Results from 120 oxyfuel installations in reheating and annealing

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Oxyfuel solutions deliver a unique combination of advantages in reheat and annealing. Thanks to improved thermal efficiency (about 80% compared with 40–60% for air-fuel), the heating rate and productivity are increased and less fuel is required to heat the product to the desired temperature, at the same time saving on CO_2 and NO_X emissions. This article discusses the results from 120 furnace installations, employing conventional oxyfuel, direct flame impingement oxyfuel, and flameless oxyfuel.

In heating, oxyfuel combustion offers clear advantages over state-of-the-art air-fuel combustion, for example regenerative technology, in terms of energy use, maintenance costs and utilization of existing production facilities. If all the reheating and annealing furnaces would employ oxyfuel combustion, the CO_2 emissions from the world's steel industry would be reduced by 100 million tonnes per annum.

Linde's experience from converting furnaces into all oxyfuel operating shows energy savings ranging from 20% to 70%, excluding savings in energy needed to bring the natural gas to the furnace. 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 (tph), increased. In 1990 Linde converted the first furnace to operation with 100% oxygen, that is, full oxyfuel combustion, at Timken in USA.

Energy efficiency

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 heating operations these two factors lead to a higher heating rate, fuel savings, lower CO_2 emissions and – if the fuel contains sulphur – lower SO_2 emissions, Today's best air-fuel solutions need at least 1.3 GJ for heating a tonne of steel to the right temperature for rolling or forging. When using Linde's REBOX oxyfuel solutions the comparable figure is below 1 GJ, a saving of 25%, compare **Table 1**.

For continuous heating operations it is also possible to economically operate the furnace at a higher temperature at the entry side of the furnace. This will even further increase the possible throughput in any furnace unit. Oxyfuel combustion allows all installation pipes and flow trains to be compact without any need for recuperative or regenerative heat recovery solutions. Combustion air-blowers and related low frequency noise problems are avoided.

Flameless oxyfuel

In recent years 'flameless combustion' has been employed. The expression communicates the visual aspect of the combustion type, that is, the flame is no longer seen or easily detected by the human eye. Another description might be that combustion is 'extended' in time and space – it is spread out in large volumes, and this is why it is sometimes referred to as 'volume combustion'. Such a flame has a uniform and lower temperature, yet containing same amount of energy, see **Fig. 1**.

Table 1: With oxyfuel it is possible to achieve an 80% thermal efficiency, as compared with 60% in the best air-fuel cases. Even if also adding the energy needed to produce the required oxygen, we would reach 285 kWh/tonne, thus still close to 1 GJ, a saving of 20%

		Air-fuel	Air-fuel with recuperator	REBOX® oxyfuel
Enthalpy in steel	kWh/t	200	200	200
Transmission losses	kWh/t	10	10	10
Flue-gas enthalpy	kWh/t	290	155*	50
Flue-gas temperature	°C	1,200	850	1,200
Air preheating	°C	20	450	20
Thermal efficiency	%	42	60	80
Energy need	**kWh/t**	**500**	**365**	**260**
Energy need	**GJ/t**	**1.8**	**1.33**	**0.94**
Oxygen production	kWh/t			25

*after recuperation

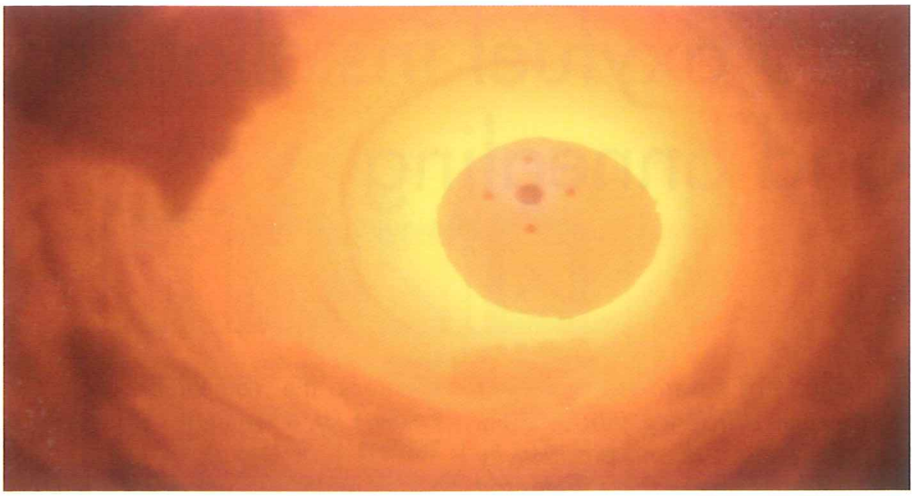

Fig. 1: Flameless oxyfuel exhibits a diluted and almost transparent flame. The flame is diluted by the hot furnace gases. This reduces the flame temperature to avoid creation of thermal NO_X and to achieve more homogenous heating of the steel

In flameless oxyfuel the mixture of fuel and oxidant reacts uniformly through flame volume, with the rate controlled by partial pressures of reactants and their temperature. The flameless oxyfuel burners effectively disperse the combustion gases throughout the furnace, ensuring more effective and uniform heating of the material even with a limited number of burners installed – the dispersed flame still contains the same amount of energy but is spread over a greater volume. The lower flame temperature is substantially reducing the NO_X formation. Low NO_X emission is also important from a global warming perspective; NO_2 has a so-called Global Warming Potential that is 296 times that of CO_2. **Fig. 2** illustrates the increased efficiency achieved with flameless oxyfuel.

There seems to be an increasing need to combust Low Calorific Fuels. For fuels containing below 2 kWh/m^3, use of oxygen is an absolute requirement. At integrated steel mills use of blast furnace top gas (<1 kWh/m^3), alone or in combination with other external or internal fuels, is becoming increasingly important. Flameless oxyfuel can be successfully employed here.

Today there are 120 reheat furnaces and annealing lines using Linde's oxyfuel solutions. During the last years flameless oxyfuel have been employed. Such flameless oxyfuel installations could be found at the following steel companies: ArcelorMittal, Ascométal, Böhler-Uddeholm, Usiminas, Dongbei Special Steel, Outokumpu, Ovako, Scana Steel and SSAB. Here follows some examples from those installations.

Linde has carried out flameless oxyfuel installations at two sites belonging to the bearing steel producer Ascométal in France, which is part of the SeverStal Group. At Fos-sur-Mer, a turnkey delivery in 2005-2007 converted nine soaking pit furnaces into all flameless oxyfuel. The delivery included a combustion system with flameless burners, furnace upgrade, new flue gas system, flow train, and a control system. The furnace sizes are 80 to 120 tonne heating capacity each. The results include 50% more heating capacity, 40% fuel savings (**Fig. 3**), NO_X emission reduced by 40%, and scale formation reduced with 3 tonne per 1,000 tonne heated. In a second and similar project in France in 2007-2008, four soaking pit furnaces at the Les Dunes plant were also converted into all flameless oxyfuel operation.

15 installations at Outokumpu

Linde has made a total of 15 installations at Outokumpu's sites in Sweden. In 2003, a walking beam furnace in Degerfors was rebuilt and refurbished in a Linde turnkey project with performance guarantees, see **Fig. 4**. It entailed replacing the air-fuel system, including recuperator, with flameless oxyfuel, and installation of essential control systems. The resultant 40-50% increase in heating capacity provided increased loading

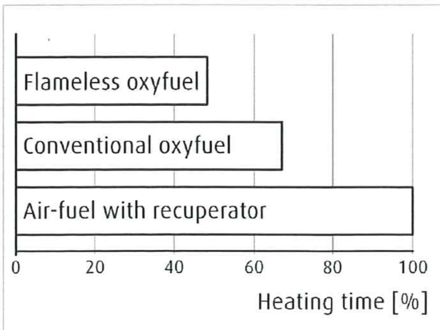

Fig. 2: A comparison of the results from installations at Ovako's Hofors Works using different combustion technologies. When conventional oxyfuel was install the heating time decreased by 30%, but with flameless oxyfuel it was possible to run with a heating time half of the original one with air-fuel. It should be noted that the power has not been increased, but actually decreased

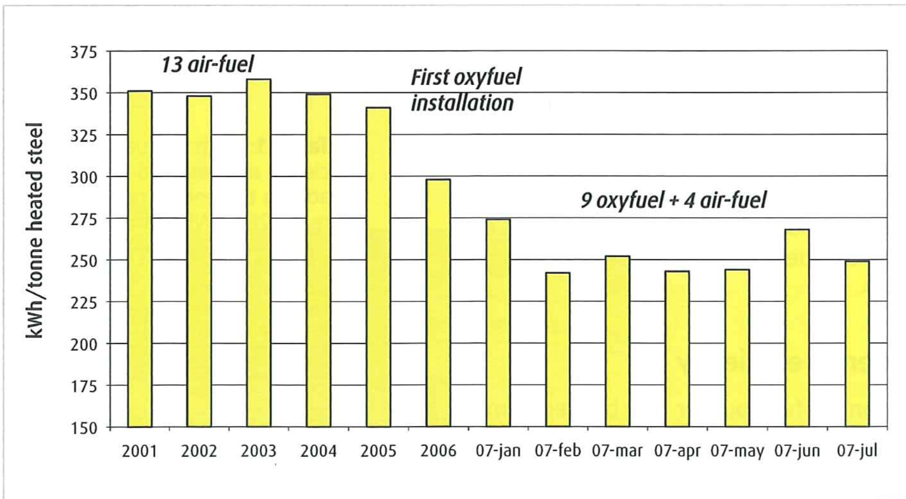

Fig. 3: The diagram shows total average fuel consumption in the 13 soaking pit furnaces at Ascométal, Fos-sur-Mer. 2001-2004 was all air-fuel combustion. The first conversion into oxyfuel took place in 2005. In 2007 nine out of 13 furnaces were operated with all oxyfuel. The average fuel consumption per tonne for all furnaces was reduced by 100 kWh or 10 Nm^3 of natural gas

of the rolling mill, reduction of over 25% in fuel consumption and NO_X emissions below 70 mg/MJ.

At the Nyby plant, there are two catenary furnaces, originally installed in 1955 and 1960 respectively. The catenary furnace on the first annealing-pickling line, for hot or cold rolled strips, was converted to all oxyfuel operation in 2003. Requirements for increased production combined with stricter requirements for low NO_X emissions led to this decision. The furnace, 18 m long, was equipped with flameless oxyfuel burners. The total power input, 16 MW, was not altered when converting from air-fuel to oxyfuel, but with oxyfuel the heat transfer efficiency increased from 46% to 76%. The replacement of the air-fuel system, combustion blowers and recuperators resulted in a 50% increase in heating capacity without any increase in the length of the furnace, a 40% reduction in specific fuel consumption and NO_X levels below the guaranteed level of 70 mg/MJ.

At Avesta we find the world's largest oxyfuel fired furnace, 40 MW. The old 24 m catenary furnace had a 75 tph capacity, but the requirement was to double this whilst at same time meeting strict requirements for emissions. The refurbishment included a 10 m extension, yet production capacity was increased to 150 tph. The conversion involved the removal of air-fuel burners and recuperators and the installation of all oxyfuel. The oxyfuel technology used involved staged combustion. The conversion reduced fuel consumption by 40%, and NO_X levels are below 65 mg/MJ. This furnace is an example of another route to flameless; having been converted from conventional oxyfuel to flameless oxyfuel last year and resulting in an additional 50% reduction of the NO_X levels.

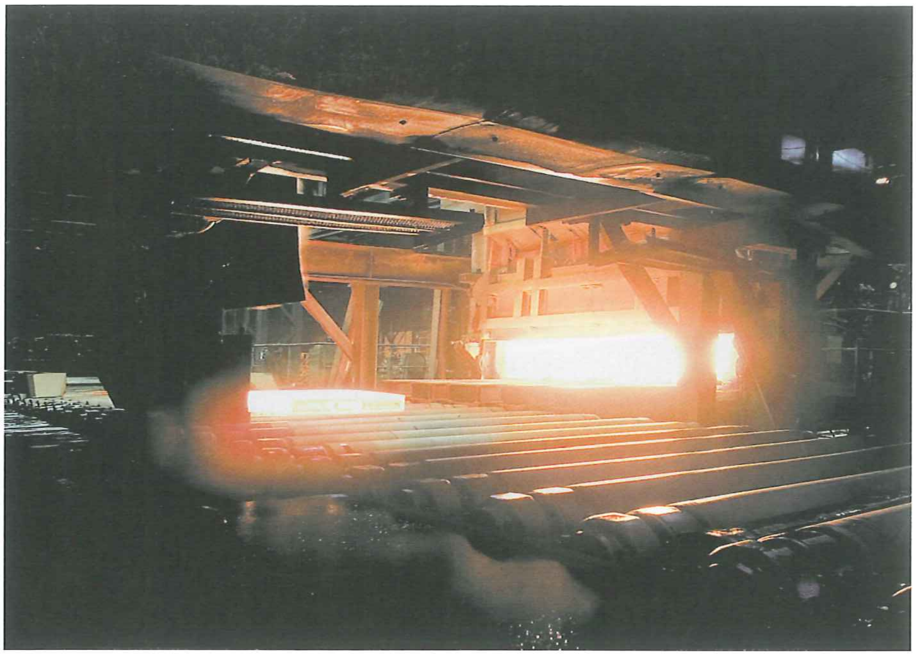

Fig. 4: The walking beam furnace at Outokumpu's Degerfors Works. Flameless oxyfuel was implemented when this plate mill should accommodate production volumes from another site; the heating capacity was increased by 40-50%

50% fuel savings at ArcelorMittal

There have been several successful installations in rotary hearth furnaces. One is found at ArcelorMittal Shelby in Ohio, USA. In 2007, Linde delivered a turnkey conversion of a 15-metre diameter rotary hearth furnace at this seamless tube producer. It included combustion system with flameless burners, furnace upgrade, new flue gas system, flow train, and a control system. The former air-fuel fired furnace was converted in two steps, first using oxygen-enrichment for a period of time and then implementation of the flameless oxyfuel operation. Excellent results have been achieved, meeting all performance guarantees. These included >25% more throughput, 50% fuel savings compared with oxygen-enrichment, NO_X

Fig. 5: Outside view of the rotary hearth furnace at ArcelorMittal Shelby, before and after the REBOX installation. Please note that all bulky equipment and piping relating to the previously used air-fuel system have been removed as it no longer is of any use

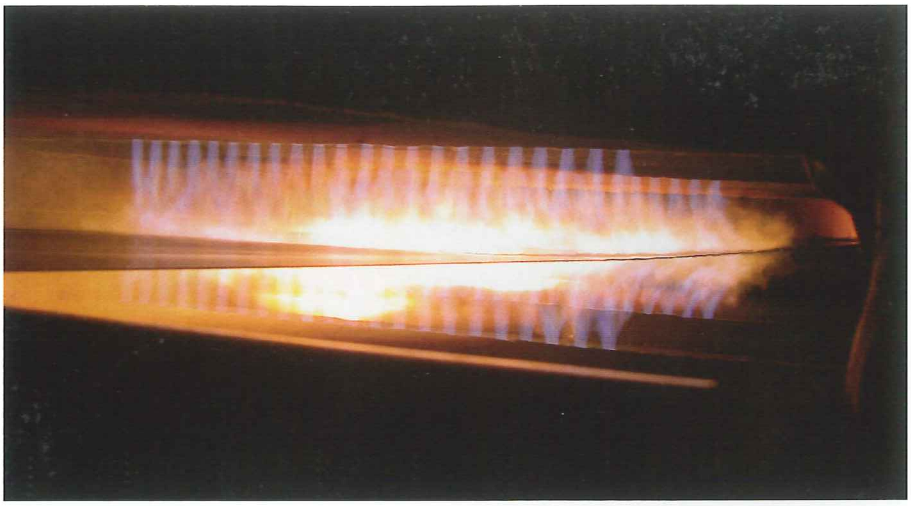

Fig. 6: REBOX DFI at ThyssenKrupp Steel at Finnentrop: oxyfuel flames are heating directly onto the moving strip

emission <70 mg/MJ, and 50% reduced scale formation. Pictures of the furnace, before and after the installation, are shown in **Fig. 5**.

At SSAB in Sweden REBOX HLL is used. The slabs are reheated in walking beam furnaces with a capacity of 300 tph per furnace, from ambient temperature to 1,230°C. The air-fuel combustion system uses a recuperation system to preheat air to 400°C. The fuel is oil, and prior to the HLL installation the consumption was 440 kWh/tonne, or 1.58 GJ/tonne.

REBOX HLL creates a type of flameless oxyfuel without replacing the existing air-fuel burners. By reducing the air flow and substituting high velocity oxygen injection into the combustion, great benefits can be achieved. 75% of the oxygen needed for the combustion is supplied with this technique. The flue-gas volume is less than 45% that of air-fuel. The system start-up took just one day. The installation in only one zone has increased the heating capacity from 300 to 320 tph.

The installation of HLL is rather easy because it does not include any replacement of burners or installation of additional burners, which minimizes the installation down time. The air-fuel system can at any time be brought back into operation as it was before. This eliminates any potential risk relating to the implemention, and it enables operation to be flexible and optimized in response to fluctuating fuel cost and production requirements.

Some important results from this installation are:

- No negative impact on the surface quality.
- A positive impact on the temperature uniformity of the slabs.
- The ideal heating curve suggested by the control system can be achieved more easily.
- Less smoke emanating from the furnace, greatly improving the plant environment.

Based on the results of current installation in one zone, SSAB has estimated that a full implementation would provide the following:

- A reduction of NO_X emission by 45%.
- Fuel consumption can be decreased by 25%, leading to the same reductions in SO_2 and CO_2 emissions.
- Production throughput can be increased by 15-20%.

Direct flame impingement

It is also possible to fire with oxyfuel flames directly onto a material. This is what we call DFI, 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. It is patented by Linde. 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. Installations are found at Outokumpu's Nyby Works in Sweden and ThyssenKrupp at Finnentrop and Bruckhausen in Germany. A picture from Finnentrop is shown in **Fig. 6**. The latest installation is in a continuous annealing line at POSCO in Pohang, South Korea.

At ThyssenKrupp REBOX DFI has resulted the 30% or more capacity increases. Additionally, it reduces the specific fuel consumption. Due to DFI's effective pre-cleaning properties there are also benefits relating to improved zinc adhesion and surface appearance.

Conclusions

Oxyfuel provides an overall thermal efficiency in the heating of 80%, air-fuel reaches 40-60%. With flameless oxyfuel, compared to air-fuel, the energy savings in a reheating furnace are at least 25%, but many times 50% or even more. It is possible to operate a reheat furnace with fuel consumption below 1 GJ per tonne. The corresponding reduction in CO_2 emissions is also 25-50%. Savings in terms of NO_X emissions are substantial. Flameless oxyfuel combustion has major advantages over conventional oxyfuel and, even more, over any kind of air-fuel combustion. The improved temperature uniformity is a very important benefit, which also reduces the fuel consumption further.

With oxyfuel it is possible to increase the throughput rate by up to 50%. This can be used for increased production, less number of furnaces in operation, increased flexibility, etc. It is also of interest when ramping up production; two furnaces can cover the previous production of 2.5-3 furnaces, meaning possibility to post start-up of the third furnace and, additionally, resulting in decreased fuel consumption. Increased capacity can also be used to prolong soaking times. Thanks to the reduced time at elevated temperatures, oxyfuel leads to reduced scale losses, at many installations as high as 50%. ■

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