Praxair CoJet™ Technology – Principles and Actual Results from Recent Installations

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Praxair's CoJet™ coherent jet technology is a patented [1,2] oxygen injection system to lower costs and improve productivity of electric arc furnaces (EAFs) via chemical energy. The system comprises multiple (usually 1-4) CoJet injectors that are fixed to the furnace wall. Each multi-purpose injector functions as a burner, lance and post-combustion device. It supplies all forms of chemical energy required by an EAF. The system is safe, automatic and easy-to-operate.

Praxair's CoJet™ gas injection system is operating successfully on **24** furnaces (June 2000). Installation on several additional furnaces will be completed this year. Results from several installations have been published [3,5-8], and they demonstrate the ability to carry out efficient lancing and decarburization from wall mounted injectors with no splash.

This paper highlights the results from more recent installations on higher productivity furnaces to demonstrate the experience gained on a range of furnace sizes, system sizes, charge materials, and furnace operating practices.

Principle of Operation

The key to CoJet technology is the invention of a process and injector nozzle that delivers a long coherent jet of oxygen at supersonic speeds into the molten bath [1]. The specialized, wall-mounted injector nozzle keeps the jet of oxygen coherent -- retaining its original diameter and velocity over long distances -- to deliver precise amounts of oxygen to the steel bath with less cavity formation and splash compared to traditional manipulators.

Figure 1 shows a comparison between lancing with a fixed, coherent jet injector versus a traditional supersonic lance which needs to be manipulated.

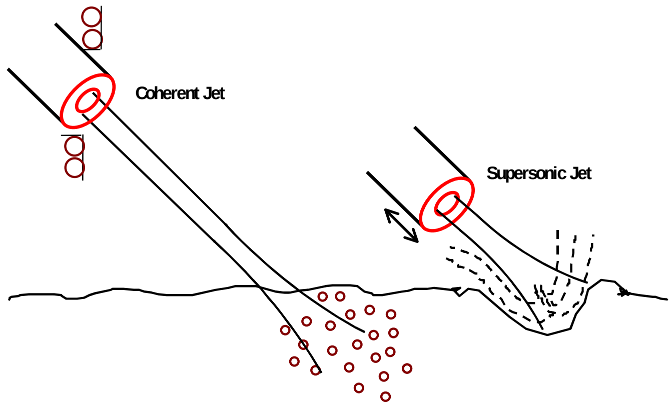

Figure 1: Coherent Jet vs Conventional Supersonic Jet

The unique distinguishing characteristics of a coherent jet are [3,4]:

- A coherent jet maintains its original velocity, diameter, gas concentration and force for distances in excess of 70 nozzle diameters or 1-2 meters; significantly longer than any conventional jet – see Figure 2.
- The rate of jet spreading and jet decay is also dramatically lower.
- The depth of penetration into a liquid bath is about 80% more than a conventional jet.
- Bath mixing time is similar to that achieved with bottom stirring.
- Splashing is considerably reduced.

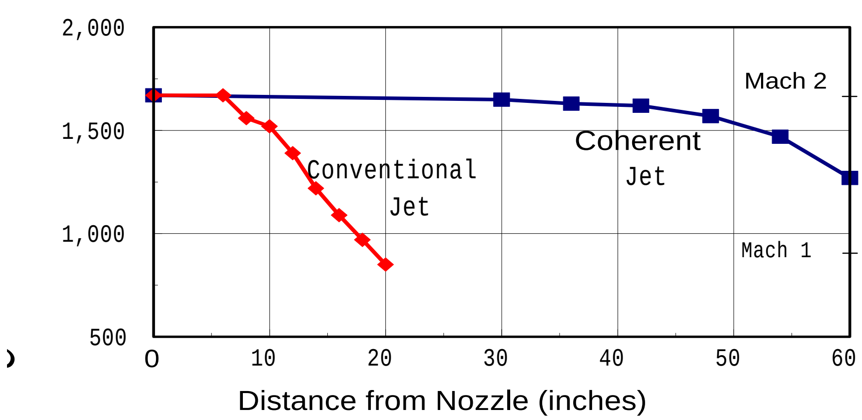

Figure 2 : Comparison of jet velocities of a conventional supersonic jet versus a coherent jet, both operating in airunder identical condiitons and flow rate of 40,000 scfh.

In an EAF, multiple Praxair CoJet injectors can be mounted on the furnace sidewall along its circumference. One to four injectors are standard -- the number of injectors per furnace depends upon the required lancing rate, burner rate and post-combustion rate. The injectors are installed in the furnace sidewall, replacing existing burners if applicable. They are piped to a valve rack with oxygen and natural gas flow legs allowing <u>independent</u> metering and controls. They are controlled by a programmable logic controller and operator station in the furnace pulpit. A typical installation is shown in Figure 3.

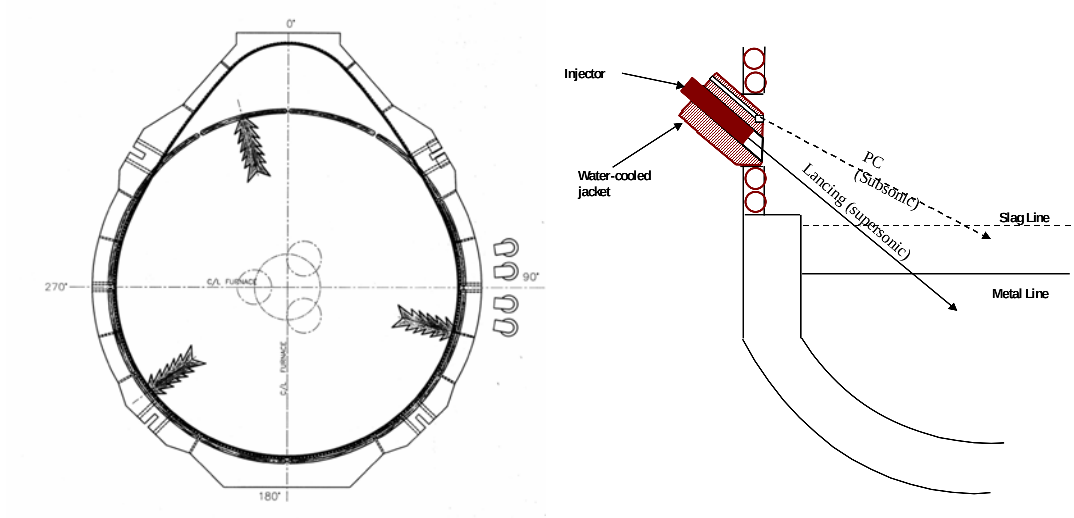

Figure 3 : Typical CoJet injector installation in and EAF

Installation in the EBT area is also possible to eliminate this cold spots and improve slag foaming at the back of the furnace - see results at BSW described later.

In addition to lancing, each injector also operates as a sidewall burner to melt scrap and as a supplemental oxygen source for post-combustion (PC) -- operations which improve furnace productivity and decrease power consumption. Therefore, each injector supplies all forms of chemical energy required in an EAF.

Burner Mode:

Once "Start" is pressed by the operator upon scrap charging, the injectors begin operation in the burner mode to heat and melt scrap. With staged firing profiles, the burner modes can be operated with varying flame shapes; going from a wide flame to preheat scrap in the beginning, to a penetrating flame for the latter part of scrap melting. After the scrap is melted, the injectors automatically switch into lancing and decarburization modes following a preprogrammed operating cycle.

Post-Combustion:
Independent post-combustion nozzles are built into the CoJet system's injector assemblies. Each nozzle injects post-combustion oxygen above the bath, in close proximity to the coherent jet which carries out lancing/decarburization. This approach conforms to Praxair's patented post-combustion method [2] that allows high efficiency post-combustion during scrap melting as well as flat bath periods with foamy slag. Results have shown that energy savings in the range of 3.0-4.5 kwh/Nm^3 have been practically achieved by injecting the PC-oxygen with a PC-lance that is mounted on the supersonic lance. The reaction and heat transfer occurs in the scrap during scrap melting, and within the foamy slag during flat bath periods

Benefits
- Lancing with fixed injectors is completely automated, not operator dependent. No need to move lances in and out of the furnace.
- Chemical energy of all forms (burners + lancing + PC) is supplied uniformly around the furnace by the injectors -- not concentrated near slag door area.
- Less splashing/furnace damage because oxygen flow per injector is lower than a traditional door lance and coherent jets inherently produce less splash.
- Faster decarburization and lower overall oxygen consumption due to more effective and efficient use of oxygen in the furnace.
- Improved and continuous slag foaming with significantly less carbon injection.
- Slag door can be kept closed — air infiltration is reduced.
- Reduced refractory wear
- Results are consistent from heat to heat.

Maximum Chemical Energy: Praxair's CoJet system can increase the level of chemical energy to the EAF for maximum productivity. Current installations safely use up to 1900 scf/t (50 Nm^3/t) of oxygen . For a typical high productivity furnace, a CoJet system offers :

1. Higher lancing, burner and post-combustion rates than conventional (up to double)
2. More oxygen goes into the bath
3. Faster decarburization (up to double)
4. Less splash
5. Improved slag foaming

Installations

Praxair's CoJet systems are currently operating on 24 furnaces. All furnaces have exceeded their normal production and achieved simultaneous reduction in operating costs compared to conventional oxygen injection methods. A list of Praxair's current operating customers is shown below:

Table 1 : Praxair CoJet™ Customer List – June 2000

	No. of Furnaces	Injectors per Furnace	Start Date	Furnace Data
MacSteel Ft. Smith, AR, USA	2	1	Sept. 1996 Mar. 1997	60T, AC, CP* 355,000 tpy
Ameristeel Jackson, TN, USA	1	2	April 1997	120T, AC, CP 535,000
Deacero Saltillo, MEXICO	1	1 3	April 1997 Jan 1999	58T, AC, WCL* 435,000
SMI Cayce, SC, USA	1	3	Sept. 1997	80T, AC, CP 315,000
MacSteel Jackson, MI, USA	2	1	Sept. 1998	60T, AC, CP 235,000
Sidertul Tultitlan, MEXICO	1	2	Nov. 1998	55MT, AC, CP 180,000
BSW Kehl, GERMANY	2	2 (1 EBT)	Feb, Apr 1999	78MT, AC, CP 1,520,000
Birmingham Steel Seattle, WA, USA	1	3	Feb. 1999	125T, AC, WCL 755,000
Lucchini Potenza, ITALY	1	3	Mar. 1999	76MT, AC, CP 525,000
Global Steel & Wire Santander, SPAIN	1	2	June 1999	125MT, AC, CP, 50% DRI 700,000
CSC Warren, OH, USA	1	3	June 1999	115T, AC, New f/c 515,000†
Siderca Campana, Argentina	1	3	July 1999	83T, AC, WCL, 60% DRI 446,000
BETA STEEL Indiana, USA	1	3	Dec 1999	125T, AC, WCL 500,000
Nucor Steel Crawfordsville, USA	2	3	Dec 1999 Feb 2000	125T, AC, WCL 1,600,000
RIVA GALTAROSSA Verona, ITALY	1	3	Jan 2000	80MT, AC, CP 350,000
RIVA – SID. SEVILLIANA Seville, SPAIN	1	2	Jan 2000	80MT, AC, CP 500,000
AUBURN STEEL Auburn, NY, USA	1	3	Apr 2000	65T, AC, CP 450,000
AUSTEEL Lemont, IL, USA	2	1	Apr 2000	40T, AC, CP 400,000
SMI Seguin, Texas, USA	1	1	Apr 2000	100-120T, AC, CP 850,000

*Lances used previously: CP = consumable pipes, WCL = water-cooled lances

Results from several installations have already been published [3-3]. The results from some more recent installtions are described below to highlight the improvement demonstrated on higher productivity furnaces, including one furnace with high DRI practice.

1. BIRMINGHAM STEEL - SEATTLE

Birmingham Steel – Seattle is a producer of SBQ grades serving the U.S. Pacific Northwest. In the ever-present drive to lower production costs while increasing production tonnage, Seattle partnered with Praxair, Inc., their oxygen supplier, and installed Praxair's CoJet™ gas injection technology on their 135-ton electric arc furnaces (EAFs) in their Melt Shop in February, 1999 [6]. They chose to replace their 4-year old burners and water-cooled door lance with 3 CoJet nozzles.

The results of using CoJet Technology at Birmingham-Seattle have been "outstanding" [6]*:* **the Seattle Division currently holds the Birmingham Steel corporate record for most tons/hr and the most tons produced in a day** (Day: 4.19.99; Tons Produced: 3043.59; Tons per Hour: 126.82). Table 2 shows a compsrison of results before and after CoJet technology was implemented.

TABLE 2 :
Comparison of Average Results at Birmingham Steel, Seattle [6]

Variable	1998	1999 w/CoJet	% Change
TPH	105.5	112.18	6.3
Delays	2.68	1.99	-25.7
Tap-to-Tap Time	65.44	54.5	-16.7
Power kwh/t.	426.12	396.87	-6.9
Electrode,kg/t	1.97	1.66	-15.4
Gunning,kg/t	1.06	1.39	31.8
Delta	88.74	219.25	147.1
Oxygen	19.2	29.7	54.8
Natural Gas	5.6	8.2	46.4

All data is per short ton of good billet.

The following conclusions were reached:

- Power consumption is down 29 kWh/good billet ton
- Electrode consumption is down 15 %, a reduction of 0.3kg/ton
- Delta life has improved an average of 150 heats/delta
- Refractory consumption, especially in the breast area of the furnace, has decreased dramatically
- Production tons per hour have been impacted in a huge way: a 11.4% increase in tons/hour from 105 to 117 TPH (best month w/CoJet)
- Turndown carbon is predictable and repeatable
- Maintenance downtime on the furnace is down, especially eliminating lance related repairs
- Foamy slag practice is improved
- Bath temperature is more homogeneous, with lancing in three as opposed to one position.

2. BADISCHE STAHLWERKE

Badische Stahlwerke GmbH (BSW) in Kehl, Germany has 2 production lines (EAF, ladle furnace, continuous casting machine) which supply billets to one bar mill and one wire rod mill. In 1998, 1.52 Million tons of good billets were produced and, for the first time, the EAF n°2 surpassed 10,000 heats in one year (10,067 heats exactly). In November 1998, BSW decided to conduct trials with PRAXAIR's CoJet technology. A CoJet injector was installed in the EBT area and operated in the burner/lance mode. The target to reduce the two top delays of EAF n°2 was achieved as shown below [7]:

- Top Delay : "carbon too high" at 1st sample – reduced approx. 50% to 6th position
- 2nd Delay : "EBT oxygen cleaning" after tapping – reduced approx. 50% to 7th position

In addition, no splashing or damage to the walls was detected. Based on these clear and beneficial results, BSW has (i) continued with the injector on EAF n°2, (ii) implemented a CoJet injector on EAF n°1 also, and (iii) now installed side-wall injectors to continue the implementation of additional CoJet injectors around the furnace. **This has helped to improve productivity on this world class furnace, and help achieve a world record of 46 heats per day on the #2 furnace in October 1999.**

3. LUCCHINI SIDERPOTENZA

Lucchini Sider Potenza in Italy operates a 76t tap weight EAF equipped with 50MW AC transformer. The furnace uses a 100% scrap charge and produced about 440,000 tpy. In March 1999, a 3-injector CoJet system was installed, replacing the existing pipe lances and 3 sidewall burners. Each CoJet injector is rated for 1200 Nm^3/hr lancing rate, 3MW burner capacity and post-combustion flow up to 500 Nm^3/hr. The results have shown **dramatic** improvement in furnace performance, including a **12% improvement in furnace productivity and many heats regularly below 300 kWh/t.**

TABLE 3 :
Results at Lucchini Sider Potenza
Compared to Baseline Data of Jan-Feb, 1999

	Oct +Dec 1999	Jan + Feb 2000
EAF electricity	- 7.5 %	-10.3 %
LF electricity	-2.2 %	- 0.5 %
Total electrical energy	-7.1 %	-9.6 %
Electrode consumption	-14.7 %	-18.9 %
Productivity	+8.9 %	+12.0%
Oxygen	+15.7 %	+20.8 %
Natural gas	0.0%	0.0%
Carbon added to the charge mix	+129.5%	+561.9 %
Pig iron to the charge mix	+173.7%	-85.5 %
Foamy slag carbon	+40.5 %	+63.0 %
Scrap rate per tonne billets	-0.55 %	-0.82 %
Nr heats per refractory campaign	+3.3 %	+40.0 %
Roof delta life	+10.0 %	+72.4 %

All data here is per metric tonne of good billet.

5. SIDERCA

Siderca is a steel pipe producer located in Campana, Argentina operating two 80 ton EAFs. To reduce cost and improve steel quality, Siderca uses scrap and **40-60% DRI**; this ratio is adjusted constantly according to the relative price and availability of scrap versus DRI. The latter is produced on-site using a MIDREX Direct Reduction Iron Furnace of 100 tph capacity.

The #5 EAF at Siderca was originally equipped with a supersonic lance on a water-cooled lance manipulator operating through the slag door. Two notable improvements were made to this practice in recent years: post-combustion and coherent oxygen injection.

In 1997, Siderca implemented post-combustion with a water-cooled PC-lance that mounted on the supersonic lance. This allowed post-combustion not only during scrap melting, but also during the flat bath period based on Praxair's patented method [1,2].

Subsequently in August 1999, Siderca replaced the supersonic and post-combustion lances with Praxair's CoJet^{TM} gas injection system consisting of 3 wall-mounted CoJet injectors that each carried out burner, lancing and post-combustion functions.

TABLE 4 compares the results of oxygen injection practices at Siderca over the last few years using:

1. Supersonic lance (SS)
2. Supersonic lance + PC-lance
3. CoJet^{TM} system

Table 4 : Results at Siderca

	Before CoJet^{TM} System		After CoJet^{TM} system
Date	Up to Mar´97	May´97-July´99	9th August´99
Burner/Lance system	1 W.C. Lance through slag door	1 W.C. Lance + Post-Comb. Lance through slag door	3 Cojet Injector$_s$.
Power, KWh/t	530	510	470
Power On Time, min	46	45	41.8
Tap to Tap time, min	65	57	53.8
Productivity, tph	73.8	84.2	89.2
Mix, % (scrap/scrap=DRI)	40%	43%	55%
Electrodes, kg/t	2.1	2.1	2.1
Charge Carbon, kg/t (included DRI´s Ceq and injected carbon, with yield%)	10.5	13.5	13.5
Injected carbon, kg/t	4.5	4.5	decreased
Metal Yield%	87	87	87
Delta Life			improved
Oxygen, Nm^3/t	23	24	39

Natural Gas, Nm3/t	0	0	6.2

The results demonstrate that significant improvements in furnace productivity (20%) and power savings (>11%) were achieved on a DRI furnace with efficient use of oxygen up to 39 Nm3/t.

Specific advantages of the CoJet system for DRI melting practices were:

- Improved bath mixing / homogeneity - uniform melting around furnace
- Extended lancing from the fixed injectors regardless of bath height changes
- Post-combustion during flat bath
- Higher bath temperature during DRI feed, allowing maximum DRI feeding rates
- Higher oxygen usage (up to 39 Nm^3/t).

These results demonstrate that efficient injection of chemical energy is a powerful tool to improve the operation of EAFs charging high levels of DRI.

6. AUBURN STEEL

Auburn Steel in Auburn, NY, recently started up a 3-injector CoJet system on their 64t EAF. The furnace is operated with a 40 MVA transformer and produces about 450,000 tpy. It was previously equipped with 4 ACI burners and a pipe lance manipulator through the slag door. Average power consumption with the old system was about 350 kWh/ short ton of good billet.

Since the implementation of the CoJet system in April 2000, melt shop manager Jim Robinson and his dedicated team have worked with Praxair to rapidly optimize the CoJet system and have reported the following significant results:

- Yield improvement > 0.5%,
- **Record power consumtion (kwh/good billet short ton, no ladle furnace):**
    - **Daily average 296.6 kWh/t**
    - **Weekly avgerage 307 kWh/t**
    - **Monthly average 325.6 kWh/ton**
    - **Current overall average 315 kWh/ton, and improving.**

- Tap-to-tap time reduced 1.0-1.5 mins
- Gunning reduced at least 1.0 lb/ton
- Electrode savings at least 0.5 lbs/ton, with a record low consumption for May 2000
- Pipe cost down 90%
- Refractory improvement in breast area, overall furnace repair, and tap hole delays reduced
- Delta life doubled.

More detailed results from this high performance furnace will be published at a later date.

QUALITY IMPROVEMENTS

Two key features of the CoJet gas injection system, namely multi-point lancing capability and deeper bath penetration, create improved bath flushing and mixing. The result is lower slag FeO and higher yield. Another benefit, especially important for steel mills producing flat products or other low nitrogen grades, is the reduction in nitrogen levels that can be achieved by this system in conjunction with other nitrogen reducing steps – see Figure 4.

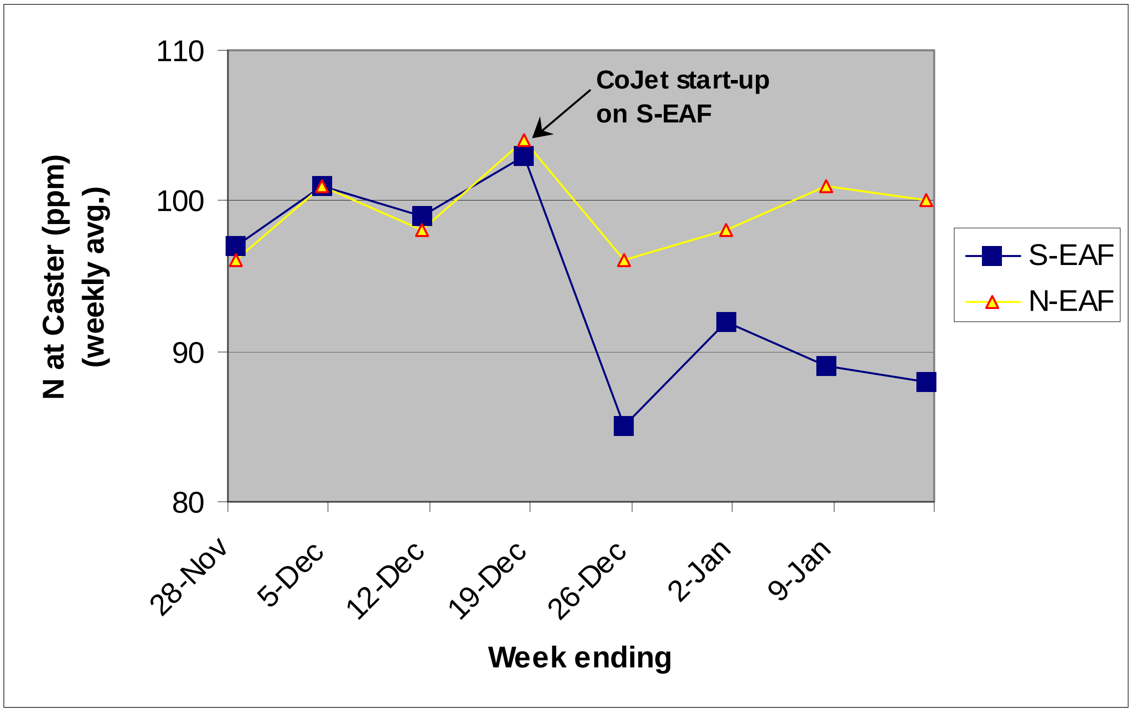

Figure 4 : Comparison of N levels before and after CoJet in a steel mill with two EAFs

The graph shows a comparison of nitrogen levels in a two-furnace shop producing thin slab. Both furnaces were initially operating with the same nitrogen levels. Then the S-EAF was equipped with a CoJet system in December 1999, and this resulted in an *immediate* 10-15ppm nitrogen reduction compared to the N-EAF as well as the previous baseline for the same furnace. Now the N-EAF is also operating with a CoJet system.

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