International Flame Research Foundation
The Finnish and Swedish National Committees
Finnish – Swedish Flame Days 2013

EXPERIENCES FROM OXYGEN LANCING IN SLAB REHEATING

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ABSTRACT

Recent developments in oxyfuel heating technology have been demonstrated to significantly enhance existing reheating furnace performance. By installing the new REBOX® HLL (High Level Lancing) technology, reheating furnaces can be upgraded with limited capital investment compared to other alternatives.

With REBOX® HLL about 75 % of the air needed for combustion is replaced by industrial grade oxygen, which corresponds to ~ 50 % oxygen in the oxidant. Existing burner systems remain in operation and are equipped with special HLL-lances that establish a flameless-like combustion. This leads to reduced NOx emissions, reduced energy usage, and increased production/heating capacity in steel reheating furnace with side- or front-wall mounted burners.

Typically this performance enhancement system can be installed during a normal operating schedule with little or no lost production. Also, potential risk relating to implementing REBOX® HLL is minimized because it enables flexibility in operating techniques (in response to fluctuating fuel cost, availability and production requirements) and is essentially reversible.

Up to date totally seven slag reheating furnaces are using this new heating technology. The results from installations in the Nordic countries will be presented.

Keywords: oxyfuel; reheating; fuel savings; increased throughput ; uniform heating; REBOX® HLL

1 Introduction

Heating and melting with oxyfuel have been used in the steel industry for decades, however, mainly in the areas of scrap melting and vessel preheating.

Prompted by rapidly rising fuel prices in the 1970s, ways of reducing fuel consumption in reheat and annealing furnaces were first considered. This laid the foundation for a development that led to the use of the oxyfuel solutions also in rolling mills and forge shops. In the middle of the 1980s AGA 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 AGA converted the first furnace to operation with 100 % oxygen, i.e. full oxyfuel combustion.

Oy AGA Ab is a member of The Linde Group, a world-leading gases and engineering company with around 62,000 employees in more than 100 countries worldwide. As of today, Linde has made more than 130 furnace installations of its REBOX® oxyfuel solutions in reheating and annealing. With in-house furnace and process engineering experts, Linde has the proven capability to deliver turnkey projects with short implementation time and guaranteed performance. Linde offers several oxygen-enhanced heating solutions for different types of furnaces in its REBOX® portfolio. The REBOX® portfolio includes equipment and control systems for reheat furnaces and annealing lines as of:

- Oxygen enrichment (where typically up to 30 % oxygen enrichment rate is used),
- Oxygen lancing (were a major share of the combustion air in the existing air-fuel burners is substituted with oxygen, resulting up to 50 % oxygen enrichment rate),
- Oxyfuel boosting and all oxyfuel (were air-fuel burners are replaced with oxyfuel burners, resulting up to 100 % oxygen enrichment rate).

Depending on the furnace size, condition, and design and the goal for revamping, different technologies may be best suited for each specific case. For large slab reheat furnaces it is often beneficial to make a partial conversion to oxygen-enhanced heating, in order to provide an optimal solution given operating goals and capital and infrastructure constraints.

2 Oxygen-enhanced combustion

When an air-fuel combustion technology is applied, the burner flame contains nitrogen from the combustion air. A significant amount of the fuel energy is therefore used to heat this nitrogen: approximately eight molecules of N_2 from combustion air per molecule of CH_4 (in the case of natural gas as the fuel). The hot nitrogen leaves through the stack, resulting in energy losses. By using industrial grade oxygen to avoid the nitrogen ballast, however, not only is the combustion itself more efficient but so is the heat transfer.

Higher oxygen content in the oxidant 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. Another result is that the concentration of the highly radiating products of combustion, CO_2 and H_2O, is increased in the furnace atmosphere. For heating furnace operations, these two factors lead to a higher heating rate, fuel savings, and lower CO2 emissions (see Table 1).

Table 1. Comparison of energy needs for reheating of steel using air-fuel (with and without recuperation) and oxyfuel employing best techniques of each kind.

		Airfuel	Airfuel w recu	REBOX® HLL	REBOX® Oxyfuel
O_2 content in oxidant	%	21	21	~ 50	100
Enthalpy to steel	kWh/ton	200	200	200	200
Transmission losses	kWh/ton	10	10	10	10
Skid cooling losses	kWh/ton	30	30	30	30
Flue gas enthalpy	kWh/ton	231	113	46	39
Flue gas temperature	°C	1000	1000	950	900
Air preheating	°C	20	450	400	20
Thermal efficiency	%	51	68	84	86
Energy need	kWh/ton	471	353	286	279
Energy need	GJ/ton	1,69	1,27	1,03	1,00

Oxyfuel combustion technology allows for installation of compact equipment, such as combustion system pipes, flow trains, controls and a flue gas handling system, without the need for recuperative or regenerative heat recovery solutions. Combustion air blowers and related low frequent noise problems are also eliminated.

2.1 NOx emissions

The legislation relating to NOx (NO and NO_2 are collectively referred as to NOx) emissions is strict, and permissible emission levels are constantly being reduced. It is worth noting that nitrous oxide, in addition to having many well-known adverse effects, is also one of the greenhouse gases listed in the Kyoto Protocol; its so-called global warming potential is 230 times that of CO_2. Bearing this in mind, development work started in collaboration with customers to find even more effective oxyfuel solutions.

Three things control the formation of thermal NOx: partial pressure of oxygen; partial pressure of nitrogen; combustion temperature, i.e. NOx formation temperature. For each of these prerequisites there are different measures that can be undertaken to minimise the formation of NOx. Thus it is possible to formulate a strategy, including – for each of the items – the following measures:

- Partial pressure of oxygen
  - Ensure a well-functioning combustion and control system
  - Minimise air ingress by means of tightness and strict control of the furnace pressure
- Partial pressure of nitrogen
  - Avoid having nitrogen present in the oxidation media
  - Minimise air ingress by means of tightness and strict control of the furnace pressure
- Combustion temperature
  - Burner design, e.g. flameless combustion

Although only oxygen is used in the conventional oxyfuel combustion process, nitric oxide is produced as a result of the high flame temperature and the ingress air. To lower the peak temperature and improve the flame conditions, the introduction of so called staged combustion was an important first step to achieve reduced NOx emissions. However, due to authorities' continuously lower emission permit levels, further technical developments had to be taken on.

2.2 Flameless oxyfuel

A key parameter in achieving low NOx is reduction of flame temperature. Below a temperature of approximately 1,400°C NOx formation is limited, but above this temperature a dramatic increase in NOx occurs (Figure 1). Conventional oxyfuel combustion can exhibit flame regions with temperatures above 2,000°C. One way of reducing the flame temperature is to use the principle of 'flameless combustion'. This principle has been known for many years but has only recently been exploited industrially.

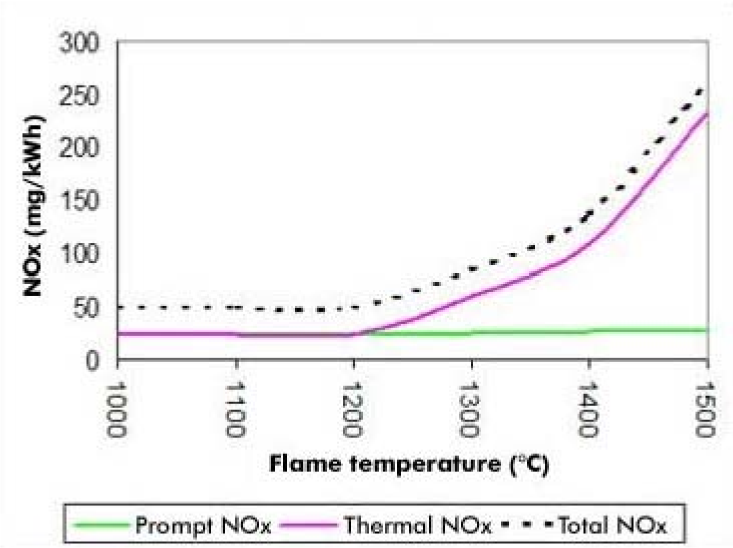

Figure 1. NOX formation in relation to the flame temperature (Article in Tecno Impianti).

There are two main ways of obtaining the flameless oxyfuel combustion mode: either dilution of the flame by recirculating part of its flue gas to the burner, or use of separated injection of fuel and oxygen at high velocities. The mixture of fuel and oxidant reacts uniformly through flame volume, with the rate controlled by partial pressures of reactants and their temperature.

In addition to reducing the temperature of the flame, flameless oxyfuel burners effectively disperse the combustion gases throughout the furnace, ensuring more effective and uniform heating of the material – the dispersed flame still contains the same amount of energy but is spread over a greater volume – with a limited number of burners installed.

2.3 Oxygen lancing

With REBOX® HLL (High Level Lancing) a type of flameless oxyfuel combustion can be created without replacing any existing air-fuel burners. By reducing air flow and substituting it by a high velocity oxygen injection into the combustion, great benefits can be achieved. Approximately 75 % of the oxygen needed for the combustion can be supplied with this technique, which corresponds to 50 % of oxygen in the oxidant. Flue gas volumes are about 65 % lower than that for air-fuel combustion. This leads to more uniform heating, reduced NOx emissions, reduced energy usage and increased production/heating capacity.

Existing burner systems remain in operation and are equipped with special HLL lances that establish a flameless-like combustion. This minimizes the installation complexity and down time. The existing air-fuel system, at any time, can be brought back into operation as it was before the HLL was employed. This eliminates any potential risk relating to implementing the HLL because it enables operating technique to be flexible, and optimized in response to fluctuating fuel cost and production requirements.

Over the past five years, seven HLL systems have been installed at steel mills located throughout the world. Compared with air-fuel technology, the effectiveness of the HLL has been shown to result in (1) reduction of specific fuel consumption, and (2) significantly shortening heat cycle time resulting in increased throughput capacity.

3 SSAB Borlänge, Sweden

SSAB is a leading producer of high strength steel. SSAB's mill at Borlänge, Sweden, produces sheet coil products. The size of the slabs is 11,000 mm long by 1,500 mm wide by 220 mm thick. The reheating takes place in two 300 t/h, 37 meter long by 12 meter wide walking beam furnaces heating slabs from 20 °C to 1230 °C. Oil and propane are used as fuels in the furnaces.

The installation of the HLL system was made in the oil fired furnaces preheating zones (zone 1 and 2), originally equipped with sixteen 3.8 MW oil burners using recuperated combustion air of 400°C. The entire installation was done during a normal production period, using some brief maintenance stops to drill the holes into the furnace. Oxygen flow trains were placed on top of the furnace to feed the zones with the required pressure and amount of oxygen. Oxygen lances connected with flexible hoses to the main supply piping's completed the installation. No changes to the original air combustion system were needed, which makes it possible to run the HLL "On" or "Off", dependent on the conditions and objectives at hand.

The system is capable to operate oxygen enrichment levels between 25 % up to 85 %. Most of the time, the operation ran with 75 % enrichment level of the total oxygen coming from the high pressure oxygen system, corresponding to an oxygen enrichment level of 51 %. The control system is a key player, because it must control both the flow of air and oxygen to the zones to achieve a correct oxygen level and desired combustion. However, due to the very fast response time of the oxygen regulation system, a correct oxygen-fuel ratio was very easy to attain at all levels of power rates. Hence, the combustion performance improved so that less excess oxygen was needed to avoid incomplete combustion and smoke generation.

The process model used for controlling the heating of slabs with the HLL is complemented with a gas composition factor, which reflects the better radiative properties of the products of combustion (higher concentrations of CO_2 and H_2O).

3.1 Results

Implementation of the HLL in the preheating zones has produced many interesting results and proven benefits.

Lower fuel consumption

The first obvious result was lower fuel consumption. This is due to two main reasons: less nitrogen to heat and a higher gas radiation factor (as explained previously). Figure 2 shows the weekly energy use as kWh/t plotted against production as t/h.

In order to evaluate the specific energy savings, different regressions were made. The result is a relationship that shows 2.5-2.6 kWh of energy savings per Nm3 of oxygen used.

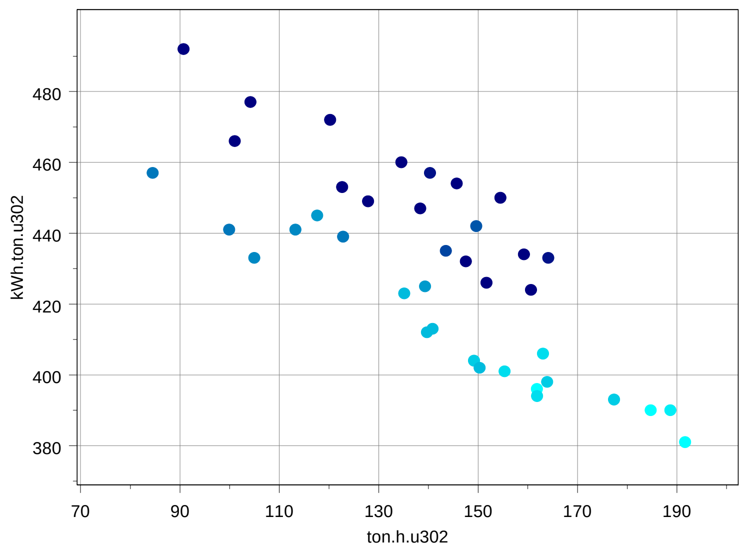

Figure 2. The fuel consumption is shown as a function of the oxygen use. Dark blue=no oxygen use, light blue= oxygen up to 4000 m3/h.

Decreased emissions

CO_2 and SO_2 emissions decreased proportionally to the reduction in fuel consumption. A lot of measures were done to lower the NOx at the same time when the HLL was implemented. All together the NOx emission decreased from 117 mg/MJ to 85 mg/MJ, which is a very low figure for a process that use of heavy fuel oil as fuel. When evaluating these figures, we should also consider the change of total energy input per tonne of produced steel. If taking this into account, on average the HLL in one zone gives an additional reduction of 7 % in total NOx per tonne of heated steel.

As mentioned earlier, it was possible to lower the oxygen/fuel ratio to provide complete combustion without producing smoke. This means that, not only is less fuel needed, less oxygen is required (compared to our earlier assumptions).

More even temperature distribution

The temperature distribution within the zones was very even, and enhances the possibility of producing a temperature profile along the slab that is more uniform (Figure 3). With the HLL, from operational point of view, a new tool has been added to control the temperature distribution inside the furnace.

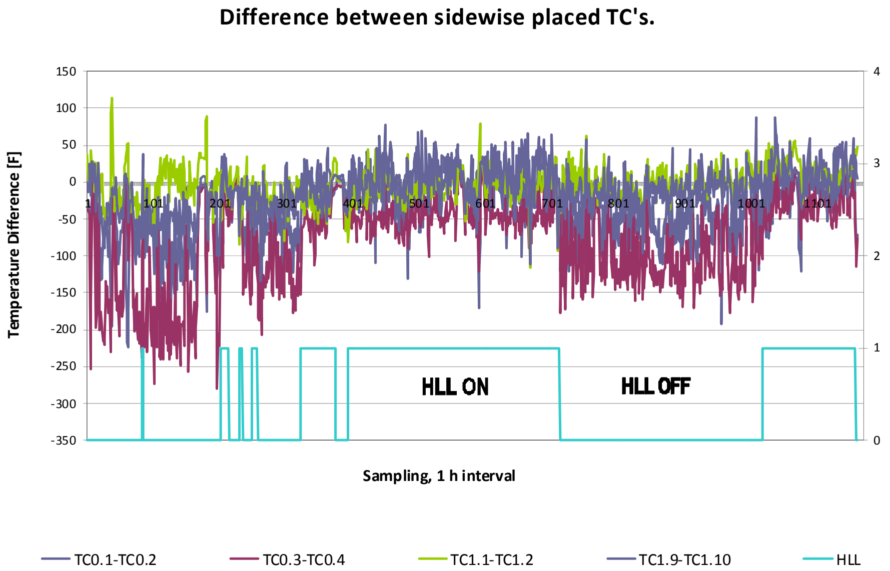

Figure 3. The impact of the HLL operation on the zone's deviation in temperature distribution.

Increased throughput

Productivity increase has not been completely validated but the possibilities have been indicated. Due to the production logistics of the rolling mill, with two parallel furnaces of nearly the same capacity, an increased capacity for one furnace can not be easily accommodated. However, it was obvious that with the HLL, the heating rate increased and the potential to increase the tonnage throughput is substantial. Simulations show that a productivity increase of 14 % is achievable with the HLL installed and operating in only two furnace zones. However, a higher productivity rate is not the only benefit that comes with higher heating capacity. Increased soaking time and a more flexible production unit for use as a stand-alone furnace are also significant advantages.

4 Outokumpu Tornio Works

Outokumpu is the global leader in stainless steel and high performance alloys. In 2011 the hot rolling mill and the walking beam furnace nr 2 was equipped with the HLL system in the preheating zones; both top and bottom (Figure 4).

The reheating takes place in two furnaces, nr 1 is 120 ton/h, and nr 2 is 250 t/h. The 250 ton/h furnace is fired with a mixture of LPG and CO gas and it's equipped with a recuperation system to preheat air to 450 °C. The furnace preheats both hot and cold slabs before hot rolling to 1260 °C. The size of the slabs is max 14,000 mm long by 1,000 - 1,500 mm wide by 167-187 mm thick.

The operating principle is identical to the SSAB Borlänge system (see Chapter 3).

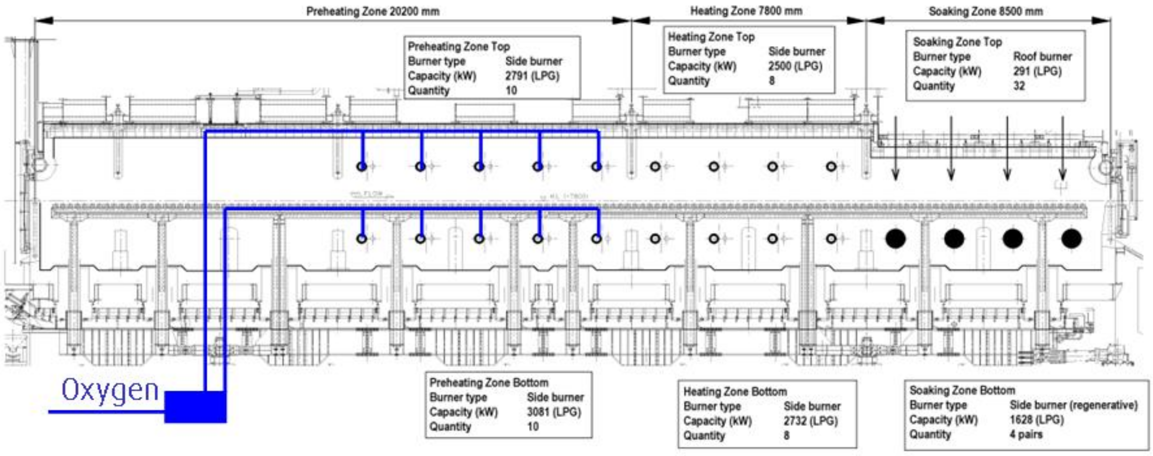

Figure 4. Walking beam furnace at Outokumpu. Twenty HLL lances are installed in the upper and lower preheating zones.

4.1 Results

Lower fuel consumption and increased throughput

In the successful performance test, heating capacity increased from 250 to >300 ton/h and at the same time specific energy consumption was reduced by ~ 30 kWh/ton (Figure 5). Typically the specific energy savings are around 2.3 kWh per Nm3 of oxygen used. During the performance test period the exhaust gas volume and temperature were reduced and the air preheat temperature was increased.

The extra capacity can be utilized in many ways, e.g. it allows so-called one furnace practice when market activity is reduced. Since late May 2012 the hot rolling mill's furnace nr 1 has been turned off and the entire production is maintained through the furnace nr 2. In practice, it means great savings in energy consumption and operation costs.

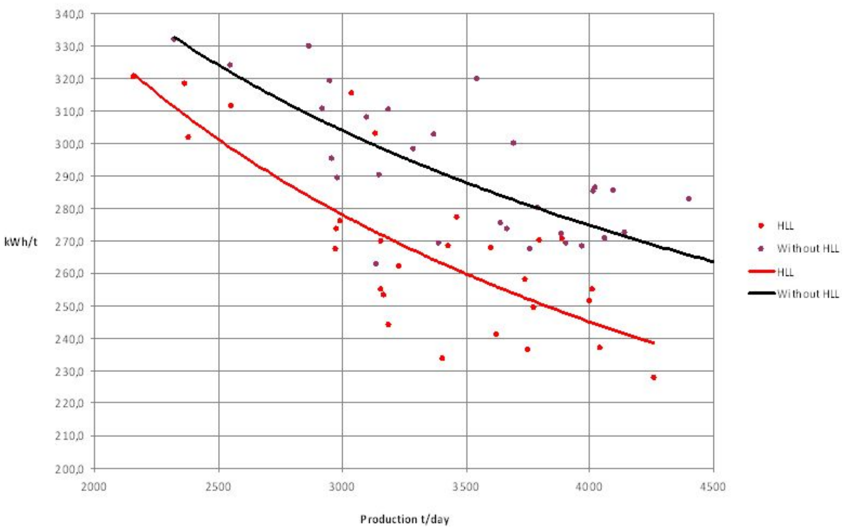

Figure 5. The energy consumption is shown as a function of the production rate.

Decreased emissions

CO_2 emissions decreased proportionally to the reduction in fuel consumption. The total NOx emission per tonne of heated steel reduced from a very low level by almost 30 %. However, it must be noted that the production rate and other process conditions varied between different NOx measurement periods and the results are not fully comparable.

The current practice with one furnace operation has a huge impact on both the CO_2 and the NOx emissions in the hot rolling mill.

Other benefits

With the HLL, the furnace is easier to operate: it helps to achieve and maintain different temperature set-points better than before. Before the HLL, the preheating zone temperatures started to fall when production rate was high. Typically, this was offset by manually increasing the number of burners in use. Today this is no longer the case.

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