Results from 120 oxyfuel installations in reheating and annealing

Joachim von Schéele

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 CO₂ and NOₓ 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 CO₂ 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, CO₂ and H₂O, is increased in the furnace atmosphere. For heating operations these two factors lead to a higher heating rate, fuel savings, lower CO₂ emissions and – if the fuel contains sulphur – lower SO₂ 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%.

<table>
<thead>
<tr>
<th></th>
<th>Air-fuel</th>
<th>Air-fuel with recuperator</th>
<th>REBOX oxyfuel</th>
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</thead>
<tbody>
<tr>
<td>Enthalpy in steel</td>
<td>kWh/t</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Transmission losses</td>
<td>kWh/t</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Flue-gas enthalpy</td>
<td>kWh/t</td>
<td>290</td>
<td>155*</td>
</tr>
<tr>
<td>Flue-gas temperature</td>
<td>°C</td>
<td>1,200</td>
<td>850</td>
</tr>
<tr>
<td>Air preheating</td>
<td>°C</td>
<td>20</td>
<td>450</td>
</tr>
<tr>
<td>Thermal efficiency</td>
<td>%</td>
<td>42</td>
<td>60</td>
</tr>
<tr>
<td>Energy need</td>
<td>kWh/t</td>
<td>500</td>
<td>365</td>
</tr>
<tr>
<td>Energy need</td>
<td>GJ/t</td>
<td>1.8</td>
<td>1.33</td>
</tr>
<tr>
<td>Oxygen production</td>
<td>kWh/t</td>
<td>1.8</td>
<td>1.33</td>
</tr>
</tbody>
</table>

*after recuperation
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 NOₓ formation. Low NOₓ emission is also important from a global warming perspective; NO₂ has a so-called Global Warming Potential that is 296 times that of CO₂. 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/m³, use of oxygen is an absolute requirement. At integrated steel mills use of blast furnace top gas (<1 kWh/m³), 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 reheating 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 tonnes heating capacity each. The results include 50% more heating capacity, 40% fuel savings (Fig. 3), NOₓ emission reduced by 40%, and scale formation reduced with 3 tonnes per 1,000 tonnes 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.

1.5 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.
of the rolling mill, reduction of over 25% in fuel consumption and NO\textsubscript{X} emissions below 70 mg/MJ.

At the Nyby plant, there are two catar- nary furnaces, originally installed in 1955 and 1960 respectively. The catar- nary furnace on the first annealing-pick- ling line, for hot or cold rolled strips, was converted to all oxyfuel operation in 2003. Requirements for increased pro- duction together with stricter require- ments for low NO\textsubscript{X} emissions led to this decision. The furnace, 18 m long, was equipped with flameless oxyfuel burn- ers. 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 recupera- tors 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\textsubscript{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 catar- nary furnace had a 75 t/h capacity, but the requirement was to double this whilst at same time meeting strict requirements for emissions. The refurbishment included a 10 m exten- sion, yet production capacity was increased to 150 t/h. 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 con- version reduced fuel consumption by 40%, and NO\textsubscript{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\textsubscript{X} levels.

**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 diam- eter rotary hearth furnace at this seamless tube producer. It included combus- tion system with flameless burners, furna- ceme upgrade, new flue gas system, flow train, and a control system. The former air-fuel fired furnace was con- verted 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 com- pared with oxygen-enrichment, NO\textsubscript{X}.

![Fig. 4: The walking beam furnace at Outokumpu's Degerfers Works. Flameless oxyfuel was implemented when this plate mill should accommodate production volumes from another site; the heating capacity was increased by 40-50%](image1)

![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](image2)
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 implementation, 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 NOX emission by 45%.
- Fuel consumption can be decreased by 25%, leading to the same reductions in SO2 and CO2 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 Finntrop and Bruckhausen in Germany. A picture from Finntrop 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 reheat 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 CO2 emissions is also 25-50%. Savings in terms of NOx 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%.

Dr. Joachim von Schéele
The Linde Group, Gases Division, Sweden
Tel. +49 89/31001 5196
joachim.von.scheele@linde-gas.com