JetBOx™ oxygen efficiency and Consteel™ results at Xining Special Steel

JetBOx is a combination carbon-oxygen injector-burner system designed to increase the chemical energy input to all designs of EAF, resulting in improved furnace productivity, improved oxygen efficiency and reduced conversion costs. The system is ideally suited to EAF operations where large quantities of hot metal are used to augment scrap melting. Operations at Xining Steel's Consteel EAF are described.

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In recent years, Process Technology International (PTI) has been very successful in developing equipment to introduce chemical energy into the EAF process. The system, using patented supersonic burner technology, provides improved oxygen efficiency and has been successfully applied in over 70 steel plants in 21 countries. It is used in all types of EAF, including twin shell, shaft, Consteel and conventional, and where use is made of 20-70% hot metal and 100% DRI. The paper describes the design and operating data of the system and concludes with a practical discussion of a JetBOx which was installed at Xining Steel, where hot metal is used in a Consteel EAF. This plant presented several challenges due to the low initial bath level and use of hot metal.

DESIGN OF THE JETBOX SYSTEM

JetBOx is a system which promotes increased efficiency in all areas of chemical energy input. It comprises a water-cooled copper box which facilitates three functions: more rapid scrap melting via an oxy-fuel burner, supersonic oxygen injection for enhanced bath decarburisation, and carbon injection for promotion of refining and production of a foamy slag (see *Figure 1*).

Burner research has shown that a supersonic stream will decrease rapidly due to turbulent mixing between the jet and the surrounding environment. Therefore, based on the theory of hydrodynamics, JetBUrner™ adopts a high temperature flame to shroud the supersonic jet. This 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 promoting oxygen efficiency is to make the stream enter the bath as early as possible, and at the shortest distance.

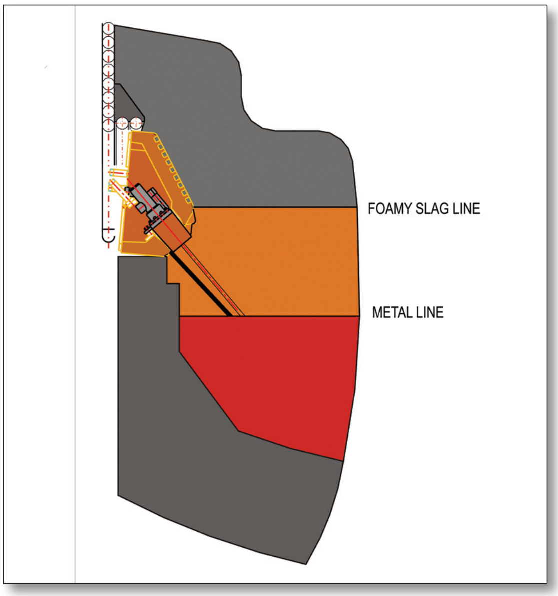

Fig 1 Schematic cross-section of JetBOx

The copper box is designed for long life. It can withstand the impact of falling scrap and provides excellent cooling. It is located just above the last course of refractory brick, with the front face in line with the brick hot face.

This provides the following advantages:

- The angle is such that splash from the electrodes or from scrap charging will not block the gas and oxygen orifices inside the combustion chamber (less plugging)
- 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 oxygen jet length 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

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	Before				After							
Steel plant	**kWh**	**kWh (adj)**	**CH_4/ t**	**O_2/ t**	**kWh**	**kWh (adj)**	**CH_4/ t**	**O_2/ t**	**Delta kWh (adj)**	**Metallurgical O_2 before**	**Metallurgical O_2 after**	**O_2 efficiency**
1	461	514	8	32.6	436	482	7	38	32	16.6	24	3.9
2	480	498	2.7	28	415	452	5.7	32	45	22.6	20.6	6.3
3	440	477	5.6	29	420	449	4.4	35	28	17.8	26.2	3.6
4	538	582	6.7	31.2	462	494	4.9	35.4	88	17.8	25.6	6
5	400	446	7	31	330	361	4.75	40	85	17	30.5	4.9
6	385	444	8.9	32.6	336	369	5	42	75	14.8	32	4.1
7	446	453	1.13	21.6	403	441	5.8	31	12	19.3	19.4	4.4
8	489	516	4.13	38.3	413	460	7.1	41.2	56	30	27	6.3
9	451	514	9.6	29.5	419	470	6.3	38.3	44	10.3	25.7	3.2
10	423	486	9.52	32.4	385	453	10.4	34.6	32	13.4	13.8	6
11	410	430	3	32.6	370	403	5	40.5	27	26.6	30.5	4.1
12	475	479	0.6	25	435	465	4.6	35	14	23.8	25.8	4
13	325	335	1.5	47	290	303	2	50	32	44	46	4.3
14	418	455	5.7	33.4	370	416	7	43	39	22	29	4.2
15	490	521	4.7	37	435	468	5	35	53	27.6	25	6.3
											Avg	**4.8**

Table 1 Data from steel plants with pre-existing burners before PTI

	Before				After							
Steel plant	**kWh**	**kWh (adj)**	**CH_4/ t**	**O_2/ t**	**kWh**	**kWh (adj)**	**CH_4/ t**	**O_2/ t**	**Delta kWh (adj)**	**Metallurgical O_2 before**	**Metallurgical O_2 after**	**O_2 efficiency**
1	330	330	0	50	276	276	0	45	54	50	45	5.4
2	350	350	0	50	296	296	0	41	54	50	41	5.9
3	281	281	0	40	190	190	3.9	44	65	40	36.2	5.9
4	310	310	0	34	271	271	0	39	39	34	39	4.3
											Avg	**5.4**

Table 2 Data from steel plants using hot metal

- The increased efficiency with supersonic oxygen also mean 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, with 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. This is accomplished by the patented JetBOx design, which allows the carbon injection point to be parallel to the hot face of the refractory and 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. This typically places the injection point 450-600mm above the hot metal level.

This gives 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 ensures that carbon is carried deep into the slag/metal interface without disturbing the supersonic jet
- 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 efficient reduction reaction limits the slag temperature to optimise slag foaming. This is especially important since JetBOx locations in the furnace without carbon injection tend to superheat the slag due to efficient post-combustion of carbon monoxide in the slag (as opposed to over it)

OXYGEN EFFICIENCY

Tables 1 and 2 summarise the data from 19 steel plants that have installed a complete PTI system. The data in *Table 1* is from 15 plants that had pre-existing burners before they were replaced by the PTI system. Although PTI has many more installations, the data for these particular plants was considered the most representative and accurate.

The efficiency of oxy-fuel burners and metallurgical oxygen has been widely discussed in the technical literature and, although significant differences are reported, the consensus seems to be that 55-65% of the total chemical energy from fuel is transferred to the steel. Therefore, for these calculations an efficiency of 60% was used for standard sidewall burners.

All fuels (LPG, oil) were converted to the equivalent of natural gas to standardise the energy input from the fuel. This means that 1Nm^3 of natural gas, at 100% efficiency, will yield 10.96kWh of energy. Similarly, lance oxygen efficiency is reported to be between 3.7 and 4.3kWh/Nm^3. For these calculations, an average of 3.74kWh/Nm^3 was used. The apparent oxygen efficiency at these plants is compared before and after JetBOx installation by adjusting the reported kWh/t for the influence of natural gas. The calculation is thus:

$$\textbf{Adjusted kWh} = \textbf{Reported kWh/t} + (\textbf{natural gas Nm}^3\textbf{/t x 10.96 x 0.6}) \qquad \textbf{(1)}$$

Metallurgical oxygen is defined as oxygen in excess of that which is required to react with natural gas to form CO$_2$ and H$_2$O (ie, natural gas consumption Nm^3/t x 2.0). In this way the effect of metallurgical oxygen can be gauged by the difference between ‘before’ and ‘after’ adjusted kWh/t.

$$\textbf{Met. oxygen} = \textbf{Total oxygen} - (\textbf{CH}_4\textbf{/t x 2.0}) \qquad \textbf{(2)}$$

The apparent oxygen efficiency therefore is defined by:

$$\textbf{Oxygen efficiency} = (\textbf{3.74 x met oxygen ‘before’} + \textbf{Delta kWht}) \,/\, \textbf{met. oxygen ‘after’} \qquad \textbf{(3)}$$

DISCUSSION OF RESULTS

When comparing steel plants that were using burners before the installation of the PTI combustion system the average calculated oxygen efficiency was 4.8kWh/Nm^3 of oxygen. This is approximately 28% higher than that taken from the literature, ie, 3.74kWh/Nm^3. With this method of calculating oxygen efficiency it is not possible to account for burner efficiency, as it is possible that a portion of the increased efficiency comes from the burner mode and not just the oxygen efficiency. Even if this is the case, the net effect shows the overall efficiency increase with the PTI system.

Worthy of note are the two plants that did not show major improvements in terms of calculated oxygen efficiencies. These are plants 3 and 9 in *Table 1* which have oxygen efficiencies of 3.6 and 3.2, respectively. The absolute reduction in power was good at 20 and 32kWh/t, respectively. On close examination of the process, it became apparent that these plants had some specific circumstances that contributed to poorer results. In the case of plant 3, PTI replaced two existing sidewall lances, but the burners were of existing PTI design, and only two JetBOxes on a 180t furnace did not fulfill the PTI concept of having multiple points of oxygen injection around the furnace. The plant has subsequently installed more reaction sites, however, performance data since then is not yet available.

In the case of plant 9 the problem was a door burner that was used for extensive periods during the heats. This meant that the efficiency of the natural gas burners ‘before’ was very poor. The consumption of 9.6Nm^3 of CH$_4$ has the effect of disproportionately increasing the adjusted kWh/t in the ‘before’ calculation. In this case, the inefficient consumption of natural gas added 61kWh/t to the ‘before’ adjusted energy. This has the effect of reducing the subsequent oxygen efficiency calculation.

It should be noted that using this method to calculate the apparent oxygen efficiency will compare the PTI efficiency relative to the baseline. In this case we used a standard efficiency of 3.47kWh/t oxygen, which gave an average PTI efficiency of 4.8kWh/Nm^3 of oxygen. For example, if we had used a standard efficiency of 4.3kWh/Nm^3, the resulting PTI efficiency would be 5.3kWh/Nm^3.

HOT METAL APPLICATIONS

Table 2 shows four plants that use hot metal in quantities of 25-60%. Although PTI has eight installations that use hot metal, data is only available for the four shown in the table. The results indicate an oxygen efficiency which, at 5.4kWh/Nm^3 average, is superior to the 100% scrap steel plants. This can be explained by the higher average carbon content of the bath. For a good portion of the heat, the carbon content is above 0.35% where the efficiency of the C+O reaction is greater.

PTI supplies two types of injector for hot metal operations. One design uses a fuel flame to shroud the oxygen jet while the other does not. Three of the plants in *Table 2* do not use a shrouding flame, whereas plant 3 does. This plant required a shrouding flame because the liquid steel level was very low during the early stages of the heat. The low liquid steel levels required a longer jet length, which was accomplished with the shrouding flame. The remaining three plants had more traditional practices that attained a higher liquid steel level earlier in the heat. As a result, these could use oxygen without shrouding.

JETBOX INSTALLATION AT XINING STEEL

China has become a world leader in the use of hot metal in

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Item	Technical parameters
Nominal capacity (t)	65
Practical tapping (t)	70
Hot heel of EAF (t)	20-30
Diameter of shell (mm)	5,400
Diameter of electrodes (mm)	550
Transformer size AC (MVA)	35
Door lance (Nm^3/hr)	supersonic flow 3,500
Carbon injection system	1 set

Table 3 **70t EAF specification before PTI installation**

	Unit	Oxygen lance (pre JetBOx)	JetBOx system	Improvement
Hot metal	%	31.7	41.7	+10
Tap-to-tap time	Min	61	54.2	-6.8
Electricity	kWh/t	281	196.5	-84.5
Oxygen	Nm3/t	46.9	46.1	-0.8
Electrodes	Kg/t	2.9	2.5	-0.4
Carbon	Kg/t	2.8	6.7	+3.9
Natural gas	Nm3/t	0	3.6	+3.6
Lime	Kg/t	59.7	55.2	-4.5
Yield	%	89	89.5	+0.5
Refractory life	%			+11

Table 4 **Operating data at Xining Steel before and after PTI**

EAFs. Up to 70% of hot metal has been required at some plants because of poor scrap availability and the need to control residual elements. At Xining Special Steel, Consteel continuous scrap charging and PTI's JetBOx technology have been combined to process high proportions of hot metal in the EAF charge.

Xining Steel installed a Consteel furnace designed by Techint to produce 350,000t/yr. The plant consists of a 90t EAF, 70t ladle furnace and a casting machine. The operating philosophy of the Consteel EAF requires a large hot heel and continuous scrap feeding. The 25–30t hot heel ensures a 'flat bath' at the beginning of the heat which makes it possible to operate the transformer at maximum power.

In 2003, Xining Steel began to use hot metal to improve its productivity. Output reached 400,000t in 2006, with an electrical consumption of 280kWh/t and power-on time of 62 minutes using an average of 31.7% hot metal. Further production increases would require a further increase in the hot metal used which, in turn, required faster decarburisation to coincide with the decreased power-on time. A more efficient oxygen introduction system was required to improve productivity.

The following additional requirements were needed:

- Provide efficient application of oxygen to the bath over a large range of metal levels, from start to finish of the heat
- Improved overall furnace productivity
- Improved consumable costs, including kWh/t and refractory
- Lower maintenance costs

A PTI JetBOx system was installed in May 2007. *Table 3* itemises the original furnace specification before the installation of the PTI system.

Figure 2 illustrates the location of the three JetBOxes within the furnace shell. Each JetBOx installation point contains a complete JetBUrner designed for 2,100Nm^3/hr oxygen flow. The JetBOx is located on the refractory, 0.4m higher than the top metal level. In addition, the oxygen streams are angled at 48 degrees down from the horizontal. This installation position ensures the shortest distance of injection and minimises splashing. Each JetBox also provides carbon injection to the slag/metal interface.

A typical heat cycle starts by charging the hot metal via a launder through the door. This process takes 5-8mins, after which the scrap conveyor and power are turned on. The rest of the heat cycle finishes conventionally.

The combustion system is controlled by a Siemens S7-300 PLC, which automatically controls oxygen flow and carbon dosage according to the changes of electric energy input to the furnace. The shrouding gas flow is lowered as the bath level increases. This reduction in maximises oxygen injection efficiency, while minimising gas consumption.

Operating results Xining Special Steel has successfully coupled Consteel technology with the use of significant amounts of hot metal (see *Table 4*). Expected results were achieved within two weeks of start up and the system has been running smoothly since.

The following changes were observed:

- The occurrence of violent boils in the furnace was reduced when compared to the one point of oxygen injection through the slag door. The reduction in boils is attributed to better homogeneity via three points of oxygen injection, better control of FeO in the slag and better kinetic energy of the oxygen jet in the early stages of melting
- Oxygen efficiency and decarburisation rates were increased
- The foamy slag improved because of the multiple points of carbon and oxygen injection. Previously the door lance allowed foamy slag to exit the slag door, which was lost to the ground. The PTI system allowed the slag door to remain closed during the heat keeping more slag in the furnace and improving metallic yield.

CONCLUSIONS

JetBOx technology is successfully used in applications that require long supersonic jet lengths such as with the Consteel process. This is demonstrated by improvements in productivity and cost.

- JetBOx is effective for arc furnace operations using hot metal. It eliminates many negative factors when hot metal is charged, such as long decarburisation times, dry viscous slag, splash and violent boiling
- Improved foamy slag extends the life of water cooled parts and refractory
- The PTI design can improve oxygen efficiency by an average of 28%, as demonstrated at several plants
- By calculating the oxygen efficiency, poor performing operations can be identified and subsequent corrective action can be taken MS

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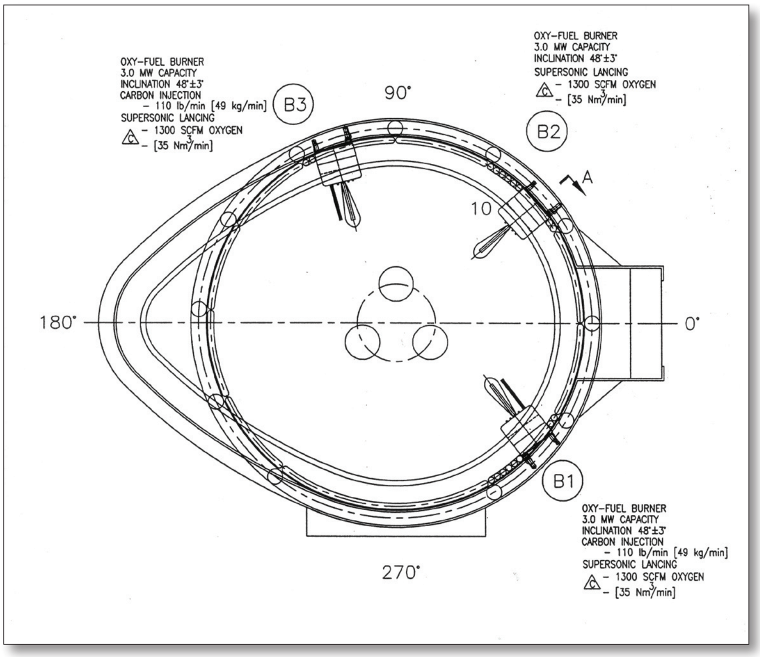

Fig 2 **Plan view of equipment installation**