INCREASING CAPACITY IN GALVANISING AND OTHER STRIP PROCESSING LINES BY USING DIRECT FLAME IMPINGEMENT OXYFUEL[1]

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Abstract
In parallel to the conventional oxyfuel there are today established very interesting technologies; one of the most important ones being Direct Flame Impingement (DFI). This technology has been proven to deliver outstanding results. The main benefits of DFI Oxyfuel, where oxyfuel flames directly heat the moving metal, are: Significantly higher heat transfer (10 times the one in use) resulting in higher capacity and less fuel consumption; Compact and powerful unit for easy retrofit; Provides options to modify surface conditions. So far the use of DFI Oxyfuel has been to boost strip annealing and hot dip metal coating lines. Use of DFI Oxyfuel reduces the specific fuel consumption while delivering a powerful 30% capacity increase, or more. In a galvanising line, for example, additional benefits include improved zinc adhesion and surface appearance; this is due to the DFI's effective pre-cleaning properties, leaving both strip and furnace rolls cleaner than before. Successful installations are in operation at ThyssenKrupp Steel's coating lines at Finnentrop and Bruckhausen, Germany. In 2002 the first installation of a compact DFI Oxyfuel unit took place. It was at Outokumpu's Nyby site in Sweden. It resulted in the possibility to increase the production by 50% without extending the furnace length. It should be noted that this furnace already was all equipped with oxyfuel combustion. The paper describes the state-of-the-art of DFI Oxyfuel, including results from installations, and discusses its future very interesting possibilities to make the steel production more effective.
Key words: Oxyfuel; Galvanizing; Strips; Direct flame impingement.

AUMENTO DE PRODUÇÃO NA GALVANIZAÇÃO E OUTRAS LINHAS DE PROCESSAMENTO DE TIRAS UTILIZANDO "DIRECT FLAME IMPINGEMENT -DFI" OXYFUEL

Resumo
Em paralelo ao Oxyfuel convencional existem hoje em dia, tecnologias muito interessantes já estabelecidas; uma das mais importantes é a "Direct Flame Impingement - DFI". Esta tecnologia foi testada e apresenta excelentes resultados. O principal beneficio do DFI Oxyfuel, onde a chama oxyfuel aquece diretamente o metal em movimento, são os seguintes: Aumento significativo da transferência de calor (10 vezes maior do que o existente) resultando numa maior capacidade de aquecimento e menor consumo energético; Unidade compacta e robusta de fácil instalação; Garante opções para modificar as condições superficiais. Até agora o uso do DFI oxyfuel tem sido usado para aumentar a capacidade do recozimento de tiras e de linhas de galvanização. O uso do DFI oxyfuel reduz o consumo específico de combustível com um aumento de produção de 30%, ou mais. Na linha de galvanização, por exemplo, benefícios adicionais incluem uma melhor adesão do zinco e melhor aparência superficial; isto é devido as propriedades efetivas de pré-limpeza do DFI, deixando as tiras e os cilindros do forno mais limpos antes do sistema. A tecnologia DFI está operando com excelente resultados nas plantas de galvanização da ThyssenKrupp Steel de Finnntrop e Bruckhausen na Alemanha. A primeira instalação de um sistema DFI compacto ocorreu em 2002 na Outokumpu na planta de Nyby na Suécia. Resultando num aumento de produção de 50% sem estender o comprimento do forno. Vale salientar que tal forno havia sido totalmente convertido à tecnologia Oxyfuel anteriormente. O trabalho descreve o processo DFI Oxyfuel como tecnologia inovadora, incluindo os seus resultados e discute o seu futuro e as possibilidades de produzir aços com mais eficiência.
Palavras-chave: Oxyfuel; Galvanização; Tiras; Direct flame impingement.

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1 INTRODUCTION

In an air-fuel burner 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. For melting and heating furnace operations these two factors lead to a higher melt or heating rate, fuel savings, lower CO_2 emissions and – if the fuel contains sulphur – lower SO_2 emissions.
The most frequent use of oxyfuel combustion in the steel industry is in the electric arc furnace (EAF), to enhance the melting process. Most of the modern EAFs are today equipped with oxyfuel burners, frequently using so-called coherent jet technology, i.e., including the possibility to inject high-velocity oxygen through the centre of the flame. For EAFs, conventional oxyfuel is used as it provides the feature of substantially raised flame temperature; the higher the flame temperature, the faster the scrap melting.
Among the existing uses is vessel preheating. Though very clear benefits, the number of installations is surprisingly low. Apart from that most suppliers of ladle preheating stands, etc., for unknown reasons do not have oxyfuel included in their offerings, another explanation – at least valid in some parts of the world – may relate to NO_X emission. In such installations this can for sure be a problem when applying conventional oxyfuel, but it is solved by using flameless oxyfuel, cf. below.
Prompted by rapidly rising fuel prices in the 1970s, ways of reducing fuel consumption in reheat and annealing furnaces were first considered within the steel industry. This laid the foundation that led to the use of oxyfuel solutions in rolling mills and forge shops. In the mid 1980s Linde began to equip the first furnaces with oxygen-enrichment systems. These systems 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 tonnes per hour, increased. In 1990 Linde converted the first furnace to operation with 100% oxygen, that is, full oxyfuel combustion, at Timken in USA. For the past 17 years Linde has been pioneering the use of oxyfuel in this field. Today the number of such oxyfuel installations has reached 115.
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 NO_X emissions

New demands and challenges from the industry have been met by a continuous development work. As a result, in parallel to the conventional oxyfuel – for example widely used to boost melting in electric arc furnaces – there are today established very interesting technologies. Among those, the most important ones seem to be flameless combustion and Direct Flame Impingement (DFI). These new technologies

not only fulfil the existing needs with astonishing results, they also open up for completely new areas of application.
Flameless oxyfuel provides even higher production rates, excellent temperature uniformity and very low NO_X emissions. The first installations of this innovative flameless oxyfuel technology took place in 2003. Linde has made over 30 installations of flameless oxyfuel at more than dozen different sites.
Direct Flame Impingement (DFI) Oxyfuel is a fascinating compact high heat transfer technology, which since 2002 provides enhanced operation in strip processing lines, for example at galvanizing.

2 THE DFI OXYFUEL TECHNOLOGY

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

- Significantly higher heat transfer (10 times the one in use) resulting in higher capacity and less fuel consumption
- Compact and powerful unit for easy retrofit
- Provides options to modify surface conditions

The REBOX® DFI unit has a thermal efficiency of around 80%, higher than electrical pre-heaters. This reduces the specific fuel consumption while delivering a powerful 30% capacity increase in an existing strip processing line. In galvanising, 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.

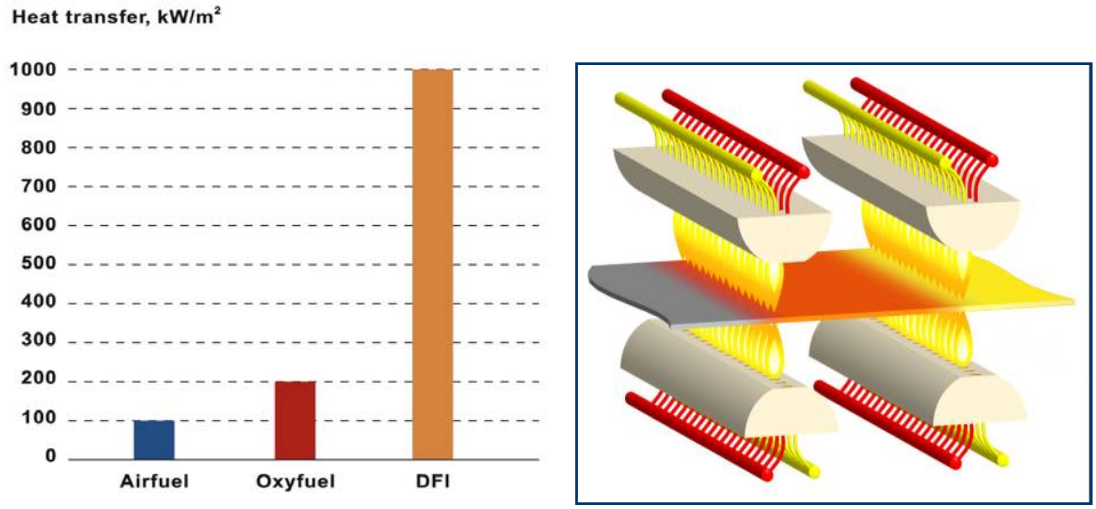

Figure 1. Oxyfuel combustion is much more energy efficient than air-fuel. However, DFI oxyfuel technology is even more efficient; the heat flux could be as high as 1000 kW/m^2. DFI Oxyfuel unit, shown in a principle sketch to the right, has a high thermal efficiency of around 80%, higher than electrical pre-heaters, and the very high ability to transfer heat to the material.

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 primarily due to the fact that radiant heat transfer of furnace gases produced by oxyfuel combustion is significantly more efficient than those of air-fuel. Due to the absence of nitrogen in the combustion mixture which does not need to be heated up, 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, at the same time saving on fuel and CO_2 emissions.
It is important to note, that applying DFI Oxyfuel for pre-heating a strip does not create any problem with oxidation; experience with pre-heating up to 300°C shows no problem relating to that. In metal coating lines, the thin oxide layer formed is reduced in the subsequent reduction zone. It is also possible to influence the oxidation to a certain extent by adjusting the stoichiometry of the flames.

Figure 2. Oxyfuel flames in Direct Flame Impingement.

3 FIRST REFERENCE AT STAINLESS ANNEALING

Since the beginning of the 1990s, Linde has pioneered the use of 100% oxyfuel applications in reheat furnaces in close co-operation with customers such as Outokumpu. Outokumpu was one of the first customers to which Linde provided turnkey solutions. At its Nyby site in Sweden a stainless strip annealing line needed further increased capacity, but the furnace already contained oxyfuel combustion and there was extremely limited physical space available. In 2002 the first compact DFI Oxyfuel unit was installed here, making it possible to increase the production by 50% without extending the furnace length. The Nyby site in particular, has benefited hugely from the use of oxyfuel in its annealing operations.
Some data on this installation:

- 2 m long DFI unit at the entry side
- 4 burner rows
- 4 MW installed power
- 120 oxyfuel flames

The result of the DFI Oxyfuel installation was that the furnace throughput capacity was increased from 23 to 35 t/h.

4 METAL COATING LINES AT THYSSENKRUPP

Last year Linde installed its REBOX® DFI solution at ThyssenKrupp Steel's (TKS) galvanising and aluminising line in Bruckhausen, Germany. The results at the Bruckhausen installation are as good as that at the galvanising line in Finnentrop, Linde's first REBOX® DFI installation for TKS. At Finnentrop the REBOX® DFI solution resulted in a production increase of 30%, from 82 to 105 t/h. Oxyfuel not only effectively heats – contributing to a reduction of fuel consumption – but also cleans, thus eliminating the need for the pre-cleaning section. Besides this, it made it possible for ThyssenKrupp to pre-oxidise steel strips in a precise and controlled

manner. TKS' requirements were perfectly met with Linde's installation of the DFI oxyfuel boosting unit at the entry side of the existing furnace in early 2006.

Figure 3. The DFI Oxyfuel unit installed at Finnentrop, replacing part of the dark-zone and boosting the output by 30%.

5 THE INSTALLATION AT TKS FINNENTROP

The Finnentrop plant carries out zinc coating of hot and cold strip of 650-1,550 mm width and 0.3-3.25 mm thickness. 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 48 m pre-heating section. The total installed power was 22 MW, 17.5 MW for preheating with air-fuel (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/min. and the maximum production capacity 82 t/h.

TKS' 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 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 results from electrical strip pre-heaters. However they soon realized that electric strip pre-heaters typically have poor thermal efficiency and low reliability with too much maintenance required. The required boosting unit needed to allow strict control of the required surface properties essential for successful galvanising of the strip, which electrical strip pre-heaters could not provide.

Prior to the installation of the DFI Oxyfuel boosting unit at Finnentrop, TKS had conducted several tests together with Linde at its 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 also looking at impact on surface.

To minimise line downtime, care was taken to find a solution for easy integration with the existing furnace. The design resulted in a 3-metre long DFI unit equipped with 4 burner row units, having a total of 120 oxyfuel flames and 5 MW installed power, with an option of 2 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, the 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 which is not normally available in existing galvanising or other strip processing lines.
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 4 days were used for installing the DFI unit), production could be resumed.

Figure 4. In 2006 the REBOX® DFI unit was installed at the entry side of the galvanising line at TKS' Finnentrop Works, where it has resulted in 30% increased production capacity and elimination of the use of a pre-cleaning section.

6 INCREASED GALVANISING CAPACITY

With initial tuning and subsequent optimization of the DFI unit and the total line, capacity evolved from 82 to 109 t/h. The DFI Oxyfuel unit also manages to burn off residues, 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.
The alternative to DFI Oxyfuel at ThyssenKrupp Steel at Finnentrop was a 10-m extension of the furnace, but that would not have provided decreased fuel consumption and elimination of the cleaning section.
The diagram shows the results. It includes a calculated alternative with a 10-m extension of the furnace for reaching the higher capacity, this is what the DFI Oxyfuel results should be compared with.

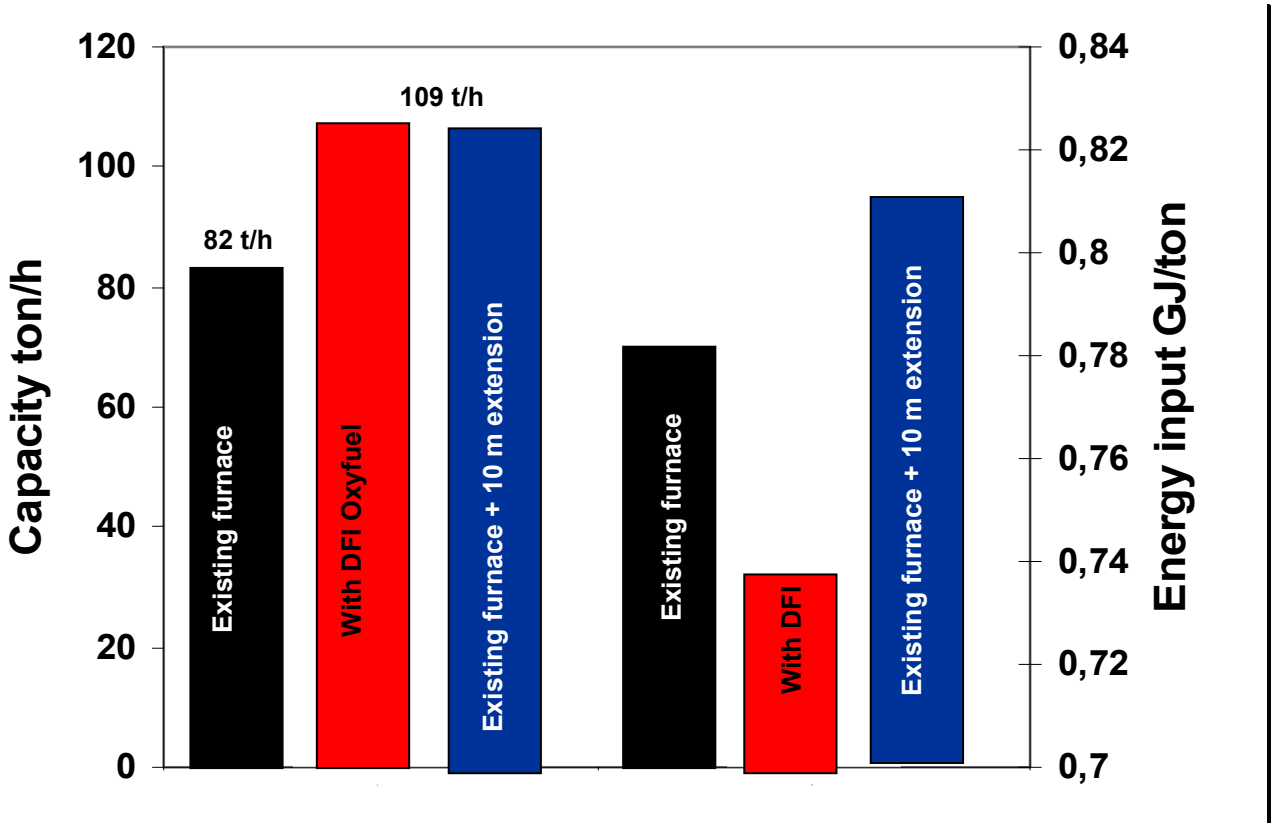

Figure 5. Comparison of results with DFI Oxyfuel at TKS Finnentrop with the situation prior to the installation and with the alternative of extending the furnace.

7 CONCLUSIONS

In 115 reheating and annealing installations, REBOX® oxyfuel solutions provide more capacity and flexibility as well as less fuel and emissions. Since 2003, most new installations employ flameless oxyfuel. It provides excellent temperature uniformity and reduced NO_X emissions.
Also DFI Oxyfuel is an important part of the successful solutions portfolio, clearly demonstrated by the 30% or more capacity increases at ThyssenKrupp Steel in Bruckhausen and Finnentrop and Outokumpu in Nyby.
In addition to the production capacity increase, REBOX® DFI reduces the specific fuel consumption. In a galvanising line, for example, 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 use of DFI Oxyfuel is being evaluated at many strip processing mills around the world, most of them working with metal coating – galvanising and others coatings – but some also dealing with annealing and processing of silicon steel.
DFI oxyfuel has a heat transfer 10 times the one in use, and many additional benefits, this is now about to be applied by galvanisers and others.

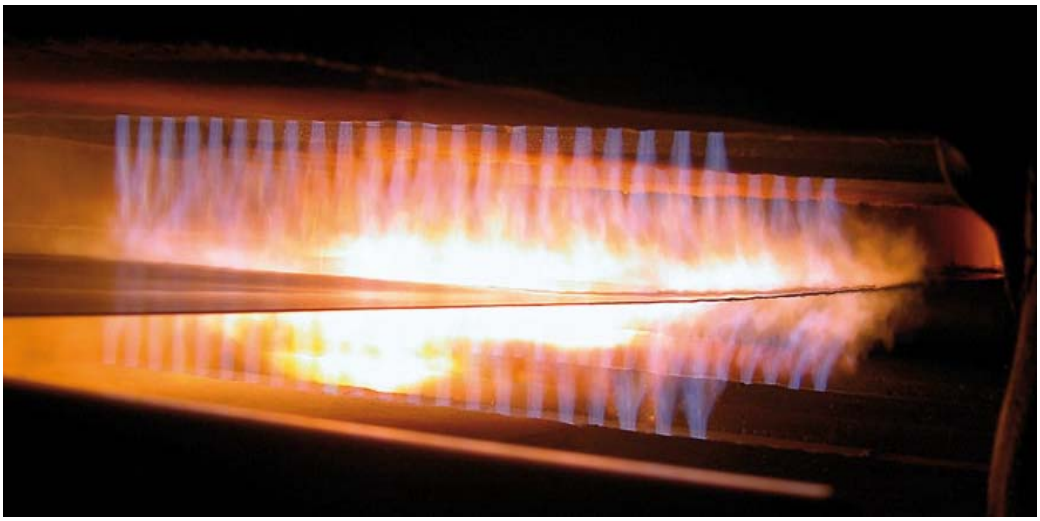

Figure 6. A look inside the DFI unit in Finnentrop: Oxyfuel flames are heating directly onto the moving strip, increasing the temperature more than 200°C.