BOF POST COMBUSTION OXYGEN LANCES AS A PRODUCTION AND MAINTENANCE TOOL[1]

Louis S. Valentas[2]
John A. Barbus[3]
Jeff A. Jones[3]

Abstract
BOF Post Combustion Oxygen Lances continue to be used as a production and maintenance tool to improve the steelmaking process. By optimizing the Post Combustion Ratio inside the BOF vessel, steelmakers can take full advantage of the increase in chemical energy, which can result in faster blow times, higher scrap-to-hot metal ratios, and reduced skulling on the lance barrel and reduced build-up on the furnace mouth. New developments with post combustion will be described, along with the operational results and benefits.
Key words: Post combustion; BOF oxygen lances; Auxiliary lance tip; Distributor; Split flow; Double flow.

1 *Tecnhical contribution to XXXVIII Steelmaking Seminar – International, May 20th to 23rd, 2007, Belo Horizonte, MG, Brazil.*
2 *Berry Metal Company, 2408 Evans City Road Harmony, PA 16037, Phone: 724-452-8040, Fax: 724-452-4115, E-mail: info@berrymetal.com*
3 *Berry Metal Company, 11 Pine Lake Ave., LaPorte, IN 46350, Phone: 219-326-5175, Fax: 219-324-0265*

Review:

Post combustion in the steel industry is nothing new. Steelmakers in both BOF's and EAF's have been increasing the amount of oxygen into their furnaces in order to burn or "post combust" the CO off-gas inside the vessel by reacting it with additional oxygen to create CO_2 dating back to the 1960's and 1970's. Oxygen, as we know, is the primary agent in converting hot metal to steel. The basic equations of steelmaking are as follows:

$C + ½O_2 = CO$
$2C + O_2 = CO_2$
$Si + O_2 = SiO_2$
$Mn + ½O_2 = MnO_2$
$2P + 5/2O_2 = P_2O_5$

The progress of these reactions starts with the early oxidation of silicon, an exothermic reaction, which results in silica formation and is combined with added flux to form the slag; the other elements also join the slag phase by combination with oxygen.
The principal reaction in steelmaking which results from oxygen lancing is the removal of carbon from the bath as CO. A small amount of CO_2 is also produced, but 90% or more of the gas normally exiting the furnace is CO.[1] This exothermic reaction generates approximately 245 BTU per SCF of oxygen which can be very beneficial for melting scrap. Typically very little CO is further combusted into CO_2 inside the vessel. Most of the CO_2 generated occurs in the hood or duct work where it is least desirable. In the case of a suppressed combustion hood, the additional CO is carried by the ductwork and is burned off as CO_2 at the flare stack.
By adding a secondary sub-sonic oxygen stream into the slag layer above the molted steel bath, we can combust the unburned CO in the slag layer into CO_2. This equation is commonly known as: $CO + ½O_2 = CO_2$. This reaction generates about 2.5 times the amount of energy (630 BTU per SCF of oxygen) that the CO combustion reaction generates.[2] This reaction offers the potential for much higher energy use inside the vessel.
Post Combustion Lances allow BOF operators to take maximum advantage of the heat energy contained in the carbon monoxide (CO) gas produced in the vessel during the refining of a heat of steel. By increasing the Post Combustion Ratio (reducing CO by the reaction $CO + ½O_2 = CO_2$) inside the BOF vessel, the thermal efficiency of the process is greatly enhanced.
If we can harness and control this additional energy inside the vessel, there are many positive benefits for the steelmaker. Alternatively, if not used properly, this additional energy can be detrimental to a furnace lining.

Lance Styles

The basic equation $CO + ½O_2 = CO_2$ shows that 1 kg of bath carbon reacts stoichiometrically with 2 Nm^3 of injected oxygen with 2 Nm^3 of CO generated, creating a lack of oxygen above the bath. Therefore, the ideal approach to BOF post combustion is to inject additional oxygen during the decarburizing period and to add energy without introducing other fuel sources.[1]

There are several methods of injecting post combustion oxygen into the furnace. The first way is to add several small orifices around the main supersonic nozzles on the Tip face as shown in Figure 1. This practice of post combustion has been used for the last 30 years. This Tip, a Main/Auxiliary Lance Tip, diverts a small percentage of the total oxygen flow though the side oxygen ports to promote post combustion closer to the bath. Post combustion occurs at the Tip face, roughly 70 inches above the steel bath. This method of post combustion is effective; however, it is not as efficient as some other means. This practice is currently used in a non-domestic BOF shop. A similar design is also implemented in two domestic Q-BOP shops.

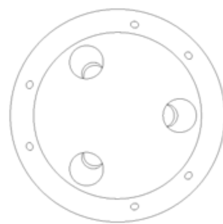

Figure 1. Auxiliary Lance Tip front view

The second method of injecting post combustion oxygen into the bath is with the addition of a second oxygen Tip or “Distributor” located between 4 and 12 feet above the main Oxygen Tip. The Distributor, as it is commonly known, injects oxygen above the Tip in the slag zone where there are high levels of CO. The majority of steel shops employee this style of post combustion.

There are two styles of Distributor or Post Combustion Lances: a Single or “Split” flow design and a Double Flow design. Figure 2 shows a schematic of the Distributor and Lance Tip.

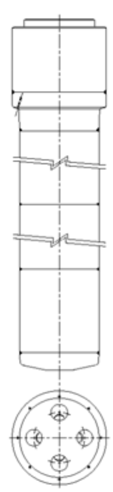

Figure 2. Side and front view of a post combustion Distributor and Lance Tip

With the split flow design, there is one oxygen supply and inlet. A small percentage of the oxygen is split inside the Lance from the main oxygen supply with the Distributor and injected out though side ports in the Lance. The post combustion oxygen through a Split Flow Lance is strictly dependent on the port diameter. The flow is based on an area calculation of the Distributor holes. Typically, 1% to 4% of the total oxygen flow is diverted through the post combustion holes depending on the desired outcome.

The Double Flow Post Combustion Lance requires a separate oxygen inlet and oxygen control system solely dedicated to the post combustion oxygen. This secondary oxygen line is separately controlled to allow the steelmaker the ability to increase or decrease the oxygen flow during peak times of CO generation, typically during carbon burning periods when carbon in the bath is at higher levels. The percent of oxygen flow in a Double Flow Lance can vary from a few hundred SCFM to several thousand SCFM. The separate oxygen controls and typically larger port sizes result in less velocity to help avoid the potential for refractory damage.

Figure 3 shows the inlets required for the Split Flow and Double Flow Lances. The Split Flow Lance requires one oxygen connection and two water connections. The Double Flow Lance requires two oxygen connections and two water connections.

Figure 3. Split flow post combustion top adaptor on the left; double flow post combustion top adaptor on the right

In both designs, post combustion oxygen is introduced through the Distributor and is combined with the CO produced from the main oxygen reaction to liberate extra heat energy within the vessel.

Most steel shops in North America utilize Post Combustion Lances to some degree. Some steel shops run with 100% Post Combustion Lances, while others have a few in their shop in case there is a need for higher scrap charges, or there are issues with Lance skulls due to practice changes. The majority of post combustion users have Split Flow Post Combustion Lances.

Three BOF shops presently utilize Double Flow Lances for increased scrap charges. There is however a renewed interest in Double Flow Post Combustion Lances to give the steelmaker an additional tool depending on scrap costs and hot metal availability.

Designs

An Auxiliary Tip can be easily retrofitted to an existing Lance and requires little more than matching up the pipe diameters and designing the proper nozzle sizes. A new Tip and possibly pipe reducers are required.

The Single Flow Post Combustion Lance design can be easily retrofitted to an existing BOF system and requires modification to the lower Lance barrel only. The bottom 4 to 12 feet of the Lance would be replaced with a Distributor and new Lance Tip Assembly with all pipe diameters matching properly to the existing Lance body.

A Double Flow Post Combustion Lance requires an extensive modification to an existing Lance, or in some cases a completely new Lance. In each case, a second oxygen inlet is required as is a secondary oxygen pipe through the Lance body.

The design of the post combustion nozzle diameters, the oxygen impingement angle, the port location, and the number of ports will vary depending on the furnace geometry, size, operation, and desired results. All four variables are critical to provide optimized use of the post combustion oxygen. By varying the size of the port diameter, the operator can control the amount of post combustion oxygen into the vessel. One concern often brought up during initial conversations regarding post combustion is the issue of refractory wear. By controlling the port diameter, the oxygen flow rate and velocity can be controlled and limited to a few percent of the total oxygen flow, or roughly a few hundred SCFM.

The port angle can also be adjusted to maximize the post combustion efficiency and minimize negative effects on refractory lining. Steeper angles allow for better skull removal from the Lance, while a shallow angle provides better coverage for improved post combustion efficiency.

The height of the Distributor or “step height”, can be adjusted to help with mouth and cone wear or to better control where the post combustion reaction occurs depending on the furnace size and characteristics.

The location of the ports and the number of ports are typically related to the size of the Lance and the size of the vessel as well as the specifics of the vessel, like tap and charge side.

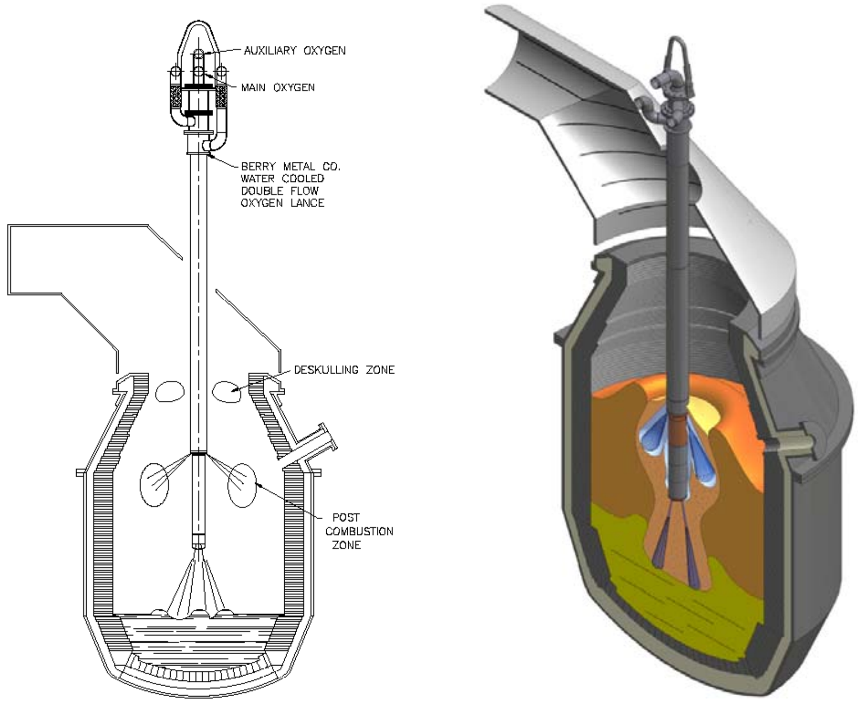

Figure 4. Post Combustion Lance in operation

Benefits

Post combustion was initially promoted for its benefits related to process improvements and increased production. Though these benefits are still very real, there is an increasing number of “side” benefits that in some instances far outweigh the production-related improvements.

More and more steelmakers are employing post combustion as a maintenance tool to reduce Lance skulls and furnace mouth and cone build up. Some of the production and maintenance benefits are as follows:

- Increased scrap consumption allowing greater flexibility in scrap-to-hot-metal ratio. This is dependent upon scrap prices and hot metal availability.
- Reduction in CO off-gas as CO is combusted to CO_2.
- Reduction in heat times with the increase in chemical energy.
- Assistance with dephosphorization by using high flows of post combustion oxygen.
- Improved safety by eliminating the need for manual deskulling.
- Reduction in damage to the Lance barrel from manual deskulling.
- Increased Lance utilization as Lances are no longer required to be cleaned and deskulled – Lances remain in service longer.
- Furnace utilization is optimized – the ability to use one Lance for the oxygen blow and for slag splashing with a reserve Lance in the other carriage.
- Reduction in mechanical damage to the furnace mouth and cone areas caused by heavy mechanical equipment, resulting in increased furnace availability.

Lance repair and maintenance data taken from several steel shops in North America are shown below. Each plant uses Post Combustion Lances:

Plant A: Prior to the introduction of combustion, standard Oxygen Lances were removed from service after 30 to 40 heats for manual deskulling. This required two men approximately 6 hours each, not including transfer and handling time for deskulling. The net result at this plant was a savings of $7,500.00 per Lance using an hourly wage of $40 per hour. The first Post Combustion Lance was removed from service with over 600 heats and did not require removal for deskulling during its usage. The plant also experienced similar savings with furnace mouth skulls. By eliminating manual cleaning of the furnace mouth by mechanical means, a savings of $35,000 per month was realized.

Plant B: This shop was vulnerable to delays due to Lance skulling. Two men routinely deskulled Lances after every heat with torches, pry bars, and water sprays. This work was very physical and hazardous to the employees. The torch cutting was a difficult task and as a result, several Lances were damaged due to torch marks. The Post Combustion Lance enabled the plant to use two men in a different capacity. It also reduced the risk of injury involved in manual Lance deskulling [3]. The estimated annual savings for two men at $40 per hour was approximately $166,000. Injuries due to Lance deskulling were also eliminated.

Plant C: Lances were routinely removed from service after 30 heats for manual deskulling. This required two men approximately 8 hours each at $40 per hour. This translated into a savings of $21 per heat, which equated to an annual projected savings of $150,000 (assuming 20 heats per day). The Post Combustion Lance eliminated manual deskulling during the entire Lance campaign.

Plant D: This plant reduced cone, Lance, and mouth skulling with the introduction of Post Combustion Lances. The Post Combustion Lance reduced Lance repairs by a factor of 2.5. The majority of Lance failures were due to cutting torch damage attributed to skull removal.

Plant E: This shop reduced Lance skulling and Lance changes by 75%.

Applications

Post combustion can be used in all types of BOF shops – suppressed combustion hoods and open combustion hoods, large 300 ton converters and small 80 ton converters. Post Combustion Lances are also used in Q-BOP and EAF shops.

The Q-BOP process uses bottom blown tuyeres and a top Oxygen Lance. Special auxiliary Tips are employed to provide the main oxygen jet as well as to deskull or clean the heavy skull areas. In 198, as stated by Messina and Peterson [4], the Q-BOP top Oxygen Lance was changed to a Post Combustion Lance. This Post Combustion Lance increased scrap melting capability by 5% and reduced mouth and cone skulls. Below are several configurations of Q-BOP auxiliary Tips.

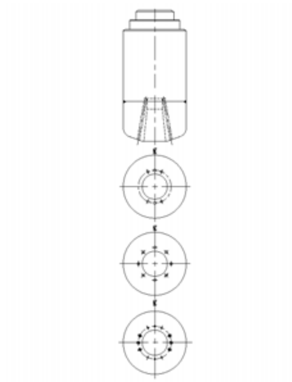

Figure 5. Side and front view of a Post Combustion Tip

Many EAF shops also utilize post combustion for the benefit of increased scrap melting capabilities. This is normally done with sidewall and/or top Oxygen Lances or with Oxy/Gas Burners. EAF's utilize post combustion more for the increased energy to help with scrap melting. Many EAF's use gas monitoring systems to measure CO, CO_2, and H_2O off-gases to assist them in determining when to increase post combustion oxygen. This allows them to control the amount of oxygen injected into the vessel for optimized energy efficiency.[5]

Post Combustion Lances work well with shops using slag splashing. During the nitrogen blow, slag is blown at high flow rates for 1 to 2 minutes to cover the vessel lining with furnace slag. During this process, slag can also be blown back onto the Oxygen Lance resulting in large slag skulls. These slag skulls tend to slide off the Lance once the Lance is retracted. However, if the furnace is not free of steel during the slag blow, a steel/slag skull forms on the Lance. This type of skull does not easily break free from the Lance. A Post Combustion Lance does not help to minimize the skull formation during the nitrogen blow because nitrogen is inert. During the nitrogen blow, slag builds on the Lance. But, once the next heat is started and the oxygen blow commences, the skull tends to "burn" off the Lance. A Post Combustion Lance can permit the steelmaker to use the same Lance for oxygen and nitrogen blowing. Some shops use separate Lances to oxygen blow and slag blow due to the steel/slag skull build up created during slag splashing.

A few BOF shops using double flow post combustion, increase scrap melting and utilize 4% to 5% more scrap per heat when production is high and metal is in short supply

Failure Modes

BOF post combustion Distributors typically last 2 to 3 times longer than a Lance Tip, roughly 800 to 1,200 heats on average. Distributor life varies based on the furnace operation and design. Life of a BOF Post Combustion Oxygen Lance is strongly affected by cooling water parameters. The proper flow rate, temperature, and water quality must be maintained to achieve optimum heat transfer [6]. The nozzle diameters, angles, location, and the number of ports are all critical design parameters and must be properly designed to minimize distributor wear and to eliminate any chances of furnace wear. If designed improperly or used improperly, post combustion oxygen can be detrimental to a furnace and its lining.

Future Developments

With the international market becoming increasingly competitive, the need to produce more steel and reduce costs per ton is a reality. Decreasing heat times, reducing maintenance downtime, and the ability to vary the scrap-to-hot metal ratio based on scrap prices makes post combustion a good tool to have in the BOF arsenal.
There is renewed interest in Double Flow Post Combusting Lances to control the amount of secondary oxygen that is injected into the converter. The combustion of CO to CO_2 is a large untapped energy source. Advances in off-gas measurement technology allow for the extraction and analysis of the off-gas to optimize energy inside the furnace.[5]

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