ISSN 1983-4764

SUCCESSFUL USE OF FLAMELESS OXYFUEL REHEATING OF SLABS IN A WALKING BEAM FURNACE AT SSAB[1]

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Abstract

The installation in a 300 tonnes/hour walking beam furnace at SSAB uses the REBOX® HLL technology, which 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. Approximately 75% of the oxygen needed for the combustion is supplied with this technique. The fluegas volume is less than 45% that of air-fuel. System start-up took only one day as the REBOX HLL technology continues using the existing air-fuel burners. This eliminates any potential risk relating to implementing the technology because it enables operating technique to be flexible, and optimized in response to fluctuating fuel cost and production requirements. The walking beam furnace had prior to the installation good permance data, including a fuel (oil) rate at 440 kWh/t (1.58 GJ/t). Following is a summary of achieved results from the REBOX HLL installation: emission of NO_X can be reduced by 45% (-14% by one zone); fuel consumption can be decreased by 25% (-7% by one zone); leading to the same reductions in SO_2 and CO_2 emissions, the use of flameless oxyfuel has no negative impact on the surface quality; flameless combustion has a positive impact on the temperature uniformity of the slabs; production throughput can be increased by 15-20% (+6% by one zone); the ideal heating curve suggested by the control system can be achieved more easily and there is less smoke emanating from the furnace, greatly improving the plant environment.

Keywords: Flameless; Oxyfuel; Reheating; REBOX HLL

[1] *Technical contribution to the 47th Rolling Seminar – Processes, Rolled and Coated Products, October, 26th-29th, 2010, Belo Horizonte, MG, Brazil.*
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ISSN 1983-4764

1 INTRODUCTION

Over the past five years, 30 flameless oxyfuel systems have been installed at 15 steel mills located throughout the world. Compared with air-fuel technology, the effectiveness of the flameless oxyfuel technology has shown to result a in reduction of specific fuel consumption of up to 50%, while significantly shortening heat cycle time, resulting in increased throughput capacity in ranges of 25% to 50%. In a furnace operating with 100% flameless oxyfuel, the specific energy intensity could be below 1 GJ/tonne, i.e., 25% lower than the best available air-fuel technologies. This paper discusses experiences from installations of flameless oxyfuel in slab reheating furnaces, along with important developments and results. We will discuss the installations of REBOX® HLL technology at the 300 tonnes/hour walking beam furnace at SSAB's Borlänge mill. By applying different versions of oxygen boosting or full conversion into flameless oxyfuel operations in walking beam slab reheating furnaces, combustion and heat transfer efficiency improved significantly, and the scale losses and emissions of CO_2 and NO_X were substantially reduced.

2 OXYFUEL TECHNOLOGY

When an air-fuel combustion technology is applied in a steel furnace, the burner flame contains nitrogen from the combustion air. A significant amount of the fuel energy is therefore used to heat this nitrogen: eight molecules of N_2 from combustion air per molecule of CH_4. 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.

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, which is normal for all types of oxyfuel burners. 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 melting and heating furnace operations, these two factors lead to a higher melt or heating rate, fuel savings, and lower CO_2 emissions, see Table 1. For continuous heating operations, it is also possible to efficiently and economically operate the furnace at a higher temperature at the front of the furnace. This will further increase the potential throughput in any furnace unit. Oxyfuel technology combustion allows for installation of compact equipment, such as combustion system pipes, flow trains, control and 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.

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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. REBOX® is Linde´s trademark for oxyfuel solutions in reheating and annealing

		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

3 FLAMELESS OXYFUEL

In conventional oxyfuel combustion, the relatively high flame temperature creates a potential for forming thermal NO_X. It is important to note that NO_X formation is highly dependent on the design of the oxyfuel burner, furnace specifics and the process control system. In fact, oxyfuel combustion has been used for many years to reduce NO_X emissions to meet environmental regulations. Although only oxygen is used in the conventional oxyfuel combustion process, NO_X 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 NO_X emissions [1]. However, due to regulatory authorities' continuously lower emission permit levels, further technical developments were required. Conventional oxyfuel combustion can exhibit flame regions with temperatures above 2,000°C [2]. One way to reduce the flame temperature is to use the principle of "flameless combustion". This technology has been around for many years. However, only recently has it been exploited industrially.

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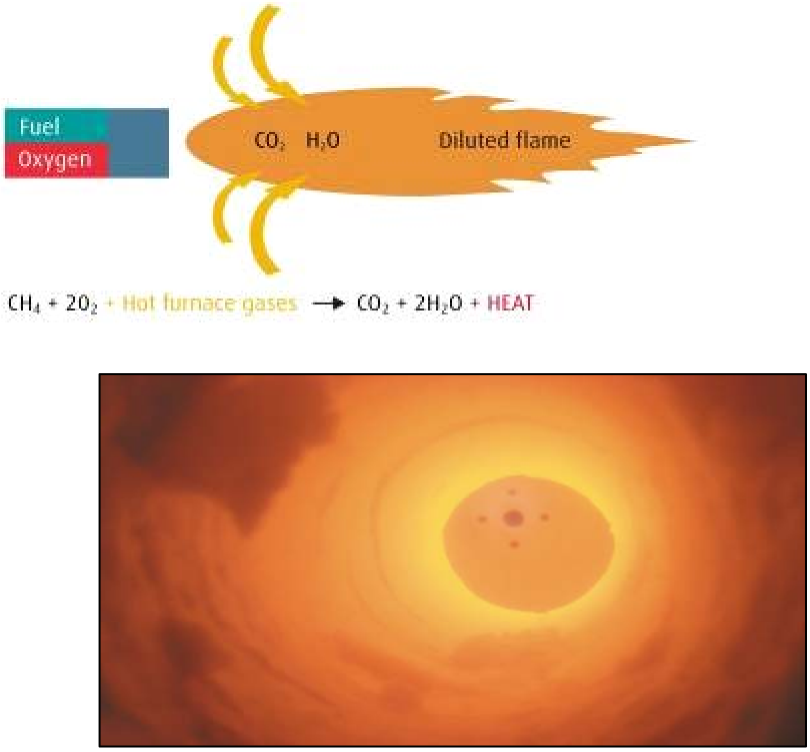

Figure 1. In flameless oxyfuel combustion the flame is diluted by the hot furnace gases. This reduces the flame temperature to avoid creation of thermal NO_X and to achieve more homogenous heating of the steel. The photograph shows flameless oxyfuel combustion with a diluted and almost transparent flame.

The term “flameless combustion” expresses the visual aspect of the combustion type, i.e., 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 because it is spread over a large volume. This is the reason it is sometimes referred to as “volume combustion”. Such a flame has a uniform and lower temperature, yet contains high amount of energy.

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 contains the same amount of energy but is spread over a greater volume – with a limited number of burners installed. Figure 2 shows the results of many years of operation at Ovako’s Hofors Works [3].

Typically, NO_X is a problem for old and continuous type furnaces. Use of conventional oxyfuel and regenerative air-fuel technology that is much more sensitive to furnace air in-leakage creates higher levels of NO_X than flameless oxyfuel. However, with the low flame temperatures of flameless oxyfuel, formation of thermal NO_X is minimized and insensitive to air in-leakage. This was confirmed in an investigation carried out by the Royal Institute of Technology in Stockholm, Sweden. Trials in pilot-scale furnace showed that, even with large volumes of ingress air entering the furnace, NO_X levels remained low [4]. This has been proved further in several additional industrial installations.

There also seems to be an increasing need to combust Low Calorific Fuels [5]. For fuels containing less than 2 kWh/m^3, use of oxygen is a must. Flameless oxyfuel can be successfully employed for this application. At integrated steel mills, use of blast

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furnace top gas (less than 1 kWh/m^3), alone or in combination with other external or internal fuels, is becoming increasingly important. Low Calorific Fuels, such as blast furnace top gas, not only have a low energy density, which requires large volumes have to be transported; they have a low pressure that is costly to increase.

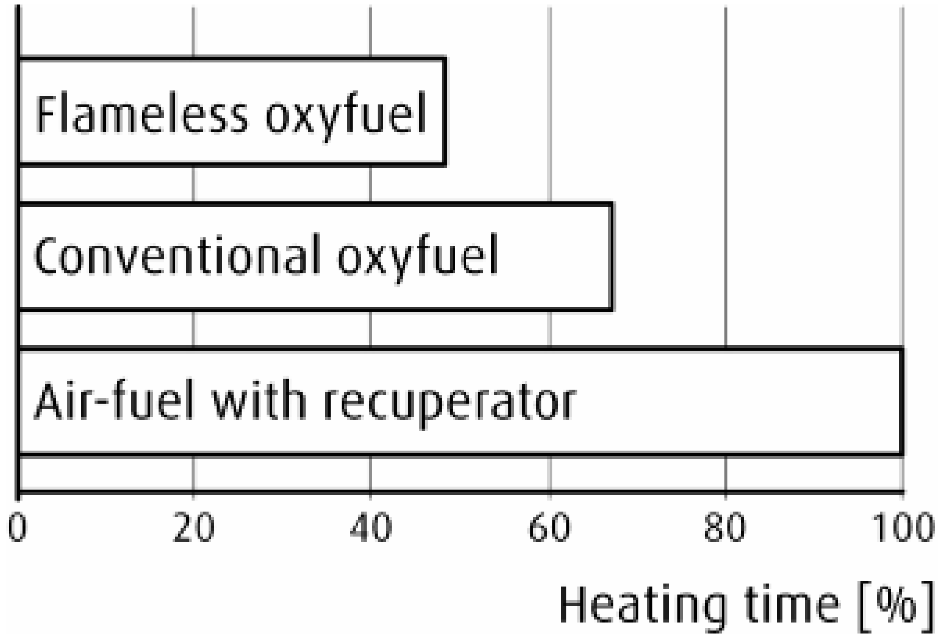

Figure 2. Comparison of total heating time at Ovako's Hofors Works using different combustion technologies.

For the past 20 years, Linde has been pioneering the use of oxyfuel in reheating and annealing furnaces [6]. To date, Linde has installed 120 of its REBOX® solutions and 30 flameless oxyfuel systems in steel mills around the world. Currently, these installations are either up and running or in the process of installation at a total of 15 production sites among the following steel companies: Acerinox, ArcelorMittal [7] , Ascométal (Severstal), Böhler-Uddeholm (Voestalpine), Usiminas, Dongbei Special Steel, Kanthal, Outokumpu, Ovako, Sandvik, Scana Steel and SSAB.

4 REBOX HLL AT SSAB, BORLÄNGE, SWEDEN

SSAB is global niche producer of high strength steel with a leading market position because of its productivity and its innovative solutions that help increase the competitiveness of its customers. SSAB's production capacity in Sweden and the US, totals more than six million tonnes.
SSAB's mill at Borlänge, Sweden, produces sheet coild 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 37 meter long by 12 meter wide walking beam furnaces, compare Figure 3, heating slabs from 20°C to 1,230°C. Designed maximum capacity was 300 tonnes/hour per furnace, the mill produced 2.8 million tonnes of hot rolled coils per year. Oil is used as fuel in the reheating. The air-fuel combustion system uses a recuperation system to preheat air to 400°C.

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The new installation at SSAB uses the REBOX® HLL technology, which 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. Approximately 75% of the oxygen needed for the combustion is supplied with this technique. Looking at the flue gas volumes, we could say that for full oxyfuel it is more than 70% lower that of air-fuel however for REBOX HLL technology, it is approximately 50% lower.
It is important to repeat that the REBOX HLL technology continues using the existing air-fuel burners. This means that installation of this technology is rather easy because it does not include any replacement of burners or installation of additional burners, which minimizes the installation down time. Also, the existing air-fuel system, at any time, can be brought back into operation as is was before the REBOX HLL technology was employed. This eliminates any potential risk relating to implementing the REBOX HLL technology because it enables operating technique to be flexible, and optimized in response to fluctuating fuel cost and production requirements.
Following is a summary of achieved results, which will be discussed later:

- Emission of NO_X can be reduced by 45%.
- Fuel consumption can be decreased by 25% (leading to the same reductions in SO_2 and CO_2 emissions).
- The use of flameless oxyfuel has no negative impact on the surface quality.
- Flameless combustion has a positive impact on the temperature uniformity of the slabs.
- Production throughput can be increased by 15-20%.
- The ideal heating curve suggested by the control system can be achieved more easily.
- There is less smoke emanating from the furnace, greatly improving the plant environment.

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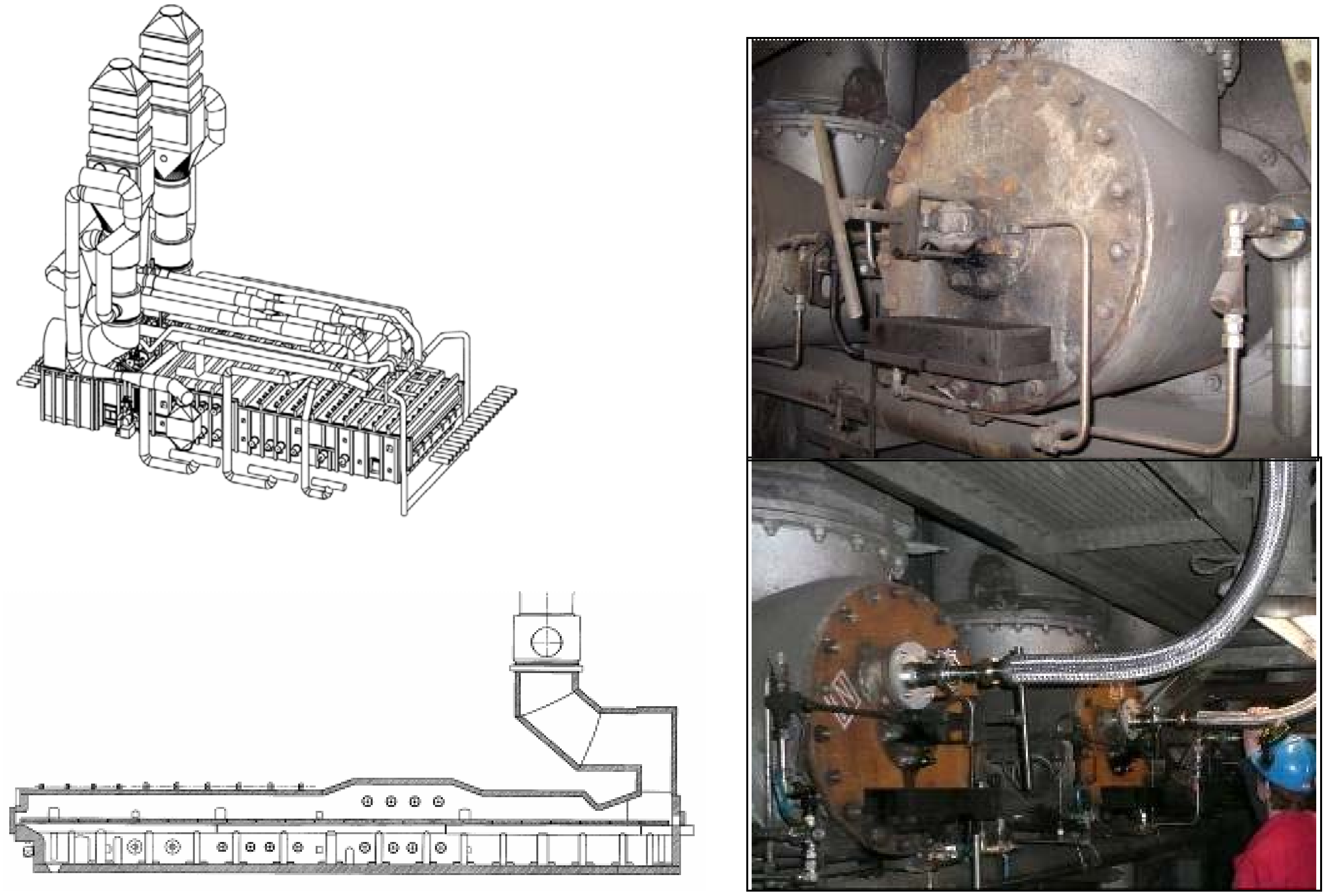

Figure 3. Walking beam furnace at SSAB, Borlänge, Sweden. The original furnace equipped with recuperative air-fuel system (top) and REBOX HLL arrangement (bottom).

4.1 The Rebox HLL Installation

The installation of the REBOX HLL system was made in the upper preheating zone (Zone 1), originally equiped with eight 3.5 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, compare Figure 4, were placed on top of the furnace to feed the zone with the required pressure and amount of oxygen. Oxygen lances connected with flexible hoses to the main supply pipings completed the installation. No changes to the originally air cumbustion system were needed, which makes it possible to run the REBOX HLL system “On” or “Off”, dependent on the demands.

It was decided to have an operating range of the REBOX HLL system corresponding to oxygen-enrichment levels of 25% to 85%. Most of the time, the operation ran with 75% of the total oxygen coming from the high pressure oxygen system. The control system is very important because it must control both the flow of air and oxygen to the zone to achieve a correct oxygen level and complete 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 lower set-points for oxygen-fuel ratios could be used without producing smoke or incomplete combustion.

From an operating point of view, the system was quite simple, the main parameters being oxygen-enrichment level and lambda for the oxygen-fuel ratio.
The model used for controlling the heating of the slab was complemented with a gas composition factor, which reflects the higher gas radiation when having higher concentration of CO_2 and H_2O when operating with REBOX HLL.
During four weeks of trial in April and May 2008, the REBOX HLL system was employed. The system start-up took only one day; some adjustments on control parameters were required, and, after checking temperatures and quality of the first discharged slabs, the system was allowed to run full time. As of Mars 2009, the system is running continuously.

Figure 4. Compact oxygen flow train installed on the walking beam furnace at SSAB, Borlänge in Sweden.

Figure 5. Highly diluted flames created by the REBOX HLL installation at the walking beam furnace in SSAB, Borlänge in Sweden.The fuel used is heavy oil.

5 RESULTS

Implementation of the REBOX HLL system in the upper preheating zone (Zone 1) has produced many interesting results and proven benefits.

5.1 Lower Fuel Consumption

The first obvious result is the lower fuel consumption. To reach the same temperature in the zone and the slabs as with all air-fuel, the fuel consumption using

the REBOX HLL system is approximately 40% less. This is due to two main reasons: less nitrogen to heat; and a higher gas radiation factor. As a result the overall fuel consumption decreases as well. Figure 6 shows the weekly energy use in the HLL equipped furnace compared to the equally producing other parallel walking beam furnace. It's obvious that more use of oxygen lower the energy consumption. This could also be seen in the other diagram where weekly kWh/t is plotted against t/h.
In order to evaluate the specific energy savings from using oxygen, different regressions where made. The result is 2.5-2.6 kWh per Nm^3 of oxygen.

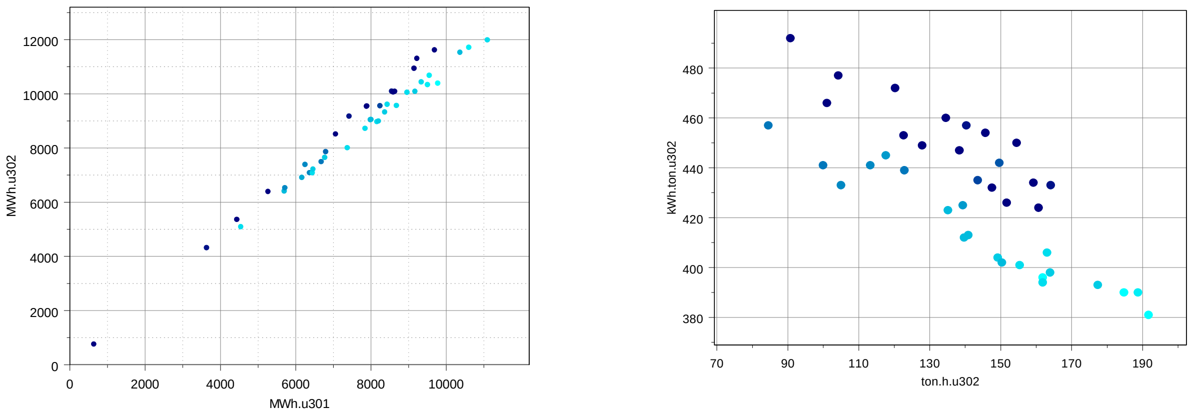

Figure 6. Fuel consumption as a function of oxygen use. The left diagram compares the two walking beam furnaces, one using air-fuel (x-axis) and one using REBOX HLL (y-axis). The right diagram shows thefuel consumption in the furnace with the REBOX HLL installation as a function of the oxygen use. In both diagrams: dark blu e=no oxygen use, light blue= oxygen up to 4000 m3/h used.

5.2 More Even Temperature Distribution

The temperature distribution within the zone was very even, and the possibility to producing a profile along the slab that is more uniform increase. These results are shown in Figure 7. With REBOX HLL, from operational point of view a new tool has been added to control the temperature distribution inside the furnace.

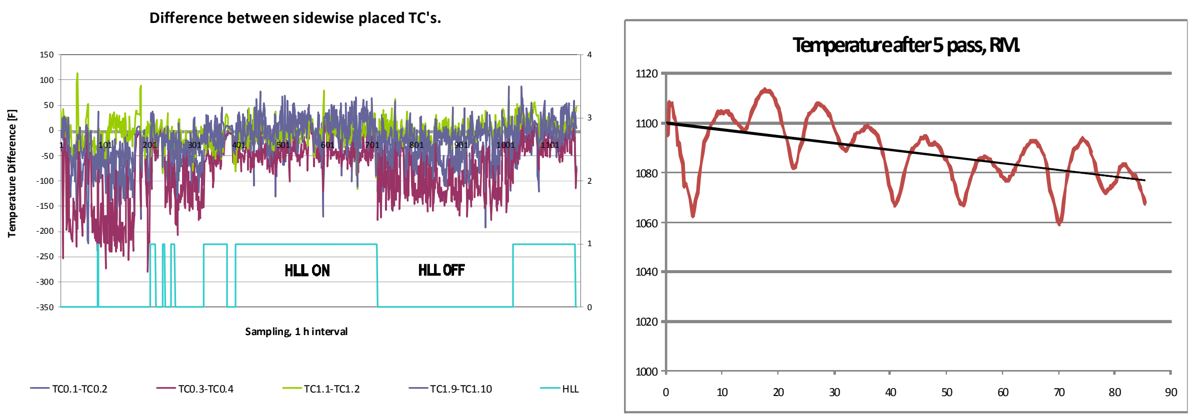

Figure 7. The left diagram shows the impact of REBOX HLL operation on the zone's deviation in temperature distribution. In the right diagram, it is presented the temperature profile along heat transfer bar after5 passes through rougher mill.

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5.3 Decreased Emissions

From an environmental point of view, there are also benefits from employing the REBOX HLL technology: CO_2 and SO_2 emissions decrease proportional to the reduction of fuel consumption [8]. The NO_X emissions change by REBOX HLL technology is more difficult to emphasize in general terms. It's depends of the burner configuration you apply the technology on and what you compare with. In the current application, a lot of measures have been taken to lower the NO_X at the same time as the HLL technology was implemented and began to be used. All together the NO_X emission has decreased from 117 mg/MJ to 85 mg/MJ, which is a very low figure for the 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 REBOX HLL system in one zone gives an additionally reduction of 7% of total NO_X per tonne of produced steel.

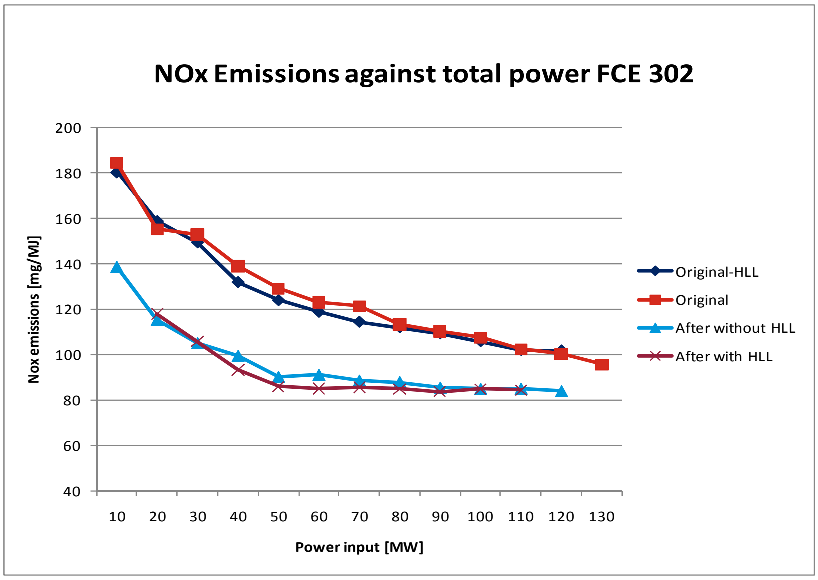

Figure 8. NO_X emissions have been significantly decreased since the installation of REBOX HLL. "Original" means the operation in early 2009. "After"represents operation in 2010. At both time periods the furnace has been operated both with and without REBOX HLL technology.

As mentioned earlier, it was possible to lower the oxygen/fuel ratio to provide complete combustion without producing smoke [9]. This means that, not only is less fuel needed, less oxygen is required (compared to first our earlier assumptions).

5.4 Increased Throughput

Productivity increase is not completely validated but the possibilities are indicated. Due to the production logistics of the rolling mill, with two parallel furnaces of nearly the same capacity feeding the mill at the same tonnage, an increased capacity for one furnace can not be easily accomodated. However, it was obvious that with the REBOX HLL system, the heating rate increased and the potential to increase the tonnage throughput is substantial [10]. For example, no limitations which normally are present, such as low pressure of combustion air or not enough heat to the material occurs when using HLL operation, see Figure 9. Simulations show that a productivity increase of 6% is achievable with the REBOX HLL installation in the one single zone. However, a higher productivity rate is not the only benefit that comes with higher

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heating capacity. Increased soaking time and a more flexible production unit for use as a stand-alone furnace are also significant advantages.

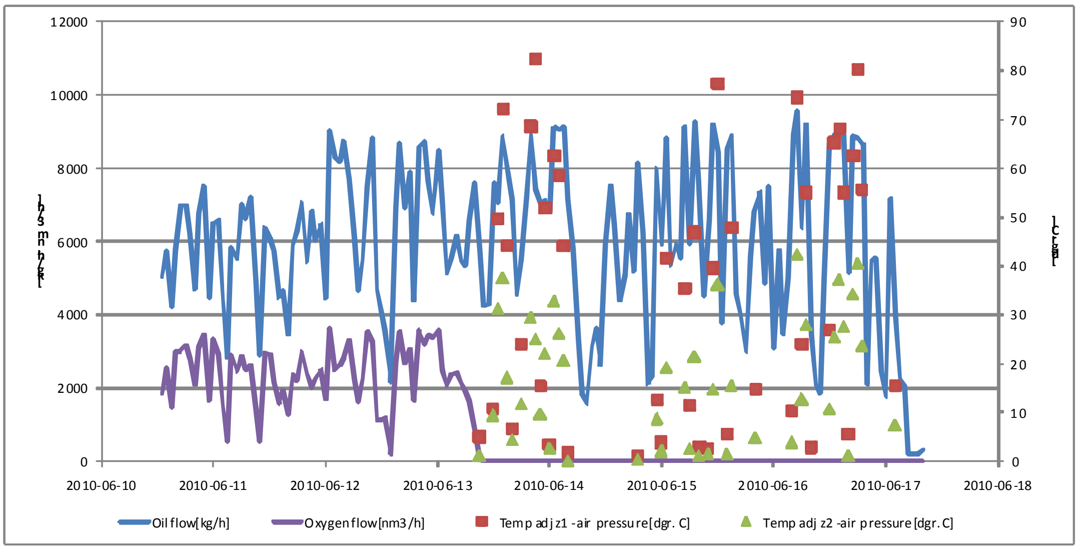

Figure 9. Limitations of Zone 1 and 2 due to air-pressure control.As can be seen, with REBOX HLL these have been eliminated.

In Table 2 the achieved results could be seen as well as the estimated performance were more zones are equipped with REBOX HLL technology.

Table 2. Actual and expected results of the REBOX HLL installation in the walking beam furnace operation.

	Air- fuel	REBOX HLL Zone 1	REBOX HLL Zone 1&2
Conversion to HLL of total installed power (HLL/Total)	0/152	28/152	56/152
Fuel consumption at 140 t/h [kWh/t]	448	417(-7%)	376 (-16%)
NO_X [tonnes/year] at 1.6 million tonnes production	304	205*	186*
Max oxygen consumption [Nm3/h]	-	3,500	7,000
Production limit [t/h]	300	320	340

* Includes other NO_X reducing measures.

6 FUTURE EXTENSION OF INSTALLATION

The results from the installation of HLL in Zone 1 have been so successfully that SSAB has decided to extend the installation to include also the bottom preheating zone, Zone 2. To exemplify the simplicity of installation the HLL technology, it could be mentioned that HLL has already been tested in Zone 2, by using the oxygen flow control train for Zone 1 and extend the flexible oxygen hoses to reach the burners at the bottom zones. However, before being able to operate both of preheat zones with HLL, the capacity of storage and supply of oxygen has to be increased.

7 SUMMARY

REBOX Flameless oxyfuel is a proven leading combustion technology, which provides substantial benefits for slab reheating in large continuous reheat furnaces.

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REBOX Flameless oxyfuel technology is known as an attractive solution not only for improvement of heating efficiency and to increase steel reheating capacity, but also to significantly reduce emissions to environment and improve quality of product.
The successful results from REBOX [11] industrial installations of flameless oxyfuel in 30 furnaces, demonstrates clear advantages over other alternatives. Further optimization of REBOX HLL installation in the walking beam furnace at SSAB in Borlänge, Sweden grants additional benefits as to those already achieved. Production flexibility, capacity increase, energy efficiency and higher production limits with fewer furnaces are all achievable based on the mill demand.

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