne Podbrezová as (Slovakia), \*\*\*\*Air Products spol sro, (Czech Republic)

- The proximity of the carbon to the oxidising shrouding flame promotes excellent evolution of carbon monoxide, which in turn enhances slag foaming;
- The carbon is driven deep into the slag, where it reacts with iron oxide to maximise metallic yield, since it promotes conditions closer to equilibrium. The high velocity carbon injection system is also important for slag penetration, low velocity systems are unsuitable for efficient carbon blowing;
- The efficient reduction reaction limits the slag temperature and optimises slag foaming. This is especially important since the location of the JetBOx in the furnace promote efficient oxidising reactions in the slag that may superheat it if carbon injection is not introduced at the same spot.

**Installation at Pilsen Steel**

The business activities of Pilsen Steel, Czech Republic, include production and sale of steel, ductile- and grey-iron castings and ingots, through to machined forgings for various industries, in particular power generation, shipbuilding and rolling mills. The scope of the company activities allows for complete product making and processing ‘under one roof’ from steelmaking to finish machining according to the customer needs. Exports represent more than two thirds of the company production.

*Steel qualities*

The extremely heavy ingots and castings produced require ultra high purity steel. The general analysis of purity levels is:

- S < 0.005%      P < 0.005%
- O < 20ppm      H < 1ppm

The specifications range from carbon to low and high alloyed steels with variety of chemical composition. Requirements on very low phosphorus, low oxygen and variable

tapping carbon make the operation particularly challenging.

*Electric Arc Furnace*

The melt shop is equipped with a 60t EAF with a sliding gate tapping system. The furnace was upgraded to this size from originally only a 30t vessel. The inside diameter of the hearth is 4.3m. The power supply is limited and the transformer size is only 15MVA. The crane capacity is also rated according to the original smaller size furnace so typical heat requires 4 to 5 bucket charging. Due to the low installed power the furnace uses a refractory lining up to the top of the vessel to avoid excessive energy losses by water cooling.

Prior to the installation of the PTI JetBOx the input of chemical energy was only possible by manual slag door lancing and two post combustion injectors in the upper shell. The furnace layout after the JetBOx installation is shown in Fig 3. The burners/injectors are installed in two positions around the furnace shell. The important features are a 50° oxygen injection angle and the 800mm distance of the jet to the metal line. The furnace is often overcharged up to 80t in which case bath level increase and jet distance to liquid bath is less than 600mm.

*Operating experience*

The small transformer size and large number of charges create a relatively long time for the burners to be on. The burners are located low under the scrap charge, so the operation is fairly effective. There are three different operating burner profiles for different grades:

- Programme 1 is used for light scrap and when tapping steel with carbon below 0.15%. The burners are operated with the maximum power of 3.0MW in the burner mode up to an input of 150kWh/t of scrap for each basket

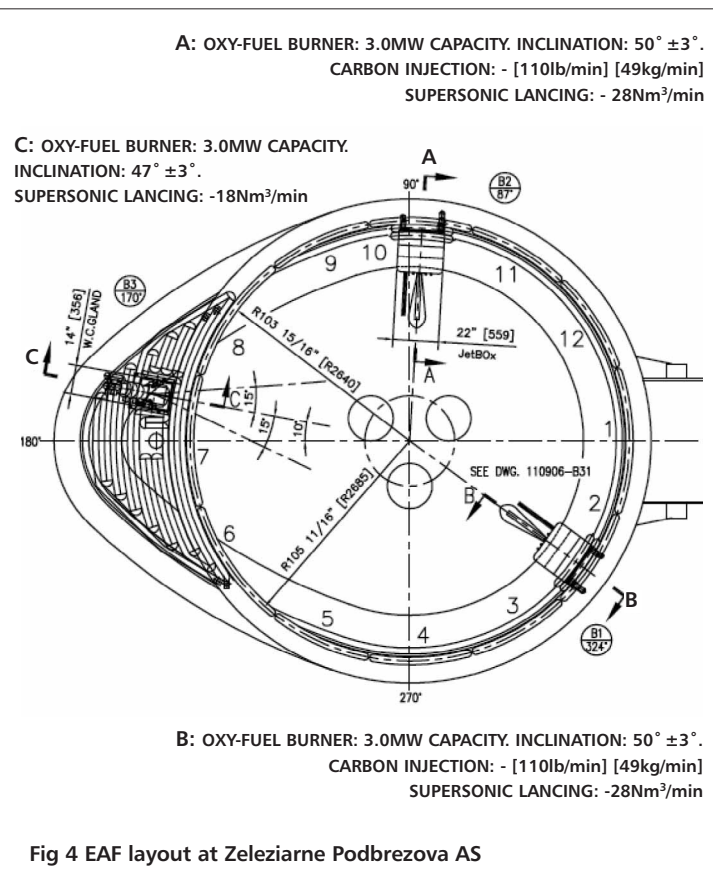
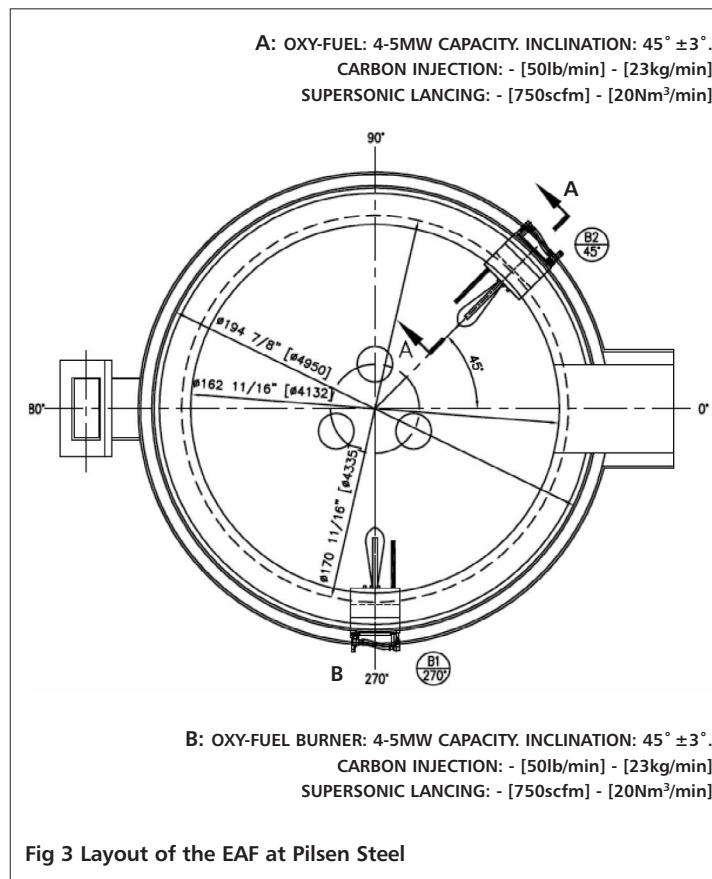
charged and up to 20.0Nm<sup>3</sup>/min of oxygen in the lancing mode at the end of each bucket and during the refining period. Carbon injection is via each JetBOx position and a flow of 10-30kg/min is applied every time oxygen is injected.

- Programme 2 is used for melts with higher amounts of return material, which in general consist of very heavy scrap such as ingot tops, gatings, and feeders from heavy castings. The operating time of burners in this case is shorter up to 100kWh/t of scrap is input and oxygen lancing is used only after the third bucket is charged when the heavy scrap has melted. The reason is the limited ability of heavy scrap to absorb the energy generated by the burners and the risk of deflection of oxygen into the molten steel and slag splashing when the burners are operated in the lancing mode at too early a time causing oxygen bounces from not fully molten pieces of heavy scrap.

- Programme 3 is used for the melts which require low tapping oxygen <200ppm generally needed for the production of rotors where final dissolved oxygen must be very low. Tapping at an oxygen content greater than 200ppm leads to an excessive treatment time at the vacuum ladle furnace which reduces productivity and increases secondary metallurgy cost. Therefore oxygen lancing is used only at the last bucket charged and later on during refining. The injection time during refining depends on metallurgical analysis checked when the last bucket charge has melted.

*Equipment reliability*

The system started operation in February 2007. There have been no problems with any part of the system since then. There are no water leaks from the JetBOx and only two cases of water leaking from the burner copper tip which can be easily changed.





*Results summary*

The results of operation very much depend on which of the three programmes is used. In general, programme 1 produces the fastest heats because of the use of lighter scrap and higher chemical energy input. Programmes 2 and 3 are slower because of the heavier scrap charged and that the steel quality required restricts the input of oxygen. The long term results obtained by averaging data from each of the three programmes is compared to the results before installation of the system in **Table 1**.

Power consumption has been compared to the model by Köhle<sup>[2]</sup>. The measured results are lower than the model predicts which is probably caused by the fact that furnace operation is not very typical and the furnace walls are refractory lined to retain heat because of the low capacity of the transformer. However, the difference in power consumption before and after installation of new chemical energy system fits well with model prediction.

In addition to a large increase in productivity and reduction in electrical power consumption there have been significant refractory savings. The campaign time has extended by over 100 heats and gunning consumption has been reduced by more than half.

**Installation at Železiarne Podbrezova**

Železiarne Podbrezova as (Ironworks Podbrezova) is among the most important producers of hot-rolled and cold drawn seamless steel tubes in Europe. Today the company works on the principle of a complete cycle of steel manufacturing. This includes meltshop with EAF – LF – CCM, rolling and drawing tube mills with integrated heat treatment.

*The furnace*

The original furnace was built in 1992 as part of a completely new meltshop. The furnace tapping weight is 54t with a 6t hot heel and it is equipped with a 50MVA transformer. The inside diameter of the upper shell is 5.2m. A three bucket charge of 100% scrap is used.

Chemical energy prior the installation of JetBOx was via a slag door burner and a supersonic water cooled oxygen – carbon door lance. The door burner power was 5.0MW and the slag door lance capacity 1600Nm<sup>3</sup>/h. Ongoing demand for higher steel production and increasing electrical energy cost led to the decision to improve furnace productivity and efficiency by installing the PTI JetBOx.

The furnace layout is shown in **Fig 4**. There are two JetBOxes in the furnace walls and one EBT burner – injector. The applied capacity of each JetBOx burner is 3.0MW and 30.0 Nm<sup>3</sup>/min of supersonic oxygen. The EBT burner capacity is 2.0MW and 20.0Nm<sup>3</sup>/min of supersonic shrouded oxygen.

The oxygen impact angle is 50° and distance to the liquid steel bath is 850mm for the burners – injectors in the JetBOxes. The EBT burner is installed at 47° and at a distance of 965mm from the liquid steel.

*Operating experience*

JetBox implementation started in April 2007 with the initial focus to minimise electrical power consumption and power-on time. During the first week of operation the slag door supersonic lance was used in parallel with the JetBOxes. The power consumption was around 350kWh/t compare to 430kWh/t

Description	Unit	Before	After	diff.	diff %
Tapping Weight	t	61	61	0	0
Power Input	MW	9	10	1	11
Tap to Tap Time	Min	250	218	-32	-13
Power on Time	Min	217	140	-77	-35
Power off	Min	33	33	0	0
Electrical Consumption	kWh/t	534	426	-108	-20
Fuel (Nat Gas)	Nm <sup>3</sup> /t	0	10.5	10.5	-
Oxygen Consumption	Nm <sup>3</sup> /t	17.0	36.0	19	112
Electrode Consumption	kg/t	4	4	0	0
carbon (bulk + injected)	kg/t	20	33	13	65
<b>Kohle model prediction</b>	<b>kWh/t</b>	<b>667</b>	<b>557</b>	<b>-110</b>	
Productivity	t/h	14.6	16.8	2.1	15
<b>Annual Production capacity</b>	<b>7500</b>	<b>109 800</b>	<b>125 917</b>	<b>16 117</b>	<b>15</b>

**Table 1 Pilsen Steel EAF #5 – Results before and after installation of JetBOx**

Description	Unit	Before	After	diff.	diff %
Tapping Weight	tonne	54	54	0	0
Power Input	MW	33	33	0	0
Tap to Tap Time	Min	65	58	-7	-11
Power on Time	Min	42	37.5	-4.5	-11
Power off	Min	23	20.5	-2.5	-11
Electrical Consumption	kWh/t	432	379	-53	-12
Fuel (nat. Gas)	Nm <sup>3</sup> /t	3.8	5.6	1.8	47
Oxygen Consumption	Nm <sup>3</sup> /t	22.5	36.9	14.4	64
Electrode Consumption	kg/t	2.27	2.1	-0.17	-7
Carbon consumption	kg/t	6.2	11.1	4.9	79
Common Scrap	kg/t	1032	1032	0	0.00
DRI + HBI	kg/t	0	0	0	
shredded scrap	kg/t	100	100	0	0.00
<b>Kohle model prediction</b>	<b>kWh/t</b>	<b>458</b>	<b>404</b>	<b>-53.8</b>	
Productivity	t/h	49.8	55.9	6.0	12%
<b>Annual production capacity</b>	<b>7300 hrs</b>	<b>363 877</b>	<b>407 793</b>	<b>43 916</b>	<b>12%</b>

**Table 2 Average results summary at Železiarne Podbrezova before and after JetBOx installation**

before installation and the power-on time dropped from 42 to 35 minutes. Oxygen consumption was 43Nm<sup>3</sup>/t. However, there was a problem of increased scrap consumption due to a lack of carbon in the charge for high oxygen consumption. Attempts to increase the carbon content were limited by the relatively low capacity of the fume exhaust system, which overheated if the carbon was increased either in a charge or by injection. The second campaign started with a strict limitation in oxygen consumption to a maximum of 38Nm<sup>3</sup>/t. The slag door lance was used only for door cleaning (max 4Nm<sup>3</sup>/t). This configuration produces optimal results with metallic charge consumption the same as prior to the installation of the JetBOx (1132 kg/t of good billet including alloys). Despite a relatively small furnace diameter there were no problems with splashing to the roof, thanks to the steep injection angle, short distance to the liquid bath and good efficiency of oxygen injected through the foaming slag. The EBT burner also is used in the lancing mode and the furnace is slightly tilted towards the tapping side during refining to hold the slag in the furnace for longer and to reduce the distance from the EBT injector tip to the steel bath.

*Equipment reliability*

Since start-up there has been no problems with any part of the control system. There has been no leakage of the JetBOxes and only one case of a water leak from the copper tip so the equipment reliability is very satisfactory.

The results are very consistent after an initial period of optimisation. The key benefits are a 4.5 minute reduction of

power-on time and over 50kWh/t power savings. The electrical energy consumption has been compared to the model developed by Köhle. The measured results are approximately 20kWh/t lower than those predicted by the model but the difference between the previous mode of operation and when using JetBOx is almost exactly in line with the prediction of the Köhle model.

The total cost of metal conversion has been reduced by €1.3/t and productivity increased by more than 10%. This ensures a fast return on the investment (ROI). **Table 2** summaries key parameters before and after the PTI JetBOx system was installed.

Both installations have proven that the PTI JetBOx system is an efficient and reliable means of increasing production and achieving energy savings. Important rules for its use in smaller size furnaces are a steep injection angle, proximity of the jet to the liquid metal bath and consistent slag foaming. Heavy scrap melting and high purity steel production require separate melting profiles, but even in this case the system brings significant benefits. Even relatively low oxygen flow per injector can secure it good penetration and oxygen efficiency when properly installed. ■

**References**

- [1] Dang Fufei, Xiao Feihu, Wang Dong, Malcolm Coburn, Dave Stanton – JetBOx Oxygen Efficiency and Consteel Results at Xining Special Steel, Millenium Steel Journal 2007
- [2] S Köhle 'Recent improvements in modeling energy consumption of electric arc furnace', 7th European Electrical Steelmaking Conference proceedings, Vol 1, 1.309
- [3] Jaroslav Brhel, 'The JetBOx burner/injector system for EAF steelmaking' Journal Steel Millenium 2006, p87-89