EVOLUTION OF JetBOx™ SYSTEM FOR EAF[1]

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Abstract
Invented by PTI, Inc. the patented JetBOx™ supersonic oxygen injection system has proven to be an effective tool in increasing Electric Arc Furnace (EAF) production at the same time reducing conversion costs of the EAF. This effect has been achieved by developing for each individual meltshop a unique, efficient method of chemical energy introduction. As each system installation was optimized, the JetBOx™ system evolved to meet the different demands of each meltshop. The JetBOx™ system has been installed in EAF's utilizing batch scrap charging, ConSteel™ process, DRI and hot metal operations with equally good results. Since 2001 JetBOx™ systems efficiently and safely operate at over 50 different steel facilities meeting the challenge presented at each individual mill.
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INTRODUCTION

Oxygen injection into the EAF has evolved over the years. The first attempts to inject oxygen were done with consumable lance pipes. This method worked reasonably well, but had some significant drawbacks. The consumable pipe was, at first hand held, and then stationary mounted with manual feed and eventually fully automated. While the insertion of the oxygen pipe into the furnace became easier for the operator, the oxygen was still injected at a rather slow rate, which at best only impinged on the surface of the steel. Eventually, the benefits of injecting oxygen at a much higher velocity were recognized and super sonic oxygen injection was introduced through a water-cooled lance. Injecting Oxygen at higher, supersonic velocities allowed the oxygen to further penetrate the steel bath and significantly increase the efficiency of oxygen injection, which resulted in productivity and cost improvements[1].

While the water-cooled, supersonic lance increased oxygen usage efficiency, the rather short distance that the oxygen remained supersonic once it left the tip of the nozzle, required the lance to be placed quite close to the steel bath. Large positioning mechanisms were needed to locate the oxygen lance close to the steel bath and then move the lance out of the furnace during scrap additions. These positioning mechanisms consumed vast amounts of space on the furnace deck and vast amounts of the maintenance budget. The next phase in oxygen injection evolution - the gas shrouded, oxygen injector – eliminated the need for complicated positioning mechanisms. By shrouding a supersonic stream of oxygen with sub-sonic gas, the distance the oxygen stream remained supersonic from the tip of the nozzle greatly increased[2]. With proper shrouding, supersonic oxygen streams could penetrate the steel bath from as far away as two (2.0) meters[3]. This allowed the oxygen injector to be located in a fixed position on the furnace sidewall without the need for large and complicated positioning mechanisms and still deliver oxygen to the steel bath at efficiencies as good or better than retractable oxygen injection lance systems. Injecting oxygen with a gas shroud increased the efficiency of oxygen injection and eliminated the cost of maintaining a large positioning mechanism on the EAF deck[4].

The first gas-shrouded injectors were placed high on the furnace sidewall and were at first, only installed in 100% scrap furnaces. The next step in the evolution of gas shrouded oxygen injection systems is the JetBOx™ system. As the methods of injecting oxygen into the furnace have evolved from simple pipes placed in the slag door to highly engineered systems, the JetBOx™ system has adapted to every type and configuration of Electric Arc Furnace. This paper details how, since its inception in 2001, the JetBOx™ oxygen injection system has evolved beyond scrap only processes to fit all types and configurations of Electric Arc Furnaces.

JetBOx™ TECHNOLOGY

Burner Placement

PTI has developed the next step in the evolution of oxygen injection technology. While the first gas shrouded, oxygen injection systems eliminated the need for complicated lance positioning devices, the injector was moved farther away from the steel bath as seen in Figure 1. Since the gas-shroud increased the effective length of the injected oxygen, placing the injector farther away from the steel bath was, at first, not a big problem. The first gas shrouded oxygen systems showed operational improvements over the floor mounted systems. However, the closer the oxygen injection is moved towards the steel bath, the more efficient the injected oxygen becomes.

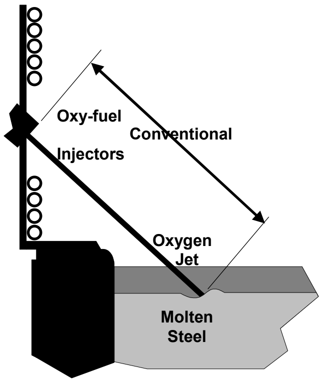


Figure 1. Conventional placement.

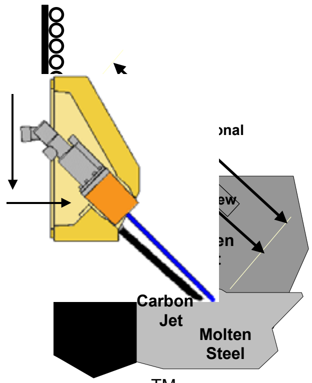


Figure 2. JetBOx™ placement

PTI was the first company to move the oxygen injection point directly over the steel bath as shown in Figure 2. This was accomplished by the innovative JetBOx™ design. The JetBOx™ allowed the oxygen injector to be moved down and into the furnace until it was directly over the sidewall refractory. By shortening the distance to the hot metal, the new design allowed the oxygen to achieve the best efficiency and give the best productivity at the lowest cost to the steel producer. See Figure 3.

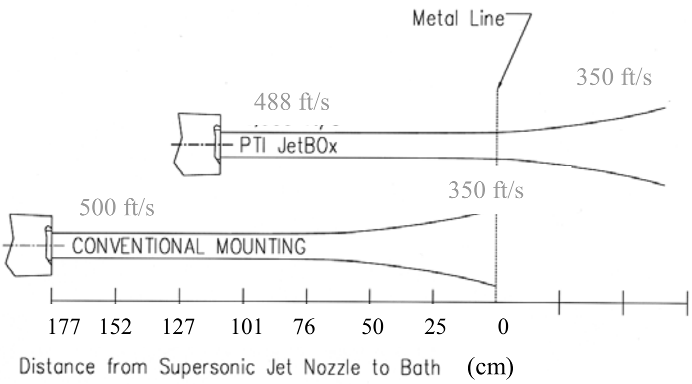


Figure 3. Oxygen stream bath penetration comparison

Another benefit of moving the burner/injector out into the furnace is that the chemical energy injected into the furnace is moved away from the water-cooled panels. This decreases the risk of damage due to splashing or flashback. The JetBOx™ design not only increases the efficiency of the injected oxygen, but also reduces the risk of damage to the water-cooled panels. While the injector was moved out and into the furnace, there is no fear of damage during the scrap addition. The JetBOx™ is made of solid, water-cooled copper. In addition, the front of the JetBOx™ is angled to direct falling scrap away from the burner face.

Multifunctional Injector/Burner

Many mills have installed separate chemical energy burners and oxygen injection equipment on their EAF. PTI has combined these two pieces of equipment and made them one. There is never a time in the melting process when super sonic oxygen and chemical energy are needed at the same time. Instead, chemical energy is needed when solid scrap is present in the furnace and oxygen injection is needed during flat bath operation.

The PTI JetBOx^{TM} system is designed to:

- Deliver over 4.5 MW of chemical energy to the scrap during the early stages of melting
- Transition to higher volume, low velocity oxygen during the middle stage when semi-solid scrap is still present
- Finish with high-velocity supersonic oxygen when flat bath is achieved.

Since the JetBOx^{TM} delivers the functionality of several different devices, the need for several different control trains is eliminated. This reduction in needed equipment reduces the overall cost of the project and allows the JetBOx^{TM} system to deliver superior value to the mill.

Single Oxygen Control Line

The evolution of the JetBOx^{TM} system continued with the elimination of the need for two oxygen control lines. Traditional gas shrouded oxygen injection systems need two oxygen lines. One line controlled the oxygen delivered to the shroud fuel and one line delivered the supersonic oxygen to the injector. The JetBOx^{TM} has evolved to only need one oxygen line. The patented burner design uses a bypass valve to deliver the correct amount of shroud oxygen during supersonic operation mode. The bypass oxygen is tailored to each mill and is driven by the operational needs of each EAF. The elimination of one oxygen line also eliminates the need for a separate oxygen control train and thus greatly reduces the cost of installation. The single oxygen control line used by the JetBOx^{TM} system reduces capital and maintenance costs while improving the reliability of the injectors.

Optimal Carbon Injection

Most mills used their floor mounted oxygen lance mechanism to deliver carbon to the slag as well as inject carbon. However, when the lance mechanism was eliminated, the carbon injection was usually positioned parallel to the new gas shrouded oxygen injection location, which was usually placed high on the furnace wall. This new position caused a problem because carbon injection is even more sensitive to traveling large distances than un-shrouded oxygen. Since shrouding oxygen increases the effective length of the stream, it was reasonable to assume that shrouding carbon would produce similar results. Unfortunately, the shrouding of the carbon is not an effective method for improving this characteristic. Several carbon injection methods used in the EAF operation resulted in uncontrolled carbon dispersion into the furnace or poor utilization of the carbon for FeO reduction. Carbon, which is introduced with these methods, is inefficiently consumed resulting in higher off-gas heat loads and higher carbon consumption.

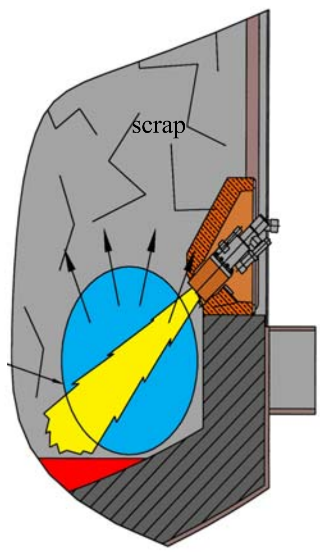
The JetBOx™ moves the carbon injection source beneath the slag surface near the oxygen injection point. Minimal carbon is lost to the exhaust system, or consumed above the bath. Most importantly the carbon is introduced where it is needed the most. The PTI JetBOx™ system injects the carbon and oxygen streams parallel or slightly angled to each other. With parallel direction, the Bernoulli convection generated by the oxygen stream will entrain the carbon stream in its dense phase to

ensure that it is delivered to the slag metal interface. Changing the angle between the oxygen and carbon streams controls the Bernoulli convection.
With the JetBOx™, carbon is injected close to the oxygen reaction site and between the oxygen stream and the sidewall. The close proximity allows for precise control of the FeO reaction and increases the predictability of decarburization and the tap carbon content. Injecting the carbon in between the reaction site and the refractory reduces the FeO concentration in the vicinity of the refractory and helps prevent brick oxidation and wear.

SCRAP PROCESS

Optimal Chemical Energy Delivery

Chemical energy is introduced into the EAF process in the form of fuel combustion, oxygen lancing, and carbon injection. The time and duration of introduction as well as the flow rates determine how much energy is introduced into the process. The location and direction in which the energy is introduced defines how useful and efficient is the chemical energy. Herein lies the key to optimizing the introduction of chemical energy. By optimizing the location, direction and time of implementation, more fuel, oxygen, and carbon can be used at a higher efficiency.
The JetBOx™ system puts the chemical energy source directly under the scrap pile. This location, low in the furnace shell, eliminates the need to penetrate though the scrap or travel long distances before becoming effective in this region of the furnace. The inward position of the burner injector in front of the furnace refractory allows the injection angles to be increased for ideal impingement of the oxygen and carbon streams. Due to increased hot gas residence time and scrap surface area available for preheating, the process efficiently accepts the chemical energy introduced into the furnace in this location. The energy introduced in goes directly to heating the scrap and avoids the negative effects commonly found with systems mounted higher on the furnace sidewall. (Figure 4).



The JetBOX™ Provides following benefits:

- Chemical energy can be introduced into the scrap for a longer period of time because the burner is below the scrap level longer.
- The heat from combustion makes contact with more scrap and there is a longer residence time for heat transfer.

Figure 4. The JetBOx™ is used longer because the energy source is below the scrap level.

CONSTEEL™ PROCESS

Injecting oxygen on a ConSteel™ process is relatively easy. The furnace is never full of scrap, so no damage is expected for sidewall or floor mounted lances. Full charges of scrap are rarely if ever added to the furnace, so a scrap-preheating mode is not needed. The ConSteel™ process may appear to be one process where gas shrouded oxygen injection and conventional water-cooled lance technology have an even chance of producing similar results. However, there are several advantages that the PTI JetBOx™ system possesses that allow it to produce above average results on ConSteel™ applications.
The lance design is slightly altered for ConSteel™ applications. Since the oxygen lance is very rarely used as a chemical energy burner, the shroud oxygen is minimized. By allowing only the minimal amount of oxygen to bypass the supersonic oxygen stream, the flow of super sonic nozzle is increased which in turn lengthens the injected oxygen stream (see Figure 5). This is an advantage to the ConSteel™ process since it remains on a flat bath for the entire melt down process. Oxygen injection is started almost immediately, which requires the maximum length of the oxygen stream.

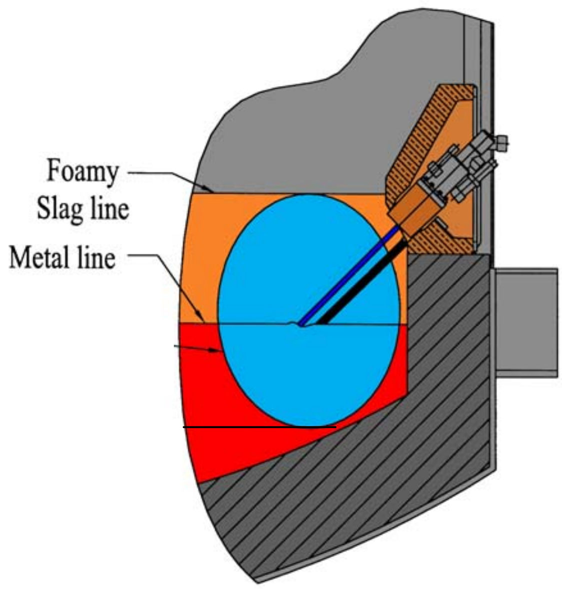


Figure 5. Oxygen Injection on ConSteel™ Operation

Not only has the JetBOx™ system been changed, but the flow control program has also adapted to the unique requirements of the ConSteel™ process. Since the effective length of the oxygen stream is a function of the temperature of the surrounding shroud gas, the fuel flow is maximized during the early part of the heat. Maximizing the temperature around the oxygen stream decreases the density of the atmosphere and allows the oxygen to travel farther. As more scrap is added to the furnace and the bath level rises, the fuel flow is also decreased. The diminishing distance between the JetBOx™ and the steel bath requires the oxygen stream to remain supersonic a shorter and shorter distance. Reducing the fuel flow as the heat progresses reduces operating costs with out sacrificing operational efficiency in any way. The JetBOx™ system has once again evolved to meet the specific needs of the ConSteel™ Process. Refer to Table 1 for process results from a ConSteel™ operation

ConSteel™ Operation
30 MVA transformers, 38 tonne tap weight

Table 1. ConSteel™ Production Improvements

	Before	**After**
Injectors	1 lance	2 JetBOx™
Total Inj. rate	28 m^3/min	51 m^3/min
Oxygen	26.4 m3/tonne	32.6 m3/tonne
Fuel (NG)	0.0 m3/tonne	2.5 m3/tonne
Carbon	15.0 kg/tonne	17.5 kg/tonne
KWh/tonne	422 kWh/tonne	366 kWh/tonne
Power On	45 min	41 min
Electrode	1.5 kg/tonne	1.5 kg/tonne

DRI/HBI PROCESS

The addition of DRI as a scrap substitute in the EAF has many variations. The amount of scrap displaced by DRI can range from 5% to 100%. In addition, there can be many ways of adding this material, but most mills either add the DRI/HBI to the scrap bucket or continuously through the roof. Both means of addition have their own operational issues to overcome. The JetBOx™ system is easily adapted to all variations. (See Figure 6)
When DRI comprises 20% or less of the total charge, it is usually added to the scrap bucket. Additions of 10% or less DRI to the scrap bucket usually show very little difference to 100% scrap heats. In most cases, the same melt profile used for 100% scrap works equally as well for this level of DRI use. As the DRI usage increases above 10%, a noticeable difference in kWh usage is seen. As the usage increases above 20%, a roof feed system is usually employed. Adding the DRI continuously on a flat bath provides better melting characteristics than adding the DRI in one large charge. Large amounts of DRI tend to clump together and form “icebergs” in the furnace which prolong melting. The JetBOx™ system can quickly adapt to any amount of DRI usage. See Table 2 for operation results of a 100% DRI EAF.

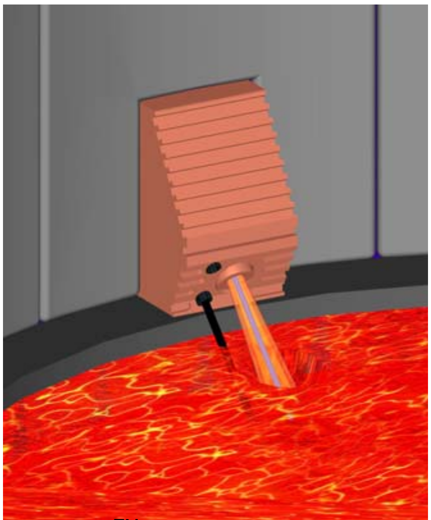


Figure 6. JetBOx™ injection into flat bath operation.

DRI Operation
30 MVA transformers, 38 tonne tap weight

Table 2. DRI process Improvements

	Before	**After**
Injectors	2 lance	2 JetBOx™
Total Inj. rate	50 m^3/min	51 m^3/min
Oxygen	24.0 m3/tonne	24.0 m3/tonne
Fuel (NG)	0.0 m3/tonne	1.0 m3/tonne
Carbon	4.7 kg/tonne	6.0 kg/tonne
KWh/tonne	615 kWh/tonne	595 kWh/tonne
Power On	64 min	62 min
Electrode	1.1 kg/tonne	1.1 kg/tonne

The JetBOx™ system increases productivity when DRI is used in the EAF by maximizing the energy at the point that the DRI enters the steel bath. The cold DRI causes localized cooling at the point of entry, but the JetBOx™ negates this by adding energy precisely where needed in the furnace. In addition – just as in the ConSteel™ process – as the DRI usage climbs above the 50% usage mark, the point at which flat bath is achieved is lower and lower in the furnace. The JetBOx™ is readily adapted to reach lower and lower bath levels and introduce oxygen to the steel bath when and where it is needed each heat.

HOT METAL PROCESS

Once used exclusively for 100% scrap melting, more and more Electric Arc Furnaces are utilizing hot metal as an alternative to scrap. Some shops use the EAF as an outlet for excess hot metal production, but other mills incorporate hot metal as a standard addition. It is here, when hot metal is used in the EAF, that the JetBOx™ system is most effective. The burner quickly clears a path through the scrap to the steel bath. Then, the efficient JetBOx™ oxygen injection quickly reduces the carbon in the hot metal while adding energy to the steel bath. Because the JetBOx™ is so efficient at adding oxygen to the bath, it is also efficient at de-carburizing the steel. The fast de-carburization of the hot metal improves process times and reduces kWh usage. Table 3 shows the improvements from three different EAF operations utilizing different levels of Hot Metal.

An issue that PTI has encountered in many EAF operations that utilize hot metal in the process is the lack of shrouding fuel. Some mills do not possess the capability to deliver any type of fuel – natural gas, LPG, diesel fuel, coal gas, etc – to the furnace. In these cases, the JetBOx™ system has adapted the oxygen injector to run efficiently with out a shroud gas. While the ability of non-shrouded oxygen injection to de-carburize the hot metal is not as efficient as a shrouded oxygen stream, the improvements to the process over traditional floor or high sidewall mounted oxygen lances is significant. Once again, the JetBOx™ has evolved to the existing environment to achieve fantastic results.

Hot Metal Operation

Table 3. Hot Metal Process Improvements.

	15 % Hot Metal		**50 % Hot Metal**		**70% Hot Metal**	
	Before	**After**	**Before**	**After**	**Before**	**After**
Injectors	1 lance	4 JetBOx™	1 lance	3 JetBOx™	1 lance	2 JetBOx™
Total Inj. Rate (m^3/min)	50	80	20	50	12	24
Oxygen (m3/tonne)	31.0	40.0	50	44	60	65
Fuel (NG) (m3/tonne)	7.0 l/t oil	1.9 LPG	0	0	0	0
Carbon (kg/tonne)	8.0	12.0	8	6	8	8
KWh/tonne	400	330	340	286	110	50
Power On (min)	45	42	53	44	30	15
Electrode (k)g/tonne	1.05	0.8	2.0	1.2	-	-

CONCLUSIONS

Twenty years ago, the Electric Arc Furnace accounted for only 10% of the worldwide steel production and was considered to produce lower quality steel[5]. Now, in 2006, the Electric Furnace is responsible for producing half of the worlds steel supply and is producing all types and levels of quality steel[5]. The JetBOx™ oxygen injection system has evolved to meet the needs of the constantly changing Electric Arc Furnace configuration. From all scrap to ConSteel™, DRI to Hot Metal usage, the JetBOx™ system has adapted to all types and configurations of Electric Furnaces. The JetBOx™ continues to improve and produce outstanding results in an increasingly demanding marketplace.

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