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Using 100% Hydrogen on an Industrial Scale to Reheat Steel Before Rolling

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ABSTRACT

In early 2024, Ovako began the use of 100% hydrogen to fuel its existing Flameless Oxyfuel combustion systems in the soaking pit furnaces where steel is reheated before rolling. This was the successful conclusion of a five-year journey including laboratory scale tests and full-scale demonstrations in cooperation between Ovako, Sweden and Linde, Germany. A total of 48 furnaces, typically charged with about 25 tonnes of engineering or bearing steel grade ingots, are now running permanently in this operation mode. The hydrogen is supplied by an onsite alkaline electrolyzer powered entirely by fossil free power. The technology applied, the challenges overcome, and the excellent results achieved are discussed in this paper.

Keywords: Reheat Furnaces, Hydrogen, Oxygen, Oxyfuel, Decarbonization, Energy Efficiency, Flameless Combustion, NOx

INTRODUCTION

The modernization of industrial heating systems is becoming a major focus area in the drive to address the global challenges of reducing both energy usage and pollution. One method that has been identified to address this challenge is to modify the combustion system by using oxygen instead of air as the primary oxidizer. This technology, called Oxyfuel combustion, has been extensively investigated and gradually employed in industry. Naturally, Oxyfuel combustion is an example of a near-term approach to decarbonization focused on minor alterations and improvements in parallel to mapping out longer term options to reduce the carbon footprint of the steel industry. In general, it has the potential to substantially decrease both energy use and emissions. If existing Oxyfuel technologies were implemented fully across the steel industry, the sector's total CO_2 emissions could be decreased by several hundreds of millions of tonnes annually. [1][2]

Linde's experience of converting reheating furnaces into complete Oxyfuel operations has shown energy savings ranging from 20% to 60%. It should be noted that the total energy saving is much greater than the amount observed simply by reading a meter at the furnace. This is because the energy needed to transport the natural gas, for example, to be used in the furnace, is also saved. In the mid-1980s Linde began to equip the first furnaces with oxygen-enrichment systems that increased the oxygen content of the combustion air to 23-24%. The results were encouraging as fuel consumption was reduced and the output, in terms of tonnes per hour, increased. In 1990 Linde converted the first furnace to operation with 100% oxygen, that is full Oxyfuel combustion, at Timken in the US. Today, the total number of installations exceeds 180.

Among the early adapters of Oxyfuel combustion was Ovako, a leading European manufacturer of engineering steel for customers in the bearing, transportation and manufacturing industries, that belongs to the Nippon Steel Group. Ovako's first installation of full oxyfuel combustion took place as far back as 1994, at a reheat furnace for a soaking pit. When Linde introduced Flameless Oxyfuel combustion in 2003, Ovako quickly became a user of the new technology. Previous conventional Oxyfuel installations were converted into Flameless Oxyfuel and since then many additional installations using Flameless Oxyfuel have taken place at Ovako's steel mills. Today, in terms of number of installations, Ovako is the world's most prominent user of Flameless Oxyfuel, contributing to its globally leading position in energy-efficient and sustainable steel production. Further conversion to using hydrogen as a fuel, as discussed in this paper, was therefore a natural next step for Ovako.

FLAMELESS OXYFUEL COMBUSTION

The expression 'flameless combustion' explains the visual aspect of this type of combustion. This is because the flame is no longer seen or easily detectable by the human eye. Another description is that the combustion is extended in time and space – it is spread out in large volumes, that is why it is sometimes referred to as 'volume combustion'. This flame has a uniform and lower temperature, practically the same temperature as air-fuel combustion, yet it contains the same amount of energy as conventional Oxyfuel.

The development of Flameless Oxyfuel was driven by increasingly stricter legislation on emissions. Flameless Oxyfuel combustion occurs under diluted oxygen concentration as flue gases are mixed into the combustion zone. This slows down the oxyfuel combustion reactions and results in lower flame temperatures, below the point of thermal NOx creation. It reduces flue gas volumes by 75-80% due to lower fuel consumption and no nitrogen in combustion. Low flue gas volumes with very high CO_2 concentration are of course favorable for Carbon Capture Utilization and Sequestration (CCUS). The mixing of flue gases into the flame also disperses the energy throughout the entire vessel or furnace for faster and more uniform heating. Linde started applying Flameless Oxyfuel in 2003, with the first installations at the stainless steel producer Outokumpu in continuous furnaces for strip annealing and slab reheating. The capability to reduce NOx emission has been an important factor, but the large improvement in temperature uniformity has been key to its success. Use of Flameless Oxyfuel has demonstrated energy savings of up to 65%; most installations with an operation fully converted from air-fuel to Flameless Oxyfuel show fuel and CO_2 savings of 20% to 50%. Linde has made around 500 installations of Flameless Oxyfuel in practically all kinds of steel reheating and annealing furnaces, aluminum and copper melting furnaces, and ladle and other vessel preheating systems.

In Flameless Oxyfuel the mixture of fuel and oxidant reacts uniformly through the reaction flame volume, with the rate controlled by partial pressures of reactants and their temperature. In Flameless Oxyfuel, the combustion gases are effectively dispersed throughout the furnace, ensuring more effective and uniform heating of materials even with a limited number of burners installed. Although the first installations took place in reheating and annealing, Flameless Oxyfuel was quickly adopted for preheating of ladles and converters where it has also demonstrated good results. The next area to be exploited, with a substantial positive impact, could be blast furnace hot stoves. Another interesting area is the use of low calorific fuels, e.g., blast furnace top gas; use of Oxyfuel strongly supports the successful use of low calorific gases. The lower flame temperature – same temperature as at traditional air-fuel combustion, together with temperature uniformity – substantially reduces NOx formation so it is lower than with air-fuel combustion. Moreover, the excellent temperature uniformity leads to reduced heating times and, in reheating applications, to reduced scale losses. [2][3][4]5]

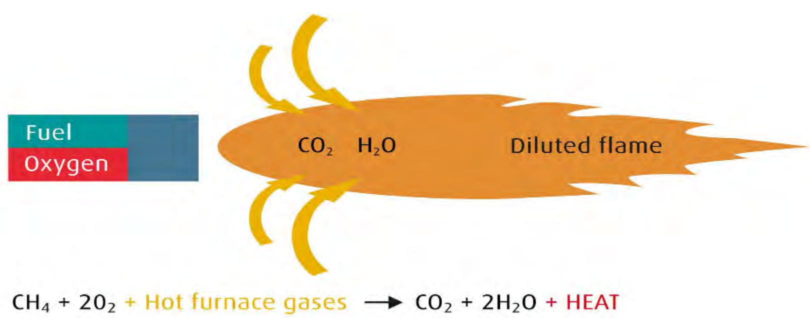

Figure 1. The principle for obtaining Flameless Oxyfuel.

Reheating furnaces typically consume 1.2-1.6 GJ/t of steel, and Flameless Oxyfuel solutions can reduce fuel and CO_2 emissions from reheat furnaces by up to 60%. Linde is the world-leader in Oxyfuel steel reheating; its Flameless Oxyfuel technology for reheating and annealing was introduced more than 20 years ago. It now has over 180 installations – in all types of furnaces and for all kinds of steel grades – and at more than 40 steel mills worldwide. Converting a reheat furnace completely into full Flameless Oxyfuel combustion is a major project, particularly if it is a large continuous furnace. Therefore, most such complete conversions have been for batch furnaces, e.g., soaking pit and chamber furnaces, but there are also many examples of installations in continuous furnaces.

THROUGH ENERGY EFFICIENCY TO HYDROGEN

Reheating furnaces are a substantial source of emissions and generally the second or third largest GHG (greenhouse gas) emitter in integrated mills, and the top emitter in many mini mills. This is due to the furnace's fuel needs which are currently met with natural gas, LPG, coke oven gas, blast furnace gas, oil, or other carbon-bearing fuels. Using hydrogen as a fuel is one pathway to decarbonize the reheating furnace, with the potential to eliminate 100% of the Scope 1 emissions by directly replacing carbon-bearing fuels. Full or partial replacement is possible and may be done as a retrofit application with minimal impact on the overall furnace operation.

Oxyfuel combustion can significantly increase energy efficiency and immediately reduce the carbon footprint, paving the way for the efficient future use of hydrogen as fuel. Moreover, Oxyfuel combustion produces a much lower flue gas volume with a high concentration of CO_2, and this also supports CCUS.

For the foreseeable future, the cost of hydrogen is expected to be relatively high, and not below $2/kg, roughly equivalent to $15/MMBTU (Million Metric British Thermal Units). Currently the cost is much higher in many parts of the world. This makes it essential to minimize the use of hydrogen by making the combustion process as energy efficient as possible. Accordingly, applying Flameless Oxyfuel that immediately reduces the fuel consumption is an important first step. However, the conversion must be done using a hydrogen-ready technology to ensure a swift changeover when a viable supply of hydrogen is in place. Figure 2 illustrates the transition from air-fuel via Oxyfuel with a fossil fuel and then to use of hydrogen.

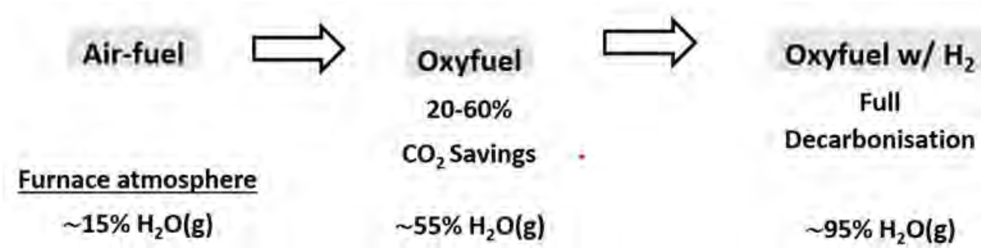

Figure 2. The pathway to Flameless Oxyfuel with 100% hydrogen.

Ovako was one of the first steel producers to use Oxyfuel in its reheating furnaces. From 1994 onwards, and with Flameless Oxyfuel since 2003, installations have been made in soaking pit, rotary hearth, and walking beam furnaces at multiple Ovako sites in Sweden and Finland. The benefits are summarized (see Figure 3) as:

- Reduced heating time, up to 50% less
- Reduced fuel consumption, up to 45% less
- More uniform heating
- Reduced scale losses.

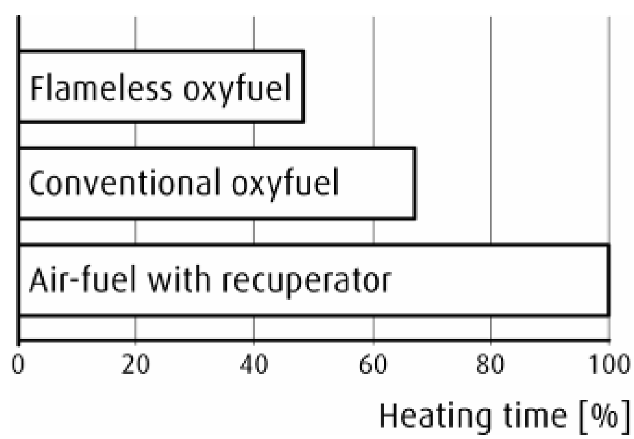

Figure 3. The diagram shows heating times in same furnaces at Ovako, but with different combustion technologies and unchanged or reduced power inputs.

SUSTAINABILITY AT OVAKO – EFFICIENT PRODUCTION FOR A BETTER ENVIRONMENT

Environmental aspects have always been a fundamental part of Ovako's business. It has reduced its relative carbon emissions by 56% from a baseline set in 2015 through efficient processes, the use of fossil-free electricity and dedicated investments such as the conversion to fossil-free electricity for heat treatment. The result is a carbon footprint 80% lower than the global average. Ovako's goal is to achieve zero-carbon emission steel.

THE PATHWAY TO USING 100% HYDROGEN IN FLAMELESS OXYFUEL COMBUSTION

The combustion of hydrogen produces only water (H_2O), so there are no CO_2 emissions. Linde's technology designed to utilize oxygen in reheat furnaces has been further developed to use hydrogen as a fuel while maintaining similar performance to fossil fuel, with the same NOx emissions and heat transfer profile. The Flameless Oxyfuel burners utilize high momentum oxygen and hydrogen jets, which quickly entrain furnace gases, and reduce the overall concentration of the fuel and the oxidant prior to combustion – it is extremely important that these features are maintained when switching to hydrogen.

For some years Linde has performed tests at its technology centers to develop hydrogen burners and to assess the impact of hydrogen combustion. Starting in 2018, Linde has evaluated combustion with Flameless Oxyfuel up to 1.0 MW in scale using hydrogen as fuel, both partly and fully. The results clearly showed the benefits of Flameless Oxyfuel, and that temperature uniformity and low NOx emissions could be maintained. The next step was then to evaluate the effect on materials, and pilot reheating tests were carried out on 10 kg samples from four steel producers that contributed their various steel grades. The results of thesee pilot tests were encouraging, displaying no negative impact on the heated materials.

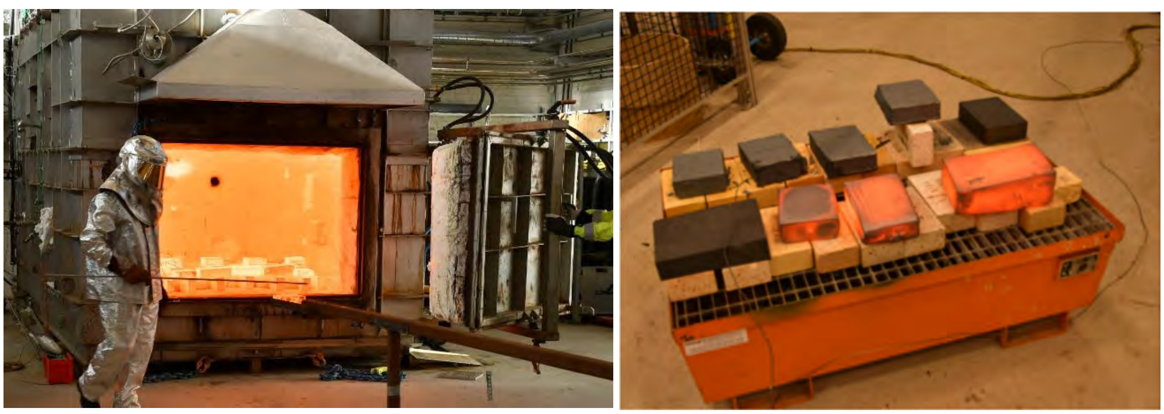

Figure 4. Laboratory tests with 100% hydrogen as a fuel using 10 kg samples of various steel grades at Linde's Technology Center in Stockholm, Sweden.

Based on the positive outcome from the pilot tests, Ovako then decided to carry out a full-scale demonstration of hydrogen reheating in a soaking pit furnace at its Hofors mill in Sweden. The test in March 2020 was the world's first time that heating of steel with 100% hydrogen as the fuel was carried out. The test material was 25 tonnes of bearing steel ingots. The pit furnace was fired with Hyox hydrogen Flameless Oxyfuel. After heating and soaking, the ingots were successfully rolled to bars in the rolling mill. Rolling forces, dimensions, scale losses and temperature uniformity were at the same high level of quality achieved with conventional heating. A thorough inspection and analysis of the final bars showed that heating using hydrogen as fuel does not impact the quality. The Ovako project team concluded that they were confident hydrogen can be used simply and flexibly, with no impact on steel quality, which would mean a very large reduction in the carbon footprint. Based on this, Ovako decided to embark on the journey towards permanent full-scale implementation.

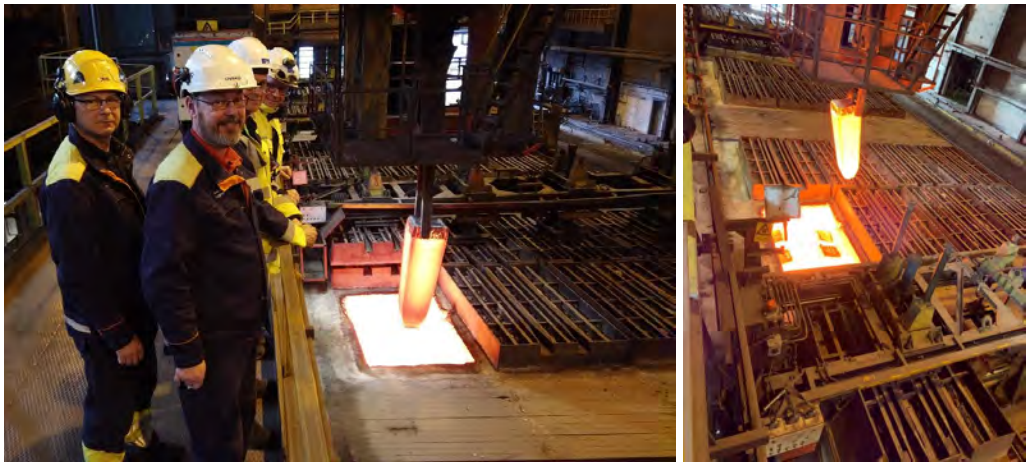

Figure 5. The world's first full-scale reheating of steel with 100% hydrogen as fuel, using REBOX Hyox Flameless Oxyfuel, at Ovako's Hofors mill in Sweden in March 2020.

FULL-SCALE IMPLEMENTATION

A permanent full-scale installation of REBOX Hyox Flameless Oxyfuel reheating went into operation at Hofors in early 2024. The site now operates a 20 MW electrolyzer, one of Europe's largest. Powered by renewable energy [7][8] it can produce 3,880 cubic meters of hydrogen per hour, along with oxygen. By using fossil-free hydrogen, the plant has the potential to reduce the site's carbon footprint by 20,000 tonnes a year.

Figure 6. Photograph from current full scale operation reheating with 100% hydrogen as a fuel.

The electrolyzer is located near the furnaces at Hofors, allowing the hydrogen production process to be seen as 'borrowing' water for a short time. The plant takes water from the local supply and splits it into hydrogen and oxygen. And when burned, the oxyfuel returns to water. This approach requires only a few minutes of storage as a buffer for fluctuations in production and demand. [6]

The system has many different components, including the electrolyzer itself, scrubbers, storage tanks, compressors, pipes, and electrical equipment like transformers and rectifiers. A smart control system has also been developed for a smooth switch between hydrogen and propane (LPG) oxyfuels. Before the plant became operational, Ovako experts conducted extensive tests to ensure all parts of the system worked correctly.

Figure 7. The 20 MW alkaline electrolyzer plant, which provides hydrogen to the operations at Ovako Hofors.

This project relied on collaboration with several key partners for both funding and technical expertise. Sweden's Energy Agency provided financial support through its Industrial Decarbonization initiative, backed by the EU's Recovery and Resilience Facility (RRF), part of the NextGeneration EU program aimed at promoting a more sustainable Europe.

From a technical and operational standpoint, Hitachi Energy and Nel Hydrogen contributed their expertise to advance the plant for fueling the furnaces and supporting grid stability.

Other collaborators in the project include Volvo Group and H2 Green Steel, both working to expand the use of hydrogen. Volvo, through its partnership with Daimler Trucks, is using lessons from Hofors to explore how hydrogen could be used as a fuel for zero-emission road transport. Meanwhile, H2 Green Steel is using the project's experience to guide its own efforts to produce low-emission steel powered by hydrogen.

Excess heat from the plant is also being used for district heating.

POTENTIAL PROVED, LOOKING AHEAD

The Hofors installation was created as a 'lighthouse project'. It continues to demonstrate the potential for high-grade industrial heat to be generated entirely from fossil-free fuel. With the installation of eight alkaline electrolysers, the plant sets a precedent for reducing CO_2 emissions by 50% from current levels.

In addition to the successful implementation of REBOX Hyox Flameless Oxyfuel at Ovako's Hofors mill, several other activities supporting further development and implementation in this area have taken place and are under way. These include, for example, full-scale tests completed in a soaking pit furnace in operation at a stainless steel producer, and full-scale tests and installation of a permanent system in a 20 MW Flameless Oxyfuel powered continuous furnace for the production of high-alloyed steel grades.

In the US Linde is involved in the H2RF project. This is a Department of Energy (DOE) funded project with partners including Gerdau Monroe Special Steel as the pilot plant, Purdue University Northwest (SMSVC) as the prime DOE contract, Linde as the burner technology and hydrogen/oxygen supply system provider, as well as ArcelorMittal, Argonne National Laboratory, Cleveland-Cliffs, and Oak Ridge National Laboratory. The projects are investigating the impact on furnace combustion, heating curves, scale formation, refractory, NOx, and other aspects surrounding reheat furnace operation. A main element of H2RF is the full-scale testing of oxygen-hydrogen combustion in a Gerdau Monroe continuous reheat furnace.

Within Ovako, in parallel to the success with permanent full-scale use of hydrogen at the Hofors mill, activities along the same pathway are also in progress at two other steel mills. In 2023 a continuous reheat furnace at Imatra, Finland, was converted from air-fuel to hydrogen-ready Flameless Oxyfuel operation. The results include better than 25% fuel savings and a 50% reduction of NOx emissions. When a viable supply of hydrogen is available in the coming years, this furnace is planned to be run entirely using hydrogen as fuel. In 2024 another conversion was successfully completed for a continuous reheat furnace at Boxholm, Sweden. Here truly excellent results were achieved including a 50% reduction of the fuel consumption.

Figure 8. A reheat furnace at Ovako Boxholm, equipped with a hydrogen-ready REBOX Flameless Oxyfuel system. Installation and commissioning took place in in 2024.

CONCLUSIONS

The successful introduction of the hydrogen plant and consequently hydrogen-fueled reheating of steel at Hofors is just the beginning. Ovako's goal is to implement local hydrogen production at all Ovako facilities where steel is rolled by 2030, provided there is sufficient access to fossil-free electricity to support the electrolysis process.

This journey began as a theoretical exercise. It is now a tangible and fully practical solution with the potential to significantly reduce carbon emissions. The potential of hydrogen technology in our industry is enormous. If more steel plants and other industries around the world adopt this solution, it could save 300 million tonnes of carbon dioxide annually.

Linde's REBOX Flameless Oxyfuel solutions have proven successful operation in full industrial scale using 100% hydrogen as a fuel.

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