Application of oxyfuel combustion in reheating at Ovako, Hofors works, Sweden – Background, solutions and results

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1. INTRODUCTION

Since the first oxyfuel installation, in 1994, at a reheating furnace at Ovako, Hofors works, Sweden, the technology has shown interesting results: increased throughput of 30-50%, fuel savings in the order of 30-45%, more uniform heating, less scale formation and reduced CO_2 and NO_X emissions.
This paper will discuss how oxyfuel combustion requires both correct technical application and control in order for such results to be achieved. In this context oxyfuel combustion is defined as a replacement for all combustion air, containing 78% nitrogen, with industrial-grade oxygen, and combusted with a fuel, gaseous or liquid, this is then referred to as All Oxyfuel. A presentation of installations and important results achieved with current oxyfuel installations for reheating in 40 pit and 2 rotary hearth furnaces at Ovako is also covered.

2. OVAKO – LEADER IN THE FIELD OF BEARING STEELS

Figure 1: Ovako, Hofors, 3 hours' drive north of Stockholm, Sweden

Ovako is a leading European producer of long special-steel products for the roller-bearing, heavy vehicle, automotive and general-engineering industries. Production consists of low-alloy and carbon steels in the forms of bar, wire and wire rod, tubes, rings and pre-components. The company has 16 production sites, nine of them in Sweden, three in Finland, two in Holland and one each in France and Italy. Total turnover is close to € 1.3 billion. The company employs 4,600 people. Total steel production is 2 million tonnes. Ovako's Hofors plant (fig.1) provides steel-making, ingot-casting, billet and heavy-bar mills, and tube and ring-rolling mills. Billets, heavy bars, tubes, rings and pre-components from tubes and rings are produced here. The Hofors plant has about 1400 employees.

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A continuous quest for better performance

In the early 1990s Ovako set out to lower fuel consumption and raise heating capacity in their reheating operations. Local authorities were positive about the planned increases but imposed further reductions in NO_x emissions. The search for alternatives to a solution to this led to Ovako defining some important parameters for such a project.

1. **Product quality** – It is unacceptable for a supplier of bearing and special engineering steel to reduce product quality – an improvement in quality should be sought, if possible.
2. **Productivity** – More production capacity was needed to meet market needs and facilitate a more flexible approach.
3. **Cost reduction** – Any employed method should reduce the cost of fuel, maintenance, equipment, and emissions management.
4. **Environment** – Ambitious goals were to be set to reduce NO_X and CO_2 emissions - an extra tax had already been added to the fuel cost in Sweden.

AGA Gas, a member of Linde, were approached due to their knowledge of oxyfuel in reheating applications, including bearing steels. Ever since 1990 AGA has been using all oxyfuel at TIMKEN, USA. They have had interesting results, including a 63% reduction in specific fuel consumption, 74% less flue-gas emissions and a reduction in heating time from 5 hr to 2.5-3 hr.

3. MORE HEATING CAPACITY, LESS ENERGY AND REDUCED EMISSIONS

The first oxyfuel installation in a reheating furnace took place in 1994. Ovako wanted to test and evaluate the technology supplied by Linde. The installation replaced existing airfuel burners, recuperator and electrical ventilator fan. Oxyfuel was installed in a soaking pit battery of four soaking pits. The results were rewarding, and this far a total of 40 pit and 2 rotary-hearth furnaces have been converted to oxyfuel (fig. 2).

Figure 2: Ovako, Hofors works, Sweden, uses oxyfuel in 40 pit and 2 rotary-hearth furnaces for greater throughput capacity, providing flexibility and better-planned maintenance activities.

Ovako has achieved a 30-50% increase in heating capacity in the existing furnaces, coupled with a 30-45% reduction in specific fuel consumption. This has had the same CO_2-reducing effect. The extra throughput capacity has provided Ovako with greater flexibility, enabling them to follow variations in order intake and business cycles, and facilitating better-planned maintenance stoppages. The rotary-hearth furnaces have today a fuel consumption of 290 kWh/tonne heated steel, effective for cold-charged material during manned hours at a temperature range of 1120-1270°C. When a new tube mill was erected in 1998 a new rotary hearth furnace was needed. Ovako instructed the furnace supplier to equip it with oxyfuel for optimum performance and to maximize furnace output for the possible furnace size. The oxyfuel technology used has undergone several shifts in technology: initially conventional oxyfuel and later staged combustion, which has been continuously upgraded when necessary. Ovako is now evaluating flameless oxyfuel combustion to see if it has even better uniform heating and lower NO_X emissions.

Investments & work to reduce NO_X emissions

Ovako in Hofors is a mini-mill where most of the CO_2 and NO_X emitted originates from the reheating and annealing processes. When applying oxyfuel the emissions of NO_X, measured in the flue gases, dropped below the Swedish legislation's levels of 150 mg/MJ for liquid fuels and 100 mg/MJ for gaseous fuels. In parallel to the frequent measurements taken by Ovako, the local authorities of Hofors town have been running air-quality tests since 1993 (Fig 3). These tests have been repeated at intervals of several years at locations around the town of Hofors, involving measurement just outside the Ovako works (1). Oxyfuel reduces NO_X emissions by first reducing the fuel consumption, as seen in the CO_2 emissions (fig. 3), and secondly having no nitrogen present in the combustion. This and other measures at Ovako – tight furnaces, pressure control and short opening intervals – have improved the situation. Since 1995 the NO_X levels have been dropping, whilst reheated volumes have been constant: close to 700.000 tonnes/year.

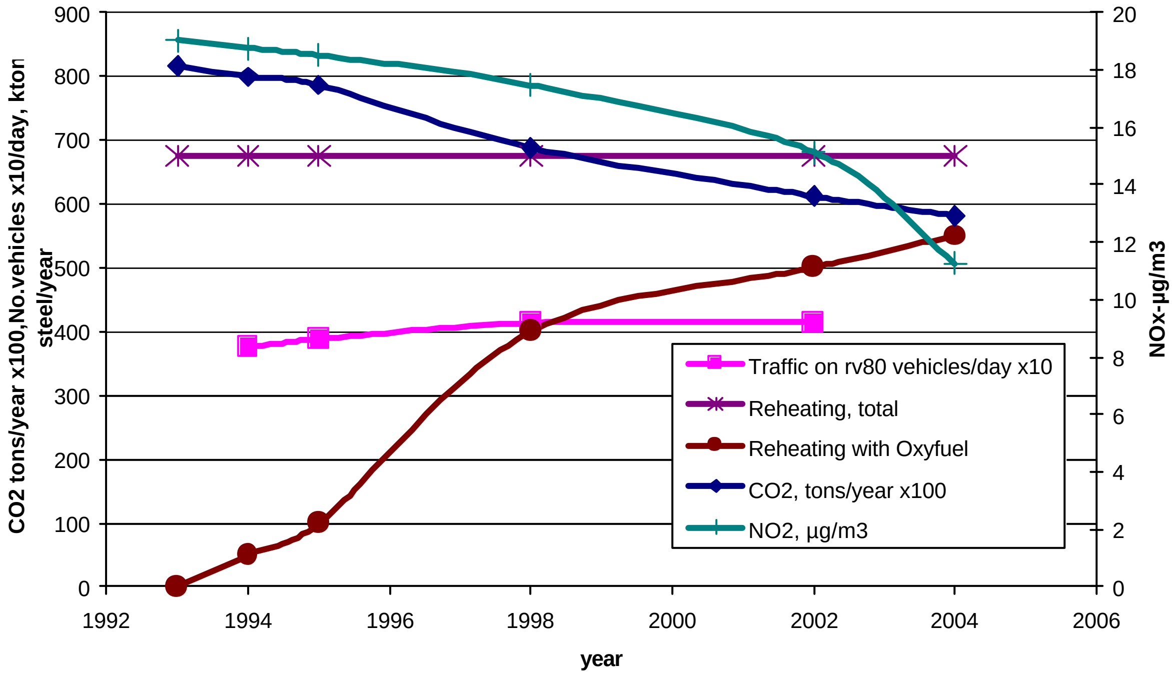

Figure 3: Whilst tonnage reheated with oxyfuel has increased, a drop in fuel consumption (CO_2) and NO_x emissions can be seen at Ovako, Hofors works, Sweden.

More uniform heating with reduced scale formation

Trials involving conventional- and flameless oxyfuel combustion have recently been performed at the billet mill in Hofors. NO_X emissions, rolling force, scale formation, heating times, soaking times and billet temperature out of rolling mill have been investigated. Propane was used to test flameless oxyfuel, whilst current conventional oxyfuel combustion in the pit furnaces uses oil.

It was noticed that the flameless oxyfuel technology offered a further reduction in heating time and NO_X emissions at maximum power compared to conventional oxyfuel. It should also be pointed out that the NO_X level at ordinary power was decreased. Owing to the lower flame temperature, which is typical of flameless oxyfuel and effective stirring of flue gases, more uniform temperature distribution within the ingot was noticed during the rolling operation.

A decrease in heating and soaking time creates not only a decrease in media input but also a reduction in scale formation. Scales from ingots from both conventional oxyfuel and from flameless oxyfuel were sampled. The results indicate a reduction in thickness of several per cent. No difference in chemistry was seen.

4. OXYFUEL COMBUSTION

The combustion process is most efficient if the fuel and oxygen can meet without any restrictions. In practical heating applications, however, it is not sufficient only to consider efficient combustion; heat-transfer must also be taken into consideration. Air in which the oxygen has been diluted by 78% nitrogen will not provide optimum conditions for combustion and heat transfer. The nitrogen ballast is heated and the heat that has to be recovered from the nitrogen must be recovered in order to save fuel (2). When replacing air with oxygen, several important changes in combustion and heat-transfer conditions occur:

- Input and output gas volumes are reduced
- Partial pressure of the 3-atomic, highly radiating gases (H_2O and CO_2) increases
- Combustion efficiency increase

These changes have great impact on the furnace and heating conditions, which can lead to considerable benefits in operating costs, greater heating capacity and improved product quality. The main advantages of using oxyfuel in reheating and annealing operations are:

- Higher production capacity (tonnes/hour) in new and existing furnaces
- Reduced specific fuel consumption and possible to use in-house low-calorific fuel types
- Reduced CO_2 and NO_X emissions
- The possibility of increasing the power input (W/m^3) into the furnace
- Reduced scale formation and more homogenous material temperature for improved downstream processing
- Improved control of furnace atmosphere and pressure
- No degeneration after time of combustion and heat-transfer process
- Lower capital expenditures
- Simple retrofitting and low maintenance

Flameless oxyfuel – faster & more uniform heating with ultra-low NO_x

Although oxyfuel means combustion without any nitrogen, there are always small volumes of ingress air entering the furnace. In conventional oxyfuel the high flame temperatures greatly encourages generation of thermal NO_X.
Recently, reheating and annealing furnaces have been equipped with so-called flameless oxyfuel combustion technology. This is sometimes also referred to as volume combustion, whereby the flame is diluted with the hot furnace gases. As a result of this the flame becomes practically invisible, as illustrated (fig. 4). As a result of this a cooler and more widely spread flame is obtained. The diluted flame still contains the same amount of heat, but it is more evenly distributed for uniform heating of the object in the furnace.

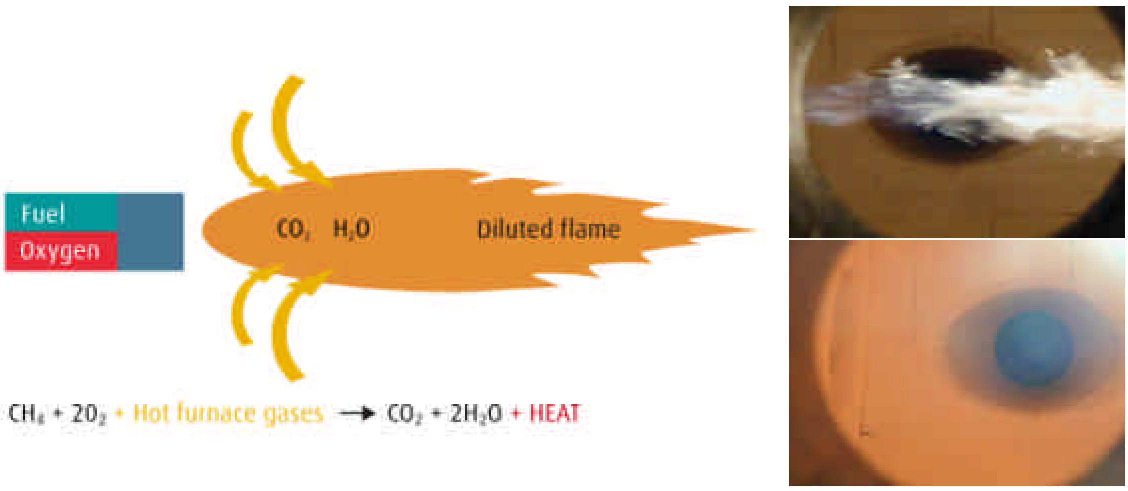

Figure 4: In flameless oxyfuel the flame is diluted by the hot furnace gases. This reduces the flame temperature to avoid creation of thermal NO_x and to achieve more homogenous heating of the steel. The top-right photo shows the hot oxyfuel flame coming from the burner on the left. The bottom photo shows flameless combustion – a diluted and almost transparent flame.

With the low flame temperatures of flameless oxyfuel, formation of thermal NO_X is avoided. This was confirmed in an investigation carried out by the Royal Institute of Technology in Stockholm, Sweden (3). Trials in pilot-scale furnace showed that even with large volumes of ingress air entering the furnace NO_x levels remained low (fig. 5). This is a typical problem for old and continuous type of furnaces. Conventional oxyfuel and regenerative airfuel technology created similar NO_X levels.

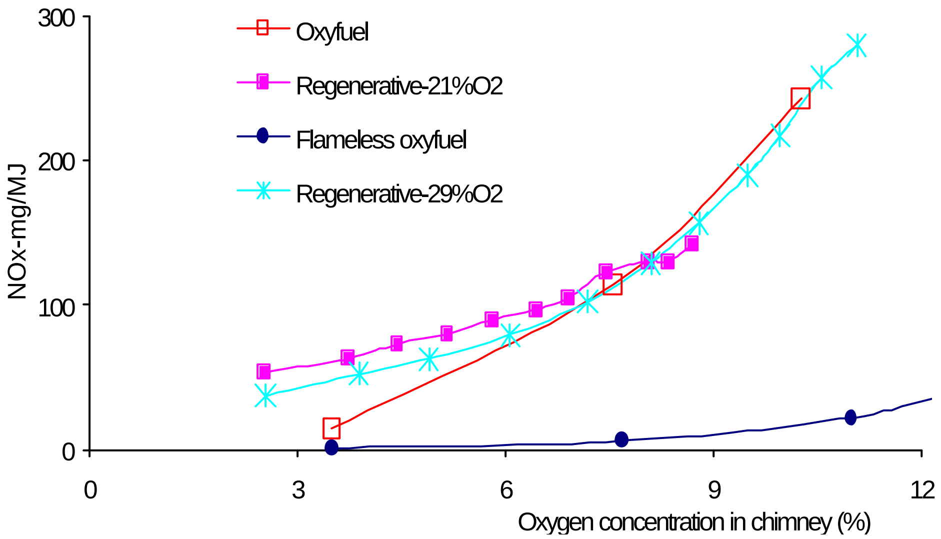

Figure 5: Emissions for conventional oxyfuel are comparable to regenerative airfuel technology, whereas flameless oxyfuel remains almost insensitive to ingress air.

There are clear advantages of flameless oxyfuel, and today there are only a few cases where this technology should not be employed. It combines the benefits of conventional oxyfuel combustion; powerful and compact burners for easy installation, reduced fuel consumption with equal reduction of CO_2 and decreased NO_X emissions, increased heating capacity in existing furnaces with the features of the flameless oxyfuel for ultra-low emissions of NO_X and more uniform heating of the material.
Flameless oxyfuel has already been implemented in 10 customer projects, e.g. Outokumpu Stainless, Ascometal, Uddeholm Tooling, and has now also been installed and evaluated by Ovako.
Flameless oxyfuel has also been implemented in several vessel-preheating operations.

5. OXYFUEL – APPLICATION

With oxyfuel it is possible to operate at higher heat-transfer rates (fig. 6), thus creating a higher speed for increased furnace throughput and lower fuel consumption and lower emissions than with airfuel systems. In order to achieve such results several factors must be taken into consideration.

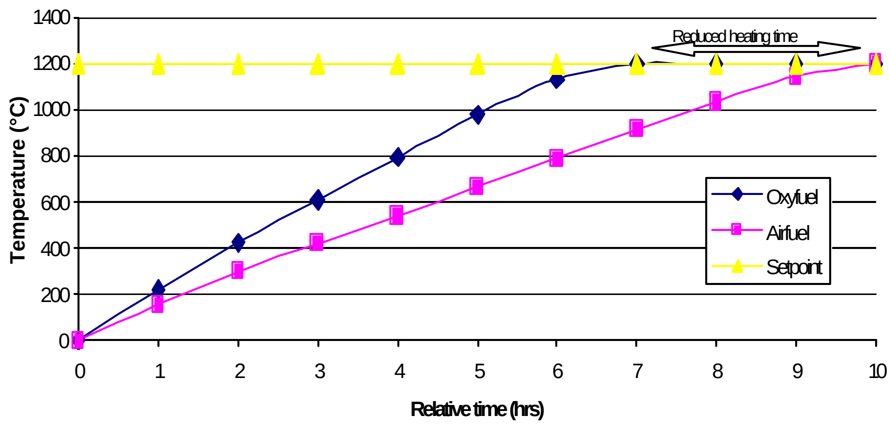

Figure 6: Example of heating profiles to achieve a material-temperature Setpoint of 1,200°C. The more efficient combustion and heat transfer of oxyfuel results in more rapid heating.

Requisite production capacity - redefining the heating profile

Often, old metallurgical standards and what has been technically and economically feasible with airfuel technology have defined existing heating profiles for the various steel grades. In over 90 installations since 1990 Linde has proved that these heating profiles can be challenged and that with oxyfuel combustion it is possible for such a challenge to be successful. This experience and knowledge is based on thorough understanding of the metallurgical considerations, customer processes and constraints, application expertise regarding oxyfuel burners and control system gained through close cooperation with customers such as Ovako, development, testing and implementation, with follow-up for feedback for improvements.
However, with oxyfuel it is often economically viable to add extra furnace power because of the efficient combustion and the beneficial heat-transfer process, with moderate losses to the chimney.

Power input – defining heating zones, burner sizing & position

The defined heating profiles are used when deciding on the requisite heating zones, positioning of burners and the requisite power input. Furnaces rather frequently do not require the same burner-power input as the once-specified nominal value. On many occasions this level has never been reached or used, owing to poor performance or other malfunctions of the airfuel systems, recuperators, regenerative systems, ventilators, etc. One should also bear in mind that a 10 MW airfuel and recuperator system can be replaced by a 6.7 MW oxyfuel system. The maximum power of a burner cannot always be used, unless for short periods. It may thus be appropriate to choose a somewhat smaller burner. It will then more often operate close to its nominal setting which is more advantageous regarding both fuel savings and emissions. To further optimize combustion the turndown ratio is limited and on/off regulation is used to reach furnace-temperature setpoint.

Figure 7: Oxyfuel burners are both compact and powerful. In this boosting application an additional 2 MW oxyfuel burner (left) are placed next to an existing 0.5 MW airfuel burner (right).

Definition of the heating zones and burner positions depends on the type of furnace and its specific design and function. This is achieved by experience and calculation tools, which Linde has based on data from over 90 installations, numerous laboratory tests and various combustion solutions. Positioning of oxyfuel burners is normally easier with the small, powerful oxyfuel burners (fig. 7), with no need for any bulky combustion air ducting. A water-cooled flameless oxyfuel burner, with integrated UV sensor and ignition, for a max power of 2.5 MW has a burner diameter of 105 mm and a weight of 10-20 kg depending on refractory thickness.

Temperature & pressure measurement

In order to achieve the desired and defined heating profiles in accordance with set targets, feedback on supervision, control and safety is needed. Positioning of the thermocouples and the various measurement strategies must be defined for the furnace and process in question.
Temperature measurement to comply with safety regulations is equally important – e.g. with regard to overheating, flue-gas temperatures and maximum temperature at old and unused but still remaining recuperators.
For instance, it is vitally important to keep furnace pressure under strict close control otherwise NO_X emissions will raise to high levels. Flameless oxyfuel has however proven to be almost insensitive to ingress air, as has been demonstrated in pilot-scale testing and verified in full-scale production furnaces. But it is vital for anyone interested in the energy efficiency of any kind of combustion system to keep track of the furnace pressure. Specially designed pressure transmitters must be used to be able to measure and control furnace pressures less than 10 Pa (~1 mmWc).

Flow trains – measurement & control

Choosing the correct power input would affect the design and dimensioning of the requisite flow trains. Excessively large burners, whereby the nominal maximum power is never or seldom used, also causes an over dimensioning of the flow trains, and the total system performance will suffer.

In order to get the best out of a burner system, accurate flow measurements are needed. Of course this is also of great importance for good performance in an airfuel system, but with an oxyfuel system in which a deviation of lambda with 1/100 will affect the excess-oxygen level in the furnace atmosphere by over 1% it is even more important. In an airfuel system the same deviation will instead have an effect of approximately 0.2%. Using a V-cone flow meter results in good measurements, but accuracy of all other sensors such as differential pressure transmitter, pressure reducer, control valve, temperature and pressure measurement will also affect the accuracy of the system (4). However, in oxyfuel combustion both medias are more accurately measured in terms of flow and pressure compared to what is normal in airfuel combustion. In the case of airfuel, an electric fan blows the large volumes of normally preheated combustion air through large ducts to the burner. This results in temperature variations in the preheated air as well the flow and pressure. The nitrogen ballast, present in airfuel combustion, conceals such malfunctions and makes quick corrections difficult.
The introduction of limited turn-down ratio in combination with on/off regulation of the burners, already mentioned with regard to maintenance of optimal combustion and limited emissions, keeps regulation of the flow train within a limited range, thus creating better accuracy and control. For future adjustments, flow trains could be adapted using orifice plates depending on the new requests for possible drastically different heating profiles. Superior and more advanced control systems are today often integrated; with preset heating profiles and logging functions and in continuous furnaces they normally monitor and adjust for new steel grades, different sizes and temperature setpoints.
FOCS (Furnace Optimization Control System) is one such a system, which has been implemented, in one of the rotary furnaces at Ovako in Hofors.

Maintenance

Ovako has applied a strategy where the furnace status is frequently monitored, thus providing an early indication to facilitate rapid actions. This saves fuel, maintains the quality of the product, keeps emissions below set requirements and avoids a sudden and much more costly unplanned production stoppage. Furnace lids, refractory, openings, dampers and burners should be kept well-fitting, tight and properly working for optimal performance and safety. With increased production capacity in an existing furnace, this implies more frequent charging and discharging of the furnace in question, thus more tonnage passing through the furnace, which eventually means some more physical wear and tear on the furnace. With properly installed oxyfuel combustion there has been no reported wear on the furnace. Furthermore, cleaning and maintenance of recuperators or regenerative solutions are not required, thus also no degeneration in performance of combustion and heat-transfer processes.
Not only does the reduced scale formation reduce the cost of lost material, but there will also be less maintenance work in ridding the rolling mill from scale, and reduced costs for depositing this scale.

6. OVER 2 BILLION TONNES HEATED ANNUALLY

World steel production now exceeds 1 billion tonnes – by far the highest production ever. When steel has been cast it is transferred to the metalworking part of the process route, including rolling mills and forge shops to shape it into finished products. This area involves heating of the material so it reaches the correct temperature for each operation (approx. of 1200°C), e.g. hot rolling, annealing, and forging (ex.fig. 8). Actually, on average each tonne of casted steel undergoes this kind of heating operation and passes through reheating furnaces and annealing lines twice on its way towards finished product. Accordingly, the volume of steel heated in those furnaces will exceed 2 billion tonnes. Thus large volumes of steel are made each year, and twice the volume is heated to high temperatures for long periods. This means large quantities of energy are used with subsequent effects on the environment (5). The energy cost and dependency of supply has recently been highlighted, and emissions costs are already existent when it comes to complying with legislation. In scrap-based mini-mill production most of the CO_2 emissions emanates from the reheating and annealing processes. It also seems that these processes will soon also be included in the Kyoto protocol. This scenario calls for additional possible solutions. In this context oxyfuel has a long record of being useful in steel-making, and has for the past 15 years also constituted an economically viable solution for application in reheating and annealing.

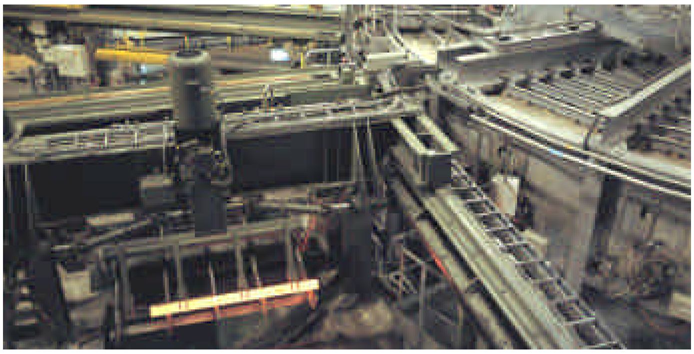

Figure 8: Rotary hearth furnace at Ovako in Hofors. Here billets, 170.000 tonnes/year, for tube rolling is heated with oxyfuel to a temperature of 1200°C prior to piercing.

The advantages mentioned regarding oxyfuel in reheating and annealing operations can only be fully attained by continuously treating all the operations as an integrated process. To exploit the faster heating capacity of oxyfuel, it is necessary to apply constraint management and throughput issues in all the operations – this is demanding but highly rewarding. Increased furnace throughput, fuel savings and reduced NO_X emission levels are possible if the furnace and measurement systems are well engineered and in good condition.

Not only Ovako but also other world leading steel producers have all seen that oxyfuel in reheating and annealing leads to economically viable results when it comes to expanding business and creating more production capacity and requisite flexibility, improving and maintaining profit margins and meeting environmental targets. The introduction of flameless oxyfuel already constitutes an established new generation of solutions that combines the efficiency of oxyfuel with low flame temperatures, thus resulting in more rapid and uniform heating of the steel and ultra-low levels of NO_X emissions.

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