

25% Increased Reheating Throughput and 50% Reduced Fuel Consumption by Flameless Oxyfuel at ArcelorMittal Shelby – Tubular Products, Ohio

THIS ARTICLE IS AVAILABLE ONLINE AT WWW.AIST.ORG FOR 30 DAYS FOLLOWING PUBLICATION.

In 2005, ArcelorMittal Shelby, together with Linde, formerly known as Linde Gas, implemented a 5% oxygen enrichment technology on the Shelby, Ohio, seamless tube mill's rotary hearth furnace, resulting in a 29% fuel savings. Later, ArcelorMittal Shelby sought to boost heating capacity in order to increase the seamless tube mill output for larger billet dimensions while reducing fuel consumption. So in 2007, Linde led a four-month turnkey project to implement the Linde REBOX[®] oxyfuel solutions at the furnace. The result was a 25% increase in reheating capacity and a 50% decrease in fuel consumption over oxy-enrichment. Overall, fuel consumption decreased by 65% versus airfuel. This paper explores the project's objectives and the implementation of flameless oxyfuel, with results from performance tests and daily operation, which also included improved temperature uniformity for better piercing results, a 50% reduction of scale formation, and minimized nitrogen oxide (NO_x) and carbon dioxide (CO₂) emissions.

ArcelorMittal Shelby – Tubular Products, Ohio

The Tubular Products division of ArcelorMittal is one of the world's largest producers of pipe and tube products, located in nine different countries with 18 different operating locations. Dofasco Tubular Products was formed in 2005 when Dofasco de Mexico, Hamilton

and Marion tubing plants merged with Copperweld's Automotive and Mechanical businesses. The Tubular Products division of ArcelorMittal is the result of merging Dofasco

When flameless oxyfuel was implemented in one rotary hearth furnace at ArcelorMittal Shelby, reheating capacity increased by 25% while fuel consumption decreased by 50%. The objectives, implementation and results of the project are discussed.

Tubular Products and ArcelorMittal Pipes and Tubes assets in 2007.

ArcelorMittal Shelby manufactures precision welded and seamless tubular products. At this location, 643 employees manufacture approximately 207,000 tons of all the principal types of mechanical steel tubing: seamless hot finish, seamless cold drawn, welded drawn-over-mandrel (DOM), and as-welded tubing. Most of the facility's volume is electric resistance welded tubing that is produced in an extensive range of sizes and wall thicknesses, whereas rotary piercing of solid round billets produces the seamless product. Primary markets for the facility include the automotive, industrial and construction equipment



Authors

Mike Lantz (top left), general foreman — Plt. 1 Primary Mills, and **Douglas Hassenzahl** (top right), superintendent — hot mill, ArcelorMittal Shelby – Tubular Products, Shelby, Ohio (mike.lantz@arcelormittal.com, douglas.hassenzahl@arcelormittal.com); **Anders Lugnet** (bottom left), senior research and development engineer — steel industry, Linde Gas, Lidingö, Sweden (anders.lugnet@linde-gas.com); **Grzegorz Moroz** (bottom center), senior engineer — metals and glass segment, Linde LLC, Murray Hill, N.J. (grzegorz.moroz@linde.com); and **Anders Carlsson** (bottom right), sales manager — furnace technology, UTAB Division, Linde Gas, Vasteras, Sweden (anders.carlsson@linde-gas.com)



Figure 1



In August 2007, ArcelorMittal Shelby (Ohio) revamped their billet reheating rotary hearth furnace to flameless oxyfuel, reaching an additional 25% heating capacity while reducing fuel consumption by 50% over an oxygen-enriched airfuel system.

industries, recreation equipment, oil drilling and production, as well as steel service centers. The Shelby plant purchases long bars that are then cut to length, charged, and reheated in the rotary hearth furnace prior to downstream processing. The furnace was originally equipped with an airfuel system without any recuperator to preheat the combustion air (Figure 2). Some energy was recovered from the flue gas in a boiler producing steam for a downstream pickling line.

Boosting Tube Mill Output for Larger Billet Dimensions

In 2004, ArcelorMittal Shelby and Linde discussed how to reduce the existing rotary hearth furnace's energy consumption, and the result was that, in 2005, oxygen enrichment technology was applied to the existing airfuel combustion system. Following the positive results of 29% reduction in fuel consumption, Shelby later aimed to further reduce energy costs and also boost the seamless tube mill output, especially for larger billet dimensions. The Shelby project team identified several aspects of the project to achieve a successful implementation:

- *Increased furnace capacity.* Target was set for 25% more heating capacity (tons/hour) for billets 6 inches and larger.
- *Reduced operating costs.* Reduce energy and equipment maintenance costs.
- *Better product quality and temperature uniformity.* The applied solution should improve the quality and temperature uniformity of the billets for downstream processing in the tube mill.
- *Environmental compliance.* The fossil fuel-fired furnaces are recognized as major contributors of emissions, and it was important to find solutions to minimize this impact in accordance with existing and future regulations for nitrogen oxides (NO_x) and carbon dioxide (CO₂).
- *Short project payback.* Preferably within 24 months.

Figure 2



The original furnace (a) had three flue gas exits and baffles cooled by an air blower, seen in front of the furnace. The Linde REBOX[®] oxyfuel solutions (b) minimized piping and ducting with only one remaining flue gas exit.

- *Efficient and safe implementation.* A short project timeline that results in minimum furnace and production downtime, and preferably as a turnkey project.
- *Guaranteed performance.* Ability for supplier to achieve predefined contract targets.

Discussions with Linde ensued, and several scenarios and solutions were discussed. The positive discussions led the ArcelorMittal Shelby team to travel to Sweden for a reference visit to Ovako Steel, in Hofors. Ovako Steel has a process similar to the one at Shelby and is a longtime oxyfuel user, dating back to 1994 for soaking pit furnaces. In addition, two of Ovako's rotary hearth furnaces have been completely heated with oxyfuel since 1998. In 2006, Ovako converted the soaking pit furnaces to flameless oxyfuel, reducing the total heating time by 43% compared with airfuel (Figure 3). The conversion from conventional oxyfuel to flameless oxyfuel also delivered more uniform heating, additional fuel savings of 17% and 5–20% less scale formation.¹

In April 2007, ArcelorMittal Shelby contracted with Linde after concluding that full implementation of flameless oxyfuel would be the only efficient solution, both in terms of cost and time, to meet the predetermined project targets. The other possibilities — building an additional furnace, creating a preheating section, or using other types of airfuel systems — would be too difficult to implement, since they would change the logistical setup of the production, would take too long to implement or would not be cost-effective.

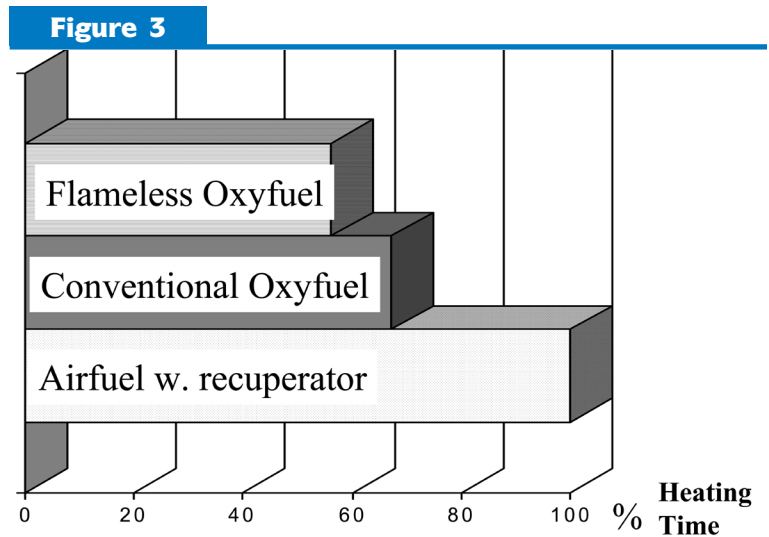
Flameless Oxyfuel — State-of-the-Art Combustion Technology

Flameless combustion is named for the human eye's inability to identify smaller temperature differences at elevated temperature levels. In flameless oxyfuel, the temperature difference between the flame and the furnace wall is around 180–360°F; at a furnace temperature of 2,200–2,400°F, the flame appears to be invisible.

The main objectives of applying flameless oxyfuel are:

- To further reduce heating time.
- To reduce creation of thermal NO_x, made possible by the low flame temperatures.
- More uniform heating conditions.
- Reduced energy consumption.
- Less scale formation as a result of more effective heating and reduced heating time.

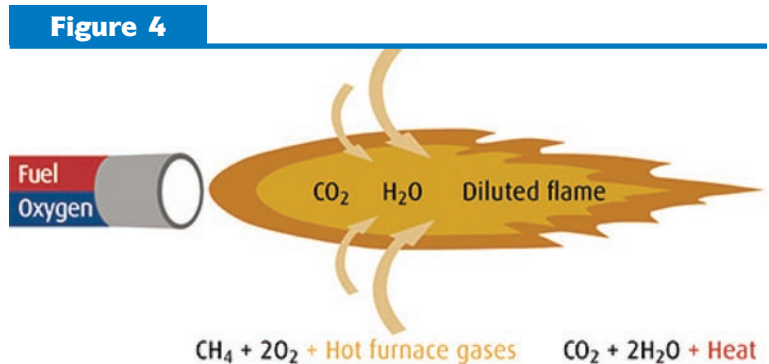
All these objectives are possible due to the lower flame temperature of flameless oxyfuel.



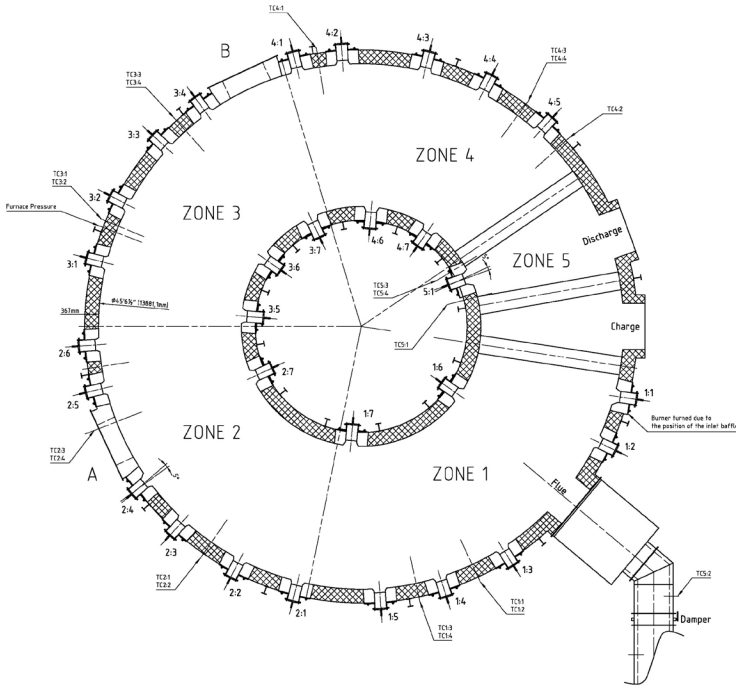
At Ovako Steel, Hofors, Sweden, installation of flameless oxyfuel has reduced the total heating time by 43%, at the same time improving the quality of the heating process and with less fuel.

The flameless nature of the combustion is created by diluting the flame with the furnace gases, which in oxyfuel combustion contain no nitrogen ballast (Figure 4). The dilution also causes an effective stirring of the flue gases, which promotes heat transfer as well as a more uniform heating. The flameless oxyfuel burners from Linde are dual-mode, meaning they heat as conventional oxyfuel burners until the furnace temperature of 1,400°F has been reached. Over that temperature, fuel auto-ignition occurs, and the flame is diluted to achieve the more favorable conditions of flameless oxyfuel.²

To date, Linde has fully converted more than 120 furnaces to oxyfuel operation. Of those, 30 have been equipped with flameless oxyfuel technology. The performance results from such installations at Outokumpu Stainless, Ascometal, Uddeholm Tooling, Scana, Ovako, SSAB and now also at ArcelorMittal Shelby have met or exceeded the defined objectives. The low NO_x emission levels have also



In flameless oxyfuel, the flame is diluted by the furnace gases. This effectively lowers the flame temperature, despite still having the same energy content, for a more homogenous heating of the steel.

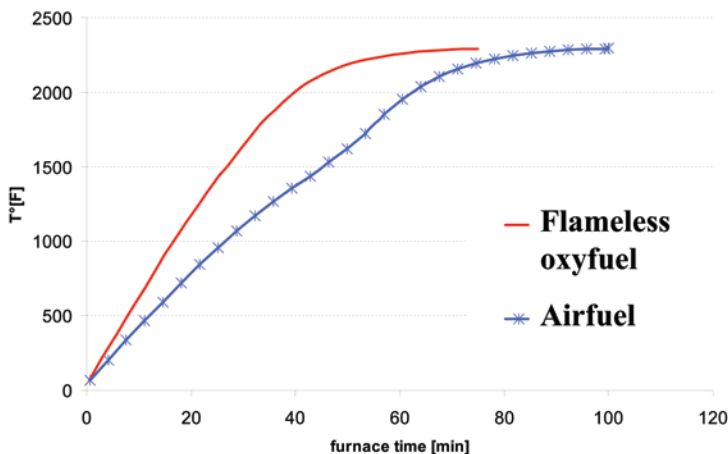
Figure 5

Linde proposed to close two of the three flue gas exits (pos. A & B), remove two baffles and add an extra heating zone (#4). Flameless oxyfuel burners were placed in the existing positions of the airfuel burners.

been confirmed by semi-industrial investigations carried out by the Royal Institute of Technology in Sweden.³

Implementing Flameless Oxyfuel on the Shelby Rotary Hearth Furnace

Linde reviewed Shelby's existing rotary hearth furnace and designed a new combustion solution based on process experience, application

Figure 6

The heating profile was revised so a 6.5-inch billet would be properly heated at 75 minutes with flameless oxyfuel, versus 100 minutes for airfuel.

knowledge, and simulation and calculation modeling. The elements of implementing the Linde REBOX[®] oxyfuel solutions were as follows:

- Complete turnkey project, to be implemented and commissioned within four months.
- Replacement of existing airfuel burners (109 mmBtu/hour) by ceramic, self-cooled flameless oxyfuel burners (60.6 mmBtu/hour).
- Revised heating zones, from four to five zones, with appropriate temperature measurement.
- Improved pressure control, by closing two of three existing flue gas exits and adding an active damper.
- New combustion control system for fuel and oxygen, including flow trains for natural gas and oxygen.
- Removal of two air-cooled baffles.
- Removal of combustion air blowers.
- Performance guarantee.
- 16-day revamp with production start-up on August 26, 2007.

Revised Heating Profile for New Heating Zones

— The proposed furnace and combustion system changes were based on a revised heating profile. This profile takes into account the typical properties of flameless oxyfuel, which has higher combustion efficiency, better and more uniform heat transfer properties, and 70–80% less flue gases. This makes it possible to heat more efficiently early in the furnace without compromising large energy losses to the flue. The heating profile was especially designed to increase the furnace heating capacity for the 6-inch and larger billet dimensions, while providing additional fuel savings and improved temperature uniformity (Figure 6).

The heating zone configuration was changed to include the addition of one extra zone (#4). These changes accounted for the closing of two of three flue gas exits. The new, self-cooled ceramic flameless oxyfuel burners were placed in the same position as the earlier airfuel burners (Figures 1 and 5). Burners in two zones include starter burners and UV sensors for flame supervision. Zone 5 is the discharge zone, where one burner provides final heating of the billet. Since no nitrogen ballast is present in the combustion process, the burners and associated hardware are much smaller, making them ideal for both new and retrofitted furnaces. Plus, their simple and compact design makes them easy to handle during routine inspection and maintenance. The efficiency of flameless oxyfuel enabled the furnace burner's total power input to be lowered to 60.6 mmBtu/hour from the 109

mmBtu/hour of the previous airfuel system (Figure 7).

Removed Baffles and Improved Control — Temperature control of each zone is easily managed with oxyfuel, since 70–80% of flue gas volumes have been reduced. These reduced volumes stem from the absence of nitrogen in the combustion process and the reduced fuel consumption. As mentioned above, the reduced flue gas volumes required closing two flue gas exits, at positions A and B, and enabled removing the baffles between heating zones. Today, only the baffles at the charge and discharge zone (#5) remain in their original positions (Figure 5). The removal of the air-cooled baffles has further improved the furnace’s thermal efficiency and lowered the maintenance costs.

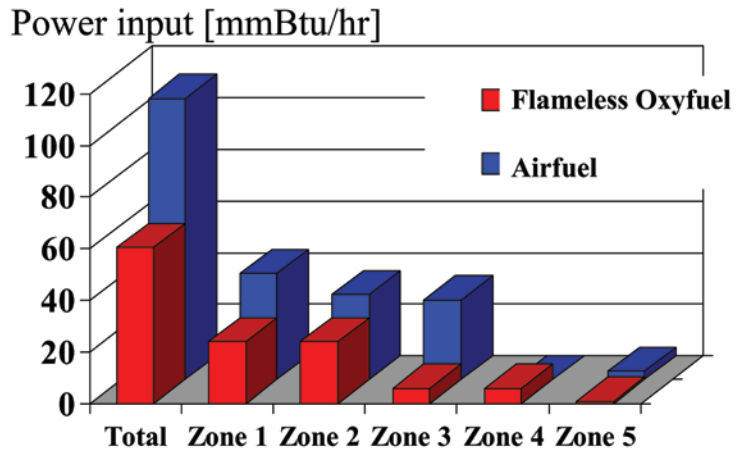
To ensure energy efficiency and minimize unwanted emissions, such as NO_x, it is important to keep furnace pressure under strict control. This is a must for any kind of combustion system. However, with oxyfuel combustion, furnace flue gas volumes are drastically reduced, creating a need for active and dynamic furnace pressure control. At the remaining flue gas exit, an active damper was installed, and the pressure control system was redesigned under Linde’s supervision.

In order to achieve the new heating profiles, feedback on supervision, control and safety is needed. Correct temperature measurement is important with regard to overheating, flue gas temperatures and maximum temperatures. Thermocouples were repositioned in accordance with the new zone arrangement and control requirements.

A temperature controller and a programmable logic controller (PLC) with human machine interface (HMI) are used as a stand-alone system to operate the temperature control and the furnace interlocks. The system controls the flow, ratio and temperature of the rotary hearth furnace, as well as burner ignition sequences and safety interlocks. Start, stop and setpoint functions are operated from the present control room, or local HMI at the system control cabinet (Figure 8). There are local cabinets near the burners that contain the burner management system (BMS) and operation indications and switches.

Four-Month Turnkey Project and On-Time Installation — A four-month project timeline was necessary to conclude system design, programming, establish a pre-test control system, assemble flow trains and manufacture proprietary flameless oxyfuel burners. The natural gas and oxygen piping, as well as electrical wiring, were done prior to the furnace’s planned outage. During the 16-

Figure 7



With flameless oxyfuel, it has been possible to reduce the total power input by 44%, from 109 to 60.6 mmBtu/hour. The power input has also been rearranged in order to meet the revised heating profile.

day outage, from August 10 to 26, 2007, ArcelorMittal Shelby also scheduled refractory repairs and the removal of the identified baffles. The flameless oxyfuel burners were easily installed in the positions left vacant by the airfuel burners.

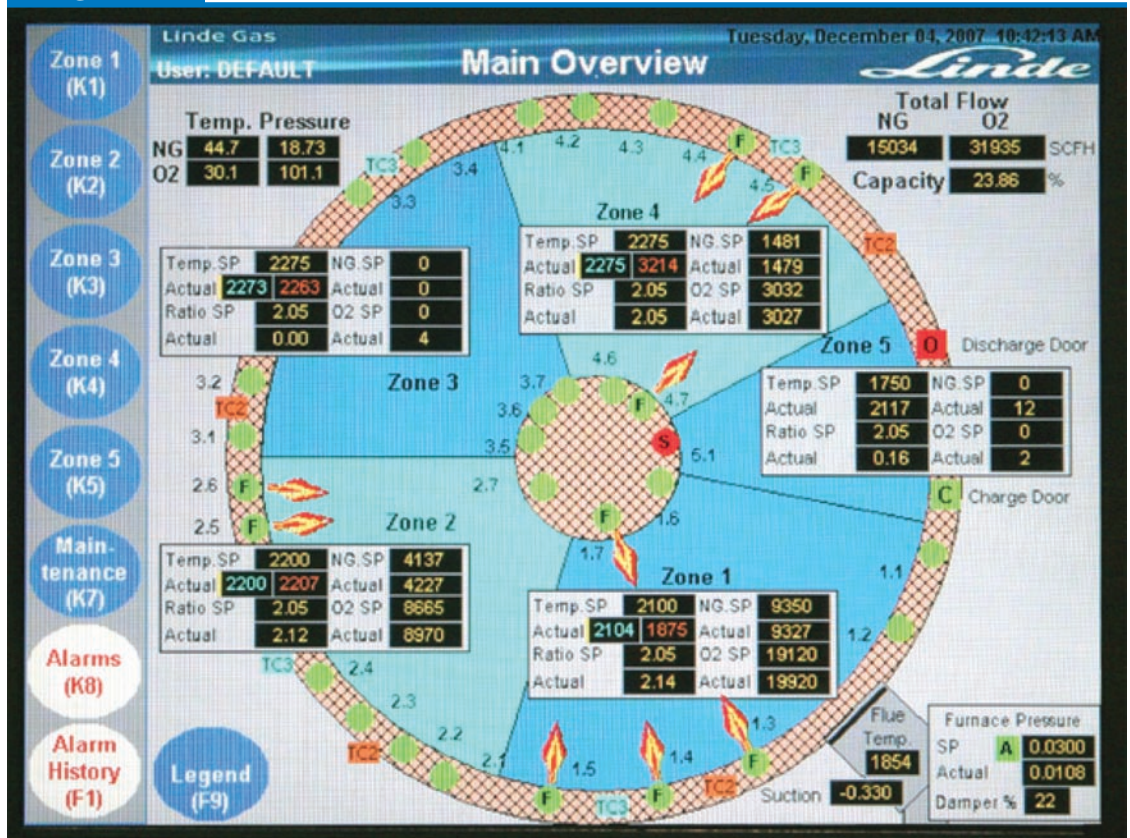
Fulfilled Performance Guarantee

As part of the project, performance tests were carried out to verify results of the rotary hearth furnace’s conversion to flameless oxyfuel technology. These tests were done in early September 2007 and validated the performance guarantee. Since then, ArcelorMittal has been able to see the same results in the daily operation of the furnace.

Furnace Capacity Increased by 25% — The oxygen enrichment carried out in 2005 did not increase the furnace heating capacity, but with full application of flameless oxyfuel, the performance tests showed a 35% increased heating capacity for 6.5-inch billets. With airfuel and also oxygen-enriched combustion technology, the required soak time for a 6.5-inch billet was 100 minutes, whereas with flameless oxyfuel it is 75 minutes (Figure 6). The average increase in capacity for larger billet dimensions (6 inches and more) is typically at 25%, which was the defined target for the project. The reduced heating time has been achieved with no negative impact on product quality, and has instead delivered improved and more uniform heating, which reduces scale formation.

Specific Gross Fuel Consumption Decreased by 50% (Btu/ton) — The furnace’s specific gross fuel consumption, or all the energy that passes through the furnace during operation, standby and start-up, had decreased by 29% following oxygen enrichment. With flameless

Figure 8



A screenshot from the HMI module. The furnace and combustion system can be controlled from the operator room.

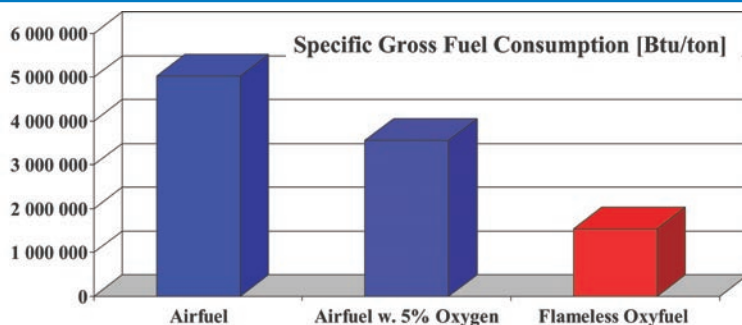
oxyfuel, specific gross fuel consumption has fallen by an additional 50%, or a total decrease of more than 65% from the original airfuel installation (Figure 9). The specific energy consumption — the energy required to effectively heat billets — is now 1.1 mmBtu/ton for cold charged 6.5-inch billets. Total energy savings also has been helped by removing the electrical air blowers.

Improved Temperature Uniformity and 50% Less Scale Formation — Thermal images were captured for a large number of 6.5-inch billets,

both prior to and after the revamp into flameless oxyfuel, to establish final temperature and uniformity of the heating (Figure 10). Improved temperature uniformity, which is beneficial for improved downstream processing in the piercing mill, was realized, based on the recorded data and operators' experience. The operators also recognized that the furnace wall now has a more uniform temperature, which is beneficial to efficiently heating the billets. With an increased overall furnace capacity of 25%, temperature differences over the billet length were reduced by 50%, enabling improved downstream processing.

The strongest single parameter for reducing scale formation is limiting the exposure time for steel at elevated heating temperatures.⁴ For Shelby, flameless oxyfuel has reduced the reheating cycle time for larger-dimension billets. The PLC system and the flow trains for natural gas and oxygen precisely control combustion, furnace atmosphere and pressure, keeping the furnace oxygen level at a correct and controlled level. This has resulted in an estimated 50% reduction of scale formation, which is in line with the results Linde has achieved in more than 110 reheating and annealing furnaces fully converted to oxyfuel. Cleaning and removal of scale formation from Shelby's production line has now been rescheduled to once a week instead of the previous daily cleaning.

Figure 9

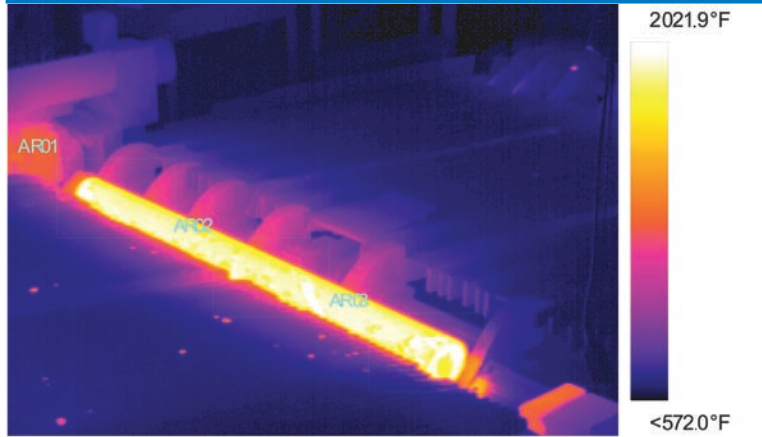


The specific gross fuel consumption has dropped over 65% since the first work was done to apply oxyfuel combustion.

NO_x Emissions Reduced by 76% (lb/year), CO₂ by 65% (lb/year) Over Airfuel — The Shelby project team had outlined in the project specification that any solution would have to reduce the current emissions level, especially for NO_x, and be able to meet increasingly stricter regulations for maximum allowable emissions levels. Results from Linde's numerous reference installations, including data from the Ovako rotary hearth furnace in Sweden, indicated that flameless oxyfuel would reduce NO_x emissions, due to the lower flame temperature and resulting reduction in the creation of thermal NO_x. Semi-industrial tests and industrial operations of flameless oxyfuel both show that the level of ingress air has virtually no effect on thermal NO_x formation, which help to maintain low NO_x emission levels. Measurement of NO_x emissions was carried out prior to and after the installation of flameless oxyfuel. The results project a drastic, 76% reduction in annual NO_x emissions in pounds per year and 85% lower levels of NO_x emissions in pounds per mmBtu (Figure 11). CO₂ emissions are directly proportional to fuel consumption. Thus, the 65% lower fuel consumption compared with the original airfuel installation corresponds to an equal reduction of CO₂ emissions.

Improved Working Conditions and Reduced Maintenance — Today, Shelby furnace operators report improved working conditions following the flameless oxyfuel implementation. Not only do they have less cleaning and removal of scale from the furnace, but they have a much quieter work environment following the removal of the electric air-blowers. The overall noise level today is so low that the

Figure 10



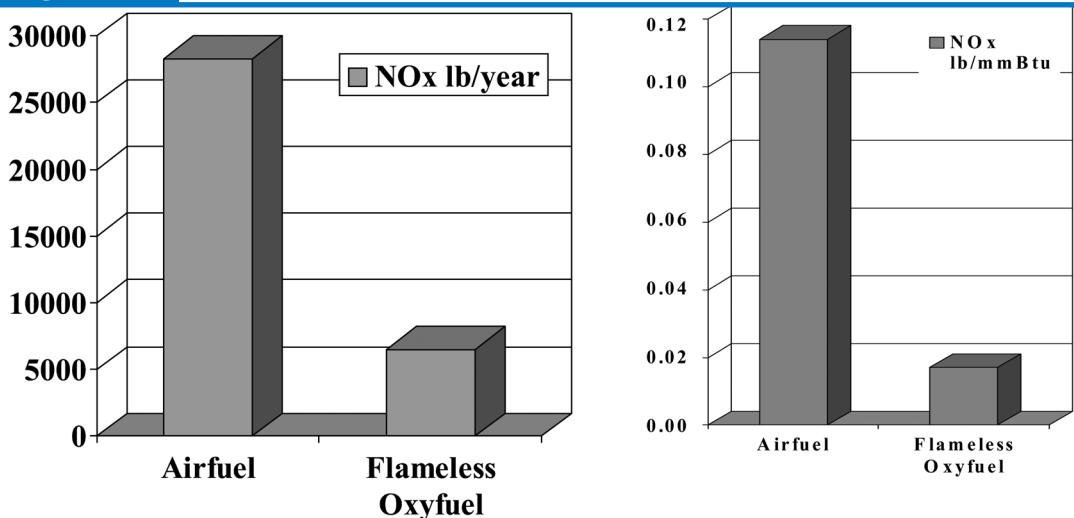
Billet ready for piercing — 50% less temperature difference over billet length when heated by flameless oxyfuel.

operators have stated, “We can now even hear the hydraulic pumps working.” Removal of the blowers also eliminates associated maintenance. The furnace's outer shell is also cooler now, making it more comfortable during maintenance and repair activities and suggesting less wear from extreme heat on refractory and furnace structure. At the discharge door, the discharge manipulator operator is no longer blinded by the airfuel burner's glare (Figure 12). Plus, the new burner's modular design allows inspection and maintenance to be performed during production. Lastly, having only one flue gas exit made it possible to remove a majority of the bulky piping and ducting around the furnace (Figure 2).

Summary

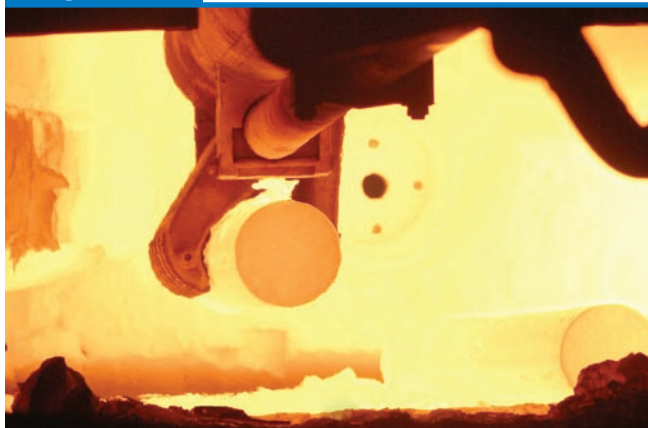
ArcelorMittal Shelby and Linde began in 2004 working jointly to improve the reheating process in an existing rotary hearth

Figure 11



NO_x emissions (lb/year) have been reduced by 76% with the implementation of flameless oxyfuel.

Figure 12



Flameless oxyfuel at ArcelorMittal Shelby increased the heating capacity for larger billet dimensions by 25% and cut fuel consumption by 50% over oxygen-enriched airfuel. It also improved temperature uniformity and reduced scale formation by 50%.

furnace. The methodical implementation of the Linde REBOX[®] oxyfuel solutions has rapidly and cost-efficiently brought long-term, viable results without a long project period or extensive production downtime. In 2005, a 5% oxygen enrichment of the airfuel system delivered a 29% specific gross fuel savings. Later, ArcelorMittal Shelby wanted to boost capacity, especially for large-size billets, and in 2007 Linde was awarded a turnkey project for a full conversion of the same rotary hearth furnace to flameless oxyfuel technology. Several process parameters have been monitored prior to and after the restart of the furnace at the end of August 2007, and the important results of the project are summarized as follows:

- An overall capacity increase of 25% for billet dimensions 6 inches and larger.
- Specific gross fuel savings of 50% over oxygen-enriched airfuel and 65% over the original airfuel.
- Improved temperature uniformity with 50% less temperature difference over billet length.
- A 50% reduction in scale formation.
- Annual NO_x emissions lowered by 76%, a 50% reduction in CO₂ emissions over oxygen-enriched airfuel and 65% reduction over the original airfuel.
- A short, four-month timeline for implementation and on-time commissioning.
- Project payback within 24 months.

Related Discussion

An optional solution to oxygen enrichment is to install a limited number of flameless oxyfuel burners in pre-defined positions of the furnace, in parallel to the existing airfuel combustion system. This is sometimes referred to as “boosting” and has a similar effect as oxygen enrichment but, most importantly, makes it possible to tailor the exact solution needed for defined problems and targets, such as:

- Providing extra heating capacity for certain steel grades, dimensions and processes.
- Improving yield and furnace output through more uniform heating.
- Adding flexibility to recover lost production or accommodate peak order situations, etc.
- Saving fuel and adding capacity even with an aging and failing recuperator system.
- Eliminating risk of overheating existing airfuel burners, flue gas and recuperator system.
- Minimizing NO_x generation with flameless oxyfuel.

The rapid implementation of flameless oxyfuel boosting gives full furnace and burner control. The flameless oxyfuel burners are also compact and rugged for installation next to or in old burner positions, and the boosting system can be turned off when an improved reheating or annealing process is not required. The introduction of flameless oxyfuel for boosting applications has interested several major steel producers, demanding a rapid implementation for increased capacity and fuel savings in their existing furnaces without any increased levels of NO_x.

References

1. P. Fredriksson, et al., “Ovako, Hofors Works — 13 Years Experience of Using Oxyfuel for Steel Reheating; Background, Solutions and Results,” *AISTech 2007 Proceedings*, AIST, Warrendale, Pa.
2. J. von Schéele, P. Vesterberg and O. Ritzén, “Invisible Flames for Clearly Visible Results,” *Nordic Steel & Mining Review 2005*, p. 16, Sweden.
3. W. Blasiak, K. Narayanan and W. Yang, “Evolution of New Combustion Technologies for CO₂ and NO_x Reduction in Steel Industries,” *Air Pollution 2004*, Greece, 2004.
4. J. Adolphi, et al., “Scale Formation and Surface Quality of Carbon Steel at Oxyfuel Heating,” *Steel Rolling 2006*, Paris, France. ♦

This paper was presented at AISTech 2008 — The Iron & Steel Technology Conference and Exposition, Pittsburgh, Pa., and published in the Conference Proceedings.



Did you find this article to be of significant relevance to the advancement of steel technology? If so, please consider nominating it for the AIST Hunt-Kelly Outstanding Paper Award at www.aist.org/huntkelly.