Advanced combustion systems for tube manufacturing

As part of a major energy reduction programme Tenaris has successfully implemented advanced combustion systems for high temperature furnaces in its tube manufacturing plants which provide a significant contribution to saving primary energy and in curbing polluting emissions such as NOx.

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Tenaris

Since 2006, an energy manager has been appointed in the Tenaris Dalmine plant to implement an energy management system based on a detailed energy assessment survey, and a master plan, closely defining the goals of efficiency improvements with respect to the current practice, has been put into operation.

Investment and training have been provided, resulting in a reduction in natural gas and electricity consumption of more than 10% (budget year 2009/10 vs baseline), with a corresponding reduction of CO₂ emissions. Energy reduction measures include the wide use of high efficiency motors and frequency control drivers, management of compressed air and water, lighting efficiencies, energy waste reductions, optimisation of electric arc furnace controls and heat recovery from heating furnaces. In June 2010, Tenaris Dalmine was certified with the EN UNI 16001 for its Energy Management System [1].

This positive experience in the Italian plant enabled Tenaris to launch a CO₂ emissions and energy saving plan in September 2009 throughout its worldwide operations, with further expected reductions of 10% in electricity and 15% in natural gas consumption. This article describes the energy reduction achievements in the area of reheating furnaces for tube manufacture.

HIGH TEMPERATURE FURNACES

Combustion furnaces account for more than 50% of the energy consumption in seamless tube manufacturing. An approximate evaluation of thermal efficiency for furnaces equipped with traditional as well as with the ‘best’ or ‘target’ combustion systems is shown in Table 1.

The efficiency indicates how much of the thermal power delivered by the lower heating value of the fuel is effectively exploited to heat the product. In a reasonably well designed, well maintained and well insulated furnace, heat losses due to unburned fuel, radiation, water cooling and cold air in-leakage are relatively small and do not offer a great margin for improvement.

Consequently, the minimum target of efficiency increase in Table 1, conservatively estimated to be 15% (25% for
low productivity), can only be obtained by means of new combustion techniques.

In the temperature range considered (~800 to 1,300°C), the largest heat share is in the hot combustion products leaving the combustion chamber. Figure 1 shows the computed thermal efficiency of combustion (defined as the difference between heat input and heat taken away by the products of combustion, referred to as the lower heating value [2]) as a function of furnace temperature. At 800-1,300°C, ~40–75% of the heating value is contained as sensible heat in the exhaust combustion products and so the main issue for energy saving is in recovering as much heat as possible from these hot products of combustion (POC).

In these circumstances the main heat recovery route is to preheat the combustion air with the POC issuing from the furnace: clearly the air temperature cannot exceed that of the combustion products and this limit can be defined as 100% preheating effectiveness. The thermal efficiency at 100% preheating is plotted in red as the upper curve in Figure 1. Inspection of the figure shows that thermal efficiency may be significantly increased with respect to cold air, depending on expected preheat and on starting conditions, e.g., from 50 to 90% (minimum excess air, from cold to the 100% limit at 1,050°C), to 70% (by application of current central heat recovery), to 85% (high temperature regenerative heating), etc.

Air preheating carried out in a heat exchanger upstream of the exhaust chimney (central recuperator) has been the traditional technique in the steel industry. However, this design has temperature limits due to the thermal resistance of materials: the flue gases upstream of the recuperator should not exceed ~850°C and it is difficult to distribute, via insulated manifolds, air hotter than ~500°C to many burners installed in the furnace. This temperature limit has been exceeded by decentralised or burner-integrated heat recovery. The basic idea is illustrated in Figure 2. Many burners in the furnace pick up their own flue gases, (or a large fraction of them), thereby realising a local heat recovery system as opposed to central heat recovery at the chimney. In the former case, cold combustion air is supplied to the burners and air may be effectively preheated up to ~60–90% of process temperature at the burner nozzle, where it is required and can be tolerated by suitable materials. In Figure 2, D is the outer diameter and L is the furnace wall thickness.

Decentralised air preheating is more efficient, thanks to a more favourable layout and design. Based on the standard theory of counter-current heat exchangers, air preheating can be computed as a function of the Number of Transfer Units (NTU) as shown in Figure 3. The parameter: \[ \text{NTU} = \frac{k A}{(c_p Q)_{\text{min}}} \]
depends on a heat transfer coefficient ‘k’ and on the least heat capacity ‘c_p Q_{\text{min}}’ of the two fluids (air and POC); however, the main quantity available to the designer is the heat transfer area ‘A’. Air preheating is poor for smooth cylindrical coaxial geometries that have small specific heat transfer area, but it increases very much with finned or corrugated surfaces, several tubes in parallel or regenerative burners [2].

By so doing, very efficient preheating is possible. However, very hot air increases the local temperature within the flame, producing intolerable NO formation and then NOx emissions, and this has prevented application of high preheat until suitable, dedicated low-NOx combustion technologies have been developed and applied. These include in particular the flameless oxidation combustion process whereby a flame front is deliberately suppressed by a controlled inertisation of the reactants [3]. This combustion mode is very effective in preventing...
NOx formation in the combustion chamber, and NOx emissions are thereby reduced by an order of magnitude. Flameless oxidation is only possible above a threshold furnace temperature (850°C for safety), because steady combustion is then triggered and stabilised by preheating the reactants above self-ignition and this is carried out by diluting air and fuel with hot, chemically inert products of combustion. This inertisation is brought about by fluid dynamic entrainment of the surrounding fluid made possible by high momentum of air and fuel injected at the burner nozzle. Flameless oxidation is quite suitable for high air preheating, not only for low-NOx purposes but also for improved uniformity of the heat transfer pattern in the furnace [2, 3].

**COMBUSTION SYSTEMS**

High temperature combustion techniques complying with environmental regulations have been implemented in numerous furnaces for ferrous and non ferrous metals, in process furnaces, in glass tanks and in other applications [3]. Flameless oxidation technology has made it possible to push burner integrated heat recovery towards higher temperatures without infringing NOx emission regulations. Due to the NO formation mechanism in the flame, NOx emissions increase very rapidly with the air preheat temperature. However, above the threshold 850°C (furnace temperature), flameless technology can reduce NOx formation by almost one order of magnitude.

This is the reason for the term 'high temperature' techniques. Air preheating close to the process temperature allows, in principle, a substantial increase in thermal efficiency and greatly affects the furnace conceptual design. Decentralised heat recovery seems to be the unique design solution for this purpose. Cold air is distributed to burners and relatively cold flue gases are collected from the burners, which is good for a compact tube plant and installation of the furnace structure. Furthermore, lack of a recuperator at the chimney means the elimination of, or at least a great reduction in the passive zone, thus reducing the length of the furnace (or increasing productivity with the same length).

A further distinctive feature of the technique is the control mode, which is based on the 'on-off' (or pulse firing) principle, instead of the traditional modulating control. This is a consequent and logical choice especially for regenerative burners. Regenerative burners (see Figure 4) use the principle of heat storage consisting of twin heat reclaiming beds; this ceramic mass (pebbles, honeycomb, foam, etc) stores the heat contained in the flue gases extracted from the furnace and yields it back to the combustion air in the second phase of the inversion cycle. If the flue gases are clean enough to avoid blockage problems, fine ceramic honeycomb structures can be used as bed reclaimers, making a high transfer surface possible in a compact volume. In this way even compact units have been built and adopted in order to carry out very efficient preheating. The more usual design includes twin separate units. The connected power can be as high as several MWth, ie, the design can be scaled up from small to large. The system is based on a fixed inversion cycle time, usually 10-60s, and on automatic inversion valves aboard the burner itself, as shown in Figure 4. With the valves closed the burner couple is in stand-by and this idle time can be exploited to control power input to the furnace (on-off). A blower is required to overcome the pressure losses and to extract the flue gases.

Recuperative burners are equipped with a coaxial, tubular, counter-current heat exchanger as shown in Figure 2. Figure 3 shows that preheating efficiency is noticeably lower than with regenerators, though corrugated and finned surfaces are adopted in order to increase heat transfer. This is better carried out with heat resistant alloys (up to about 1,100°C), while less performing ceramic (SiSiC) recuperators are used for high temperature duty.
FORMING PROCESSES

**Revamping Projects**

**Rotary Hearth Furnaces (RHF)** An RHF is typically used for reheating billets to be delivered to the perforating mill and is the main natural gas consumer in a pipe mill.

The new furnace at Tenaris, Dalmine started operation in 2010 and has been equipped with:

- Regenerative burners in the heating zones
- Roof burners in the soaking zones with air preheated in a central recuperator
- Billet preheating with the exhaust gas of the furnace

Assessment of furnace efficiency had shown poor performance of the recuperator due to heat losses and leakages, so a two-step project was implemented. The first step was the substitution of the central heat recuperator with a new, high-performance one. Step two was the installation of regenerative burners in the heating zone.

Results after substitution of the recuperator show improvements better than 10% when compared to the previous plant conditions. After implementation of the second step, the expected thermal efficiency should be above 70% and the energy saving should reach more than 30% compared with the starting configuration.

**Intermediate furnaces** Two recent combustion system revamp projects were carried out in 2008 and 2009 on two intermediate walking beam furnaces at Tenaris, Dalmine. These furnaces reheat still hot tubes after rolling to a soaking temperature typically 1,050°C to be processed in the sizer mill or in the stretch reducing mill.

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<table>
<thead>
<tr>
<th>Furnace type</th>
<th>Productivity t/h</th>
<th>Reference plants: traditional efficiency</th>
<th>Target efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary hearth</td>
<td>High &gt;100</td>
<td>0.55</td>
<td>0.70</td>
</tr>
<tr>
<td>(~1,250°C)</td>
<td>Low &lt;60</td>
<td>0.50</td>
<td>0.65</td>
</tr>
<tr>
<td>Intermediate</td>
<td>~ 60</td>
<td>0.40</td>
<td>0.65</td>
</tr>
<tr>
<td>(~1,050°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austenitising</td>
<td>High 30-50</td>
<td>0.55</td>
<td>0.70</td>
</tr>
<tr>
<td>(~950°C)</td>
<td>Low &lt;30</td>
<td>0.50</td>
<td>0.65</td>
</tr>
<tr>
<td>Tempering</td>
<td>High 30-50</td>
<td>0.65</td>
<td>0.80</td>
</tr>
<tr>
<td>(500–700°C)</td>
<td>Low &lt;30</td>
<td>0.50</td>
<td>0.75</td>
</tr>
</tbody>
</table>

**Table 1** Reheat furnace reference and target efficiencies

<table>
<thead>
<tr>
<th>Productivity t/h</th>
<th>Specific gas consumption Nm³/t</th>
<th>CO₂ emissions t/y</th>
<th>Flue NOₓ emissions mg/Nm³</th>
<th>Total NOₓ kg/y</th>
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</thead>
<tbody>
<tr>
<td>Before revamping</td>
<td>20</td>
<td>38.6</td>
<td>13,726</td>
<td>20,018</td>
</tr>
<tr>
<td>After revamping</td>
<td>22</td>
<td>20.7</td>
<td>7,831</td>
<td>3,447</td>
</tr>
<tr>
<td>Difference %</td>
<td>+10</td>
<td>-46</td>
<td>-41</td>
<td>-83</td>
</tr>
</tbody>
</table>

**Table 2** Comparison of Intermediate furnace before/after revamping

(maximum about 1,250°C). Recuperative (also called self-recuperative) burners of limited capacity (25-150kW) are very much utilised in radiant tubes. In free flame (direct heating) furnaces they usually provide a hard, jet-like flame, which is very convenient to stir up the furnace atmosphere. Typically, there are numerous burners installed along walls and controlled via on-off (or pulse) firing. The concept of the standard design is best suited for capacities limited to ~400kW, whereby the overall size ‘D’ of the burner plus recuperator assembly is compatible with the furnace wall thickness ‘L’ (Figure 2).

The traditional modulated control (power controlled by throttling air and fuel supply to the control zones), is inherently inaccurate because the flame cannot be maintained at the optimum conditions during turn-down. The use of pulse firing minimises the furnace consumption especially at minimum loads or in stand-by. In this way the burners supply heat at their maximum thermal efficiency and the best temperature uniformity can be achieved. Of course, the furnace pressure, and the air/fuel ratio has to be properly controlled in order to reach these values.

In summary, with the performance expected from the burner integrated heat recovery system, the rotary hearth furnace can profit from using large regenerative burners aiming at a thermal efficiency of about 70-75%, while a similar thermal efficiency with recuperative burners in pulse firing control is expected for intermediate and heat treatment furnaces. This would be a consolidated step forward in thermal efficiency as expected from Table 1.
In the first furnace the side walls were equipped with recuperative burners close to one another (see Figure 5). In Table 2, the comparison of the first revamped furnace with the original obsolete system (cold air and poor control) emphasises the benefits obtained, namely: consumption almost halved and NOx emissions reduced by a factor of five. The table does not quantify the improvement in temperature uniformity and product quality, which has been ascertained in operating practices.

In the second furnace, the discharging wall only was equipped with recuperative burners. The specific natural gas consumption exhibits an average saving after revamping, of ~40% during normal production, while the reduction of gas flow is up to 70%, for stand-by conditions. This is a relevant feature in tube manufacturing technology since the productivity and therefore the power demand of the intermediate furnaces are quite variable with time.

CONCLUSIONS

The combustion systems implemented at Tenaris, Dalmine using the best available technology achieve high performance regarding NOx and CO2 emissions, so reducing the environmental impact of tube manufacturing. The overall investment cost of this advanced combustion equipment is higher than traditional systems, but it is compensated for partly by the efficiency improvements, providing reasonable payback times depending on the present or expected natural gas availability and price. MS

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REFERENCES