First Operating Experiences with Post-Combustion Lances at BOF shop LD3

Authors

H. Panhofer, J. Lehner, M.W. Egger, voestalpine Stahl GmbH, Austria
M.J. Strelbisky, A.H. Tallman Bronze Company Limited, Canada

Contact data

Harald Panhofer, voestalpine Stahl GmbH, voestalpine-Straße 3 4020 Linz, Austria,
email: harald.panhofer@voestalpine.com,T. +43/50304/15-5416, F. +43/50304/55-2911

Michael J. Strelbisky, A. H. Tallman Bronze Company Limited, 2220 Industrial Str,. Burlington, Ontario, Canada L7P1A1,
Email: mjs@tallman-bronze.com T. +1/905/335-3491, F. +1/905/335-5896

Summary

The application of post-combustion to avoid skull formation on BOF lances was tested in industrial trials. The main findings are that no negative impact on the metallurgical targets (i.e. carbon, temperature and phosphorus at end of blow as well as iron–oxide in the slag) could be observed. The technology is capable of avoiding the buildup of lance skull and consequently increasing the average life of lance tips. The application of post-combustion not only affects the skull formation, there are also interactions with the refractory lining, especially thermal wear, and the utilization of the process gases that have to be considered. Special attention has to be paid to the parameters determining post-combustion because rather small changes can strongly affect the points mentioned above.

Key Words

BOF, lance skulling, post-combustion

Introduction

In BOF steelmaking skulling of lances is a well-known issue. One widely applied technique to overcome this problem is the usage of mechanical cleaning devices. These high-maintenance wipers are costly and industrial safety during repairs is often a challenge. Due to these disadvantages voestalpine Stahl GmbH was looking for an alternative and ran trials with post-combustion lances supplied by Tallman Bronze Ltd.

The objectives for this trial were: To increase the average life cycle of BOF lances, to discontinue the wipers, to increase the overall availability of the BOF´s and to improve workplace safety. The following boundary conditions had to be satisfied - minimum influence on the utilization of the process gas, no negative influence on the refractory lining, especially in the cone and mouth area, and no negative effects on the metallurgical performance of the process. The aim of this paper is to present the initial results of these tests.

Post-Combustion

Carbon monoxide is the main component in BOF off-gas. From an energy related point of view the carbon monoxide is unutilized energy. According to *Table 1* roughly three times the energy of the decarburization can be harvested when carbon monoxide is post–combusted to carbon dioxide.

Table 1: Thermochemical Data for the Combustion of Carbon and Carbon Monoxide [1]

Reaction	ΔH [MJ/Kg]	ΔS [MJ/K Kg]
$[C]_{T=TR} + {}^{1}/_{2}\{O_2\}_{T=28°C} \rightarrow \{CO\}_{T=TR}$	-10,128	0,01
$\{CO\}_{T=TR} + {}^{1}/_{2}\{O_2\}_{T=TR} \rightarrow \{CO_2\}_{T=TR}$	-32,455	0,014

When the enthalpy of these two reactions is compared the generated heat of the post–combustion is more than three times that of the decarburization. The entropy of both reactions is not exactly equal and the contribution of post-combustion increases with an increase in the reaction temperature. This connect-edness is shown in Figure 1. According to Figure 1 the energy harvesting strategy with the highest output would be to operate the BOF with the highest possible rate of post–combustion. However there are complications, especially when cold oxygen is used for post–combustion. Transferring the generated heat to the bath leads to the development of special process variants. [3]

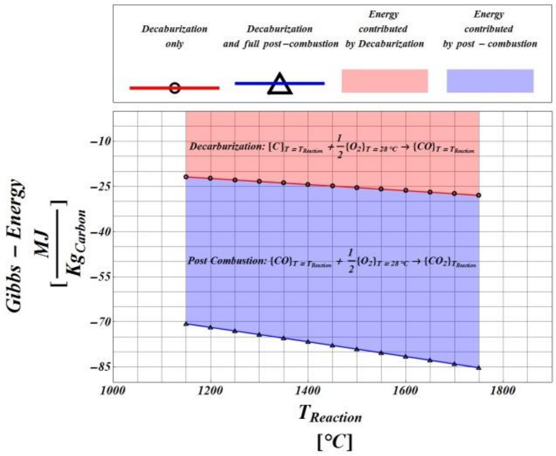

Figure 1: Gibbs – Energy for Decarburization and Decarburization with Full Post – Combustion [2]

Especially in Europe, a widely used energy harvesting practice is to operate the BOF with suppressed post-combustion, quench, de-dust, collect the off–gas and then reuse it as fuel gas.
Figure 1 clearly shows that there is the potential of additional heat generation in the converter when at least a part of the off–gas is post–combusted.

Application of Post-Combustion for Lance Cleaning.

Contrary to the concept of “full post-combustion” [3] which aims at using the highest possible amount of chemical energy in the off–gas and transferring the generated heat to the melt, this application intends to use a well dosed amount of oxygen for post-combustion and generate just enough heat for the purpose at a specific location in the converter.
To achieve this, specially designed devices, so called Post Combustion Distributors (PCD), are used. These PCDs allow for the branching off and distribution of some of the oxygen. From a construction point of view this is demanding because usually oxygen flows in the innermost pipe of a BOF lance and is encapsulated by the cooling water supply and return. This is shown in Figure 2.

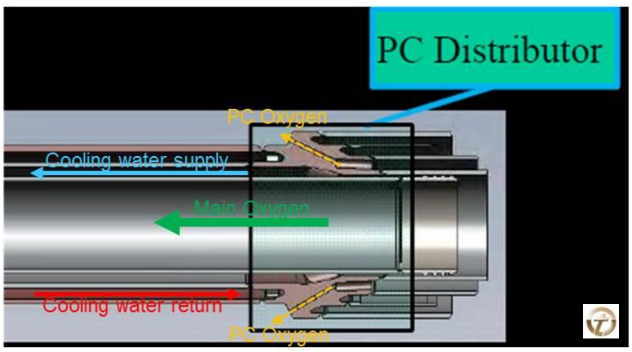

Figure 2: Diversion of Oxygen for Post – Combustion from the Main Oxygen Flow Source: Tallman

The integration of a PCD to a lance as shown in Figure 2 causes an additional challenge. The PCD is made of copper, and as a result, the stiffness of the whole construction is decreased. To overcome this issue, additional patented strengthening elements are added to the construction.
As mentioned above, the aim for this application was to avoid skull formation on the lance. In order to accomplish this the PCD was positioned at a distance above the lance tip which is roughly three times the height of the lance tip above the bath surface during main blowing. Approximately 3% of the total oxygen flow rate was chosen for the secondary oxygen flow rate based on Tallman's experience with previous PCD .Due to the construction of the PCD, the amount of oxygen used for post-combustion is dependent on the main oxygen flow rate. The design parameters determining the share of oxygen for post-combustion are the number and diameter of the exit holes in the PCD.
To achieve the desired effect of heat generation around the lance, the distance of the secondary oxygen holes to the lance tip, the amount of secondary oxygen, and the number of secondary oxygen holes are important variables that must be considered. Also, the angle at which the oxygen is injected, in combination with the current conditions of the off–gas, have a significant influence on the formation of the post-combustion area. *Figure* 3 is a simplified illustration of this relationship.

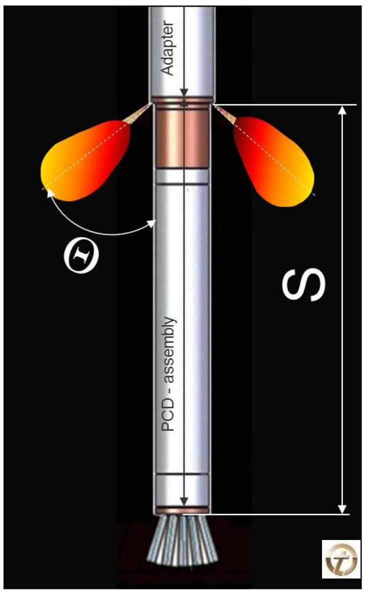

Figure 3: Formation of the Post – Combustion Area Source: Tallman

The shape of the post-combustion zone in *Figure 3* is a rough estimation since the current conditions of the off–gas are not exactly known. Also the mixing behavior of oxygen and the off–gas that determines the chemical reaction is strongly affected by these current conditions.

Industrial Tests

voestalpine Stahl GmbH in Linz operates three LD type converters with a nominal tapping weight of 180 metric tons. Each converter is equipped with bottom stirring equipment, a sub–lance, and a mass spectrometer for off–gas analysis. The converters are operated with suppressed post-combustion. The off–gas is collected, dedusted, cooled and utilized as fuel gas.

Adoption of Lances

For the industrial tests, two lances were equipped with PCD`s supplied by Tallman Bronze. Tallman designed the PCD to be compatible with the voestalpine's current lance configuration. An adapter, that acted as connector between the existing lance and the PCD assembly, shown in *Figure 3*, was attached to each lance. The PCDs themselves are designed to accept lance tips which are normally used at voestalpine. So the most common maintenance procedure, the exchange of worn out lance tips, was not affected by this conversion. The two converted lances were used alternating with the standard lances during a converter campaign (life cycle of a refractory lining). The design parameters (number and diameter of exit holes in the PCD, angle of the exit holes Θ and distance of the exit holes to lance tip S) were proposed by Tallman.

Results of Initial Design

Avoidance of Skull Formation

In Figure 4 a hard case of lance skulling is compared to the typical deposit buildup when post-combustion is used.

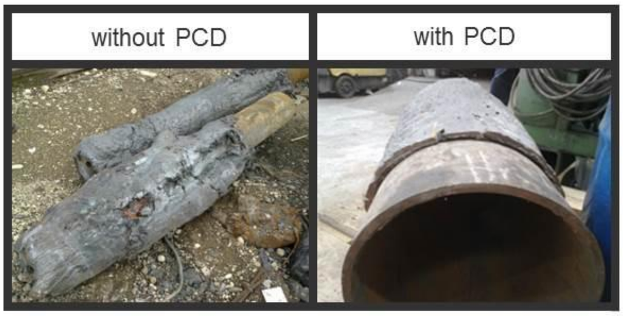

Figure 4: Comparison of Skull Formation
Source: voestalpine

The effectiveness of the PCD is obvious. The deposit is a result of the thermal conductivities of the outer steel pipes and the deposit itself. The outermost pipe in the lance construction guides the cooling water return. Consequently, the inside of the pipe is constantly cooled while the deposit on the outside is constantly heated by post-combustion. The deposit forms in an equilibrium of heat delivery and removal. Without the heat delivered by the PCD the skull can grow further.

During the usage of the PCDs, the wipers (mechanical lance cleaning device) were mechanically locked and out of use.

Achievement of Metallurgical Objectives

Since the PCD lances were used alternating to the standard lances, a fair comparison can be drawn. Neither the average of the target metallurgical performance comparison nor its distribution was affected by the use of the PCDs.
A closer inspection of the oxygen consumption showed an increase of approximately 5% when the PCDs are used. This value is in accordance with Tallman's engineered PCD design.

Influence on Composition and Amount of the Collected Off-Gas

One unique aspect of the off-gas utilization at voestalpine is that despite operating with suppressed post-combustion the skirt is not closed completely. The aim is to keep a small gap to avoid sticking of the skirt to the cone of the converter. To prevent bleeding of the process gas to the surrounding environment, a slight under-pressure is maintained at this gap. Due to this practice some false air is drawn in via the gap, reacting with the off-gas and causing post-combustion in the flue.
The under-pressure has a significant influence on the amount and composition of the collected off–gas as well as in the amount of saturated steam produced.
A higher ratio of false air increases the CO_2 and N_2 content in the off–gas and also increases the amount of steam produced. On the other hand, the CO amount an the ratio of CO/CO_2 are decreased.
During a converter campaign the refractory wears, thus increasing the volume and bath diameter of the converter and reducing the steel bath height. To compensate for these changes in bath geometry varying blow patterns are used.
Figure 5 depicts the difference in under-pressure in the gap between the skirt and the top of the converter for various blow patterns used during the converter campaign.

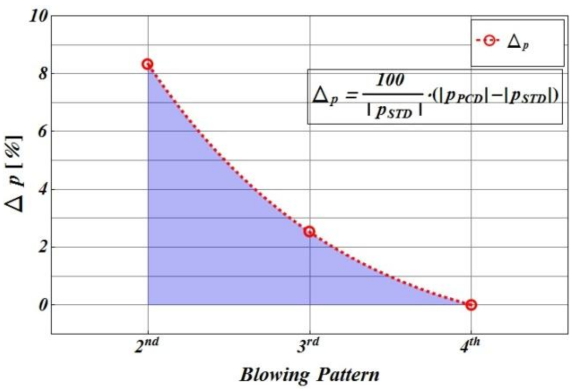

Figure 5: Pressure Difference for Different Blowing Patterns

The trend in Figure 5 leads to the conclusion that the under-pressure at the gap between the skirt and the top of the converter is influenced by the distance between the secondary oxygen holes and the gap. As mentioned previously the variation in under-pressure influences the off-gas composition and the amount of steam generation.

Improvement of Average Lance-Tip Life

Like stated above the skulling of lances was completely avoided when the PCDs were in use. Figure 6 shows that the lance tip life more than doubled as a result of PCD use.

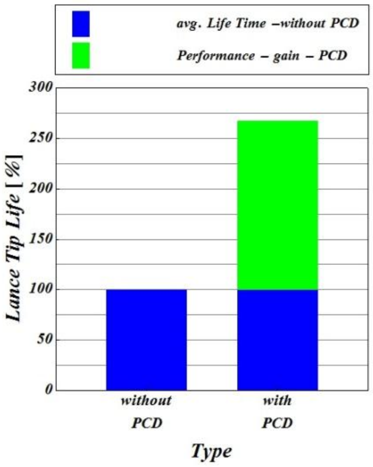

Figure 6: Results of Average Lance Tip Life - Initial Design

Thermal Wear of Refractory in the Converter Cone Area

During the first PCD trial it was observed that as the converter aged the thermal wear of the converter cone increased to the point that the trial was terminated. Figures 7 depicts the hot spots in the mouth area of the converter

Figure 7: Hot Spot in the Mouth Area Due to Post-Combustion Source: voestalpine

Adaption to the Initial Design

Because of the promising results regarding increase in lance-tip life it was decided to test modifications of the existing PCDs. Since the angle Θ could not be changed, on one lance the number of exit holes was reduced while on the other lance the distance between secondary oxygen holes and lance tip was reduced. Both lances were tested in short term trials that could be terminated if the prevention of skulling was insufficient or if overheating of the converter cone area was observed. In these tests the reduction of distance turned out to be particularly promising. So the second lance was also shortened.

Results of Modified Design

Both modified lances were used alternating to the standard lances during a whole converter campaign.

Thermal Wear of Refractory in the Converter Cone Area

For the duration of the campaign no overheating of the converter cone area was observed. Also the skull formation in the converter cone area appeared to be slightly more than with the initial design but still less than with the standard lances.

Avoidance of Skull Formation

Since the same angle and number of exit holes were used, the skull formation below the PCD was comparable to the initial design. However some skulling appeared above the PCD that had not been present during the trial with the initial design. To overcome this issue approximately every 10^{th} heat the wipers were used to remove the skulling above the PCD. This was much easier than removing skulls from standard lances and the wear of the wipers was significantly reduced.

Achievement of Metallurgical Objectives

As in the first campaign there was no difference in the target metallurgical performance.

Improvement of Average Lance Tip Life

The gain in average lance tip life was significant but less than observed with the initial PCD design. The comparison for the second campaign is shown in Figure 8.

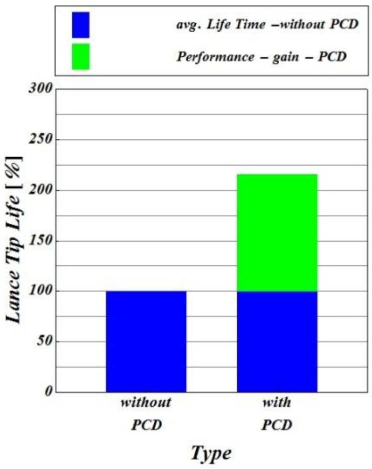

Figure 8: Results of Average Lance Tip Life - Modified Design

Conclusion

The utilization of energy generated from post-combustion of a rather small amount of the off–gas is a practical way to avoid skulling of BOF lances. Special attention has to be paid when the amount of secondary oxygen used and the location of post-combustion reaction in the converter are chosen. The potential of post-combustion to overcome other issues like skull formation in the mouth and cone area of the converter should also be considered.

The results of these trials show that a balance between the avoidance of skull formation, the thermal wear of the refractory lining and the impact on off-gas utilization has to be found. The factors affecting this balance may vary between different steel plants. As a result of this, onsite fine tuning of parameters determining post-combustion is essential for everyone who wants to use post-combustion effectively.

Abbreviations

PC	post-combustion
PCD	post-combustion distributor
BOF	basic oxygen furnace
[C]	carbon in melt
{CO}	carbon monoxide in gas phase
{CO2}	carbon dioxide in gas phase
$\{O_2\}$	oxygen in gas phase
T =	Temperature of phase
TR	Reaction temperature
S	Distance lance tip to secondary oxygen holes
Θ	Angle of the secondary oxygen holes –ports to lance

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