Installation of Praxair's *CoJet*® Gas Injection System at Sumikin Steel and other EAFs with Hot Metal Charges

Presented at the AISTech 2008 Iron & Steel Technology Conference and Exposition, Pittsburgh, PA

Larry Cates
Praxair, 1500 Polco Street, Indianapolis, IN 46222,

Kuniharu Fujimoto
Yasukazu Okada
Hiroyoshi Okano
Sumikin Steel, Wakayama Plant, 1850 Minato, Wakayama, Japan

Eiji Hirooka
Air Water, Inc., 20-16 Higashi Shinsaibashi 1-Chome, Osaka City, Osaka, Japan

INTRODUCTION

During the last few years the use of blast furnace hot metal in electric arc furnaces has increased substantially, especially in Asia. Due to the rising price of scrap and the increased availability of hot metal produced from ore, it has become more economical in certain locations to charge substantial quantities of hot metal. This paper describes some of the issues with using hot metal in electric arc furnaces and the benefits of using coherent jet oxygen injection technology on these furnaces. The paper will focus on the installation of the CoJet system for Sumikin Steel, Wakayama Works.

The multifunction CoJet® gas injection system [1-3] includes oxygen injection, carbon injection, preheating, and post-combustion, integrated in one, water cooled, wall mounted injector to provide chemical energy to an EAF in the most effective way to reduce production cost and improve productivity.

The CoJet® gas injection system was developed to inject oxygen in the form of a laser like coherent jet at supersonic speeds into the steel bath. The oxygen jet from a coherent injector travels significantly farther than an oxygen jet from a conventional supersonic lance. Hence, coherent jet injectors can be positioned well above the bath in the sidewall of the furnace, and still carry out effective injection. When the coherent jet of oxygen produced by the nozzle impinges on the molten steel bath, the concentrated momentum of the oxygen jet dissipates in the steel as fine bubbles, providing deep penetration and effective slag-metal mixing. This results in high efficiency injection and decarburization.

Up to now, Praxair has installed its CoJet® gas injection system on seven furnaces using hot metal charges in Japan, China, India, and North America. Some of these furnaces have used up to ~80% hot metal, with the elimination of electric power altogether. One of the common objectives of such installations is to increase the hot metal ratio while maintaining/improving the tap-to-tap time with significantly higher blow rates. A typical result from one customer using high levels of hot metal is illustrated below. Previously to the installation of CoJet this customer injected oxygen through a retractable side wall lance.

	Baseline	**CoJet®**
Tap wt.	**90t**	**95t**
% Hot Metal	**30%**	**70-90%**
Kwh/ton:	**280**	**~ 0**
Tap-to-tap, min:	**60**	**58**

Table 1

SUMIKIN STEEL INSTALLATION

Five furnaces in Japan, both scrap and hot metal based, have been equipped with CoJet® systems since early 2006 by Praxair, working in partnership with Air Water, Inc, a Japanese industrial gas supplier. In February 2007, Praxair and Air Water, Inc commissioned a new CoJet system installation at Sumikin Steel, Wakayama Works, in Osaka, Japan on an EAF. This project resulted in a reduction in electrical power consumption of 12% and reduced tap to tap time of 6% during the first month of operation.

Sumikin Steel is located about 60 km south of Osaka, Japan. The plant contains a meltshop and a hot strip rolling mill (HSM). The plant produces 300,000 tons of “H” shapes (beams) each year.

The EAF at Sumikin is a nominal 100 ton (tap weight) furnace supplied by JP Steel Plantech Co. in 1990. Direct Current (DC) power is supplied to the furnace at 53 MW maximum power. Prior to the installation of the CoJet system, oxygen was injected through a water-cooled lance from the wall and consumable lance pipes through the slag door.

Sumikin Steel decided to install the CoJet system in order to:

- increase oxygen injection rates

- reduce power on time
- reduce tap to tap time
- reduce electrical power consumption
- increase productivity
- increase flexibility for hot metal charging

Under normal operation about 30% of the total charge is made up of hot metal supplied from the blast furnace at Sumitomo Metal Industry. However, as much as 80% of the charge could be hot metal depending on economic conditions. As of the writing of this paper, however, Sumikin Steel has not charged more than 31% hot metal.

Safety of the operating personnel was also a primary factor in the decision to install the CoJet® system. Operators are no longer required to handle oxygen injection or carbon injection pipes in front of the working door during operation, thus reducing the time that they need to be near the furnace.

Table II lists results for important operating parameters before installation of the CoJet system and the average for the first six months of operation after the installation of the CoJet system.

	Baseline	**CoJet®**
Tons/hr	**88**	**91**
Hot Metal (tons)	**30**	**30**
Tap to Tap Time (minutes)	**68.0**	**63.8**
Power (KWH/t)	**349**	**304**
Oxygen (NM3/t)	**24**	**34**
COG (NM3/t)	**0**	**10**
Yield (%)	**92.9**	**92.9**
Slag (kg/t)	**93**	**93**
Injection Carbon (kg/t)	**2.9**	**2.6**
Gunning (kg/t)	**3.5**	**2.6**
Electrode Consumption (kg/t)	**1.2**	**1.0**

Table II

Coke oven gas (COG) is used for burner and shroud fuel for the CoJet injectors. COG has proved to be very effective for use in CoJet injectors, although it must be cleaned to remove the sulfur in order to prevent erosion of the copper portions of the injectors and water cooled panels. In most cases it is also necessary to increase the pressure to allow its use for CoJet injectors. At Sumikin, no additional cleaning was required, however, a new compressor station was installed by Air Water, Inc to provide sufficient pressure.

The control system equipment used for this installation makes significant use of Japanese sourced equipment, including Mitsubishi PLCs and Yokagawa instrumentation. The HMI system is based on "Wonderware" software, which includes a convenient dual language function for displaying operator screens in both Japanese and English languages. This basic control package has been used for all of the CoJet systems installed so far in Japan by Praxair and Air Water.

The piping, coke oven gas compressor station, and CoJet® system control equipment were installed by Air Water, Inc during December 2006-February of 2007. Final installation of the CoJet system equipment was completed during a three day outage in February. This was followed by two weeks of commissioning and optimization by Praxair and Air Water.

Photo 1 – Burner flame at the primary test (2007.2)

Photo 2 – Hi Fire Rate at the primary test (2007.2)

Photo 3 – COG Compressor

Photo 4 – COG Receiver Tank

ISSUES WITH USING HOT METAL IN EAFs

Electric arc furnaces are designed to accommodate rapid charging of large amounts of scrap and heating with electrical energy. Therefore, a relatively wide, shallow furnace is required. Basic oxygen furnaces (BOFs), on the other hand are designed to use small amounts of scrap and high rates of oxygen injection to remove the high amounts of carbon present in the hot metal. These furnaces are taller than the typical EAF vessel to accommodate the reactions encountered when using high rates of oxygen injection.

The use of hot metal in the EAF therefore requires special consideration in the placement of oxygen injectors, injection rates, and operating practices to allow sufficient oxygen to be delivered, while preventing excessive skulling, slopping, and eruptions. Praxair has studied these effects extensively in order to determine the best arrangements for high hot metal consumption.

Praxair has studied a number of EAFs using hot metal for 35% to 90% of their total metallic charge, and compared the results of their operation with each other and with Basic Oxygen Furnaces (BOF). This study included factors such as:

- Furnace geometry
- Specific oxygen flow rate
- Jet penetration
- Jet induced stirring energy
- Droplet formation from jet impact and from a vaporization-oxidation mechanism
- Flux practice
- Carbon injection

This analysis has resulted in adjustments to guidelines for the installation and operating practices of EAFs using CoJet® injectors, to reduce the build up of skull in the upper part of the furnace and the potential for furnace "eruptions" when hot metal is used as a charge material.

A model has been developed that takes these factors into account and predicts jet penetration through flat or foamy slag into the metal bath, stirring energy created by reaction of the jet with dissolved carbon, and the rate of droplet formation by the shearing force of the gas. The model is adapted to the geometry of each EAF vessel.

Based on this model, graphs were produced for 30% and 80% hot metal charges at Sumikin Steel depicting jet penetration, stirring energy, and droplet formation. As noted previously, Sumikin Steel has not charged more than 31% hot metal. This analysis was performed for the purpose illustrating the potential results of charging higher amounts of hot metal than their normal charge.

The 30% case is based on a "standard recipe" assuming a 25 ton heel and 2400 kg of burnt lime charged at the beginning of the heat. This results in a relatively small slag volume, but the basicity (C/S) is 4.3, assuming 0.6% silicon in the hot metal and 0.1% silicon average in scrap.

The 80% case assumes 88 tons hot metal, 22 tons scrap, and a 25 ton heel. The CoJet® injectors would be operated for one minute on Hold Fire, then the balance of the heat at design "Lancing" oxygen flow. The predicted decarburization time with this assumption is about 55 min. The lime charge is increased to 6.8 tons, in rough proportion to the silicon charged in the hot metal. This amount of lime is 54 kg/t, similar to other shops where this flux practice has been found to avoid furnace buildup.

Furnace Geometry

Important aspects of furnace geometry include vessel diameter (D), height of the roof above the bath (H), bath depth (B), and the distance from the CoJet to the bath (L). A shallow bath depth will significantly increase the volume of droplets ejected above the bath. A lower roof height will allow more droplets to reach the roof causing increased skulling. Larger furnace diameters require more stirring energy. The distance of the CoJet injector from the bath affects jet penetration.

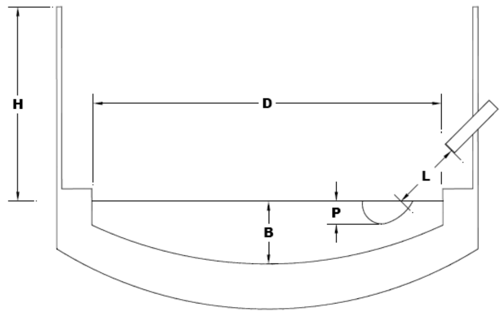

Figure 1 – Furnace Geometry

Jet Penetration

Shallow penetration through the slag layer and into the bath can lead to excessive droplet formation, low oxygen efficiency, highly oxidized slag, and eruptions. Factors that affect penetration include the angle at which the CoJet is mounted, distance from the bath, flow rate, and proper shrouding.

Changing bath height will affect the bath penetration. At Sumikin Steel, when the bottom refractory is appreciably worn toward the end of a campaign, there has been an increased incidence of eruptions. This is caused by highly oxidized slag due to less than optimum penetration because of the lower bath height. Increasing the amount of the hot heel did not improve this situation, so during December 2007 the angle of the CoJet injectors was increased to reduce the distance to the bath. The result of this change is still being evaluated

Figure 2 shows the predicted jet penetration at Sumikin Steel for the 30% and 80% hot metal cases during oxygen lancing based on the mounting arrangement shown in Figure 3. At about 30% of completion of the heat with the higher hot metal charge there is less predicted penetration and at about 60-70% completion the lower hot metal charge experiences reduced penetration. At these times, the furnace could experience reduced stirring energy, higher droplet formation, and more slag oxidation.

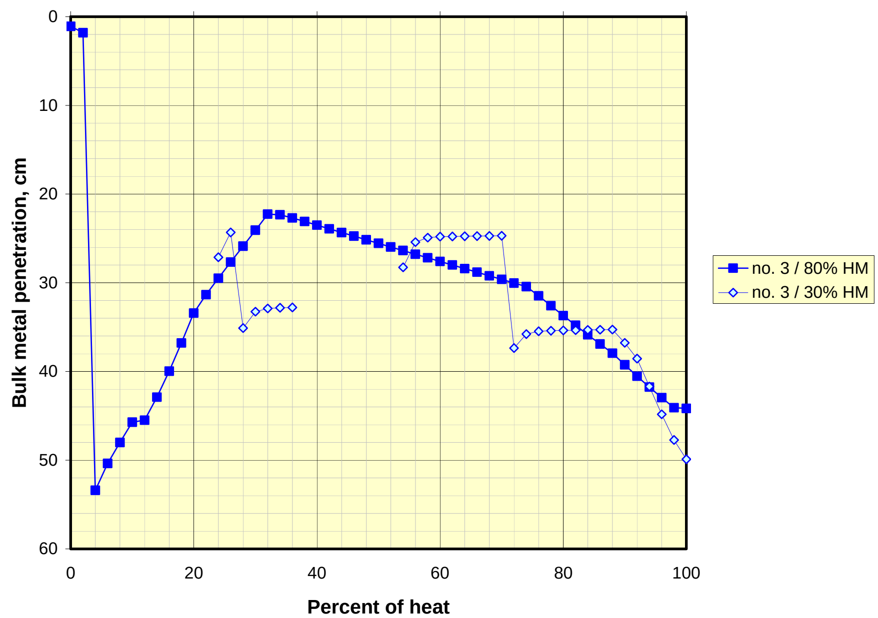

Figure 2 – Jet Penetration

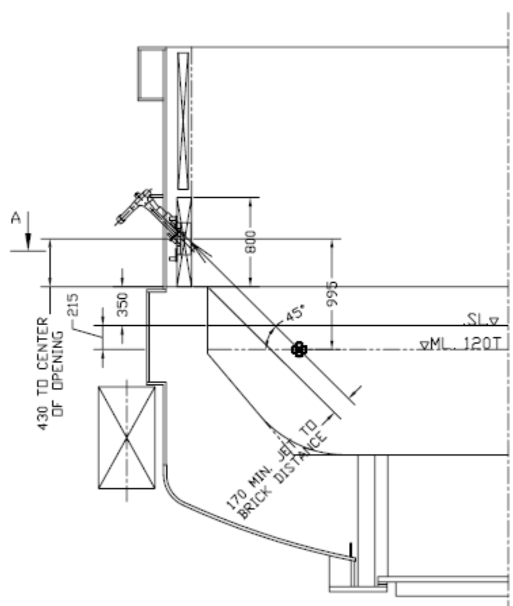

Figure 3 – CoJet Mounting

Stirring Energy

Closely related to jet penetration is the stirring energy generated by the reaction of the oxygen jets in the bath. Stirring is important to ensure a sufficient supply of carbon to the reaction site to ensure high oxygen efficiency and avoid excessive FeO formation, which could lead to a reactive eruption from the furnace. Stirring energy is created by the formation of CO deep in the metal bath, as well as the impact force of the oxygen.

Figure 4 shows the predicted decreased stirring energy for the 80% hot metal case, especially at 30% completion and at end of the heat. This can lead to a higher tendency for eruptions.

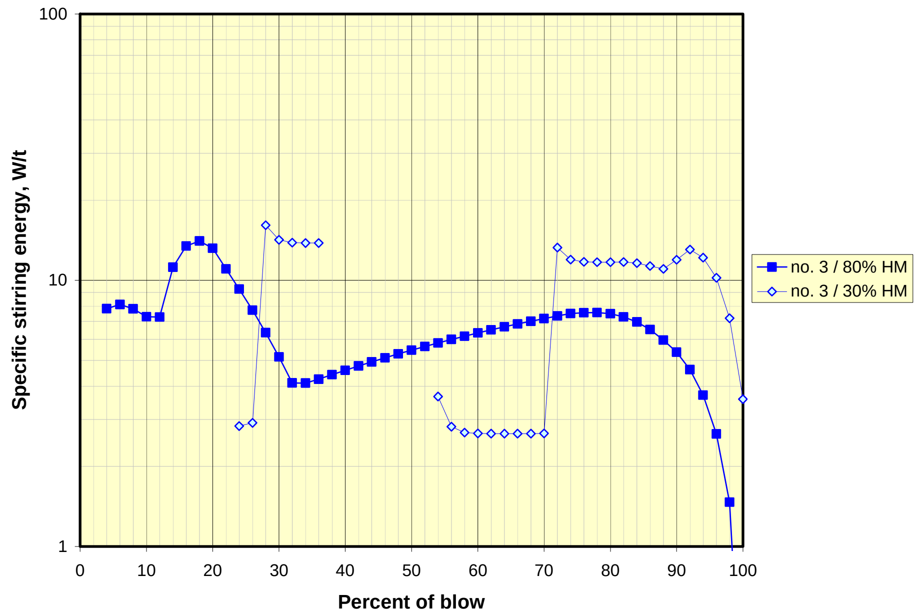

Figure 4 – Stirring Energy

Droplet Formation

Droplet generation by an impinging jet reaches a maximum at a given nozzle height above the bath, based on the relative gas and liquid densities. Due to the shape and capacity of the EAF vessel, sidewall injectors will typically be mounted close to this critical height. Raising or lowering the nozzle height from this position will reduce droplet formation. However, raising the height will reduce penetration and stirring. This could increase slag oxidation and increase the chance of a sudden, strong reaction between oxygenized slag and high carbon metal, resulting in an eruption. Lowering the height may put the nozzle too close to the bath, resulting in short injector life. The actual height chosen must take into account these factors as well as factors such as bath depth.

Another extremely important factor for droplet formation is the slag condition. A slag with sufficient volume and the proper viscosity will capture droplets of metal before they are ejected from the bath. BOF steel makers typically use higher amounts of lime than EAF shops to control "slopping" and skulling of the upper vessel. Slag condition in the EAF can also be influenced by carbon injection, a tool which is not available in BOFs.

Figure 5 shows the droplet formation index for Sumikin Steel. Early in the heat there is a much heavier droplet formation predicted for the 80% hot metal case, leading to a greater tendency for skull formation.

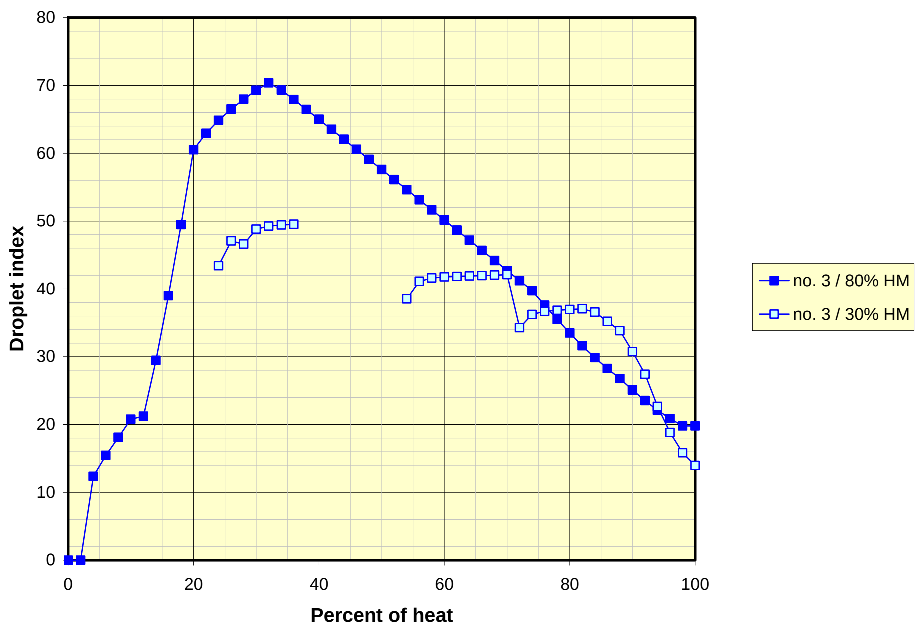

Figure 5 – Droplet Formation

Effect of Carbon Levels

At high carbon levels in the melt, the rate of CO formation is controlled by the oxygen availability. At lower levels, decarburization is limited by carbon availability. This transition level is strongly affected by stirring energy and jet penetration.

The mixing time in a molten metal bath is proportional to the bath dimensions (diameter and depth) and the stirring energy. Due to the differences in vessel shape, flow rates, and angle of injection the mixing time in EAF cases is approximately five times that of BOF vessels. The concentration where carbon becomes the limiting factor is about 0.3% in the BOF vessel. In EAFs this concentration is between 0.3 and 1.5% due to the geometry of the vessel and the stirring energy. This means that a localized high concentration of highly oxidized FeO may occur, even though the overall carbon concentration in the bath is relatively high. Carbon injection can be very effective at reducing the FeO concentration of the slag in the area of oxygen injection, which will reduce the possibility of eruptions.

EAFs charging less than about 40% hot metal will usually not be as severely affected by skulling from excess droplet formation and eruptions due to slag/carbon reactions. When the concentration of the hot metal charge is greater than 50%, however, these effects must be carefully considered.

SUMMARY

Hot metal can be used effectively in the electric arc furnace as a charge material – however, special considerations must be taken into account at very high levels of hot metal to limit potential problems with furnace skulling and eruptions. Praxair's CoJet® gas injection system brings several advantages to an EAFs using hot metal, including the ability to inject high oxygen rates, achieve high decarburizaation rates, and maintain/improve tap-to-tap times. Hot metal ratios as high as ~80% have been achieved at some installations, with attendant elimination of electric power altogether.

A model has been developed specifically to understand oxygen injection with hot metal charges, and to predict regimes of optimum operation. Based on model results, for example, adjustments can be made to CoJet injector mounting, oxygen flow rates, carbon injection, and flux practices to minimize any potential problems.

Sumikin Steel has experienced significant improvements in productivity, power consumption, electrode consumption, and safety due to the installation of the CoJet gas injection system. Hot metal charges of 30% have been used without excess skulling or eruptions.

REFERENCES

1. D. Koncsics, P. C. Mathur and D. Engle : "Results of Oxygen Injection in the EAF with Praxair Coherent Jet Injectors : A Novel Technology"; 1997 Electric Furnace Conference Proceedings, ISS (Warrendale, PA).
2. B. Sarma, P.C. Mathur, R.J. Selines and J.E. Anderson : "Fundamental Aspects of Coherent Gas Jets; 1998 Electric Furnace Conference Proceedings, ISS (Warrendale, PA).
3. S. K. Warty and P.C.Mathur: "Praxair's *CoJet*® gas injection system - delivering benefits, and gaining useful knowledge for future enhancements**"**, 2002 Electric Furnace Conference Proceedings, ISS (Warrendale, PA)

P-10104

Making our planet more productive.™

Praxair, Inc.
39 Old Ridgebury Road
Danbury, CT 06810-5113
USA
www.praxair.com
info@praxair.com

Telephone:
1-800-PRAXAIR (1-800-772-9247)
(716) 879-4077
Fax:
1-800-772-9985
(716) 879-2040