# SIX YEARS EXPERIENCE FROM LOW-TEMPERATURE OXYFUEL IN PRIMARY AND RE-MELTING ALUMINIUM CAST HOUSES

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## Abstract

Low-temperature Oxyfuel technology provides lower peak flame temperatures and a more uniform heat flux and temperature profile in the cast house furnace. The objectives with the technology are to improve melt rates, save energy, reduce dross formation and to reduce NOx and $CO_2$ emissions. The paper will discuss operational results, process optimizations and economy from installations in reverberatory melting furnaces, mixing furnaces and tiltable rotary furnaces. The theory behind the technology will be described including reference to CFD simulations and laboratory testing. Low-temperature Oxyfuel is used by a number of aluminium producers including Hydro Aluminium, Sapa Heat Transfer AB, Stena Aluminium and others.

## Introduction

Combustion of fossil fuels with technical oxygen, oxyfuel technology, is state of the art for heating and melting of metals since more than 30 years. The technology was first adopted by the steel industry followed by glass melters, cast iron foundries, melting of copper scraps, recycling of lead batteries and recycling of secondary aluminum in rotary furnaces. Burner systems were developed for all kinds of furnace shapes and temperatures. Oxyfuel reduces the energy consumption and increases process productivity. Side effects are reduced emissions like $CO_2$ and $NO_x$. [1,2].

## Low-temperature Oxyfuel technologies

Low-temperature Oxyfuel is designed and developed for the melting of aluminum. It is a further development of the conventional oxyfuel burners that are state of the art for melting of secondary aluminum in rotary furnaces.

In oxyfuel combustion the combustion air is replaced by industrial grade oxygen. This has consequences for the combustion process in three main areas:

1. Thermal efficiency
2. Gas radiation
3. Flame temperature

The first obvious result is the increase in thermal efficiency due to the reduced exhaust gas volume and energy losses as illustrated in Figure 1.

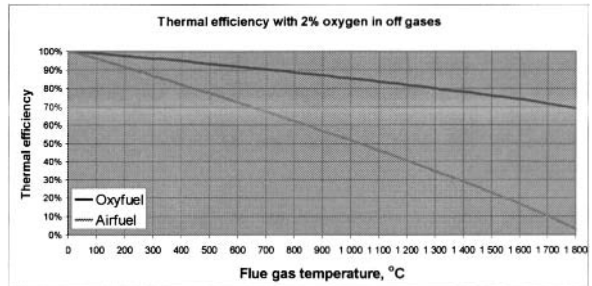



Figure 1. Combustion with industrial oxygen increases the thermal efficiency

The second fundamental consequence is the increased concentration of the highly radiating products of combustion, $CO_2$ and $H_2O$ in the furnace atmosphere. Calculations according to VDI – Värmeatlas, Figure 2, indicate that the emissivity of oxyfuel burner exhaust gases is 30-60% higher than air-fuel burner exhaust gases in the temperature range 400-1200°C. Therefore the heat transfer through radiation increases.

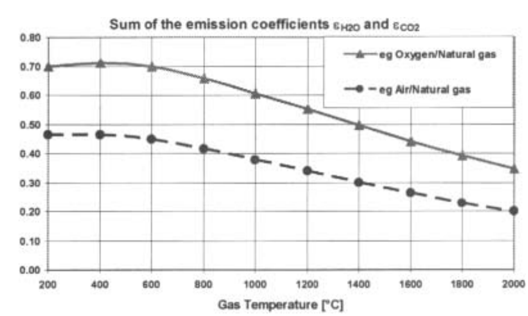



Figure 2. Calculated emission coefficients of products of combustion from natural gas/oxygen and natural gas/air burners. The higher emission coefficient from oxyfuel combustion indicates higher heat transfer through gas radiation.

As the "radiative component of the heat flux dominates the heat transfer between gas and metal by far" [3] this leads to a more efficient heating and melting process.
In a recent study [4], aluminum samples were heated in a 8-$m^3$ pilot scale furnace comparing heating with an air-fuel burner and a Low-temperature Oxyfuel burner. The furnace temperature was kept the same in both cases. The furnace is equipped with water cooled steel tubes at the floor. The temperature of the furnace is set by adjusting the power of the burners and the flow of cooling water. The temperature of the aluminum samples was measured and recorded during the trial. Table I shows a summary of results.

Table I . Results from trials, heating of aluminum samples in a 8-$m^3$ pilot scale furnace [4].

| Case | Burner power (kW) | Water cooling (kW) | Temperature at Al sample (°C) | Heat flux ($kW/m^2$) |
|---|---|---|---|---|
| Air-fuel | 311 | 23 | 1151 | 79 |
| Low-temperature Oxyfuel | 257 | 66 | 1152 | 109 (+38%) |

The average heat flux into the aluminum sample is 38% higher in the oxyfuel case. This was despite that the air-fuel case used higher burner power and more cooling of the furnace. This experiment illustrates the positive influence on the heat transfer caused by the high concentration of radiating products of combustion.

The third influence of conventional oxyfuel on the combustion process is the increase in the burner flame temperature. This can under certain process and furnace conditions be negative as it could lead to a localized energy spot with very high temperature. The consequence could be local overheating of the aluminium metal or of the refractory lining. The Low-temperature Oxyfuel burner is designed to address these possible problems.

In Low-temperature Oxyfuel the flame temperature is reduced by the use of the principle of flameless combustion. The expression illustrates the visual aspect of the combustion, i.e. the flame is no longer seen or easily detected by the human eye. Another description is that the combustion is dispersed, spread out in a larger volume [2,5], Figure 3.

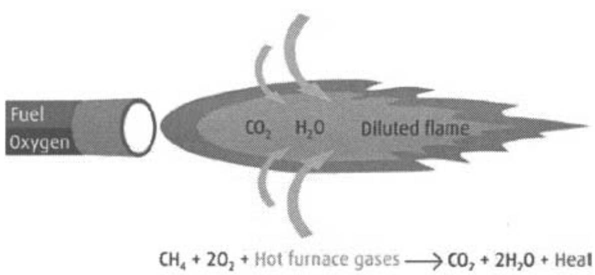



Figure 3. Low-temperature Oxyfuel combustion occurs under diluted oxygen concentration by mixing the furnace gases into the flame. This slows down the reactions and results in lower flame temperature and a more dispersed flame.

The dispersed flame still contains the same amount of energy but is more spread over the furnace volume. Low-temperature Oxyfuel provides a more uniform heating and melting, avoiding hot spots and dross formation. Figure 4 illustrates the flame temperature distribution of Low-temperature Oxyfuel compared to conventional oxyfuel. As $NO_x$ formation is depending on temperature, flameless combustion means ultra-low $NO_x$ emissions. Low-temperature Oxyfuel provides the same high thermal efficiency and high gas radiation from the products of combustion as conventional oxyfuel.

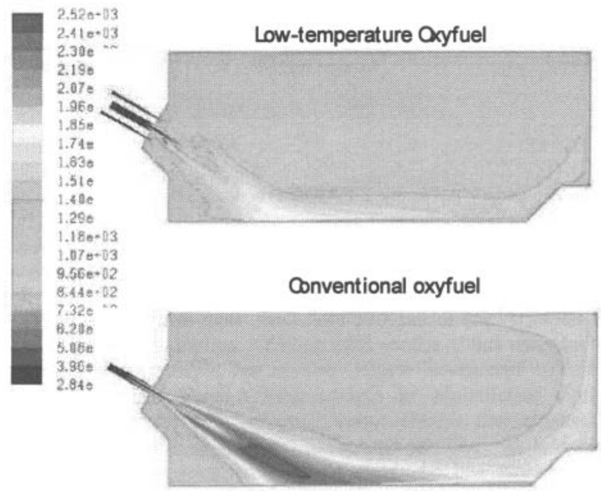



Figure 4. Temperature (K) contours along a cross section, calculation in Fluent for a 50-tonne furnace

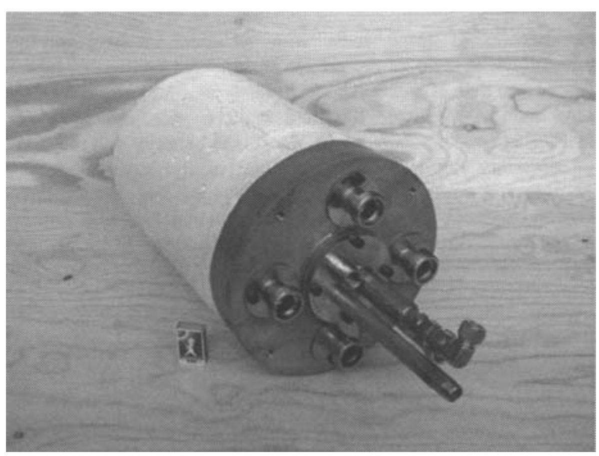


Figure 5. Low-temperature oxyfuel burner for aluminium melting. The burners are available in power range 0.2-4 MW and has a diameter of 300 mm and weights only 80 kg including refractory. UV-cell flame safeguard and ignition flame are integrated to the burner.

**Reference installations**

Low-temperature Oxyfuel has gained wide acceptance in the industry. It is today used in a number of furnaces. Ten furnaces at four plants are listed in table II.

Table II. Low-temperature Oxyfuel installations

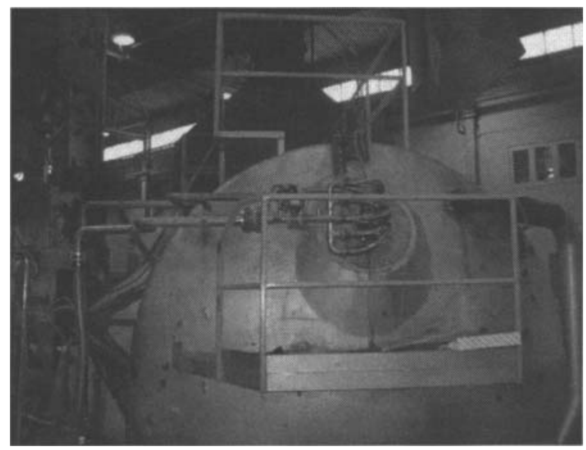
| Customer | Furnace type | Fraction solid metal in the charge | Year |
|---|---|---|---|
| Sapa Heat Transfer | 28t, reverberatory | 100% (s) | 2005 |
| Rusal, KUBAL | 50t, reverberatory | 70% (s) | 2007 |
| Hydro, Årdal, PFA2 | 2x30t alloying/casting | 45% (s) | 2007 |
| Hydro, Årdal PFA1 | 2x38t alloying/casting | 45% (s) | 2008 |
| Stena Aluminium | 25t alloying/casting | 10% (s) | 2009 |
| Stena Aluminium | 25t tiltable rotary furnace | 100%(s) | 2010 |
| Rusal, KUBAL | 50t, reverberatory | 30%(s) | 2011 |
| Sapa Heat Transfer | 40t, reverberatory | 100%(s) | 2012 |

**Low-temperature Oxyfuel at Hydro Aluminium, Årdal**

Hydro Aluminium Årdal produces 175 000 t/y pot-room metal today. There are two cast houses, one for sheet ingots and one for primary foundry alloys, PFA. There is a capacity to produce about 130 000 t/y PFA. The main alloys produced are AA4000 series. There are two parallel production lines called PFA1 and PFA2. Each line consists of two gas fired furnaces feeding one casting system. PFA1 has horizontal continuous casting making 75 x 50 mm bars in different lengths. PFA2 casts 8 kg ingots on a casting mould belt [6].

In year 2007 the old 50 000 t/y Söderberg pot-room at Hydro Årdal was closed. This reduction of the pot-room metal supply meant that Hydro Årdal had to increase the re-melting of commodity metal in order to keep up the production of cast house products. However the re-melting capacity was limited by the air-fuel combustion systems used. The objective for PFA was thus to increase the amount of solid metal in the batch from 27% to 43%. That is to re-melt more solid metal using the same furnace and casting equipment.

Hydro Aluminium first converted the PFA2 line to Low-temperature Oxyfuel The conversion was made in June 2007. The old 3MW air-fuel burner systems were completely removed. One 3MW Low-temperature Oxyfuel burner was installed in each of the two furnaces at the same positions as the air-fuel burners, figure 6. The oxyfuel systems installed are fully automated with touch screen operator interface and advanced power control.



Fiure 6. Low-temperature Oxyfuel installation at PFA2, Hydro Aluminium, Årdal, Norway

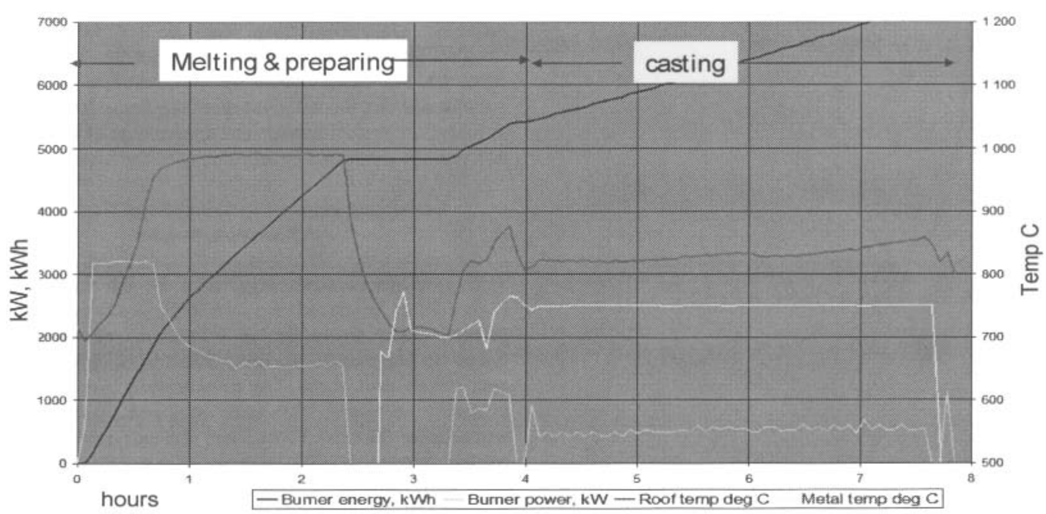



Figure 7. Process diagram from PFA2 operating with Low-temperature Oxyfuel and 40% solid metal in the batch

The power control is illustrated in figure 7. The burner power is gradually reduced during the solid / liquid phase transformation. This is to balance for the drop in heat transfer when liquid metal starts to form and thereby avoid overheating of this liquid metal. By controlling the balance between burner power and process energy need, the melting is performed under nearly constant or slowly increasing furnace temperature.

The results are excellent, the objective of increasing the amount of solid metal in the batch from 27% to 43% without increasing the cycle time was reached. This represents a 60% increase in re-melting capacity. Fuel energy efficiencies of 55% are obtained, if the fuel used for the 4h casting is excluded, the fuel energy efficiency increases to over 60%. It is also concluded that the amount of dross formation was unchanged when converting from air-fuel into Low-temperature Oxyfuel.

Performance of the refractory lining

The Low-temperature Oxyfuel installation at PFA2 was made after the second year of a refractory lining campaign planned to last five years. That is, no changes in refractory materials or design were made. The lining concept and burner position are shown in figure 8 and 9. The furnace floor and metal bath line is made of a standard high alumina brick with 81.5%$Al_2O_3$. The refractory above the bath level is a monolithic bauxite based gunning mix with 77.5% $Al_2O_3$. The temperature limit for application is 1720°C according to the manufacturers data sheet. This set up of the refractory linings is standard procedure at the plant. The intervals between re-linings are five years.

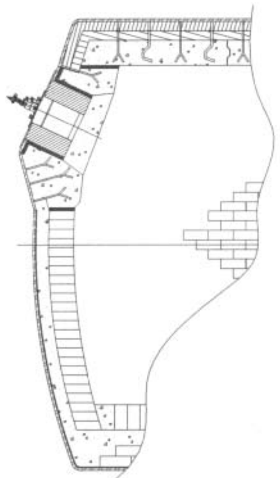


Figure 8. The refractory lining at PFA2.

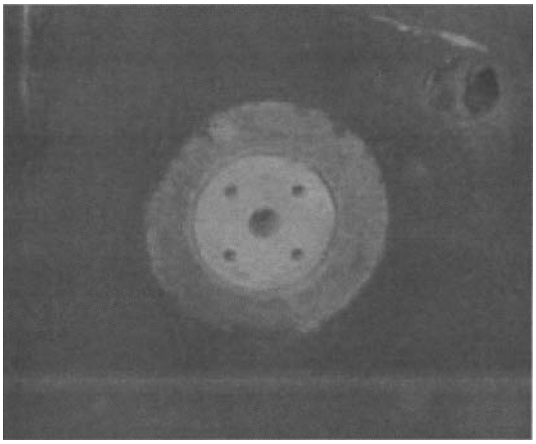


Figure 9. The Low-temperature Oxyfuel burner refractory block is fitted into a sleeve made of a low expansion refractory castable with 40% $Al_2O_3$ and 43%$SiO_2$

The refractory lining performed excellent together with the new Low-temperature Oxyfuel burner system.

The furnace was re-lined after the normal five year cycle. At that time the furnace had been run for two years with the old air-fuel burner and three years with the new Low-temperature Oxyfuel burner. During the three years with oxyfuel, 47% more tons solid aluminum blocks were charged into the furnace. This lead to an expected increase of mechanical wear on the furnace bottom and around the charging door caused by the impact of the charging tool and the solid blocks. There was no increased wear due to interactions between the flame and the monolithic refractory above the bath level. Owing to these very good results the refractory materials and design were kept the same for the re-lining [7].

To conclude, the results from this refractory campaign at PFA2 Hydro Årdal show that there is no need to change refractory lining materials when converting from air-fuel to Low-temperature Oxyfuel burners. The reason being that the temperature of the flame and the furnace gases are well distributed over the furnace volume and that the temperature of the flame is on the same level as that of an air-fuel burner. The temperature of the refractory roof and walls is controlled by adjustment of the burner power.

**Low-temperature Oxyfuel at Sapa Heat Transfer, Finspång, Sweden**

Sapa produces heat-exchanger strip for the automotive market. Main alloys produced are AA3003. Rolling mill scrap and primary ingots are molten in a 28-tonne reverberatory furnace, figure 10. The metal is transferred to a holding furnace and is cast into rolling mill slabs. The reverberatory melting furnace was originally designed for and equipped with two pairs of regenerative burners. These were replaced for four conventional oxyfuel burners in 1995. During 2005 the furnace was equipped with four Low-temperature Oxyfuel burners replacing the old oxyfuel burners. This was the first installation of this new burner technology, based on flameless combustion, in an aluminium melting furnace.

The first observation made by the operators was that the scrap melt down was more uniform. Further that the roof temperature set point was reached much later in the melting process. This resulted in that full burner power was maintained longer. These observations are in line with the properties of the Low-temperature Oxyfuel technology, the heat is distributed more uniform over the batch and the furnace. This resulted in increased melt rate and fuel savings. Another consequence was that the used burner power could be increased and this lead to a further increase in melt rate.

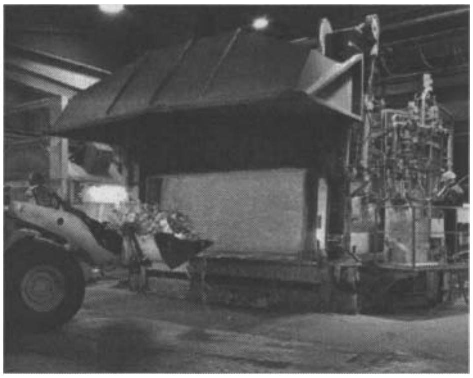


Figure 10. 28-tonne reverberatory melting furnace at Sapa Heat Transfer operated with four Low-temperature Oxyfuel burners since year 2005.

Studies were made on how the new burners influenced the melt rate, dross formation, energy consumption and emissions [2]. Some of these results are referred to below.

An evaluation of melt rates comparing the two burner systems operated with and without electro magnetic stirring (EMS) is summarized in table III. The evaluation indicates an increase in melt rate with up to 23% with Low-temperature oxyfuel.

Table III. Relative melt rate at different process cases

| EMS | Conventional oxyfuel 2.6MW | Low-temperature Oxyfuel 2.6MW | Low-temperature Oxyfuel 3.0MW |
|---|---|---|---|
| OFF | 1 | 1.04 | |
| ON 500A | | 1.18 | 1.34 |
| ON 550A | 1.09 | 1.20 | |

An investigation of dross formation comparing Low-temperature Oxyfuel and conventional oxyfuel with and without EMS is summarized in table IV. Each process case was run for two weeks. The results indicate that the dross formation was reduced up to 9% when using Low-temperature Oxyfuel.

Table IV. Relative dross formation recorded at different process cases

| | Conventional oxyfuel 2.6MW | Low-temperature Oxyfuel 2.6MW |
|---|---|---|
| No EMS | 1 | 0.91 |
| With EMS | 0.88 | 0.81 |

A study of the furnace heat balance and $NO_x$ emissions was made by following a sequence of seven furnace cycles. The measured NOx values indicated 90% reduction of NOx emissions. The average of the seven batches was well below 100mg/MJ.

The heat balance determined from the seven furnace cycles is summarized in table V. The average fuel consumption was 495kWh per tonne of liquid aluminium. This corresponds to an energy efficiency of 66%. The fuel consumption over a 12 months period is as expected slightly higher, 550kWh/tonne.

Table V. Heat balance for the 28-tonne melting furnace. Represents the average of seven furnace cycles

| | kWh/tonne liquid Al | |
|---|---|---|
| Fuel gas input | 495 | 100% |
| Al (melting & heating) | 328 | 66% |
| Furnace losses | 78 | 16% |
| Exhaust gas losses | 73 | 15% |
| Leak air losses | 16 | 3% |

The studies referred to above showed that the Low-temperature Oxyfuel technology provided excellent process results. A further consequence was that the burner power could be increased owing to the more uniform heat distribution in the furnace. The burner power was therefore upgraded in steps and it is today 4MW in total. This has lead to further increases in melt rate and the plant has had a continuous improvement in productivity and energy consumption over the years. Owing to these results, Sapa Heat Transfer decided to install Low-temperature Oxyfuel also when building a new 40-tonne melting furnace.

New 40-tonne reverberatory furnace

Sapa Heat Transfer is currently carrying out an expansion of the cast house at the Finspång plant. The investment involves a new melting furnace, a casting furnace, flue-gas treatment plant and further equipments. The new one chamber direct charged reverberatory furnace will be equipped with four Low-temperature Oxyfuel burners with a total power of 8MW. The capacity of the furnace will be in the order of 35 000 tonne per year.

**Low-temperature Oxyfuel in tiltable rotary furnaces**

Recently Low-temperature Oxyfuel has been applied also in tiltable rotary furnaces using the dry salt-process for the recycling of various secondary aluminium scraps and UBC. The objectives being to further improve metal yields. Compared to conventional oxyfuel, operators observe a more uniform heating and melting of the scrap charge. This is despite the fact that rotary furnaces provide a more uniform heating compared to stationary furnaces owing to the tumbling of the scrap charge. The process results are excellent and will be published later.

## Conclusions from six years of operation

Low-temperature Oxyfuel is installed in ten furnaces. The first installation has been in operation since 2005. The overall performance has been excellent in comparison to air-fuel burners and conventional oxyfuel burners. It has also proven to be a reliable heating system that performs year after year with low maintenance efforts and costs. Low-temperature Oxyfuel has provided:

- Increased productivity
- Lower energy consumptions
- Reduced $CO_2$ and $NO_x$ emissions
- Unchanged or reduced dross formation
- No need for changing refractory material
- Low maintenance needs and costs
- No need for expensive and maintenance intensive heat recovery systems

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