30% Increased Capacity of Metal Coating Lines at ThyssenKrupp Steel

In airfuel combustion, the burner flame contains nitrogen from the combustion air. A significant amount of the fuel energy is used to heat up this nitrogen. The hot nitrogen leaves through the stack, creating energy losses. When avoiding the nitrogen ballast, by the use of industrial-grade oxygen, then not only is the combustion itself more efficient, but also the heat transfer. Oxyfuel combustion influences the combustion process in a number of ways. The first obvious result is the increase in thermal efficiency due to the reduced exhaust gas volume — a result that is fundamental and valid for all types of oxyfuel burners. Additionally, the concentration of the highly radiating products of combustion, CO_2 and H_2O, is increased in the furnace atmosphere.

Prompted by rapidly rising fuel prices in the 1970s, the steel industry began to consider methods to reduce fuel consumption in reheating and annealing. This laid the foundation for the use of oxyfuel solutions in rolling mills and forge shops. In the mid-1980s, Linde first began to equip these furnaces with oxygen-enrichment systems, which increased the oxygen content of the combustion air to 23–24%. The results were encouraging: fuel consumption was reduced and the output, in terms of tons per hour, increased.

In 1990, Linde converted the first steel reheating furnace in the world to operate with 100% oxygen, or full oxyfuel combustion, at Timken in the United States. Since then, Linde has been pioneering the use of oxyfuel for this application. Today, the number of such oxyfuel installations has reached 120. Overall, the results can be summarized as:

- Capacity increase of up to 50%.
- Fuel savings of up to 50%.
- Reduction of scaling losses.
- Reduction of CO_2 emissions by up to 50%.
- Reduction of NOx emissions.

Linde has continued to develop the processes to meet new demands and challenges. As a result, some interesting technologies have emerged in parallel with conventional oxyfuel, which is widely used to boost melting in electric arc furnaces. Among those, the most important ones are flameless combustion and Direct Flame Impingement (DFI). These new technologies not only fulfill existing needs with astonishing results, they also open up completely new areas of application.

Flameless oxyfuel provides even higher production rates, excellent temperature uniformity and very low NOx emissions. The first installations of this innovative flameless oxyfuel technology were made by Linde in 2003. Linde now has more than 30 installations of this technology at more than a dozen sites, some using a low-calorific fuel.

Recent installations of REBOX® Direct Flame Impingement oxyfuel systems at ThyssenKrupp Steel plants in Germany have delivered up to 30% increased throughput capacity in galvanizing and aluminizing lines, with no extension of furnace length.

DFI Oxyfuel is a compact, high-heat transfer technology that provides enhanced operation in strip processing lines, such as galvanizing lines. DFI Oxyfuel has been used to boost capacity of strip annealing and hot-dip metal coating lines by 30% or more, while reducing the specific fuel consumption. Systems are in operation at Outokumpu's Nyby Works in Sweden and ThyssenKrupp's works at Finnentrop and Bruckhausen in Germany. In October 2009, a unit was installed in a continuous annealing line at POSCO in Pohang, South Korea.

The DFI Oxyfuel Technology

DFI Oxyfuel, where oxyfuel flames directly heat the moving metal, is a patented solution within Linde's portfolio of REBOX® Oxyfuel solutions. The main benefits of DFI Oxyfuel, where oxyfuel flames directly heat the moving metal, are:

- Significantly higher heat transfer (10 times the process in use), resulting in increased production capacity.

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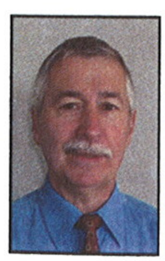
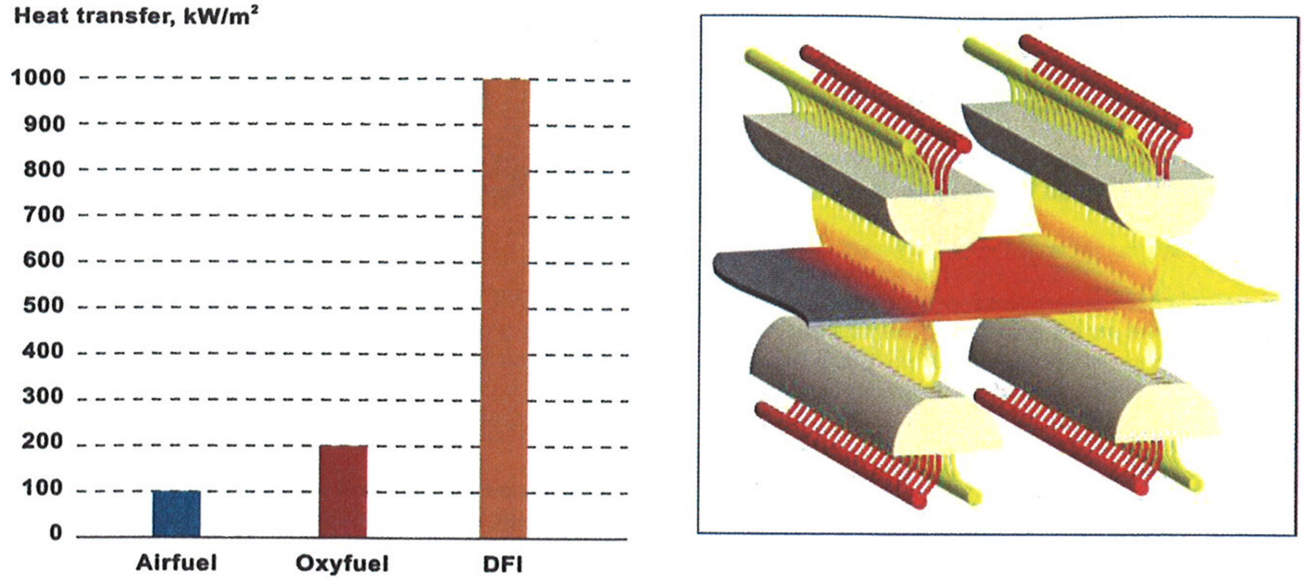



Figure 1

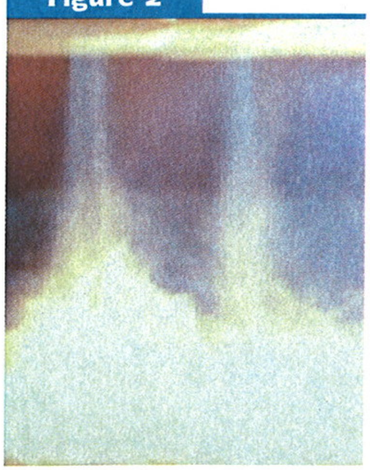


Oxyfuel combustion is much more energy efficient than airfuel. However, DFI Oxyfuel technology is even more efficient; the heat flux could be as high as 1,000 kW/m^2. The DFI Oxyfuel unit, shown in the principle sketch on the right, has a thermal efficiency of around 80%.

- Low fuel consumption due to small flue gas volume.
- Ability to use high power input in limited furnace volume.
- Compact and powerful unit for easy retrofit.
- Heating and cleaning in one operation.
- Option to modify surface conditions.

Tests have verified the higher level of local heat flux for the DFI Oxyfuel technology. In general, the use of oxyfuel combustion substantially increases the thermal efficiency of a furnace. This is due primarily to the fact that radiant heat transfer of furnace gases produced by oxyfuel combustion is significantly more efficient than that of airfuel. Due to the absence of nitrogen in the combustion mixture, which does not need to be heated, the volume of exhaust gas is also substantially reduced, thus lowering total heat loss through the exhaust gas. Thanks to improved thermal efficiency, the heating rate and productivity are increased and less fuel is required to heat the product to a given temperature, while at the same time economizing on fuel and reducing CO_2 emissions.

Figure 2



Oxyfuel flames in Direct Flame Impingement.

The REBOX DFI unit has a thermal efficiency of around 80%. This reduces the specific fuel consumption while delivering a powerful 30% capacity increase in an existing strip processing line. In galvanizing, zinc adhesion and surface appearance are also improved due to DFI's effective pre-cleaning properties, leaving both strip and furnace rolls cleaner than before.

It is important to note that applying the DFI Oxyfuel system for pre-heating a strip does not create an oxidation problem; for example, experience with pre-heating up to 300°C shows no problems. In metal coating lines, any thin oxide layer formed is reduced in the subsequent reduction zone. It is also possible to influence the oxidation level to a certain extent by adjusting the stoichiometry of the combustion.

First Installation at Stainless Annealing

Since the beginning of the 1990s, Linde has pioneered the use of 100% oxyfuel applications in reheat furnaces in close cooperation with customers such as Outokumpu, which was one of the first customers to which Linde provided turnkey solutions. At Outokumpu's Nyby site in Sweden, the company wanted to increase the production capacity of a stainless strip annealing line, but the furnace already contained an oxyfuel combustion system and had extremely limited physical space available. In 2002, Linde installed the first compact DFI Oxyfuel unit, making it possible to increase the production by 50% (from 23 to 35 tonnes/hour) without extending the furnace length.

This REBOX DFI Oxyfuel installation consisted of:

- 2-m-long DFI unit at the entry side.
- Four burner row units.
- 4 MW installed power.
- 120 oxyfuel flames.

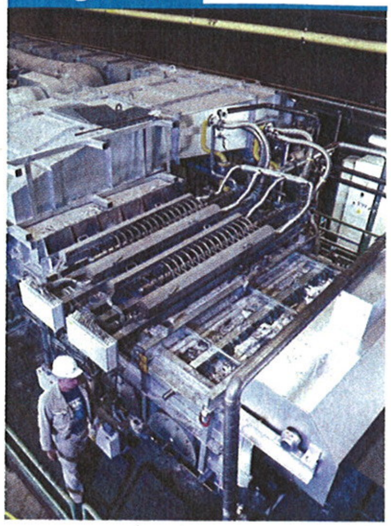
Metal Coating Lines at ThyssenKrupp

In 2007, Linde installed its REBOX DFI system at ThyssenKrupp Steel's (TKS) galvanizing and aluminizing line in Bruckhausen, Germany. Earlier, Linde had

Figure 3

The DFI Oxyfuel installation at the entry side of the stainless strip annealing line at Outokumpu, Nyby Works, Sweden.

Figure 4



The DFI Oxyfuel unit installed at Finnentrop, replacing part of the dark-zone and boosting the output by 30%.

Figure 5

In 2006, a REBOX DFI unit was installed at the entry side of the galvanizing line at TKS's Finnentrop Works, where it has resulted in 30% increased production capacity and elimination of the use of a pre-cleaning section.

installed a REBOX DFI unit at the TKS galvanizing line at Finnentrop, and increased production capacity from 82 to 105 tonnes/hour, or more than 30%. The results at the Bruckhausen installation matched those in Finnentrop, increasing capacity from 70 to 90 tonnes/hour. Oxyfuel not only effectively heats — contributing to a reduction of fuel consumption — but also cleans, thus eliminating the need for the pre-cleaning section. In addition, the process made it possible for ThyssenKrupp to pre-oxidize steel strips in a precise and controlled manner.

The Installation at TKS Finnentrop

The Finnentrop plant carries out zinc coating of hot and cold strip of 650–1,550 mm wide and 0.3–3.25 mm thick. Prior to the REBOX DFI installation, it had a 25-m-long pre-cleaning section with electrolytic cleaning and brushes. The total furnace length is 130 m, with a 48-m pre-heating section. The total installed power was 22 MW, 17.5 MW for preheating with airfuel (pre-heated air temperature at 450°C) and 4 MW in radiant tubes in the reduction zone. Natural gas is used as fuel. The maximum line speed was 180 m/minute, and the maximum production capacity 82 tonnes/hour (t/h).

TKS's brief to Linde was based on having identified that, by increased strip heating, the production capacity of the line could reach 105 t/h. It also required that the appropriate heating solution should free the strip surface from unwanted contaminants, such as emulsions, oils, grease and particles, which originate from the upstream production process. TKS had earlier tried to get the same result from induction-type strip pre-heaters, but soon realized that these pre-heaters typically have poor thermal efficiency and low reliability and require too much maintenance. The boosting unit had to allow strict control of the required surface properties essential for successful galvanizing of the strip, which induction-type strip pre-heaters could not provide.

Prior to the installation of the DFI Oxyfuel boosting unit at Finnentrop, TKS and Linde had conducted several tests at Linde's laboratory facilities in Sweden. These studies were aimed at determining the exact levels of pre-heating that could be achieved with DFI Oxyfuel for the particular steel grades and thickness conditions at Finnentrop, while assessing the surface property impact.

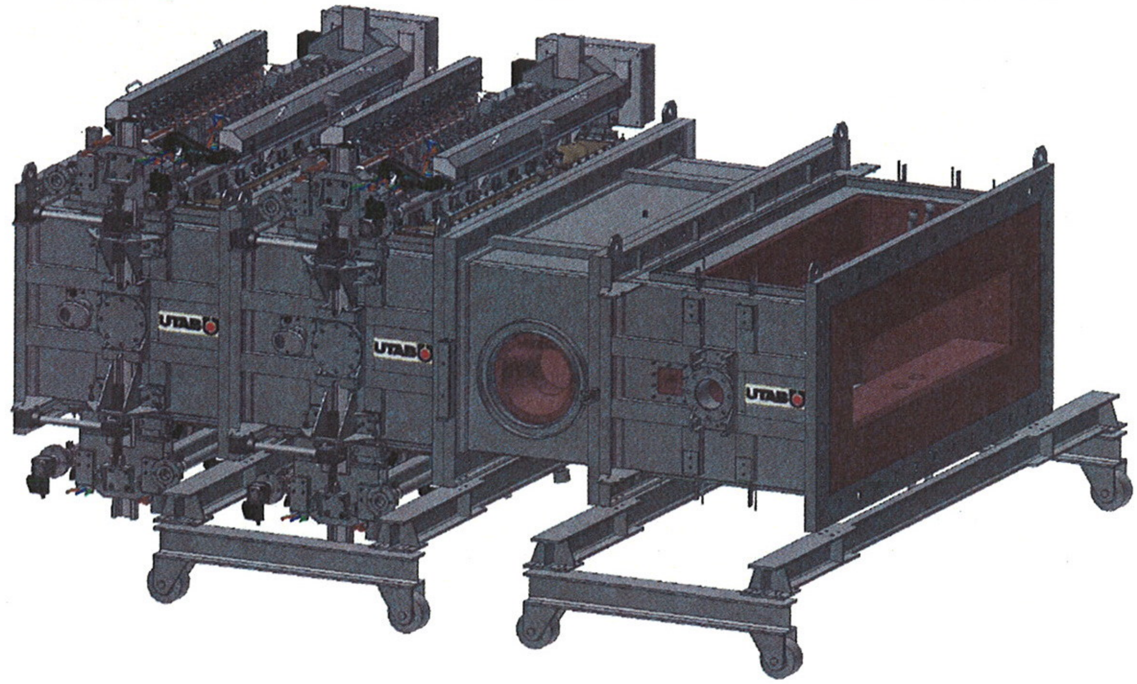
To minimize line downtime, TKS wanted a solution that would be easily integrated with the existing furnace. The design resulted in a 3-m-long DFI unit equipped with four burner row units, with a total of 120 oxyfuel flames and 5 MW installed power, with an option of two more row sets for an additional 2.5 MW. The number of burner row units and burners employed depend on set pre-heating temperatures and the actual strip width and tonnage. At 105 t/h, DFI Oxyfuel results in an immediate steel strip surface temperature increase of more than 200°C. This would equal a 10-m extension of the direct-fired furnace, a length that is not normally available in existing galvanizing or other strip processing lines and which would not have provided decreased fuel consumption and elimination of the cleaning section.

For the installation, 3 m of the existing recuperative entry section was removed to fit the DFI Oxyfuel unit. After a 12-day line stop (of which four days were used for installing the DFI unit), production resumed.

Increased Galvanizing Capacity

With initial tuning and subsequent optimization of the DFI unit and the total line, capacity increased from 82 to 109 t/h. The DFI Oxyfuel unit also manages to burn

Figure 6

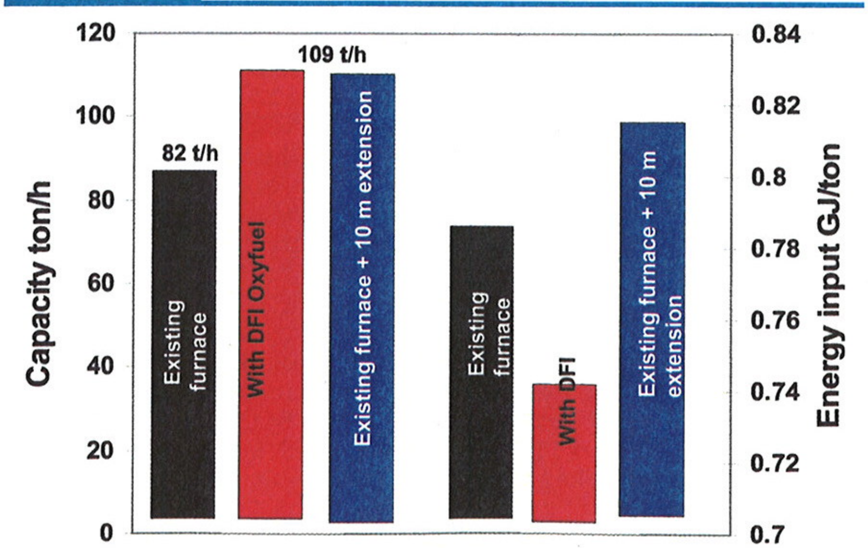


View of the DFI Oxyfuel unit at the galvanizing and aluminizing line at TKS's Bruckhausen works. Four burner row units were installed, but there is room for adding an additional two if required.

off residue, particles, grease and oil from the strip rolling process, providing a cleaner strip than the 25-m-long electrolytic and brush strip pre-cleaning section, which has now been removed.

Figure 7 shows the results. It includes a calculated alternative using a 10-m extension of the furnace in order to reach the higher capacity, which should be used as the reference when comparing with DFI Oxyfuel results.

Figure 7



Comparison of results of DFI Oxyfuel at TKS Finnentrop versus extending the furnace.

The Finnentrop results show the impact of the DFI Oxyfuel installation on fuel and emissions. At a production level of 36,000 tonnes per month, the solution including DFI Oxyfuel leads to at least a 5% reduction in natural gas consumption, almost 20% lower NOx emissions, and a reduction of 1,200 tonnes per year in CO_2 emissions.

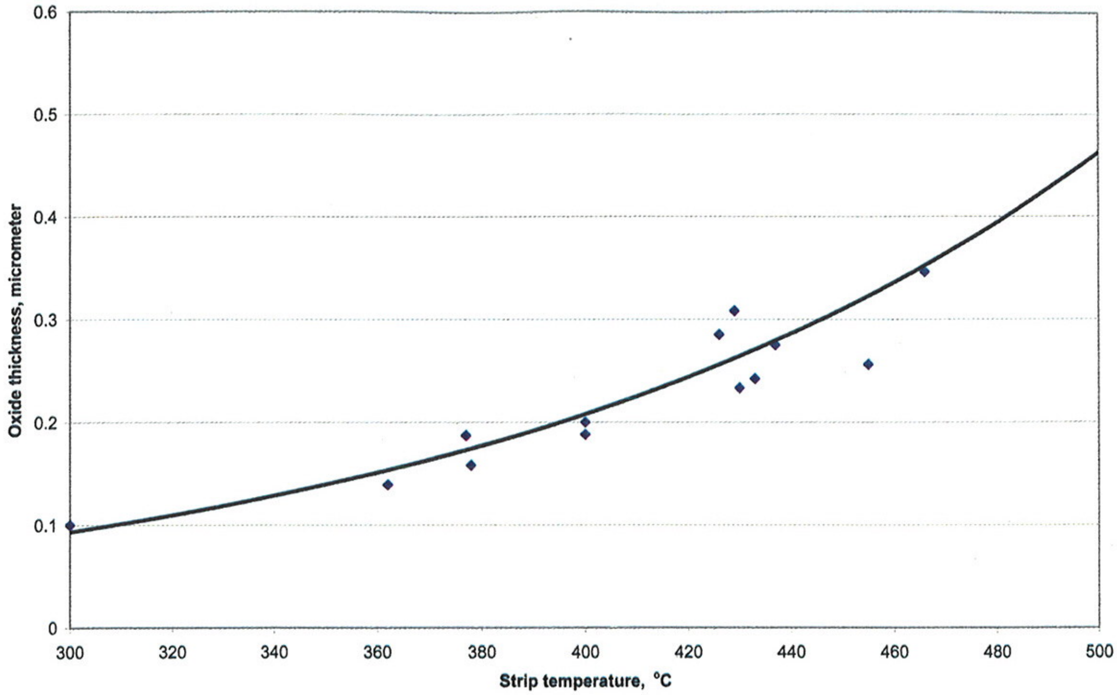
Oxidation Control

Using REBOX DFI, the oxidation is lessened at a specific temperature, since the dwell time is very limited. The simplified Wagner model for parabolic scale formation can be used to explain growth at a specific time and temperature.

It is important to note that applying DFI Oxyfuel for pre-heating a strip up to 300°C does not create any issues related to excessive oxidation. In metal coating lines, the thin oxide layer formed is reduced in the subsequent reduction zone. It is also possible to influence the oxidation by adjusting the stoichiometry of the combustion, for example by changing the lambda value from 1.0 to 0.9.

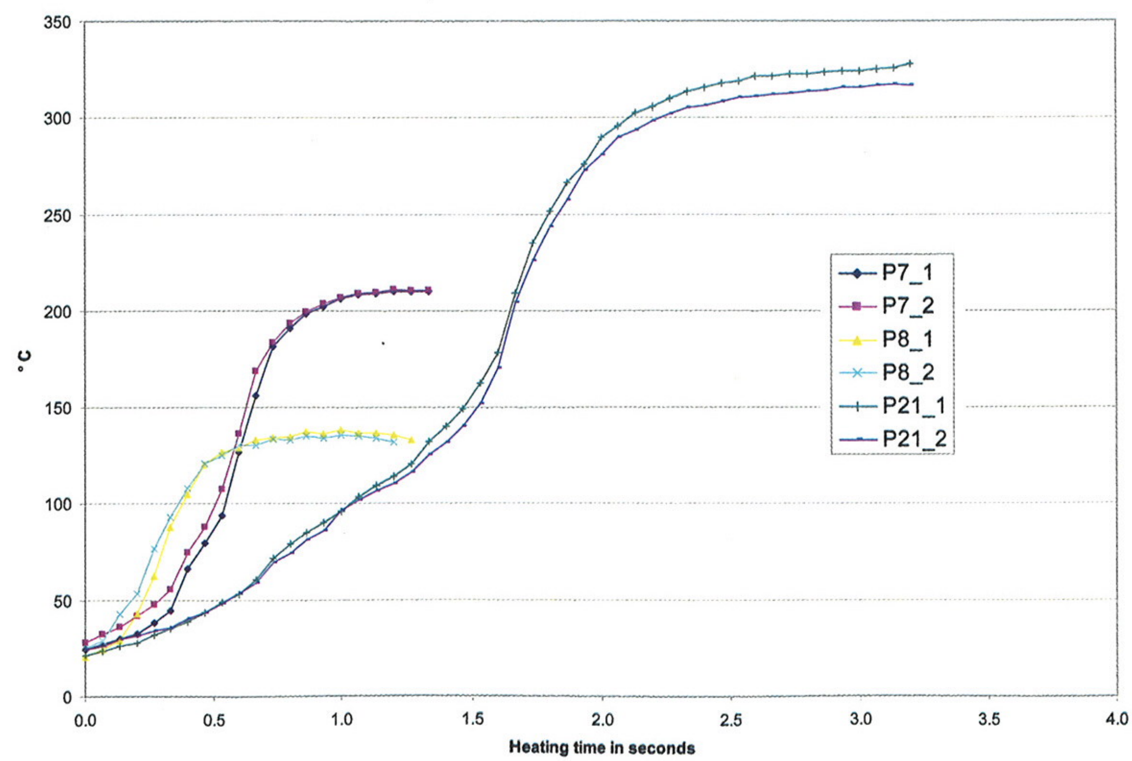
The oxide layer thicknesses have been measured to be in the range of 50–100 nanometers, even at high strip temperatures. A well-performing reduction zone should be able to sufficiently reduce this oxide. For high-strength steel, a small formed oxide layer, e.g., 200 nm, may be beneficial,

Figure 8



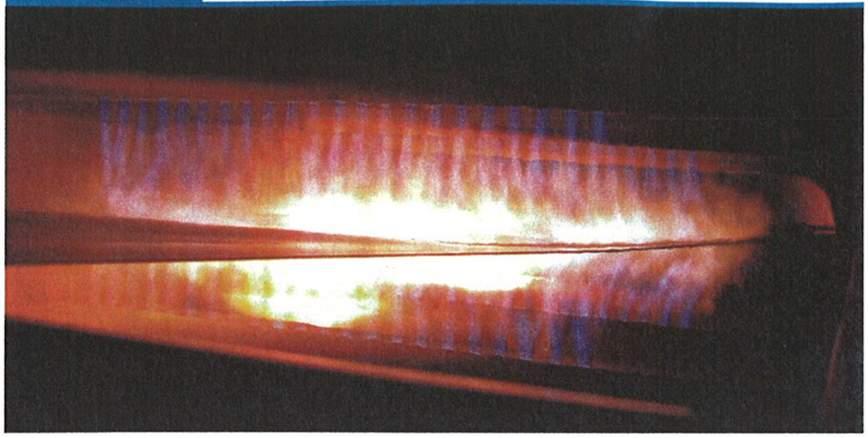
Oxide layer thickness when heating with DFI Oxyfuel. Results from laboratory tests using different strip thicknesses, line speeds and firing power to achieve different strip temperatures.

Figure 9



Surface temperatures when heating with DFI Oxyfuel. Results from laboratory tests using different strip thicknesses, line speeds and firing power.

Figure 10



A look inside the DFI unit in Finnentrop: Oxyfuel flames are heating directly onto the moving strip, increasing the temperature more than 200°C.

since after reduction in the radiant tube furnace section, pure iron will form on the surface for improved zinc adhesion.

Conclusions

In 120 reheating and annealing installations, REBOX oxyfuel solutions provide more capacity and flexibility, as well as a reduction in fuel consumption and substantially lower emissions. Since 2003, most new installations employ flameless oxyfuel, which provides excellent temperature uniformity and reduced NOx emissions.

Also, DFI Oxyfuel is an important part of the successful REBOX solutions portfolio, clearly demonstrated by the 30%+ capacity increases at ThyssenKrupp Steel in Bruckhausen and Finnentrop, and Outokumpu in Nyby. The next installation will take place in 2010 at POSCO in Korea.

DFI Oxyfuel has a heat transfer that is 10 times better than the system previously used. In a galvanizing line, additional benefits include improved zinc adhesion and surface appearance; this is due to DFI's effective pre-cleaning properties, leaving both strip and furnace rolls cleaner than before. Currently, the DFI Oxyfuel system is being evaluated at many strip processing mills around the world, most of which work with metal coating such as galvanizing and aluminizing, and others which anneal and process silicon steel.

References

1. J. von Schéele and T. Ekman, *Nordic Steel & Mining Review* (2000), p. 23.
2. A. Scherello, W. Högner, E. Claesson, P. Bamforth and C. Mercier, InSteelCon, Düsseldorf (2007), p. 776.
3. S. Ljungars and J. von Schéele. *Gaswärme International 54* (2005), Nr. 3, p. 193.
4. H. Eichelkraut, H-J. Heiler, W. Högner, R. Paul, O. Ritzén and P. Vesterberg, ATS/JSI, Paris (2006).
5. H-J. Heiler, H. Eichelkraut, W. Högner, R. Paul, O. Ritzén and R. Eichler, *Stahl und Eisen* 128 (2008), No. 4, p. 81.
6. J. von Schéele. SCANMET III, Luleå, Sweden (2008), p. 397.
7. O. Ritzén, M. Gartz and J. von Schéele, 3rd International Conference on Thermo Mechanical Processing of Steels (2008), Padua, Italy.

This paper was presented at AISTech 2009 — The Iron & Steel Technology Conference and Exposition, St. Louis, Mo., and published in the Conference Proceedings.