**Light Metals 2015**
*Edited by: Margaret Hyland*
*TMS (The Minerals, Metals & Materials Society), 2015*

# DIRECT FLAME IMPINGEMENT: A NEW OXY-FUEL BASED TECHNOLOGY FOR CONTINUOUS ANNEALING OF ALUMINIUM STRIP

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Keywords: oxygen, burner, aluminium, annealing, auto body sheet, heat treatment

## Abstract

In the Direct Flame Impingement (DFI) process, oxy-fuel flames directly heat the moving metal strip. The resulting heat transfer can be up to ten times higher than in conventional fuel fired furnaces. Characteristic of the process is that the material temperature rises very quickly within a compact furnace body. The DFI process is successfully applied in the steel industry, for example to boost productivity in continuous steel galvanizing lines. Linde has performed several DFI aluminium strip annealing tests in its pilot plant laboratory. These results predict that the technology would play an important role in the aluminium industry. One important example is annealing of Auto Body Sheet. The paper will discuss the DFI technology and its applications in the Aluminium Industry, hardware, lab facilities, and results.

## Introduction

In air –fuel combustion, the burner flame contains nitrogen from the combustion air; hence, 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 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. Additionally the concentration of the highly radiating products of combustion, $CO_2$ and $H_2O$ is increased in the furnace atmosphere. Linde has since the 1970s been in the forefront in developing and applying oxyfuel technologies for the metallurgical industries.

Pioneer work has been done in developing flameless, Low-temperature Oxyfuel burners for steel re-heating furnaces and for aluminium melting furnaces. Flameless and Low-temperature Oxyfuel provides excellent temperature uniformity, high production rates, energy savings and low emissions. The first installation of this new technology was made in 2003. Linde has now installed flameless and Low-temperature Oxyfuel in more than 80 furnaces. Fifteen of these furnaces are for aluminium melting [1,2].

Overall the results can be summarized as:

- Capacity increase of up to 50%
- Fuel savings of up to 50%
- Reduction of scaling losses and dross formation
- Reduction of $CO_2$ emissions by up to 50%

Another unique new oxyfuel technology developed by Linde is Direct Flame Impingement (DFI). DFI Oxyfuel is a compact high heat transfer technology that provides enhanced operation in strip annealing and processing lines

## The DFI technology

In the DFI oxyfuel process, oxyfuel flames directly heat the moving metal strip, figure 1.
This results in:

- Significantly higher heat transfer than in conventional fuel fired furnaces.
- Increased production capacity
- A high power input can be used in a limited furnace volume
- Heating and cleaning of the strip can be done in one operation

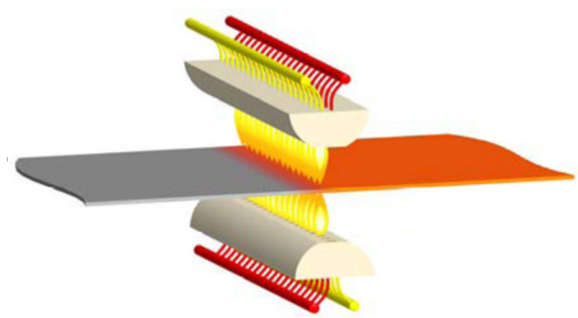

Figure 1. Firing with oxyfuel flames directly onto the moving metal strip results in efficient heat transfer.

Industrial installations and tests have verified the higher level of local heat flux into the strip.
In addition to the improved heat transfer by the higher concentration of three atomic gases in the flame and the elimination of the nitrogen ballast, the heat transfer is further improved by forced convection and by live convection. Live convection can be explained as that dissociated products of combustion in the hot oxyfuel flame recombine close to or at the cold metal strip. This releases energy in the absolute vicinity of the strip surface.

The DFI oxyfuel burners are arranged in rows with multiple burners to cover the entire width of the strip. The rows are mounted in modules, where one module consists of two burner rows firing from above and below the strip. Figure 2. shows a DFI burner row

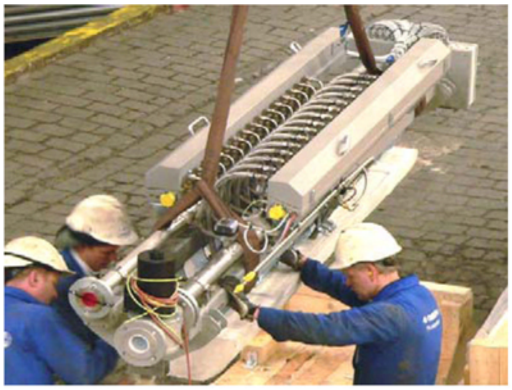

Figure 2. A DFI burner row unit ready for installation.

**DFI experience in the steel industry**

The DFI technology is successfully applied in the steel industry. Figure 3, shows the oxyfuel flames inside a DFI unit operating at Thyssen Krupp Steel, in Finnentrop. It shows four burner rows, having totally 120 oxyfuel flames and 5MW installed power. The installation at Finnentrop is working as a pre-heater of the steel strip in a continuous annealing furnace at a galvanizing line. The three meter long DFI unit provided a 30% capacity increase to the 130 meter long annealing furnace, figure 4.

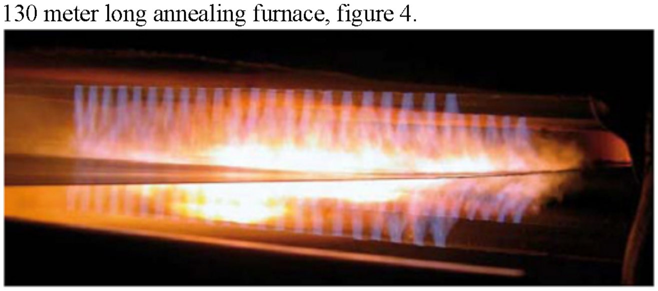

Figure 3. In the photo, four oxy-fuel burner rows are seen directly firing onto a steel strip.

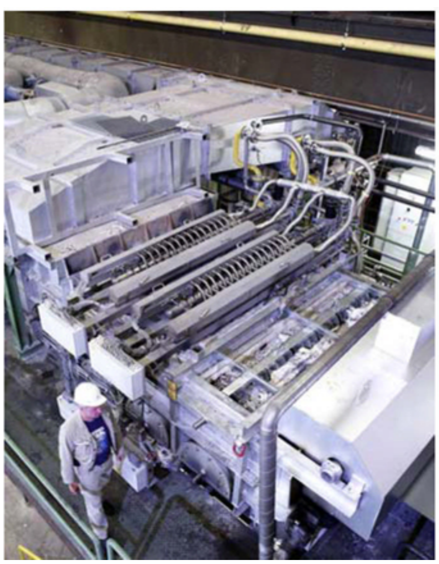

Figure 4. The three meter long DFI oxyfuel unit integrated with the annealing furnace at Thyssen Krupp Steel in Finnentrop.

The DFI technology is currently installed at four plants processing steel strip. Capacity increases of 30% have been reached. In galvanizing lines additional benefits include improved surface properties, due to the cleaning effect of the flames, [3]

**DFI and the Aluminium industry**

There are a number of potential benefits the technology could provide for the aluminium industry, for example:

- More homogeneous properties compared to coil annealing, as every part of the strip will get the same energy input
- The very fast heating process improves productivity and logistics.
- The quick heating of the strip could improve the metallurgical properties of the strip, for example the grain size.
- Cleaning, organic substances on the strip surface can be removed by the flames.

The DFI technology is currently being investigated for annealing and treatment of aluminium strip. Linde has a pilot plant scale DFI oxyfuel furnace at its laboratories in Stockholm. The laboratory furnace and coil to coil machine set up can treat up to 200mm wide samples, either plates or continuous annealing of strip coils, figure 5,6. The DFI burners in the lab furnace fire from below and above the strip. It is used the same flames and burner hardware as in an industrial installation. The equipment thus makes it possible to extrapolate results from the pilot scale to full industrial scale.

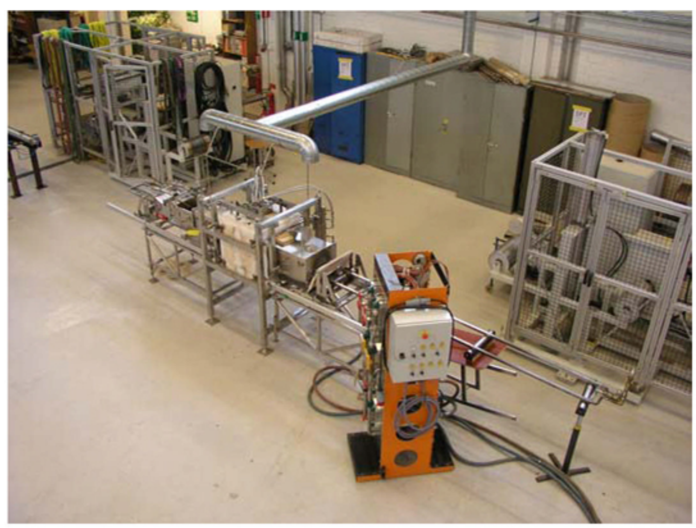

Figure 5. View of the DFI pilot plant at Lindes laboratories in Stockholm.

Tests have been made with various alloys and annealing and heating process simulations.
The strip thicknesses that have been tested so far vary between 0.07mm and 1.5mm.

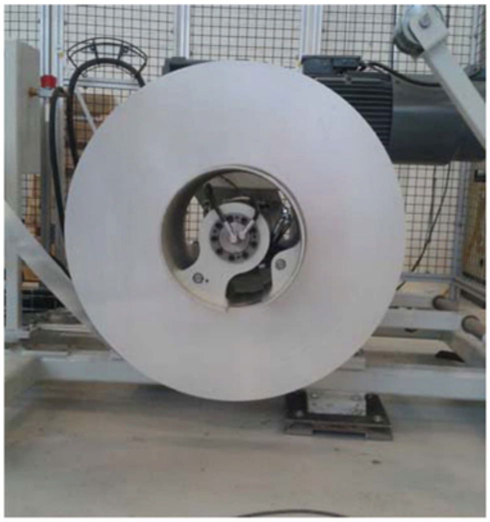

Figure 6. A 200mm wide aluminium coil ready for testing at Lindes DFI pilot plant lab in Stockholm.

In an example experiment a 1.5mm aluminium strip was heated from room temperature to 400C in four seconds. This indicates a heating rate that is at least ten times higher than conventional continuous annealing processes.

It is foreseen that the DFI technology has potential for improving aluminium strip annealing and treatments, for example:

- Pre-heating of the strip before a continuous furnace, e.g. in Auto Body Sheet annealing
- Integrate the DFI unit in continuous annealing and treatment lines
- Replace coil annealing processes

The aluminium industry has provided a very positive response to the DFI technology concept and parallel investigations are being performed. The results are very promising.

## References


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